SELECTED ATTRIBUTES OF CONFINING BEDS, SELECTED LOCALITIES, NORTH-CENTRAL OKLAHOMA

By

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"By the word of the LORD were the heavens made; and all the host of them by the breath of his mouth. He gathereth the waters of the sea together as an heap: he layeth up the depth in storehouses. Let all the earth fear the LORD: let all the inhabitants of the world stand in awe of him. For he spake, and it was done; he commanded, and it stood fast." Psalms 33.6-9 (KJV)

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CHAPTER I

INTRODUCTION

Statement of Purpose

Safe injection of fluids in the subsurface depends on the thickness, areal extent, and low permeability of continuing units. These properties must be sufficient to prevent migration of injected fluids upward into underground sources of drinking water. Shale probably is the most common confining unit, although it is far from being the only rock capable of acting as such. It is valuable as a confining unit at least partially because of its abundance, ductility and low permeability. However, in areas where fracturing is common either in the injected horizon or in the units surrounding it, questions have arisen regarding the effects of those fractures on shale as a confining unit.

The purpose of this study was to examine fractures and joints either above or below units of shale, in order to test hypotheses about their effects on those shale packages as confining units. In order to do this, data from both surface and subsurface were examined.

Outcrops were chosen that showed obvious evidence of fracturing or jointing in beds of competent rock bounded above or below by shale. Orientations and extents of fractures and joints in competent beds were examined and compared with evidence of fracturing, jointing, or fluid migration within shales adjacent to them in order to test the following hypotheses: (1) Joints in competent beds are unrelated to fractures or joints within shales. (2) Joints in competent beds either end at the bed boundary or die out in a relatively short distance within shale. If shales adjacent to fractured or jointed competent rocks are largely unaffected by fractures or joints, then it might be postulated that the function of those shales as confining units has not been compromised.

The Burbank Sandstone [1] (Figure 1) and the shale directly above are subject to fracturing by fluid injection (Trantham and others, 1980). Rocks at the surface are jointed systematically (Hagen, 1972). This information has prompted certain important questions: (1) Are joints and fractures at the surface contiguous with, related to, or unrelated to joints and fractures in the subsurface? (2) Are potential confining units compromised by such joints and fractures? (3) Is it possible to develop a relatively simple method of synthesizing information from the surface

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[1] "Burbank Sandstone" refers to the reservoir at Burbank Field (Figure 1). The name is informal, but is commonly used in regard to subsurface geology -- as are other names shown in Figure 1. In this report lithologic terms are capitalized, for clarity, although this practice is not in keeping with the Code of Stratigraphic Nomenclature (North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: Amer. Assoc. of Petroleum Geologists Bull., v. 67, no. 5, pp. 841-875.).

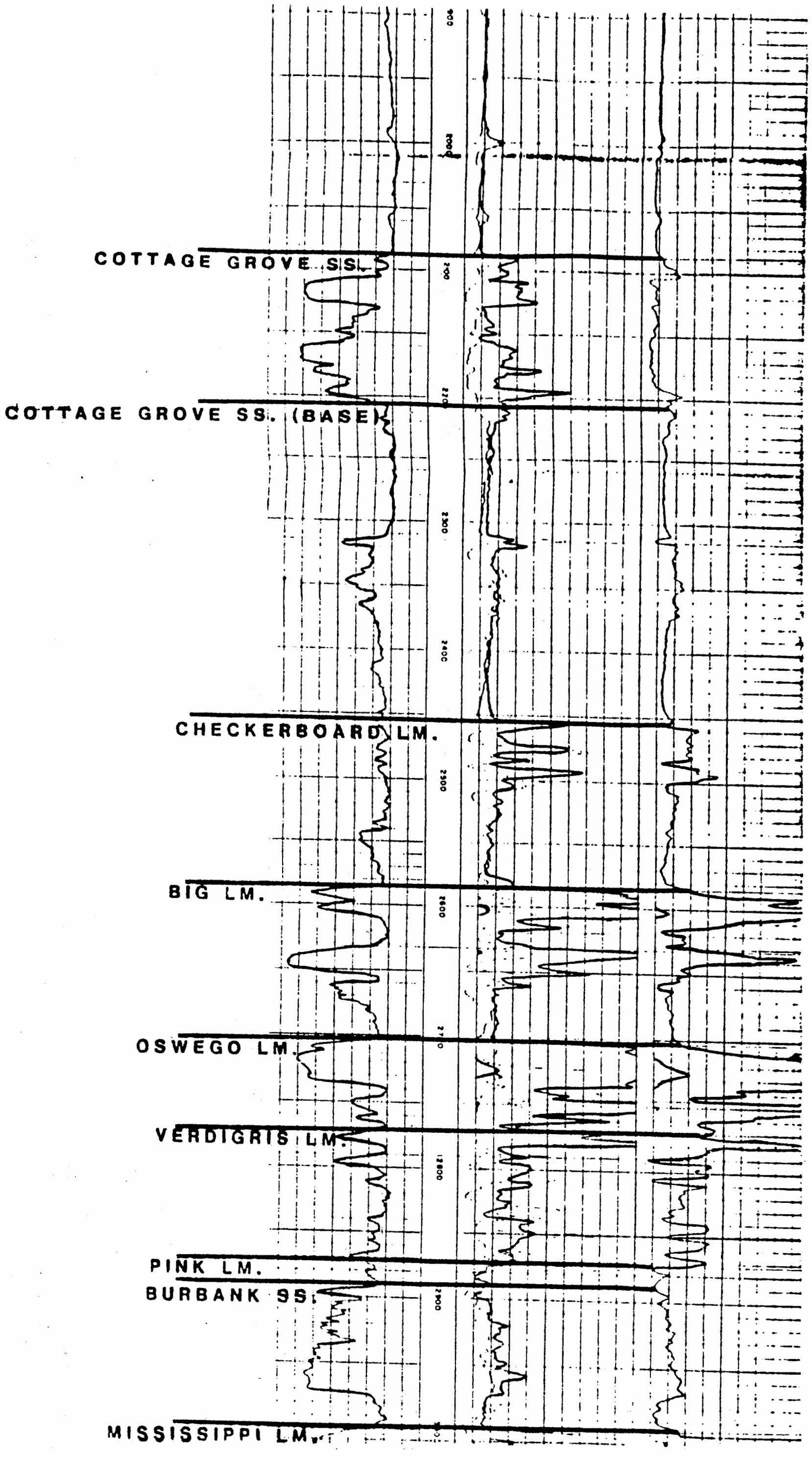


Figure 1: Type electric log, Burbank Field. All strata shown above "Mississippi Lime" are Pennsylvanian.

and subsurface to estimate the potential sensitivity of an area for potential migration through fractures into shallow sources of drinking water?

In an attempt to answer these questions, available wireline logs were examined and a computer data base was developed of the Cottage Grove stratigraphic interval. With the aid of this data base, both computer and manual techniques were used to develop maps that show various relationships between the confining interval and the potential injection horizon. Information from the above sources was used to develop a map of the area showing "sensitivity" to fluid injection.

Location of the Study Area

Burbank Oil Field, in T. 25-27 N., R. 5 and 6 E., Osage and Kay Counties, Oklahoma (Figures 2, 3) was chosen as an area of study because the reservoir is fractured. Within this field most wireline logs are of wells in Townships 25 and 26 North, Range 6 East; work was concentrated in this area. The Cottage Grove interval was chosen for more study because it is has been used injection of oil-field brines.

Geologic Setting

Burbank Field is the western flank of the Ozark Dome (Figure 3). The Burbank sand occurs as sand lenses of various thicknesses and lengths. These lenses are generally longer than they are wide and sometimes referred to as "shoestring" sands (Figure 3). Trantham and others (1980)

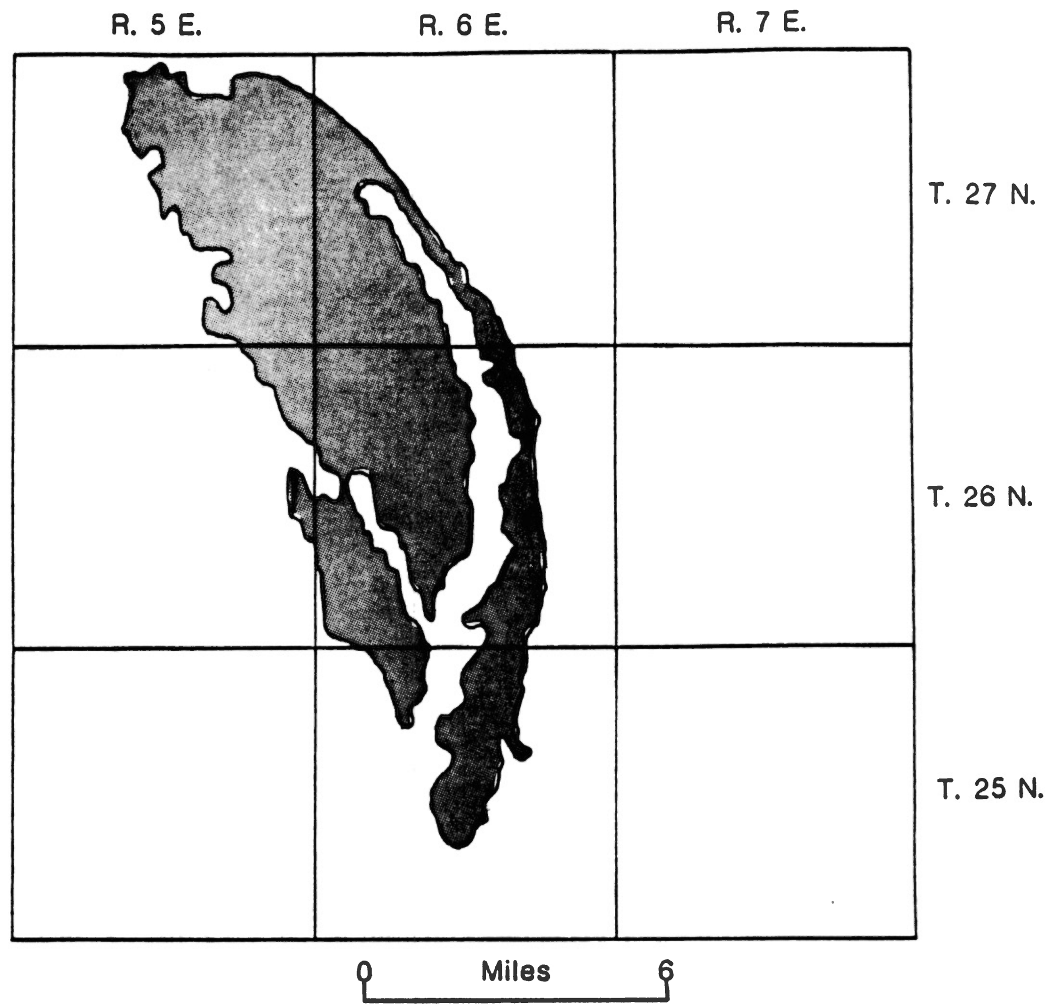


Figure 2: General configuration of Burbank Field. All but the northwesternmost part of the oil field is in Osage County, Oklahoma. The Burbank Sandstone dips southwestward; the arcuate eastern boundary of the field is the up-dip limit of permeable sandstone. The reservoir is a multistoried, multilateral, alluvial-deltaic channel-fill reservoir. In general, trends of the more permeable sandstone "stringers" follow the configuration of the eastern border of the field.

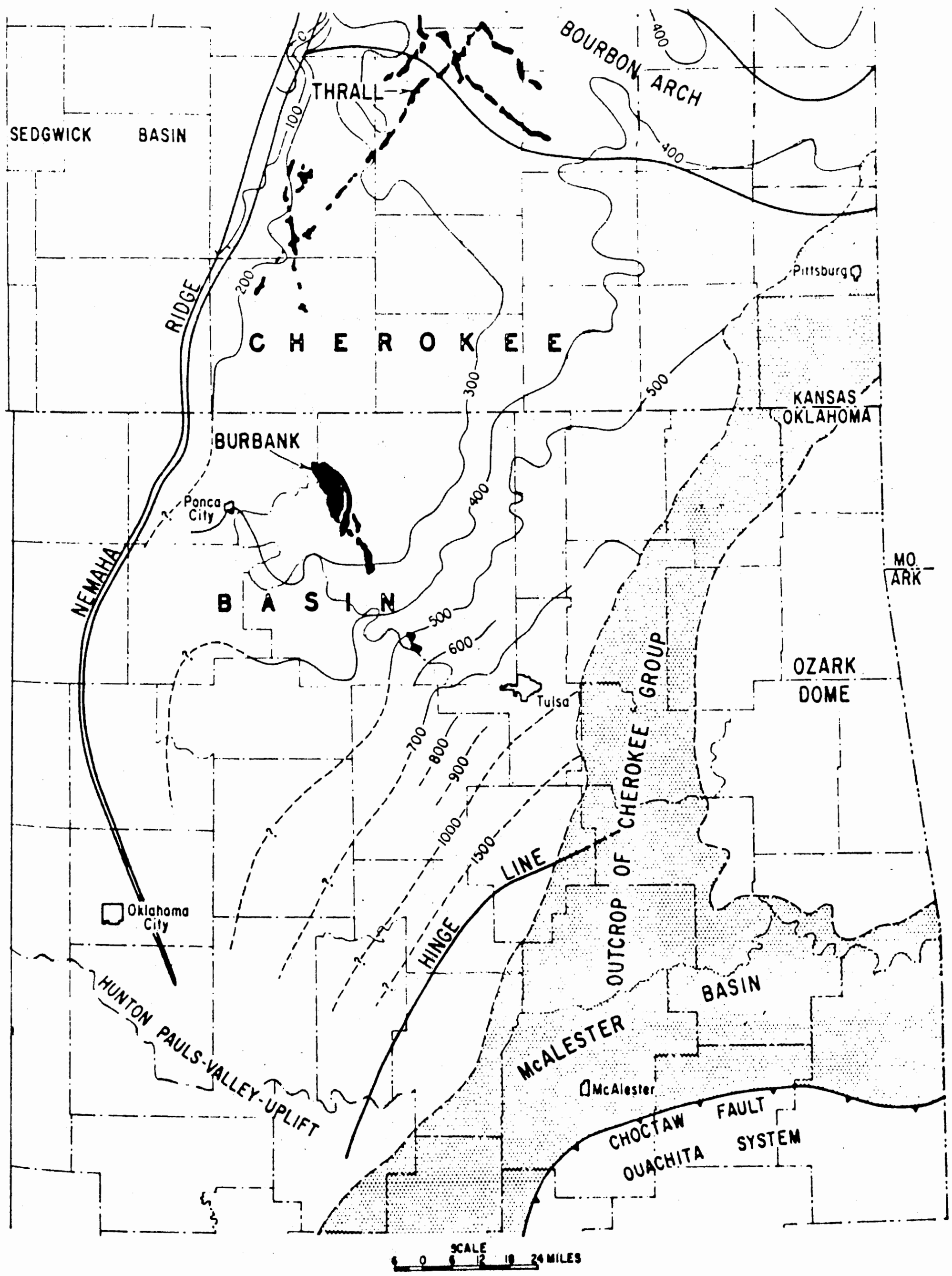


Figure 3: Cherokee Basin of northeastern Oklahoma and southeastern Kansas. Numerous so-called "shoestring-sand" oil fields are shown, of which Burbank Field is the largest. (After Baker, 1962.)

observed rock from cores that showed well-developed cross-bedding, climbing ripples, strongly contorted bedding, and other sedimentary structures indicative of fluvial origin. They concluded that the sand was deposited in fluvial channels that cut into each other both laterally and vertically. Wireline logs examined in the present work also support this conclusion.

Stratigraphy

Rocks at the Surface

Rocks exposed at the surface in Osage County are Pennsylvanian and Permian. In the Burbank area Pennsylvanian beds range upward from the Pony Creek Shale to the Brownville Limestone. Permian rocks exposed in this area include units from the base of the Admire Group to the Blue Rapids Shale of the Council Grove Group (Plate 1). In rocks at the surface, fractures and lineaments are numerous (Plate 2). For a more detailed description of surface stratigraphy of the area the reader is referred to Beckwith (1928), Bowen (1922), and Hagen (1972).

Rocks in the Subsurface

The Burbank Sandstone is overlain and underlain by shales of the Pennsylvanian "Cherokee Group." The group includes rock units "from the base of the Ft. Scott Limestone to the sub-Pennsylvanian unconformity on the Mississippian 'chat'" (Baker, 1962, p. 1625). The Burbank

Sandstone is fine grained and siliceous (Beckwith, 1928). It ranges in thickness from 0 to over 100 feet (Plate 5).

