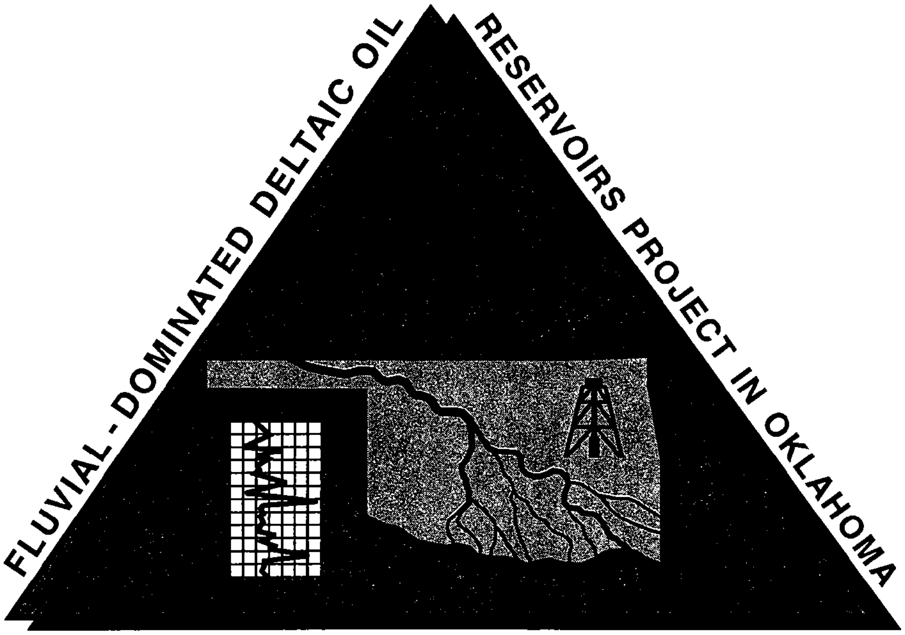
Oklahoma
Geological
Survey
1997

Special Publication 97-3

Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Tonkawa Play



ERRATA

Oklahoma Geological Survey Special Publication 97-3

The Tonkawa Play

Page 16, Table 3: the cumulative gas reported is 46,275,231 MCF, not MMCF.

Page 37, Figure 29: the contour label "–1270 ft" in Sec. 26, T. 28 N., R. 1 W. is placed on the wrong contour. The –1270 label should be on the unlabeled contour to the northeast.

Oklahoma Geological Survey
Charles J. Mankin, *Director*

Special Publication 97-3
ISSN 0275-0929

Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Tonkawa Play

PART I.—Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma

by
Richard D. Andrews
with contributions from Jock A. Campbell and Robert A. Northcutt

PART II.—The Tonkawa Play: Regional Geology

by
Jock A. Campbell

PART III.—Geology of the Tonkawa Sand Reservoir, Blackwell Oil Field

by
Kurt Rottmann

PART IV.—Reservoir Simulation of a Tonkawa Sand Reservoir, Blackwell Oil Field, Kay County, Oklahoma

by
R. M. Knapp, Z. Samad, and C. Xie

This volume is one in a series published as part of the Fluvial-Dominated Deltaic (FDD) Oil Reservoirs project, jointly funded by the Bartlesville Project Office of the U.S. Department of Energy and by the State of Oklahoma.

The University of Oklahoma
Norman, Oklahoma

1997

SPECIAL PUBLICATION SERIES

The Oklahoma Geological Survey's Special Publication series is designed to bring timely geologic information to the public quickly and economically. Review and editing of this material has been minimized in order to expedite publication.

This publication, printed by the Oklahoma Geological Survey, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1981, Section 3310, and Title 74, Oklahoma Statutes, 1981, Sections 231–238. 1,000 copies have been prepared at a cost of $4,806 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

◁ CONTENTS ▷

LIST OF ILLUSTRATIONS

Figures

continued on next page ➔

Plates

TABLES

PART I

Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma

Richard D. Andrews
Geo Information Systems

with contributions from

Jock A. Campbell *and* ***Robert A. Northcutt***
Oklahoma Geological Survey
Consulting Geologist, Oklahoma City

INTRODUCTION TO THE FDD PROJECT

This volume is one in a series addressing fluvial-dominated deltaic (FDD) light-oil reservoirs in Oklahoma, published as part of the Fluvial-Dominated Deltaic (FDD) Reservoir project conducted by the Oklahoma Geological Survey (OGS), with participation from the University of Oklahoma Geo Information Systems and OU's School of Petroleum and Geological Engineering (all located in the Sarkeys Energy Center). Primary funding for project, which began in 1993, is provided through a grant from the Department of Energy's Bartlesville Project Office under the Class I reservoir program, and by matching State funds.

The objectives of the Fluvial-Dominated Deltaic (FDD) Reservoir project are to identify all FDD light-oil reservoirs in the State of Oklahoma; to group the reservoirs into plays with similar depositional and diagenetic histories; to collect, organize, and analyze all available data on the reservoirs; to conduct characterization and simulation studies on selected reservoirs in each play; and to implement an information- and technology-transfer program to help the operators of FDD reservoirs learn how to increase oil recovery and sustain the life expectancy of existing wells.

The FDD project was designed to assist operators in Oklahoma by providing them with practical ways to improve production from existing leases and/or to reduce operating costs. Currently available technologies can improve recovery in FDD reservoirs if there is sufficient information about a reservoir to determine the most appropriate course of action for the operator. The needed reservoir-level information is available through the FDD project, and staff will advise interested operators about the implementation of appropriate improved-recovery technologies.

Light-oil production from FDD Class I oil reservoirs is a major component of Oklahoma's total crude oil production. Nearly 1,000 FDD Oklahoma reservoirs provide an estimated 15% of the State's total oil production. Most FDD reservoir production in Oklahoma is by small companies and independent operators who commonly do not have ready access to the information and technology required to maximize exploitation of these reservoirs. Thus, production from Class I oil reservoirs in Oklahoma is at high risk because individual well production commonly is low (1–3 barrels per day) and operating costs are high. Declines in crude oil prices or increases in operating costs can cause an increase in well-abandonment rates. Successful implementation of appropriate improved-recovery technologies could sustain production from these reservoirs well into, and perhaps throughout much of, the 21st century. Without positive intervention, most of the production from Oklahoma FDD oil reservoirs will be abandoned early in the next century.

The technology-transfer program has several parts. Elements include play publications and workshops to release play analyses that identify improved recovery opportunities in each of the plays. In addition, there are other sources of publicly accessible information related to FDD reservoirs, including the OGS Natural Resources Information System (NRIS) Facility, a computer laboratory located in north Norman.

First opened in June 1995, the OGS NRIS Facility provides access to computerized oil and gas data files for Oklahoma and software necessary to analyze the information. Both well history data and oil and gas production data are available for the entire State. Plugging report data are currently being added to the system on a county-by-county basis. Access to the files is through menu-driven screen applications that can be utilized by computer novices as well as experienced users. There are technical support staff to assist operators in obtaining information about their producing properties as well as geological and engineering outreach staff to help operators determine appropriate improved-recovery technologies for those properties. The lab is equipped with Pentium PCs—each with a CD-ROM drive, full-scale inkjet plotter, laser printer, log scanner, and Zip drive. Geology-related software to do mapping, contouring, modeling and simulations, log analysis, volumetrics and economics, pump optimization, fracture design and analysis, and 3D seismic interpretation is available for public use. In the future, it will be possible to access the facility's data files remotely, most likely via the Internet.

Technology-transfer events began with the first workshop and publication, addressing the Morrow play, on June 1, 1995. Other plays in this series include the Booch play, the Layton & Osage-Layton play, the Skinner and Prue plays, the Cleveland and Peru plays, the Red Fork play, the Bartlesville play, and the Tonkawa play.

FDD-DETERMINING CRITERIA

For purposes of this project, fluvial-dominated deltaic (FDD) reservoirs were interpreted to consist of sandstones that were deposited in a deltaic or strictly fluvial environment.

Depositional environments of sandstone bodies in the Midcontinent region were identified using specific criteria which differentiate between fluvial-dominated deltaic (FDD) and marine deposits. These criteria were interpreted from information gathered from well logs and from the literature and include:

1. Electric log signatures (gamma ray, density-neutron, and resistivity are the most dependable).
2. Geometry of the sand body (from isopach mapping).
3. Texture (grain size and sorting).
4. Fossils and trace fossils.
5. Authigenic minerals (formed in-place after deposition). *Glauconite* is considered a marine indicator although its presence can indicate postdepositional reworking by marine processes (then it is allogenic). *Siderite* is considered evidence of subaerial deposition, of fresh-water origin.
6. Sedimentary structures (bedding types, bioturbation, soft-sediment deformation).
7. Thickness.
8. Contacts (sharp or gradational).
9. Rock type and lithologic relationships (vertical and lateral).
10. Paleocurrents.

DEPOSITIONAL SETTING OF FLUVIAL-DOMINATED DELTAIC RESERVOIRS

The depositional setting of a fluvial-dominated deltaic reservoir system is located at the boundary between a continental landmass and the marine environment where the products of a drainage basin are deposited. The character and distribution of the depositional products depend upon the size and relief of the drainage basin, the composition and distribution of the source rocks, the climate of the region, and the behavior of the marine environment. Brief discussions of the significant features of such a depositional setting are presented here to help readers better understand the properties of the individual fluvial-dominated deltaic reservoirs identified in this project.

For more detailed background information, readers are referred to Brown (1979), Coleman and Prior (1982), Galloway and Hobday (1983), and Swanson (1993).

COASTAL FLOOD-PLAIN SYSTEMS

In the context of fluvial-dominated deltaic reservoir systems, a subaerial coastal plain is considered a depositional environment that extends inland from a marine shoreline or landward from a delta plain. A coastal plain can overlie preexisting strata of any origin or age and may include a variety of fluvial depositional settings, such as flood plains (Fig. 1), incised valley-fill systems, and lowlands containing swamps or marshes. These settings may be controlled structurally or they may be topographic depressions caused by subsidence or erosion. In the case of incised valley-fill systems, the transition from fluvial to marine deposits may be abrupt, and there may be little or no delta formation. On the other hand, there may be a gradational transition in the coastal plain from fluvial to deltaic deposits, and it may be difficult to distinguish between coastal-plain (or flood-plain) deposits and those of an upper delta plain (Fig. 1) except by their geographic relationship to the shoreline. Nevertheless, a coastal flood plain is considered distinct from an upper delta plain, and subaerial deposition in an identified coastal flood-plain environment is considered to occur inland from a delta or marine shoreline.

The most common reservoirs in coastal flood-plain environments occur in channel deposits. Several types of such deposits are identified in the Pennsylvanian of the Midcontinent region; they include point bars, braided river deposits, anastomosing river deposits, and longitudinal and transverse river bars. Point bars

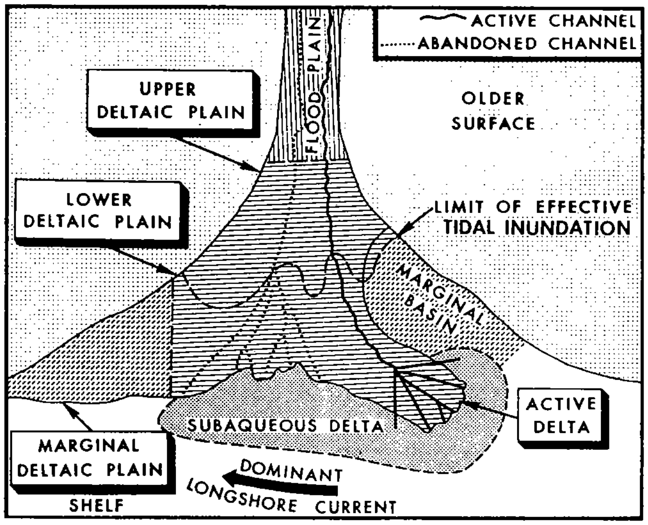
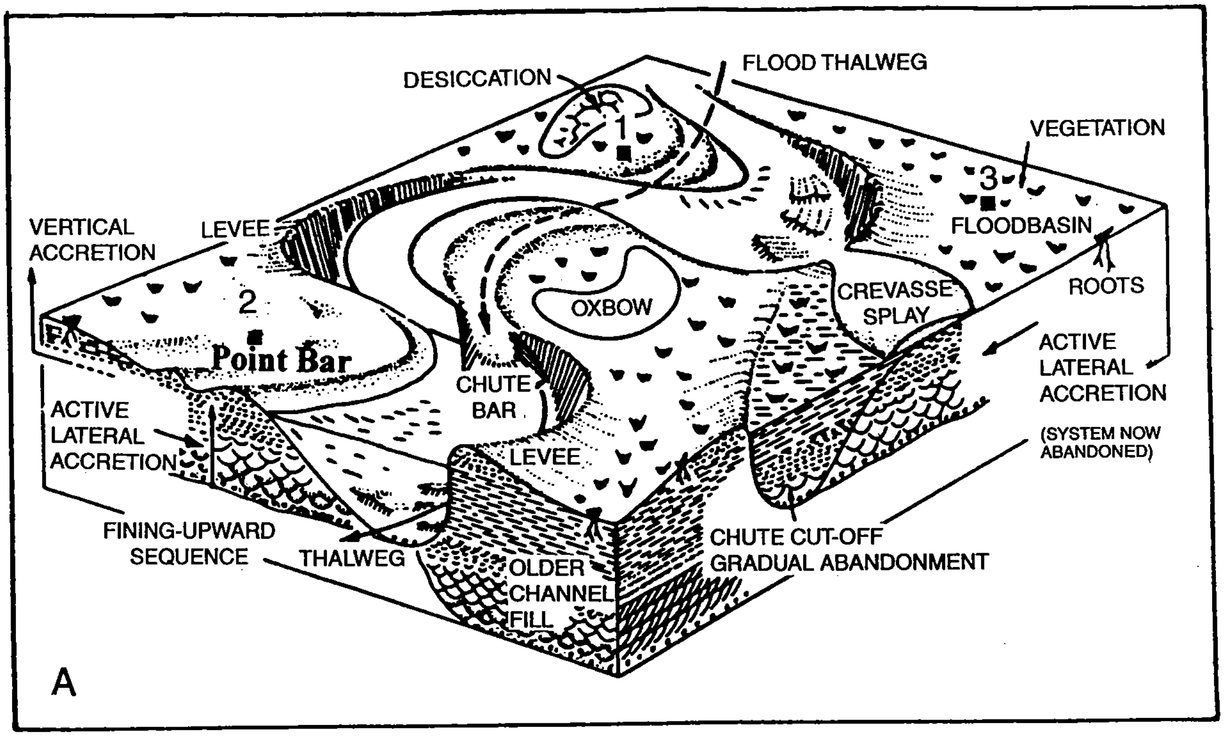


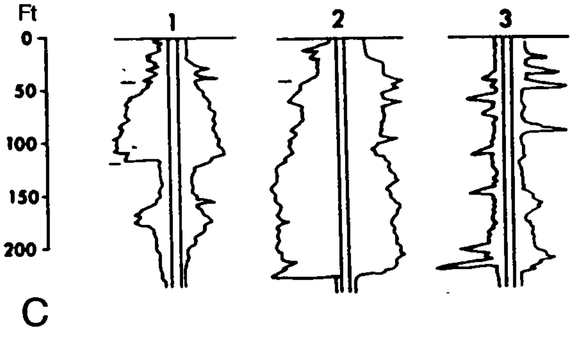
Figure 1. Components of a delta system. From Coleman and Prior (1982).

are the most common components of fluvial systems in Oklahoma.

Fluvial Point Bars

Point bars are fluvial accumulations of sand, silt, and mud that are deposited on the down-flow, inside bank of a meander bend, commonly referred to as the depositional bank (Fig. 2A). They are formed by common depositional processes and are not unique to any single depositional environment. Point bars occur in all coastal flood-plain systems as well as in upper delta plains. Point bars also are found in nondeltaic, semimarine environments such as estuarine channels where tidal forces, rather than riverine processes, are the principal sources of energy. Individual point bars may be much more than 100 ft thick and can extend





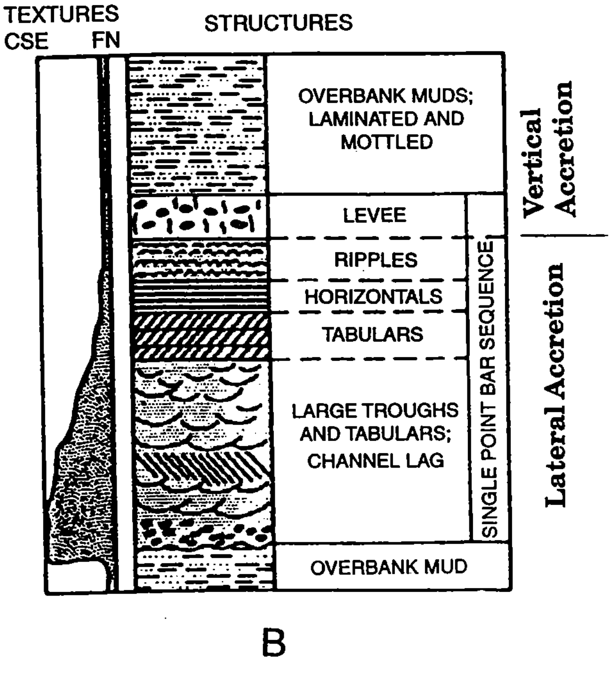


Figure 2. (A) Schematic model of a meandering river system. Erosion of the outside bend of a meander loop leads to lateral accretion of a point bar down-flow on the inside bank of the meander bed. Modified from Walker (1984). (B) Textural and facies characteristics of typical point-bar deposits. Modified from Brown (1979). (C) Idealized electric log responses related to point-bar deposits in (A). From Coleman and Prior (1982).

laterally for more than a mile. Stacked assemblages commonly are hundreds of feet thick. In the Pennsylvanian of the Midcontinent, point bars commonly are 20–50+ ft thick and occur laterally within meander belts that are <2 mi wide. Important attributes of point-bar deposits are included in a summary of fluvial-deltaic sandstone characteristics (Fig. 3).

In the sense of depositional processes, point bars are unique because they form by lateral accretion rather than direct vertical aggradation of the sand body. This depositional style promotes the lateral growth of a sand body over considerable distances without complete inundation. Lateral accretion also accounts for inconsistent deposition of sand which in turn causes compartmentalization of potential reservoirs. This compartmentalization promotes hydrocarbon entrapment but also is an impediment to hydrocarbon recovery and stimulation, and to reservoir characterization. Figure 4 illustrates the depositional environment of point bars and related flood-plain deposits in a tidally influenced, valley-fill river system. This type of depositional model is applicable to many Pennsylvanian sandstones in Oklahoma that were deposited during transgressive events. Descriptions and depositional-environment interpretations are given in Figure 5.

Point bars can make excellent reservoirs but their heterogeneity is a significant problem in reservoir management. In a vertical profile, such as in outcrop, core, or well logs, a typical point bar has a finer grain size upward or blocky textural profile (Fig. 2B). In the lower point bar, coarser fractions commonly are medium to coarse grained, in places are conglomeratic, and commonly contain pebble-size rip-up clasts. Successively higher sediments include fine- to medium-grained sand, silt, and clay. Overall, point bars have individual graded-bed sets that become thinner and finer grained vertically. Shale commonly is interbedded with sandstone in the middle and upper part of a point bar and these bed sets are inclined at a distinct angle that is unrelated to true dip. These shale interbeds, referred to as clay drapes, are effective visual illustrations of the lateral accretionary nature of point-bar deposits. They also are effective in isolating individual sand layers even within a single point bar. Clay drapes originate during periods of decreasing river discharge in mixed-load fluvial systems. Clay drapes seldom are mentioned or implied in most core studies, yet, they can be interpreted from serrated log signatures such as in Figure 2C. They also are visible in outcrops of practically any fluvial meandering system. Sedimentary structures commonly found in lower point-bar sequences consist of massive to graded bedding, high angle tabular and trough cross-bedding, and rip-up clasts. Common sedimentary features found in the upper part of a point bar include root traces, carbonaceous debris, and sandstone with horizontal and ripple laminations.

Because of the above-mentioned heterogeneities in point bars, the potential for hydrocarbon entrapment in a meandering system is very good. However, recovery of oil and/or gas from these types of deposits commonly is restricted to those portions of a point bar that have a reasonable degree of vertical and lateral continuity. Although many authors avoid this issue for fear of being overly pessimistic, in reality, recovery is concentrated in only certain portions of point bars. If a water-saturated zone is present, the best portion of the reservoir (lower point-bar facies) may occur below the oil/water contact. Hydrocarbons then may be concentrated within the central and upper portions of the point bar which commonly are finer grained and more likely to have the greatest amount of reservoir heterogeneity. If the upper part of a point bar is absent due to erosion or nondeposition, hydrocarbons then may be trapped lower within the point-bar interval. This situation is considerably more favorable for oil recovery because sandstone within the lower part of a point bar is generally coarser grained, occurs in thicker beds, and normally has better effective porosity. Consequently, recoverable reserve calculations can be vastly incorrect when they are based on the assumption that the entire sand body represents the true reservoir thickness. Corresponding recoveries from primary production methods commonly are only about 10–20% of the calculated recoverable reserve, and yield is mostly in the range of 50–150 BO/acre-ft, which is typical for many Pennsylvanian sandstones in Oklahoma. Secondary recovery methods, such as water flooding, normally will double the primary recovery, but reservoir response is highly dependent upon proper field engineering and reservoir characterization.

Point bars sometimes are referred to as shoestring or ribbon sands because of their tendency to occur in a sinuous, meandering pattern. An awareness of this characteristic pattern is important to understanding the spatial relationships within, and the physical parameters of, fluvial systems and associated sand deposits. Swanson (1976) and Coleman and Prior (1982) show that the average meander amplitude of an active meandering stream is about half the width of its enclosing meander belt. But as a meander system aggrades vertically above its own flood plain, the hydraulic difference creates instability and leads to avulsion, a lateral shift of the fluvial system to other portions of the flood plain. Obviously, in such a system, lateral and vertical relationships of sandstone beds are complicated.

DELTA SYSTEMS

In this study, a delta is defined as an accumulation of river-derived sediment that is deposited as an extension to the coast (Fig. 1). In a relatively stable tectonic setting and in a moderately subsiding shelf, sediments commonly consist of sand and finer grained clastics, which are deposited in interdistributary bays and in front of the delta. In such settings, however, marine forces such as waves and tidal currents commonly redistribute the sediments and produce different delta

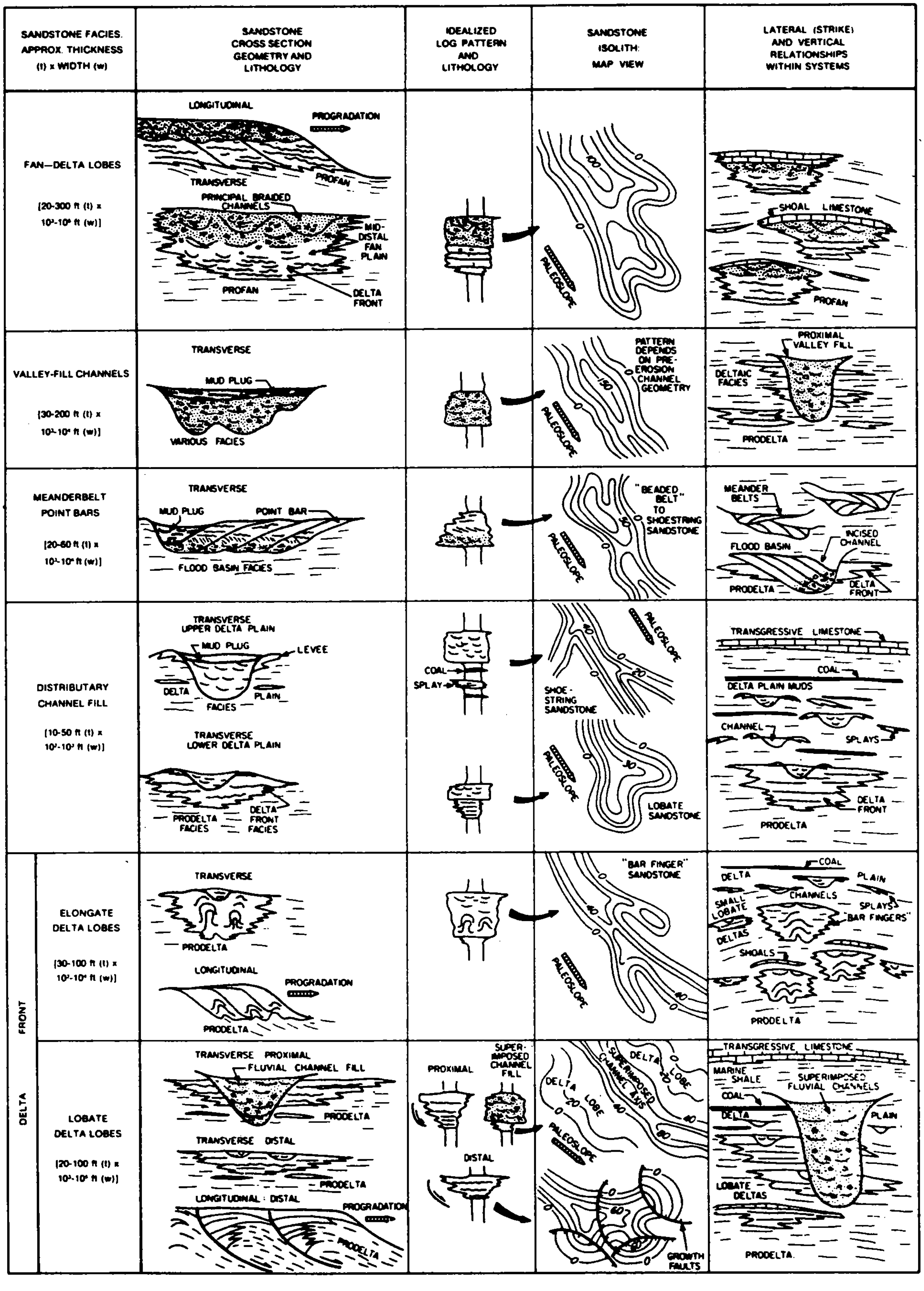


Figure 3. Summary of the characteristics of Midcontinent fluvial and deltaic sandstone bodies. From Brown (1979).

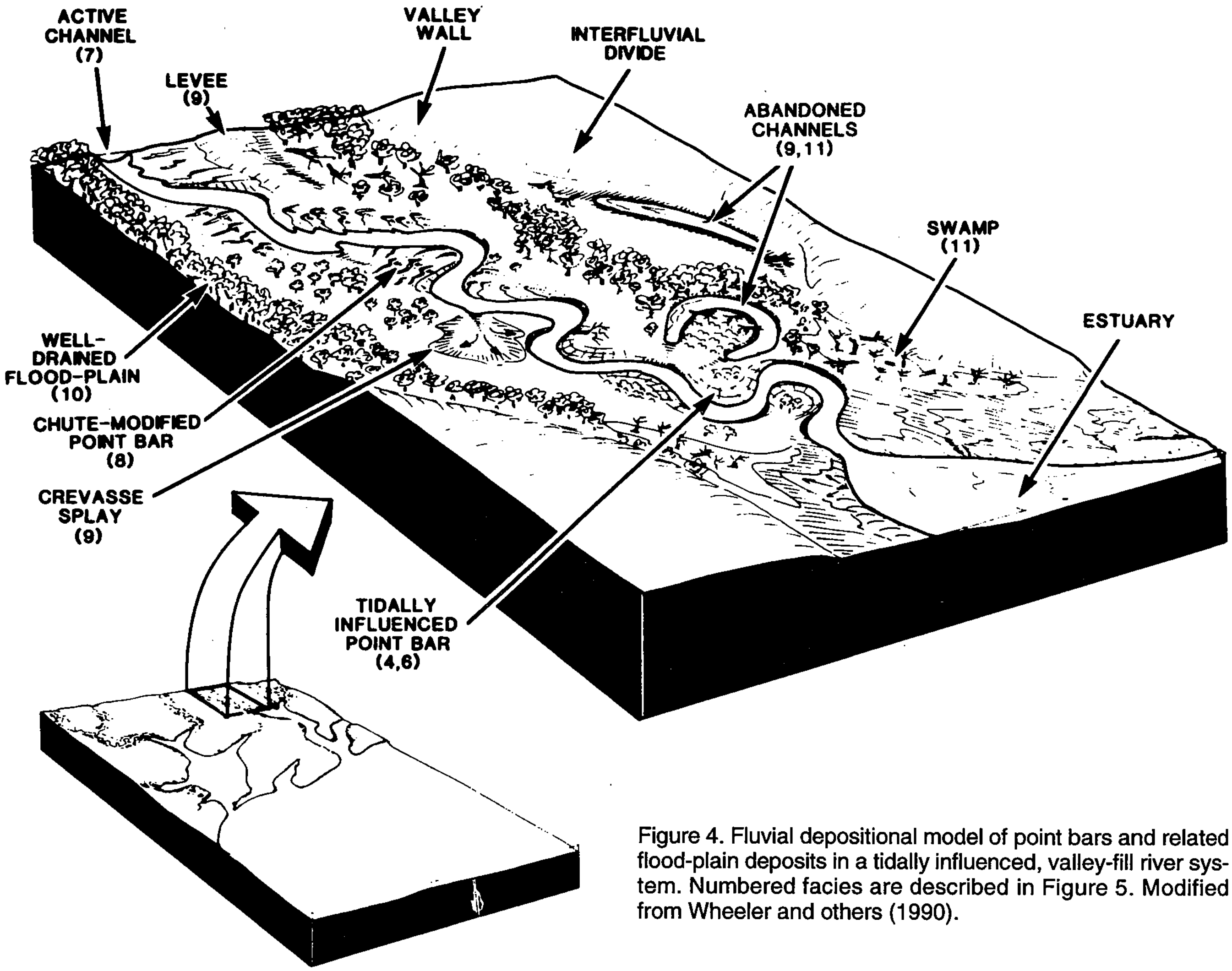


Figure 4. Fluvial depositional model of point bars and related flood-plain deposits in a tidally influenced, valley-fill river system. Numbered facies are described in Figure 5. Modified from Wheeler and others (1990).

morphologies. Figure 6 illustrates the classification of delta systems, which is based on the relative intensity of fluvial versus marine processes. The main emphasis in this project is on reservoir-quality sandstones that are components of fluvial-dominated delta systems.

The basic components of a prograding delta system are shown in Figure 1 and include the upper delta plain, lower delta plain, and subaqueous delta or delta front. In an idealized vertical depositional sequence, fluvial point bars and distributary channels of the delta plain overlie delta front sands and prodelta shale. This relationship is illustrated in Figure 7, which also shows typical log patterns, lithology, and facies descriptions of the various depositional phases of a typical progradational sequence. Progradation refers to a depositional system that is built seaward (offlap). Sedimentary facies in a progradation typically show an upward shallowing depositional origin. Progradation is similar in meaning to regression, which refers to a general retreat of the sea from land areas so that shallower water environments occur in areas formerly occupied by deeper water. This is in contrast to transgression (onlap), which occurs when the position of the sea moves landward and brings deeper water depositional environments to areas formerly occupied by shallower water or by land.

Upper Delta Plain

As shown in Figure 1, the upper delta plain extends from the down-flow edge of the coastal flood plain to the limit of effective tidal inundation of the lower delta plain. The upper delta plain essentially is the portion of a delta that is unaffected by marine processes. Recognizable depositional environments in the upper delta plain include meandering rivers, distributary channels, lacustrine delta-fill, extensive swamps and marshes, and fresh-water lakes. Some of these environments are recognized in normal well log interpretations. For example, meandering rivers have the classic bell-shaped electric log curves of fluvial point bars, and distributary channels tend to have more blocky log profiles. Coal and interbedded shale deposits, evidence of swamps and marshes, also can be interpreted from well logs. Although not diagnostic by

#	FACIES DESCRIPTION	INTERPRETATION
1	**DARK-GRAY, THINLY LAMINATED SHALE:** Slightly calcareous or dolomitic; thinly planar- to wavy-laminated, fissile or platy; includes starved ripple-laminations; rare *Planolites*, *Zoophycus*, and *Thalassinoides*; occurs in both the lower and upper Morrow; ranges from 1 to 57ft (0.3 to 17.4m) in thickness.	**OFFSHORE MARINE:** Inner to Outer Shelf
2	**SHALY CARBONATE:** Gray to dark-gray calcareous wackestone to packstone; generally wavy-laminated but may be burrow-mottled or cross-bedded; skeletal material generally re-oriented and moderately abraded; includes crinoid, brachiopod, bryozoan, mollusc and pelecypod fragments; 0.5 to 10ft (0.2 to 3.1m) thick in the upper Morrow, up to 18ft (5.5m) thick in the lower Morrow.	**SHALLOW MARINE:** Open Shelf or Transgressive Lag
3	**SKELETAL WACKESTONE TO GRAINSTONE:** Gray to tan, limestone or dolomite; planar- to wavy-laminated or cross-bedded; may appear massive or nodular due to weathering or burrowing; includes crinoids, brachiopods, bryozoans, corals, molluscs, gastropods, echinoderms, peloids and intraclasts; occurs only in the lower Morrow; 0.5 to 46ft (0.2 to 14m).	**RESTRICTED TO OPEN MARINE PLATFORM:** Shoals and Bioherms
4	**INTERLAMINATED TO BIOTURBATED SANDSTONE AND SHALE:** Includes interbedded and homogenized lithologies; light-gray, very fine- to fine-grained sandstone and gray to dark-gray shale and mudstone; planar-, wavy- and ripple-laminated; convoluted bedding common; glauconitic; moderately burrowed to bioturbated; *Thalassinoides*, *Planolites*, *Skolithos*, *Asterosoma*, *Chondrites* and *Rosellia*(?); occurs in both the lower and upper Morrow; 1 to 28ft (0.3 to 8.5m) thick.	**NEARSHORE MARINE OR ESTUARINE:** Shoreface or Delta Front; Tidal Flat or Tidal Channel
5	**CROSS-BEDDED, FOSSILIFEROUS SANDSTONE:** Light-gray, fine- to coarse-grained quartz arenite to sublitharenite; trough or tabular cross-bedded in 3 to 18in (7.6 to 45.7cm) thick sets; up to 50% skeletal debris; crinoid, brachiopod, bryozoan and coral fragments; glauconitic; occurs only in the lower Morrow; units up to 25ft (7.6m) thick.	**UPPER SHOREFACE OR TIDAL CHANNEL**
6	**CROSS-BEDDED SANDSTONE WITH SHALE DRAPES:** Gray to tan, fine- to coarse-grained quartz arenite or shaly sandstone; trough or tabular cross-bedded with incipient stylolites, shale drapes and interlaminations between foreset laminae; foresets are often tangential with the lower bounding surfaces and grade laterally into ripple laminations, some oriented counter to the cross-bedding; cross-bed set thickness is 3 to 12in (7.6 to 30.5cm); sparsely burrowed, *Planolites*; glauconite and carbonaceous debris; occurs primarily in the upper Morrow; up to 28ft (8.5m) thick.	**FLUVIAL OR ESTUARINE:** Upper Point-Bar or Flood-Plain; Tidally Influenced Fluvial Channel
7	**CONGLOMERATE TO CONGLOMERATIC SANDSTONE:** Gray to light-brown; granules and pebbles of mudstone and composite quartz; matrix is fine- to very coarse-grained, poorly sorted, quartz arenite or sublitharenite to subarkose; massive appearing, planar-bedded or cross-bedded; carbonaceous debris; glauconite and phosphate scarce; occurs only in the upper Morrow; up to 21ft (6.4m) thick.	**FLUVIAL CHANNEL:** Braided Stream, Channel-Bottom Lag or Lower Point-Bar
8	**COARSE-GRAINED, CROSS-BEDDED SANDSTONE:** Medium- to very coarse-grained quartz arenite or subarkose to sublitharenite; trough or tabular cross-bedded in sets ranging from 3in (7.6cm) to over 2ft (0.6m) thick; in many cases foreset laminae alternate between coarser and finer grain-size fractions; convoluted bedding is common; carbonaceous debris, including coaly fragments, macerated organic material ("coffee grounds"), leaf and log impressions is prevalent; *Planolites* burrows are rare; occurs in the upper Morrow; units up to 29ft (8.8m) thick.	**FLUVIAL CHANNEL:** Chute-Modified Point-Bar
9	**RIPPLE-LAMINATED SANDSTONE:** Very fine- to fine-grained quartz arenite; symmetrical or asymmetrical ripples; glauconite and carbonaceous debris are common; trace fossils include *Planolites* and *Skolithos*; occurs with many other facies throughout the Morrow; ranges up to 30ft (9.2m) thick.	**FLUVIAL OR MARINE SHOREFACE:** Upper Point-Bar, Splay, Levee or Abandoned Channel-Fill; Middle Shoreface
10	**GRAY-GREEN MUDSTONE:** May have brick-red iron oxide speckles; generally blocky and weathered in appearance; very crumbly; moderate to abundant amounts of carbonaceous debris; compaction slickensides and root-mottling common; calcareous nodules occur in the lower Morrow and beds are 0.5 to 2ft (0.2 to 0.6m) thick; up to 30ft (9.2m) thick in the upper Morrow.	**FLUVIAL FLOOD-PLAIN OR EXPOSURE SURFACE:** Well-Drained Flood-Plain; Alteration Zone or Soil
11	**DARK-GRAY CARBONACEOUS MUDSTONE:** Generally planar-laminated; abundant carbonaceous debris including leaf and stick impressions; pyrite, root traces and slickensides common; occurs only in the upper Morrow; units range up to 30ft (9.2m) in thickness.	**FLUVIAL FLOOD-PLAIN:** Swamp or Abandoned Channel-Fill
12	**COAL:** Massive or laminated; commonly pyritic; occurs only in the upper Morrow; generally 1 to 6in (2.5 to 15.2cm) thick, but ranges up to 2ft. (0.6m).	**SWAMP**

Figure 5. Fluvial facies descriptions and depositional environment interpretations for numbered facies shown in Figure 4. This information was used originally by Wheeler and others (1990) to describe the Morrow in southeastern Colorado and southwestern Kansas, but it is also useful in clastic facies interpretations of many other Pennsylvanian meandering river systems in Oklahoma.

themselves, point bars, coal, and migratory distributary channels are primary elements that characterize the upper delta plain. By combining information about those elements with other data, such as from cores or sequential stratigraphic analysis (Fig. 7), a more accurate depositional interpretation can be made. Such a combination of data can lead to a better understanding of sandstone distribution trends and reservoir characteristics in any depositional environment.

The principal reservoirs found within the upper delta plain are fluvial point bars and distributary channel sands. Point bars have been discussed in the section on coastal plain deposits. Distributary channels are more characteristic of the lower delta plain and are discussed in the following section.

Lower Delta Plain

In the rock record, each component of a delta has characteristics that are determined largely by vertical

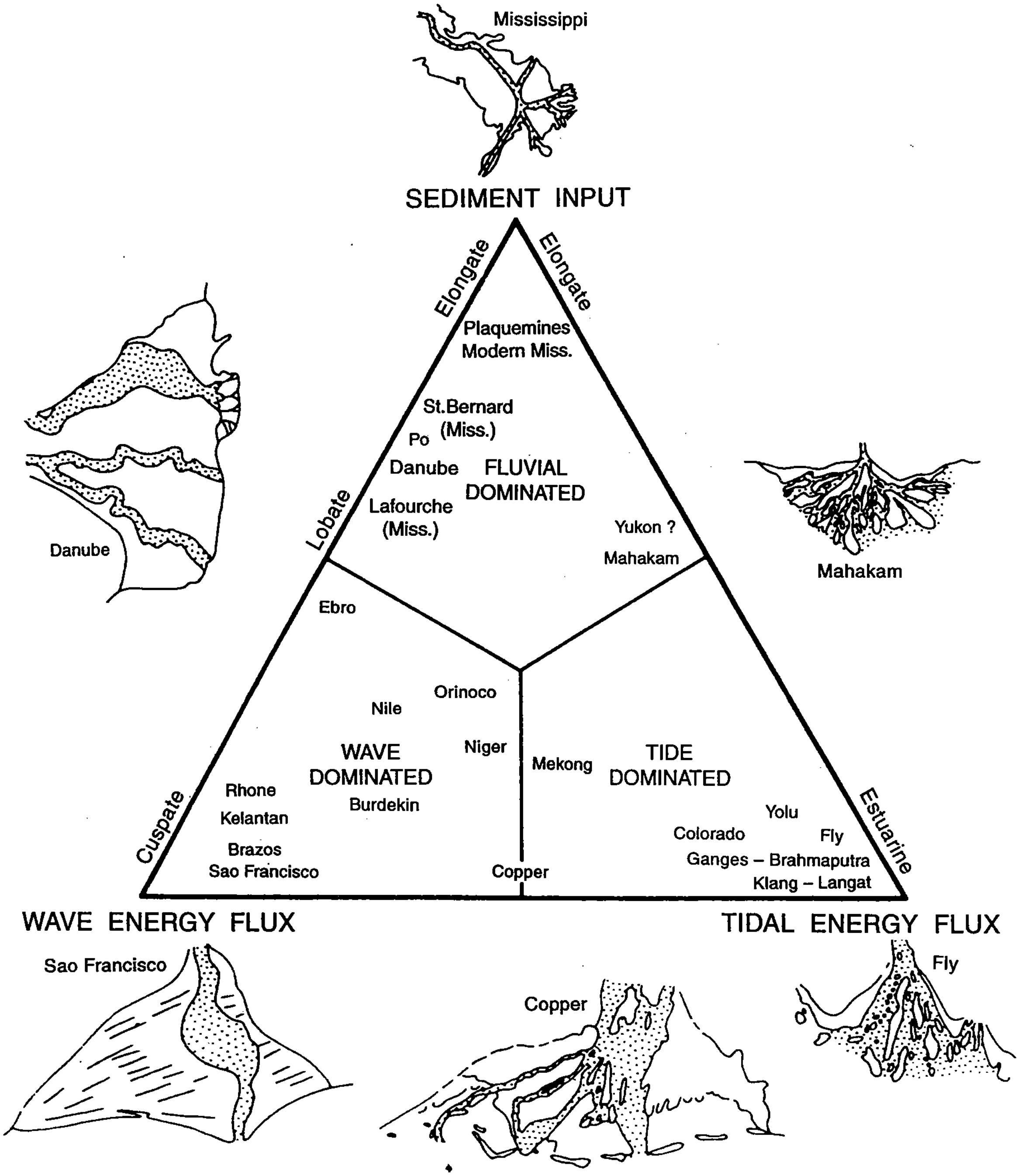
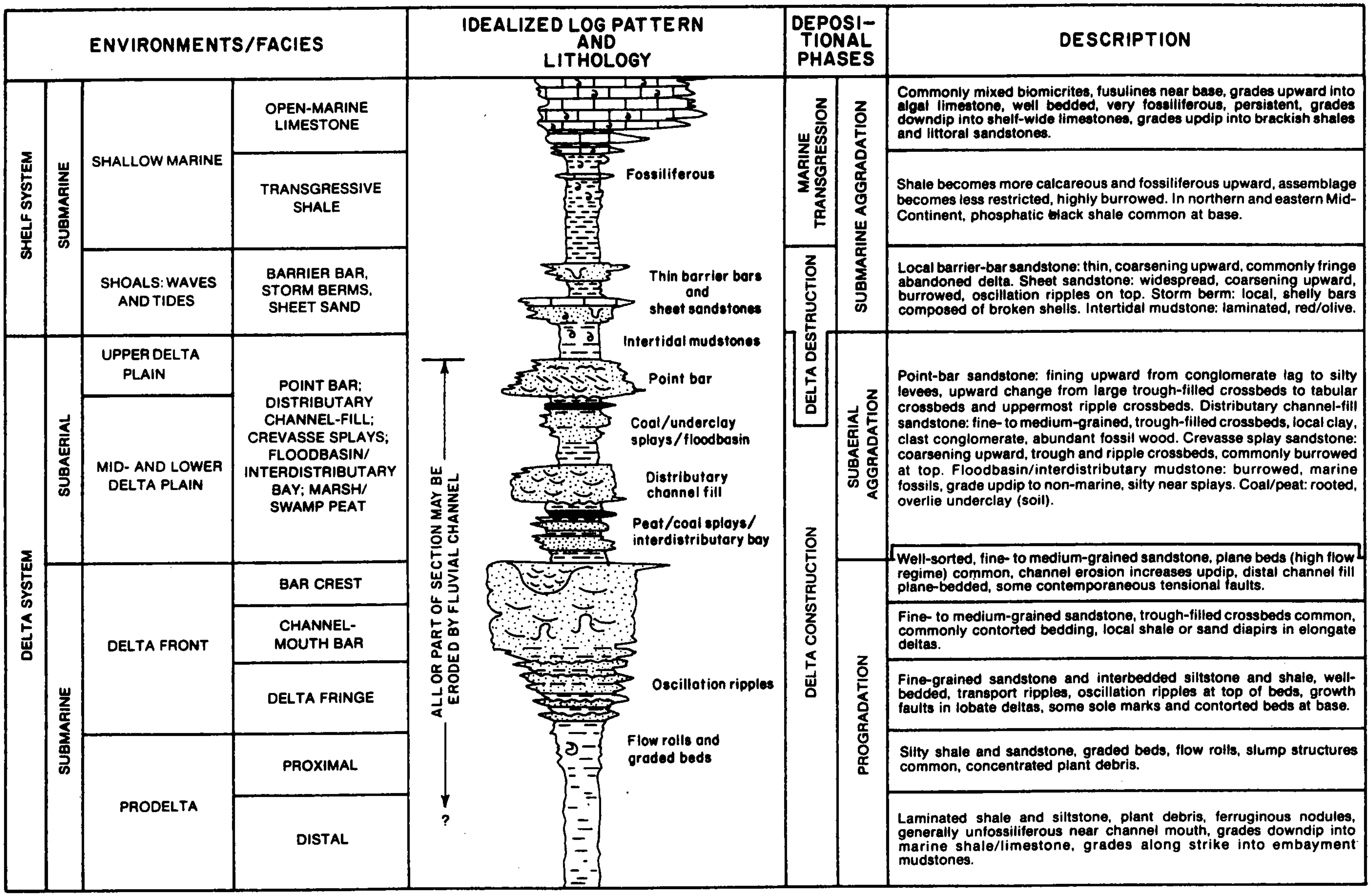


Figure 6. Morphologic and stratigraphic classification of delta systems based on relative intensity of fluvial and marine processes. From Galloway and Hobday (1983).