Below the sub-Pennsylvanian unconformity, the "Mississippi Lime" is a "series of hard, semicrystalline, blue limestone beds, divided by more shaly or chalky, softer members," (Sands, 1927, p. 1048). Chattanooga Shale lies beneath the Mississippi Lime, with "Wilcox Sandstone" underlying the shale. A thick section of siliceous limestone separates the base of Wilcox sand from granite basement rock (Sands, 1927).

Structural Geology

The dip of the beds in the Burbank area is about 40 to 50 feet to the mile in a westerly direction (Plate 3). Bowen (1922) describes various anticlines and domes in T. 25 and 26 N., R. 5 and 6 E. with closures ranging from near zero to about 30 feet. These structures may be the result of differential compaction of sediments as described by Gay (1989).

Fractures are common in this area. They are generally east-trending and almost vertical (Hagen, 1972; Trantham and others, 1980). Trantham and others (1980, p. 1649) described the fractures as "incipient parting planes (joints) that open easily when water is injected, even at moderate rates."

Petroleum Occurrence

Petroleum development in Osage County progressed from east to west. Burbank Oil Field in Kay and Osage Counties, Oklahoma (Figure 2), is a large stratigraphic trap where the "Burbank" Sandstone is encased in shale with hydrocarbons trapped against the updip limit of reservoir rock. In 1920, Marland Oil Company drilled its first well in the Burbank Field, in Sec. 36, T. 27 N., R. 5 E., and Carter Oil Company drilled its first in Sec. 9, T. 26 N., R. 6 E., thus beginning the development of the field (Beckwith, 1928). Since 1920, Burbank Field has undergone several stages of development, including secondary and tertiary enhanced-oil-recovery projects. Oil is produced from three or four zones within the Burbank.

Oil seems to have migrated from the northwestern portion of the field toward the eastern and southeastern portions. In the extreme northern end of the field, gas is structurally below oil (Sands, 1927). Oil migrated eastward, accumulating in more porous portions of the reservoir until it reached the updip limit at the east edge of the field (Sands, 1927). Oil production in Burbank reservoir is only secondarily related to structural condition. The highest structural areas of the field are among the less productive areas.

Hagen (1972) conducted an extensive study of trends of subsurface fractures and of joints in bedrock at the surface; he also mapped surface geology of the eastern portion of Burbank Field (Plate 1). The research produced strong evidence of systematic fractures within the Burbank Sandstone reservoir and in strata immediately above the reservoir. When the reservoir was pressured by water-flooding, these fractures opened and served as conduits for migration of fluids from one well to another. Based on interpretation of data from the field Hagen (1972) indicated that overpressuring of the Burbank reservoir during secondary recovery was primarily responsible for opening of the existing zones of weakness in and above the Burbank interval. Hagen's (1972) access to data from oil-company files, normally unavailable for public use, separates his methods from methods employed in the study at hand.

Although the work reported on herein primarily was that of the author, a portion of another geologist's work was included for the purpose of supporting the author's hand-contoured maps in comparison with those generated by computer. J. O. Puckette used standard subsurface-mapping techniques to examine thicknesses, structural geology and isopotential data of the Burbank reservoir, to test the working hypothesis that potential fracture-trends would be revealed (Plates 4 and 5). In addition, satellite imagery and topographic-map data were used to compare lineaments in rocks at the surface (Plate 2) with results of some previous studies of Burbank Field.

CHAPTER II

SUMMARY REVIEW OF LITERATURE

Early Ideas About Migration of Petroleum

Howell (1934) reported that by as early as 1844 many oil seepages were noticed as being on hills near crests of anticlines; at the time this correlation was considered not to be of great importance. In 1861 T. S. Hunt made the first clear declaration of the structural or anticlinal theory (Howell, 1934). Fissures or faults were considered as necessary conduits for migration, and as reservoirs for oil. By 1865, E. W. Evans had discussed the mode of gravitational separation of gas, oil, and water in reservoirs (Howell, 1934), and shale was recognized as a trapping agent. By 1875, the anticlinal (or structural) theory was accepted by most geologists.

Migration and Entrapment

Gussow (1954) described some theoretical fundamentals for entrapment of oil and gas, based upon the structural theory (Figure 4). The basic assumption was that oil and gas migrate across large distances from a source basin to the final trapping location; local source beds do not provide enough oil or gas to be of economic importance.

Gussow (1954) explained the occurrence of gas in traps downdip from oil traps. He proposed that oil formed in source beds is expelled by "filter pressing." Petroleum migrates from source beds into adjacent carrier or reservoir beds, due to differential pressures, porosities and permeabilities. As oil and gas enter a trap, gas rises above oil to the trapping surface. Oil fills the reservoir to the spill point. If the amount of oil exceeds the volume of the reservoir, oil spills out and migrates updip to the next higher trapping locality, leaving gas, or oil and gas in the filled reservoir. As summarized by Gussow (1954) gas may be trapped at a lower elevation than oil (Figure 4). If the initial reservoir is too small to contain all available gas, then additional gas and oil will migrate updip to the next trap and the sequence will begin again. If migrating gas encounters a trap filled with oil, it will displace oil downward toward the spill point of the trap spilling some or all from the trap until either all of the gas is contained in the trap along with some remaining oil, or the trap is completely full of gas. Displaced oil and any excess amount of gas will migrate from the trap updip to the next higher trapping location where again, the sequence will repeat itself. Because of its higher density, oil does not displace gas from a trap. The principle "rule" of this sequence is that a trap filled with gas will not accept any oil, but a trap filled with oil is still a possible trap for gas.

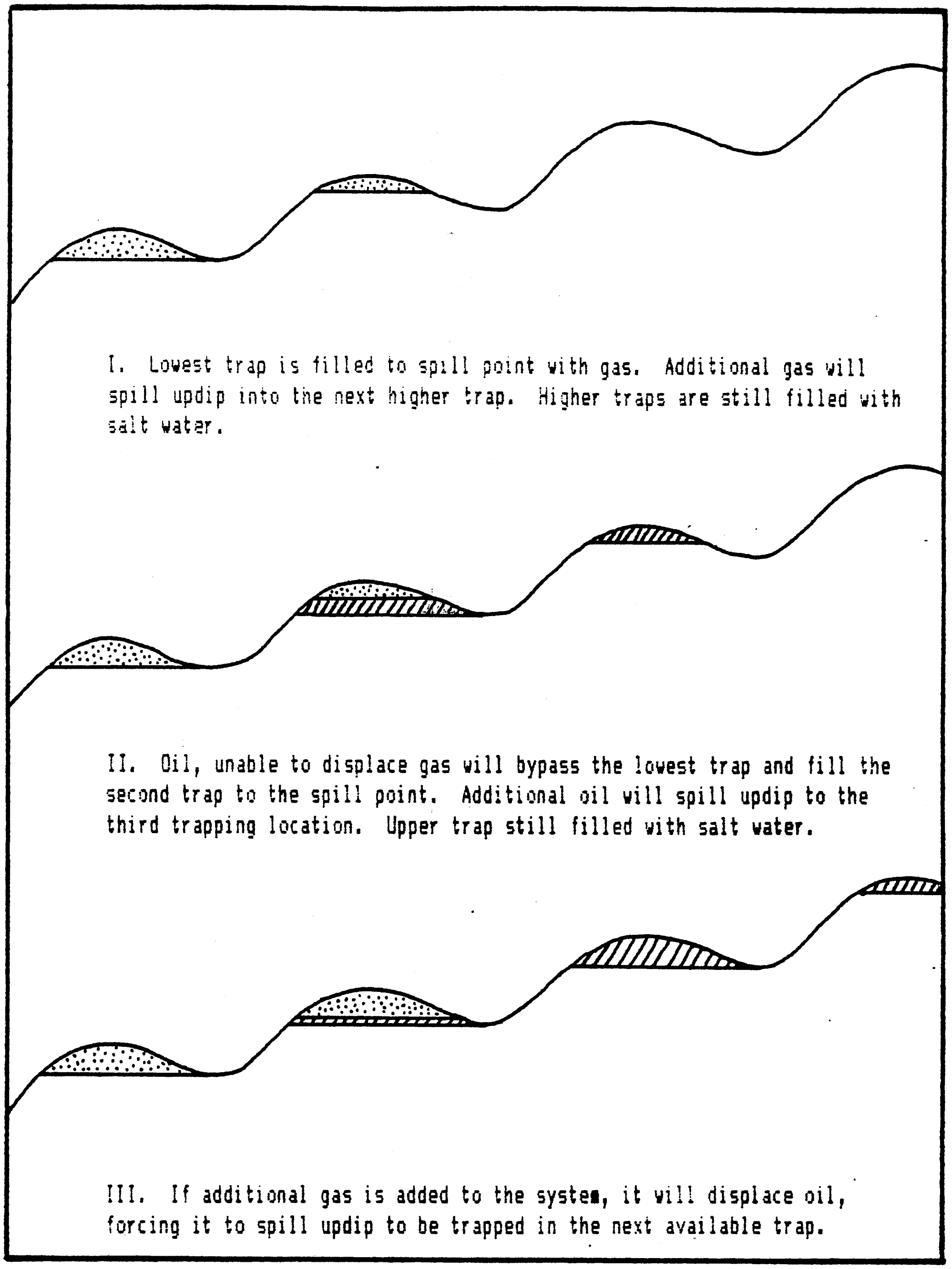


Figure 4: Three stages in the migration and accumulation of oil and gas in interconnected reservoirs showing how oil can be positioned structurally higher than gas. The curved lines represent the upper trapping surfaces of the reservoirs. The stippled pattern represents gas. The diagonally striped pattern signifies oil and the blank pattern represents salt water. (After Gussow, 1954.)

Migration of oil can be broken into three stages; primary migration, secondary migration, and remigration. Primary migration occurs as oil is expelled from source beds into adjacent carrier or reservoir beds as small finely dispersed droplets (Gussow, 1954). Droplets form globules, which in turn connect into stringers of oil. Secondary migration usually occurs as relatively long thin stringers of oil migrate through carrier beds (Gussow, 1954). See also Figures 5 and 6. Figure 5 depicts two stringers of oil that are long enough for migration to occur. Stringer "B" has migrated to a contact with finer grained rock, which has higher capillary pressure and has halted migration. Figure 6 shows a stringer of oil globules as it might appear through uniform spherical grains. In order for secondary migration to occur, dips of beds must be great enough to overcome frictional drag upon oil induced by the carrier beds it is passing through (Gussow, 1954). "Remigration" refers to migration of oil from a trap due to a new episode of regional tilting, decantation, or expansion of a gas cap (Gussow, 1954, p. 822).

Gussow (1954) discussed hydrostatic entrapment of oil and gas, but Hubbert (1953) dealt with hydrodynamic conditions for entrapment of petroleum. Under ideal hydrostatic conditions the forces acting to propel oil and gas act strictly vertically and the various fluid contacts are horizontal. However, under hydrodynamic conditions the forces acting to propel petroleum would do so in some

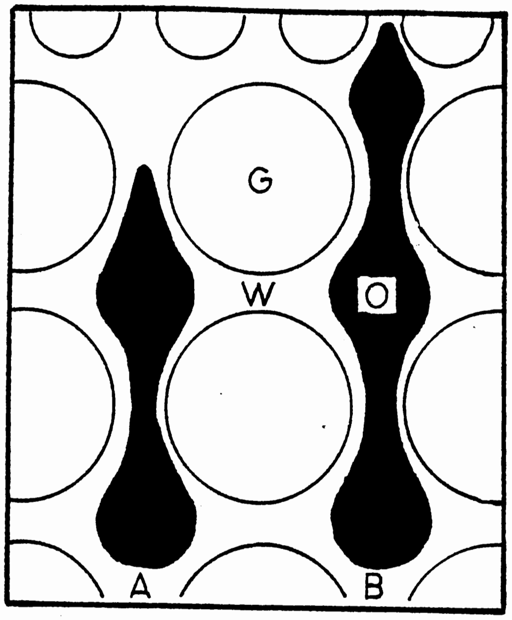


Figure 5: Migration of oil into "tight" rock. Stringer "A" is of critical height for upward migration. Stringer "B" represents a height of oil column trapped by the decrease in grain size. Letters G, W, and O, represent grain, water, and oil, respectively. (After Berg, 1975.)

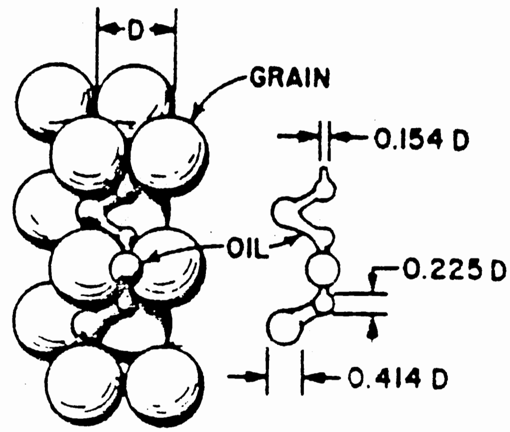


Figure 6: Oil globules connected through pores between uniform spherical grains packed in a rhombohedral arrangement. "D" is grain diameter; porosity is 26 percent. (After Berg, 1975.)

direction other than vertical. In addition, fluid contacts could be tilted downward in direction of flow of water, and the fluids would not lie directly one above the other but would be separated, to one degree or another (Hubbert, 1953).

Hubbert (1953) stated that if ground water is of constant density and is in motion in one region, it will also be in motion in all areas that are not isolated by impermeable barriers. Because water that enters the ground is fresh, wherever fresh or brackish water is in the subsurface, it may be presumed to be in motion. Saline waters may be in motion. Gussow (1954) wrote of "filter pressing" as a method of removing oil from source shales. Hubbert credits capillary pressure as the mechanism by which filter pressing operates. Smith (1966, p. 363) defined capillary pressure as "the differential pressure between the hydrocarbons and the water at any level in the reservoir." Hubbert showed that capillary pressure for oil in shale is on the order of ten times greater than capillary pressure of oil in sandstone. This explains why a shale-sandstone interface will act to conduct oil only in a direction from shale and into sandstone, and will act as an impermeable barrier to oil that is in sand. However, this interface will not be a permeability barrier to water traveling in either direction (Hubbert, 1953, Figure 7).

Because in the hydrodynamic case the oil-water or gas-water interface will not be level but will be tilted to some

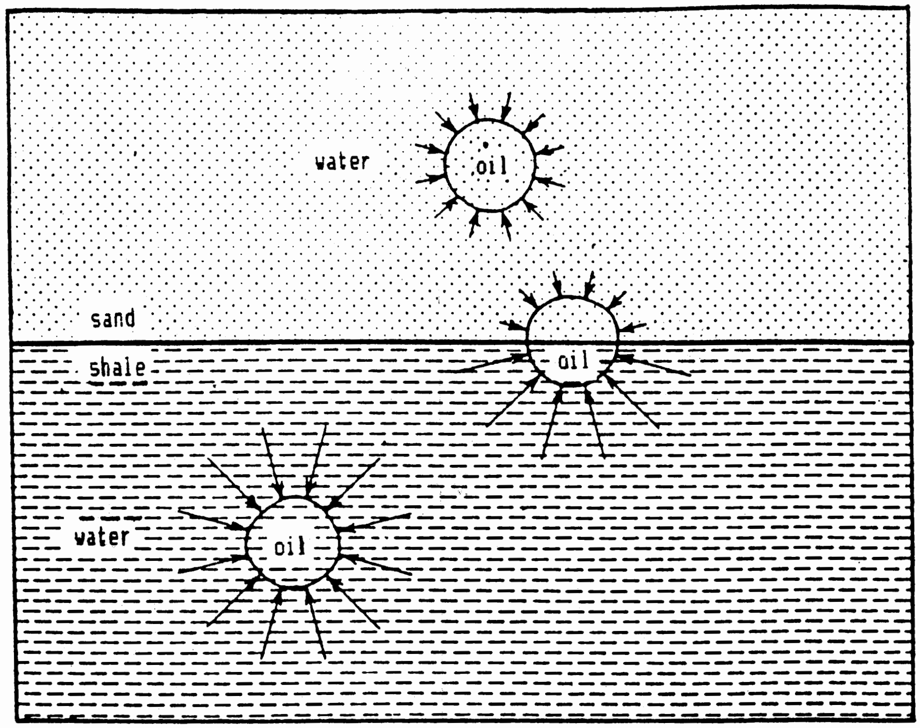


Figure 7: Diagram showing how capillary pressure of water against oil in preferentially water-wet environment facilitates passage of oil globules from fine- to coarse-textured rocks. Arrows represent the relative pressures acting against the oil droplets. (After Hubbert, 1953.)

degree, traps for oil and gas may not coincide with each other, but may show some amount of overlap (Hubbert, 1953). Also, traps may not lie exactly where one might expect based upon positions of structural contours, but may be offset by direction and magnitude of water flow.

Once oil has reached carrier beds, buoyancy seems to be the main force involved in migration (Schowalter, 1979). Capillary pressure acts as the force resistant to migration. Capillary pressure is governed by the radius of pore throats of the rock, the hydrocarbon-water interfacial tension, and wettability of the rock (Schowalter, 1979; Downey, 1984). As radii of pore throats decrease, the hydrocarbon-water interfacial tension increases, wettability of the rock decreases, and the capillary pressure increases. In a hydrodynamic system water alters the relative buoyant force of petroleum and capacity of the trap. If water is moving downward, the relative buoyant force of the hydrocarbon column will be reduced and sealing capacity of the trap will be increased. However, if water is moving upward toward the sealing surface the buoyant force of hydrocarbons will be increased and trapping capacity of the seal will be decreased.

Petroleum will enter pores only when a pressure exists that is great enough to displace water in those pores. Schowalter (1979), Berg (1975), and Smith (1966) defined "displacement pressure" similarly. Schowalter (1979) used the above term and Berg (1975) used the term "injection pressure" to refer to the minimal pressure required to displace water and replace it with petroleum. Smith (1966) defined displacement pressure more specifically as the minimal pressure required to displace water in such a way that a continuous filament of oil is extended through the rock within the largest interconnecting water-saturated pore throats of that rock. For different rocks generalized estimates have been made of the oil and gas necessary to accumulate displacement pressure sufficient for secondary migration. Schowalter (1979) concluded that for most rock types, migration may occur when a "nonwetting phase saturation" reaches approximately 10 percent. Aschenbrenner and Ashauer (1960) estimated critical oil columns needed for migration as ranging from 1 to 10 feet for sandstones and 3 to 5 feet for carbonate reservoirs.

Schowalter (1979, p. 755) stated that "if geologic conditions remain constant oil or gas will remain permanently trapped and there will be no gradual leakage of bulk-phase hydrocarbons out of the trap." It would appear the conditional phrase "if geologic conditions remain constant" implies the reasoning behind the belief of many geologists that no matter how effective a sealing surface in a trap may appear, and whether or not that sealing surface is formed by a fault, with time petroleum will leak from the trap. According to Schowalter (1979, p. 756) "for snap-off or collapse in an oil or gas filament migrating through a rock to occur, the capillary pressure must be reduced to approximately one-half of the displacement pressure." From this one might infer that if a trap along a migration path were to leak, it should reseal itself after about one-half of the originally trapped hydrocarbons have escaped updip. Further, once a trap has resealed itself, it could refill.

Hydrocarbon Seals

In the study of integrity of confining beds in waterflood injection projects, knowledge of thickness and lateral extent of sealing shale beds is of primary importance. Thicknesses of shale may be measured or inferred from wireline logs and/or cores but direct measurement of lateral extents of shales is not possible. Traditionally, shale is usually thought of as the seal for most traps. Other rock types that commonly form seals are evaporites, fine-grained clastic rocks and organic-rich rocks (Downey, 1984). Whereas these rock types form the most common types of seals, practically any rock type may serve as a seal under certain circumstances.

As mentioned above, capillary pressure is the mechanism for both expulsion of oil from source rock and entrapment of oil in the reservoir. If capillary pressure exceeds displacement pressure, the pressure necessary to force oil into the largest interconnected pores of a preferentially-water-wet rock (Smith, 1966), hydrocarbons will invade the rock and no trap will be formed. A trap is formed only where capillary pressure is less than displacement pressure, whether that pressure differential exists at a boundary between two different lithologies, at a fault boundary, or even at some boundary within similar rock types (Smith, 1966). Further, it has been shown that capillary pressure or sealing capacity of rock increases as maximum pore throat radius decreases, as wettability of the rock decreases, and as hydrocarbon-water interfacial tension decreases (Downey, 1984). The relationship of these factors to capillary pressure (Pd) may be shown by the equation:

$$Pd = (2 * g * \cos W)/ R$$

where g represents hydrocarbon-water interfacial tension, W symbolizes wettability, and R stands for the maximum pore throat radius. Downey (1984) shows an equation similar to the above with only slightly different use of symbols.

Based upon the above equation it can be shown theoretically that a few inches of clayey shale are sufficient to seal column of hydrocarbons of large thickness compared to the thickness of the shale layer. Unfortunately, a shale layer only a few inches thick is unlikely to be as extensive and unbroken as would be required to form an effective seal (Downey, 1984). The benefit of a thick seal then, is not necessarily that it can withstand more pressure from hydrocarbons below, but it is more likely to cover a large area and to have a lower potential for vertical breaches.

In many localities rock that is not economically productive of petroleum is referred to as a seal when in fact it is not (Downey, 1984). In areas where facies changes are gradual, petroleum may invade porous and permeable reservoir rock and move upward into rock that is less porous and permeable; however this rock may have porosity and permeability insufficient for commercial recovery of oil and gas. The rock should not be referred to as a seal, the difference being that a reservoir is a "commercial term, whose definition depends on the economics of the moment and a seal is a technical term and does not vary with the price of oil" (Downey, 1984, p. 1757).

Fundamental Ideas about Joints and Fractures

Billings (1972, p. 140) described joints as "relatively smooth fractures." Hobbs and others (1976, p. 289) defined joints by referring to them as rock displacements in which "the component of displacement parallel to the structure is zero (or too small to be apparent to the unaided eye)." Ramsay and Huber (1983, p. 235) described joints as "very fine cracks which develop generally as a result of crustal uplift and the associated release of elastically stored stresses." Pollard and Aydin (1988, p. 1286) proposed that the definition of joints be restricted to "those fractures with field evidence for dominantly opening displacements." As might be inferred from the above, joints can be considered as a special type of fracture. Joints are distinguished from faults by their lack of shear displacement, and by characteristic surface textures (Pollard and Aydin, 1988). In places where characteristic surface textures are absent, Pollard and Aydin (1988) suggest that features should be referred to simply as fractures, rather than joints.

Joints may be hairline cracks, open fissures, or fissures that are coated or filled with some type of secondary mineral. Joints may be related to folding or other types of rock deformation, or to erosional or stress release-processes.

Fracture (or joint) density is "the spacing between parallel fractures, corrected for effects of thickness of the fractured bed" (Narr and Lerche, 1984, p. 637). As implied here, density can be related to thickness of the fractured bed of rock. According to Narr and Lerche (1984), fracture density varies linearly in inverse proportion to bed thickness (see also, Nelson, 1985). Other factors that might influence spacing of joints include rock type, porosity, grain size, nearness to folds and faults, and burial history (Narr and Lerche, 1984, p. 637).

Joints seem to have been initiated at flaws (as fossils, inclusions, pores, microcracks, etc.) that altered stress in such a way that local tensile stress exceeded tensile strength of the rock (Pollard and Aydin, 1988). Once a joint has been initiated, it propagates as long as tensile stress near the joint tip is greater than rock tensile strength. Joints may develop with velocity ranging from very rapid (near elastic wave speed) to very slow (less than 1 cm/s), depending upon available energy (Pollard and Aydin, 1988).

Effects of Faults on Seals

In each petroleum trap a set of specific sealing problems is inherent (Downey, 1984). For instance, in an anticlinal or domal structure one formation may form top and lateral seals of the reservoir. Unfortunately, tectonic forces that formed the reservoir may have fractured the seal, if the rock was not ductile enough to bend without forming extension fractures. Downey (1984) suggested that through a long time, even a seemingly insignificant fracture that contains interconnected open spaces may act as a conduit for a large amount of oil. In fact, the amount of oil and the rate of loss through such a fracture is more a function of permeability of the reservoir than of size of opening of the fracture (Downey, 1984). Bosscher and others (1988) studied fine-grained soils with large clay contents. They determined that joint permeability and orientation, even where joints are discontinuous, are variables important in determining the amount of increase of permeability in a low-permeability matrix (Bosscher and others, 1988). By a series of experiments they showed that "at high joint permeabilities, the model flow is limited by the matrix permeability," which substantiated Downey's statements (Bosscher and others, 1988, p. 1328). This seems to hold, except where the angle between joint and direction of fluid-flow is large. They also showed that the closer the orientation of a joint to direction of fluid flow, the higher the effective permeability. They found that the critical angle at which flow was increased significantly apparently is between 20 and 30 degrees (Bosscher and others, 1988).

Fault entrapment of oil is a function of two properties, neither of which specifically is the type of rock bounding the fault. These two properties are (1) capillary pressure, and (2) displacement pressure of reservoir rock and boundary rock on the opposite side of the (Smith, 1966, p. 363). If displacement pressure of rock opposite the reservoir is greater than capillary pressure of the reservoir, the fault will act as a seal (Smith, 1966). The most common occurrence of this circumstance is fault-contact of sandstone and shale (shale having the larger displacement pressure). Even sandstone with a higher displacement pressure than the reservoir can be the trapping boundary. Additionally, if fault-zone material has displacement pressure greater than capillary pressure of the reservoir, it will be seal, regardless of displacement pressure of rock across the fault from the reservoir (Smith, 1966).

In contrast, if fault zone material has displacement pressure less than that of reservoir rock, or if it is composed of open, interconnected fractures it will be nonsealing, regardless of displacement pressure of rock across the fault from the reservoir (Smith, 1966). Oil and gas will migrate up the fault. Further, in certain hydrostatic cases, a fault may be a seal with respect to petroleum and not a seal with respect to water (Smith, 1966). The converse is not necessarily true. Also, a fault that may be shown to be a seal for a certain petroleum column cannot be assumed to be a seal for any greatly thicker column (Smith, 1980). On the other hand, Smith (1980, 1966) pointed out that a fault that is not acting as a seal may begin to act as a seal when thickness of the hydrocarbon column is reduced by production (Figures 8 and 9).

Allan (1989) developed a model relating hydrocarbon migration and entrapment to faults, based on the assumption that faults acted neither as seals nor conduits. Allan (1989) showed that juxtaposition of units on either side of a fault would determine the presence of absence of a seal. If permeable units are juxtaposed on opposite sides of a fault, then hydrocarbons may migrate upward across the fault from one unit to the next (Allan, 1989). If permeable units lie both across from and beneath thick sections of impermeable units, then a seal might be expected.

Smith (1980) discussed various postulated causes of sealing faults. Perhaps the most common cause of sealing is juxtaposition of two units of differing capillary pressure (such as sandstone next to shale). Another possible cause is cementation of fractures in fault zones and of porous fault-zone material by secondary minerals from subsurface waters (Smith, 1980, p. 168). In some localities, fault gouge is known to serve as a sealing material even without secondary cementation. Still another seal may be "soft shale" coated along a fault plane. Shale between two sandstone bodies may not be faulted as early as the sandstone but first may become highly deformed (Smith, 1980). As deformation continues it may be faulted, and a portion of the shale may become greatly attenuated, positioned between two sandstones and acting as a fault-plane-filling seal (Figure 10). Other seals may be cataclastic gouge, mineral deposits, or impregnations of asphalt or tar (Harding and Tuminas, 1988, p. 738).

Several factors may increase or decrease leakage up a fault, including permeable gouge, fractures, and fault rejuvenation (Harding and Tuminas, 1988, p. 743). A smear-gouge with relatively high sand content might be permeable. Harding and Tuminas (1988) concluded that if faulted rocks are young or relatively unlithified they are likely to be deformed in ductile fashion, resulting in enhancement of the shear gouge and better seals. They also state that older, more lithified and more brittle rocks tend to produce cataclastic gouge and better seals. Open interconnected

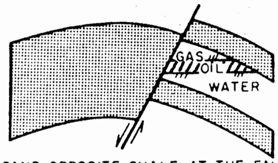
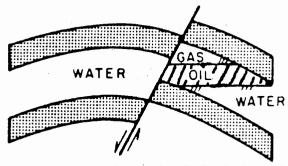
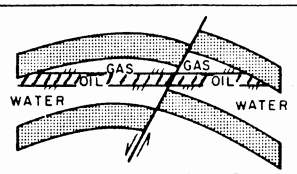
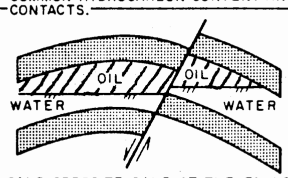
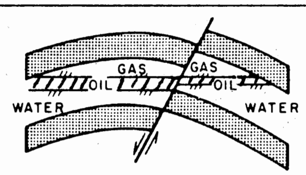
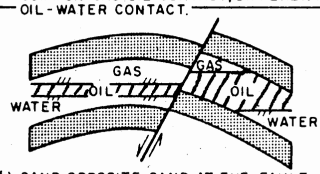
HYPOTHETICAL SITUATION	ANALYSIS OF FAULT SEAL	
	VERTICAL MIGRATION	LATERAL MIGRATION
 (a) SAND OPPOSITE SHALE AT THE FAULT. HYDROCARBONS JUXTAPOSED WITH SHALE.	SEALING	SEALING RESERVOIR BOUNDARY MATERIAL MAY BE THE SHALE FORMATION OR FAULT ZONE MATERIAL.
 (b) SAND OPPOSITE SAND AT THE FAULT. HYDROCARBONS JUXTAPOSED WITH WATER.	SEALING	SEALING SEAL MAY BE DUE TO A DIFFERENCE IN DISPLACEMENT PRESSURES OF THE SANDS OR TO FAULT ZONE MATERIAL WITH A DISPLACEMENT PRESSURE GREATER THAN THAT OF THE SANDS.
 (c) SAND OPPOSITE SAND AT THE FAULT. COMMON HYDROCARBON CONTENT AND CONTACTS.	SEALING	NONSEALING POSSIBILITY IS REMOTE THAT FAULT IS SEALING AND THE RESERVOIRS OF DIFFERENT CAPACITY HAVE BEEN FILLED TO EXACTLY THE SAME LEVEL BY MIGRATING HYDROCARBONS.
 (d) SAND OPPOSITE SAND AT THE FAULT. DIFFERENT WATER LEVELS.	SEALING	UNKNOWN NONSEALING IF WATER LEVEL DIFFERENCE IS DUE TO DIFFERENCES IN CAPILLARY PROPERTIES OF THE JUXTAPOSED SANDS. SEALING IF WATER LEVEL DIFFERENCE IS NOT DUE TO DIFFERENCES IN CAPILLARY PROPERTIES OF THE JUXTAPOSED SANDS.
 (e) SAND OPPOSITE SAND AT THE FAULT. COMMON GAS-OIL CONTACT, DIFFERENT OIL-WATER CONTACT.	SEALING	NONSEALING POSSIBILITY IS REMOTE THAT FAULT IS SEALING AND MIGRATING GAS HAS FILLED THE RESERVOIRS OF DIFFERENT CAPACITY TO EXACTLY THE SAME LEVEL.
 (f) SAND OPPOSITE SAND AT THE FAULT. DIFFERENT GAS-OIL AND OIL-WATER CONTACTS	SEALING	SEALING A DIFFERENCE IN BOTH GAS-OIL CONTACT AND OIL-WATER CONTACT INFERS THE PRESENCE OF BOUNDARY FAULT ZONE MATERIAL ALONG THE FAULT.

Figure 8: Analysis of the sealing potential for some hypothethical fault-lithology-accumulation relationships. Depending upon capillary properties of lithologies juxtaposed on either side of the fault, different sealing combinations are possible. (After Smith, 1980.)