ENVIRONMENTS/FACIES				IDEALIZED LOG PATTERN AND LITHOLOGY	DEPOSITIONAL PHASES		DESCRIPTION
SHELF SYSTEM	SUBMARINE	SHALLOW MARINE	OPEN-MARINE LIMESTONE		MARINE TRANSGRESSION	SUBMARINE AGGRADATION	Commonly mixed biomicrites, fusulines near base, grades upward into algal limestone, well bedded, very fossiliferous, persistent, grades downdip into shelf-wide limestones, grades updip into brackish shales and littoral sandstones.
			TRANSGRESSIVE SHALE	Fossiliferous			Shale becomes more calcareous and fossiliferous upward, assemblage becomes less restricted, highly burrowed. In northern and eastern Mid-Continent, phosphatic black shale common at base.
		SHOALS: WAVES AND TIDES	BARRIER BAR, STORM BERMS, SHEET SAND	Thin barrier bars and sheet sandstones Intertidal mudstones	DELTA DESTRUCTION		Local barrier-bar sandstone: thin, coarsening upward, commonly fringe abandoned delta. Sheet sandstone: widespread, coarsening upward, burrowed, oscillation ripples on top. Storm berm: local, shelly bars composed of broken shells. Intertidal mudstone: laminated, red/olive.
DELTA SYSTEM	SUBAERIAL	UPPER DELTA PLAIN MID- AND LOWER DELTA PLAIN	POINT BAR; DISTRIBUTARY CHANNEL-FILL; CREVASSE SPLAYS; FLOODBASIN/ INTERDISTRIBUTARY BAY; MARSH/ SWAMP PEAT	Point bar Coal/underclay splays/floodbasin Distributary channel fill Peat/coal splays/ interdistributary bay ALL OR PART OF SECTION MAY BE ERODED BY FLUVIAL CHANNEL	DELTA CONSTRUCTION	SUBAERIAL AGGRADATION	Point-bar sandstone: fining upward from conglomerate lag to silty levees, upward change from large trough-filled crossbeds to tabular crossbeds and uppermost ripple crossbeds. Distributary channel-fill sandstone: fine- to medium-grained, trough-filled crossbeds, local clay, clast conglomerate, abundant fossil wood. Crevasse splay sandstone: coarsening upward, trough and ripple crossbeds, commonly burrowed at top. Floodbasin/interdistributary mudstone: burrowed, marine fossils, grade updip to non-marine, silty near splays. Coal/peat: rooted, overlie underclay (soil).
	SUBMARINE	DELTA FRONT	BAR CREST			PROGRADATION	Well-sorted, fine- to medium-grained sandstone, plane beds (high flow regime) common, channel erosion increases updip, distal channel fill plane-bedded, some contemporaneous tensional faults.
			CHANNEL-MOUTH BAR				Fine- to medium-grained sandstone, trough-filled crossbeds common, commonly contorted bedding, local shale or sand diapirs in elongate deltas.
			DELTA FRINGE	Oscillation ripples			Fine-grained sandstone and interbedded siltstone and shale, well-bedded, transport ripples, oscillation ripples at top of beds, growth faults in lobate deltas, some sole marks and contorted beds at base.
		PRODELTA	PROXIMAL	Flow rolls and graded beds			Silty shale and sandstone, graded beds, flow rolls, slump structures common, concentrated plant debris.
			DISTAL	?			Laminated shale and siltstone, plant debris, ferruginous nodules, generally unfossiliferous near channel mouth, grades downdip into marine shale/limestone, grades along strike into embayment mudstones.

Figure 7. Idealized cratonic delta sequence showing principal depositional phases, idealized electric log pattern, and facies description. From Brown (1979).

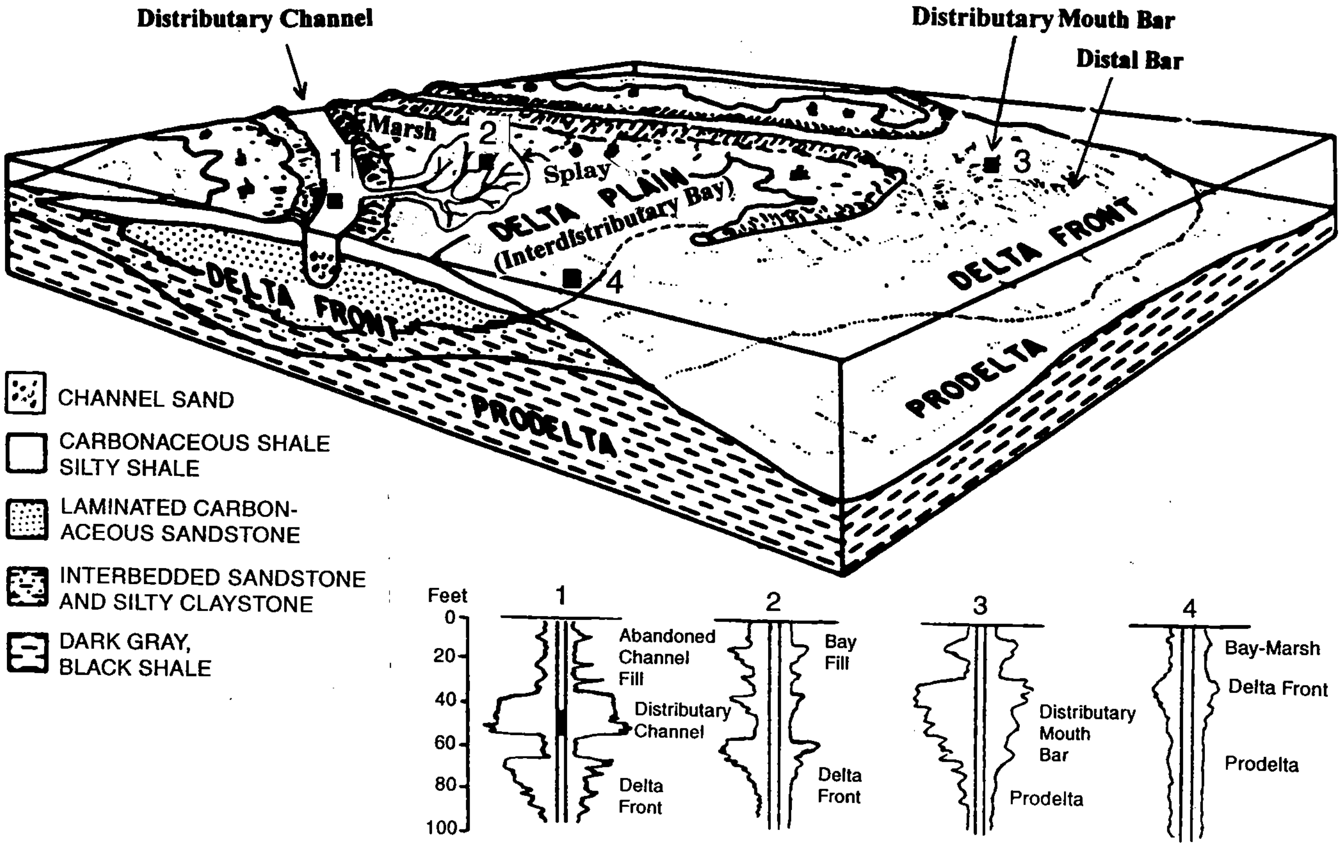


Figure 8. Schematic model of deltaic depositional environments. Idealized electric log responses and inferred facies are shown for locations Nos.1–4. Modified from Brown (1979).

and lateral relationships of rock facies and by faunal content. In the lower delta plain, sediments are influenced highly by marine conditions, which extend from the subaqueous delta front to the landward limit of marine (tidal) influence (Fig. 1). The lower delta plain consists primarily of bay-fill deposits, which occur between or adjacent to major distributarics, and secondarily of distributary-channel deposits. Distributary mouth bars and bar-finger deposits are the principal components of the subaqueous delta front (Fig. 1) and are attached to the lower delta plain. These environments and idealized electric log patterns of associated clastic facies are illustrated in Figure 8.

Lower-delta-plain sediments characteristically overlie delta-front sands and prodelta shale. In the upper reaches of the lower delta plain, coal commonly is associated with marshy areas that are insulated from rapid sedimentation or destructive marine events that typify the lower reaches of the delta plain. Through continued progradation of a delta, the lower delta plain is overlain by upper-delta-plain sediments. Unless the stratigraphic relationship is unconformable, coastal flood-plain sediments commonly are not recognized in succession above delta-plain deposits.

Bay Fill and Splays

Bay-fill sediments originate from several sources including effluent plumes of major distributaries and crevasse splays. Splays, however, are the dominant source of bay-fill sandstone and constitute much of the sediment in fluvial-dominated deltas as shown in Figure 9, which identifies the distribution of principal sand facies in the modern Mississippi River delta. Splays originate during flooding events when sediment is carried through a breach in a distributary levee and distributed into shallow bays through a branching network of smaller channels. The lenticular, fan-shaped deposits (crevasse splays) commonly are 10–40 ft thick and consist of individual sequences of sand and mud that increase in grain size upward. This stratigraphic characteristic is caused by the rapid deposition of suspended sediments ahead of current-induced bed-load transport of coarser sand. However, because splays are driven by fluvial processes, thin distributary-channel deposits also are constituents of every splay. The thickness of a splay deposit commonly is proportional to the depth of the interdistributary bay and the hydraulic advantage between the distributary channel and the receiving area. Thus, splays characteristically are thinner than distributary mouth bars and contain less sand. After abandonment of a crevasse system and subsequent subsidence, the area reverts to a bay environment when marine waters encroach. This entire cycle lasts about 100–150 years (Coleman and Prior, 1982) and may be repeated several times to form a stacked assemblage such as that shown in log signature on Fig-

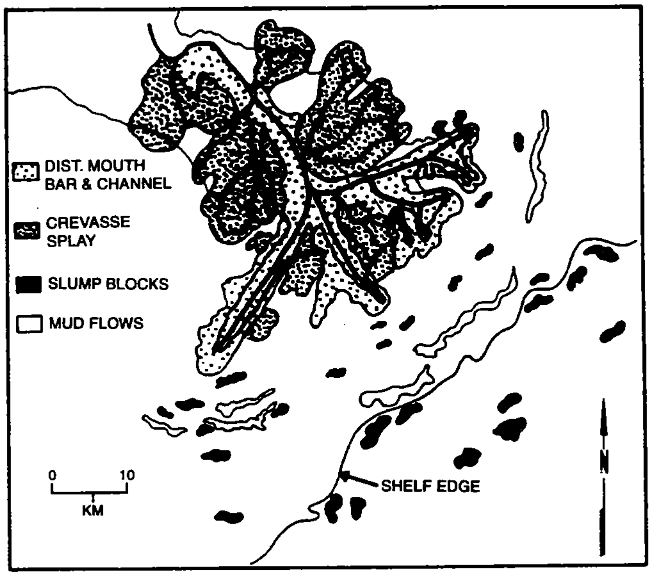


Figure 9. Distribution of principal sand facies in the modern Mississippi River fluvial-dominated delta. From Coleman and Prior (1980).

ure 8. Splay deposits are not considered to be good reservoirs because they contain large amounts of detrital clay, which reduce the effective porosity and permeability of the sandstone beds.

Distributary Channels

Distributary channels are responsible for the primary distribution of nearly all sediments within the lower delta plain. Despite their conspicuous presence, however, they account for a relatively small volume of sediment in the delta, as is illustrated in the schematic model of a delta (Fig. 8) and in the sand facies distribution map of the modern Mississippi River delta (Fig. 9).

Distributary channels typically are incised upon preexisting interdistributary or delta-front sediments. Because they occur at the end of a fluvial transport regime, distributary-channel sands commonly are uniformly fine grained and well sorted. As shown in Figure 3, distributary-channel sand bodies commonly are 10–50 ft thick and 100–1,000 ft wide. Sedimentary structures consist of tabular and trough cross-bedding, clay clasts, and contorted beds (Fig. 10).

The extension of distributary channels into the subaqueous marine environment and the concurrent deposition of levee structures help prevent lateral migration of distributary channels. This stabilizing condition inhibits the formation of point bars that characterize coastal flood-plain meander-belt systems. Since distributary channels occur within, or in close proximity to, marine conditions, they may incorporate marine constituents such as shell fragments, fossils, and glauconite.

Distributary Mouth Bars and Bar Fingers

The progradation of a fluvial-dominated system such as the modern Mississippi River delta is sustained by a series of finger-like sand bodies that are deposited ahead of the main river distributaries. These sand bars are the subaqueous extensions of major distributary channels formed because of confined flow and directed transport of suspended sediments into the open gulf. The tendency of distributary channels and accompanying bar-finger sands to be nonbranching seems to be a result of several factors such as sediment load characteristics of the river, water depth and salinity contrasts in the receiving basin, and river discharge rates. Most investigators believe that bar fingers form when river discharge is confined by the development of subaqueous levees and when sediment transport is aided by the buoying effect of saline water. Conversely, non-directed dispersal of river-mouth sediment in shallow, fresher water bays causes multiple branching distributaries

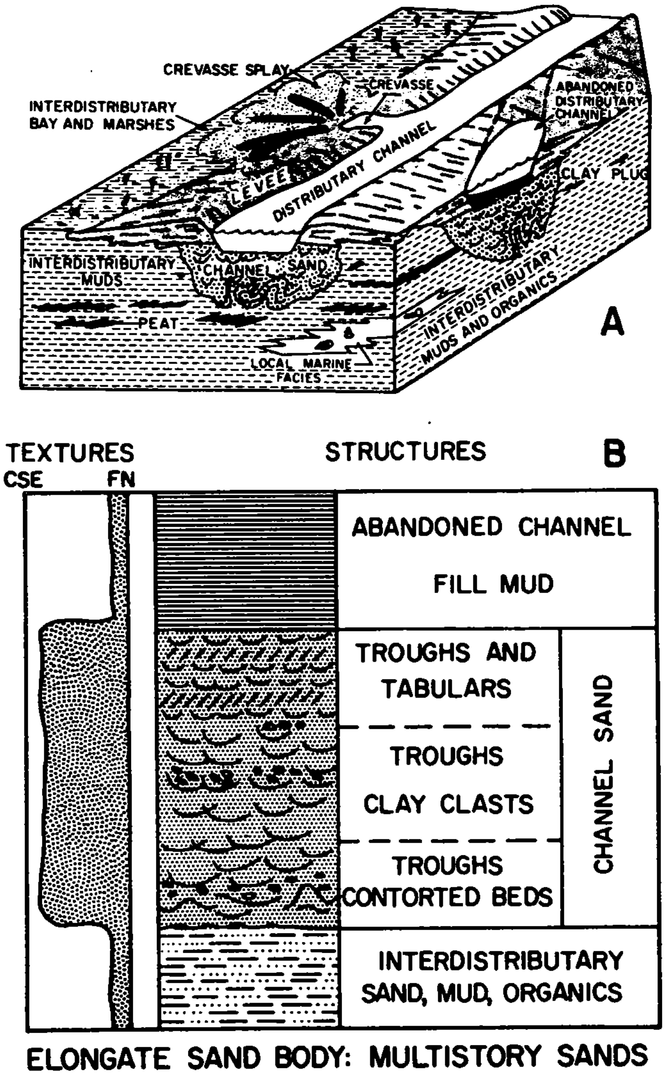


Figure 10. Distributary channel model. (A) Schematic model of channel-fill sands, lower delta plain setting; (B) idealized vertical sequence of distributary channel-fill sandstones. Modified from Brown (1979).

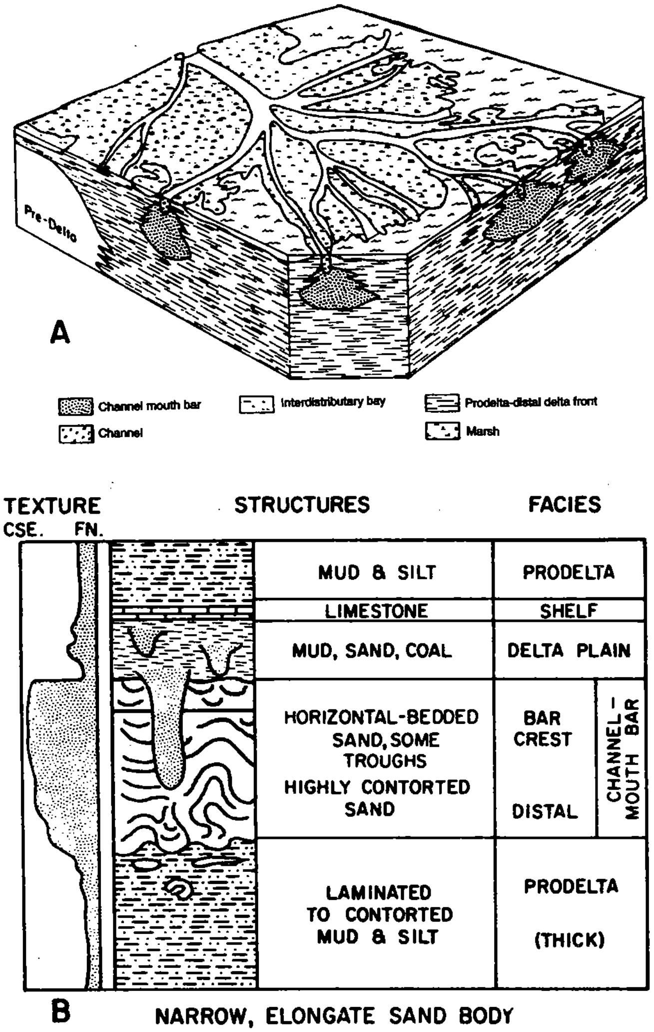


Figure 11. Elongate-delta model. (A) Birdfoot lobe, Holocene Mississippi delta; (B) idealized vertical sequence of a distributary mouth bar and associated deposits in an elongate delta. Modified from Brown (1979).

such as those that characterize other parts of the Mississippi River delta. In the latter case, distributary mouth bars are lobate rather than elongate and become progressively finer grained seaward.

Distributary mouth bars have the highest rate of deposition in the subaqueous portion of a delta. They are composed of the same sediments that constitute splays and distributary channels in the lower delta plain but are distinctly different morphologically. In the upper portion of the bar (bar crest), sands are reworked continually by wave and storm currents to produce some of the best and most laterally extensive reservoirs in delta environments. Large-scale sedimentary structures, such as high-angle and trough cross-bedding, are the result of this energy. The rapid clastic buildup also causes soft-sediment instability in the form of mud diapirs and contorted beds. These types of sedimentary structures are illustrated in Figure 11.

Distributary mouth bars make up most of the delta front and may be >200 ft thick, but commonly they are ~100 ft thick. Redistribution of the same sand by marine currents may promote the deposition of distal bars; in the event of eustatic sea level rise (transgression), barrier islands may form. Characteristically, distributary mouth bars have serrated, coarsening-upward logs and textural profiles (Figs. 8,11). In places, the facies are subdivided into a distal bar facies (lower, shaly part of profile) and a proximal bar facies (upper, sandy part of profile). The coarsening-upward stratigraphic profile is caused by the dispersal of buoyed sediment and progressive deposition of coarse-grained sediment on top of previously dispersed fine-grained sediment. Additionally, carbonaceous debris from continental sources commonly is interbedded with the sand. Distributary mouth bars commonly overlie prodelta muds and provide a relatively stable foundation over which delta-plain sediments are deposited during regressive depositional periods.

NOTE TO READERS

Industry participation in the FDD program is heartily encouraged. We welcome any comments that you may have about the content of this publication and about the ongoing needs of industry with respect to information and technology relating to FDD reservoirs. Please contact Charles J. Mankin at the Oklahoma Geological Survey, 100 East Boyd, Room N-131, Norman, OK 73019 with your questions or comments.

PART II

The Tonkawa Play: Regional Geology

Jock A. Campbell
Oklahoma Geological Survey

INTRODUCTION: OIL AND GAS PRODUCTION

The Tonkawa is the youngest of the fluvial-deltaic reservoirs to be investigated in the FDD series of workshops. Although other Virgilian formations probably include sandstones of fluvial origin (e.g., Endicott, Elgin, and Hoover sands), they are not believed to contain significant quantities of light oil.

Oil and gas are produced from the Tonkawa sand in central and western Oklahoma (Fig. 12; Pls. 1,2,3 [in envelope]) and in adjacent Kansas and the Texas Panhandle. However, the FDD play is limited to north-central Oklahoma (Pl. 3) and adjacent Kansas. The Tonkawa is known as the Stalnaker sand in Kansas. Appendix 1 is a tabulation of Tonkawa oil and gas fields in Oklahoma and is designed to accompany Plates 1 and 2.

Tonkawa reservoirs have produced oil and gas for 76 years in Oklahoma. The historical record of that production is incomplete; however, from 1979 through 1996, 29 fields produced oil from the Tonkawa sand in the area of fluvial-dominated deltaic sand deposition (Pl. 3). Several other fields are known to have produced from Tonkawa reservoirs prior to 1979: Barnes, Garber, Myers Dome, Otstot, Perry, Roxana, Vernon, and Webb (Mills-Bullard, 1928). Much of the lease production shown in the study area (Pl. 1) represents only the recent activity in formerly larger areas of oil production from Tonkawa reservoirs. Oil and gas production from Tonkawa reservoirs, separated into FDD and non-FDD regions of Oklahoma, is summarized in Tables 1 and 2, and Figures 13 and 14. In Kansas, subcommercial quantities of gas and oil were discovered in the Stalnaker sand in 1914 and 1915, respectively (Winchell, 1957). By late 1927, commercial production from the Stalnaker was well established at the Oxford field in Sumner County (Swindell, 1935). Table 3 summarizes oil and gas production of record from Stalnaker and Tonkawa reservoirs in Kansas.

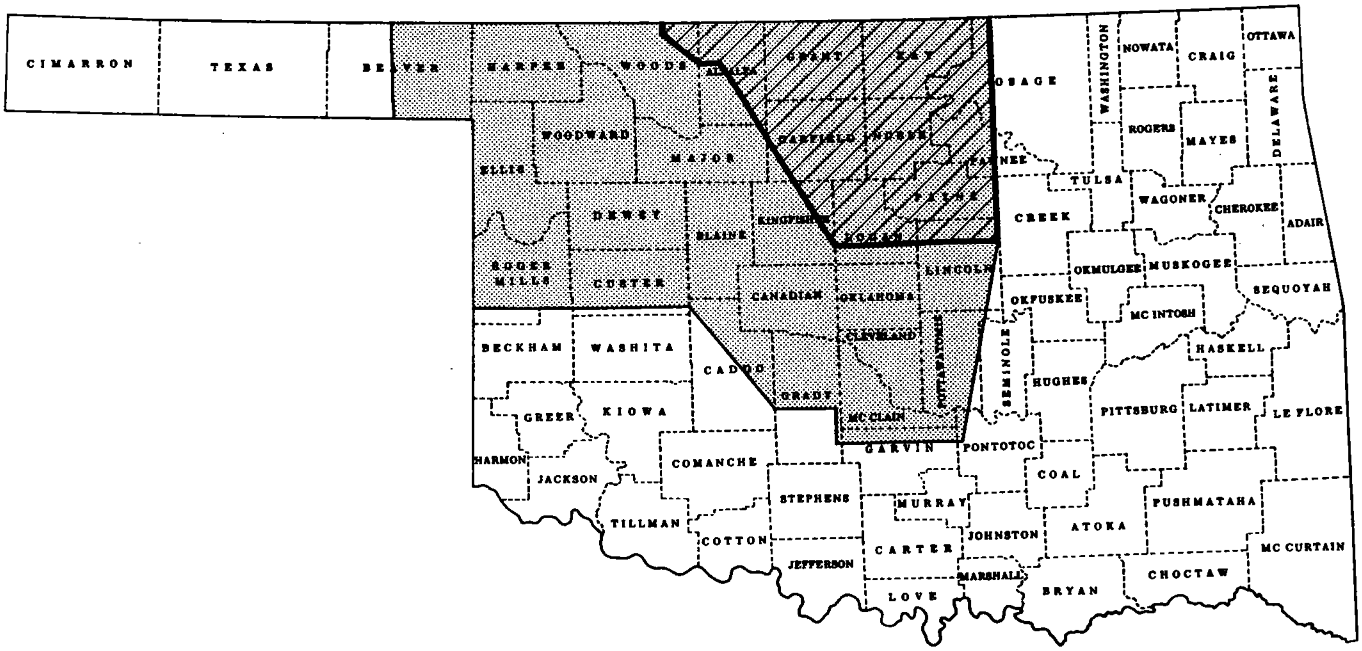


Figure 12. Region of hydrocarbon production from Tonkawa sand in Oklahoma (stippling). Tonkawa FDD study area is in north-central Oklahoma (hachures).

TABLE 1. – Crude-Oil and Natural-Gas Production from Tonkawa Sand Reservoirs, FDD Study Area, North-Central Oklahoma

(Includes Alfalfa, Grant, Kay, Osage, Garfield, Noble, Pawnee, Payne, Logan, and Lincoln Counties)

	Tonkawa reservoirs only[a]		Tonkawa and other reservoirs[b]	
	Leases reporting		Leases reporting	
	Oil	Gas	Oil	Gas
	62	82	72	17
Cumulative 1979–96	1,598,159 BO	48,041 MMCF	—	—

Note: Data from NRIS database.

[a] Includes Stalnaker sand.

[b] Tonkawa production cannot be identified because production is combined for two or more reservoirs and reported by lease.

TABLE 2. – Crude-Oil and Natural-Gas Production from Tonkawa Sand Reservoirs, Beyond the Limit of FDD Study Area, Northwestern Oklahoma

(Includes Beaver, Harper, Woods, Ellis, Woodward, Major, Roger Mills, Dewey, Custer, Kingfisher, Canadian, Grady, and Garvin Counties)

	Tonkawa reservoirs only		Tonkawa and other reservoirs[a]	
	Leases reporting		Leases reporting	
	Oil	Gas	Oil	Gas
	434	662	123	192
Cumulative 1979–96	4,617,972 BO	411,386 MMCF	—	—

Note: Data from NRIS database.

[a] Tonkawa production cannot be identified because production is combined for two or more reservoirs and reported by lease.

The regional structural dip is westward to southwestward at about 300 ft/mi (Fig. 15). The accumulation of commercial amounts of oil and gas in Tonkawa sand reservoirs is associated mainly with the Nemaha uplift and Nemaha fault zone (Pls. 1,2,3), shown in the central part of Figure 15. Fault-controlled structures are common in the area, and anticlines associated with basement-rooted faults have trapped hydrocarbons in many of the producing fields (Table 4). Oil and gas may also be found off-structure in those areas where good reservoirs have developed in the Tonkawa sand (Rottmann, Part III, this volume).

There are no published studies of source-rock quality and/or maturity of lower Virgilian shales in the Midcontinent region. The depth of burial of those strata in the study area is unlikely to have reached more than 5,000–5,500 ft. That burial is insufficient for the generation of petroleum liquids in significant quantities, except in some regions of abnormally high geothermal gradients (Hunt, 1979). This, however, does not discount the possibility that some natural gas may have been generated from cojacent shales. The generation of oil *and* gas from source rocks that may be in juxtaposition with Tonkawa reservoirs is more probable farther west in the Anadarko basin. Thus, the association of Tonkawa oil production with geologic structure is not surprising. Oil and gas generated at deeper stratigraphic and structural positions have doubtless migrated up fault zones to saturate Tonkawa and other relatively shallow reservoirs locally. Therefore, the existence of stratigraphic accumulations of oil that are not associated geographically with major faults and structural traps seems improbable. The same, of course, is not necessarily true for gas.

Oil and gas were first discovered in a Tonkawa reservoir in the Tonkawa field in 1921 (Clark and Aurin, 1924). That discovery gave the Tonkawa sand its informal subsurface name. The discovery well was the Marland Refining Co. No. 1 School Land, NE¼ sec. 16, T. 24 N., R. 1 W., completed in late June 1921. Initial production was reported to be 850 barrels of oil per day (BOPD) from the Tonkawa sand by Clark and Aurin (1924), although that figure was later reported to be 1,000 BOPD (Mills-Bullard, 1928). Initial production from the second well, completed 3 months later, was reported to be 3,300 BOPD by Clark and Cooper (1927). The field produced from at least five Pennsylvanian sandstones, the deepest and easily the most significant of which was the Tonkawa. The field produced only from those reservoirs until April 1924 (about 33 months), with discovery of oil in the deeper (Ordovician) "Wilcox" sand reservoir (Clark and Cooper, 1927). Less prolific oil production was found in the Endicott, "Carmichael," Hoover, and Newkirk sands, and gas alone was produced locally from the above, and from some other formations (Clark and Cooper, 1927; Mills-Bullard, 1928). There is imprecise agreement as to the identity of the Pennsylvanian oil reservoirs of the Tonkawa field. An earlier but more detailed study (Ross, 1923) lists upper, middle, and lower Hoover sands and "Carmichael" sand in addition to Tonkawa. The significance of production from the Tonkawa sand and shallower reservoirs is realized with the knowledge that the field reached its peak production of 112,000 BOPD in May 1923 (Owen, 1975, p. 448), nearly a year before discovery of the deeper "Wilcox" sand reservoir. If average production was as little as 10% of that peak, the total production from the Pennsylvanian reservoirs for 33 months would be more than 11 million bbl.

The Tonkawa field played a pivotal role in the exploration for petroleum. By the late teens, the most easily mappable anticlines in the Midcontinent region had been drilled. At about that time, a method for defining geologic structure in areas of poor surface exposure was developed that employed the drilling of shallow core holes to determine structural dip. The method became widely used after its "spectacular success" at the Tonkawa field (Owen, 1975, p. 332). It was the method that led also to the discoveries at Braman (Mills-Bullard, 1928), Crescent-Lovell (Bale, 1928), and Lucien (Zavoico, 1934) fields, among others. The method was also used to define structure more accurately at previously discovered fields, including Garber (Gish and Carr, 1929).

STRATIGRAPHIC NOMENCLATURE

The Tonkawa sand and oil field were named for the town of Tonkawa, in Kay County, in 1921. The town previously had taken its name from the Tonkawa tribe (Shirk, 1965).

The Tonkawa sand in the subsurface is equivalent to the lower Virgilian Cheshewalla Sandstone in northern Oklahoma, and the Tonganoxie Sandstone in Kansas (Fig. 16). The Tonkawa is commonly known as the Stalnaker sand in Kansas, and that name is also used lo-

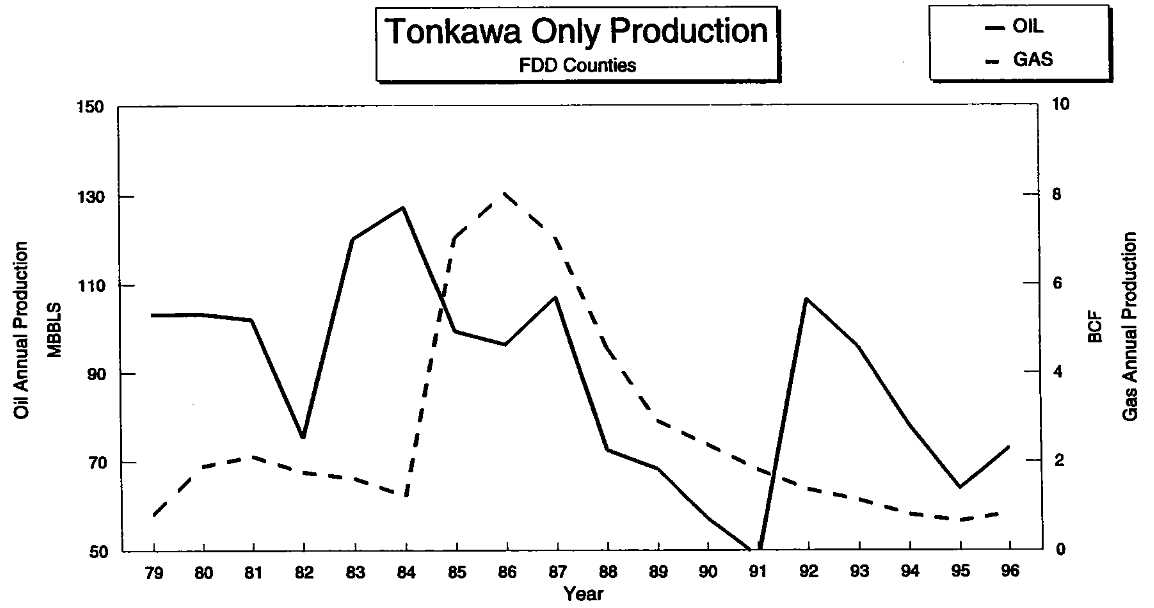


Figure 13. Oil and gas production from Tonkawa sand reservoirs, FDD study area, north-central Oklahoma, 1979–96. Includes reservoirs identified as Stalnaker sand. Data from NRIS database for Alfalfa, Grant, Kay, Osage, Garfield, Noble, Pawnee, Payne, Logan, and Lincoln Counties.

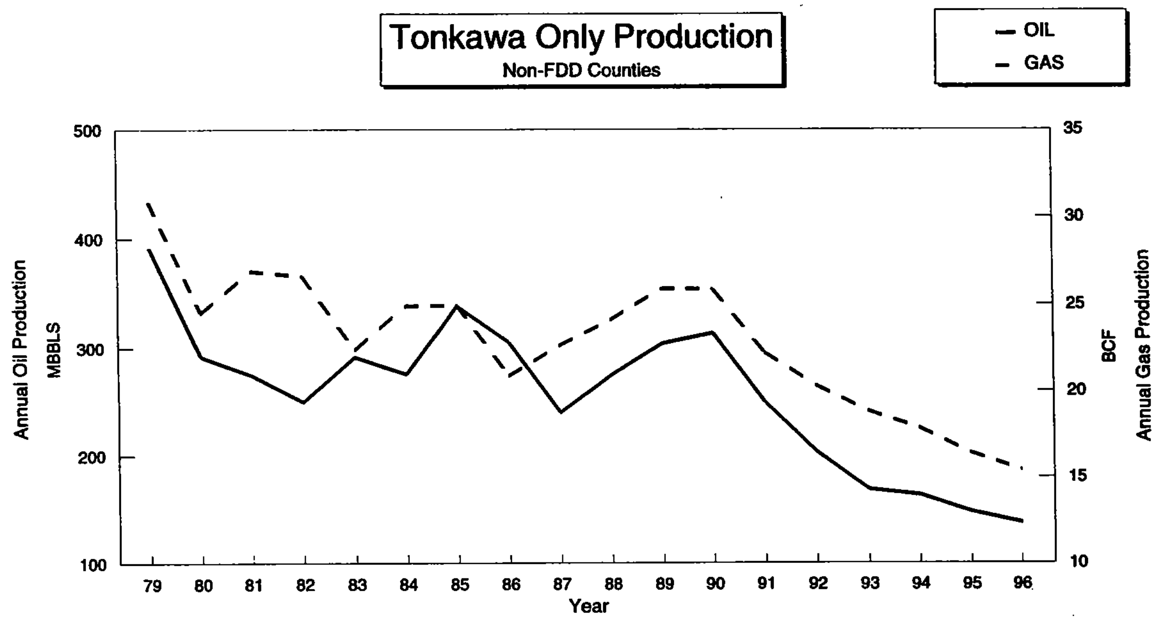


Figure 14. Oil and gas production from Tonkawa sand reservoirs, beyond the limit of FDD study area, northwestern Oklahoma, 1979–96. Includes reservoirs identified as Stalnaker sand. Data from NRIS database for Beaver, Harper, Woods, Ellis, Woodward, Major, Roger Mills, Dewey, Custer, Kingfisher, Canadian, Grady, and Garvin Counties.

TABLE 3. – Crude-Oil and Natural-Gas Production from Stalnaker Sand Reservoirs, South-Central Kansas

(Includes 36 fields in Barber, Butler, Kingman, Harper, Sumner, and Cowley Counties)

	Stalnaker reservoirs only	
	Leases reporting	
	Oil	Gas
	67	79
Cumulative	1,081,422	46,275,231
1970–95	BO	MMCF

Note: Does not include minor quantities of oil and gas produced from Stalnaker sand in Sedgwick and Elk Counties. Data courtesy Kansas Geological Survey.

cally in north-central Oklahoma, particularly in Kay and Grant Counties. Oil and gas production shown on Plates 1, 2, and 3 (in envelope) includes that from the Stalnaker sand. Plates 1, 2, and 3 also include, locally, production from other intervals between the Iola Formation and the Heebner Shale (Fig. 16), as will be discussed.

Tonkawa sand is a drillers' or wildcatters' name for sandstone that occurs below the Haskell Limestone and, locally, the Westphalia Limestone in the Tonkawa field (Fig. 17; wells 4 and 14, Pl. 4 [in envelope]). The name *Tonkawa sand* is best applied to the widely occurring, uppermost sandstone interval below the Haskell Limestone (the Westphalia is not a widely occurring, correlatable formation in the subsurface).

At least six sandstone-dominated intervals, mapped at the surface as members of two formations, occur above the Iola Formation, and below the Haskell Limestone Member (in the lower part of the Labadie Limestone) in Oklahoma (Fig. 16). All of the sandstone bodies, and most of the other lithologic members, were originally identified and named in a regional study by the U.S. Geological Survey (White and others, 1922). Where the Wildhorse(?) Limestone is present, three sandstone-dominated intervals occur above it and below the Haskell. However, in the subsurface, the number and relative stratigraphic position of sandstone bodies are variable (Pl. 4). The Tonkawa sand is mapped in the present study as the uppermost of those sandstone bodies; however, where all or most of the sandstone between the Wildhorse(?) and Haskell Limestones occurs essentially as a continuous sandstone-dominated interval (Fig. 17), it is unknown—clearly, it may be unknowable—how the Cheshewalla Sandstone is related to the underlying Revard Sandstone and/or Bigheart Sandstone in the subsurface. The interpretation of depositional environments has been useful in making the locally arbitrary separation of the Tonkawa sand from underlying formations. Thus, *Tonkawa sand* is a very useful, if general, term applied to sandstones in the upper part of the interval between the Wildhorse(?) and Haskell Limestones in the subsurface. However, the name *"Tonkawa sand"* has been applied also locally to other sandstone intervals that occur above the Muncie Creek Shale marker and below the Heebner Shale marker (Fig. 17; Pl. 4). Such misapplication of the name is confusing and unnecessary, as adequate, correlatable limestones and shales provide a framework for separation of the major sandstone intervals within and beyond the study area to the west and southwest (Pl. 4) (Lukert, 1949; Nolte, 1951; McKenny, 1952, 1953; Dana, 1954a,b; Cary, 1954, 1955; Caylor, 1956, 1957; Querry, 1957, 1958; Fambrough, 1962, 1963).

In this study, quotation marks are used in reference to subsurface names misused locally (e.g., "Wilcox"), and with subsurface names that replace a formal name that is also used widely in subsurface nomenclature, and which also may duplicate another name, adding to confusion (e.g., "Tonkawa lime"). Quotation marks are also used with names that are commonly applied incorrectly to the subsurface (e.g., "Avant" lime and "Wilcox" sand).

The name *"Tonkawa lime"* has been applied to the Haskell Limestone and also locally to the Westphalia Limestone where it is well developed. The name implies that the Tonkawa sand and lime occur as a pair, or even that the limestone is a predictor of the underlying Tonkawa sand, neither of which is necessarily true. The Haskell is poorly developed locally (wells 1 and 2, Pl. 4), and the Tonkawa sand is locally not present, as in part of T. 27 N., R. 13 W. *Haskell Limestone* is a name in wide surface and subsurface use; I recommend continued use of this name and abandonment of *"Tonkawa lime."*

The Muncie Creek Shale Member of the Iola Formation was identified in the subsurface by Lukert (1949). A widely occurring, highly radioactive zone in that formation is identified as a major stratigraphic marker in this study (Pl. 4). The Perry sand, or "Perry gas sand," occurs irregularly above the Iola Formation and below the Wildhorse(?) Limestone. Its thickness and geographic distribution are highly variable (Pl. 4), and its surface equivalent has not been identified. Although I suggest on the log of well 8 (Pl. 4) that the Perry sand may be equivalent to the Torpedo Sandstone Member of the Wann Formation of Hopkins (1922), it is only speculation.