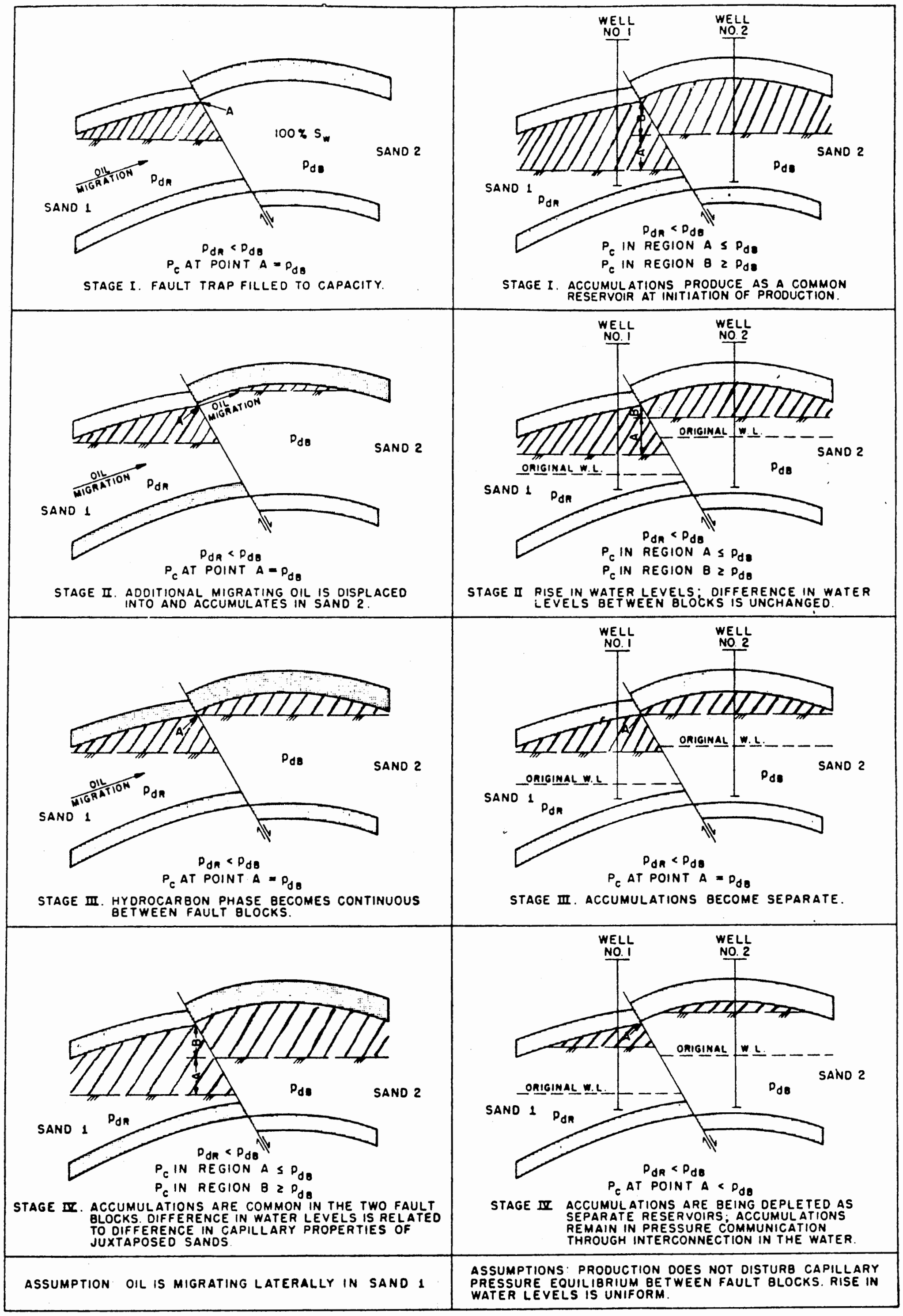


Figure 9: Schematic sections illustrating a hypothetical migration and accumulation history (left diagram of each stage), and production history (right diagram of each stage) of juxtaposed reservoir sands of different capillary properties. (After Smith, 1966.)

fractures obviously would leak. Harding and Tuminas (1988) believe that extension fractures would be more likely to leak than would shear fractures, and that younger, shallower fractures would be more likely to leak than older fractures that may have filled with cement. Rejuvenated or younger, shallower faults would seem more likely to leak than would older or deeper faults for reasons similar to those involved in fractures (Harding and Tuminas, 1988). All things being equal, Harding and Tuminas (1988) expected faults that penetrate younger, shallower beds to be more likely to leak than those which penetrate only older, more deeply buried strata. The results of studies done by Harding and Tuminas (1988) seem to suggest that strike-slip faults are perhaps the most likely to be sealed. They believe that strike-slip faults are more likely to seal than are reverse faults, which are more likely to seal than are normal faults. Their reasoning is that shear fractures and cataclastic gouge along strike-slip and reverse faults should be greater than in normal faults.

Relationships of Joints and Fractures at the Surface and in the Subsurface

Do the patterns and locations of fractures and faults at the surface correspond to similar, or even the same patterns in the subsurface? Simply because rocks at the surface are fractured or faulted, can we safely say that rocks in the subsurface are fractured in similar fashion?

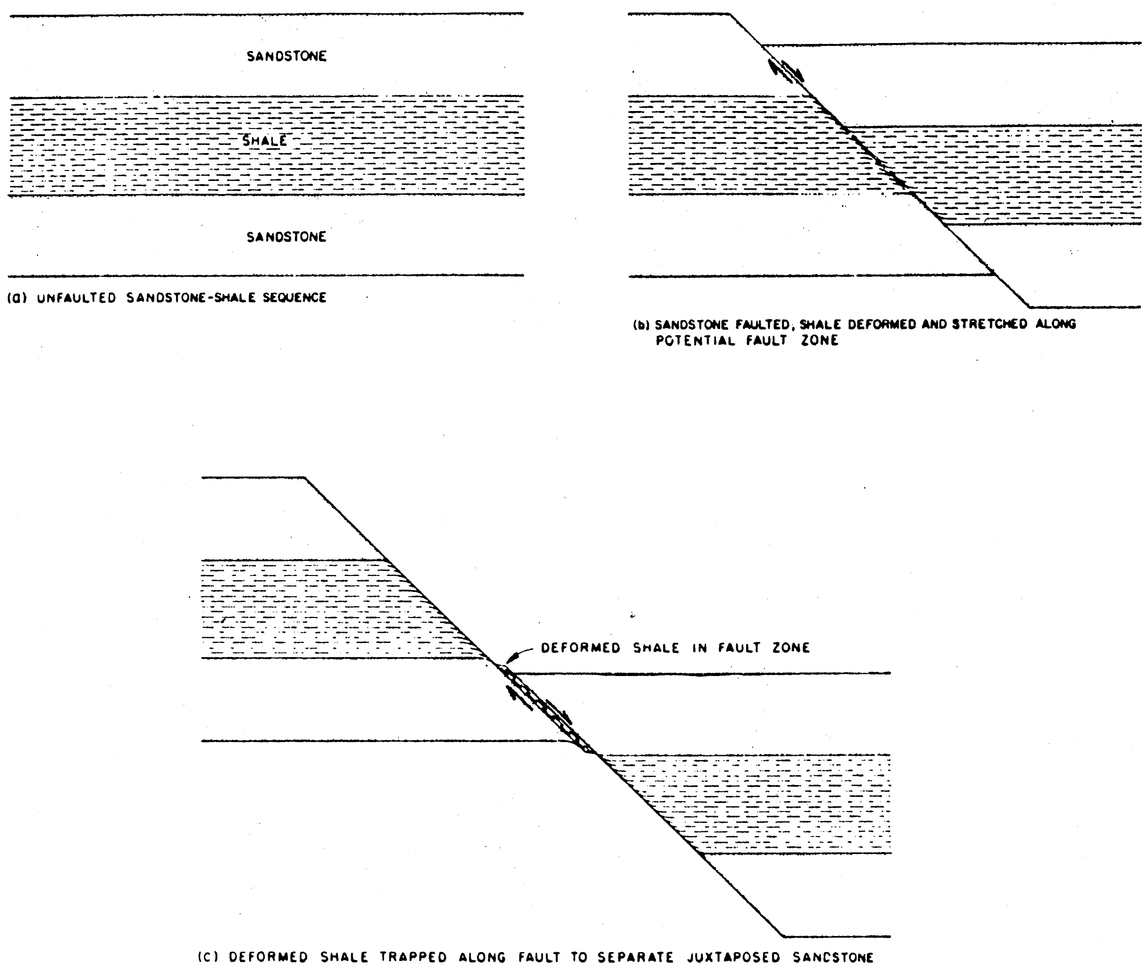


Figure 10: Schematic sections illustrating hypothetical emplacement of fault-zone shale based on experimental data concerning relative ductilities of sandstone and shale. (After Smith, 1980.)

If so, can we predict the patterns and locations of those features? Perry and Colton (1981) measured a total of 13,339 joints in various lithologies at 629 localities in the northern and central Appalachian Basin, an area of approximately 100,000 square miles. An interesting discovery was distinct decrease in abundance of joints downward and away from zones of recent weathering. This suggests that many joints in outcrops may have formed in response to unloading and weathering, rather than or in addition to regional or local tectonic stresses.

In studies of joints in shales of West Virginia, Perry and Colton (1981) found that in black shales of various ages joint patterns displayed different trends at the surface as compared to the subsurface. At few localities were joint patterns in gray shale and mudrock the same as patterns in sandstones interbedded with the shales. Patterns of joints in gray shale were almost random, whereas black shales showed patterns with consistent trends. Further, many joints in exposures on valley walls and in deep road cuts seemed to be related to release of stress (Perry and Colton, 1981, p. 8).

In sandstones many joints in steep-walled road cuts many joints were associated with weathering. Joints in sandstones and siltstones differed significantly from patterns in other types of rock (Perry and Colton, 1981, p. 9). Exceptions to this general rule were similarities of patterns of joints in limestones and dolomites and those in sandstones and siltstones, within the same geographic area. This seems to imply that brittle rocks develop similar jointing, in response to the same stress field (Perry and Colton, 1981, p. 9).

A somewhat similar study was conducted by Babcock (1977) in which fractures in Pleistocene lacustrine deposits were compared to joints in bedrock, in central Alberta, Canada. This was done to test the hypothesis that fractures in bedrock were propagated through glacial drift to the surface (Babcock, 1977). Where successive beds showed consistent grain size (which was presumed to imply similar mechanical properties) fractures tended to extend vertically from one bed into another (Babcock, 1977). Where grain size differed significantly from bed to bed (such as between sandstone and shale) joints were more likely to be confined to a single bed. This study resulted in the following basic conclusions: (1) Some major joints may be propagated through drift to the surface. (2) Fractures in lacustrine sediments studied are not related genetically to joints in underlying bedrock. (3) Fractures studied are a result of weathering processes acting on nearly vertical scarps with the free face providing a direction of relief for stresses. These stresses may be the result of "volume changes associated with hydration and desiccation, expansion caused by freezing of water within the sediments, or stress release associated directly with valley erosion" (Babcock, 1977, p. 365).

Fracture Propagation

Hydraulic fracturing has long been used as a method of reservoir enhancement, particularly in "tight" natural gas reservoirs. To have some idea as to how fractures induced in rock will propagate is important. For example, when fracturing reservoir rock, it is desirable to fracture neither the confining beds above the reservoir nor possible water bearing strata below. For this reason, much work has gone into study of fracture propagation through various types of rock materials, some of which may be applicable to the present study -- particularly the study by Teufel and Clark (1984). Laboratory experiments were conducted in an attempt to determine extents of vertical fractures or their confinement in layered rock. Their experiments resulted in determination of two main geologic conditions that might inhibit propagation of fractures vertically from one rock type to another: (1) weak interfacial shear strength of layers, and (2) increase in minimal horizontal compressive stress in the bounding layer (Teufel and Clark, 1984, p. 19).

If the boundary between two strata is smooth and even, interfacial shear strength of layers would be expected to be weak (Teufel and Clark, 1984). A gradational boundary, or a boundary between two sandstone layers, might be rougher, thus having stronger interfacial shear strength and more likelihood of propagating a fracture across the boundary. An abrupt boundary, such as exists between some sandstones and overlying shales might be more smooth, have a lower interfacial shear strength and less probability of propagating a fracture across the boundary.

Where layered materials are under compression with no lateral restraint, individual layers tend to expand laterally. Lateral expansion of each layer is determined by mechanical properties of that rock, specifically Poisson's ratio and the elastic modulus (Teufel and Clark, 1984). If layers have differing mechanical properties, horizontal stresses in each layer will differ. If no slippage occurs at the boundary between layers, expansion of each layer surrounding the boundary will be altered near the boundary (Teufel and Clark, 1984). The layer that shows a higher Poisson's ratio will be under higher horizontal compressive stress. Fractures will tend to be contained within a layer of rock if the overlying rock possesses a higher minimal horizontal stress (Teufel and Clark, 1984). In studies of unconfined layers, increase in minimal horizontal stress should occur in passing from a layer of low Poisson's ratio into a layer of higher Poisson's ratio (Teufel and Clark, 1984). If a fractured layer is overlain by a layer with a higher Poisson's ratio (which for the purpose of this discussion may be weakly correlated to a lower degree of elasticity), then fractures will have a tendency not to propagate into the overlying layer. Such a case might be expected in some instances where sandstone is overlain by shale.

Many other papers have been published concerning the propagation of fractures through various other types of materials. Some of this information might prove in to be correlative to the present study, but most of them were deemed not sufficiently so to discuss here. Other papers dealing more specifically with mechanics of unloading appeared either to not discuss fracturing in soft, ductile layers or to be unavailable for the present study.

Conclusions

In the first thirty or so years of the history of oil industry the structural theory was developed. Gussow (1954), Hubbert (1953), Schowalter (1979) and others defined principles by which oil and gas migrate and are trapped. Although shale is perhaps the most common seal, various rock types may act as sealing surfaces depending upon the relative capillary and displacement pressures. Further, the lateral extent of a sealing surface is as important, if not more so, than the thickness of the seal.

Faults will affect a sealing surface in various ways, depending upon such factors as type of fault, rock packages bounding the fault, and type of fault zone material. Not all faults are detrimental to the integrity of reservoir confining beds. However, if a fault is nonsealing, the reservoir will leak at a rate and amount related its porosity and permeability.

When joints have been examined in beds of shale at the surface with the intention of correlating them with similar joints or fractures in the subsurface, few direct correlations have been satisfactory. Many joints in shales at the surface seem to be related to unloading processes and weathering phenomena rather than or in addition to local tectonic stresses. Correlations of greater reliability have been possible with more brittle rocks.

Fracture propagation across boundary layers appears to be related to mechanical properties of the rocks involved. Experiments suggest that low interfacial shear strength between two layers hinders propagation of fractures across boundaries. Locations of low interfacial shear strength might be expected where bed boundaries are sharp and smooth, such as might occur between some sandstones and shales.

CHAPTER III

SURFACE GEOLOGY: METHODS OF STUDY

Estimation of Confining Bed Integrity By Study of Outcrops

In outcrops, many shales adjacent to jointed or fractured competent beds also are jointed or fractured. Four hypotheses seem to explain this phenomenon: (1) Fractures in such shales are unrelated to those in adjacent competent beds, and were formed by processes of weathering and unloading after the outcrop or roadcut was formed. (2) Fractures in such shales are unrelated to those in adjacent competent beds, and were formed as a result of erosional unloading before the roadcuts were excavated. (3) Fractures in shales and in the competent beds adjacent to them formed concurrently as a result of the same local tectonic stresses. (4) Some combination of the above hypotheses or of others not realized.

Studies were conducted of various outcrops that show obvious evidence of fracturing or jointing in competent units adjacent to shale (Figure 11). Orientations of fractures or joints in competent beds were examined and

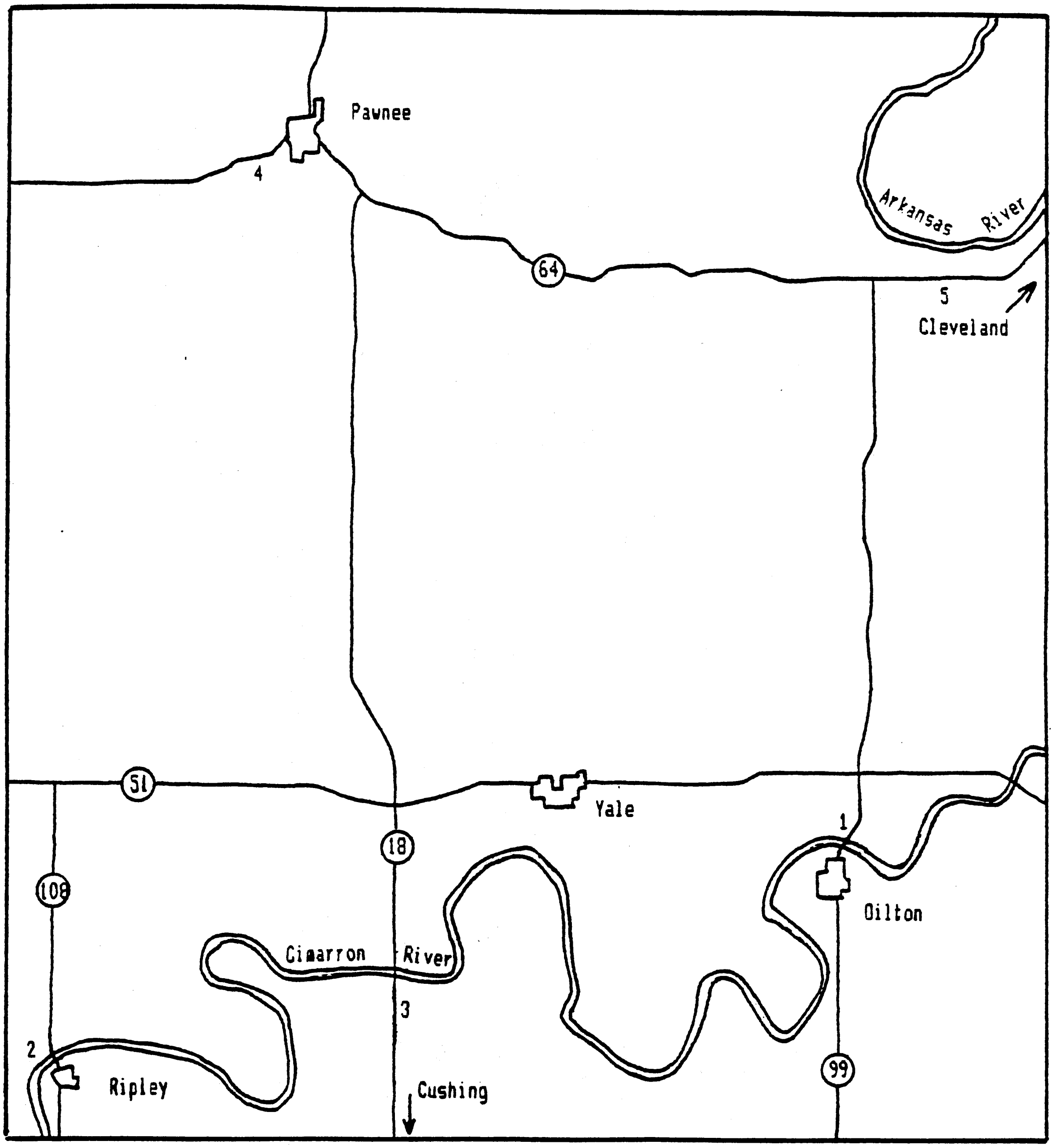


Figure 11: Index map showing locations of outcrops studied: (1) Oilton outcrop, (2) Ripley outcrop, (3) Cushing outcrop, (4) Pawnee outcrop, and (5) Cleveland outcrop. Scale 1:250,000.

compared with evidence of fracturing, jointing, or fluid migration within overlying or underlying shales, in an attempt to determine the relationships pertaining at each locality. If shales adjacent to fractured or jointed competent rocks are largely unaffected by the processes that formed the fractures or joints, then it might be postulated that the competency of those shales as confining units has not been compromised.

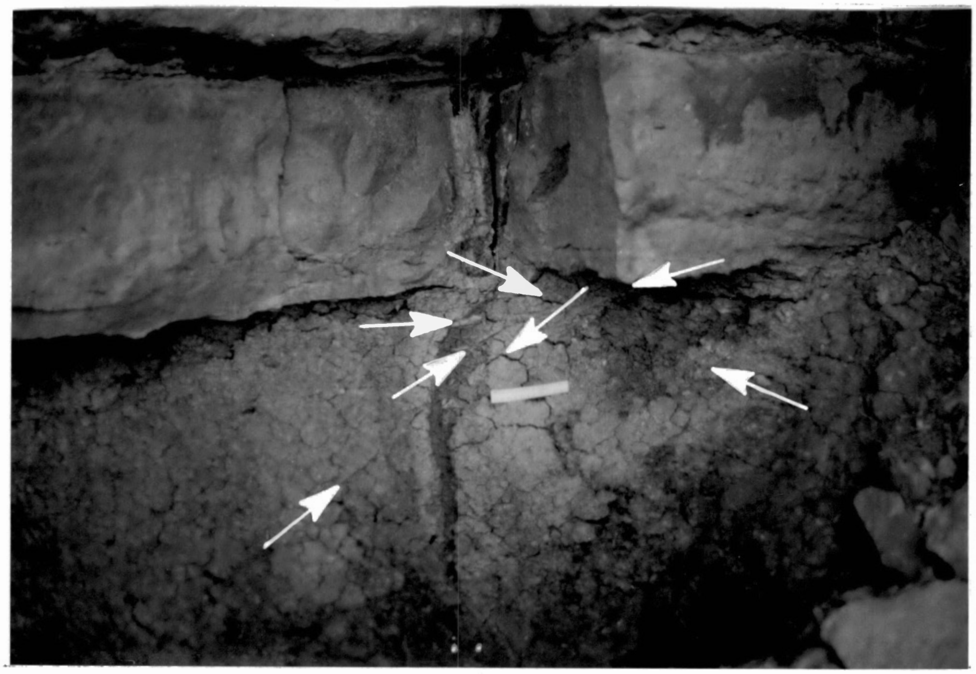
Oilton Outcrop

On State Highway 99 approximately 1/4 mile north of Cimarron River is an outcrop of the Lecompton Limestone Member of the Pawhuska Formation (Figure 12, photograph of a portion of the outcrop). This outcrop is in Section 28, T. 19 N., R. 7 E. (Figure 11).

At this locality, in shale below the Lecompton Member, a network of joints contains a precipitate, which is evidence that the joints once transported fluid (Figure 13, photograph and accompanying sketch). These joints appear to be confined to shale and to bear no relation to overlying limestone. Joints in limestone appear to die out abruptly in the shale (Figure 13).

A few faults at this locality penetrate the Lecompton, the shale above it and also the sandstone. Evidence of a throughgoing fault was found by digging into shale that lies directly above the Lecompton (Figures 14, 15).

Figure 12: Photograph of a portion of the Oilton outcrop showing the jointed Lecompton Limestone, overlying shale that contains an unrelated set of mineralized joints. (Ruler is 6 inches long.)



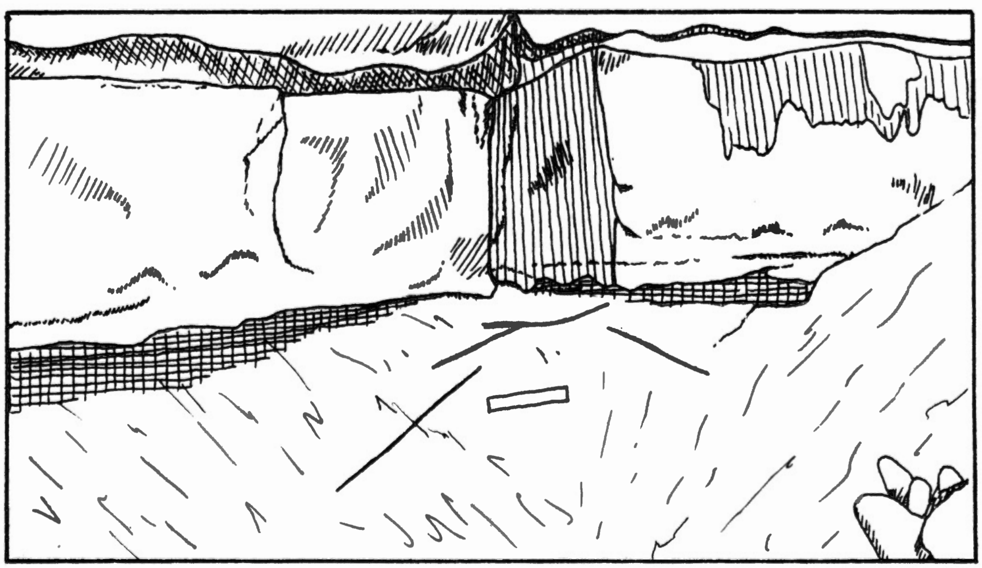


Figure 13: A closer photograph of the view seen in Figure 12 with accompanying sketch. Notice that the mineralized layers (indicated by arrows) have a different orientation than that of the joint in the overlying limestone. (White ruler is 6 inches long.)

Figure 14: Photograph of the outcrop location of a throughgoing fault in the Lecompton Limestone near Oilton. Arrows indicate the position of the fault and the location of the close-up photograph in Figure 15.

Figure 15: Photograph of a throughgoing fault in the shale directly above the Lecompton Limestone. Arrows indicate the trace of the fault. (Ruler is 6 inches long.)

Ripley Outcrop

Sandstone from the upper part of the Roca Shale is well exposed in the northwest quarter of Section 19, T. 18 N., R. 4 E. (Figure 11). This is approximately 3/8 mile west of State Highway 108 along the north side of Cimarron River, just north of Ripley. Figure 16 is a photograph of a part of the stratigraphic section at this locality. Figure 17 is a close-up photograph of the part of the outcrop shown in Figure 16, depicting some characteristic relationships of shale to jointing in sandstone above it. The shale varies from silty to very clayey shale. Where shale is silty, joints pass from the overlying sandstone straight through shale, into sandstone below (Figures 17 through 19). However, where jointed sandstone is underlain by clayey shale, joints end abruptly at the upper boundary of the shale.

Cushing Outcrop

North of Cushing on State Highway 18, about 1/2 mile south of Cimarron River, in the southwest quarter of Section 10, T. 18 N., R. 5 E. (Figure 11), several thin beds of finegrained sandstone are interbedded with shale beneath the Grayhorse Limestone (Figure 20). At places where shale is clayey with little silt, the shale shows no evidence of jointing that extends from adjacent sandstones. Where shale is silty, evidence of jointing may be found. In such cases, jointing in shale seems to be related directly to joints in adjacent competent beds (see Figure 21). Most shales in

Figure 16: Photograph of a portion of the outcrop at Ripley showing a jointed sandstone overlying shale. (Camp shovel is approximately 24 inches long)

Figure 17: Close-up photograph of rocks shown in Figure 16. Joint passes from sandstone, through shale, into sandstone below. (Ruler is 6 inches long.)

Figure 18: Photograph of a portion of the Ripley outcrop showing a joint that penetrates sandstone and underlying shale. (Camp shovel is approximately 24 inches long.)

Figure 19: Close-up of rocks in Figure 18. (Ruler is 6 inches long.)

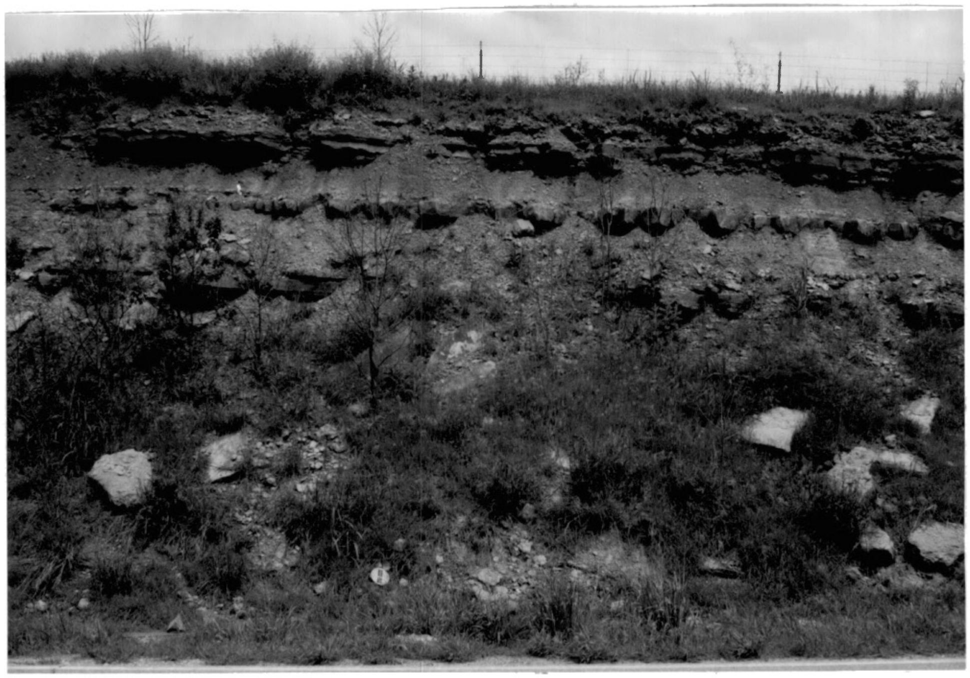


Figure 20: Photograph of a portion of an outcrop in SW/4, Sec. 10, T. 18 N., R. 5 E., showing several thin beds of sandstone interbedded with shale. (Thickness of prominent sandstone near the center of the outcrop is about 12 inches.)

this outcrop tend to be more silty away from the middle of the bed, toward the bounding sandstones. In some places joints in shale die out away from sandstone into more clayey portions of the shale. Where this occurs, joints extend into shale from both sides, but they seem not to penetrate the entire bed.

Pawnee Outcrop

An outcrop studied on State Highway 64 approximately 1 mile west of Pawnee, in the northwest quarter of Section 1, T. 21 N., R. 4 E. (Figure 11), is an excavation where shale was dug for fill material. The outcrop is capped by sandstone that is in the upper part of the Roca Shale (Figure 22).

A very clayey, ductile layer is directly below the capping sandstone. Although this layer has the appearance of being separate, an alternative hypothesis suggests that its appearance is due to hydration of the upper portion of the shale, as water seeps from above. Joints in the sandstone appear to end abruptly at the top of the clayey shale (Figure 23). Below the uppermost very clayey part of the shale, are many joints. Some trend vertically, having the appearance of meagerest hairline separation; they may be related genetically to joints in the overlying sandstone. However, joints primarily seem to be related to weathering (for example, joints tend to strike parallel to the slope face) and a definite relationship with

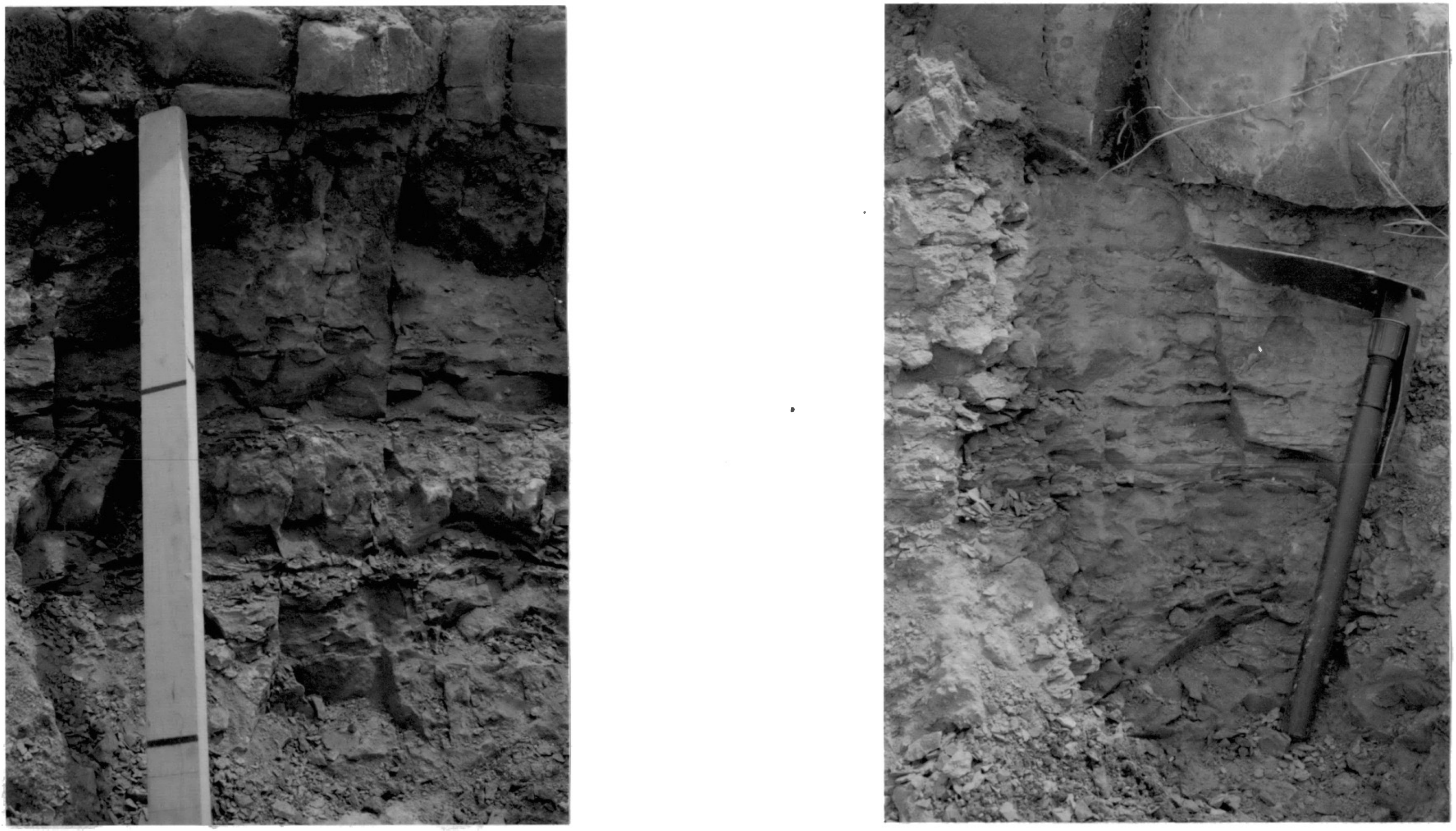


Figure 21: Each photograph shows joints in shale related to joints in overlying competent beds. (Jacob staff showing markings at one-foot intervals for scale in left photograph; camp shovel is approximately 24 inches long in right photograph.)