The Wildhorse Limestone was identified and named in eastern Osage County by Greene (1918), which he spelled *Wild Horse*; the name was later applied to and correlated in the subsurface by Lukert (1949) as the Wildhorse Limestone and by Clare (1963) as the Wildhorse(?) lime. Although the nomenclature is fraught with difficulties, the name *Wildhorse* is preferable to *"Avant" lime*, which is a miscorrelation of the Avant Limestone Member of the Iola Formation (Lukert, 1949; Jordan, 1957). Uncertainties associated with the Wildhorse Limestone include the fact that Greene (1918) did not map or describe the formation, and cited a broad area of occurrence (the western part of T. 22 N., R. 10 E.) rather than a specific type locality. Although there is a Wild Horse Creek in Osage County, Wildhorse

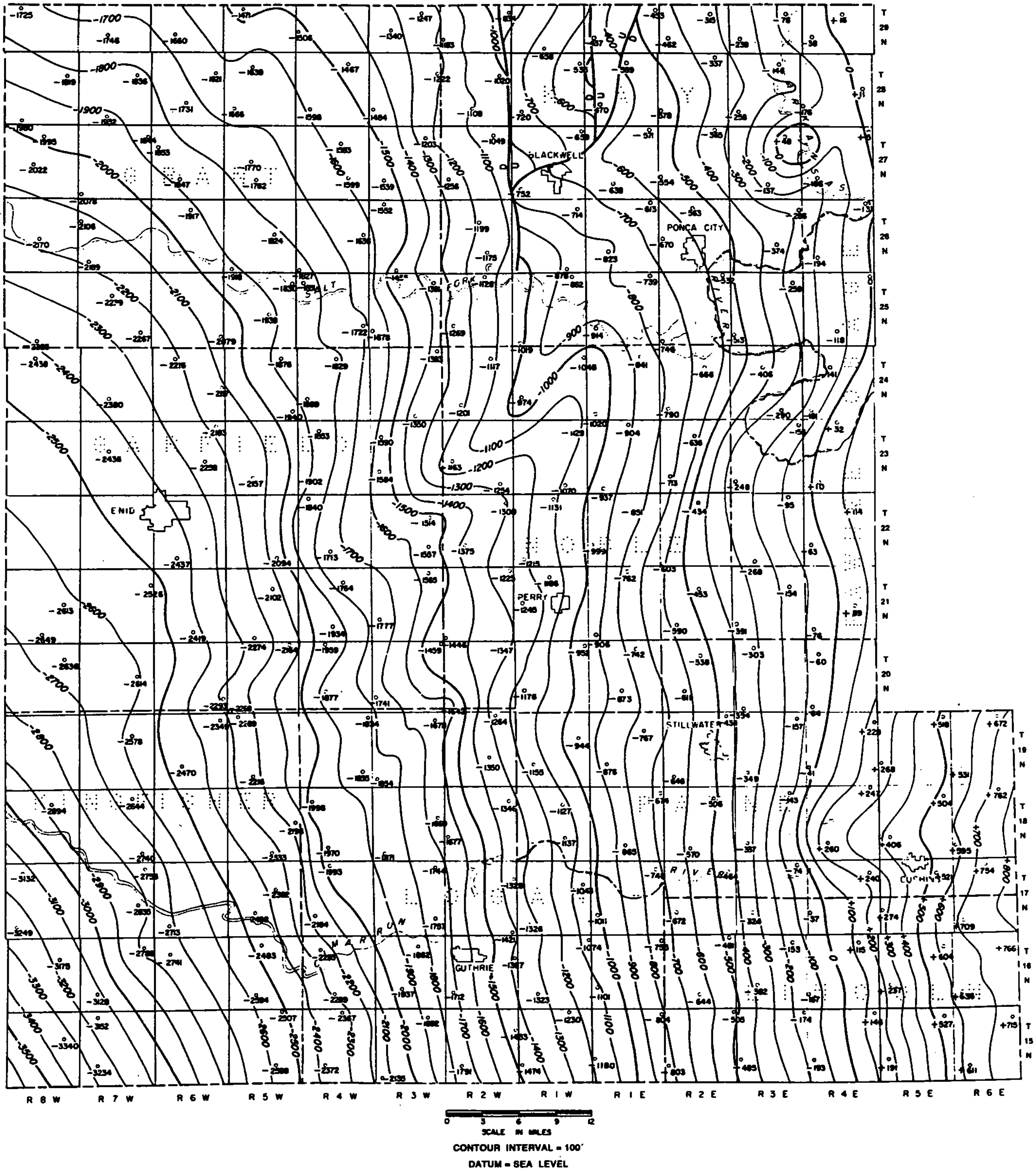


Figure 15. Regional geologic structure at the top of the Pawhuska Limestone (lower Virgilian) in north-central Oklahoma. Contour interval, 100 ft. The Pawhuska Limestone is approximately 300 ft above the Oread Formation (Figs. 16,17). From Fambrough (1962).

TABLE 4. – Hydrocarbon Production from Tonkawa Sand in Association with Identified and Probable Fault-Associated Structures

Field[a]	County	Township & Range[b]	Discovery	Structure	References
Deer Creek	Grant	27N–3W	1920	Fault and anticline	Clark and Cooper, 1927 Mills-Bullard, 1928
Webb	Grant	27N–3W	1921	Fault and anticline	Mills-Bullard, 1928
Barnes	Garfield	(23N–3W)	1918	Anticlinal nose	Mills-Bullard, 1928
Garber	Garfield	(22N–3W) (22N–4W)	1917	Fault and anticline	Mills-Bullard, 1928 Cary, 1955
Blackwell (Dilworth District)	Kay	28N–1E	1914	Fault and anticline	Mills-Bullard, 1928 Clark and Daniels, 1929
S. Blackwell (Blackwell)	Kay	27N–1W	1914?	Fault and anticline	
Mervine	Kay	27N–3E	1913	Fault and anticline	
Ponca (Ponca City, NW.)	Kay	26N–2E	1917	Fault and anticline	
Braman, N. Braman, and Braman District	Kay	28N–1W 29N–1W	1924	Fault and anticline	Clark and Cooper, 1927 Mills-Bullard, 1928
Blackwell (Dilworth)	Kay	29N–1E	1911	Asymmetric anticline; closure increases with depth	Weinzierl, 1922 Mills-Bullard, 1928
Hubbard	Kay	26N–2W	1925	Fault and anticline	Vanzant, 1926
Vernon (Blackwell?)	Kay	(29N–1E)	1925	Fault and anticline	Clark and Cooper, 1927 Mills-Bullard, 1928
Otstot (Blackwell)	Kay	(27N–1W)	1920	Anticline	Mills-Bullard, 1928
Tonkawa	Kay and Noble	25N–1E 24N–1W	1921	Fault and anticline	Clark and Aurin, 1924
Billings	Noble	23N–2W	1917	Fault and anticline	Mills-Bullard, 1928 Hoffman, 1940
Bu-Vi-Bar (Sams)	Noble	21N–2W	1926	"Monocline at surface"	Mills-Bullard, 1928
Lucien	Noble	20N–2W	1932	"Structural folding"	Zavoico, 1934
Perry	Noble	(21N–1W)	1922	Anticlinal nose	Mills-Bullard, 1928
Polo	Noble	21N–1W	1920	Anticlinal noses	Mills-Bullard, 1928
Crescent (Crescent–Lovell)	Logan	18N–4W	1926	Fault and anticline	Mills-Bullard, 1928 Wilson, 1935
Roxanna (Marshall, E.)	Logan	(19N–4W)	1927	Fault and anticline	Mills-Bullard, 1928
Hardy	Osage	25N–3E	?	Anticline at surface	Bowen and others, 1922
Myers Dome (Myers?)	Osage	(26N–8E)	1916	Anticline	Mills-Bullard, 1928
Morrison (Watchorn, E.)	Pawnee	23N–3E	1917	Asymmetric anticline; closure increases with depth	Mills-Bullard, 1928 Carpenter, 1929
March (March, N.)	Payne	18N–5E	1922	"Local anticlinal folding"	Mills-Bullard, 1928
Yale (Yale Quay)	Payne	18N–6E	1914	Fault and anticline	Bosworth, 1920 Mills-Bullard, 1928

[a] Present field name in parentheses.

[b] Parentheses indicate no record of production in the period 1979–96.

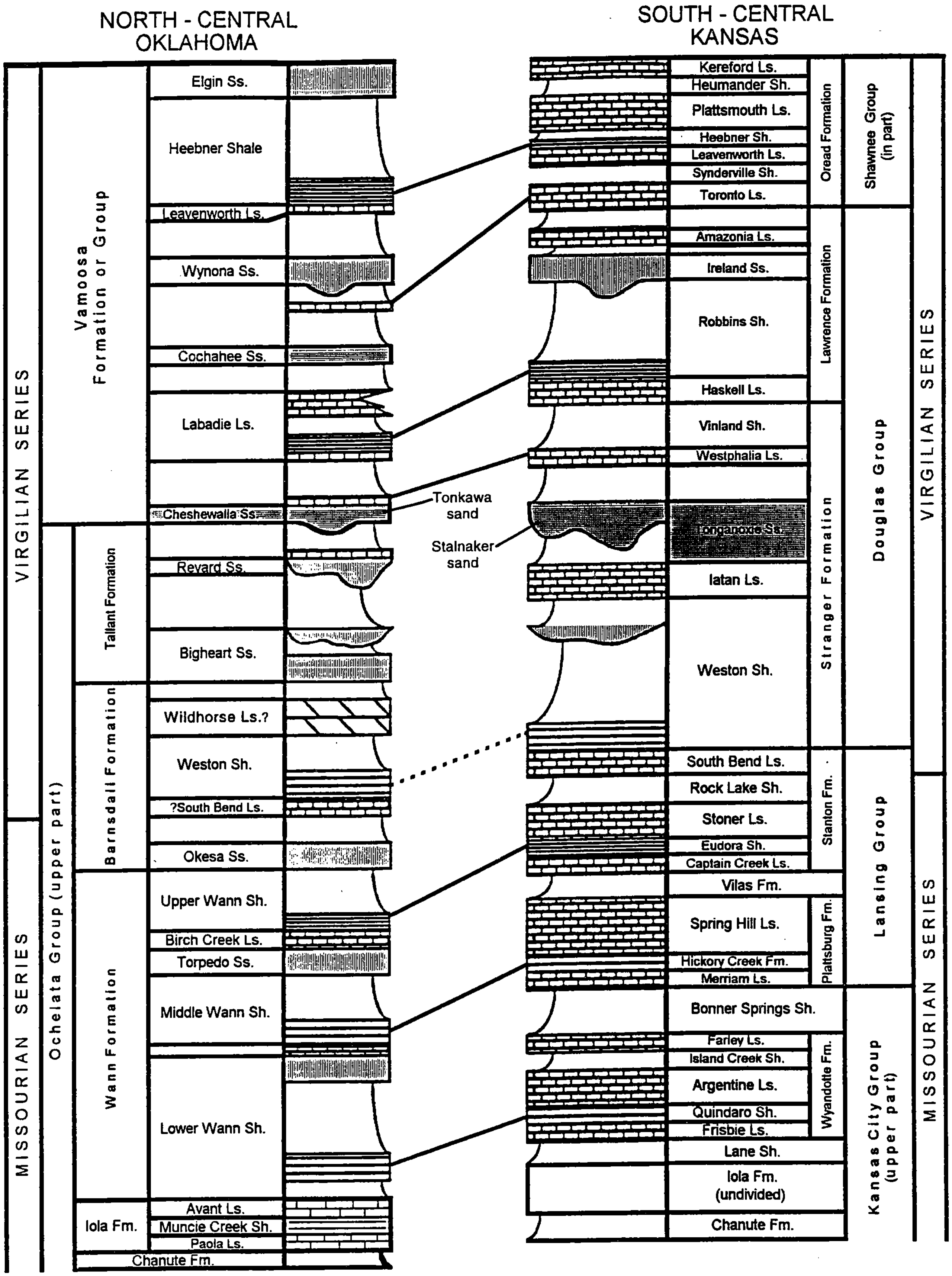


Figure 16. Stratigraphic columns of upper Missourian and lower Virgilian strata in north-central Oklahoma and south-central Kansas. Solid and dotted lines connecting limestones and shales in the separate columns indicate biostratigraphic correlations. Modified from Boardman and others (1989).

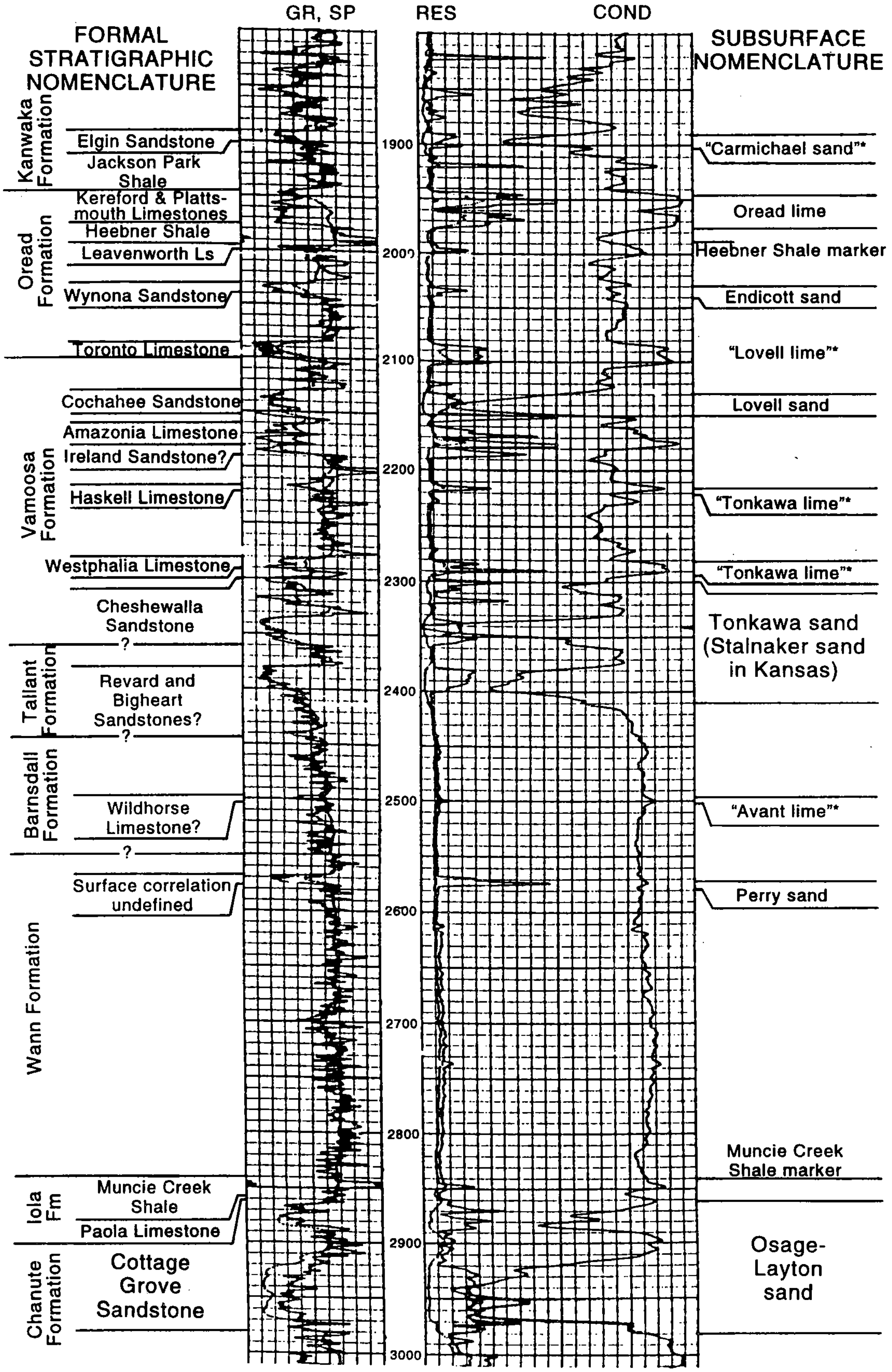


Figure 17. Reference wireline log for the fluvial-dominated deltaic reservoirs of the Tonkawa play. Combines Oklahoma and Kansas stratigraphic columns (Fig. 16) in part: Wicklund Petroleum Corp. No. 1 Lyons, E½SW¼SW¼NW¼ sec. 6, T. 26 N., R. 2 E., Kay County, Oklahoma, with spontaneous-potential (*SP*), gamma-ray (*GR*), resistivity, and conductivity profiles. Asterisks denote names that cause misunderstanding of identity (explanation in text). Depths in feet.

(one word) Creek occurs in the western part of T. 22 N., R. 10 E.; therefore, Greene (1918) was evidently in error in his use of the name Wild Horse (two words). Furthermore, his Wild Horse Limestone is in the stratigraphic position of the Panther Creek Limestone (Roundy and others, 1922), which was thought to be the possible equivalent of the Stanton Limestone in Kansas by Clark (1922) as well as by Roundy and others (1922). The formation is evidently discontinuous at the surface, for Hopkins (1922), Hopkins and Powers (1922), Oakes (1940), and Tanner (1956) did not identify limestone in that stratigraphic position. Because of the absence of positive identification of the surface formation, the name *Wildhorse(?)* is used in this study.

The Toronto Limestone occurs at the base of the Oread Formation and is one of the most persistent subsurface markers in the study area and in the Anadarko basin to the west. It is commonly called the "Lovell lime" in the subsurface, apparently so named for the Lovell sand, the first published reference to which was in 1955 (Jordan, 1957). The name *Toronto* also is applied to the subsurface. The formation was first named in Kansas in 1894 (Keroher and others, 1966) and was correlated to Oklahoma in the subsurface by Lukert (1949). The name *Toronto* therefore predates the name *"Lovell lime,"* the latter also having the disadvantage of duplicating the informal name of the underlying sandstone. Thus, the use of the formal name *Toronto Limestone* is more desirable.

The Oread Formation consists of seven members, from the top of the Kereford Limestone to the base of the Toronto Limestone (Figs. 16,17). The subsurface Oread lime differs from it in that the latter includes only the limestone interval near the top of the Oread Formation, whether it is the Kereford Limestone or the Plattsmouth Limestone or both. This difference is not of great importance if one does not confuse them, because the primary purpose for defining the subsurface interval is ease of correlation.

One and locally two sandstone intervals occur in the Oread Formation. They are present in the Snyderville Shale, above the Toronto Limestone, and below the Leavenworth Limestone (Figs. 16,17; Pl. 4, section *A–A′*). The most persistent of the two sandstone bodies is the Endicott sand (Pl. 4, sections *A–A′* and *B–B′*), well known in the petroleum industry. The Endicott sand is considered equivalent to the Wynona Sandstone at the surface (Jordan, 1957). The same sandstone has been called "Turk sand" locally, particularly in the Thomas field, Kay County (Jordan, 1957). *Turk* is therefore a local name, and its abandonment is recommended in favor of the much more widely used term *Endicott sand.* Locally, another discreet sandstone body occurs in the same stratigraphic interval (wells 1–5, Pl. 4). If this sandstone bears hydrocarbons, it is probably called *"Endicott"* or *"upper Endicott."* Locally, only the unnamed sandstone is present (well 3, Pl. 4).

The Elgin Sandstone lies above the Oread Formation within the study area (Jordan, 1957, p. 96; wells 14 and 15, Pl. 4). An informal subsurface formation, the "Carmichael sand," was identified at the same stratigraphic position as the Elgin Sandstone in Tonkawa field, in sec. 3, T. 24 N., R. 1 W. (Jordan, 1957). A review of available well-completion cards and corresponding logs in secs. 1, 2, and 3 of the same township found the name *"Carmichael sand"* applied to sandstones within the Oread Formation rather than above it. In view of inconsistent application, it is apparent that the name *"Carmichael sand"* is of no value and should be abandoned.

CORRELATION

Within the study area, correlation in the subject part of the geologic section is straightforward if not always unambiguous. The persistence of the Haskell, Amazonia, and Toronto Limestones, and the Kereford Limestone and/or Plattsmouth Limestone at the top of the Oread Formation (Oread lime of the subsurface), helps to provide a framework for identifying intervening sandstones, which are commonly variable and locally discontinuous. The above limestones are augmented by persistent "hot" shale markers in the Muncie Creek Shale, a member of the Iola Formation, and in the Heebner Shale Member of the Oread Formation. The play is associated geographically with the Nemaha uplift and the Nemaha fault zone. As the result of episodic movement on faults, variations in thicknesses of stratigraphic intervals, and changes in log signature of specific formations or other correlatable intervals, are common. The best practice to counter ambiguity and to maintain integrity in identifying subsurface stratigraphic intervals is the simultaneous correlation of several limestones.

A case in point is well 9 (Pl. 4). The Marjo Oil Co. No. 1-7 Donoghue well was completed in the "Tonkawa," according to the operator. However, the Tonkawa sand occurs >200 ft higher in the section; it seems probable that the limestone at 3,481–3,486 ft bears such a resemblance to the Haskell Limestone that the "call" of "Tonkawa" was easy. The log signature of the Haskell is weak at this particular well, but it is much more typical in adjacent well 10 (Pl. 4). The Haskell Limestone also exhibits a very weak resistivity response in wells 1 and 2; however, the presence of the Oread lime and the Toronto and Amazonia Limestones is a great help in identifying the Tonkawa sand as well as the Endicott sand in the above wells. Although Lukert's (1949) pioneering work established the correlation of many stratigraphic units in the subsurface (including the Tonkawa sand), the correct correlation of some sandstones between the Iola Formation and the Oread Formation has remained a challenge, as reflected in the published and unpublished literature. The absence of persistent limestones or "hot" shale markers between the Avant and Haskell Limestones makes correlation of intervening sandstones progressively more difficult east of Kay and Noble Counties. Notably, even the Amazonia and Toronto Limestones and the Oread Formation become weak to uninterpretable to the east in the subsurface (this study, Pl. 4; Lukert, 1949, pl. II).

Miscorrelation of the Avant Limestone Member of the Iola Formation as the "Avant lime" in the subsurface of the study area was shown by Lukert (1949). Both Lukert (1949) and Jordan (1957) correlate the "Avant lime" of the study area with the Wildhorse Limestone at the surface in eastern Osage County. It is also apparent that the correlation of the "Avant lime" is not consistent in the subsurface. According to G. C. Hinshaw (personal communication, 1997), the top of the "Avant lime" in common use in the Anadarko basin correlates to the No. 1-7 Marjo well (section *B–B′*, Pl. 4) at 3,890 ft, about 300 ft below its position in the present study. Much of the problem probably relates to the variability of limestone in the formation, which results in its being poor for regional correlation.

The Wildhorse(?) Limestone is discontinuous and highly variable in thickness in the subsurface. It commonly includes variable thicknesses of shale and minor calcareous sandstones (Pl. 4). It is difficult to reach a consensus on its mapping in the subsurface, as the highest stratigraphic occurrence of limestone is highly variable in its relation to the main body of carbonate (wells 9–11, Pl. 4). However, where the Wildhorse(?) Limestone is present, it can be useful in correlation, separating the Perry sand below from the Tonkawa sand and local, unnamed sandstones above (Pl. 4).

The subsurface stratigraphic column is similar to that at the surface, including the presence of three sandstone bodies between the Wildhorse(?) and Haskell Limestones on the east end of stratigraphic section *A–A′* (Pl. 4). The outcrop lies >20 mi farther east (Pl. 3); therefore, this is not to be considered definitive. However, the uppermost of the three sandstone intervals is the most persistent and exhibits good continuity in terms of interpretation of depositional environments. This is the Tonkawa sand of this report. The lower sandstones are separate from the Tonkawa, and their correlation to the surface is uncertain (Pl. 4).

The Amazonia Limestone is a formation unfamiliar to many subsurface geologists, but it is useful in the study area for purposes of correlation as well as for identifying the Lovell sand, which occurs between it and the overlying Toronto Limestone (Figs. 16,17). However, the Amazonia is not present at well 10, evidently having been eroded prior to deposition of the overlying Lovell sand. The Amazonia also disappears south of well 11 (Pl. 4), probably as the result of erosion at well 10 and possibly the result of nondeposition farther south, including well 9 (Pl. 4).

The Toronto Limestone is also persistent in the subsurface, although it is highly variable in thickness and wireline-log response. These variations are evident on both the north-south and east-west sections (Pl. 4). The Toronto is absent, apparently the result of nondeposition, at well 14, and it has been eroded prior to deposition of the Endicott sand at well 5 (Pl. 4).

West of the study area, in the Anadarko basin, the most dependable correlations are highly radioactive zones in the Heebner Shale and in the Toronto Limestone, as illustrated by Allen (1953, 1954), Caylor (1956, 1957), Capps (1959), Pate (1959), Gibbons (1960, 1962), and Fambrough (1962, 1963). Some authors (Pate, 1959; Gibbons, 1960, 1962; Kumar and Slatt, 1984) also correlate the Haskell Limestone, especially in local areas. The limestone called *Haskell* may not be the same formation as the Haskell of this study area and of south-central Kansas, however.

DEPOSITIONAL ENVIRONMENTS OF THE TONKAWA SAND

The Tonkawa sand crops out in east-central Kansas as the Tonganoxie Sandstone, and in Osage County, Oklahoma, as the equivalent Cheshewalla Sandstone. It is known in the subsurface southwestward in south-central Kansas, in north-central and northwestern Oklahoma, and in the panhandles of Oklahoma and Texas. Although the region has been the focus of a number of subsurface studies (Pl. 5 [in envelope]), few of these studies address the Tonkawa sand specifically. Depositional environments over that broad area are varied and complex. Several local studies provide an incomplete view of depositional environments and sediment-source areas. The Tonkawa was interpreted as having deep-water origins as submarine fan and slope deposits in parts of Blaine, Custer, and Dewey Counties, Oklahoma, by Kumar and Slatt (1984). They proposed a Ouachita uplift source, some 170 mi to the east-southeast, largely on the basis of the presence of lithic clasts of shale and cherty shale and the absence of other diagnostic lithologies.

A prograding Tonkawa delta that developed from a northerly sediment source was inferred in Woods and adjacent Harper and Woodward Counties by Fies (1988). Cored intervals from four wells within the area, however, exhibit characteristics of shallow-marine, delta-front environments of deposition. The existence of *fluvial* depositional environments has not been established in that area. Farther south, in Dewey County, Padgett (1984) interpreted delta-front sedimentation in the Tonkawa. Sedimentary structures of six studied cores, as well as the common presence of marine fossils and the mineral glauconite, indicate a shallow-marine environment of deposition. Padgett (1984) did not propose a source for the Tonkawa sand; however, if the southwest- to northeast-trending marine bars he describes (Padgett, 1984, pl. 9) are subparallel to the paleoshoreline, a northwesterly sediment source is apparent.

The Tonkawa sand was reported as deltaic also in Woodward, Harper, and adjacent parts of Beaver, Ellis, and Woods Counties by Khaiwka (1968). That investigation did not incorporate the study of well cores and was completed prior to the widespread use of gamma-ray logs. Resistivity profiles selected by Khaiwka (1968, figs. 2,7,8) suggest both upward-coarsening and -fining sequences in the three sandstone intervals of the Tonkawa sand. Further study will be necessary to deter-

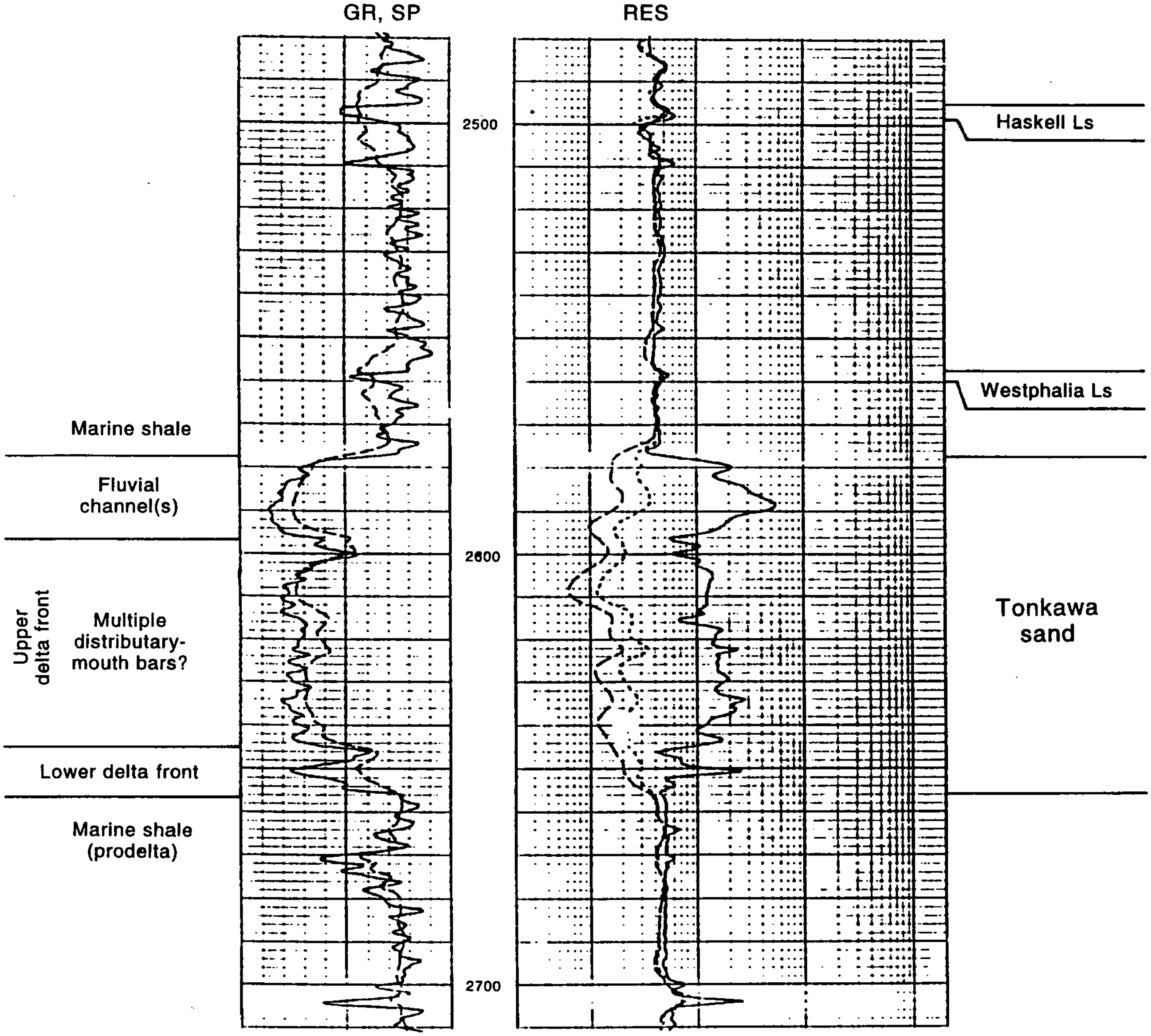


Figure 18. Reference wireline log to depositional environments in the Tonkawa sand, with spontaneous-potential (*SP*), gamma-ray (*GR*), resistivity, and conductivity profiles: Pathfinder Petroleum Corp. No. 1-13 Johnson, C SW¼SW¼SE¼ sec. 13, T. 22 N., R. 1 E., Noble County, Oklahoma. Depths in feet. (See also well 13, Pl. 4, in envelope.)

mine depositional environments of the Tonkawa sand in that area. Also, see Hinshaw and Rottmann (1997) for a more detailed regional synthesis of the Tonkawa sand in western Oklahoma and adjacent Texas. The apparent existence of several source areas for the Tonkawa sand suggests that it may occur as more than one stratigraphic entity, probably in slightly different stratigraphic positions. This may or may not be the cause of the common occurrence of two or three sandstone intervals in the Tonkawa of western Oklahoma.

Depositional environments of the Tonkawa sand, or the Cheshewalla Sandstone, in north-central Oklahoma have not been studied previously. Thus, information of value to the interpretation of depositional environments is sketchy at best. In the original reference to the Cheshewalla Sandstone, Winchester and others (1922) described it as a cross-bedded, fine-grained sandstone, varying from 20 to 50 ft thick along most of its outcrop. It was also described as having few fossils other than plant fragments, except for a local pelecypod fauna at its base (Winchester and others, 1922). Tanner (1956, p. 42) described the Cheshewalla as "thin-bedded to massive, cross-bedded, fine- to very fine-grained sandstone or siltstone" with localized "clay-pebble conglomerates." Tanner (1956) also described locally abundant bottom markings, and he interpreted the Cheshewalla Sandstone to be largely of marine and partly of fluvial origin in northeastern Osage County.

The Tonkawa sand, farther west in the subsurface, was described as fine to medium grained by Cary

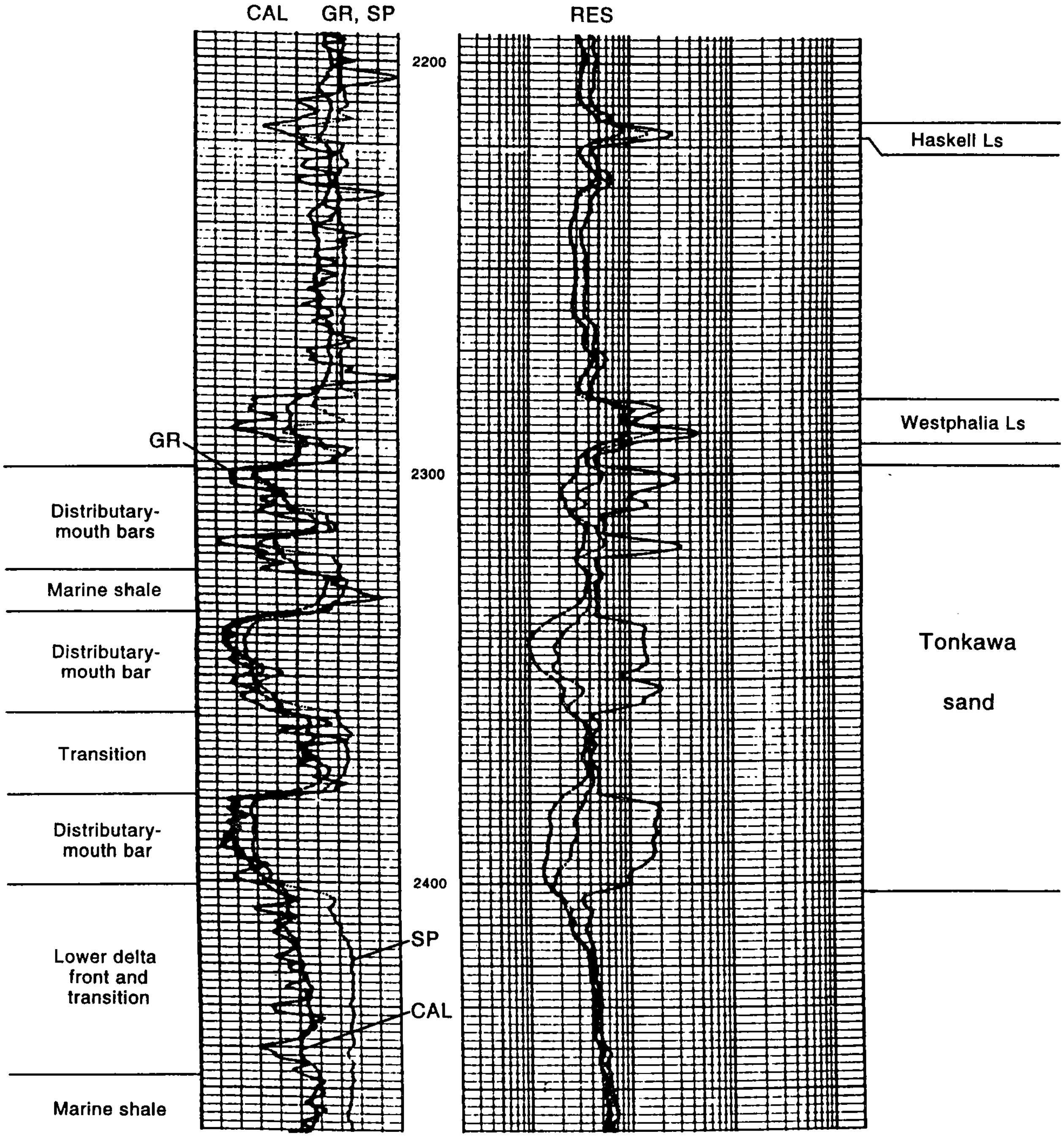


Figure 19. Reference wireline log to depositional environments in the Tonkawa sand, with spontaneous-potential (*SP*), gamma-ray (*GR*), caliper, resistivity, and conductivity profiles: Wicklund Petroleum Corp. No. 1 Lyons, E½SW¼SW¼NW¼ sec. 6, T. 26 N., R. 2 E., Kay County, Oklahoma. Depths in feet. (See also Fig. 17.)

(1954, 1955) and Page (1955a,b). The sandstone was also described as “slightly glauconitic” in the Garber area (eastern Garfield County) by Cary (1955, p. 6). Caylor (1956, 1957) remarked about local coarse grain size, as did Dana (1954a,b). The Tonkawa was described as micaceous by Caylor (1956, 1957), and Dana (1954a,b) remarked that the sandstone became more micaceous northeastward across Grant County.

The Tonkawa sand reaches its greatest thicknesses in the northern and central parts of the study area and thins to the south, east, and west (Pl. 4). The maximum gross thickness of Tonkawa sandstone shown on Plate 4 is 130 ft at well 16, but the Tonkawa reaches thicknesses of at least 200 ft locally.

In Kansas, there is no question of the fluvial origin of the Tonganoxie Sandstone, essentially the equivalent of the Stalnaker and Tonkawa sands in the subsurface. The Tonganoxie Sandstone was studied at the surface and correlated to the Stalnaker sand in the subsurface in south-central Kansas by Winchell (1957). At the sur-

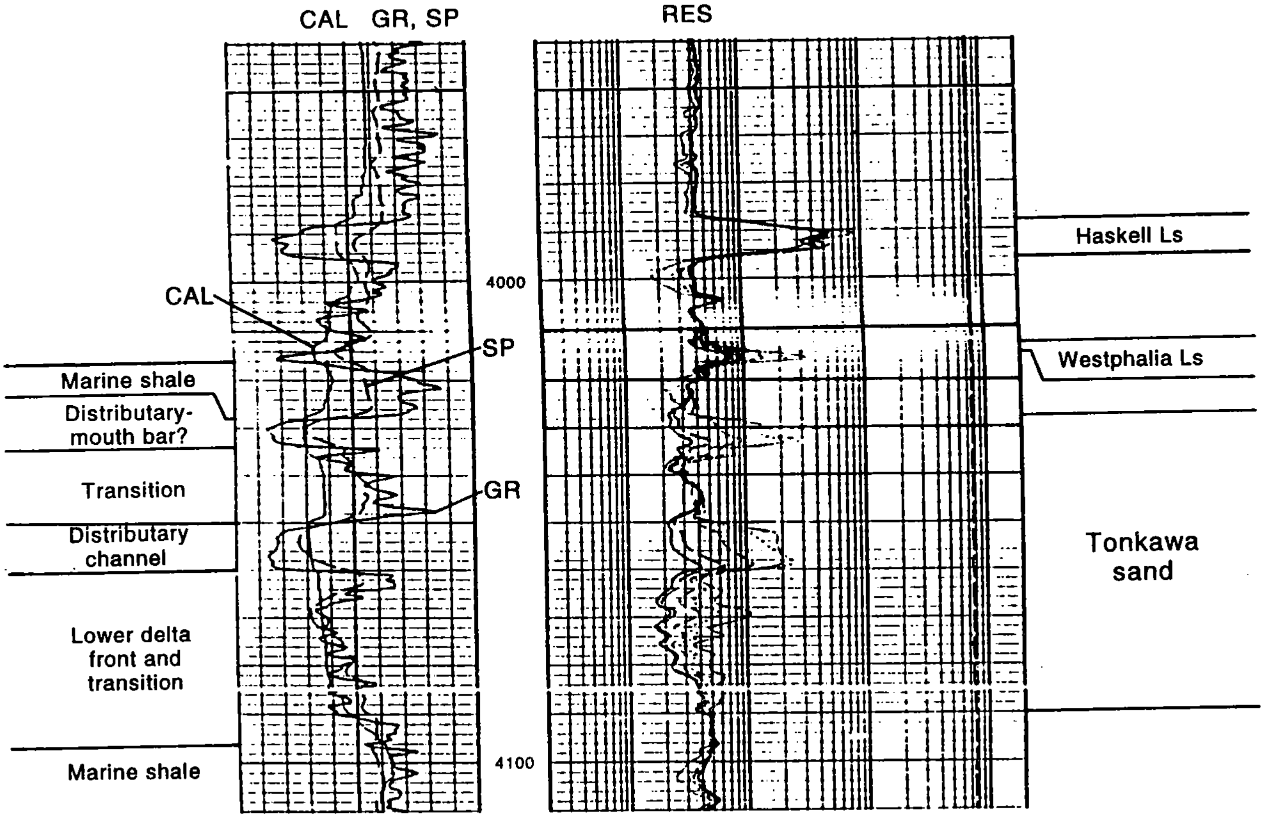


Figure 20. Reference wireline log to depositional environments in the Tonkawa sand, with spontaneous-potential (*SP*), gamma-ray (*GR*), caliper, and resistivity measurements: Mustang Fuel Corp. No. 6-21 Blaney, NW¼SE¼SW¼ sec. 21, T. 18 N., R. 4 W., Logan County, Oklahoma. Depths in feet.

face, Winchell (1957) specifically described thin-bedded, shaly sandstone and siltstone (probably delta-front deposits) and massive, cross-bedded channel sandstones. Channel-fill sandstones were described for the subsurface as well. Erosion at the outcrop occurred as low stratigraphically as the Captain Creek Limestone (Fig. 16), although erosion in the subsurface was not specifically observed to be that deep. The isopach map of the Stalnaker sand (Winchell, 1957, pl. 2) shows sandstone generally thickening southward, locally exceeding 200 ft adjacent to Grant and Kay Counties, Oklahoma. In a separate study, Walton and Griffith (1985) examined a 57-ft core of Stalnaker sand from the Sullivan field in Harper County, Kansas. In that core, they found delta-front, delta-plain, and fluvial-channel deposits. Farther to the north, toward the sediment source, the Stalnaker sand is restricted to a broad paleovalley. Strata that fill that paleovalley include estuarine deposits, bayhead deltas, and channel-fill deposits (Feldman and others, 1995).

The presence of a fluvial delivery system in Kansas (above), and the common occurrence of mica in cuttings (Caylor, 1956, 1957) and in cores (Appendix 2; Hinshaw and Rottmann, 1997, tables W2, W3) indicate that the ultimate sediment source for the Tonkawa delta was crystalline rocks in the northern part of the Midcontinent region.

Depositional environments of the Tonkawa sand in the present study (Pl. 3) were mapped entirely from interpretation of wireline logs, primarily gamma-ray profiles, as discussed in Part I of this volume. Most interpretations were made with logs at a scale of 2.5 in. to 100 ft; some large-scale logs were not available, however, in which cases the 1-in. to 100-ft scale was used, although many logs were not interpretable at that scale. Gamma-ray logs that accompany density-porosity tools were found to be the most desirable, albeit the least available. Those tools are pulled up the well bore more slowly and therefore respond to rock properties the most accurately. The density of well-log control varied greatly; in some townships, only a few gamma-ray logs are available for the Tonkawa sand interval. For some areas for which more plentiful gamma-ray logs are available, not every log was studied. More than 500 logs in about 90 townships were examined to produce the interpretation shown on Plate 3. Two cores of the Tonkawa sand were studied, one of which is described in Appendix 2.