Figure 22: Photograph of a portion of an outcrop in NW/4, Sec. 1, T. 21 N., R. 4 E. showing a jointed sandstone overlying shale. (Jacob staff marked in one foot intervals.)

Figure 23: A close-up view of the main joint seen just left of the Jacob staff in Figure 22. The joint ends abruptly at contact with shale. (Ruler is 6 inches long.)

joints in sandstone was not documented confidently.

The floor of the excavated portion of this exposure is shale. Shale within several millimeters either side of joints is bleached somewhat, suggesting transmission of fluids (Figure 24).

Cleveland Outcrop

About 3 miles west of Cleveland on State Highway 64, in the northeast quarter of Sections 22, T. 21 N., R. 7 E. (Figure 11), is an outcrop of calcareous sandstone of the Pawhuska Formation (Greig, 1959; Figure 25, this paper). Hard, massive calcareous sandstone is underlain by shale. Joints in the sandstone die out a short distance into shale, where the shale is clayey. In some locations, a hard clayey shale is interbedded with fine laminae of silty shale. Where this type of hard clayey shale is present, joints in overlying sandstone appear to pass through shale, through a thin limestone below, and into a second shale (Figure 26). Where these joints penetrate shale, they splay, close to near-hairline width. Wider-open joints (nearly 1/16-inch wide) contain a fine residue, suggesting they once transported fluid.

Conclusions

1. In places where ductile, clayey shale is adjacent to a competent jointed bed, joints in the competent bed ordinarily end abruptly at contact with shale.

Figure 24: Photograph of the excavated floor of a pit in NW/4, Sec. 1, T. 21 N., R. 4 E. Bleached rock near joints (irregular tan markings) which suggests that joints once have transported fluids. (Ruler is 6 inches long.)

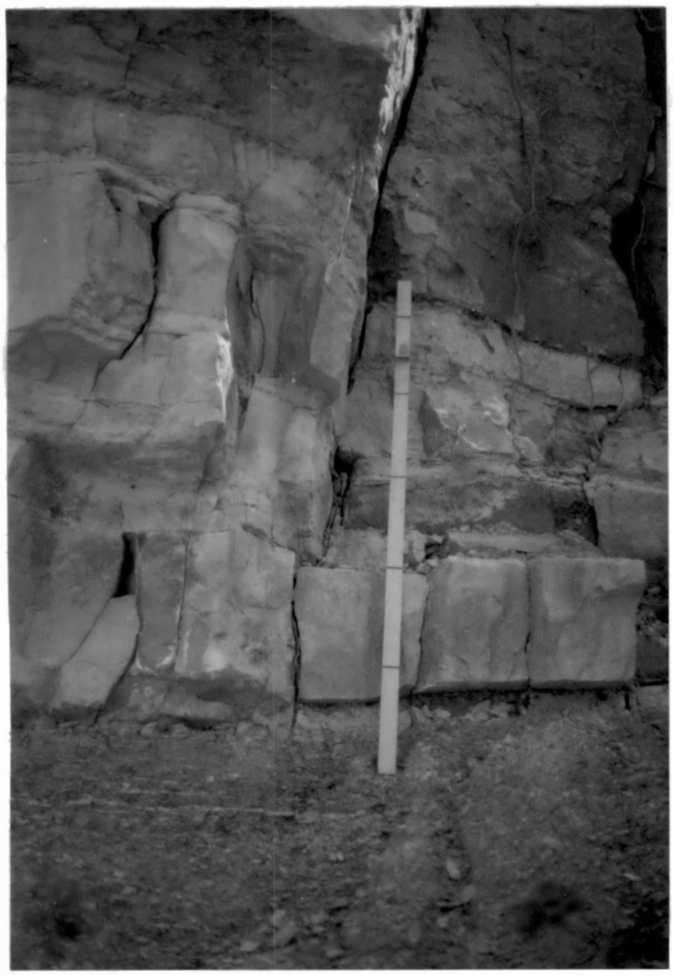


Figure 25: Photograph of a portion of an outcrop in NE/4, Sec. 22, T. 21 N., R. 7 E. A major joint penetrates the massive calcareous sandstone just left of the Jacob staff. (Jacob staff with markings at one foot intervals.)

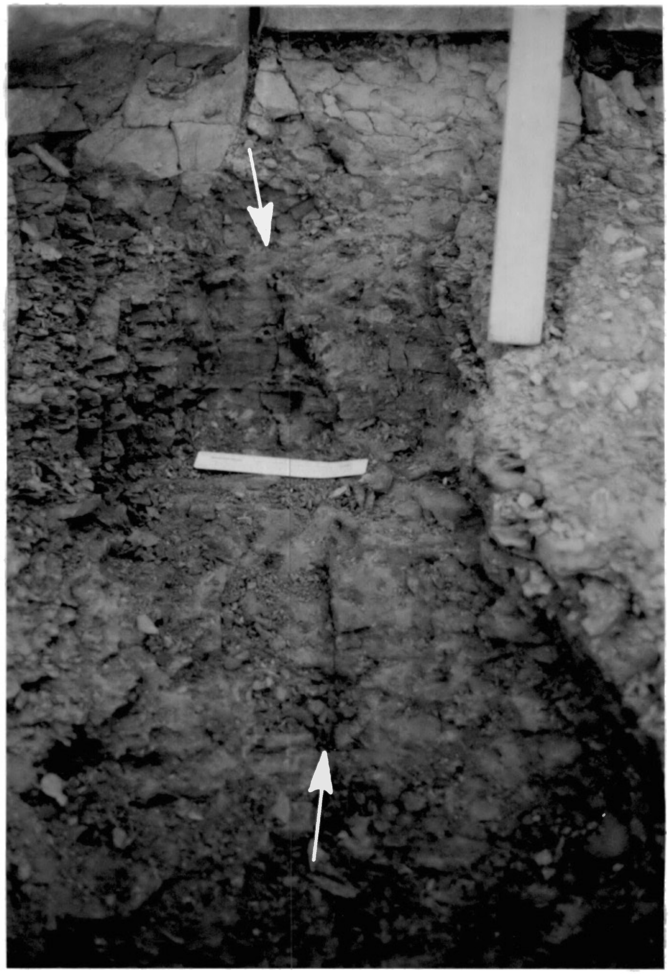


Figure 26: Close-up of rock shown in Figure 25. Joint extends through calcareous sandstone into shale below (arrows). (Ruler is 6 inches long.)

2. Any increase in silt content an otherwise clayey shale seems to result in a similar increase in likelihood of joint-extension across the bed boundary.
3. At some locations compacted clayey shale shows a tendency to propagate joints, although with some amount of bifurcation.
4. All shales examined in outcrop (with the exception of thin clayey, ductile shales) are jointed. A large proportion of this jointing is believed to have been the result of weathering and unloading. (For example, many parallel joints strike subparallel to slope faces.)

Estimation of Confining-bed Integrity by Surface-mapping Techniques

Remote Sensing Techniques

The eastern part of Burbank Field was studied using satellite imagery to delineate probable fracture-lineaments. Satellite imagery consisted of a Band-7, black-and-white image from LANDSAT 5, at an approximate scale of 1:1,000,000. Imagery was analyzed with a zoom-magnifier that enlarged the image by a factor of 5. Lineaments seen on the magnified image were traced onto a sheet of paper and transferred to Plate 2 with topographic-map lineaments and joint clusters mapped by Hagen (1972), scale 2 inches: 1 mile. Primary orientation of satellite-lineaments is northeasterly; secondary trends are northwesterly, with tertiary trends being easterly. The satellite-image lineations follow stream-drainage patterns closely and some other linear features detectable on topographic maps. From an empirical point of view, a strong relationship seems to exist between orientations of joint patterns mapped by Hagen (1972) and lineations detectable on satellite images and topographic maps. Lineaments from Hagen's (1972) geologic map were compared to U.S. Geological Survey's topographic maps, scale 1:24,000. These lineaments reflect primarily stream-drainage patterns.

Plate 2 shows orientations of joint patterns recorded by Hagen from areal geologic mapping and from photogeologic mapping. These joint patterns are represented by single lines on the map, although they were shown as joint-clusters on Hagen's original map. The rather close correlation of primary orientations of joint clusters, satellite-lineaments, and topographic features with recognized subsurface fracture trends determined by Hagen and Trantham and others (1980) indicates that each remote-sensing method used offers promise for determining primary orientations of subsurface fractures or lines of weakness.

Plate 1 is the areal geologic map of the eastern portion of Burbank Field. This map was modified from Hagen's (1972) map in order to use more nearly conventional geological-mapping nomenclature and procedure in definition of mapping units. Review of this map indicates that joint clusters mapped by Hagen (1972) are developed in thin strata of limestone, whereas the major drainage patterns and satellite-lineaments tend to be expressed and mappable across all rock types. Therefore, the major drainage patterns and satellite-lineaments are judged to be more probable evidence of fractures that penetrate the sedimentary-rock column.

Conclusions

1. Satellite imagery provides good evidence of a few large lineaments that are oriented primarily northeastward and that seem to be related closely to stream-drainage patterns.
2. Topographic maps are useful for delineating drainage-related linears; orientations of some major streams in the study area may be evidence of superposition of drainage on zones of weakness in bedrock.
3. Areal geologic maps are invaluable in determining the susceptibility of rock types to localized jointing, specific erosional or weathering patterns, and/or major fracture trends.
4. Remote-sensing imagery, including satellite imagery and topographic maps, provides information for recognition of potential fracture-trends.
5. Trends of lineaments are correlated closely with orientations of fractures and zones of weakness described in the detailed subsurface studies of

Hagen (1972) and Trantham and others (1980).

6. Remote-sensing techniques further supported inferences by Hagen (1972) that trends of fractures in rocks at the surface and in the Burbank reservoir are similar in general orientation.

CHAPTER IV

SUBSURFACE METHODS

Estimation of Confining-bed Integrity by Computer-mapping from Data Base

Methodology and Procedure

The following methods were used to evaluate confining-bed integrity in the Burbank Field.

1. Development of a computer data base of information about the Cottage Grove Sandstone and shallower rock units (Figure 27; Appendix A).
2. Generation of maps of the subsurface, showing the structural geology of certain beds or intervals (Figures 28, 29; marker beds shown in Figure 1).
3. Construction of maps showing thicknesses of rock units and of shale in the Cottage Grove Sandstone (Figures 30 through 33).
4. Generation of maps showing thicknesses and extents of certain confining beds (Figures 34, 35).
5. Development of maps showing pertinent evidence about strata that are younger than the Cottage

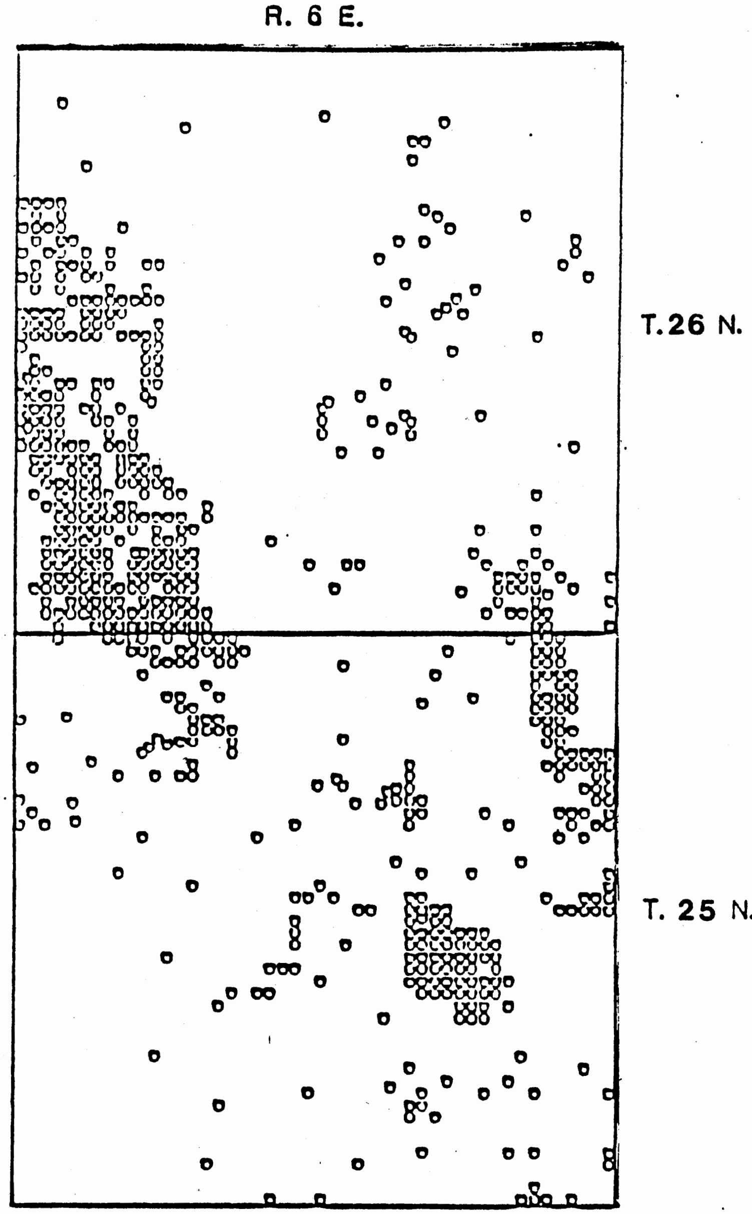


Figure 27: Locations of wells in Burbank Field from logs of which data base was compiled. Lack of control in some areas is due to the fact that much drilling predated application of wireline logs. (Scale: Width of diagram is 6 miles.)

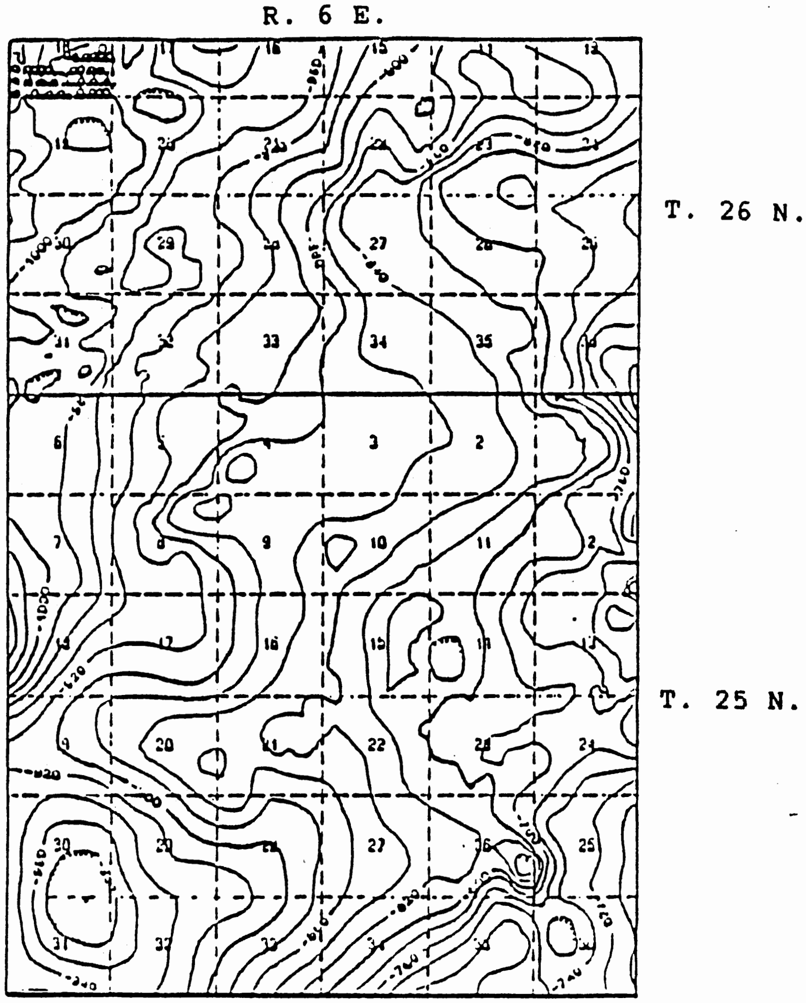


Figure 28: Structural geology, Cottage Grove Sandstone (Figure 1), Burbank Field. Contour interval 20 feet. In Sections 30 and 31, T. 25 N., R. 6 E., a large syncline is shown. Figure 27 shows absence of data in this area. The syncline is an artifact of software. In northernmost corner of map locations of wells and elevations of the datum are plotted. At this scale, to include data and contour lines is not practical. (Scale: Width of diagram is 6 miles.)