The geological interpretation (Pl. 3) maps the contiguous boundary of fluvial deposits in the Tonkawa sand interval within the framework of well-log control. Although relatively few gamma-ray profiles are textbook examples that can be interpreted without reservation (Part I, this volume), one of the least ambiguous

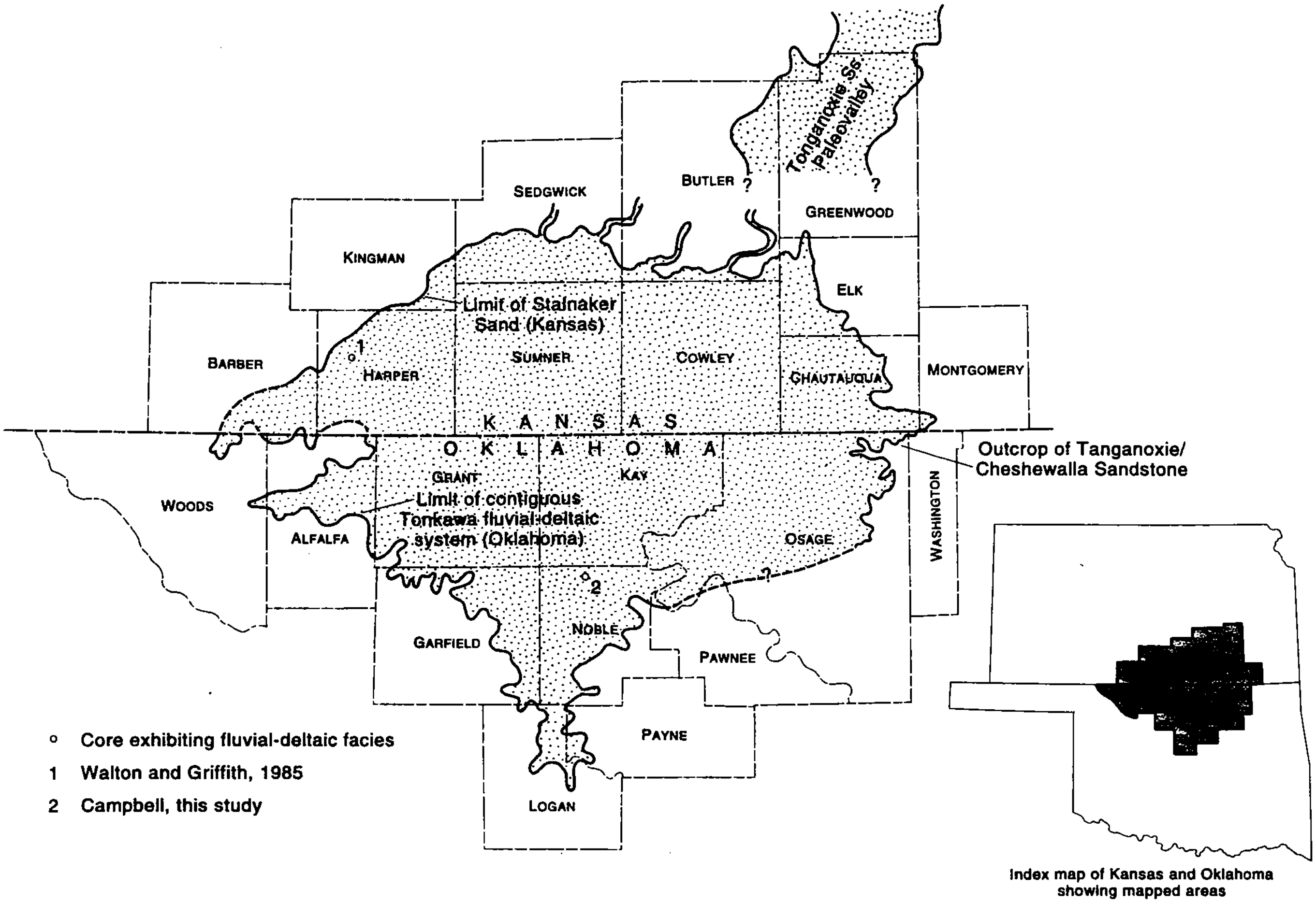


Figure 21. Tonkawa fluvial-deltaic play in Oklahoma and Kansas. Depositional environments have not been delineated in Kansas. Compiled from Plate 3 (this volume, in envelope), Winchell (1957), and Feldman and others (1995).

areas for interpretations of depositional environments in the Tonkawa sand is in the northeastern part of the Blackwell field (see Rottmann, Part III, this volume; see also Fig. 7, Part I). A representative Tonkawa sequence is also found in east-central Noble County near the East Otoe City field (Fig. 18; well 13, Pl. 4). Locally, stratigraphic sequences that appear to be entirely marine occur within the boundary but are surrounded by wells in which the Tonkawa exhibits deposits that are interpreted to be of fluvial origin. The Tonkawa sand probably was not deposited in a rapidly subsiding basin, such as the modern Mississippi River delta. In the absence of such subsidence, not all areas of marine deposition were buried or reworked by fluvial processes as the Tonkawa delta prograded southward. The reference log (Fig. 19) exhibits a sequence of four upward-fining deposits in the Tonkawa. (This log was selected for the stratigraphic-sequence and tool-response profiles, not the depositional environments.) Similarly, part of the Tonkawa sand locally includes intervals of apparent fluvial origin beyond the limit of contiguous fluvial deposits mapped on Plate 3. Such intervals of fluvial deposits are commonly below deposits of marine origin (Fig. 20) and are surrounded by wells at which the Tonkawa contains deposits that are entirely of probable marine origin. Occurrences of this nature suggest that the interval reasonably interpreted as Tonkawa sand is composed locally of more than one regressive cycle of deltaic progradation. The Tonkawa as mapped in the subsurface probably also represents, at least locally, more than one formation as mapped or described at the surface. The geographic distribution of fluvial-deltaic facies of the Tonkawa sand in Oklahoma and Kansas is synthesized in Figure 21.

CONCLUSIONS

The Tonkawa sand is the stratigraphically youngest formation that will be investigated in this series of workshops, with drilling depths of about 2,200–4,400 ft. The Tonkawa play is comparatively small for two reasons. First, the distribution of sandstones of fluvial-deltaic origin is limited. Second, Tonkawa reservoirs have a strong association with the Nemaha uplift and Nemaha fault zone, and oil probably migrated vertically to the Tonkawa in those provinces.

The play is, however, not without potential for development. Operators have focused on drilling deeper to commonly more productive "Layton" (Cottage Grove), Red Fork, "Wilcox," and other targets as economic conditions permitted. Because Tonkawa accumulations are dependent on the distribution of favorable reservoir facies and structural conditions, it was not uncommon to leave parts of shallow accumulations poorly understood and incompletely developed. An example of such a reservoir is presented by Rottman (Part III, this volume). Opportunities of this nature are likely to occur low on identified structures, or off-structure. However, stratigraphic accumulations may also exist locally adjacent to known faults where favorable Tonkawa reservoir and updip seal conditions are present.

ACKNOWLEDGMENTS

Completion of this study would not have been possible without funding from the U.S. Department of Energy and the combined efforts of many people from the Oklahoma Geological Survey (OGS), the Geo Information Systems (GeoSystems) research unit of the University of Oklahoma, and the OU School of Petroleum and Geological Engineering. The continuing effort of Rhonda Lindsey, project manager, Bartlesville Project Office of the U.S. Department of Energy, is greatly appreciated. Special recognition is given to Charles J. Mankin, director of the OGS, and Mary K. Banken, director of GeoSystems, who originated concepts for this program and provided overall leadership. The OGS and GeoSystems also provided funding for this cooperative project.

The investigators are most fortunate in having had the cooperation of Mr. Aubrey Kelle of Blackwell, Oklahoma. We extend our abundant gratitude to Mr. Kelle for having provided information supplemental to the public records that led to improved understanding of the geology and history of development of the Tonkawa reservoir, presented in Part III.

I greatly appreciate the effort of Douglas L. Beene of the Kansas Geological Survey, who provided relevant oil and gas production data for Kansas, presented in Table 3.

Much of the technical support for geological and computer map preparation, technical typing and editing, and computer graphics was contributed by G. Carlyle Hinshaw, petroleum geologist, Kathy Hines, and David Brown, all of GeoSystems; and Betty Bellis, OGS technical typist. Core examination and presentation were made possible by Walter Esry, Larry Austin, and student assistants of the OGS Core and Sample Library, and by Victoria French, student research assistant, OU School of Geology and Geophysics. Cartographic drafting and visual-aid preparation were completed by Wayne Furr, OGS manager of cartography; Jim Anderson and Charlotte Lloyd, cartographic drafting technicians; and Greg Taylor, contract drafting technician. Technical editing was completed by William D. Rose, contract geologist/editor. Christie Cooper, OGS managing editor, and Tracy Peeters, OGS associate editor, prepared the final layout and production of the manuscript for printing. Publication printing was done by Paul Smith and Richard Murray (OGS). Special recognition goes to Michelle Summers, OGS technical project coordinator, for program organization and registration. The author is most appreciative of the technical reviews by Charles J. Mankin and G. Carlyle Hinshaw. Conversations with Rick Andrews, Carlyle Hinshaw, and Bob Northcutt were most helpful; however, the author alone is responsible for the interpretations and conclusions reached herein.

PART III

Geology of the Tonkawa Sand Reservoir, Blackwell Oil Field

Kurt Rottmann
Consultant Geologist, Oklahoma City

INTRODUCTION

The Blackwell oil field lies in Kay County, north-central Oklahoma (Fig. 22). The field was originally called the South Blackwell oil field but is now known as the Blackwell field. The field lies on the Nemaha uplift (Pl. 1, in envelope). An explanation (Fig. 23), a map (Fig. 24), and a tabulation of 186 wells (Table 5) give well locations, well numbers, operators, principal leases, and producing formations within the field study area.

All available information from the Oklahoma City Geological Society Library was used to compile this report; therefore, interpretations were made by using only the available data. Drillers' logs were used to determine the top of the Haskell Limestone, and the top of the B sand layer of the Tonkawa sand, only if those logs reflected a reasonable degree of accuracy for those stratigraphic horizons above and below the Tonkawa. The wells shown in Figure 22 are located with a reasonable degree of confidence, although several wells were not included because their locations were uncertain.

Sincere appreciation is extended to Mr. Aubrey Kelle of Blackwell, Oklahoma, for his courtesy and support of this study.

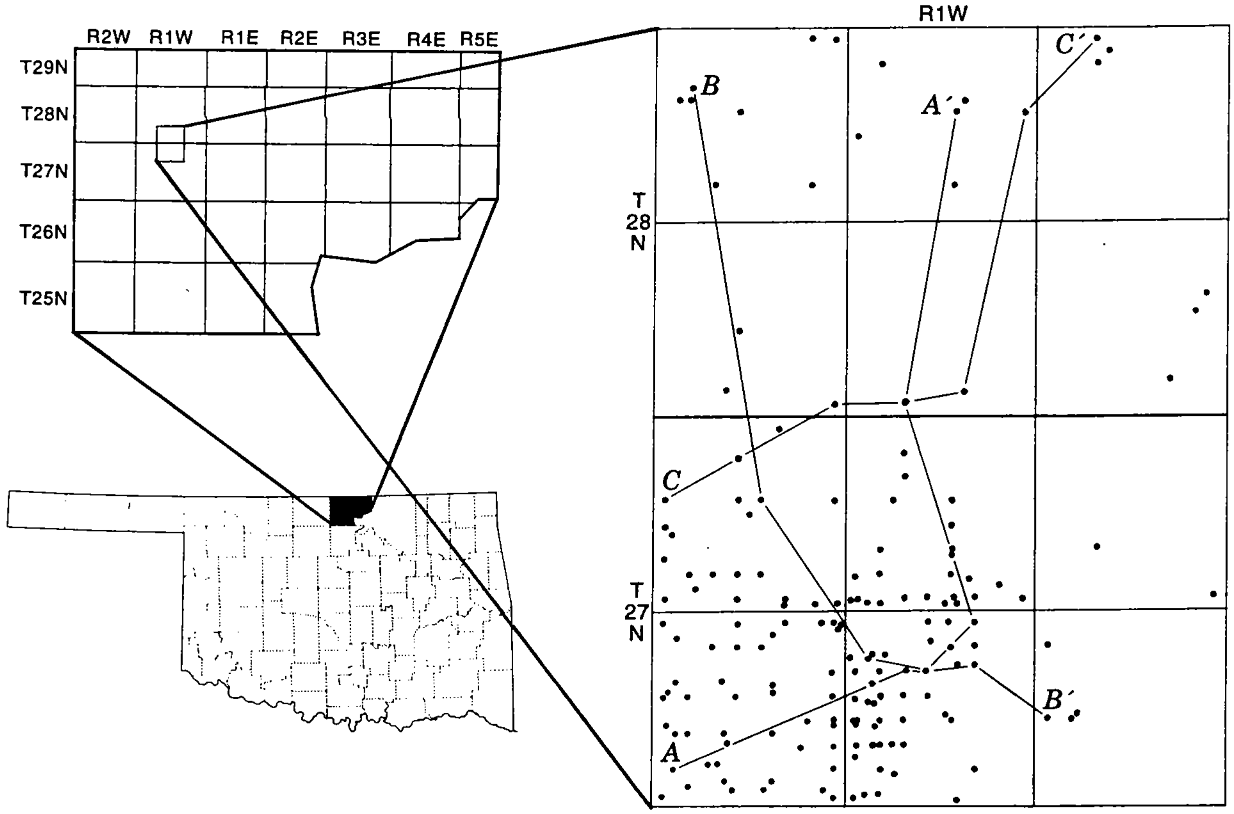


Figure 22. Generalized location map of Blackwell field study area, Kay County, Oklahoma. Lines of cross sections *A–A′*, *B–B′*, and *C–C′* (Figs. 26–28, in envelope) are indicated.

EXPLANATION

⌖	Dry hole	◈	Production period 1923–1941
●	Oil well	◙	Production period 1948–1963
☼	Gas well	▼	Production period 1977–1986
☼̸	Abandoned gas well	◓	Upper Tonkawa*
✷	Oil and gas well-dual completion	⊕	Upper and Lower Tonkawa*
✷̸	Abandoned oil and gas well	◉	Lower Tonkawa (B layer)
↙	Oil well converted to injection well	K	Kisner
○WSW	Water supply well	B	Burlingame Ls.
◬	Discovery well	N	Neva
⊛	Type or representative log well	C	Campbell
▣	Cored well	E	Endicott
NDE	Not deep enough	CV	Cleveland
DNP	Did not penetrate	BV	Bartlesville
NC	No control	MC	Mississippi chat
DNL	Did not log	M	Mississippian
NPR	No Production record	S	Simpson

* Upper Tonkawa includes the A sandstone as identified in figures 25–28 and 34, as well as localized sandstones above that layer. (Discussion in text)

Figure 23. Explanation for Figures 24, 29, 31–39, and 41.

STRATIGRAPHY AND ENVIRONMENTS OF DEPOSITION

The reference log for the Tonkawa reservoir is Prime Energy Co. No. 34-1 Wooderson, in the SW¼SE¼ sec. 34, T. 28 N., R. 1 W. (Fig. 25). *Tonkawa sand* is an informal name applied to the sandstone interval in the lower part of the Vamoosa Formation. The Tonkawa has been informally divided into an upper sand, known locally as the upper Tonkawa or upper Stalnaker, and a lower sand known locally as the lower Tonkawa or lower Stalnaker. In the Blackwell oil-field area, the Tonkawa sand lies ~40 ft below the Haskell Limestone.

The Tonkawa sand was deposited primarily in four distinct layers, identified informally in descending order as A, B, C, and D sands. Each sand is characterized by a unique depositional environment that results in similar and correlatable electric-log signatures. More detailed descriptions of these sands are given in the section "Isopach Mapping."

Stratigraphic details of the Tonkawa sand in the Blackwell field area are shown in cross sections of the field (Figs. 26–28 [in envelope]). Cross section *A–A′* (Fig. 26) is a southwest-to-north section. The stratigraphic datum is the top of the Haskell Limestone, and the section includes the entire Tonkawa interval as well as the Tallant Formation. All four layers—A, B, C, and D—are defined and their stratigraphic relationships shown. The D sand is not continuous between wells 5 and 6, because the two D sands were deposited in different depositional environments. The D sand in well 5 is interpreted to be a marine bar, whereas the same interval in well 6 is interpreted to be a delta-front deposit. Sand D has been interpreted as a distributary-channel deposit in the northern part of the study area, and as delta-front and marine-bar deposits farther south, largely on the basis of wireline-log signatures. Strip logs locally include references to sea shells in the southern part of the study area only, which is consistent with the wireline-log interpretation.

The C sand interval is much thicker, reaching a maximum thickness of 60 ft in the study area. This unit is commonly characterized by upward-coarsening profiles, which are probably indicative of delta-front facies that were deposited locally as the Tonkawa sand prograded from north to south. The delta-front facies is best shown in the log of well 3 of cross section *A–A′* (Fig. 26). The gamma-ray profiles are more blocky locally, as in the upper part of the C sand interval on the log of well 2 in cross section *A–A′* (Fig. 26). Such profiles probably represent distributary-channel facies that occur locally on top of the delta-front deposits. Strip-log descriptions also note the presence of limestone cement, or thin limestone layers, within this interval in the southern part of the study area, consistent with the interpretation of a marine origin for the deposits.

The B sand is characterized by a sharp basal contact and upward-fining to blocky gamma-ray profiles. The clean gamma-ray signature also indicates high porosity and presumably high permeability. This layer is interpreted to be a distributary-channel facies, as illustrated by the logs of wells 2, 3, and 5 in cross section *A–A′* (Fig. 26). Wells 2, 3, and 4 exhibit an oil–water contact in the upper part of the sand. This contact is sharp and grades from a resistivity of ~10 ohms in the oil-saturated reservoir to ~1 ohm in the water-saturated part. This oil–water contact is discussed in more detail in the section "Production History."

The A sand layer is one of several sands in the interval between the top of the B layer and the base of the Haskell Limestone. The A sand, as identified in cross section *A–A′* (Fig. 26), is the sandstone that is most persistent within that interval in the study area. This sandstone is interpreted to consist mainly of fluvial point-bar deposits. Each of these point bars has the potential for a local stratigraphic trap for hydrocarbons if conditions of sand geometry and structural orientation are appropriate. The productive interval of a shallower sandstone in well 6 (Fig. 26) is just such an example.

In cross section *B–B′* (Fig. 27), sand layers A, B, C, and D are similar to those of cross section *A–A′*. The D sand in well 1 (cross section *B–B′*) lies directly on marine shale and is directly overlain by the C sand; in well 2, the D sand is separated from the overlying C sand by a thin shale. This indicates that the D sandstones in the two wells probably have different depositional origins, as interpreted in cross section *A–A′* (Fig. 26). The characteristics and thicknesses of the C and B sands are similar to those illustrated in cross section *A–A′*. The B sandstone grades to shale in well 6 (Fig. 27), probably representing delta-plain deposits, as interpreted in Figure 26. An oil–water contact is present in the B sand in well 3 (Fig. 27). The A sand thickens from 8 to >20 ft between wells 5 and 6 (Fig. 27), but only well 5 is productive, owing to a higher structural position.

In cross section *C–C′* (Fig. 28), the D sandstone is discontinuous, as in Figures 26 and 27. In Figure 28, the C and B layers between wells 5 and 6 grade from sandstone to shale.

STRUCTURE

The geologic structure of the Blackwell field study area is illustrated in Figure 29. All available electric logs were used to determine the structural datum, which is the top of the Haskell Limestone. Drillers' logs were also used if the logs demonstrated correct stratigraphic relationships both above and below the Haskell.

The regional dip is to the south-southwest at approximately 50 ft/mi. A southeast-trending horst block is present in secs. 2 and 10, T. 27 N., R. 1 W. This horst block is interpreted on the basis of stratigraphic separation of the Haskell Limestone between closely spaced wells at several points. In T. 27 N., 1 R. W., between Wherry-Green No. 1 Rohrs (SW¼NW¼SE¼ sec. 3) and Royal Oil and Gas Corp. No. 4 Bumgardner (S½SW¼ NW¼SE¼ sec. 3), there is ~23 ft of structural relief. In the same township, between Blackwell Oil and Gas Co. No. 1 Geiger (SE¼SE¼NE¼ sec. 9) and Sinclair Oil and Gas Co. No. 6-A Geiger (NE¼SE¼NE¼ sec. 9), there is ~25 ft of structural relief; and between the No. 1 Geiger and Blackwell Oil and Gas Co. No. 2 Kumler (NE¼NE¼ SE¼ sec. 9), there is ~17 ft of relief. In the same township, there is also ~32 ft of structural relief at the top of the Haskell Limestone between Strike Energy Corp. No. 1 Hardin (NW¼NW¼SW¼ sec. 11) and Dave Morgan Oil Co. No. 1 McKee (NE¼NW¼SW¼ sec. 11). The differences in altitude of the Haskell Limestone at these three locations is considerably greater than the regional dip, which is essentially a horizontal plane between wells so closely spaced. These altitude differences are used as the basis on which to define the geometry and orientation of the horst block. The Neva Limestone (Lower Permian) also dips gently southwestward (Fig. 30). The vertically hatched area represents gas production from the Neva Limestone as observed in 1927. This trend approximates the position and orientation of the horst block mapped in Figure 29.

Several areas of structural closure are evident from structural mapping. One closure abuts the upthrown part of the northern fault of the horst block, in the W½ sec. 10, T. 27 N., R. 1 W. The closure extends northeastward and is more pronounced in the S½S½ sec. 3. A second closure is present in the NE¼ sec. 10, and a third is in the SE¼ sec. 9. This closure may form a trap against the upthrown side of the fault mentioned previously. A fourth area of closure is in the SW¼ sec. 4. Finally, a possible closure is suggested in the N½ sec. 3, on the basis of wells drilled to date.

ISOPACH MAPPING

As mentioned in the section "Stratigraphy and Environments of Deposition," the Tonkawa sand has been separated into four layers that represent depositional facies that are distinct and correlatable in all the wells within the Blackwell study area. The isopach values were taken from electric-log data only. All the net-reservoir isopach maps were constructed from porosity-log values using an 8% cutoff value. In the absence of porosity logs, it was necessary to estimate porosity from spontaneous-potential (SP) curves, which are an index of relative porosity. For wells with neither neutron nor density-porosity logs, the SP curve was compared to porosity measurements from those wells,

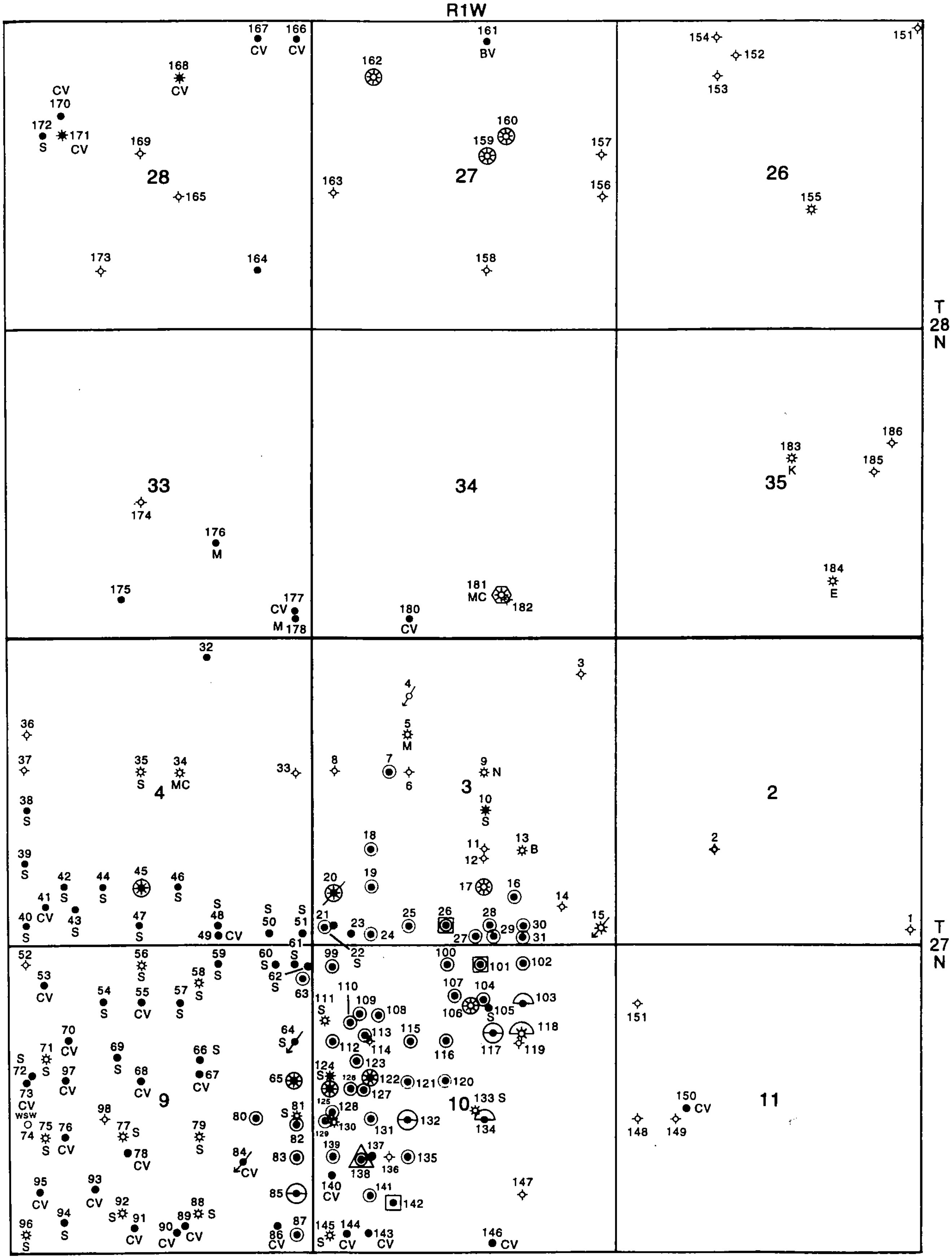


Figure 24. Map showing completion status and producing formations for wells in Blackwell field study area. Numbers refer to wells, operators, leases, and section locations listed in Table 5.

TABLE 5. – Wells, Operators, Leases, and Section Locations, Blackwell Field Area

Spot no.	Company Name	Lease Name	Section	Township	Range
1	?	Ocate #1	2	T 27 N	R 1 W
2	Dave Morgan Oil Co.	Rigdon #1	2	T 27 N	R 1 W
3	Prime Energy Co.	Hooper #1	3	T 27 N	R 1 W
4	K. & G. Production Co.	Rohrs #3-1	3	T 27 N	R 1 W
5	Artnell Co.	Rohrs #1	3	T 27 N	R 1 W
6	Royal Oil & Gas Corp.	Rohrs #1	3	T 27 N	R 1 W
7	Artnell Co.	Rohrs #2	3	T 27 N	R 1 W
8	Tidal	Davies #1	3	T 27 N	R 1 W
9	Prime Energy Co.	Hooper #1-A	3	T 27 N	R 1 W
10	Otstot Development Co. et al	Rohrs #2	3	T 27 N	R 1 W
11	Wherry-Green & Brill	Rohrs #1	3	T 27 N	R 1 W
12	Royal Oil & Gas Corp.	Geraldean Bumgardner #4	3	T 27 N	R 1 W
13	Royal Oil & Gas Corp.	Geraldean Bumgardner #3	3	T 27 N	R 1 W
14	Royal Oil & Gas Corp.	Geraldean Bumgardner #1	3	T 27 N	R 1 W
15	Royal Oil & Gas Corp.	Walter E. Rohrs #1	3	T 27 N	R 1 W
16	Royal Oil & Gas Corp.	Henry Rohrs #3	3	T 27 N	R 1 W
17	Royal Oil & Gas Corp.	Henry Rohrs #4	3	T 27 N	R 1 W
18	Harold U. Martin	Slocum-Moore #2	3	T 27 N	R 1 W
19	Harold U. Martin	Slocum-Moore #1	3	T 27 N	R 1 W
20	Arkansas Fuel Oil Co.	L. C. Moore #2	3	T 27 N	R 1 W
21	Clipper Oil Co.	L. C. Moore #1-A	3	T 27 N	R 1 W
22	Arkansas Fuel Oil Co.	L. C. Moore #1	3	T 27 N	R 1 W
23	Arkansas Fuel Oil Co.	L. C. Moore #3	3	T 27 N	R 1 W
24	?	?	3	T 27 N	R 1 W
25	Bachus Oil Co.	Slocum-Moore #4-A	3	T 27 N	R 1 W
26	Bachus Oil Co.	Slocum-Moore #3	3	T 27 N	R 1 W
27	Harold U. Martin	Rohrs #1	3	T 27 N	R 1 W
28	Royal Oil & Gas Corp.	Santa Fe "A" #1	3	T 27 N	R 1 W
29	Royal Oil & Gas Corp.	Henry Rohrs #2	3	T 27 N	R 1 W
30	Royal Oil & Gas Corp.	Walter E. Rohrs #2	3	T 27 N	R 1 W
31	Royal Oil & Gas Corp.	Henry Rohrs #1-A	3	T 27 N	R 1 W
32	Rahmco Oil & Gas Co., Inc.	C. G. D. #1	4	T 27 N	R 1 W
33	Bachus Oil Co.	Ritchie #1	4	T 27 N	R 1 W
34	Bobby J. Darnell	Tabor #1	4	T 27 N	R 1 W
35	Harold Petroleum Co.	John Moore #2	4	T 27 N	R 1 W
36	Bobby J. Darnell	Tabor #2	4	T 27 N	R 1 W
37	Harold Petroleum Co.	Moore #1	4	T 27 N	R 1 W
38	Harold Petroleum Co.	Case #4	4	T 27 N	R 1 W
39	Harold Petroleum Co.	Case #5	4	T 27 N	R 1 W
40	Harold Petroleum Co.	Case #2	4	T 27 N	R 1 W
41	Marileen Oil & Gas Co.	Case #8	4	T 27 N	R 1 W
42	Harold Petroleum Co.	Case #7	4	T 27 N	R 1 W
43	Clipper Oil Co.	Ross Kelley #1	4	T 27 N	R 1 W
44	Harold Petroleum Co.	Case #6	4	T 27 N	R 1 W
45	Harold Petroleum Co.	Case #3	4	T 27 N	R 1 W
46	Arkansas Fuel Oil Co.	Kelly #3	4	T 27 N	R 1 W
47	Harold Petroleum Co.	Case #1	4	T 27 N	R 1 W
48	Arkansas Fuel Oil Co.	Kelley #2	4	T 27 N	R 1 W
49	Atlantic Richfield Co.	Otstot Field Ut #8-1A	4	T 27 N	R 1 W
50	Arkansas Fuel Oil Co.	Ross B. Kelly #5	4	T 27 N	R 1 W
51	Arkansas Fuel Oil Co.	Ross B. Kelly #4	4	T 27 N	R 1 W
52	Texas Co.	L. J. Burkhalder #2	9	T 27 N	R 1 W
53	Flossmar Oil & Gas Co.	Burkhalter #7	9	T 27 N	R 1 W
54	Ballard & Assoc.	Burkhalter #5	9	T 27 N	R 1 W
55	Marileen Oil & Gas Co.	Burkhalter #9	9	T 27 N	R 1 W
56	Marileen Oil & Gas Co.	Burkhalter #1	9	T 27 N	R 1 W
57	Blackwell Oil & Gas Co.	Geiger #9	9	T 27 N	R 1 W
58	Blackwell Oil & Gas	Geiger #2	9	T 27 N	R 1 W
59	Blackwell Oil & Gas Co.	Geiger #4	9	T 27 N	R 1 W
60	Blackwell Oil & Gas Co.	Geiger #7	9	T 27 N	R 1 W
61	Blackwell Oil & Gas Co.	Geiger #8	9	T 27 N	R 1 W
62	Blackwell Oil & Gas Co.	Geiger #5	9	T 27 N	R 1 W

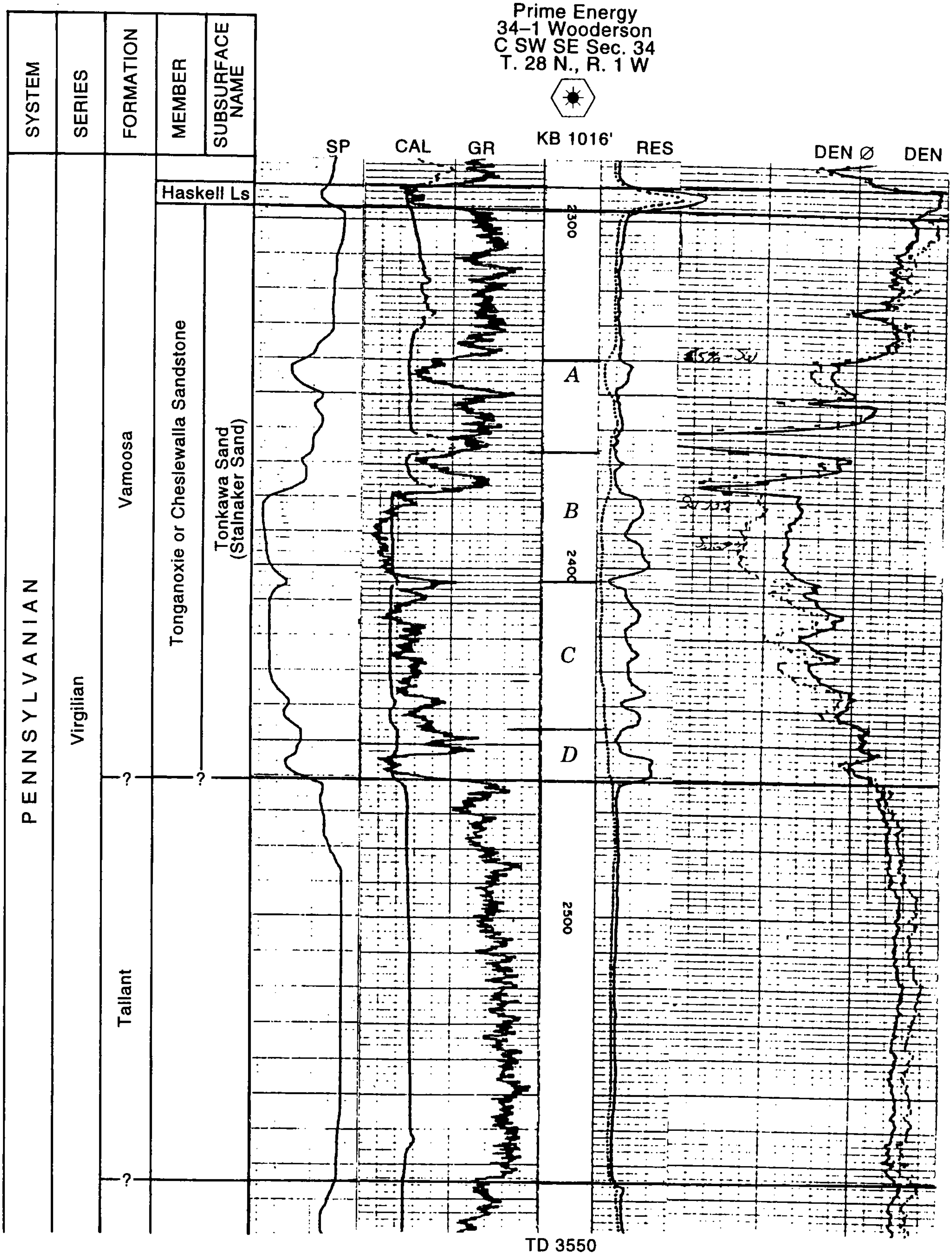
(continued on p. 34–35)

TABLE 5. – Continued.

Spot no.	Company Name	Lease Name	Section	Township	Range
63	Blackwell Oil & Gas Co.	Geiger #6	9	T 27 N	R 1 W
64	Sinclair Oil & Gas Co.	C. E. Geiger #6-A	9	T 27 N	R 1 W
65	Blackwell Oil & Gas Co.	Geiger #1	9	T 27 N	R 1 W
66	Blackwell Oil & Gas Co.	Geiger #3	9	T 27 N	R 1 W
67	Clipper Oil Co.	C. E. Geiger #10	9	T 27 N	R 1 W
68	ARCO Oil & Gas Co.	Otstot Tract 12 #11	9	T 27 N	R 1 W
69	Ballard & Assoc.	Burkhalter #2	9	T 27 N	R 1 W
70	Flossmar Oil & Gas Co.	W. Burkhalter #6	9	T 27 N	R 1 W
71	Texas Co.	L. J. Burkhalder #1	9	T 27 N	R 1 W
72	Flossmar Oil & Gas Co.	W. Burkhalter A#1	9	T 27 N	R 1 W
73	Flossmar Oil & Gas Co.	W. Burkhalter #10	9	T 27 N	R 1 W
74	Atlantic Richfield Co.	Otstot WSW #1	9	T 27 N	R 1 W
75	Harris & Haun, Inc.	J. W. Brown #4	9	T 27 N	R 1 W
76	Clipper Oil Co.	Brown Heirs #7	9	T 27 N	R 1 W
77	Harris & Haun, Inc.	J. W. Brown #2	9	T 27 N	R 1 W
78	Clipper Oil Co.	J. W. Brown Heirs #6	9	T 27 N	R 1 W
79	Blackwell Oil & Gas Co.	Kumler #6	9	T 27 N	R 1 W
80	Clipper Oil Co.	Kumler #7	9	T 27 N	R 1 W
81	Blackwell Oil & Gas Co.	Kumler #2	9	T 27 N	R 1 W
82	Blackwell Oil & Gas Co.	Kumler #2-A	9	T 27 N	R 1 W
83	Blackwell Oil & Gas Co.	Kumler #4	9	T 27 N	R 1 W
84	Clipper Oil Co.	Kumler #8	9	T 27 N	R 1 W
85	Carter Oil Co.	C. A. Kumler #2	9	T 27 N	R 1 W
86	Clipper Oil Co.	Kumler #10	9	T 27 N	R 1 W
87	Blackwell Oil & Gas Co.	Kumler #3?	9	T 27 N	R 1 W
88	Blackwell Oil & Gas Co.	Kumler #5	9	T 27 N	R 1 W
89	Clipper Oil Co.	C. A. Kumler #9	9	T 27 N	R 1 W
90	Clipper Oil Co.	Kumler #6	9	T 27 N	R 1 W
91	Clipper Oil Co.	J. W. Brown Heirs #5	9	T 27 N	R 1 W
92	Harris & Haun, Inc.	J. W. Brown #3	9	T 27 N	R 1 W
93	Clipper Oil Co.	Brown Heirs #10	9	T 27 N	R 1 W
94	Clipper Oil Co.	J. W. Brown Heirs #8	9	T 27 N	R 1 W
95	Clipper Oil Co.	Brown #9	9	T 27 N	R 1 W
96	Harris & Haun, Inc.	J. W. Brown #1	9	T 27 N	R 1 W
97	Flossmar Oil & Gas Co.	Burkhalter #8	9	T 27 N	R 1 W
98	George R. Hess	L. C. Moore # 1	10	T 27 N	R 1 W
99	Bachus Oil Co.	Slocum B #1	10	T 27 N	R 1 W
100	Royal Oil & Gas Corp.	Clift Unit #2	10	T 27 N	R 1 W
101	Royal Oil & Gas Corp.	Clift #1	10	T 27 N	R 1 W
102	Royal Oil & Gas Corp.	Clift #3	10	T 27 N	R 1 W
103	Royal Oil & Gas Corp.	Santa Fe "B" #1	10	T 27 N	R 1 W
104	Black Gold Oil Co.	Moore #1	10	T 27 N	R 1 W
105	Royal Oil & Gas Corp.	Santa Fe #A-1	10	T 27 N	R 1 W
106	Kay Production	Slocum #2-B	10	T 27 N	R 1 W
107	ARCO Oil & Gas Co.	Fred M. Jones #5-A	10	T 27 N	R 1 W
108	Clipper Oil Co.	F. Jones #8	10	T 27 N	R 1 W
109	ARCO Oil & Gas Co.	Fred M. Jones #6-A	10	T 27 N	R 1 W
110	Prairie Oil & Gas Co.	Fred M. Jones #4	10	T 27 N	R 1 W
111	Prairie Oil & Gas Co.	Fred M. Jones #5	10	T 27 N	R 1 W
112	Clipper Oil Co.	Jones #6	10	T 27 N	R 1 W
113	ARCO Oil & Gas Co.	Fred M. Jones #6	10	T 27 N	R 1 W
114	ARCO Oil & Gas Co.	Fred M. Jones #2	10	T 27 N	R 1 W
115	ARCO Oil & Gas Co.	Fred M. Jones #1	10	T 27 N	R 1 W
116	Watkins Drilling Co.	Circle X Unit #1	10	T 27 N	R 1 W
117	Royal Oil & Gas Corp.	Gladys Almack #1	10	T 27 N	R 1 W
118	Max E. Rogers	Almack #1	10	T 27 N	R 1 W
119	ARCO Oil & Gas Co.	Fred M. Jones #4	10	T 27 N	R 1 W
120	ARCO Oil & Gas Co.	Fred M. Jones #3	10	T 27 N	R 1 W
121	Clipper Oil Co.	Jones #5	10	T 27 N	R 1 W
122	ARCO Oil & Gas Co.	Fred M. Jones #7-A	10	T 27 N	R 1 W
123	Prairie Oil & Gas Co.	Fred M. Jones #3	10	T 27 N	R 1 W
124	Prairie Oil & Gas Co.	Fred M. Jones #2	10	T 27 N	R 1 W

TABLE 5. – Continued.

Spot no.	Company Name	Lease Name	Section	Township	Range
125	ARCO Oil & Gas Co.	Fred M. Jones #8-A	10	T 27 N	R 1 W
126	ARCO Oil & Gas Co.	Fred M. Jones #8-B	10	T 27 N	R 1 W
127	Blackwell Oil & Gas Co.	Humphrey #3	10	T 27 N	R 1 W
128	ARCO Oil & Gas Co.	Chan Humphrey #3-A	10	T 27 N	R 1 W
129	Blackwell Oil & Gas Co.	Humphrey #6	10	T 27 N	R 1 W
130	Clipper Oil Co.	Humphrey #12	10	T 27 N	R 1 W
131	ARCO Oil & Gas Co.	Chan Humphrey #1-A	10	T 27 N	R 1 W
132	M. F. Holomos	W. C. Ciff #2	10	T 27 N	R 1 W
133	Prime Energy Co.	Claybaker #10-1	10	T 27 N	R 1 W
134	Blackwell Oil & Gas Co.	Humphrey #4	10	T 27 N	R 1 W
135	ARCO Oil & Gas Co.	Chan Humphrey #2-A	10	T 27 N	R 1 W
136	Clipper Oil Co.	Humphrey #11	10	T 27 N	R 1 W
137	Schonwald-Gurley-Blackwell Oil & Gas Corp.	Humphreys #1	10	T 27 N	R 1 W
138	Blackwell Oil & Gas Co.	Humphrey #5	10	T 27 N	R 1 W
139	Sinclair Oil & Gas Co.	Chan Humphrey #13	10	T 27 N	R 1 W
140	Clipper Oil Co.	Humphreys #7	10	T 27 N	R 1 W
141	Clipper Oil Co.	Humphrey #9	10	T 27 N	R 1 W
142	Clipper Oil Co.	Humphries #8	10	T 27 N	R 1 W
143	Clipper Oil Co.	Humphrey #10	10	T 27 N	R 1 W
144	Blackwell Oil & Gas Co.	Humphrey #2	10	T 27 N	R 1 W
145	Indian Oil & Drilling Co.	Clift Ellidge #1	10	T 27 N	R 1 W
146	Lohman & Olsen	Cliff #2-A	10	T 27 N	R 1 W
147	Strike Energy Corp.	Herb Hardin #1	11	T 27 N	R 1 W
148	Dave Morgan Oil Co.	R. E. McKee #1	11	T 27 N	R 1 W
149	Duluth & Oklahoma Oil Co.	A. D. Landphere #1	11	T 27 N	R 1 W
150	Royal Oil & Gas Corp.	Fern Stiger #1	11	T 27 N	R 1 W
151	Duluth & Oklahoma Oil Co.	O. S. Whiteside #1	26	T 28 N	R 1 W
152	GMC Oil & Gas Corp.	Hunter #1	26	T 28 N	R 1 W
153	C. W. Dobson	Hunter #2	26	T 28 N	R 1 W
154	C. W. Dobson	Hunter #1	26	T 28 N	R 1 W
155	E. S. Adkins	Horiner #1	26	T 28 N	R 1 W
156	Cyclone Drilling	Kelle #1	27	T 28 N	R 1 W
157	Tidewater Associated Oil Co.	W. H. Kelle #1	27	T 28 N	R 1 W
158	Thunderbird Drilling, Inc.	Kelle #1	27	T 28 N	R 1 W
159	Exploration and Development, Inc.	Kelle #1	27	T 28 N	R 1 W
160	Prime Energy Co.	Grell #1	27	T 28 N	R 1 W
161	C & G Drilling Co.	Kelle #1	27	T 28 N	R 1 W
162	Jennings & Clogg & Hershey Oil Co.	Kelle #1	27	T 28 N	R 1 W
163	Simms Oil Co.	E. U. Walter #1	27	T 28 N	R 1 W
164	Boswell Energy Corp.	Wooderson #1-28	28	T 28 N	R 1 W
165	Rahmco Oil & Gas Co., Inc.	Harold Wooderson #4	28	T 28 N	R 1 W
166	John W. McKenzie	McKenzie #1-A	28	T 28 N	R 1 W
167	Marcus & May	Missell #1	28	T 28 N	R 1 W
168	Rahmco Oil & Gas Co., Inc.	Mc Kenzie #1	28	T 28 N	R 1 W
169	Atlantic Refining Co.	Clara Watson #1	28	T 28 N	R 1 W
170	Rahmco Oil & Gas Co., Inc.	Miller #1	28	T 28 N	R 1 W
171	Dave Morgan Oil Co.	Lewis Miller #1	28	T 28 N	R 1 W
172	Harris & Haun, Inc.	Watson #1	28	T 28 N	R 1 W
173	Novak Drilling Co.	Frazier #1	28	T 28 N	R 1 W
174	Simms Oil Co.	School Land #1	33	T 28 N	R 1 W
175	El Dorado Drilling, Inc.	Ghormley #33-80-2	33	T 28 N	R 1 W
176	Rahmco Oil & Gas Co., Inc.	Ghormley #2	33	T 28 N	R 1 W
177	Rahmco Oil & Gas Co., Inc.	Ghormley #1	33	T 28 N	R 1 W
178	El Dorado Drilling, Inc.	Ghormley #79-1	33	T 28 N	R 1 W
180	Prime Energy Co.	Grell #34-1	34	T 28 N	R 1 W
181	Prime Energy Co.	Wooderson #34-1	34	T 28 N	R 1 W
182	Max E. Rogers	Rogers #1	34	T 28 N	R 1 W
183	William Wilson	Pettit #1	35	T 28 N	R 1 W
184	Dave Morgan Oil Co.	Grimsley #2	35	T 28 N	R 1 W
185	North Clift Oil Co.	John Clift #1	35	T 28 N	R 1 W
186	Massey & Moore	Colwell #1	35	T 28 N	R 1 W



TD 3550
Completed 11/13/81

Figure 25. Tonkawa reservoir reference log, showing stratigraphic intervals and characteristic log signatures for Blackwell field area. *SP*, spontaneous potential; *GR*, gamma ray; *RES*, resistivity; *CAL*, caliper; *DEN*, density; *DENϕ*, density porosity. Depths in feet.

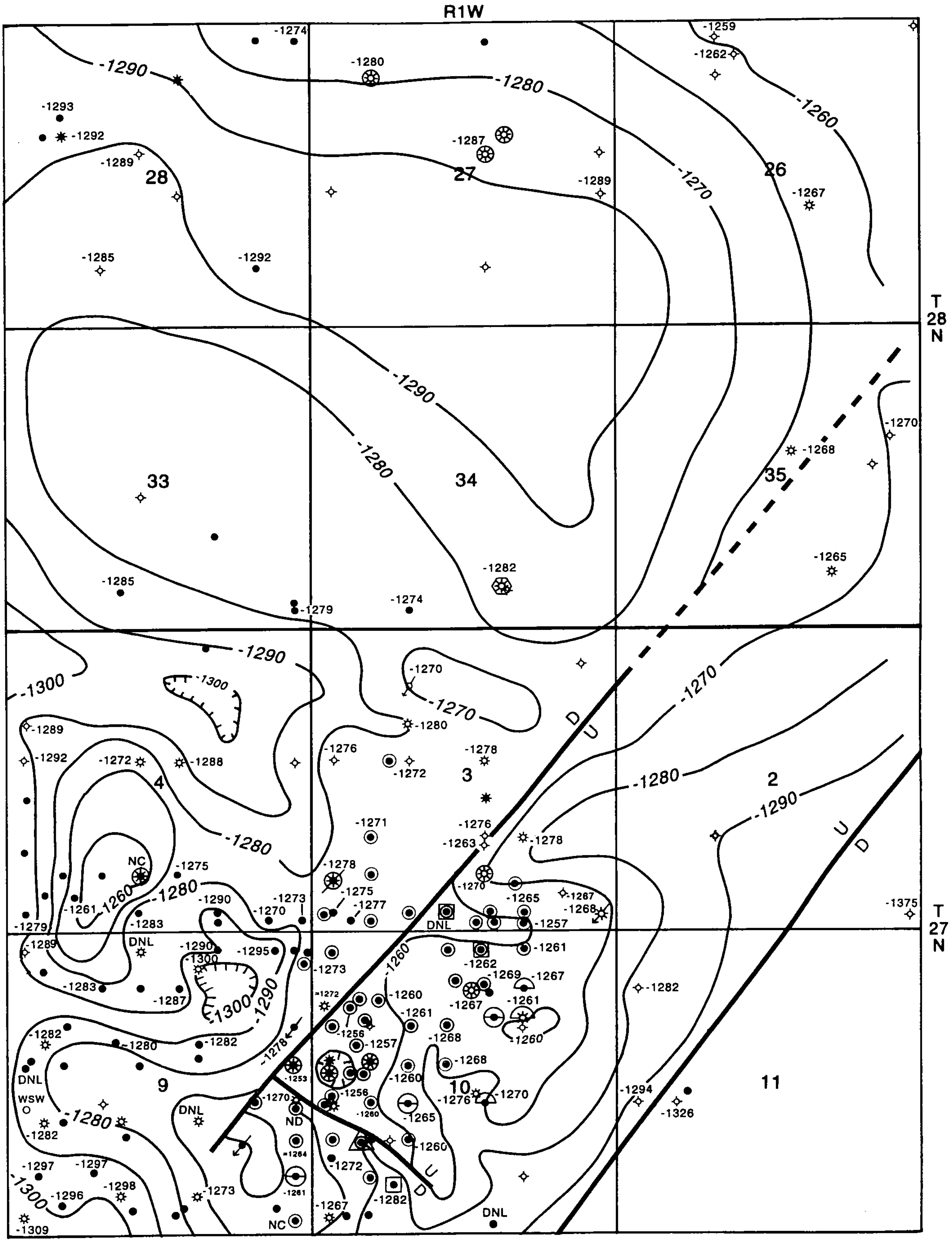


Figure 29. Structure-contour map of Blackwell field study area. Datum: top of Haskell Limestone. Contour interval, 10 ft.

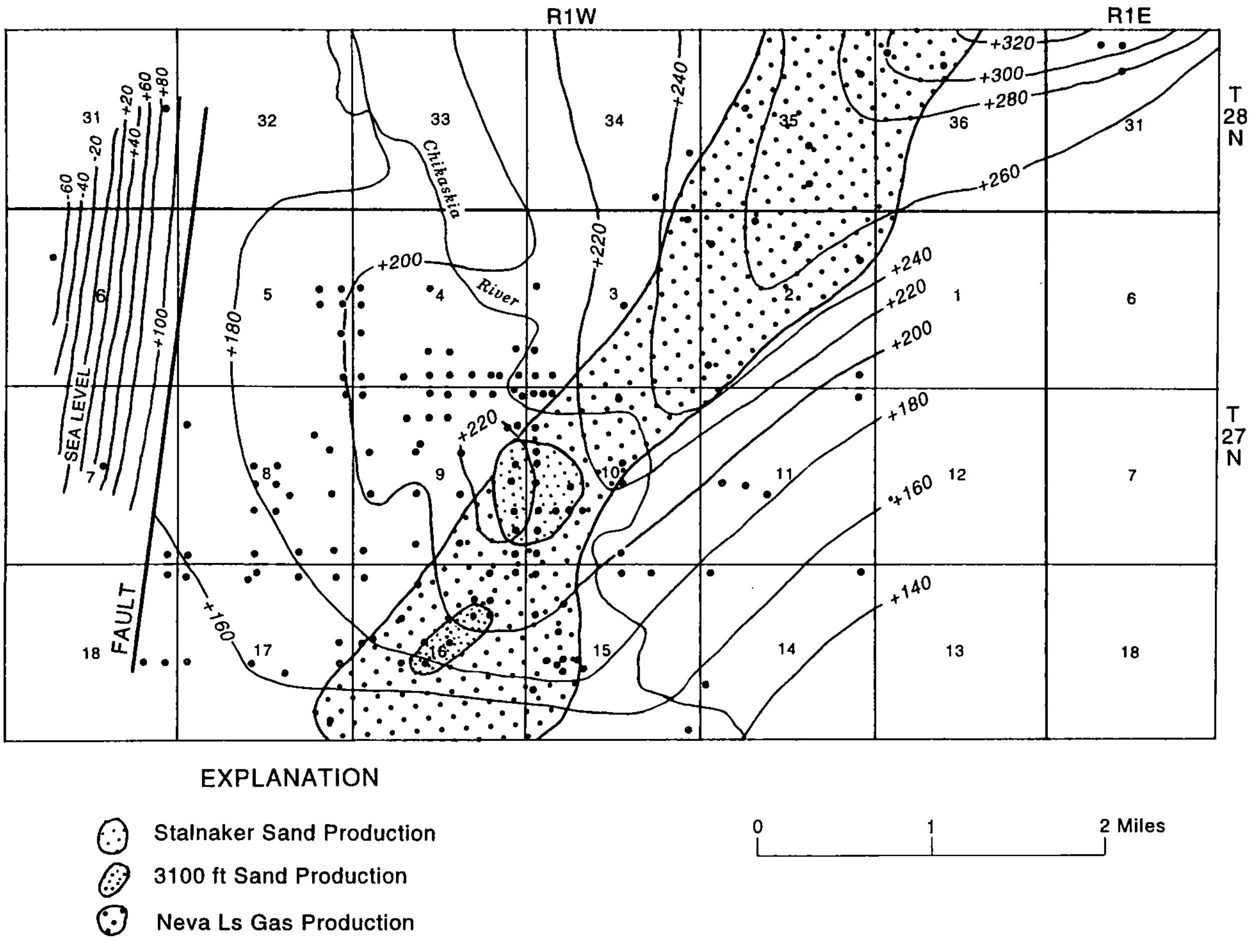


Figure 30. Structure-contour map depicting top of Neva Limestone in Blackwell field study area. Contour interval, 20 ft. (Redrafted from Clark and Daniels, 1929.)

thereby correlating the SP response as an estimate of porosity. In this way it was possible to establish net sandstone-reservoir values for the entire study area.

The net sandstone isopach for layer D of the Tonkawa sand is illustrated in Figure 31. The isopach map illustrates two major depositional environments. The first consists of delta-front sandstones and local distributary-channel deposits in secs. 26, 27, and 28, T. 28 N., R. 1 W. The D sandstone of the delta-front facies lies on marine prodelta shales and is directly overlain by the C sandstone (Fig. 26, in envelope). This relationship is illustrated by well 6 (Fig. 26), well 1 (Fig. 27, in envelope), and wells 5 and 6 (Fig. 28, in envelope). A second facies of the D sandstone interval is a marine-bar complex that lies basinward (south) of the delta-front facies. This sand was deposited by marine currents from sand introduced from the channels just beyond the delta front. Abundant marine fossils described on strip logs in wells drilled in the southern part of the study area confirm a marine origin for those sandstones. The source of clastic material was from the north, and the delta was prograding to the south.

The marine-bar facies is separated from the overlying C sandstone by 10–15 ft of shale. This relationship can be seen on the logs of well 5 of Figure 26, well 2 of Figure 27, and wells 1–4 of Figure 28. The delta-front facies has porosities of 10%–15% in comparison with porosities of 5%–10% for sandstones of the marine-bar facies, as indicated by porosity logs. Basinward of the marine-bar facies, the D sand interval is composed mostly of limy shale, sandy shale, and siltstone.

The C sandstone lies directly above the D sandstone in the northern third of the study area, and approximately 10–15 ft above the marine-bar facies of the D sand in the central part of the area. The isopach map of the C sandstone (Fig. 32) suggests that it has prograded to the south. The map illustrates that the leading edge of the delta front lies in the southernmost part of the study area and is composed mainly of a distributary-channel system. The sandstone reaches a maximum thickness of 60 ft in the northern half of the study area. Arrows indicate the general position of major distributary channels, based on isopach values only. Sandstones thin dramatically in the extreme southern part of the study area, which is the approximate position of the maximum extent of the delta front. The C sandstone facies grades to shale in the northeast part of sec. 26, T. 28 N., R. 1 W. This facies change is associated

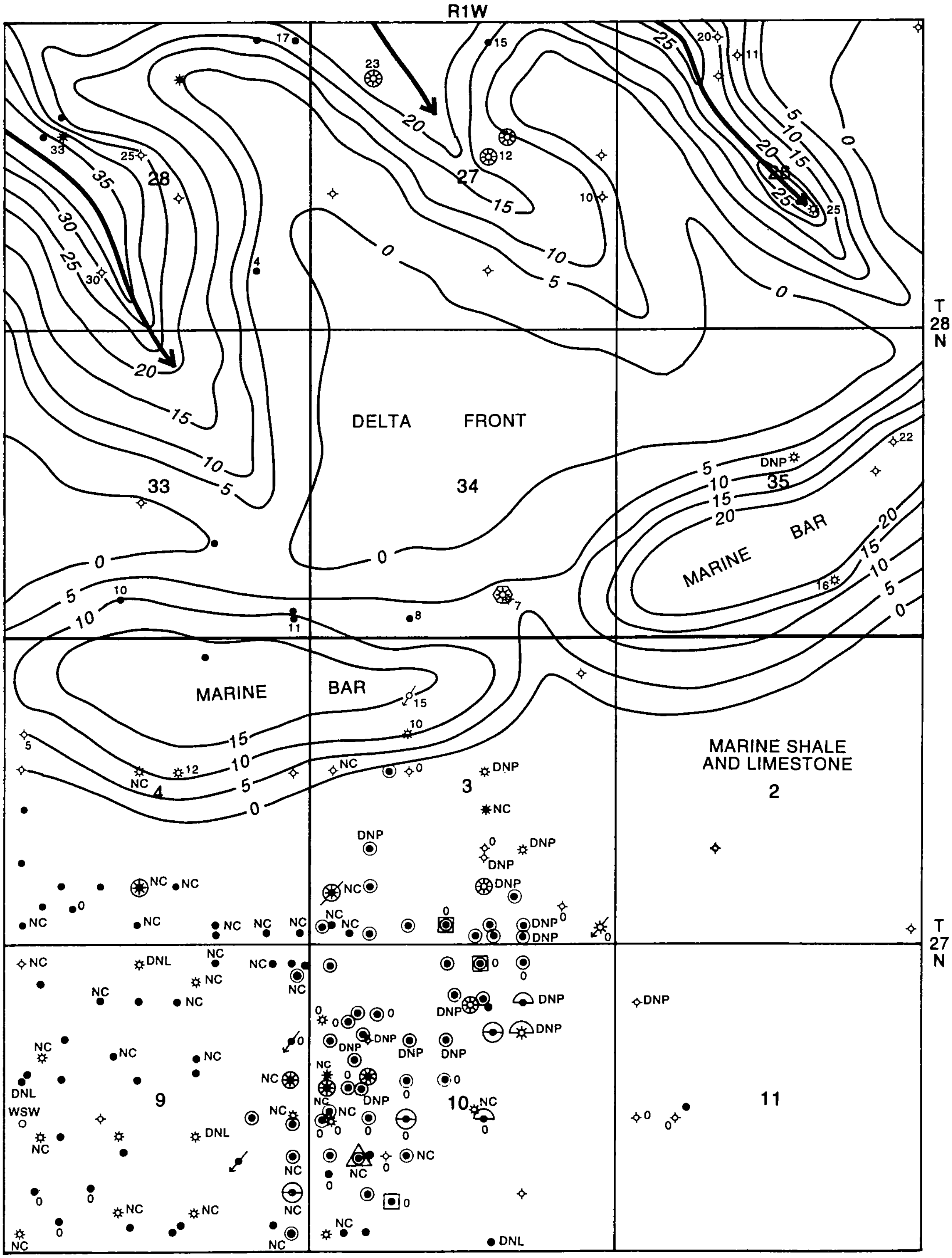


Figure 31. Isopach map of net sandstone thickness in layer D of Tonkawa sand, Blackwell field study area. Isopach interval based on minimum 8% log porosity and on approximate corresponding SP log response in wells in which porosity tools were not run, or information is not available. Contour interval, 5 ft.

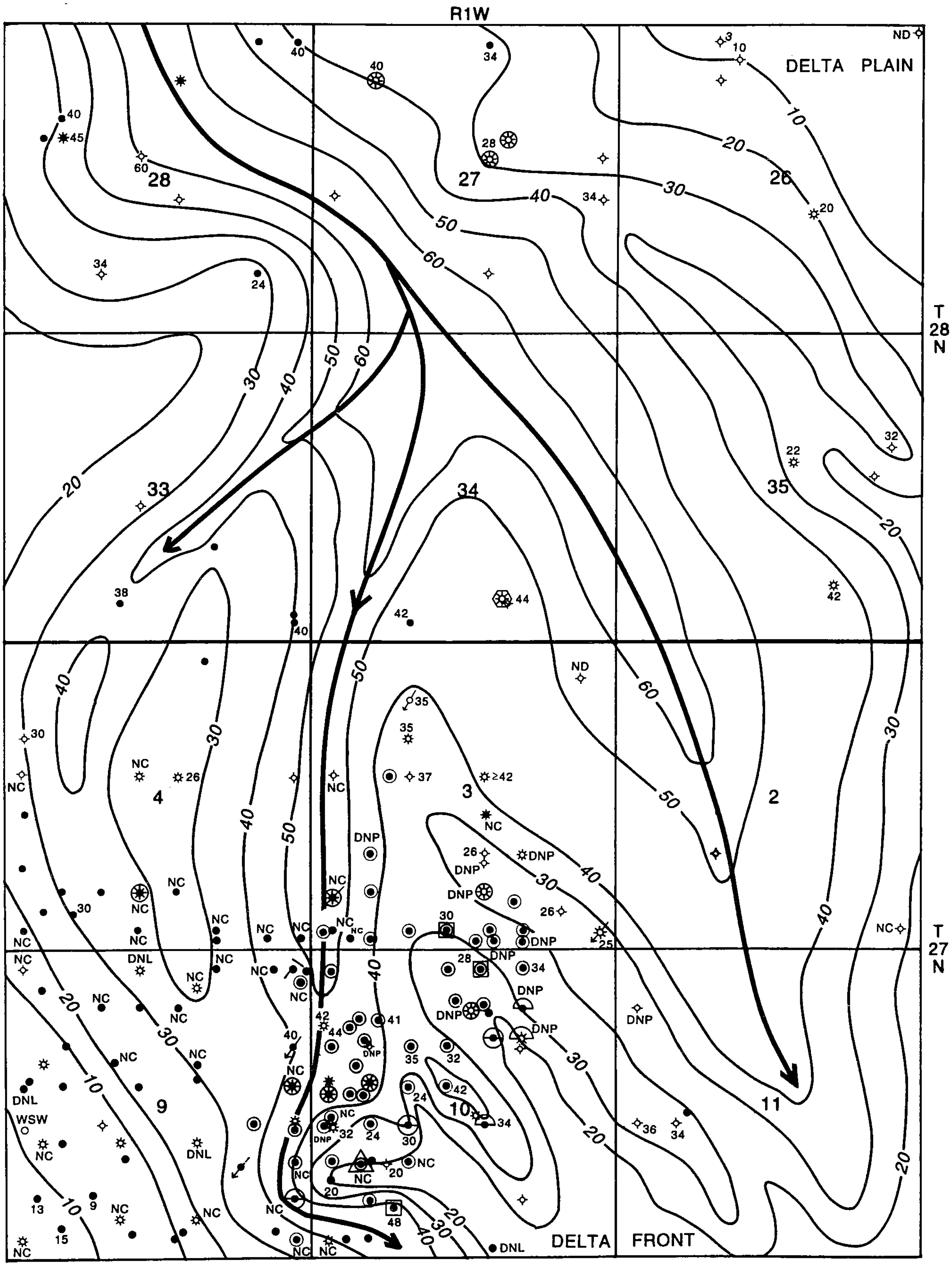


Figure 32. Isopach map of net sandstone thickness in layer C of Tonkawa sand, Blackwell field study area. Isopach interval based on minimum 8% log porosity and on approximate corresponding SP log response in wells in which porosity tools were not run, or information is not available. Contour interval, 10 ft.

with a lateral gradation from the distributary-channel environment to a delta-plain environment. As indicated on the reference log, sandstone of layer C exhibits an upward-coarsening profile on the gamma-ray curve. Porosity values for the C sandstone range from 10% to ~20%. However, no hydrocarbon production is associated with the C sand in the Blackwell field study area.

The net isopach map of the B sandstone layer is shown in Figure 33. The layer is important because it is the primary reservoir for the Blackwell field. The sandstone is bounded by delta-plain shale deposits to the east. The contact between shale and sandstone is potentially important, as it affords the opportunity for stratigraphic traps, given proper structural orientation in conjunction with the wedge edge of the sandstone. The geometry of the sandstone of layer B clearly indicates a distributary-channel environment. The sandstone facies of layer B is a clean, nonshaly body in the thicker part of the reservoir, in the central part of the map. The sandstone is characterized by a sharp basal contact with the underlying C layer and by a blocky gamma-ray profile. Its porosity values are high and generally are in the low part of the 20% range. The sand is rarely described on strip logs as having any limestone or marine fossils.

The limit of hydrocarbon production from the Tonkawa sand is defined by the oil–water contact, as shown in the southwestern part of Figure 33. This contact is interpreted from electric logs for those wells drilled between 1948 and 1963. (Very few wells were logged prior to 1941.) From the date of discovery in 1923 to the 1940s, the practice was to stop drilling just above the B sand and set casing. The operator would then cement the casing and drill out the cement plus a few feet of the B sandstone. Subsequently, the well would be produced open hole.

Production from the Tonkawa sand (Stalnaker) in 1927 is shown in Figure 30. Note that Tonkawa production at that time was limited to a small area in the E½ E½ sec. 9 and the W½ sec. 10, which is much smaller than the area defined by the currently mapped oil–water contact (Fig. 33).

The gamma-ray profile of the A sandstone on the reference log and in the cross sections (Figs. 26–28) exhibits an upward-fining profile, indicating that the interval is composed mainly of a series of point-bar deposits. The gross geometry of the sandstone of layer A (Fig. 34) indicates a fluvial-channel system with transport from north to south.

Point-bar deposits may behave as separate compartments in some reservoirs; they also may form individual traps related locally to the associated shales and to structural configuration. The three Tonkawa wells in sec. 27, T. 28 N., R. 1 W., are probably producing from a separate trap. Geologic structure (Fig. 29) indicates that had the reservoir been more continuous, the dry holes in the northwest part of adjacent sec. 26 would have encountered hydrocarbons in the Tonkawa sand. Therefore, a local trap might exist that drilling to date has not defined. As another example, the A sand is productive in several wells (identified in Fig. 34) in the NE¼ sec. 10, T. 27 N., R. 1 W. The northernmost wells of sec. 10 and the southernmost wells of sec. 3 are wet, however, even though they are structurally higher. This example indicates a shale barrier between the A sand producers and the updip wells (Fig. 34). The A sandstone thins eastward and is bounded on the west by delta-plain deposits. It attains a maximum thickness of ~20 ft.

An isopach map of the interval between the top of the Haskell Limestone and the base of the Tallant Formation is shown in Figure 35. Although the top of the Tallant Formation is easily defined at the base of the Cheshewalla Sandstone (Fig. 25), its base is not easily defined in the subsurface. That boundary is identified at the prominent resistivity marker shown on the reference log (Fig. 25) for the purpose of this study. The gross isopach interval (Fig. 35) suggests a sediment source from the north, and deltaic deposits prograding to the south-southeast, as indicated also by Figures 31–34.

CORES

Three cores are known to have been taken from the Tonkawa sand in the Blackwell field area. Those cores were drilled in T. 27 N., R. 1 W., by Bachus Oil Co. No. 3 Slocum-Moore, SE¼SE¼SW¼ sec. 3; Royal Oil and Gas Corp. No. 2 Clift Unit, NW¼NW¼NE¼ sec. 10; and Clipper Oil Co. No. 9 Humphrey, NW¼SE¼SW¼ sec. 10. The cores from these wells were not available for study when this report was written.

RESERVOIR CHARACTERISTICS

Reservoir characteristics of the Tonkawa sand in the Blackwell field area are given in Table 6. The field was drilled on 10-acre spacing. The B sandstone, the main oil and gas reservoir, has an average porosity of 24%. Permeability values are unknown as of this writing. The gas/oil ratio is estimated to be 350 standard cubic ft/stock tank barrel (SCF/STB). Measured reservoir properties include a bottom-hole temperature of 100°F, an oil gravity of 44°, and a bottom-hole pressure (BHP) of 950 pounds per square in. (PSI). Drill-stem tests from early in the life of the reservoir and from those taken recently indicate the same BHP. The persistence of reservoir pressure without pressure maintenance indicates that the reservoir has a very strong natural water drive. Additional evidence of a natural water drive in the reservoir is the fact that many early wells were completed flowing oil naturally.

The initial formation volume factor approximates 1.18. The original oil in place (OOIP) is calculated to be ~9.1 million stock tank barrels of oil (MMSTBO). The reported primary production from 1956 through 1995 is 1.282 MMSTBO, which represents a recovery factor of 14%. The primary production from discovery to 1956 was commingled with oil from other producing formations and therefore is unknown. This recovery factor is

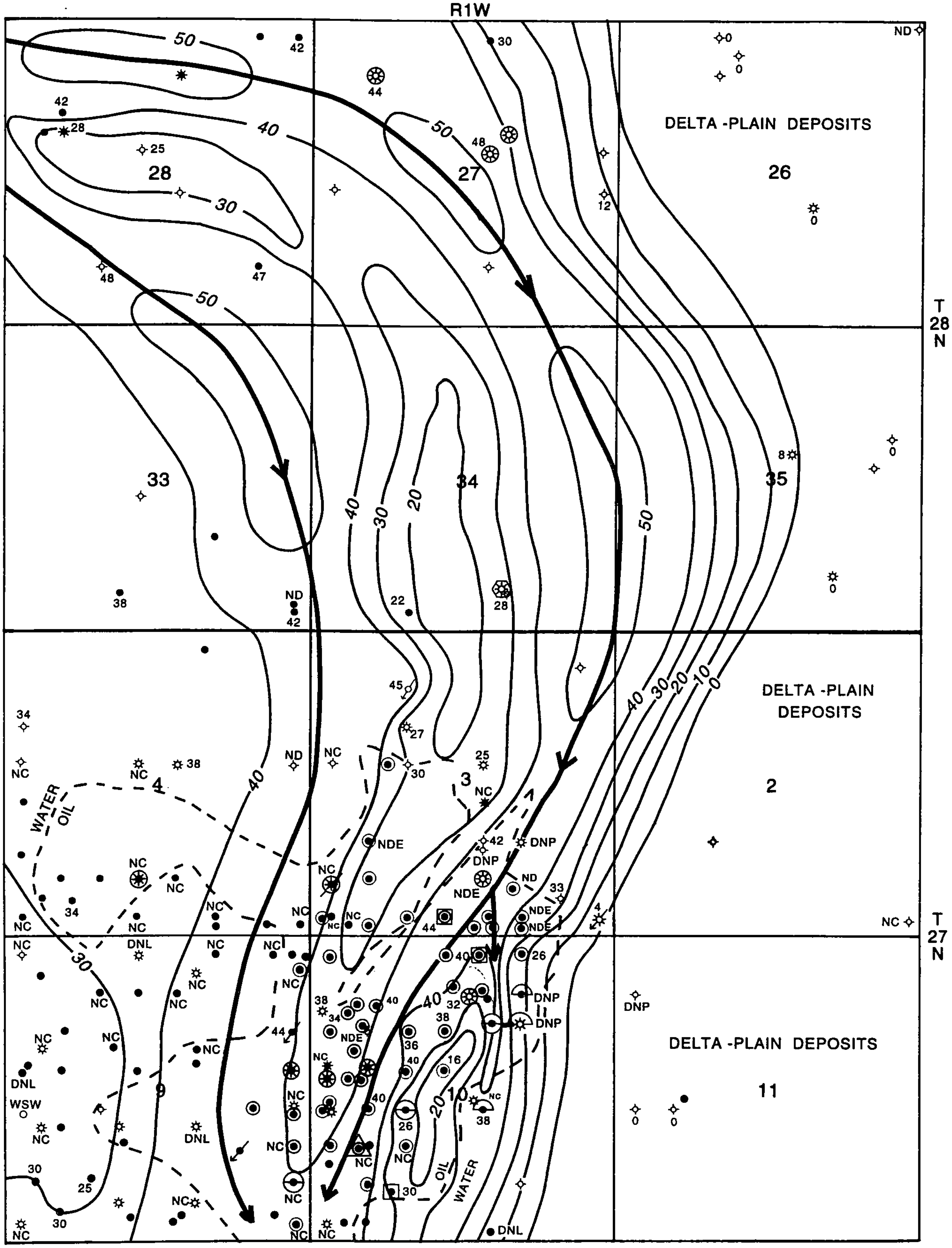


Figure 33. Isopach map of net sandstone thickness in layer B of Tonkawa sand, Blackwell field study area. Thick line indicates oil–water contact for B sandstone and represents reservoir limit. Isopach interval based on minimum 8% log porosity and on approximate corresponding SP log response in wells in which porosity tools were not run, or information is not available. Contour interval, 10 ft.

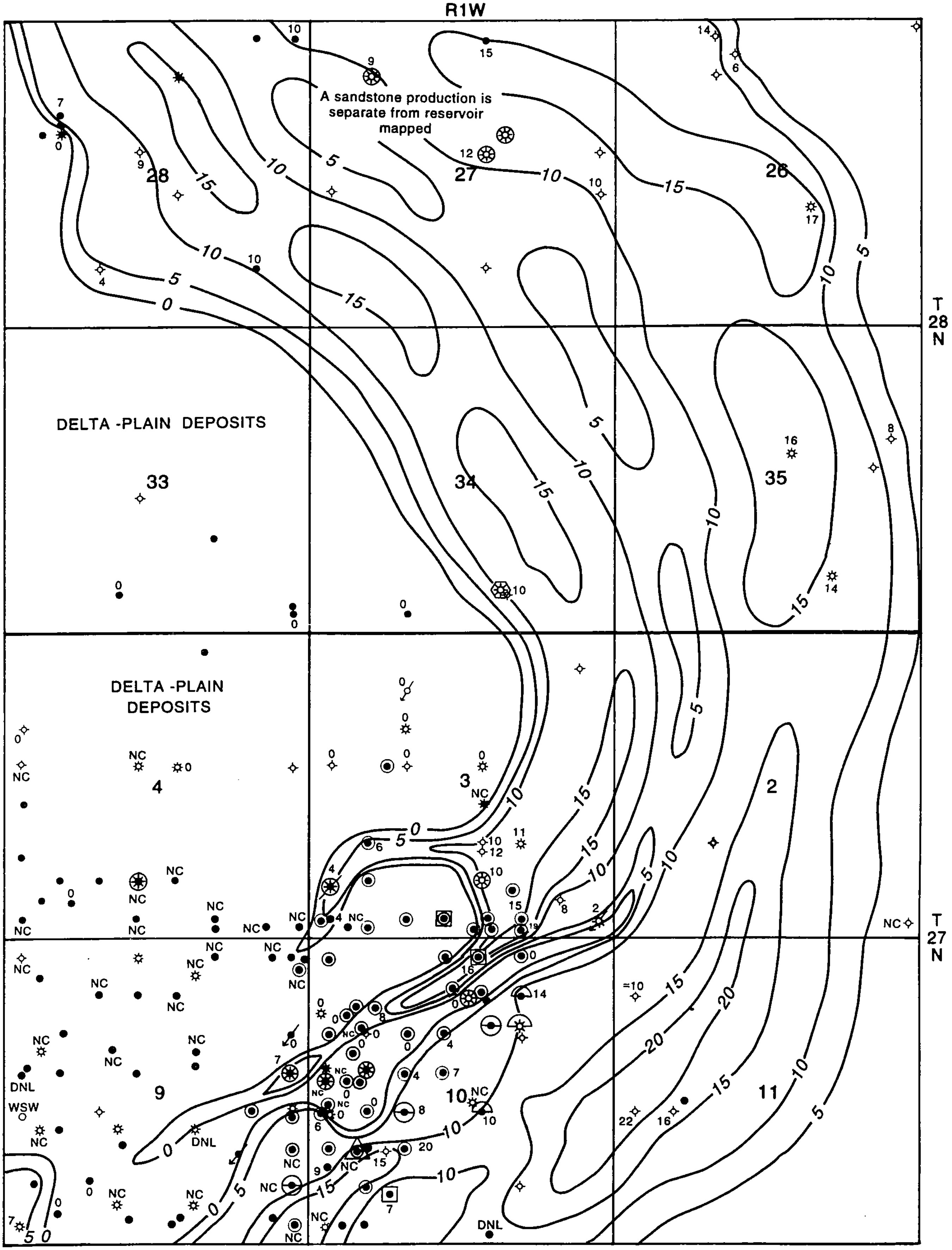


Figure 34. Isopach map of net sandstone thickness in layer A of Tonkawa sand, Blackwell field study area. Isopach interval, 5 ft.

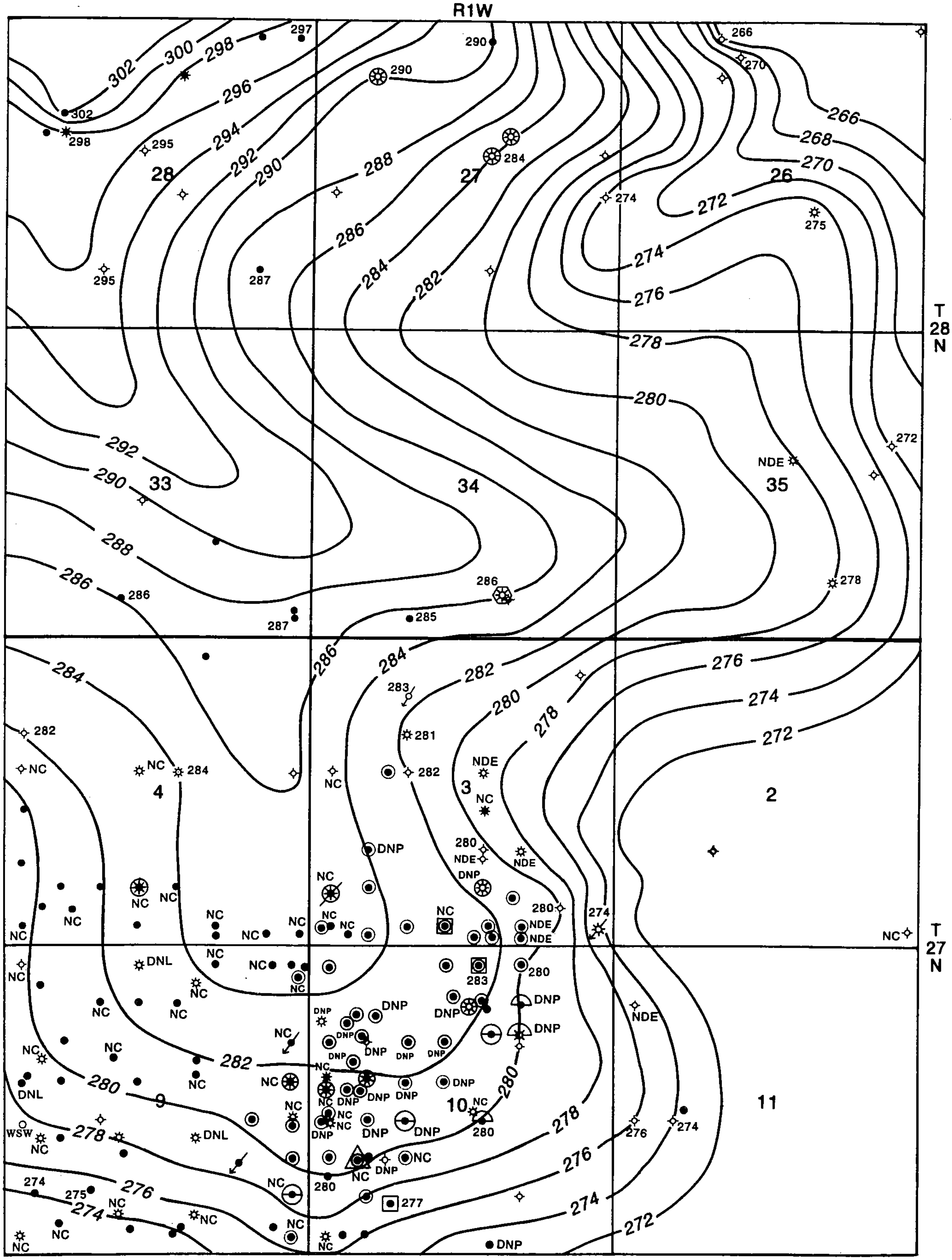


Figure 35. Isopach map of interval from top of Haskell Limestone to base of Tallant Formation (as identified for purpose of this study) in Blackwell field area. Isopach interval, 2 ft.

very low for a water-drive reservoir. It is clear that the Tonkawa sand reservoir is underdeveloped.

PRODUCTION HISTORY

Production from the Tonkawa sand reservoir in the Blackwell field was established on May 27, 1923, with the discovery of oil and gas in Blackwell Oil and Gas Co. No. 1 Humphrey, SE¼NW¼SW¼ sec. 10, T. 27 N., R. 1 W. The well was completed with an initial flow of 220 barrels of oil per day (BOPD). The field was expanded with the drilling of 15 additional Tonkawa producers developed on 10-acre spacing from 1923 through 1941. For that period, it is not known how much oil was recovered from these wells. Several factors contributed to the problem. First, almost all the wells produced for a limited and unknown time before they were deepened and recompleted in deeper formations. Second, production was gathered on a lease basis, and Tonkawa production was included with production from other zones; thus, the production history is incompletely known for the reservoir (Table 6). However, much valuable insight can be gained from a review of the history that is available, together with development of more detailed maps.

To improve an understanding of the reservoir, two additional maps showing geologic structure were developed (Figs. 36,37). Both use the top of the B sandstone as a datum to define the reservoir more accurately where more abundant well data are available from the southwestern part of the study area. A comparison of the structure maps (Figs. 29,36) shows a great deal of similarity in structural relief, areas of closure, and other features. Figure 37 is identical to Figure 36, except that it includes those wells, indicated by diamond symbols, that were completed during 1923–41. A common practice during this period was simply to top the B sand layer and complete the well open hole. As a result of this practice, information defining the original oil–water contact cannot be determined from electric logs dating from this period. The calculation of the oil–water contact was derived from the log and production information of Figure 38. The gas cap is interpreted to be at approximately –1,332 ft.

It is apparent, by comparing data from Oklahoma Corporation Commission Completion Report 1002-A with strip-log and scout-ticket information, that not all information has been reported. For example, Report 1002-A states that the production rate for Blackwell Oil and Gas Co. No. 3 Humphrey, NW¼NW¼SW¼ sec. 10, T. 27 N., R. 1 W., is 250 BOPD with no associated gas or water. The scout-ticket information, however, reveals that this well also produced gas at a rate of 45 million cubic ft/day (MMCFGPD). This probably explains why Blackwell Oil and Gas Co. No. 1 Geiger, SE¼SE¼NE¼ sec. 9, T. 27 N., R. 1 W., which is the structurally highest well in the field, had an initial flowing potential of 75 BOPD with no reported gas. Generally, the wells above –1,332 ft produced dry gas and oil, whereas the wells below –1,332 ft produced only oil with casinghead gas. Harold Petroleum Co. No. 3 Case, NE¼SE¼SW¼ sec. 4, T. 27 N., R. 1 W., produced dry gas at a rate of 30 MMCFGPD. This well was deepened after a month of production, and apparently the structural closure associated with this show has never been developed for Tonkawa production.

TABLE 6. – Geological/Engineering Data for the Tonkawa Sandstone, Blackwell Field Area, Kay County, Oklahoma

Reservoir size (oil)	7,628 acre-ft
Reservoir size (gas)	933 acre-ft
Well spacing (oil)	10 acres
Oil–water contact	about –1,348 ft
Gas–oil contact	about –1,332 ft
Porosity	24% (B sand)
Permeability	Unknown
Water saturation	24%
Gas/oil ratio	~350 SCF/STB
Thickness (net sand) (ϕ >8%)	8.98 ft (oil column)
Reservoir temperature	100° F
Oil gravity	44° API
Initial reservoir pressure	~950 PSI
Initial formation-volume factor	1.18
Original oil in place (volumetric)	9,147,518 STBO 1,200 BO/acre-ft
Cumulative primary oil production	~1,282,073 STBO[a]
Recovery efficiency (oil)	~14.0%
Cumulative gas production	Unknown

[a]Production from 1956 to 1995.

A second phase of Tonkawa reservoir development occurred from 1948 to 1963. Figure 38 shows those wells completed during this period. A few operators drilled through the Tonkawa exploring for deeper production; however, if deeper production was not found, they would case the Tonkawa sand interval, cement, and perforate. The structural datum is the same as that shown in Figure 37. The bold italicized number below the initial-potential data represents the thickness of oil column observed from the corresponding electric log. The base of the oil column is defined as the resistivity break from >10 ohms to <1 ohm.

Two relevant points should be made for this production period. First, the wells that are farthest away from the 15 original producers have an oil–water contact of approximately –1,348 ft. Royal Oil and Gas Corp. No. 1 Clift, NW¼NE¼NE¼ sec. 10, T. 27 N., R. 1 W., has a measured oil column of 12 ft, which puts the oil–water contact at –1,348 ft. This contact probably represents the original oil–water contact for the field and is also the contour used to define the hydrocarbon limits of the reservoir.

Second, the new wells drilled close to the original gas cap during the 1948–63 period have a very thin oil col-

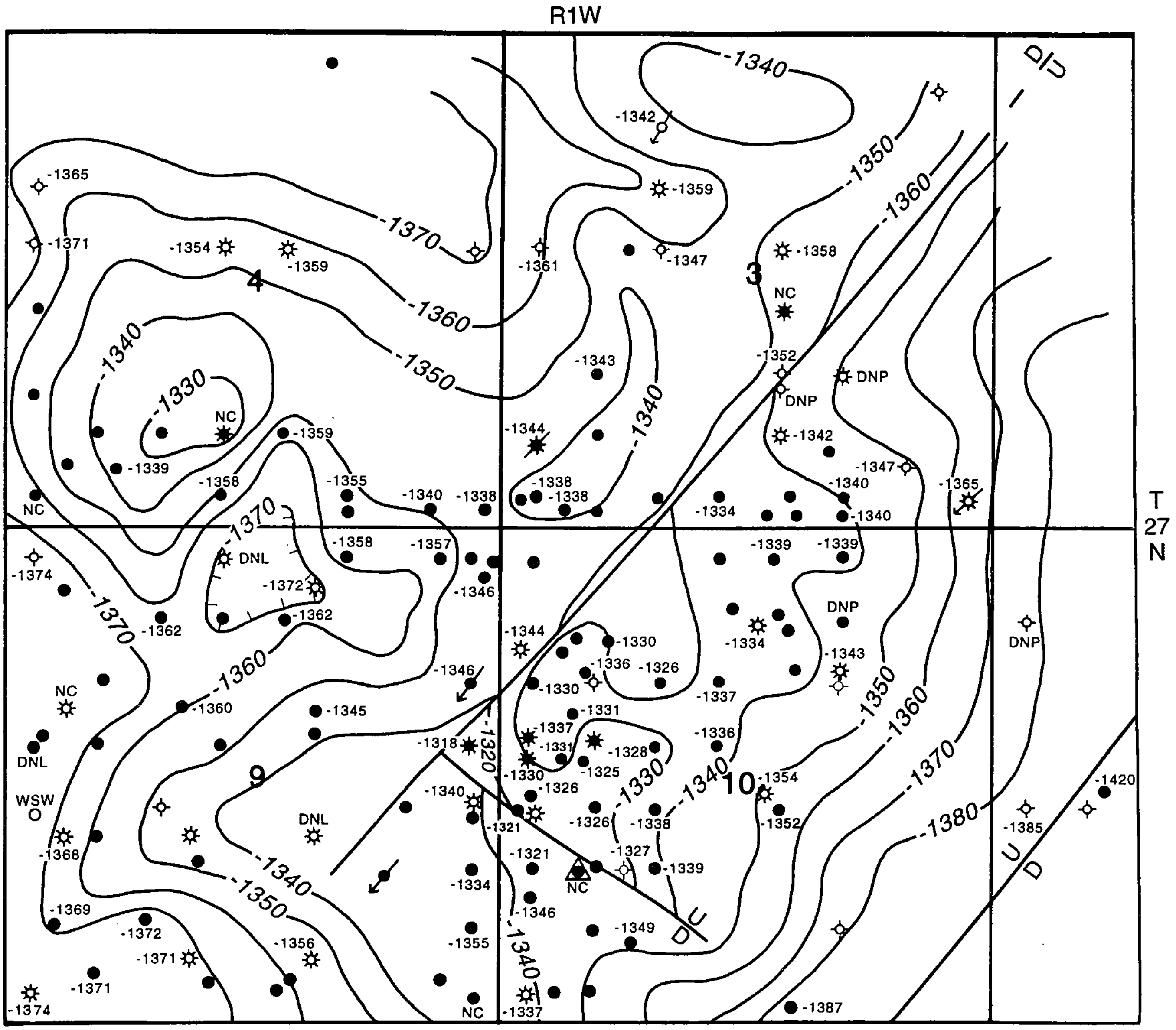


Figure 36. Structure-contour map showing top of B sandstone layer of Tonkawa sand, Blackwell field study area. Contour interval, 10 ft.

umn in comparison to the thicker original oil and gas column at the time of discovery. Also, the reporting of oil, gas, and water initial potentials for wells drilled during this period is fairly accurate. The presence of only oil with casinghead gas would indicate that the gas cap has been depleted and resaturated with oil. Therefore, the underlying oil–water contact must be distorted, as of 1948–63, because the position of the contact for the center (older) part of the reservoir is structurally higher in comparison with the northeast (newer) part of the reservoir. The heavy dashed line in Figure 38 indicates the position of the old gas–oil boundary. Perhaps the pressure from the strong water drive inhibits the oil on the outer edge of the reservoir from migrating updip.