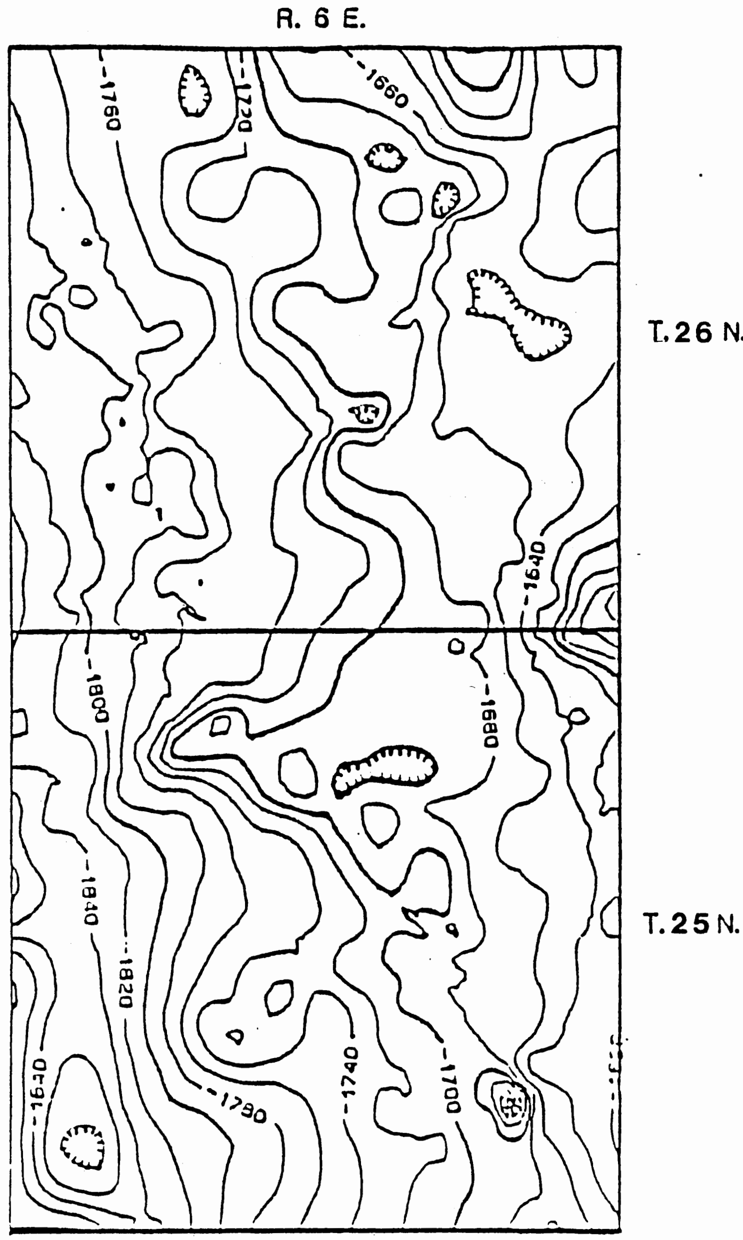


Figure 29: Structural geology, Pink Limestone, Burbank Field (Figure 1), an extensive tabular formation that is excellent for use as a mapping datum. Contour interval 20 feet. At Burbank Field and nearby, anticlinal and synclinal noses, and anticlines and synclines are superimposed on a regional, westward-dipping homocline. (Scale: Width of diagram is 6 miles.)

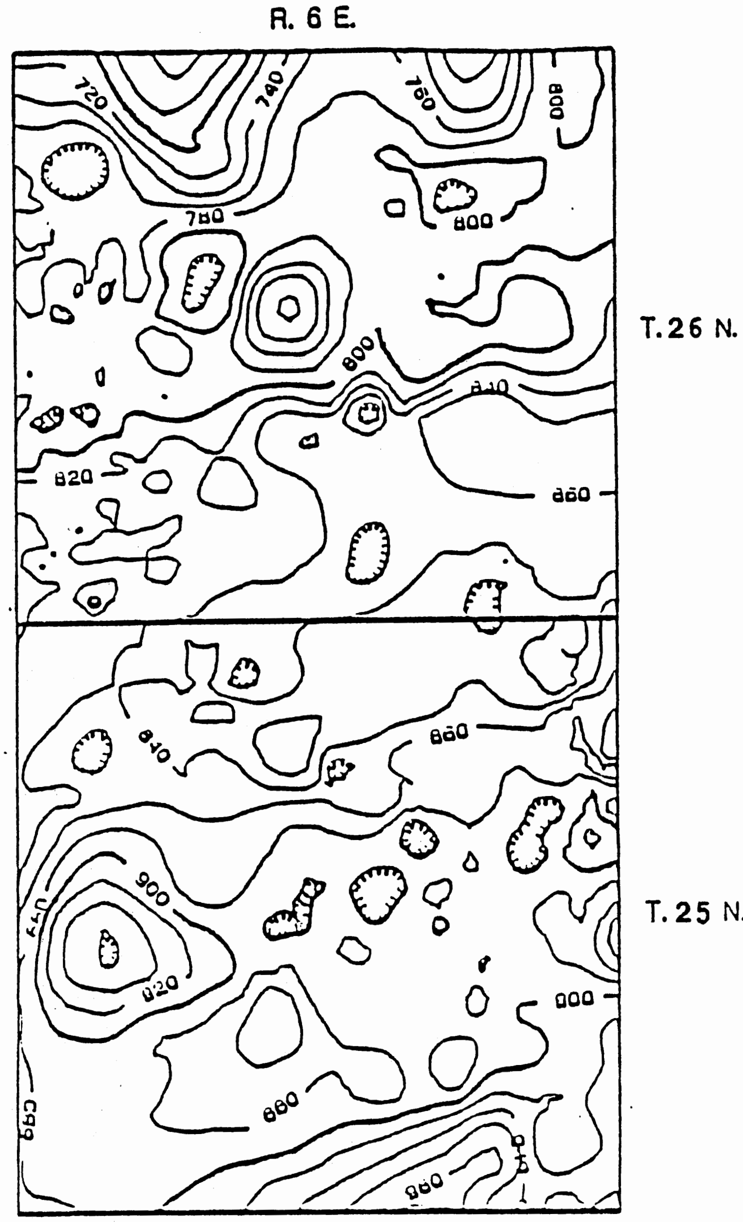


Figure 30: Thickness of stratigraphic interval, Cottage Grove Sandstone to Pink Limestone, Burbank Field. Contour interval 20 feet. The map was designed to test the working hypothesis that anomalous thickening or thinning of the interval would indicate faulting. Hachured, closed contours show areas of thick rock. (Scale: Width of diagram is 6 miles.)

R. 6 E.

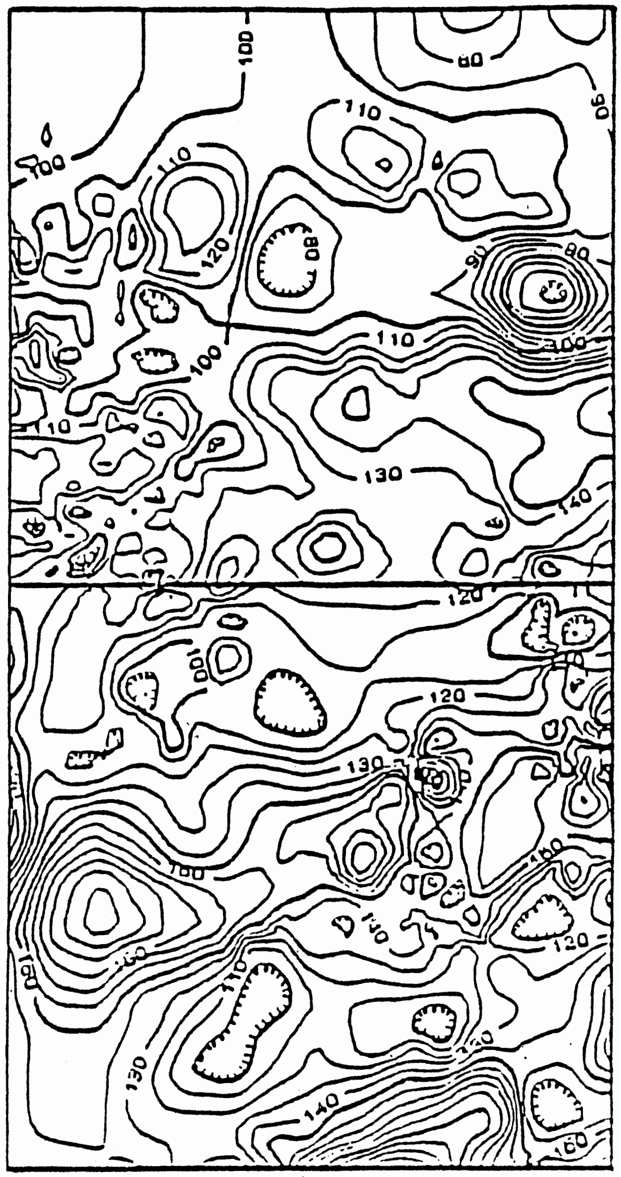


Figure 31: Thickness of Cottage Grove Sandstone, Burbank Field. Contour interval 10 feet. Compare Figures 27 and 31 for evidence that the map is rather interpretive where data are sparse, with tendency to show ovate "thicks" and "thins" at such places. In general the map is quite useful. It would be especially useful for general assessment of the extent and thickness of an injection zone. (Scale: Width of diagram is 6 miles.)

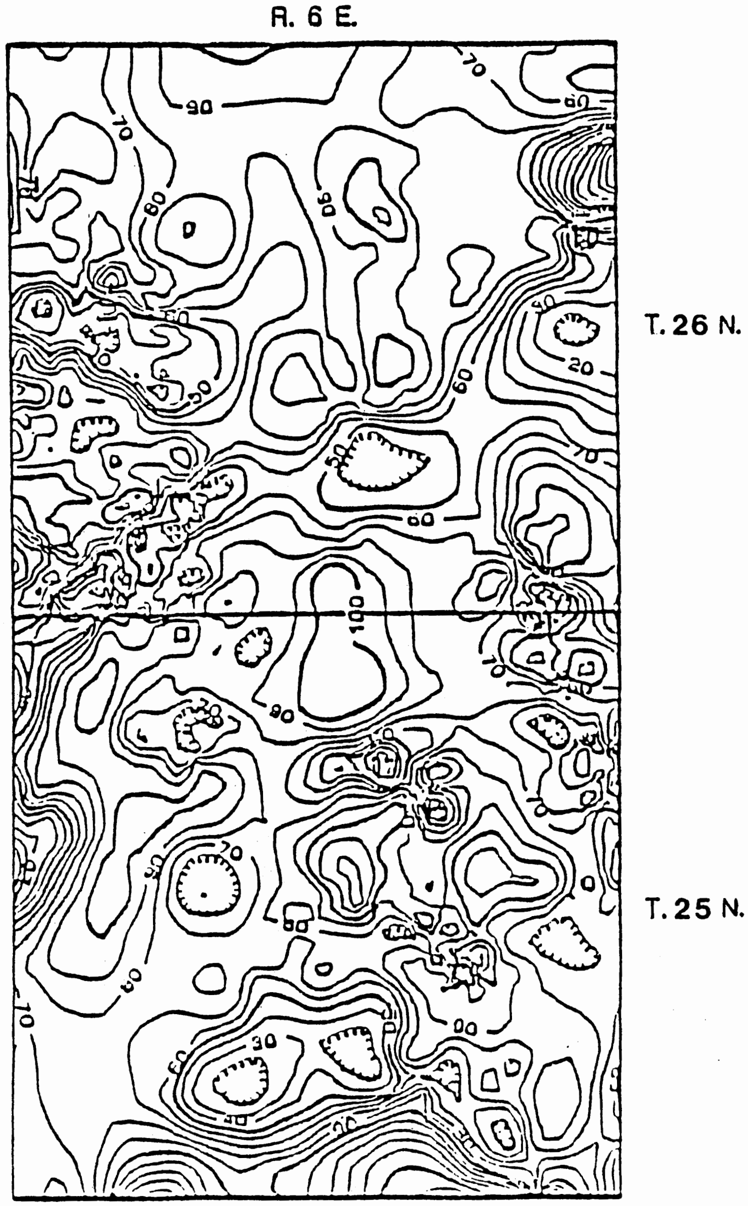


Figure 32: Thickness of net sandstone in Cottage Grove Sandstone, Burbank Field. Contour interval 10 feet. Map shows thickness of sandstone in Cottage Grove that should be of "reservoir-quality". Interbeds of shale were eliminated in calculation. The map would be useful for general assessment of storage-unit potential. (Scale: Width of diagram is 6 miles.)

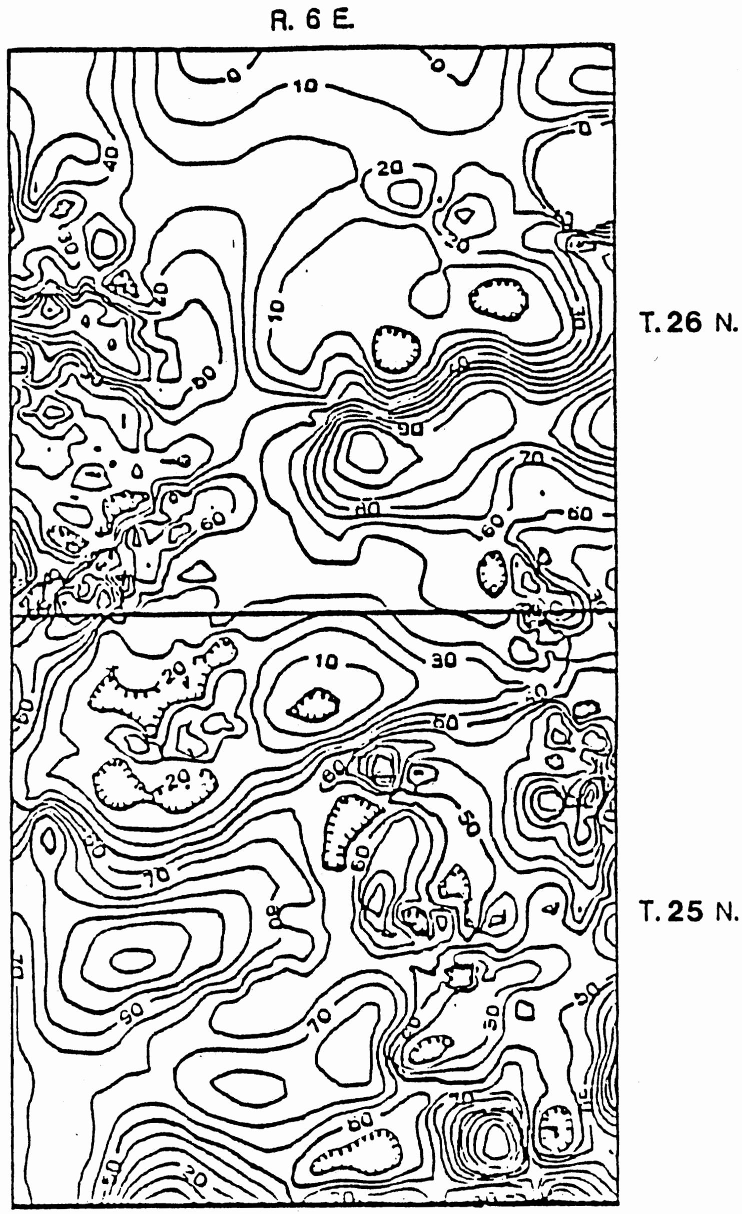


Figure 33: Thickness of net shale in Cottage Grove Sandstone, Burbank Field. Contour interval 10 feet. This map would be useful for broad assessment of potential confining beds within the Cottage Grove Sandstone. (Scale: Width of diagram is 6 miles.)