Figure 39 is an isopach map showing the thickness of the oil column as interpreted from records of the wells drilled during the third and last period (1977–86) of development of the Tonkawa reservoir. The thickness is less for the eastern part of the reservoir than the corresponding amount of closure observed in Figure 37. This thinning is due to withdrawal of oil by primary production. The thickness of the oil column for the western part of the reservoir is interpreted to be similar to the corresponding thickness in Figure 37. Some thinning, however, has been postulated because of primary production during the period 1923–41. The thickness of the oil and gas column for that part of the reservoir in sec. 4 has not changed from Figure 37. The OOIP calculated for the amount of oil-column closure in Fig-

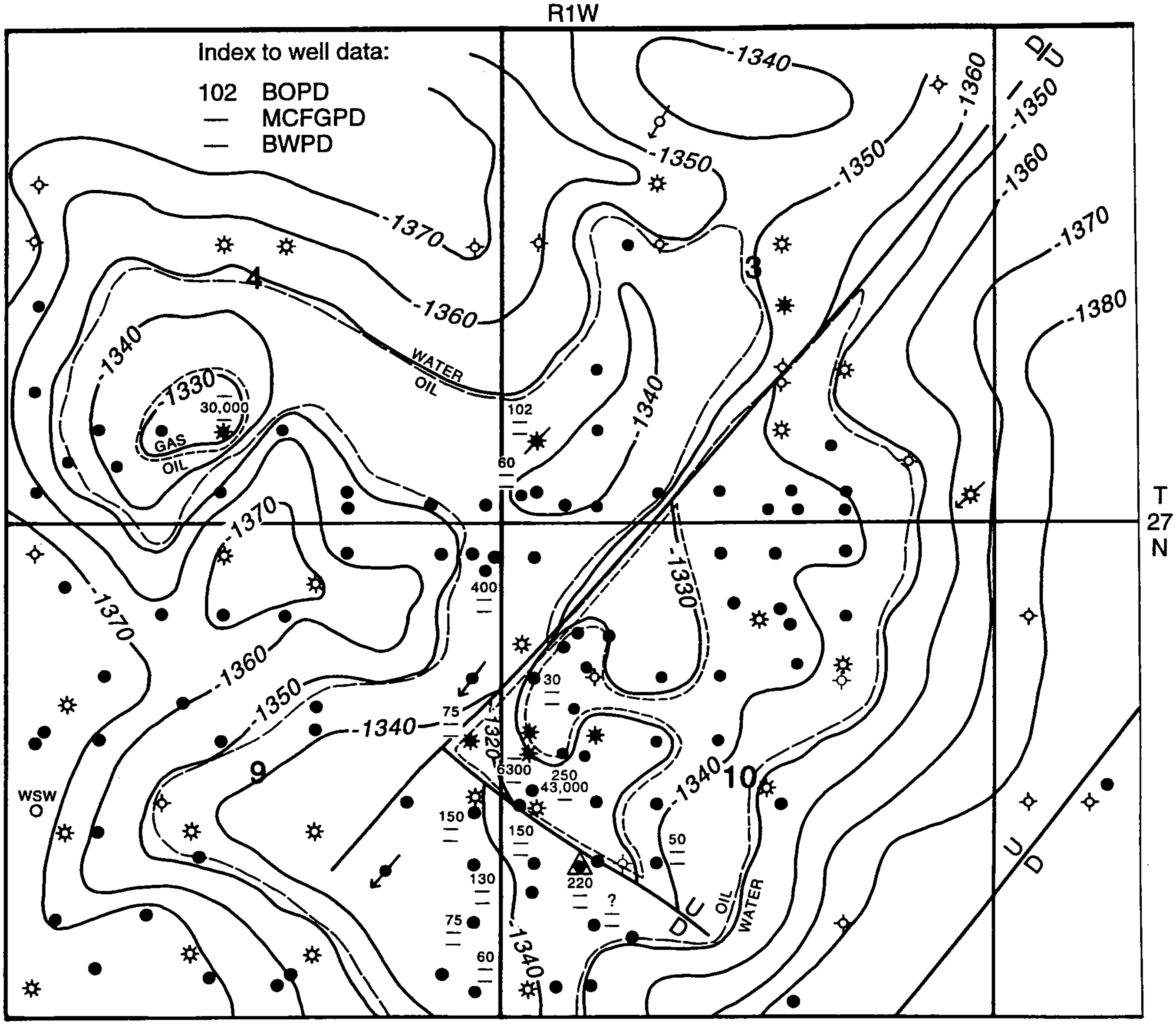


Figure 37. Map showing initial potentials and interpretation of gas–oil contact in B sandstone layer of Tonkawa sand for wells completed 1923–41, Blackwell field study area. Oil–water contact interpreted from wells completed 1948–63. Structure contours same as in Figure 36.

ure 37, minus the amount of OOIP calculated from the oil-column isopach in Figure 39, represents the delta OOIP, or ΔOOIP. This ΔOOIP is composed of four portions, of which the first three can be calculated. These portions are as follows:

1) The amount of primary production from the period 1956–77.

2) The amount of residual or immobile oil left behind from the primary production period (1956–77). A criterion for calculating the oil-column isopach is an approximate water-saturation (S_w)value of 24%. This means that immobile oil is not included in the isopach values of Figure 39.

3) The amount of residual or immobile oil that was left behind when the gas cap was resaturated during the production period 1923–41.

4) The unknown portion, which is the amount of primary and corresponding residual oil produced during the period 1923–41. This value can be approximated after the other three portions have been calculated.

Figure 40 shows the production-decline curve for the Tonkawa sand reservoir in the Blackwell field. The plot begins with 1956, owing to the lack of production data for the period 1923–56. The angle of decline indicates that the field is influenced by a strong water drive. The increase in field production in 1977 represents the increase in production from the third phase of drilling. Table 7 gives the number of active wells per year, annual oil production, average monthly oil production, average daily oil production per well, and cumulative

TABLE 7. – Oil-Production Statistics for the Tonkawa Sandstone, Blackwell Field Area, Secs. 3, 4, 9, and 10,T. 27 N., R. 1 W., Kay County, Oklahoma

Year	Number of Oil Wells	Annual Oil Production (Barrels)	Average Monthly Oil Production (Barrels)	Average Daily Oil Production Per Well (BOPD)	Cumulative Oil Production (Barrels)
1923	**	*	*	*	*
1924	**	*	*	*	*
1925	**	*	*	*	*
1926	**	*	*	*	*
1927	**	*	*	*	*
1928	**	*	*	*	*
1929	**	*	*	*	*
1930	**	*	*	*	*
1931	**	*	*	*	*
1932	**	*	*	*	*
1933	**	*	*	*	*
1934	**	*	*	*	*
1935	**	*	*	*	*
1936	**	*	*	*	*
1937	**	*	*	*	*
1938	**	*	*	*	*
1939	**	*	*	*	*
1940	**	*	*	*	*
1941	**	*	*	*	*
1942	**	*	*	*	*
1943	**	*	*	*	*
1944	**	*	*	*	*
1945	**	*	*	*	*
1946	**	*	*	*	*
1947	**	*	*	*	*
1948	**	*	*	*	*
1949	**	*	*	*	*
1950	**	*	*	*	*
1951	**	*	*	*	*
1952	**	*	*	*	*
1953	**	*	*	*	*
1954	**	*	*	*	*
1955	**	*	*	*	*
1956	3***	7,937	661	7.2	7,937
1957	7***	22,666	1,889	8.8	30,603
1958	7***	22,667	1,889	8.8	53,270
1959	7***	21,401	1,783	8.4	74,671
1960	8***	19,788	1,649	6.8	94,459
1961	9***	22,157	1,846	6.7	116,616
1962	11***	22,423	1,869	5.6	139,039
1963	13***	27,139	2,262	5.7	166,178
1964	12***	24,385	2,032	5.6	190,563
1965	11***	23,895	1,991	5.9	214,458
1966	11***	22,832	1,903	5.7	237,290
1967	11***	22,407	1,867	5.6	259,697
1968	11***	22,778	1,898	5.7	282,475
1969	11***	21,074	1,756	5.2	303,549
1970	11***	20,877	1,740	5.2	324,426
1971	11***	20,925	1,744	5.2	345,351
1972	11***	21,793	1,816	5.4	367,144
1973	11***	22,535	1,878	5.6	389,679
1974	11***	22,197	1,850	5.5	411,876
1975	10***	20,194	1,683	5.5	432,070
1976	10***	22,055	1,838	6.0	454,125
1977	10***	23,095	1,925	6.3	477,220
1978	11***	35,066	2,922	8.7	512,286
1979	13***	52,193	4,349	11.0	564,479
1980	14***	68,005	5,667	13.3	632,484
1981	14***	64,917	5,410	12.7	697,401
1982	14***	49,082	4,090	9.6	746,483
1983	14***	47,701	3,975	9.3	794,184
1984	15***	61,622	5,135	11.2	855,806
1985	14***	48,318	4,027	9.4	904,124
1986	17***	41,127	3,427	6.6	945,251
1987	19***	43,772	3,648	6.3	989,023
1988	19***	50,481	4,207	7.3	1,039,504
1989	18***	41,566	3,464	6.3	1,081,070
1990	17***	36,806	3,067	5.9	1,117,876
1991	17***	35,902	2,992	5.8	1,153,777
1992	16***	30,913	2,576	5.3	1,184,690
1993	19***	34,958	2,913	5.0	1,219,648
1994	19***	33,541	2,795	4.8	1,253,189
1995	19***	28,884	2,407	4.2	1,282,073
1996	19***	0	0	0.0	1,282,073

*Tonkawa production commingled with other zones, unable to determine.

**Records not sufficient to indicate dates of recompletion for other zones.

***Well count does not include producers completed prior to 1956.

oil production for the field. Notice that average daily production per well is between 5 and 10 BOPD. These wells were not produced at high rates because of the danger of water coning into the well bores. As a result of this production procedure, the wells are considered to be long-lived.

Figure 41 is a map showing primary Tonkawa production for the Blackwell oil-field study area. The three periods of production are indicated. Primary production for the period 1956–95 was ~1.282 million barrels of oil (MMBO). As mentioned previously, Tonkawa production data from some wells were unavailable, because Tonkawa oil was commingled with oil from other formations on a lease basis.

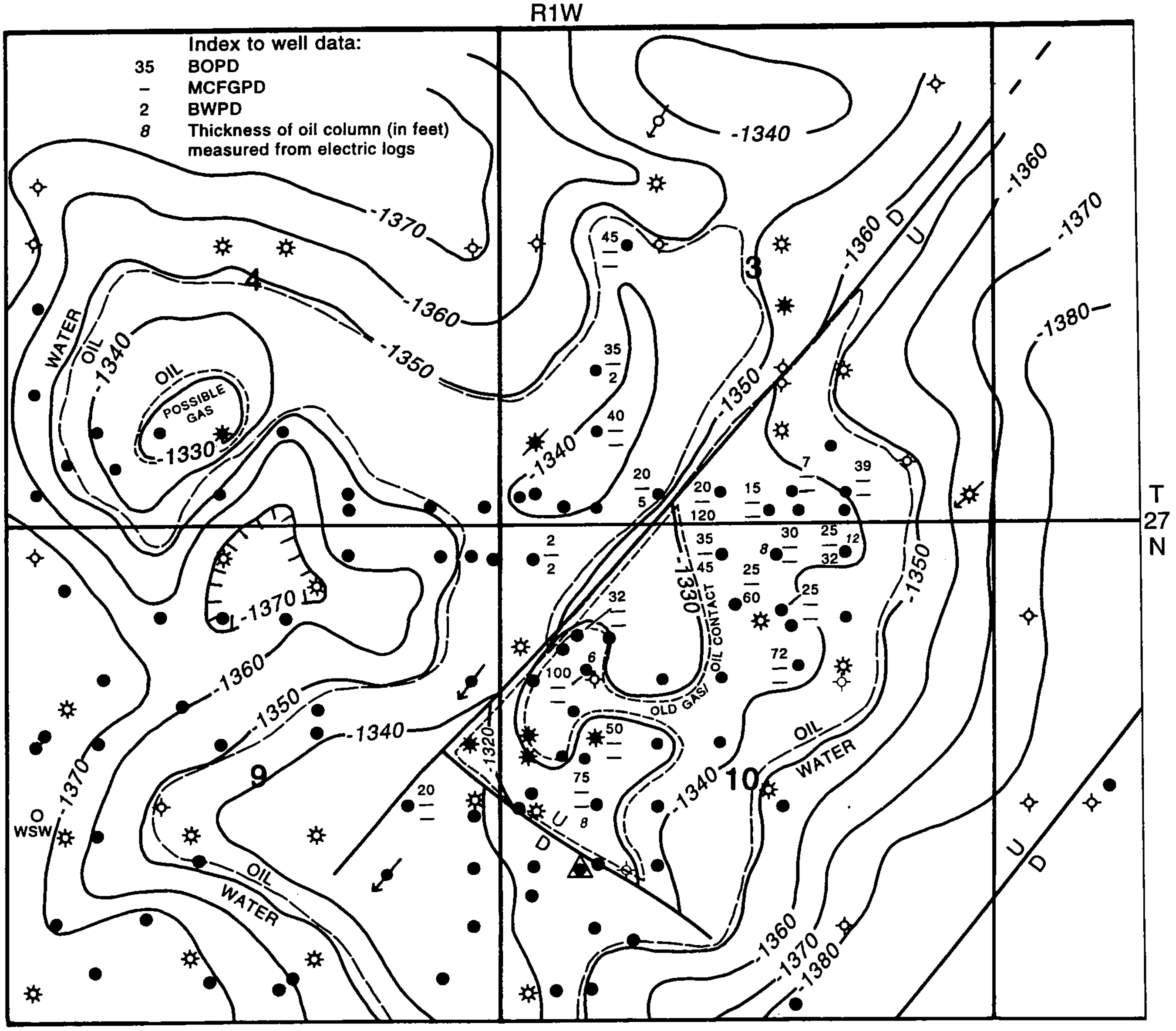


Figure 38. Map showing approximate thickness of oil column and initial potentials for B sandstone layer of Tonkawa sand for wells completed 1948–63, Blackwell field study area. Dashed line is former gas–oil contact (Fig. 37). Structure contours same as in Figure 36.

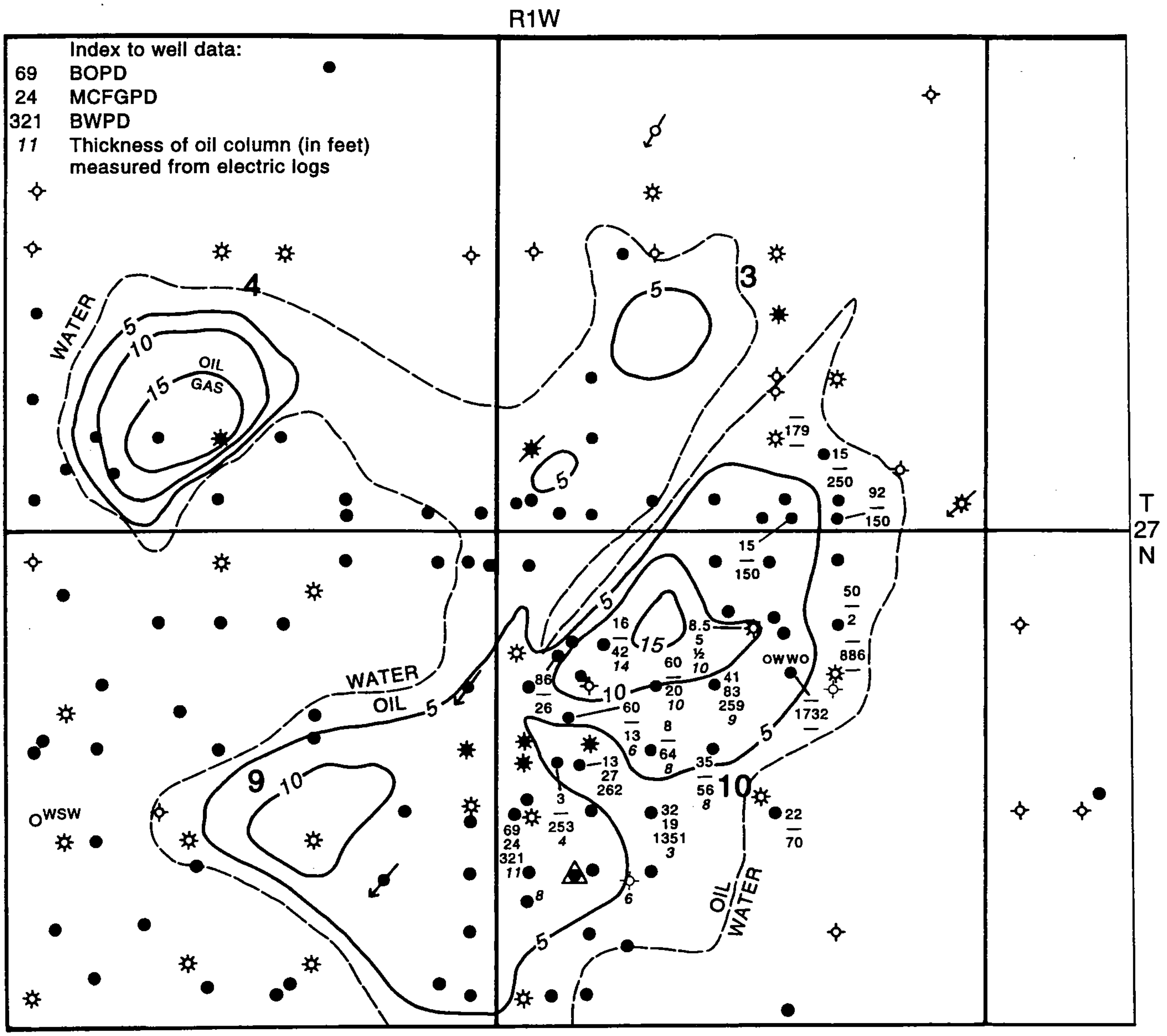
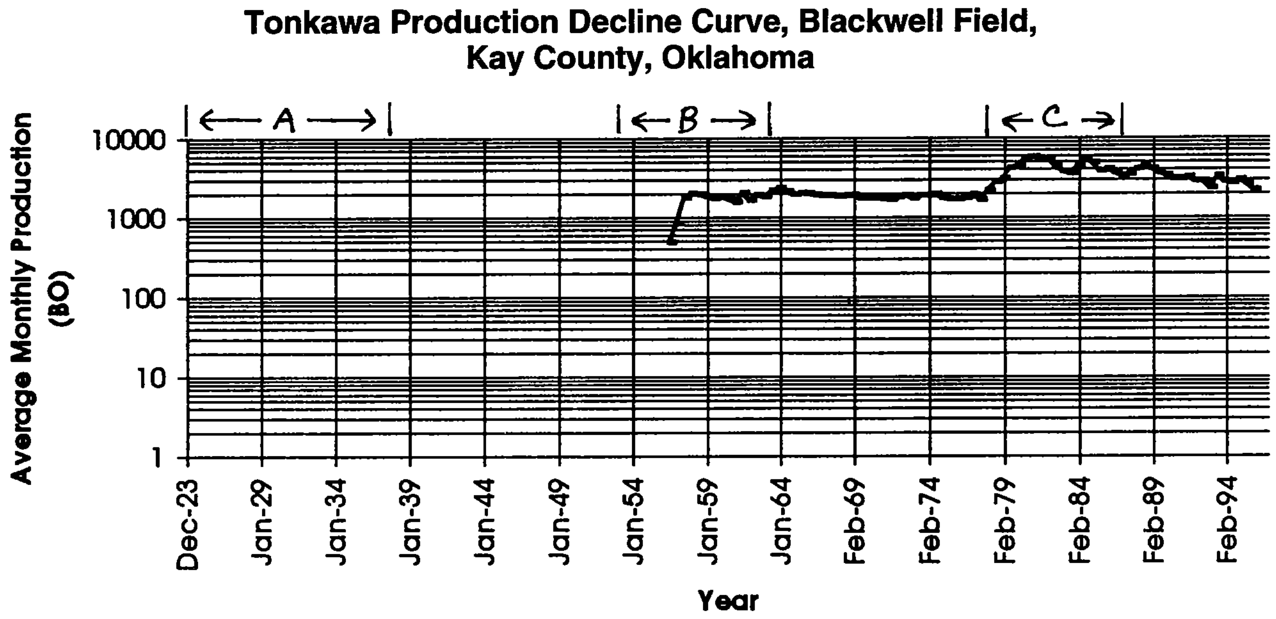


Figure 39. Map showing approximate thickness of oil column and initial potentials for B sandstone layer of Tonkawa sand for wells completed 1977–86, Blackwell field study area. Contour interval, 5 ft.



T. 27 N., R. 1 W., secs. 3 & 4 only.
Commingled with Wilcox production, 1944–56.

First Tonkawa production, 1924.

Tonkawa reservoir development

A	1924–37
B	1952–63
C	1977–86

Figure 40. Annual oil-production plot for Tonkawa sand reservoir, 1956–95, Blackwell field study area. Production is from A and B sandstone layers, shown on log in Figure 41.

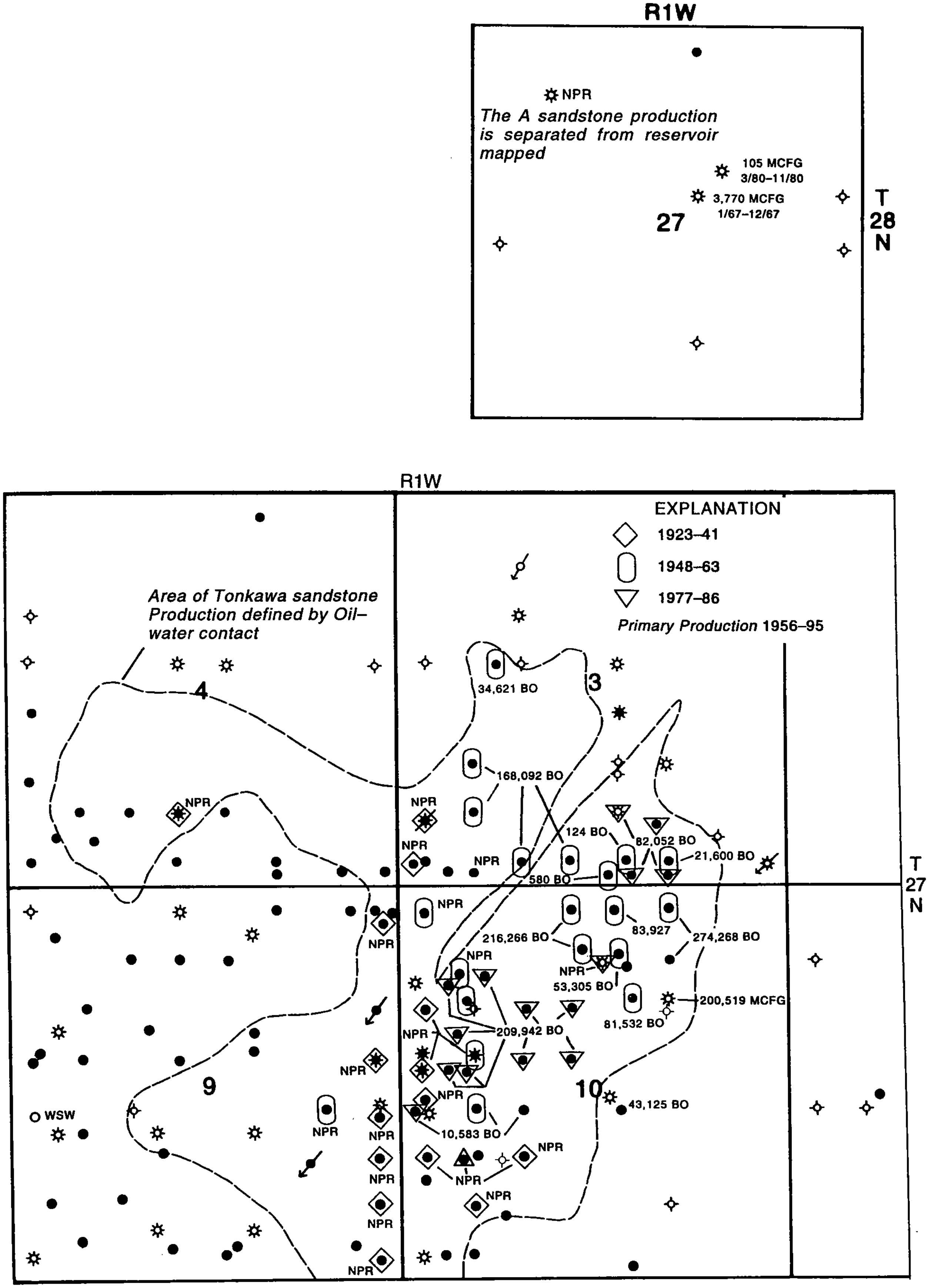


Figure 41. Map of reservoir limit of B sandstone of Tonkawa sand, Blackwell field study area. Cumulative production compiled from Petroleum Information Corp. See Figures 23, 24, and Table 5 for well-identification information.

SELECTED REFERENCES

Allen, Albert E., Jr., 1953, The subsurface geology of Woods and Alfalfa Counties, northwestern Oklahoma: University of Oklahoma unpublished M.S. thesis, 86 p.

_____ 1954, The subsurface geology of Woods and Alfalfa Counties, northwestern Oklahoma: Shale Shaker, v. 4, no. 8, p. 5–21, 23–26, 32.

Bale, Hubert E., 1928, Oil and gas in Oklahoma: Logan County: Oklahoma Geological Survey Bulletin 40-GG, 13 p. [Also published in OGS Bulletin 40, v. 2, p. 225–238, 1930.]

Bates, R. L.; and Jackson, J. A., 1987, Glossary of geology: American Geological Institute, Alexandria, Virginia, 788 p.

Bennison, Allan P., 1972, Environmental analysis of the Pennsylvanian rocks, *in* Bennison, A. P. (ed.), Tulsa's physical environment: Tulsa Geological Society Digest, v. 37, p. 19.

Blatt, Harvey; Middleton, Gerard; and Murray, Raymond, 1980, Origin of sedimentary rocks: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 782 p.

Boardman, Darwin R., II; Barrick, James E.; Heckel, Philip H.; and Nestell, Merlynd, 1989, Upper Pennsylvanian chronostratigraphic subdivisions of the North American Midcontinent, *in* Boardman, D. R., II; Barrick, J. E.; Cocke, Jim; and Nestell, M. K. (eds.), Middle and Late Pennsylvanian chronostratigraphic boundaries in north-central Texas: glacial-eustatic events, biostratigraphy, and paleoecology: Texas Tech University Studies in Geology 2, Lubbock, p. 1–16.

Bosworth, T. O., 1920, Geology of the Mid Continent oilfields, Kansas, Oklahoma and North Texas: Macmillan Co., New York, 314 p.

Bowen, C. F.; Roundy, P. V.; Ross, C. S.; and Reeves, Frank, 1922, Tps. 21–23 N., Rs. 6–7 E., and Tps. 23–25 N., Rs. 3–5 E., *in* White, David, and others, Structure and oil and gas resources of the Osage Reservation, Oklahoma: U.S. Geological Survey Bulletin 686, p. 279–301.

Brown, L. F., Jr., 1979, Deltaic sandstone facies of the Midcontinent, *in* Hyne, N. J. (ed.), Pennsylvanian sandstones of the Midcontinent: Tulsa Geological Society Special Publication 1, p. 35–63.

Capps, William M., 1959, Stratigraphic analysis of the Missourian and lower Virgilian series in northwestern Oklahoma: University of Oklahoma unpublished M.S. thesis, 48 p.

Carpenter, Everett, 1929, Morrison field, Pawnee County, Oklahoma, *in* Structure of typical American oil fields: American Association of Petroleum Geologists, Tulsa, v. 1, p. 148–157.

Cary, L. W., 1954, The subsurface geology of the Garber area, Garfield County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 51 p.

_____ 1955, The subsurface geology of the Garber area, Garfield County, Oklahoma: Shale Shaker, v. 5, no. 6, p. 5–11, 14–24, 26, 29.

Caylor, James W., 1956, Subsurface geology of western Garfield County, Oklahoma: Shale Shaker, v. 7, no. 4, p. 8–12, 15–26, 29–31.

_____ 1957, Subsurface geology of western Garfield County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 78 p.

Clare, Patrick H., 1963, Petroleum geology of Pawnee County, Oklahoma: Oklahoma Geological Survey Circular 62, 62 p.

Clark, Frank R., 1922, T. 26 N., Rs. 9, 10, and 11 E., *in* White, David, and others, Structure and oil and gas resources of the Osage Reservation, Oklahoma: U.S. Geological Survey Bulletin 686, p. 91–118.

Clark, G. C.; and Aurin, F. L., 1924, The Tonkawa field, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 8, p. 269–283.

Clark, G. C.; and Cooper, C. L., 1927, Oil and gas in Oklahoma: Kay, Grant, Garfield and Noble Counties: Oklahoma Geological Survey Bulletin 40-H, 44 p. [Also published in OGS Bulletin 40, v. 2, p. 67–104, 1930.]

Clark, Stuart K.; and Daniels, James I., 1929, Relation between structure and production in the Mervine, Ponca, Blackwell, and South Blackwell oil fields, Kay County, Oklahoma, *in* Structure of typical American oil fields: American Association of Petroleum Geologists, Tulsa, v. 1, p. 158–175.

Coleman, J. M.; and Prior, D. B., 1980, Deltaic sand bodies: American Association of Petroleum Geologists Continuing Education Course Notes Series, no. 15, 171 p.

_____ 1982, Deltaic environments of deposition, *in* Scholle, P. A.; and Spearing, D. (eds.), Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31, p. 139–178.

Dana, George F., 1954a, The subsurface geology of Grant County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 61 p.

_____ 1954b, The subsurface geology of Grant County, Oklahoma: Shale Shaker, v. 4, no. 10, p. 4–7, 10–21, 28.

Fambrough, James W., 1962, Isopach and lithofacies study of Virgilian and Missourian Series of north-central Oklahoma: University of Oklahoma unpublished M.S. thesis, 89 p.

_____ 1963, Isopach and lithofacies study of Virgilian and Missourian Series of north-central Oklahoma: Shale Shaker, v. 13, no. 5, p. 2–8, 10–12, 14–23, 26.

Feldman, Howard R.; Gibling, Martin R.; Archer, Allen W.; Wightman, Winton G.; and Lanier, William P., 1995, Stratigraphic architecture of the Tonganoxie paleovalley (lower Virgilian) in northeastern Kansas: American Association of Petroleum Geologists Bulletin, v. 79, p. 1019–1043.

Fies, Michael W., 1988, Depositional environments and diagenesis of the Tonkawa format (Virgilian) in Woods and part of Woodward Counties, Oklahoma: Oklahoma State University unpublished M.S. thesis, 123 p.

Galloway, W. E.; and Hobday, D. K., 1983, Terrigenous clastic depositional systems: Springer-Verlag, New York, 423 p.

Gibbons, Kenneth E., 1960, Pennsylvanian of the north flank of the Anadarko basin: University of Oklahoma unpublished M.S. thesis, 46 p.

_____ 1962, Pennsylvanian of the north flank of the Anadarko basin: Shale Shaker, v. 12, no. 5, p. 2–10, 12–19.

Gish, Wesley G.; and Carr, Raymond M., 1929, Garber field, Garfield County, Oklahoma, *in* Structure of typical American oil fields: American Association of Petroleum Geologists, Tulsa, v. 1, p. 176–191.

Greene, F. C., 1918, A contribution to the geology of eastern Osage County: American Association of Petroleum Geologists Bulletin, v. 2, p. 118–123.

Hinshaw, G. C.; and Rottmann, Kurt, 1997, The marine Tonkawa sands: natural gas and associated liquids production in the Anadarko basin: Oklahoma Geological Survey Open-File Report 3-97.

Hoffman, Malvin G., 1940, Structural history of Billings field, Noble County, Oklahoma, interpreted in terms of isostasy: American Association of Petroleum Geologists Bulletin, v. 24, p. 2006–2018.

Hopkins, Oliver B., 1922, T. 25 N., Rs. 11 and 12 E., *in* White, David, and others, Structure and oil and gas resources of the Osage reservation, Oklahoma: U.S. Geological Survey Bulletin 686, p. 75–90.

Hopkins, Oliver B.; and Powers, Sidney, 1922, T. 24 N., Rs. 11 and 12 E., *in* White, David, and others, Structure and oil and gas resources of the Osage reservation, Oklahoma: U.S.

Geological Survey Bulletin 686, p. 237–253.

Hunt, John M., 1979, Petroleum geochemistry and geology: W. H. Freeman and Co., San Francisco, 617 p.

Jordan, Louise, 1957, Subsurface stratigraphic names of Oklahoma: Oklahoma Geological Survey Guidebook 6, 220 p.

Keroher, Grace C., and others, 1966, Lexicon of geologic names of the United States: U.S. Geological Survey Bulletin 1200, 3 vols., 2886 p.

Khaiwka, Moayad H., 1968, Geometry and depositional environments of Pennsylvanian reservoir sandstones, northwestern Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 126 p.

Kumar, Naresh; and Slatt, Roger M., 1984, Submarine-fan and slope facies of Tonkawa (Missourian–Virgilian) sandstone in deep Anadarko basin: American Association of Petroleum Geologists Bulletin, v. 68, p. 1839–1856.

Lukert, L. H., 1949, Subsurface cross-section from Marion County, Kansas, to Osage County, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 33, p. 131–152.

Luza, Kenneth V.; and Lawson, James E., Jr., 1981, Seismicity and tectonic relationships of the Nemaha Uplift in Oklahoma—Part III: Oklahoma Geological Survey Special Publication 81-3, 70 p.

McKenny, Jere W., 1952, Subsurface geology of northeastern Logan County, Oklahoma: University of Oklahoma unpublished M.G.E. thesis, 46 p.

_____ 1953, Subsurface geology of northeastern Logan County, Oklahoma: Shale Shaker, v. 3, no. 6, p. 6–11, 14–15. [Also published, along with geologic cross sections, in Shale Shaker Digest, v. 1–5 (1950–55), p. 149–166.]

Mills-Bullard, Bess, 1928, Digest of Oklahoma oil and gas fields: Oklahoma Geological Survey Bulletin 40, v. 1, p. 101–276.

Nolte, Clifton J., 1951, Geology of the subsurface formations of northern Logan County, Oklahoma: University of Oklahoma unpublished M.G.E. thesis, 47 p.

Oakes, Malcolm C., 1940, Geology and mineral resources of Washington County, Oklahoma; Oklahoma Geological Survey Bulletin 62, 208 p.

Owen, Edgar W., 1975, Trek of the oil finders: a history of exploration for petroleum: American Association of Petroleum Geologists Memoir 6, 1647 p.

Padgett, Philip C. O., 1984, Petrology, diagenesis, and depositional environments of the Tonkawa sandstone in southwestern Dewey County, Oklahoma: Oklahoma State University unpublished M.S. thesis, 87 p.

Page, Kenneth G., 1955a, The subsurface geology of southern Noble County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 69 p.

_____ 1955b, The subsurface geology of southern Noble County, Oklahoma: Shale Shaker, v. 5, no. 10, p. 5–16, 18–22, 24–25, 34.

Pate, J. Durwood, 1959, Stratigraphic traps along north shelf of Anadarko basin, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 43, p. 39–59.

Querry, Jamie L., 1957, Subsurface geology of south central Kay County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 70 p.

_____ 1958, Subsurface geology of south central Kay County, Oklahoma: Shale Shaker, v. 8, no. 7, p. 10–21, 23–24.

Ross, J. S., 1923, Preliminary report on petroleum engineering in the Tonkawa oil field, Kay and Noble Counties, Oklahoma: U.S. Bureau of Mines, in cooperation with the State of Oklahoma, 36 p.

Roundy, P. V.; Heald, K. C.; and Richardson, G. B., 1922, Tps. 26 and 27 N., R. 12 E., *in* White, David, and others, Structure and oil and gas resources of the Osage reservation, Oklahoma: U.S. Geological Survey Bulletin 686, p. 395–420.

Sheriff, R. E., 1984, Encyclopedic dictionary of exploration geophysics [2nd edition]: Society of Exploration Geophysicists, Tulsa, Oklahoma, 323 p.

Shirk, George H., 1965, Oklahoma place names: University of Oklahoma Press, Norman, 233 p.

Swanson, D. C., 1976, Meandering stream deposits: Swanson Petroleum Enterprises, Cygnet Group, Inc., Houston, 30 p.

_____ 1993, The importance of fluvial processes and related reservoir deposits: Journal of Petroleum Technology, v. 45, no. 4, p. 368–377.

Swindell, Floyd, 1935, New Oxford deep zone: The Oil Weekly, v. 79, no. 4, p. 43–46.

Tanner, William F., 1956, Geology of northeastern Osage County, Oklahoma: Oklahoma Geological Survey Circular 40, 76 p.

Tulsa Geological Society, Stratigraphic Committee, 1984–89, Type logs of Oklahoma: Available from Riley's Electric Log, Inc., Oklahoma City.

Van Wagoner, J. C.; Mitchum, R. M.; Campion, K. M.; and Rahmanian, V. D., 1990, Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high-resolution correlation of time and facies: American Association of Petroleum Geologists Methods in Exploration Series, no. 7, 55 p.

Vanzant, J. Harvey, 1926, The geology of the Thomas and Hubbard oil pools of Kay County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 13 p.

Walker, R. G., 1984, Sandy fluvial systems, *in* Walker, R. G. (ed.), Facies models [2nd edition]: Geoscience Canada Reprint Series 1, p. 71–89.

Walton, Anthony W.; and Griffith, Gary, 1985, Deltaic deposition in the Tonganoxie or "Stalnaker" Sandstone (Stranger Formation, Virgilian): TXO Robinson C-1, Harper County, Kansas, *in* Watney, W. L.; Walton, A. W.; and Doveton, J. H. (compilers), Core studies in Kansas: Kansas Geological Survey Subsurface Geology Series 6, Lawrence, p. 145–160.

Weinzierl, John F., 1922, Subsurface geology of the north part of the Blackwell field, Oklahoma: University of Oklahoma unpublished M.A. thesis, 12 p.

Wheeler, D. M.; Scott, A. J.; Coringrato, V. J.; and Devine, P. E., 1990, Stratigraphy and depositional history of the Morrow Formation, southeast Colorado and southwest Kansas, *in* Sonnenberg, S. A., and others (eds.), Morrow sandstones of southeast Colorado and adjacent areas: Rocky Mountain Association of Geologists, Denver, p. 9–35.

White, David, and others, 1922, Structure and oil and gas resources of the Osage Reservation, Oklahoma: U.S. Geological Survey Bulletin 686, 427 p.

Wilson, W. B., 1935, Evidence of oil and gas migration, Crescent pool [abstract]: Tulsa Geological Society Digest, v. 4, p. 28–29.

Winchell, Richard L., 1957, Relationship of the Lansing group and the Tonganoxie ("Stalnaker") Sandstone in south-central Kansas: Kansas Geological Survey Bulletin 127, pt. 4, p. 123–152.

Winchester, Dean E.; Heald, K. C.; and others, 1922, T. 25 N., R. 10 E., *in* White, David, and others, Structure and oil and gas resources of the Osage Reservation, Oklahoma: U.S. Geological Survey Bulletin 686, p. 59–73.

Zavoico, Basil B., 1934, Geology and economic significance of the Lucien field: Tulsa Geological Society Digest, v. 3, p. 59–62.

APPENDIX 1
Tonkawa Oil and Gas Field Locations

No.	Field Name	T-R*	Section
1	Aledo W.	16N-19W	16
2	Alva E.	26N-12W	6,7
		26N-13W	1,2,3,4,10,11
		27N-13W	25,26,27,34,35
3	Arnett E.	20N-23W	18,19,20,23,26,27,28,29,31,32,33
		20N-24W	24
4	Arnett SE.	18N-23W	3,4,5,6,9,10
		19N-22W	8,17,18
		19N-23W	7,10,11,12,13,14,15,16,17,18,19,20,21,22, 23,24,26,27,28,29,30,32
		19N-24W	23,24,25
5	Avard NW.	26N-15W	5,6,7,8,9,10,11,14,15,16,17,20,21,22,28,29
		26N-16W	1,2,3,4,5,6,7,8,13,14,15,17,18,19,20,21,22, 23,24,25,27,28,29,30,31,34,35,36
		26N-17W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,20, 21,22,23,24,25
		26N-18W	1,2,12
		27N-15W	3,4,7,8,9,14,15,16,17,18,19,20,21,22,23, 24,28,29,30,31,32
		27N-16W	1,12,13,15,17,18,19,20,21,22,23,24,25,26, 28,29,30,31,32,33,34,35,36
		27N-17W	10,13,14,15,16,19,20,21,22,23,24,25,26, 27,28,29,30,31,32,33,34,35,36
		28N-15W	33
6	Billings	23N-2W	10,14,15,16,20,21,22,27,28
7	Bishop	17N-24W	17,18
		17N-25W	5,6,7,8,11,12,13,14,15,16,17,18,19,20,21,22, 23,30,31
		17N-26W	1,2,3,4,8,9,10,11,12,13,14,15,16,17,20,21, 22,23,24,25,26,27,28
		18N-26W	33,34,35
8	Blackwell	26N-1W	5
		27N-1W	3,4,5,7,8,9,10,11,14,15,16,17,18,19,20,21, 22,28,29,30,31,32,33
		28N-1W	32,33,34
9	Blackwell-Newkirk Gas Area	26N-2E	4,5,7,8,
		27N-1E	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18, 23,24
		27N-1W	1,2,3,4,8,9,10,11,12,14,15,16,17,18,19,20, 21,22,23,24,25,28,29,30,32,33
		27N-2E	1,6,7,8,17,18,19,20,30,31
		28N-1E	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 19,20,21,22,23,24,25,26,27,28,29,30, 31,32,33,34,35,36
		28N-1W	1,2,3,7,8,9,10,11,12,13,14,15,16,21,22,23, 24,25,26,27,34,35,36
		28N-2E	1,2,3,4,5,6,7,8,10,11,14,16,17,18,19,20,21, 22,23,24,28,29,30,31,32,33,34,35
		28N-3E	6
		29N-1E	13,14,15,16,17,18,19,20,21,22,23,24,25, 26,27,28,29,30,31,32,33,34,35,36
		29N-1W	14,15,22,23,24,24,27,28,29,30,36,
		29N-2E	18,19,29,30,31
10	Braman	28N-1W	5,8
11	Braman District SE.	28N-1W	16,17,19,20,21,28,29,30,31,32
12	Braman N.	29N-1W	15,16,17,20,21,22,28,29
13	Camargo SW.	18N-20W	33
14	Carpenter	11N-21W	2,3,4,5,6,12
		11N-22W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 19,20,21,22,23,24,25
		11N-23W	1,9,10,11,12,13,14,15,16
		12N-21W	6,7,8,9,13,14,16,17,18,19,20,21,22,23,24, 25,26,27,28,29,30,31,32,33,34,35,36
		12N-22W	1,2,3,7,8,9,10,11,12,13,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28,29,30,31,32, 33,34,35,36
		12N-23W	25,26,36
15	Cedardale NE.	21N-15W	3,4,5,6
		21N-16W	1,2,3,4,5,6,7,8,9,10,11,15,16,17,18,19
		21N-17W	1
		22N-15W	6,7,19,20,21,29,30,31,32
		22N-16W	4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20,21,22,23,24,25,26,27,28,29,30,31, 32,33,34,35,36
		22N-17W	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,20, 22,23,24,25,26,27,29,35,36
		22N-18W	1,2,3
		23N-16W	7,17,20,29,30,31,32,33
		23N-17W	6,7,8,9,17,18,19,20,21,26,27,28,29,30,31, 32,33,34,35,36
		23N-18W	1,2,3,4,5,9,10,11,13,14,15,23,24,25,26,27, 34,35,36
		24N-17W	19,29,30,31,32,33
		24N-18W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 19,20,21,22,23,24,25,26,27,28,29,30, 31,32,33,34,35,36
		24N-19W	1,2,3,12,13,14,23,24,25,26,27,28,33,36
		25N-18W	9,17,18,19,20,21,28,29,30,31,32,33
		25N-19W	2,3,4,5,9,10,11,12,13,14,15,16,17,20,21,22, 23,24,25,26,27,34,35,36
		25N-20W	1,12
		26N-19W	6,7,8,18,19,27,30,31,32,33
16	Cherokita Trend	27N-6W	4,5,6,7,8,10,15
		27N-7W	1,2,3,4,5,6,7,8,9,12
	Cherokita Trend, cont.	27N-8W	1,2,3,7,8,9,10,11,12,16,18
		27N-9W	8,11,12,13,14,15,16,17,18,20,23
		27N-10W	2,6,7,8,9,10,12,13,14,15,16,17,18,19,20,21, 22,23,24,29,30
		27N-11W	13,21,22,23,24,25,26,27
		28N-7W	26,33,34,35
17	Cheyenne	13N-23W	5
18	Cheyenne W.	11N-23W	5,6
		12N-23W	1,2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19,20, 21,22,24,27,28,29,30,31,32,34,35
		12N-24W	1,2,3,4,5,8,9,10,11,12,13,14,15,23,24,25, 26,27,35,36
		13N-23W	21,22,27,28,29,31,32,33,35
		13N-24W	3,4,5,6,7,8,9,10,11,15,16,17,18,21,22,24,25, 26,27,28,33,34,35,36
		13N-25W	1,12,13
		14N-24W	15,21,27,28,29,30,31,32
		14N-25W	25,26,35,36
19	Clear Lake District	2N-26C*	3
		3N-26C	27,32,33,34
20	Como SE.	1N-25C	1,2,3,4,9,10,11,12,13,14,15,16,20,21,22,24, 27,28,29,30,31,32,33,34,35
		2N-25C	26,33,34,35,36
21	Concho	13N-8W	1,2,3,4,9,10,11,12,13,14,15,23
22	Concho N.	14N-7W	9,10,15,16,17,18,19,20,21,22,28,29,30,31,32
		14N-8W	13,14,15,16,21,22,23,24,25,26,27,28,33, 34,35,36
23	Crawford NW.	15N-26W	4,9
		16N-24W	6,7,8,9,15,16,17,18,19,20
		16N-25W	1,7,8,12,13,14,15,16,17,18,19,20,21,22,23, 24,25,26,27,28,29,30,31,32,33
		16N-26W	5,8,11,12,13,14,15,16,21,22,23,24,25,26, 27,28,29,32,33,36
24	Crescent-Lovell	16N-4W	4
		17N-4W	3,4,9,10,11,12,13,14,15,16,21,22,23,25,26, 27,28,32,33,34,35
		18N-4W	3,4,5,6,7,8,9,10,15,16,17,18,20,21,22,26, 27,28,33,34,36
		19N-4W	4,5,7,8,9,10,17,18,19,20,21,22,27,28,29, 30,31,32,33,34,36
		19N-5W	35
25	Deer Creek	27N-3W	14,15,22,23,26,27
26	Dilworth District	27N-1W	1,2,3
		28N-1E	4,5,6,7,8,9,17,18,19,20,29,30,31
		28N-1W	1,12,13,14,23,24,25,26,35,36
		29N-1E	13,14,15,16,17,18,19,20,21,22,23,24,27, 28,29,30,31,32,22,24
		29N-1W	24,25,36
27	Edith S.	26N-18W	3,7
		26N-19W	1,2,13,14,15
		27N-18W	19,28,29,30,31,32
		27N-19W	13,14,23,24,26,34,36
28	Elk Horn NW.	20N-3W	7,17,18,19,20,29,30,31,32
		20N-4W	13,23,24,25,26,27,34,35,36
29	Elk Horn S.	18N-3W	3,4,5,8,9,16,17,18,19,20,21
		19N-3W	20,21,22,27,28,29,32,33,34
30	Fort Supply NW.	25N-22W	16,14,20,22
31	Freedom N.	27N-17W	7,8,18
		27N-18W	13,23,24
32	Fritzlen	28N-14W	3,4,5
		29N-14W	27,33,34
33	Gage	20N-23W	4,6
		20N-24W	3,12
		21N-23W	4,5,6,7,8,9,10,13,14,15,16,17,18,21,22,23, 26,27,28,29,31,32,33,35,36
		21N-24W	1,2,4,5,11,12,25,26
		22N-23W	4,5,7,8,9,10,16,17,18,19,20,21,22,23,26, 28,29,30,31,32,33
		22N-24W	1,2,11,12,14,23,25,26,27,28,32,33,34,35,36
		23N-23W	1,2,3,8,9,10,11,12,14,15,16,17,18,19,20,21, 222,27,28,9,30,32,33,34,35
		23N-24W	10,11,13,14,15,16,22,23,24,25,26,27,35,36
		24N-22W	31
		24N-23W	22,23,26,34,35,36
34	Georgia	18N-4E	35,36
35	Golden Trend	1N-1W	6,7,8
		1N-2W	1,2,3,4,11,12,14
		2N-1W	29,30,31,32
		2N-2W	3,4,6,7,9,10,13,14,15,16,17,18,19,20,21,22, 23,24,25,26,27,28,29,30,31,32,33,34, 35,36
		2N-3W	1,2,3,4,5,6,8,9,10,11,12,13,14,15,23,24,25
		3N-2W	5,6,7,17,18,19,20,28,29,30,31,32,33,34
		3N-3W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 19,20,21,22,23,24,25,26,27,28,29,30, 31,32,33,34,35,36
		3N-4W	1,2,3,4,5,8,9,10,11,12,13,14,15,16,17,23,24,25
		4N-2W	5,6,7,8,17,18,19,20,28,29,30,31,32,33
		4N-3W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 19,20,21,22,23,24,25,26,27,28,29,30,31, 32,33,34,35,36
		4N-4W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 19,20,21,22,23,24,25,26,27,28,29,32, 33,34,35,36
		4N-5W	1,2,3,4,9,10,11,12,13,14,15,16,22,23,24
		5N-2W	32

---

* C indicates ranges east of the Cimarron Meridian.

No.	Field Name	T-R*	Section
35	Golden Trend, cont.	5N-3W	25,26,27,29,30,31,32,33,34,35,36
		5N-4W	13,14,16,17,18,19,20,21,22,23,24,25,26,
		5N-4W	27,28,29,30,31,32,33,34,35,36
		5N-5W	8,9,13,14,15,16,17,20,21,22,23,24,25,26,27,28,33,34,35,36
36	Grand S.	17N-25W	28,34,35
37	Grand W.	17N-24W	5,6
		17N-24W	1,2,3
		18N-24W	4,5,8,9,10,11,13,14,15,16,17,21,22,23,24,25,26,27,28,29,34,35,36
38	Guthrie	17N-1W	7,18
		17N-2W	12
39	Guthrie Townsite	16N-2W	5,6,7
40	Hamburg N.	15N-25W	8
41	Hardy	25N-3E	2,3,4,9,11,12
42	Hawley S.	26N-8W	15
43	Higgins S.	18N-25W	6,30
		18N-26W	1,2,3,4,5,8,9,10,11,12,13,14,15,16,17,20,21,22,23,24,25,26
		19N-25W	31
		19N-26W	26,27,28,32,33,34,35,36
44	Hubbard	26N-1W	6,7
		26N-2W	1,12
45	Ivanhoe	1N-26C	1
		1N-27C	1,2,3,4,5,6,9,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,29,32,33,34,35,37
		1N-28C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,20,21,22,23,24,25,26,27,28,29,30,32,33,34,35,36
		2N-27C	25,26,27,28,33,34,35,36
46	Keenan SW.	20N-23W	10
47	Lawrie W.	17N-2W	4,5,6
		17N-3W	1,2,3,4,5,8,9,10,11,12,14,15,16
		18N-2W	29,30,31,32,33
		18N-3W	23,24,25,26,33,34,35,36
48	Leedey	16N-20W	6,8,9,10,11,14,15
49	Logan S.	1N-25C	36
		1N-26C	3,6,7,8,9,10,13,14,15,16,17,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		1N-27C	7,8,9,17,18,19,20,30,31
50	Lovedale	25N-20W	6
		26N-19W	18
		26N-20W	1,2,3,4,5,6,7,8,9,10,11,12,16,17,18,19,21,30,31,32,33,35
		26N-21W	4,5,6,10,11,12,13,14,15,16,17,20,21,22,23,24,25,26,28,32,36
		26N-22W	11,12
		27N-20W	31,32
		27N-21W	26,27,28,29,32,33,34,35,37
51	Lucien	19N-2W	3,4,5
		20N-2W	7,8,10,11,14,15,16,17,18,19,20,21,22,23,25,26,27
52	Mackie	14N-24W	7,8
		14N-25W	1
		15N-25W	36
53	Manchester S.	29N-8W	14,15,16,21,22,23,25,26,27
54	Mervine	27N-3W	2,3,10,11,14,15,22,23,27
		28N-3W	25,26,35
55	Milder	22N-25W	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20,21,22,23,24
		22N-26W	1,2,4,9,10,11,12,14,16
		23N-25W	29,32,33,34
		23N-26W	33,34,35
56	Milder SW.	22N-25W	33,34
57	Mocane-Laverne Gas Area	1N-24C	4,5,6,11,12,13,14,20,22,23,24,25,26,27,28,33,34,36
		1N-25C	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18,19,20,26,28,29,30,31,32,33
		1N-26C	6
		2N-23C	1,2,3,4,11,12
		2N-24C	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,19,22,23,24,26,27,31,33,34,35,36
		2N-25C	1,2,3,4,5,6,7,8,9,10,13,14,15,16,18,19,20,21,23,24,25,26,27,28,29,32,34,35,36
		2N-26C	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,28,29,30,31,32,33,34
		2N-27C	1,6,7,8,17,18,19,20,21,22,23,29,30,31,32
		2N-28C	2,3,5,6,8,9,10,11,14,15,16,17,20,21,22,23,26,27,28,29,32,33,34,35,36
		3N-23C	1,2,3,4,11,12,13,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		3N-24C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		3N-25C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		3N-26C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,28,29,30,31,32,36
		3N-27C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,18,19,20,21,22,23,24,25,26,27,28,29,30,35
		3N-28C	2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19,20,21,22,23,26,27,28,29,30,31,32,33,34,35
		4N-21C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,25,27,28,29,30,31,32,33,34,35,36
		4N-22C	1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		4N-23C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
57	Mocane-Laverne Gas Area, cont.	4N-24C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		4N-25C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		4N-26C	1,2,4,5,6,7,8,9,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		4N-27C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		4N-28C	2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19,20,21,22,23,28,27,28,29,30,31,32,33,34,35
		5N-21C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,25,26,27,28,29,30,32,33,34,35,36
		5N-22C	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
		5N-23C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30,31,32,33,34,35,36
		5N-24C	1,2,3,4,5,6,7,8,9,10,11,12,12,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		5N-25C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		5N-26C	2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,32,33,34,35,36
		5N-27C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,28,26,27,28,29,30,31,32,33,34,35,36
		5N-28C	2,3,4,5,7,8,9,10,11,14,15,16,17,20,21,22,23,26,27,28,29,32,33,34,35
		6N-20C	13,14,15,16,17,18,19,20,24,25,26,27,28,29,30,33,34,35,36
		6N-21C	7,9,13,14,15,17,19,22,23,24,25,26,27,28,30,31,32,33,34,35,36
		6N-22C	14,16,17,18,20,21,22,23,27,28,29,30,31,33,34,35,36
		6N-23C	11,12,13,14,15,16,23,24,25,30,31,36
		6N-24C	9,10,11,12,14,15,16,17,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		6N-25C	1,12,13,18,20,22,24,25,26,27,28,29,30,31,32,33,34,35,36
		6N-26C	8,11,13,17,18,20,21,22,25,26,28,32,33,34,35,36
		6N-27C	19,10,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,31,33,34,35,36
		6N-28C	8,9,10,14,15,16,17,20,22,23,26,29,32,33
		23N-23W	4,5,6,7
		23N-24W	1,2,4,5,6,7,8,9,18,20
		23N-25W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,23
		23N-26W	1,2,3,4,9,10,11,12,13,14,15,16,21,22,23,24,25,26,28
		24N-23W	5,6,9,17,18,19,20,28,29,30,31,32,33
		24N-24W	1,2,3,4,5,6,9,10,11,12,13,14,15,16,17,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		24N-25W	1,2,3,4,5,6,7,8,9,10,12,13,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		24N-26W	1,2,3,5,8,9,10,11,12,13,14,16,17,20,21,22,24,25,27,33,36
		25N-23W	30,31,32
		25N-24W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,20,21,22,23,24,25,26,27,28,31,32,33,34,35,36
		25N-25W	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18,19,21,22,23,24,25,26,27,28,34,35,36
		25N-26W	1,2,3,4,9,10,11,12,14,23,26,27,28,34,35
		26N-23W	5,6,7,8,9,17,18,19,30,31
		26N-24W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,36
		26N-25W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		26N-26W	1,2,3,4,9,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,33,34,35,36
		27N-23W	17,18,19,27,28,29,30,31,32,33,34,35,36
		27N-24W	1,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,25,26,27,28,29,30,31,32,33,34,35,36
		27N-25W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		27N-26W	1,2,3,9,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,33,34,35,36
		28N-23W	17,18,19,30,31
		28N-24W	5,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		28N-25W	1,2,3,4,6,7,8,11,12,13,14,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36

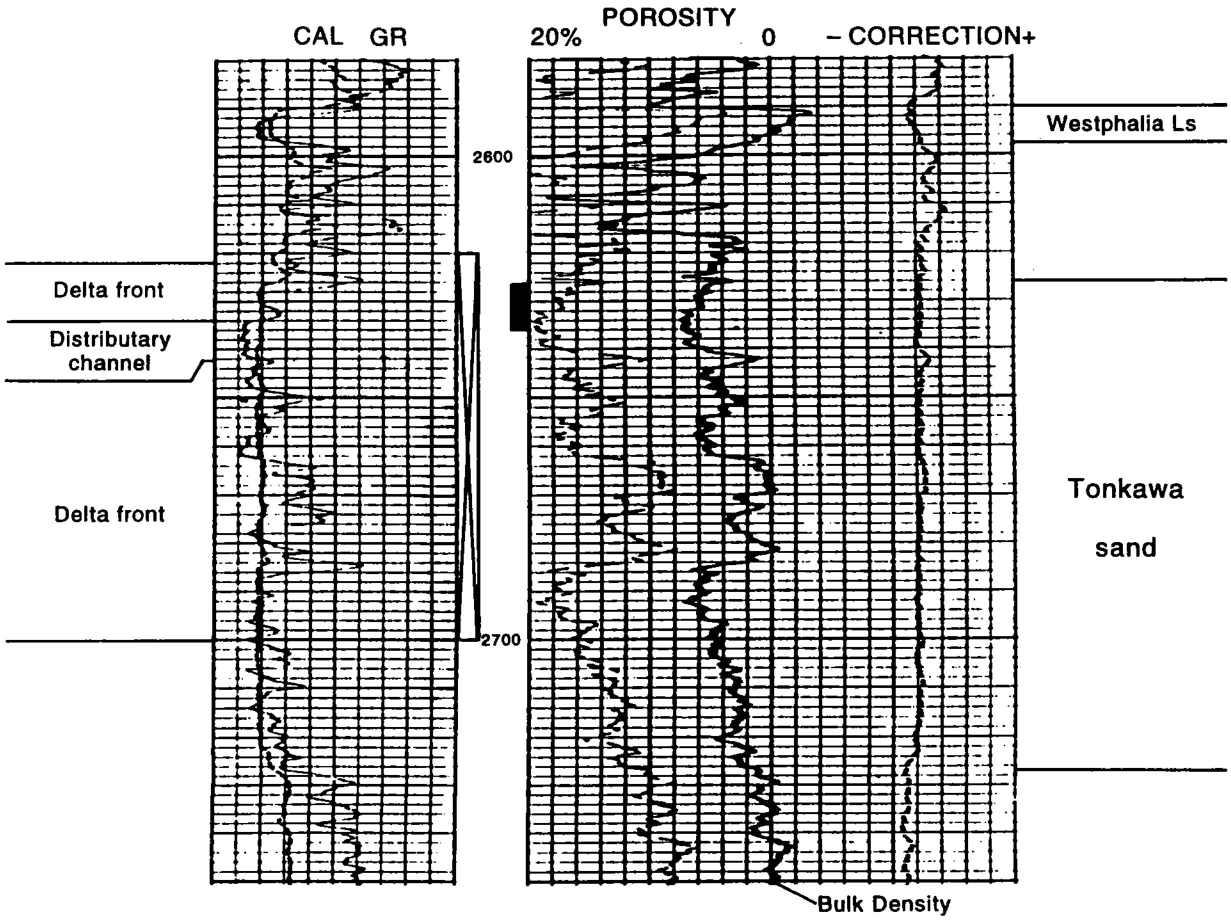
No.	Field Name	T-R*	Section
57	Mocane-Laverne Gas Area, cont.	28N-26W	1,2,3,4,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,34,35,36
		29N-25W	19,28,29,30,31,32,33
		29N-26W	13,14,15,23,24,25,26,27,35,36
58	Moorewood NE.	14N-19W	3,4,5,6,9,10,11,14
		15N-19W	19,29,30,31,32,33,34
		15N-20W	6,7,8,9,14,15,16,17,18,19,20,21,22,23,24,25,26,28,30,31,32,33,36
		15N-21W	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18
		15N-22W	1
		16N-21W	19,25,26,27,28,29,30,31,32,33,34,35,36
		16N-22W	24,25,26,36
59	Norfolk W.	18N-5E	3,4,5,8,9,10
		19N-5E	33
60	Oakdale	22N-13W	1,2,3,10,11,12
		23N-13W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		23N-14W	1,2,11,12,13,14,23,24,25,26,35,36
		24N-12W	18,19,20,29,30,31
		24N-13W	3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
60	Oakdale cont.	25N-13W	7,18,19,20,28,29,30,31,32
		25N-14W	2,10,11,12,13,14,15,21,22,23,24,25,26,27,28,34,35,36
61	Orlando	19N-1W	4,5,6,7,8,9,16,17,18
		19N-2W	1,2,11,12,13
		20N-1W	17,18,19,20,21,29,30,31,32,33
62	Pauls Valley	3N-1E	6
		4N-1E	29,30,31,32
		4N-1W	23,24,25,26,34,35,36
63	Peek NW.	18N-23W	21,28,29,30,32
64	Peek S.	16N-22W	3,4,8,9,10,15,16
		16N-23W	1,3,4,5,6,10,12
		16N-24W	1,2,3,4,10,11,12,14,15
		17N-21W	4,5,7,8,17,18,19,20,29,30
		17N-22W	1,2,3,4,7,8,9,10,11,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		17N-23W	1,4,5,7,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,31,32,33,34,35,36
		17N-24W	13,14,23,24
		18N-21W	33,34
		18N-22W	35
		18N-23W	33,36
65	Peek SW.	16N-23W	15
66	Plainview S.	1N-24C	26,34,35,36
67	Polo	21N-1W	6
		21N-2W	1,2,3,4,9,10,11
		22N-1W	16,17,19,20,21,28,29,30,31,32
		22N-2W	7,8,11,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,33,34,35,36
68	Ponca City NW.	26N-2E	19,20
69	Putnam	15N-15W	2,3,4,5,6,9,10,11,13,14,15,23,24,28,29
		15N-17W	1
		16N-15W	30,31,32,33,34,35
		16N-16W	6,18,19,20,25,26,27,28,29,30,32,33,34,35,36
		16N-17W	4,5,6,7,8,9,10,11,13,14,15,16,17,18,20,21,22,23,24,25,26,27,28,29,32,33,34,35
		16N-18W	1,2,3,4,5,6,7,8,9,10,11,12,13,15,18,19,20
		16N-19W	1,2,3,4,6,11,12,13,24
		17N-16W	2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19,20,21,22,29
		17N-17W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,26,27,28,29,30,31,32,33,36
		17N-18W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		17N-19W	1,2,3,4,5,6,7,8,9,10,11,12,13,15,23,24,25,26,27,28,29,32,33,34,35,36
		17N-20W	1,2,7,8,9,10,11,12,14,15,16,17,18
		17N-21W	3,10,11,14,15,23
		18N-16W	1,4,5,6,7,8,9,10,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-17W	2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-18W	1,3,7,8,9,10,11,12,13,14,15,16,17,19,22,23,24,25,26,27,28,29,30,31,32,35,36
		18N-19W	1,4,8,9,10,11,12,18,19,20,21,22,23,26,27,28,29,30,31,32,33,34,35,36
		18N-20W	12,13,25,34,35,36
		19N-16W	28,29,31,32
		19N-17W	32,33,34,35,36
		19N-18W	35
70	Reydon	12N-26W	2,3,4,5,6,7,8,9,10,15,23,24
		13N-25W	3,4,5,6,7,8,9,10,16,17,18,19,20,28,29,30,31,32
		13N-26W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		14N-25W	7,18,19,30,31,32,33,34
		14N-26W	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,
		15N-26W	14,15,21,22,23,27,28,32,33,34
71	Roll NW.	15N-24W	4
		16N-24W	34
72	Sams	21N-2W	13,14,15,16,21,22,23,24,25,26,27,28
73	Schlegel N.	18N-6E	4,5,6,7,8,9,15,16,17,20,21,22,23
74	Sooner Trend	15N-4W	5,6,7
		15N-5W	1,2,3,4,5,6,7,8,9,10,12,15,16,17,18,20,21
		15N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,27,29,30,31,32,33,34
		15N-7W	1,2,10,11,12,13,14,15,22,23,24,25,26,27,34,35,36
		16N-4W	4,5,6,7,8,14,16,17,18,19,20,21,22,23,27,28,29,30,31,32,33,34
		16N-5W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		16N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,32,33,34,35,36
		16N-7W	1
		16N-8W	1
		16N-9W	1
		17N-4W	5,7,8,9,16,17,18,19,20,21,29,30,31,32
		17N-5W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		17N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		17N-7W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		17N-8W	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,22,23,24,25,26,36
		17N-9W	1,12
		18N-4W	18,19,29,30,31,32
		18N-5W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-7W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-9W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		18N-10W	1,2,3,4,5,8,9,10,11,12,13,14,15,16,17,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		19N-4W	6,19,30
		19N-5W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		19N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		19N-7W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		19N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		19N-9W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,
		19N-10W	1,2,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,33,34,35,36
		20N-5W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		20N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		20N-7W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		20N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		20N-9W	1,11,12,13,14,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		20N-10W	25,36
		21N-5W	1,2,3,4,5,6,7,8,9,10,11,12,16,17,18,19,20,21,28,29,30,31,32,33,34,35
		21N-6W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,14,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,35
		21N-7W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		21N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		21N-9W	1,2,3,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		21N-10W	12,13,24
		22N-6W	15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36

No.	Field Name	T-R*	Section
74	Sooner Trend, cont.	22N-7W	3,4,5,6,7,8,9,10,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		22N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		22N-9W	1,2,11,12,13,14,22,23,24,25,26,27,28,29,33,34,35,36
		23N-7W	27,28,29,30,31,32,33,34
		23N-8W	25,326,27,28,32,33,34,35,36
		23N-9W	25,26,35,36
75	Stillwater W.	19N-2E	17,18,19,20,29,30
76	Stockholm SE.	26N-23W	19,20,21,28,29,30,31
		26N-24W	25,26,35,36
77	Strong City District	12N-22W	6
		13N-21W	1,2,3,4,5,6,7,8,9,10,14,16,17,18,19,20,21,29,30,31,32,33
		13N-22W	1,2,3,4,7,8,9,10,11,12,13,14,15,16,17,19,20,21,22,23,24,25,26,27,28,29,30,31,32,35,36
		13N-23W	12,24,25,36
		14N-21W	6,7,8,9,11,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		14N-22W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,33,34,35,36
		14N-23W	1,2,3,4,5,8,9,10,11,12,13,14,15,16,17,22,24,25,27
		14N-24W	1
		15N-21W	22,28,29,31,32
		15N-22W	4,7,8,13,14,15,16,17,18,19,20,21,22,23,26,27,28,29,30,31,32,33,34,35,36
		15N-23W	1,2,3,4,5,9,10,11,12,13,14,15,16,17,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		16N-23W	26,27,31,32,34,35,36
		16N-24W	36
78	Sumner NE.	22N-2E	28,33,34
79	Tonkawa	24N-1W	1,2,3,4,5,6,8,9,10,11,15,16,17,21
		24N-2W	1
		25N-1E	4,5,6,7,8,17,18,19,20,29,30,31,32,
		25N-1W	19,20,25,26,27,28,29,30,31,32,33,34,35,36
		25N-2W	23,24,25,35,36
		26N-1W	31,32
80	Vinco NW.	17N-2E	2,3
81	Watchom E.	22N-3E	2,10,11,15
		23N-3E	13,23,24,25,26,27,34,35,36
82	Watonga-Chickasha Trend	5N-7W	4
		6N-6W	6,7,8,19
		6N-7W	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,19,20,21,22,23,24,25,26,27,28,29,30,31,33,34
		6N-8W	2,3,4,9,10,11,12,14
		7N-6W	7,17,18,19,31
		7N-7W	3,4,5,9,7,10,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		7N-8W	1,2,3,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,33,34,35,36
		8N-7W	5,6,7,18,19,29,30,31,32,33
		8N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,33,34,35,36
		8N-9W	1,2,3,5,10,11,12
		9N-7W	6,7,8,9,15,18,19,20,22,29,30,31
		9N-8W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		9N-9W	1,2,3,4,5,8,9,10,11,12,13,14,15,16,17,20,21,22,23,24,25,26,27,33,34,35,36
		10N-7W	19,30
		10N-8W	7,8,9,16,17,18,19,20,21,25,26,27,28,29,30,31,32,33,34,35
		10N-9W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,32,33,34,35,36
		10N-10W	1,2,4,9
		11N-8W	30
		11N-9W	2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19,20,21,22,23,24,27,28,29,30,31,32,33,34,36
		11N-10W	1,2,3,5,6,7,8,11,12,13,14,15,16,17,18,21,22,23,24,26,27,28,29,33,34,35,36
		12N-9W	2,4,5,6,7,8,9,10,14,15,16,17,18,19,20,21,22,23,27,28,29,30,31,32,33,34,35
		12N-10W	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,20,21,22,24,25,26,27,28,29,30,31,32,33,34,35,36
		13N-9W	2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19,20,21,22,23,26,27,28,29,30,31,32,33,34,35
		13N-10W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		13N-11W	1,2,3,11,12,14,24,25,26,36
		14N-8W	6,7,8,17,18,19,20,29,30
		14N-9W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
		14N-10W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,23,24,25,26,27,28,30,31,32,34,25,36
		14N-11W	1,2,10,11,12,13,14,15,16,23,24,25,26,27,34,35,36
82	Watonga-Chickasha Trend, cont.	15N-10W	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,27,28,29,30,31,32,33,34,36
		15N-11W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,22,23,24,25,26,27,34,35,36
		16N-10W	6,19,20,30,31,33
		16N-11W	1,2,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,32,33,34,35,36
		16N-12W	1,2,10,11,12,13,24,25
		17N-10W	6,7,8,17,18,19,29,30,31,32
		17N-11W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36
		17N-12W	1,2,3,4,5,7,8,9,10,11,13,14,15,16,17,18,19,21,22,23,24,25,27,33,35,36
		17N-13W	2,5,6
		17N-14W	1,2
		18N-11W	7,8,15,16,17,18,19,20,21,22,23,25,26,27,28,29,30,31,32,33,34,35,36
		18N-12W	1,2,3,4,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,25,27,28,29,30,31,32,33,34,35,36
		18N-13W	1,2,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,3.0,31,35,36
		18N-14W	1,10,11,12,13,14,15,16,21,22,23,24,25,26,27,28,34,35,36
		19N-12W	33,34
83	Waynoka NE.	24N-15W	2
		24N-16W	5,6
		24N-17W	1,2,3,4,5,8,10
		25N-14W	31,32
		25N-15W	4,5,6,7,8,9,13,14,15,16,17,18,19,20,21,22,23,24,26,27,28,29,30,31,32,33,36
		25N-16W	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
		25N-17W	1,2,3,5,6,7,8,10,11,12,17,18,19,20,25,27,28,29,30,31,33,34,35,36
		25N-18W	1,2,3,5,6,11,12,13,14,15,22,23,24,25,26
		26N-15W	31
		26N-17W	18,19,26,27,28,29,30,31,32,33,34,35,36
		26N-18W	3,4,9,10,11,13,14,15,16,22,23,24,25,26,27,28,31,32,33,34,35,36
83	Waynoka NE., cont.	27N-18W	25,27,33,34,35,36
84	Willow-Garvin	3N-2E	2
85	Willow Springs E.	18N-1E	1
		18N-2E	6
86	Woodward N.	23N-20W	5,7,8,16,17,18,19,20
		23N-21W	12,13,14,15,16,20,21,23,24,26,28,29
		24N-20W	21,22,28,29,32

APPENDIX 2

Well Log, Core Description, and Digital Images of Select Rock Intervals for the Sun Oil Co.-DX Division No. 9 See Well

Sun Oil Co.-DX Division
No. 9 See
C NW NW 15, 24N–1W
Noble County, Oklahoma
TD 4567′
Core: 2620′–2700′



Completed 12–5–69
Perforated Tonkawa sand, 2626′–2636′;
Acidized/500 gal; Swbd 28 BSW with SO.
Perforated 1. Hoover sand, 2130′–2142′;
Swbd 20 BWPH with SO.
Perforated u. Hoover sand, 1986′–1994′;
Acidized/250 gal; Swbd 10 BFPH with
good SO.
IPP 1½ BOPD, 200 BWPD.

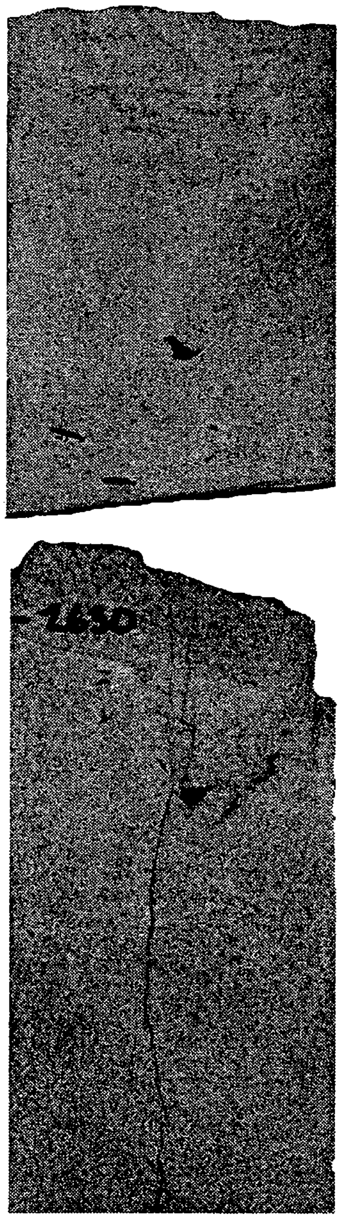
Sun Oil Co.–DX Division No. 9 See

C NW¼NW¼ sec. 15, T. 24 N., R. 1 W.
Noble County, Oklahoma
T.D. 4,567 ft
Core: 2,620–2,700 ft, rec. 77 ft

Interval	Core depth (in feet)	Lithology and sedimentary structures
1)	2,622.00–2,622.80	Black shale with interbedded gray sandy siltstone.
2)	2,623/00–2,628.65	Sandstone, fine-grained with flat, mostly very indistinct bedding. • Soft-sediment deformation at 2,623.30–23.40. Distributary-mouth bar.
3)	2,628.70–2,628.80	Black shale with interbedded gray micaceous siltstone.
4)	2,628.90–2,638.50	Sandstone, fine- to medium-grained. Bedding commonly poor to indistinct; dips locally as high as 20° (2,631.30 and 2,633.80). • Clay clasts @ 2,629.80; 30.10; 34.30; 35.00; and 35.20. • Vertical fracture, 2,630.00–30.90.
5)	2,638.60–2,639.00	Sandstone, fine- to coarse-grained, conglomeratic; with clay clasts and organic matter. Overlies eroded surface of sandstone below. Base of distributary channel deposit.
6)	2,639.10–2,645.40	Sandstone, fine- to medium-grained, bedding indistinct to vague. • Medium with clay clasts and partings of organic matter, 2,640.15–40.50 (storm deposit). • Vertical fracture, 2,643.00–45.40.
7)	2,646.00–2,646.60	Black shale and interbedded siltstone.
8)	2,646.70–2,661.30	Sandstone, fine-grained, bedding vague to indistinct with dips to 10°. • Local medium grain-size with partings of organic matter, 2,647.30–47.50 and 2,654.80–55.00 (storm deposits?). • Bioturbation, 2,656.20–56.70; 2,651.70–52.00; and 2,658.00–61.35. • Vertical fractures, 2,647.80–48.90 and 2,649.40–50.10.
9)	2,661.35–2,662.35	Black, silty shale and interbedded fine, silty, micaceous sandstone. Extreme bioturbation.
10)	2,662.40–2,670.10	Sandstone, fine-grained; bedding flat, commonly indistinct and locally vague. • Black shale and interbedded fine, silty, micaceous sandstone, 2,664.40–8864.60; 2,668.35–68.65; and 2,669.30–69.40. • Bioturbation, 2,664.40–64.60; 2,666.60–66.70; 2,668.00–68.20.
11)	2,670.60–2,671.20	Black, silty shale and interbedded fine silty micaceous sandstone.
12)	2,671.25–2,678.50	Sandstone, fine-grained. Horizontal, indistinct bedding but dips locally to 10°. • Bioturbation, 2,672.00–72.30; 2,674.20–74.50; and 2,676.20–76.40. • Reddish oxidation, 2,674.90, 2,675.50, and 2,676.75.
13)	2,678.75–2,680.80	Interbedded black shale and gray, silty fine-grained sandstone, and siltstone.
14)	2,680.90–2,698.80	Sandstone, fine to medium-grained, with mostly indistinct horizontal bedding. Dips locally as high as 15°. • Healed fracture, 2,684.30–84.80. • Shale clasts, 2,695.10–95.20. • Bioturbation and /or soft-sediment deformation, 2,697.40–97.45 and 2,698.60–98.80. Distributary mouth-bar deposits from 2,639.10 to 2,698.80 ft.

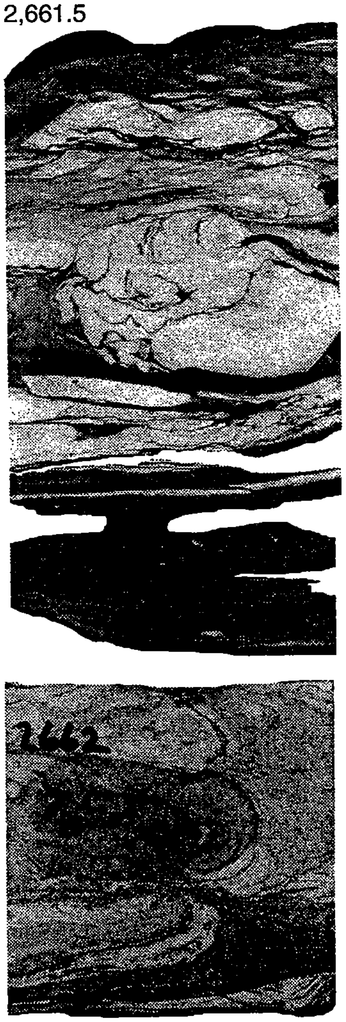
Summary: Core represents delta-front (shallow marine) and lower delta plain deposition.
Delta-front: 2,623.00–2,628.80 and 2,639.10–2,698.80.
Distributary channel: 2,628.90–2,639.00

Note: Core is about 5 ft high compared to wireline log. Depth intervals locally discontinuous because of numerous short (<1 ft each) gaps in core recovered.



A. Fine- to medium-grained sandstone. Note clay clasts, indistinct bedding, and vertical fracture. Interval 4 (upper delta front).

B. Fine- to coarse-grained sandstone; conglomerate at 2,638.6 to 2,639.0 ft. Distributary channel deposit overlies eroded surface of delta front at 2,639.1 ft (intervals 4, 5, and 6).



C. Interbedded fine, silty, micaceous sandstone and black shale. Strong bioturbation of delta front deposit (interval 9).

APPENDIX 3

Various Size Grade Scales in Common Use

(from Blatt and others, 1980)

Udden–Wentworth	ϕ *values*	*German scale*† *(after Atterberg)*	*USDA and Soil Sci. Soc. Amer.*	*U.S. Corps Eng., Dept. Army and Bur. Reclamation*‡
		(Blockwerk)		
Cobbles		—200 mm—	Cobbles	Boulders
			—80 mm—	—10 in.—
—64 mm—	−6			Cobbles
				—3 in.—
Pebbles		Gravel (Kies)		
				Gravel
—4 mm—	−2		Gravel	
				—4 mesh—
Granules				Coarse sand
—2 mm—	−1	—2 mm—	—2 mm—	—10 mesh—
Very coarse sand			Very coarse sand	
—1 mm—	0		—1 mm—	
Coarse sand		Sand	Coarse sand	Medium sand
—0.5 mm—	1		—0.5 mm—	—40 mesh—
Medium sand			Medium sand	
—0.25 mm—	2		—0.25 mm—	
Fine sand			Fine sand	Fine sand
—0.125 mm—	3		—0.10 mm—	
Very fine sand			Very fine sand	—200 mesh—
—0.0625 mm—	4	—0.0625 mm—		
			—0.05 mm—	
Silt		Silt		
			Silt	Fines
—0.0039 mm—	8			
		—0.002 mm—	—0.002 mm—	
Clay		Clay	Clay	
		(Ton)		

---

†Subdivisions of sand sizes omitted.

‡Mesh numbers are for U.S. Standard sieves: 4 mesh = 4.76 mm, 10 mesh = 2.00 mm, 40 mesh = 0.42 mm, 200 mesh = 0.074 mm.

APPENDIX 4

Abbreviations Used in Text and on Figures, Tables, and Plates

API	American Petroleum Institute
BCF	billion cubic feet (of gas)
BCFG	billion cubic feet of gas
BO	barrels of oil
BOPD	barrels of oil per day
BHP	bottom-hole pressure
BWPD	barrels of water per day
CAOF	calculated open-flow
cp	centipoise (a standard unit of viscosity)
DEN ϕ	density porosity
DST	drill stem test
GOR	gas to oil ratio
gty	gravity
IPF	initial production flowing
IPP	initial production pumping
MBO	thousand barrels of oil
MCF	thousand cubic feet (of gas)
md	millidarcies, or 0.001 darcy
MMBO	million barrels of oil
MMCF	million cubic feet (of gas)
MMCFG	million cubic feet of gas
MMCFGPD	million cubic feet of gas per day
MMSCF	million standard cubic feet (of gas)
MMSTB	million stock tank barrels
MSCF/STB	thousand standard cubic feet per stock tank barrel
MSTB	thousand stock tank barrels
NEU ϕ	neutron porosity
OOIP	original oil in place
OWC	oil-water contact
OWWO	oil well worked over
PSI	pounds per square inch
PSIA	pounds force per square inch, absolute
PVT	pressure volume temperature
RB	reservoir barrels (unit of measurement of oil in the subsurface where the oil contains dissolved gas); see STB or STBO
RB/STB	reservoir barrels per stock tank barrels
R_{xo}	resistivity of the flushed zone
R_t	resistivity of the invaded zone
SCF/STB	standard cubic feet per stock tank barrel
STB or STBO	stock tank barrels of oil (unit of measurement for oil at the surface in a gas-free state rather than in the subsurface reservoir where the oil contains dissolved gas); see RB
STB/DAY	stock tank barrels (of oil) per day
TSTM	too small to measure

APPENDIX 5

Glossary of Terms

(as used in this volume)

Definitions modified from Bates and Jackson (1987), Sheriff (1984), and Van Wagoner and others (1990).

allogenic—Formed or generated elsewhere.

anastomosing stream—A fluvial depositional system characterized by a branching network of shallow channels. Similar in form to braided river systems except that anastomosing rivers have alluvial islands covered by dense and permanent vegetation that stabilizes river banks.

authigenic—Formed or generated in place.

avulsion—A sudden cutting off or separation of land by a flood or by an abrupt change in the course of a stream, as by a stream breaking through a meander or by a sudden change in current whereby the stream deserts its old channel for a new one.

bar finger—An elongated, lenticular body of sand underlying, but several times wider than, a distributary channel in a bird-foot delta.

bed load—The part of the total stream load that is moved on or immediately above the stream bed, such as the larger or heavier particles (boulders, pebbles, gravel) transported by traction or saltation along the bottom; the part of the load that is not continuously in suspension or solution.

braided stream—A stream that divides into or follows an interlacing or tangled network of several small branching and reuniting shallow channels separated from each other by branch islands or channel bars.

capillary pressure—The difference in pressure across the interface between two immiscible fluid phases jointly occupying the interstices of a rock. It is due to the tension of the interfacial surface, and its value depends on the curvature of that surface.

centipoise—A unit of viscosity equal to 10^{-3}kg/s.m. The viscosity of water at 20°C is 1.005 centipoise.

channel deposit—An accumulation of clastic material, commonly consisting of sand, gravel, silt, and clay, in a trough or stream channel where the transporting capacity of the stream is insufficient to remove material supplied to it.

clay drapes—Layers of clay and silt deposited on lateral accretionary surfaces of point bars during periods of decreased river discharge.

crevasse-splay deposit—See *splay*.

delta—The low, nearly flat, alluvial tract of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area, crossed by many distributaries of the main river, perhaps extending beyond the general trend of the coast, and resulting from the accumulation of sediment supplied by the river in such quantities that it is not removed by tides, waves, and currents. See also: *delta plain, delta front, prodelta, lower delta plain,* and *upper delta plain.*

delta front—A narrow zone where deposition in deltas is most active, consisting of a continuous sheet of sand, and occurring within the effective depth of wave erosion (10 m or less). It is the zone separating the *prodelta* from the *delta plain,* and it may or may not be steep.

delta plain—The level or nearly level surface composing the landward part of a large delta; strictly, an alluvial plain characterized by repeated channel bifurcation and divergence, multiple distributary channels, and interdistributary flood basins.

diagenesis—All changes that affect sediments after initial deposition, including compaction, cementation, and chemical alteration and dissolution of constituents. It does not include weathering and metamorphism of preexisting sediments.

diapir—A dome or anticlinal fold in which the overlying rocks have been ruptured by the squeezing-out of plastic core material. Diapirs in sedimentary strata usually contain cores of salt or shale.

distributary channel—(a) A divergent stream flowing away from the main stream and not returning to it, as in a delta or on an alluvial plain. (b) One of the channels of a braided stream; a channel carrying the water of a stream distributary.

distributary mouth bar—The main sediment load of a distributary channel in the subaqueous portion of a *delta* (also called the *delta front*). It consists predominantly of sand and silt; grain size decreases seaward.

eustatic—Pertaining to worldwide changes of sea level that affect all the oceans.

facies—(a) A mappable, areally restricted part of a lithostratigraphic body, differing in lithology or fossil content from other beds deposited at the same time and in lithologic continuity. (b) A distinctive rock type, broadly corresponding to a certain environment or mode of origin.

fluvial—(a) Of or pertaining to a river or rivers. (b) Produced by the action of a stream or river.

formation-volume factor—The factor applied to convert a barrel of gas-free oil in a stock tank at the surface into an equivalent amount of oil in the reservoir. It generally ranges between 1.14 and 1.60. See also: *shrinkage factor.*

highstand—The interval of time during one or more cycles of relative change of sea level when sea level is above the shelf edge in a given local area.

highstand system tract (HST)—The stratigraphically higher (or younger) depositional system(s) in a succession of genetically related strata bounded by unconformities or their correlative counterparts.

incised valleys—Entrenched fluvial systems that extend their channels basinward and erode into underlying strata.

infilling—A process of deposition by which sediment falls or is washed into depressions, cracks, or holes.

isopach—A line drawn on a map through points of equal true thickness of a designated stratigraphic unit or group of stratigraphic units.

lacustrine—Pertaining to, produced by, or formed in a lake or lakes.

lower delta plain—Depositional environment within a *delta* which extends from the subaqueous *delta front* to the landward limit of marine (tidal) influence.

lowstand—The interval of time during one or more cycles of relative change of sea level when sea level is below the shelf edge.

lowstand system tract (LST)—The stratigraphically lower (or older) depositional system(s) in a succession of genetically related strata bounded by unconformities or their correlative counterparts.

meander—One of a series of regular freely developing sinuous curves, bends, loops, turns, or windings in the course of a stream. See also: *meander belt.*

meander belt—The zone along a valley floor across which a meandering stream shifts its channel from time to time; specifically the area of the flood plain included between two lines drawn tangentially to the extreme limits of all fully developed meanders. It may be from 15 to 18 times the width of the stream.

meteoric water—Pertaining to water of recent atmospheric origin.

millidarcy (md)—The customary unit of measurement of fluid permeability, equivalent to 0.001 darcy.

mud cake—A clay lining or layer of concentrated solids adhering to the walls of a well or borehole, formed where the drilling mud lost water by filtration into a porous formation during rotary drilling.

natural water drive—Energy within an oil or gas pool, resulting from hydrostatic or hydrodynamic pressure transmitted from the surrounding aquifer.

offlap—A term commonly used by seismic interpreters for reflection patterns generated from strata prograding into deep water.

onlap—The progressive submergence of land by an advancing sea.

point bar—One of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank.

prodelta—The part of a delta that is below the effective depth of wave erosion, lying beyond the *delta front,* and sloping gently down to the floor of the basin into which the delta is advancing and where clastic river sediment ceases to be a significant part of the basin-floor deposits.

progradation—The building forward or outward toward the sea of a shoreline or coastline (as of a beach, delta, or fan) by nearshore deposition of river-borne sediments or by continuous accumulation of beach material thrown up by waves or moved by longshore drifting.

proppant—As used in the well completion industry, any type of material that is used to maintain openings of induced fractures. Proppants usually consist of various sizes of sand, silica beads, or other rigid materials, and they are injected into the formation while suspended in a medium such as water, acid, gel, or foam.

regression—The retreat or contraction of the sea from land areas, and the consequent evidence of such withdrawal (such as enlargement of the area of deltaic deposition).

residual oil—Oil that is left in the reservoir rock after the pool has been depleted.

ribbon sand—See: *shoestring sand.*

rip-up—Said of a sedimentary structure formed by shale clasts (usually of flat shape) that have been "ripped up" by currents from a semiconsolidated mud deposit and transported to a new depositional site.

river bar—A ridge-like accumulation of alluvium in the channel, along the banks, or at the mouth, of a river.

shoestring sand—A shoestring composed of sand or sandstone, usually buried in the midst of mud or shale; e.g., a buried distributary mouth bar, coastal beach, or channel fill.

shrinkage factor—The factor that is applied to convert a barrel of oil in the reservoir into an equivalent amount of gas-free oil in a stock tank at the surface. It generally ranges between 0.68 and 0.88. See also: *formation-volume factor.*

splay—A small alluvial fan or other outspread deposit formed where an overloaded stream breaks through a levee (artificial or natural) and deposits its material on the flood plain or delta plain.

stillstand—Stability of an area of land, as a continent or island, with reference to the Earth's interior or mean sea level, as might be reflected, for example, by a relatively unvarying base level of erosion between periods of crustal movement.

subaerial—Said of conditions and processes, such as erosion, that exist or operate in the open air on or immediately adjacent to the land surface; or of features and materials, such as eolian deposits, that are formed or situated on the land surface. The term is sometimes considered to include fluvial.

tabular cross-bedding—Cross-bedding in which the cross-bedded units, or sets, are bounded by planar, essentially parallel surfaces, forming a tabular body.

thalweg—The line conecting the lowest or deepest points along a stream bed or valley, whether under water or not.

transgression—The spread or extension of the sea over land areas, and the consequent evidence of such advance.

transgressive system tract (TST)— A depositional episode that is bounded below by the transgressive surface and above by sediments representing a period of maximum flooding. The depositional environment of a TST becomes progressively deeper upward in the section.

transverse river bar—A channel bar deposit which is generally at an angle across the channel but prograding on the downstream side. This type of river deposit may be lobate, straight, or sinuous in map view.

trough cross-bedding—Cross-bedding in which the lower bounding surfaces are curved surfaces of erosion; it results from local scour and subsequent deposition.

upper delta plain—Depositional environment in a *delta* that extends from the down-flow edge of the flood plain to the effective limit of tidal inundation of the *lower delta plain.* The upper delta plain essentially is that portion of a delta unaffected by marine processes.

unitized—Consolidating the management of an entire oil or gas pool, regardless of property lines and lease boundaries, in the interest of efficient operation and maximum recovery.

valley fill—Sediment deposited in a valley or trough by any process; commonly, fluvial channel deposition is implied.

water leg—A water-saturated zone that extends below an oil- or gas-saturated zone.

APPENDIX 6

Well Symbols Used in Figures and Plates

○	Location
⌖	Dry hole
●	Oil well
●̸	Abandoned oil well
◒	Dry hole, show of oil
☼	Gas well
☼̸	Abandoned gas well
✹	Oil and gas well-dual completion
✹̸	Abandoned oil and gas well
●↙	Oil well converted to injection well
⊕	Salt-water disposal well
⊕̸	Abandoned salt-water disposal well
⌀w	Water injection (input) well
⊗w	Abandoned water injection well
⌀G	Gas injection (input) well
⊗G	Abandoned gas injection well
○wsw	Water supply well
⦸wsw	Abandoned water supply well
●↘x	Directionally drilled well (Surface location shows well completion status. X indicates bottom hole location.)
△	Discovery well
⬡	Type or representative log well
□	Cored well

NDE- Not deep enough

DNP- Did not penetrate

ND- No well data

NL- No well log

Notes

Oklahoma Geological Survey
Supplement to Special Publication 97-3

Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Tonkawa Play

PART IV

Reservoir Simulation of a Tonkawa Sand Reservoir, Blackwell Oil Field, Kay County, Oklahoma

◁ CONTENTS ▷

LIST OF ILLUSTRATIONS

Figures

Tables

RESERVOIR SIMULATION OF A TONKAWA SAND RESERVOIR, BLACKWELL OIL FIELD, KAY COUNTY, OKLAHOMA

R. M. Knapp, Z. Samad, and C. Xie
School of Petroleum and Geological Engineering
University of Oklahoma

INTRODUCTION

The Tonkawa oil reservoir in the Blackwell field lies in secs. 9 and 10, T. 27 N., R. 1 W., and secs. 3 and 4, T. 27 N., R. 1 W., Kay County, Oklahoma. The Tonkawa sand in this field is at depths of ~2,300 ft, or ~1,300 ft subsea (below mean sea level). Its average net thickness is ~35 ft, and its areal extent, ~850 acres. A complete discussion of the Blackwell field, including petrography, depositional environments, and exploration strategy, can be found in Parts II and III of this volume.

The major objective of this study was to analyze past performance and to identify potential strategies to improve oil recovery from the Tonkawa reservoir. Existing data were used to develop a reservoir-simulation model of the Blackwell field. BOAST3 (Mathematical & Computer Services, Inc., 1995), a three-dimensional, three-phase black oil simulator, was used to develop this model.

OVERVIEW OF FIELD DEVELOPMENT

The Tonkawa reservoir in the Blackwell field was discovered in 1923, and the wells were drilled during three distinct periods. The first period was from 1923 to 1941, the second from 1948 to 1963, and the third from 1977 to 1986. The estimated original oil in place (OOIP) in this reservoir was 9.1 million stock tank barrels of oil (MMSTBO). The production from 1923 to 1956 is unknown. From 1956 through 1995, the reported production was 1.28 MMSTBO.

January 1977 was the beginning of the last major stage of field development. The oil-water contact was believed to be drawn upward 9.5 ft under the area of early (1923–41) production in sec. 10. Elsewhere it was believed to be close to its initial elevation. Therefore, January 1977 was chosen as the beginning time for the simulation study. Nineteen production wells were active at different times from January 1977 through December 1995. The 19-year production history of the study area is shown in Figure 42. The field oil-production rate declined from the 1980 peak rate of 190 barrels of oil per day (BOPD) to 73 BOPD in 1995.

The average initial pressure of the reservoir was 950 pounds per square in., absolute (PSIA), and the oil is believed to have been initially saturated. On the basis of production data, the main recovery mechanism is believed to be a natural water drive. The average 1995 reservoir pressure is believed to have been within 100 PSI of the initial reservoir pressure.

DATA AVAILABILITY

Data used for reservoir characterization and simulation include depth to the top of the Tonkawa sandstone, sand thickness, porosity, initial gas/oil ratio (GOR), and initial water saturation. Values of these parameters were obtained from Rottman (Part III, this volume). His maps of the depth to the top of the Tonkawa sandstone (Fig. 36, Part III) and net sand thickness ($\phi \geq 8\%$) (Fig. 33, Part III) were digitized and form part of the data file that defines the reservoir. Oil-production records were obtained from Petroleum Information Corporation. Data that are useful for reservoir studies but were unavailable for this study include (1) reservoir pressure data from specific times during production, (2) permeability data, (3) capillary-pressure and relative-permeability data, and (4) water-cut and gas-production data.

ROCK DATA AND FLUID PROPERTIES

Values for average porosity and water saturation used in the reservoir-simulation model are based on data provided by Rottman and reported in Table 6 (Part III, this volume). Uniform permeabilities of 100 md were assumed. An average initial water saturation of 24% was used for the oil-reservoir blocks. A residual-oil saturation of 35% was chosen from Rottman (personal communication, 1997). Relative rock permeabilities were estimated, using Honarpour's method (Honarpour and others, 1986); these values were used to generate vertical equilibrium pseudo-functions for the oil- and water-bearing portions of the reservoir.

The average reservoir temperature reported from well logs was 100°F. The oil gravity averaged 44°API. The specific gravity (1.165) and salinity (200,000 ppm) of the water were estimated from Bradley (1987, table 24.8). The reported initial GOR was 350 standard cubic ft/stock tank barrel (SCF/STB) (Table 6, Part III, this volume). The fluid properties were estimated from the Standing correlations (Craft and others, 1991), using data reported by Rottman (Table 6, Part III). A specific gas gravity of 0.85 reported by Rottman was used to

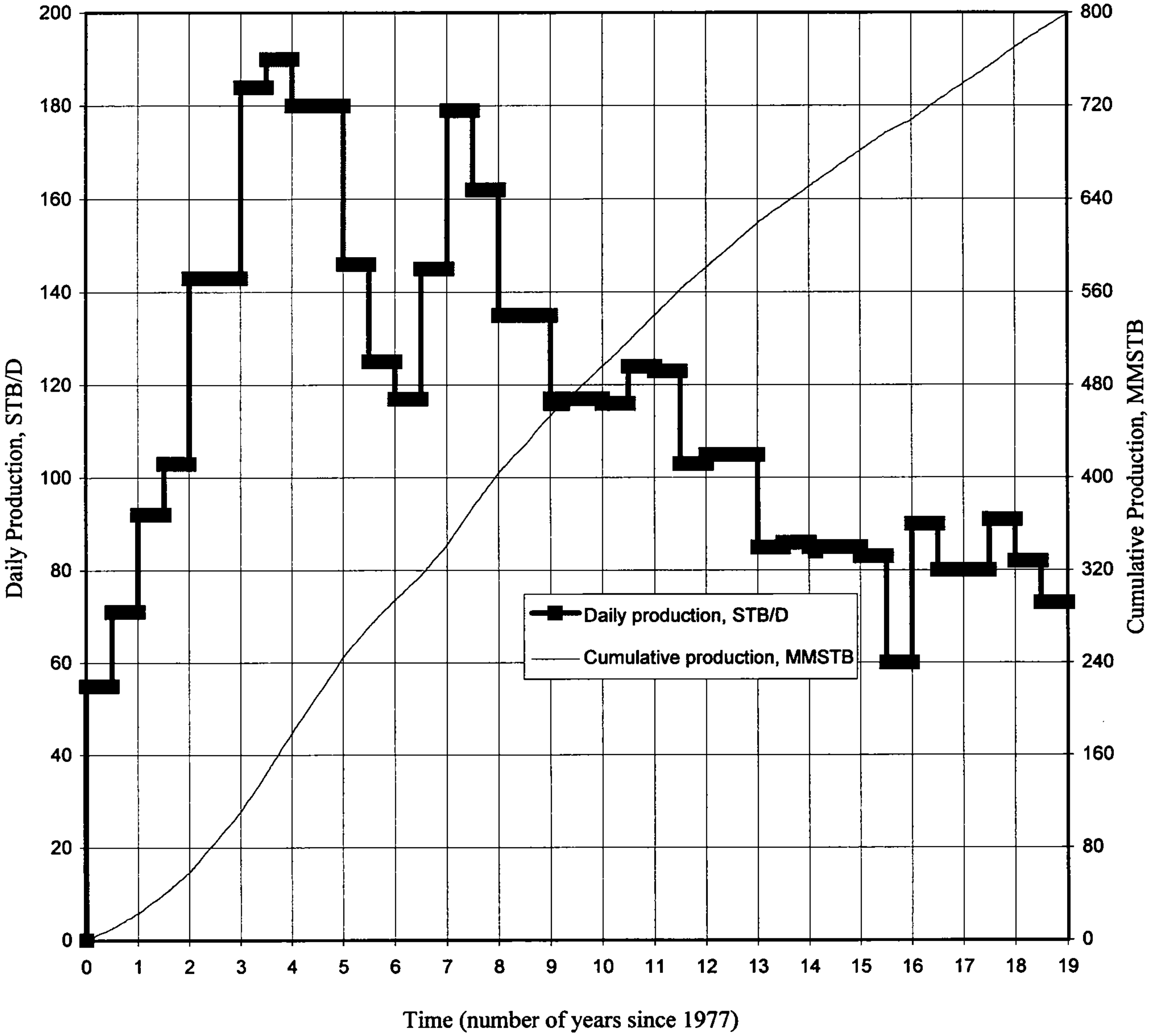


Figure 42. Daily and cumulative oil-production history (1977 through 1995) for Tonkawa sand reservoir in the Blackwell field. STB/D = stock tank barrels per day; MMSTD = million stock tank barrels.

match the average initial GOR. The original saturation (bubble-point) pressure estimated from the reservoir-fluid sample analysis was 966.5 PSIA. The estimated average initial oil formation-volume factor and oil viscosity at reservoir conditions were 1.18 reservoir barrels per stock tank barrels (RB/STB) and 0.65 cp, respectively.

HISTORY MATCHING

Normally, to be confident that the reservoir model represents the behavior of the reservoir, the model is tested by matching the model-predicted production rate to the actual production performance for each well in the study area. For the history-match simulations, the actual oil-production rates are specified because they are considered to be reliable. However, no match was possible for this reservoir, because gas- and water-production-data histories were not available. The simulation study should be able to provide information, using the geological model, to locate regions of the reservoir that are not being drained. Unfortunately, a lack of important data limits the effectiveness of this prediction. Hence, for the Tonkawa reservoir, recording reservoir pressures and water- and gas-production data during production is strongly recommended. Obtaining a fresh core for permeability and residual-oil-saturation measurements would be desirable.

TABLE 8. – Production Data at the End of 5-Year Prediction for Tonkawa Sand Reservoir in Blackwell Field, Kay County, Oklahoma

	No. of wells	Oil-production rate[a]	Water-cut[a]	Cumulative 5-year production
Case 1	17	22 STB/D	56%	87 MSTBO
Case 2	12	28 STB/D	54%	98 MSTBO
Case 3	15	40 STB/D	45%	166 MSTBO

Note: STB/D = stock tank barrels per day; MSTBO = thousand stock tank barrels of oil.

[a] Computed value at the end of simulated period.

TABLE 9. – Well Locations and Production Data for Tonkawa Sand Reservoir in Blackwell Field, Kay County, Oklahoma

No.	Wells	Spot no.	Grid			Locations	Net thk (ft)	Start–Shut (Mo/Yr)	Cum. oil prod. (MSTB) to 12/95	Start–Shut (Mo/Yr)	Cum. oil prod. (case 3) (MSTB) to 12/00
			X	Y	Z						
1	FMJ7A	122	19	13	1	Sec. 10, E½SW¼NW¼	39.90	06/83–12/95	70.10	06/83–12/00	88.60
2	FMJ6A	109	17	13	1	Sec. 10, CW½NW¼	39.80	06/83–12/95	69.70	06/83–12/00	85.40
3	FMJN2	114	18	10	1	Sec. 10, NE¼NW¼SE¼NW¼	39.80	06/83–12/95	69.50	06/83–12/00	83.70
4	HUM12	130	22	12	1	Sec. 10, NE¼NW¼SW¼	40.60	06/93–12/95	4.40	06/93–12/00	8.60
5	SAFEB	103	16	6	1	Sec. 10, SW¼NW¼NE¼	35.10	06/77–12/89	27.90	06/77–12/89	27.90
6	CRCLX	116	18	5	1	Sec. 10, NW¼SW¼NE¼	40.10	06/77–12/95	55.80	06/77–12/95	55.80
7	MSLCM	106	16	7	1	Sec. 10, SE¼NE¼NW¼	36.60	06/77–12/95	51.90	06/77–12/00	57.30
8	BSLMB	99	14	8	1	Sec. 10, NE¼NE¼NW¼	41.80	06/77–12/95	51.60	06/77–12/00	57.90
9	CLFT1	100	14	6	1	Sec. 10, NE¼NW¼NE¼	41.80	06/77–12/95	182.50	06/77–12/00	212.90
10	CLFT2	101	14	4	1	Sec. 10, NW¼NW¼NE¼	32.30	06/77–06/91	59.30	06/77–06/91	59.30
11	HROR3	16	12	5	1	Sec. 3, SW¼NE¼SW¼SE¼	45.00	06/79–12/95	21.20	06/79–12/95	21.20
12	HROR4	17	10	6	1	Sec. 3, CNW¼SW¼SE¼	44.30	12/80–12/95	18.40	12/80–12/95	18.40
13	HROR2	29	13	5	1	Sec. 3, SE¼SW¼SW¼SE¼	45.00	06/79–12/95	21.20	06/79–12/00	23.00
14	HRO1A	31	13	4	1	Sec. 3, S½SE¼SW¼SE¼	40.80	12/78–12/95	21.70	12/78–12/95	21.70
15	SLCUM	24	12	12	1	Sec. 3, NE¼SW¼SW¼	29.20	06/77–12/95	22.80	06/77–12/00	24.10
16	SCM4A	25	12	10	1	Sec. 3, SW¼SE¼SW¼	35.80	06/77–12/95	23.00	06/77–12/95	22.40
17	SLCM3	26	12	8	1	Sec. 3, SE¼SE¼SW¼	42.20	06/77–12/95	22.30	06/77–12/00	23.50
18	HUMP3	128	22	14	1	Sec. 10, NW¼NW¼SW¼	39.90	06/93–12/95	3.30	06/93–12/00	7.50
19	HUMP1	131	22	10	1	Sec. 10, NW¼NE¼SW¼	31.70	06/93–12/95	3.30	06/93–12/00	5.40
20	INFL1		16	9	1	Sec. 10, S½NW¼NW¼	40.80			06/96–12/00	17.60
21	INFL2		20	9	1	Sec. 10, S½SE¼NW¼	30.10			06/96–12/00	17.50
22	INFL3		20	15	1	Sec. 10, SE¼SE¼NW¼	40.00			06/96–12/00	25.00

Note: Net thk = net thickness; MSTB = thousand stock tank barrels.

ESTIMATION OF RESERVES AND OIL-RECOVERY FACTOR

The estimated total original oil in place for the Tonkawa reservoir is 9.1 MMSTBO. With an estimated residual-oil saturation of 35%, the maximum theoretical recovery could be as much as 4.9 MMSTBO, or 54% of the OOIP. The estimated unrecoverable immobile oil is 4.2 MMSTBO. A reported 1.28 MMSTBO was produced from 1956 through 1995, and it may be estimated that from 1923 through 1956, 800,000 (800 M) STB was produced. Together, these estimates represent 42% of the maximum recoverable oil. Consequently, more than 2.5 MMSTB of mobile oil remains in the reservoir and represents a goal for future recovery.

EVALUATION OF FUTURE DEVELOPMENT OPPORTUNITIES

Three reservoir-management strategies were simulated for 5 years, as follows: base case (case 1), current operations; case 2, current operations, except for wells that are producing at high water/oil ratios; case 3, current operations, with three infill wells. The results predicted by the three strategies are listed in Table 8.

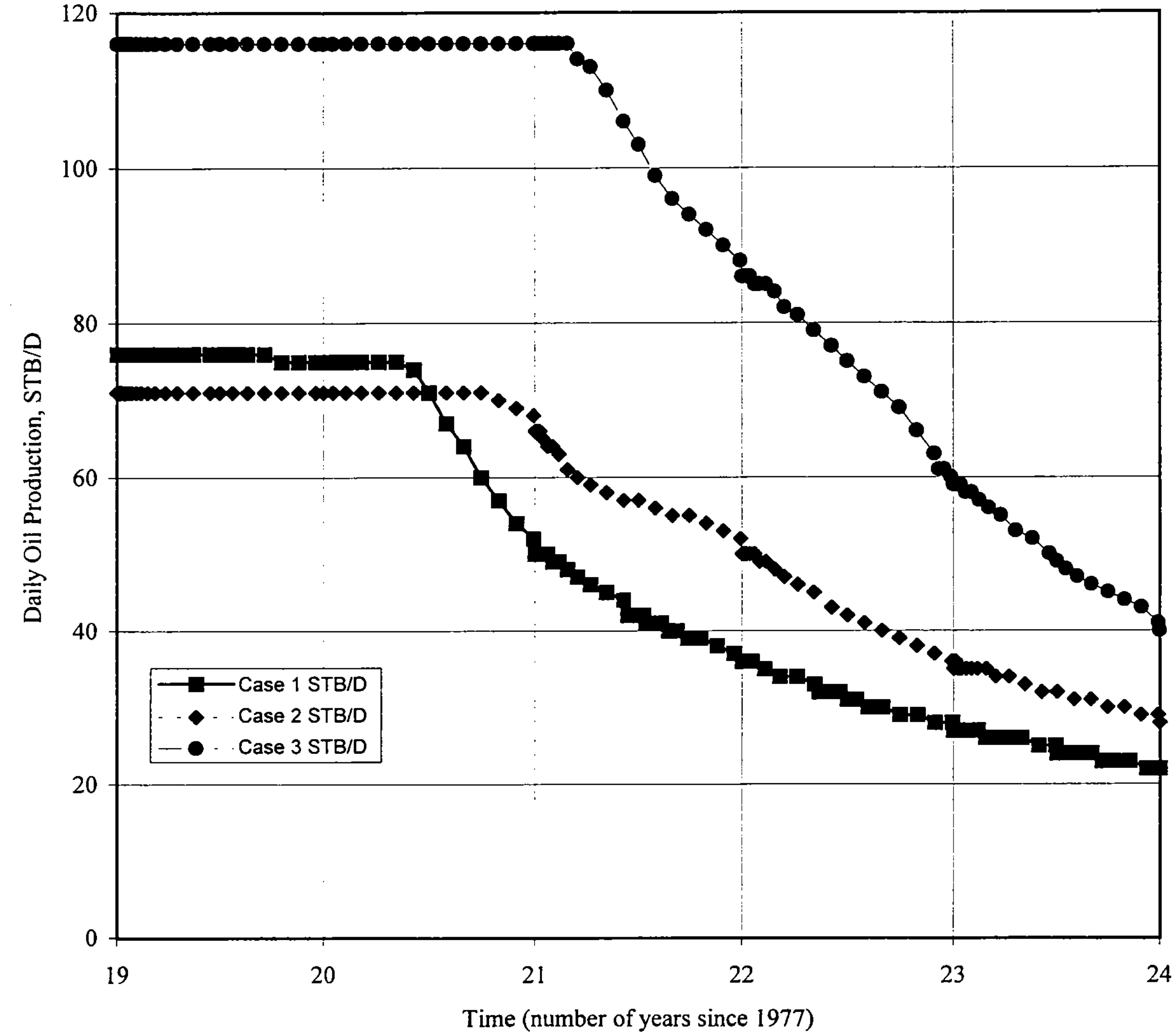


Figure 43. Three development case predictions (1996 through 2000) for Tonkawa sand reservoir in the Blackwell field. STB/D = stock tank barrels per day.

Base Case (Case 1)

The simulation of continued current operations assumes no changes in the December 1995 well configuration and well-operating conditions (i.e., bottom-hole pressures). During the 5-year production forecast, an additional recovery of 87 MSTBO (1.0% of OOIP) is estimated. The field water cut is expected to be about 56% at the end of 5 years. Also at the end of 5 years, 17 wells are estimated to produce 22 STBOPD. Simulation results are shown in Table 8 and Figure 43. From BOAST3 data output, the water/oil ratio of several low productivity peripheral wells was observed to be high, and saturation data indicated that some regions of the reservoir were not being swept.

Case 2

For this case, five wells with low productivity and high water/oil ratios were shut in (Table 9, well nos. 6,11,12,14,16). At the end of a 5-year simulated production period, the additional recovery of oil for this case is expected to be 98 MSTBO (or 1.1% of OOIP), the field water cut about 54%, and the production rate 28 STBOPD from 12 wells. The results are shown in Table 8 and Figure 43. From simulator saturation data (BOAST3), it appears that significant parts of the reservoir still would not be drained.

Case 3

The third case modeled used the case 2 configuration but added three infill production wells. These infill wells were Infill No. 1, S½NW¼NW¼ sec. 10; Infill No. 2, S½SE¼NW¼ sec. 10; and Infill No. 3, SE¼SE¼NW¼ sec. 10. These locations were selected for their high 1995 simulated oil saturations. Like case 2, wells with low productivity and high water/oil ratios were considered to be shut in at the start of the 5-year simulation period to keep water production low. The simulated oil production during 5 years is estimated at 166 MSTBO, or 1.8% of the OOIP. After 5 years, the field water cut is expected to be about 45%, and the production rate from

15 wells, 40 STBOPD. The results are shown in Table 8 and Figure 43.

SUMMARY AND CONCLUSIONS

The estimated original oil in place (OOIP) in the Tonkawa reservoir of the Blackwell field is 9.1 MMSTBO. About 23% of that amount has been recovered after 73 years of primary production. The estimated volume of unproduced mobile oil in this field, about 30% (2.7 MMSTBO) of the OOIP, provides a strong motivation to consider future oil-recovery opportunities.

The simulation study has identified potential opportunities to reduce lifting costs by suspending operation of wells with high water cuts—thereby not reducing reservoir performance—and by exploiting undrained mapped oil with additional infill wells. The results of the 5-year production simulations show that of the three alternatives considered, the configuration with three infill wells (case 3) would result in the highest additional oil recovery over the next 5 years, which would be 1.8% of the OOIP, or 166 MSTBO.

REFERENCES CITED

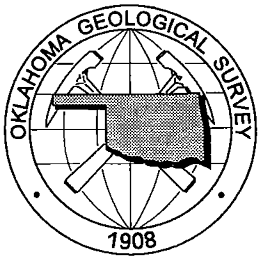
Bradley, H. B., 1987, Petroleum engineering handbook: Society of Petroleum Engineers, Richardson, Texas, p. 24–10.

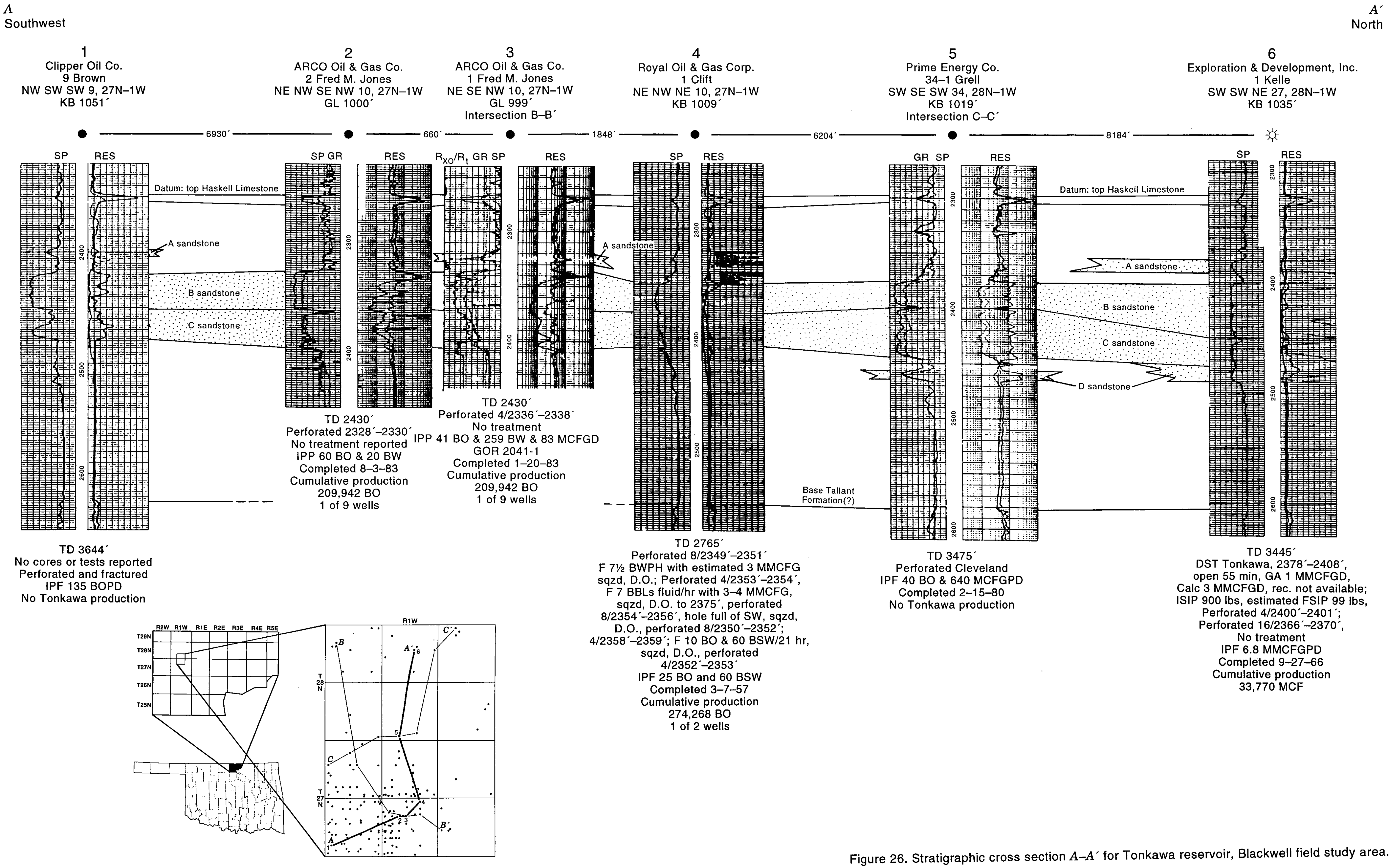
Craft, B. C.; Hawkins, M.; and Terry, R. E. (eds.), 1991, Applied petroleum reservoir engineering [2nd edition]: Prentice Hall, Englewood Cliffs, New Jersey, p. 9–55.

Honarpour, M.; Koederitz, L.; and Harvey, A. H., 1986, Relative permeability of petroleum reservoirs: CRC Press, Inc., Boca Raton, Florida, p. 40.

Mathematical & Computer Services, Inc., 1995, BOAST3, a modified version of BoastII with post processors B3PLOT and COLORGRID, 63 p.

Notes


OKLAHOMA GEOLOGICAL SURVEY
1908



1
Clipper Oil Co.
9 Brown
NW SW SW 9, 27N–1W
KB 1051′

TD 3644′
No cores or tests reported
Perforated and fractured
IPF 135 BOPD
No Tonkawa production

2
ARCO Oil & Gas Co.
2 Fred M. Jones
NE NW SE NW 10, 27N–1W
GL 1000′

TD 2430′
Perforated 2328′–2330′
No treatment reported
IPP 60 BO & 20 BW
Completed 8–3–83
Cumulative production
209,942 BO
1 of 9 wells

3
ARCO Oil & Gas Co.
1 Fred M. Jones
NE SE NW 10, 27N–1W
GL 999′
Intersection B–B′

TD 2430′
Perforated 4/2336′–2338′
No treatment
IPP 41 BO & 259 BW & 83 MCFGD
GOR 2041-1
Completed 1–20–83
Cumulative production
209,942 BO
1 of 9 wells

4
Royal Oil & Gas Corp.
1 Clift
NE NW NE 10, 27N–1W
KB 1009′

TD 2765′
Perforated 8/2349′–2351′
F 7½ BWPH with estimated 3 MMCFG
sqzd, D.O.; Perforated 4/2353′–2354′,
F 7 BBLs fluid/hr with 3–4 MMCFG,
sqzd, D.O. to 2375′, perforated
8/2354′–2356′, hole full of SW, sqzd,
D.O., perforated 8/2350′–2352′;
4/2358′–2359′; F 10 BO & 60 BSW/21 hr,
sqzd, D.O., perforated
4/2352′–2353′
IPF 25 BO and 60 BSW
Completed 3–7–57
Cumulative production
274,268 BO
1 of 2 wells

5
Prime Energy Co.
34–1 Grell
SW SE SW 34, 28N–1W
KB 1019′
Intersection C–C′

TD 3475′
Perforated Cleveland
IPF 40 BO & 640 MCFGPD
Completed 2–15–80
No Tonkawa production

6
Exploration & Development, Inc.
1 Kelle
SW SW NE 27, 28N–1W
KB 1035′

TD 3445′
DST Tonkawa, 2378′–2408′,
open 55 min, GA 1 MMCFGD,
Calc 3 MMCFGD, rec. not available;
ISIP 900 lbs, estimated FSIP 99 lbs,
Perforated 4/2400′–2401′;
Perforated 16/2366′–2370′,
No treatment
IPF 6.8 MMCFGPD
Completed 9–27–66
Cumulative production
33,770 MCF

Figure 26. Stratigraphic cross section *A–A′* for Tonkawa reservoir, Blackwell field study area.

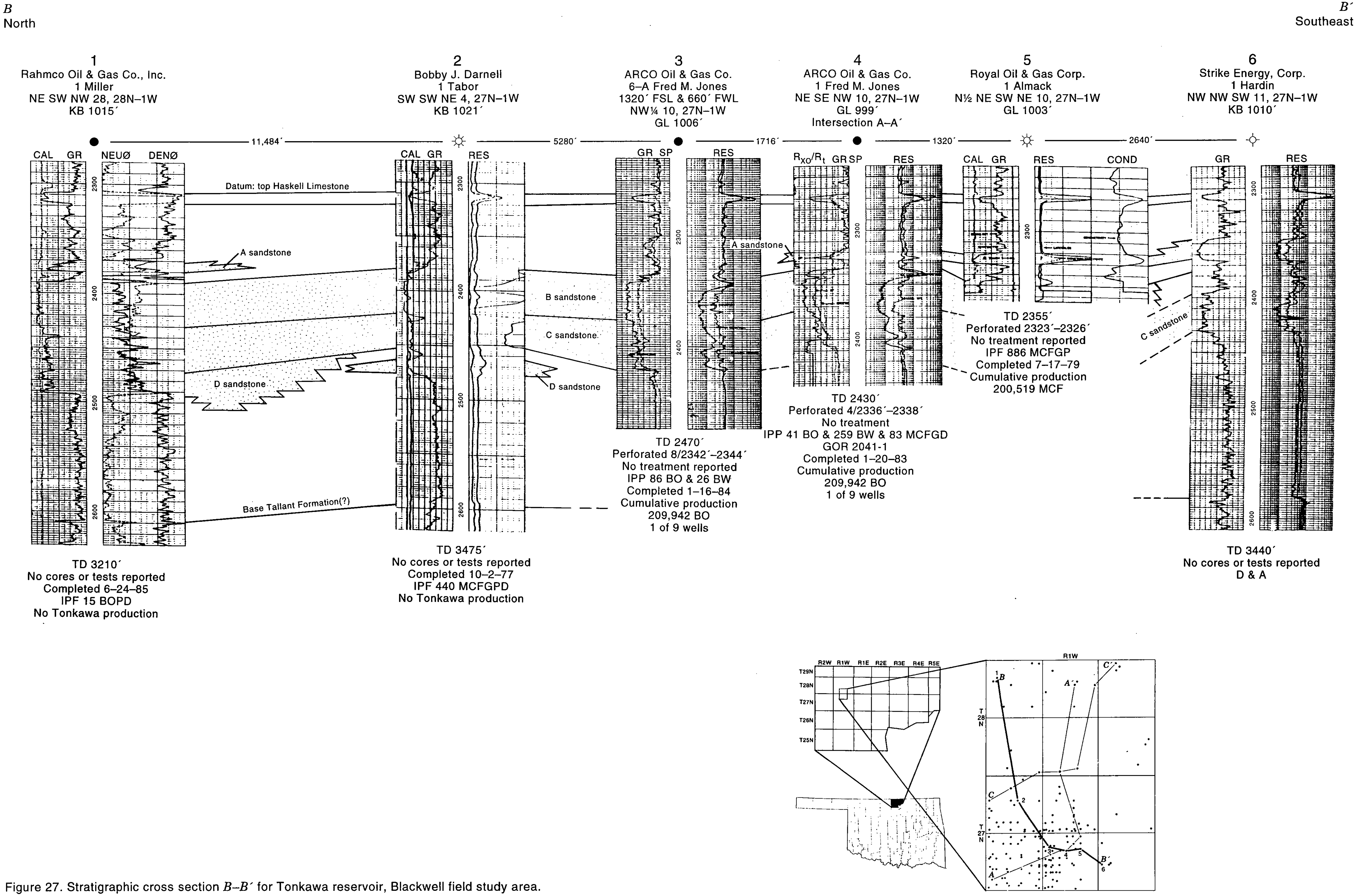
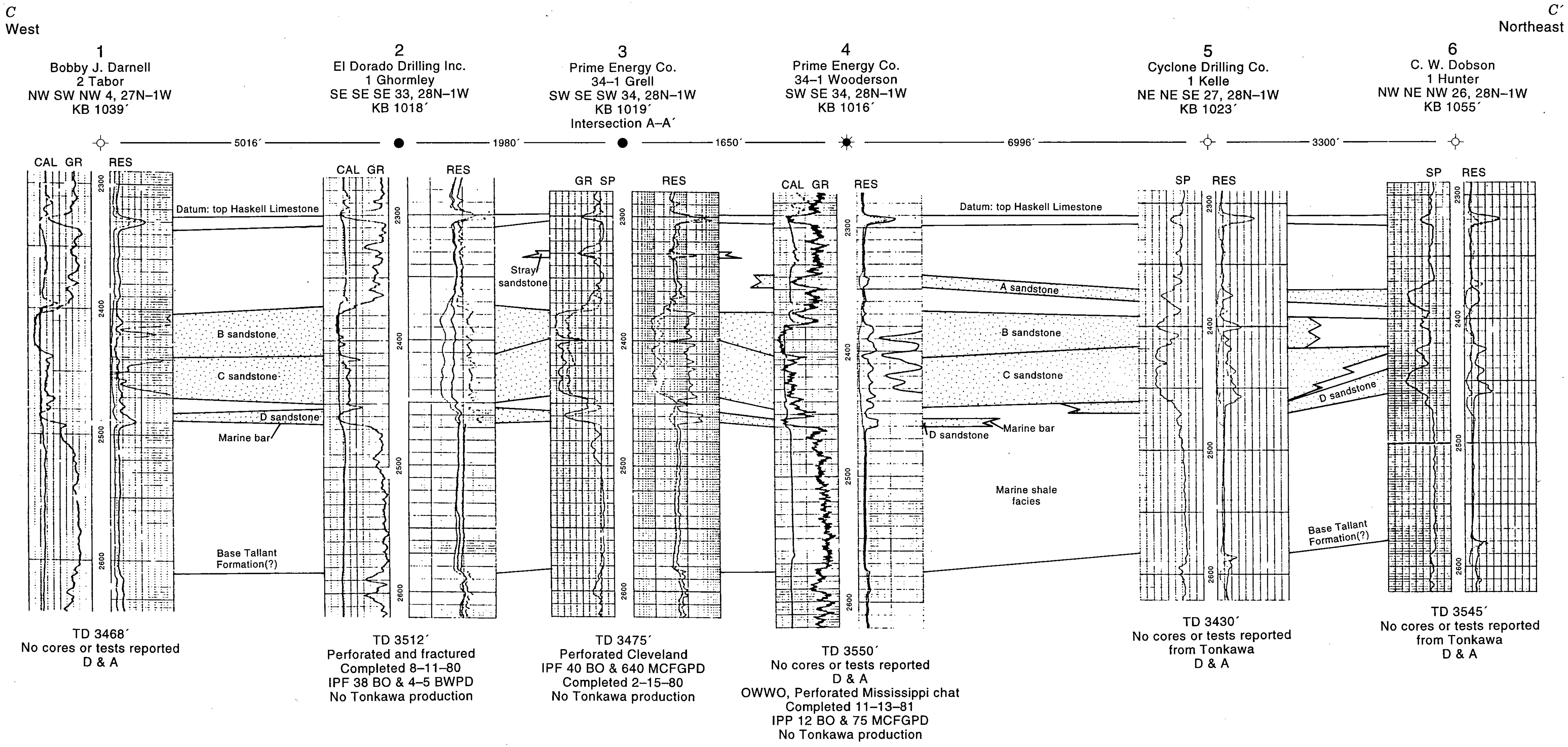


Figure 27. Stratigraphic cross section *B–B′* for Tonkawa reservoir, Blackwell field study area.



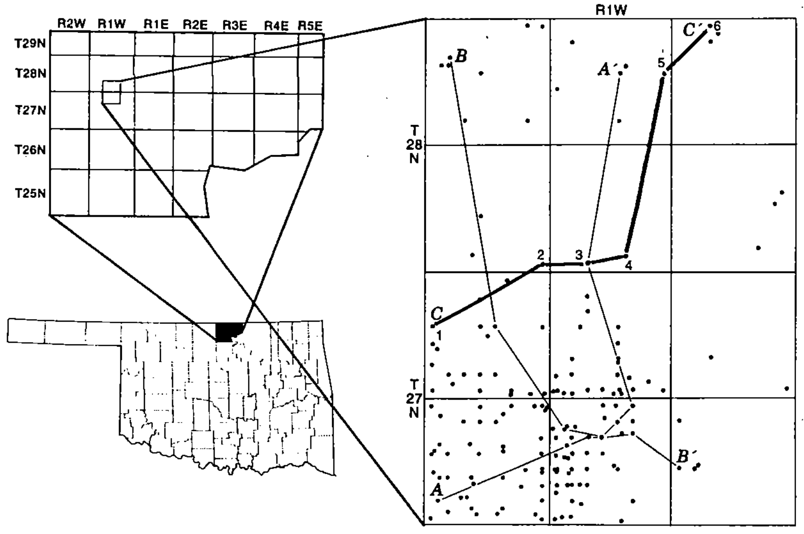


Figure 28. Stratigraphic cross section *C–C′* for Tonkawa reservoir, Blackwell field study area.