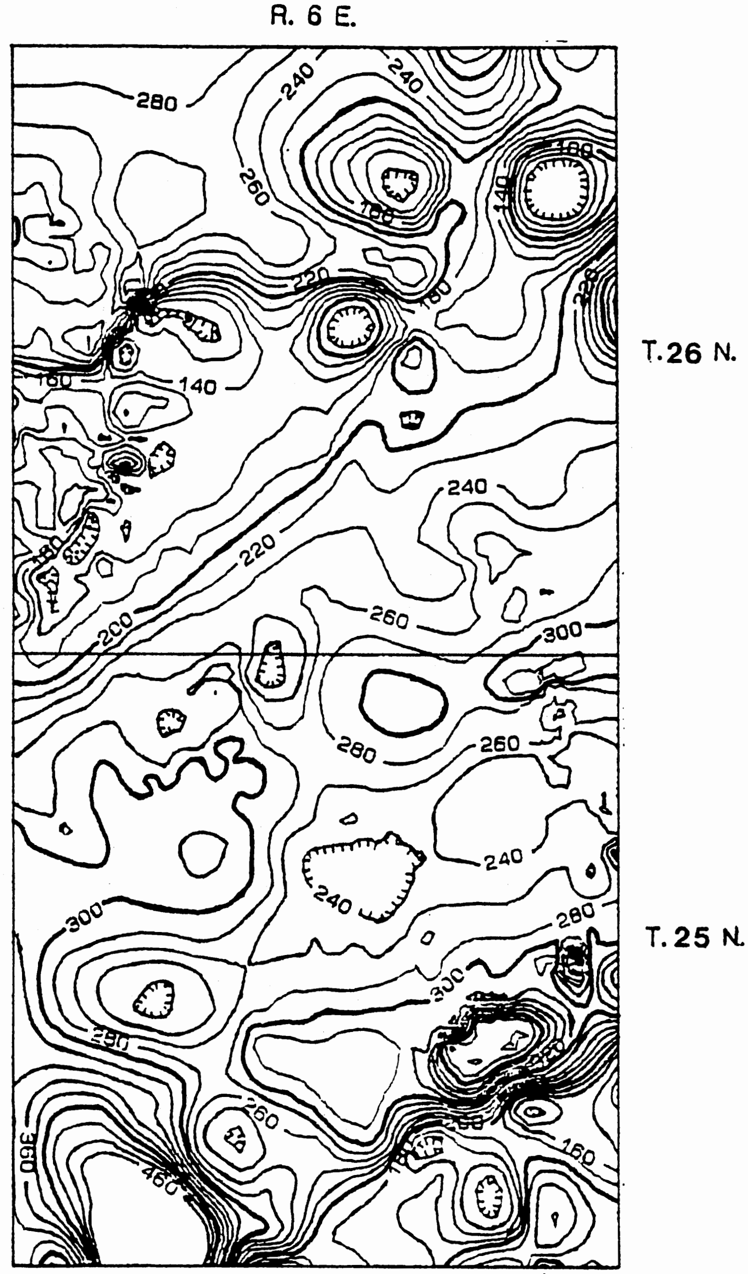


Figure 34: Thickness of confining unit directly above Cottage Grove Sandstone, Burbank Field. Contour interval 20 feet. Maps of this type would be useful in general evaluation of confining-bed potential. Merging of lines is due to small scale and small contour interval, both of which could be modified during use of the software. (Scale: Width of diagram is 6 miles.)

R. 6 E.

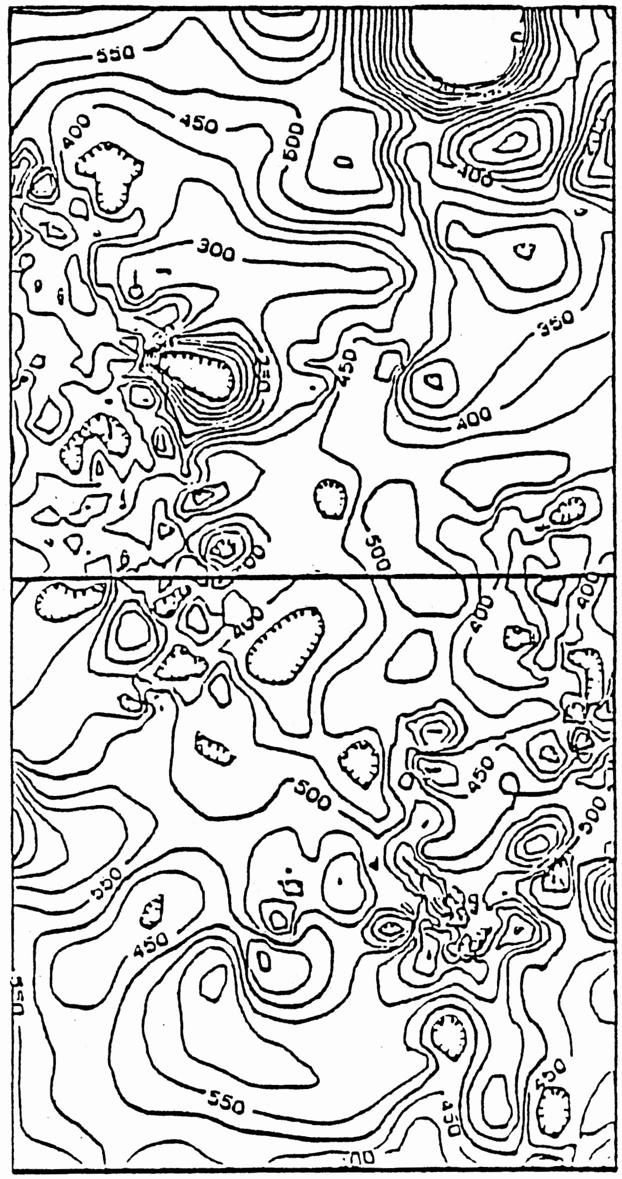


Figure 35: Cumulative thickness of shale above Cottage Grove Sandstone, Burbank Field. Contour interval 50 feet. The map shows general distribution of total shale (and total confining-bed potential) in stratigraphic section overlying Cottage Grove. (Scale: Width of diagram is 6 miles.)

Grove Sandstone, where injection of fluids is concerned (Figures 36, 37).

In order to estimate confining bed integrity in Burbank Field, the following maps were produced.

1. Structure contour map of the "Pink Lime," the stratigraphic position of which is a short distance above the Burbank Sandstone reservoir (Figures 1 and 29; Plate 3).
2. Structure contour map of the Cottage Grove reservoir, which might be used for injection (Figure 28).
3. Thickness map of the stratigraphic interval between the Pink Lime and Cottage Grove Sandstone (Figure 30).
4. Thickness map of the Cottage Grove Sandstone (Figure 31).
5. Effective-sand-thickness map of the Cottage Grove Sandstone (Figure 32).
6. Thickness map of shale in the Cottage Grove Sandstone (Figure 33).
7. Thickness map of the effective confining bed above the Cottage Grove Sandstone (Figure 34).
8. Thickness map of the cumulative thickness of shale above the Cottage Grove Sandstone (Figure 35).

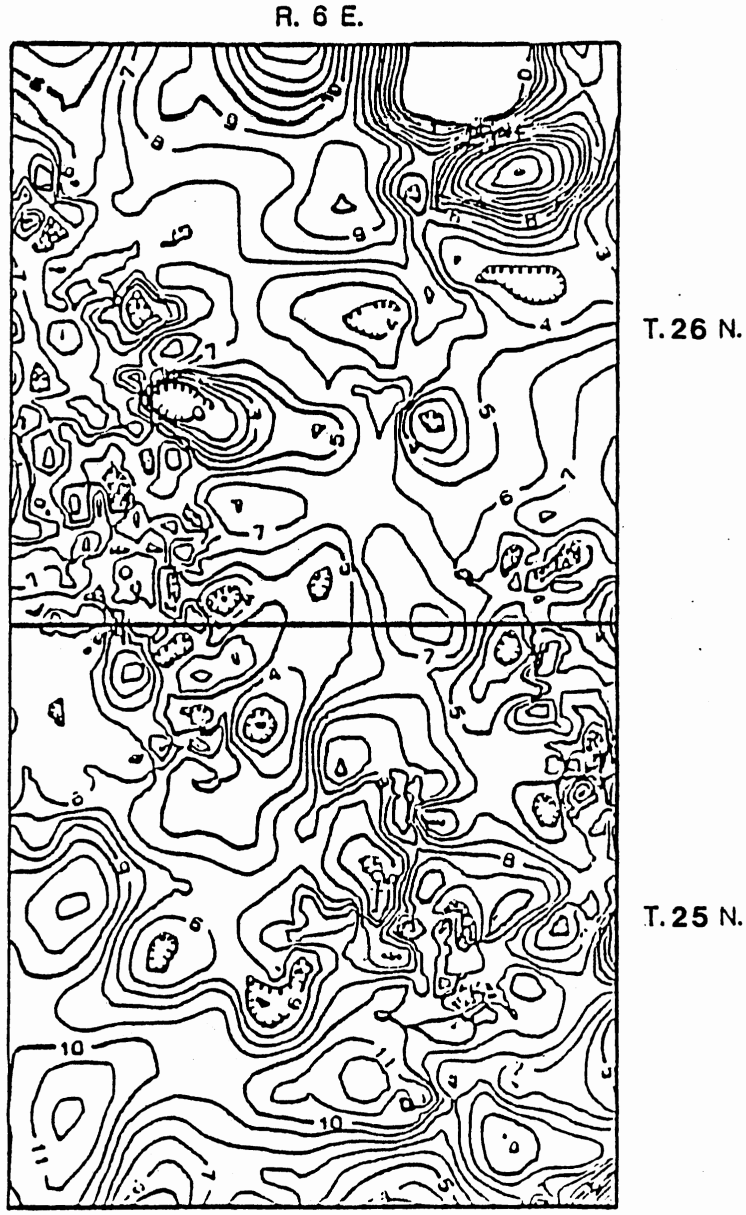


Figure 36: Total number of shale "breaks" in stratigraphic section above Cottage Grove Sandstone, Burbank Field. Each shale break is 20 feet thick or thicker, by definition. In effect, the map shows the number of confining beds above the Cottage Grove. This map would be useful for general evaluation of the study area. (Scale: Width of diagram is 6 miles.)

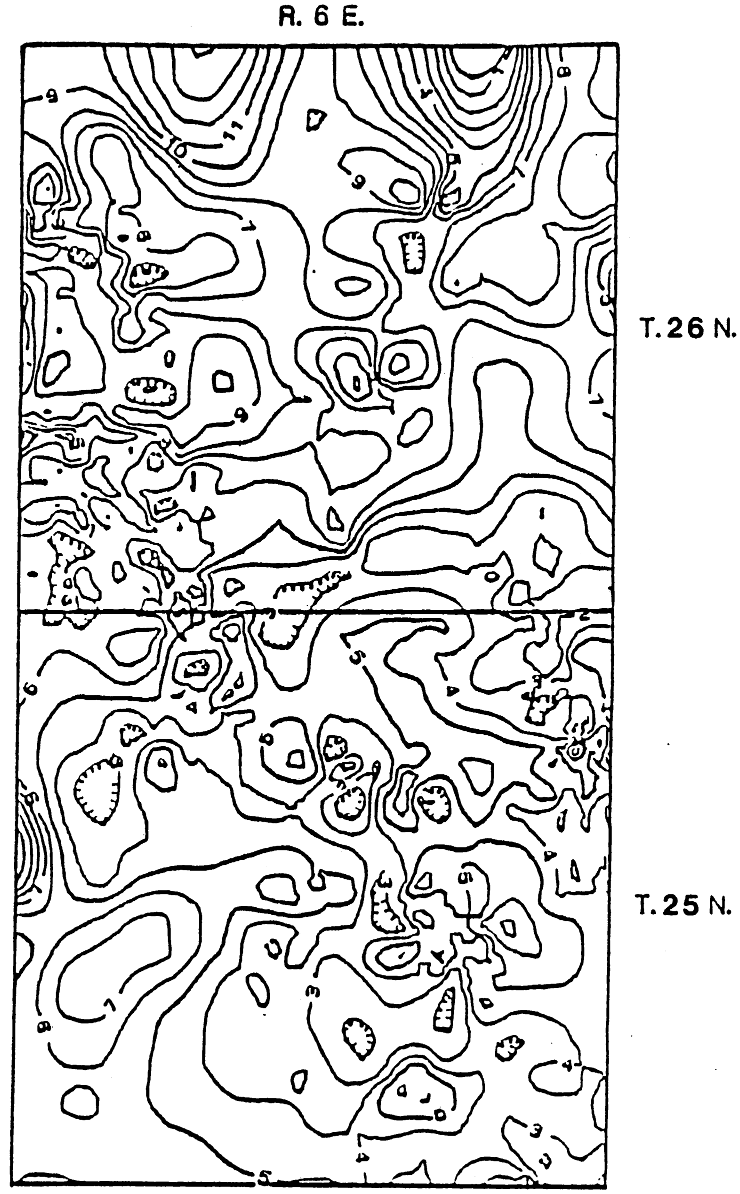


Figure 37: Possible injection zones between top of Cottage Grove Sandstone and depth of about 1000 feet, Burbank Field. Map shows number of sandstone formations as thick as about 6 feet or thicker. These data also would be useful for estimation of the number of reservoirs into which upwardly mobile, overpressured fluids might escape. (Scale: Width of diagram is 6 miles.)

9. Thickness map of the number of probable confining beds above the Cottage Grove Sandstone (Figure 36).

10. Thickness map of the possible fluid-injection intervals above the Cottage Grove Sandstone (Figure 37).

These maps were made by personal computer from a data base built by using wireline logs of wells in Burbank Field. To construct the data base, the Lotus 1-2-3 spread-sheet program was used, whereas mapping was done with the Jupiter Mapping System and a multiple-pen line plotter. (See Appendix A for an evaluation of the graphic limitations of Figures 27 through 37.)

The Jupiter Mapping System contours data on the basis of a neighborhood-based interpolation. "Neighborhood-based interpolation is a method for estimating the value of a spatial function, at a given location, by forming a weighted average of known values at nearby locations," (Watson and Philip, 1987, p. 12). In doing this, the software first sorts the data to determine natural neighbors of each data point. The next step is to compute estimated gradient at each data location. Once this has been accomplished, the program estimates values at specific interpolation points, as required for contour mapping (Watson and Philip, 1987, p. 12).

Structural Geology

Mapping of the Pink Lime marker bed shows that structural geology in the study area fundamentally is homoclinal, with dip westward at about one-half degree. The homocline is interrupted by anticlinal and synclinal noses, and by a few anticlines and synclines (Figure 29; Plate 3).

Structural geology of the Cottage Grove Sandstone is similar to that of the Pink Limestone. Figure 28 shows general westerly dip with few closed folds. Because no data were available in the southwesternmost part T. 25 N., R. 6 E., the software interpreted a closed syncline, where the minimal elevation is shown to be less than -980 feet (Figure 28).

Figure 30 indicates the rates of variation in thickness of the stratigraphic section between the Cottage Grove Sandstone and the Pink Limestone marker. This map was intended to test the working hypothesis that through-going faults might be suggested by abrupt and linear changes in thickness of the interval. The stratigraphic interval thickens from north to south, but abrupt changes in thickness are few. In the lower middle part of T. 26 N., R. 6 E., the east-northeast-trending gradation from about 800 feet to about 860 feet seems to be anomalous, and generally to be located on-trend with lineaments shown in Plate 2.

The thickness of the Cottage Grove Sandstone (Figure 31) shows that the rock-stratigraphic unit extends throughout the study area; its thickness and extent indicate that the Cottage Grove has good potential as a fluid-injection reservoir. Figure 32, a net-sandstone-thickness map indicates the general amount of reservoir-quality sandstones at specific sites, exclusive of shale interbedded with sandstone. Cumulative thickness of shale within Cottage Grove is shown in Figure 33. Figures 31, 32, and 33 emphasize that the Cottage Grove is not a homogeneous reservoir. Nevertheless, net thickness of sandstones in the Cottage Grove is more than 50 feet at most places.

The Cottage Grove is overlain by a thick sequence of clayey shale (Figure 34). At some places this shale is thicker than 400 feet, but at some localities it is as thin as about 100 feet. Thicknesses of over 200 feet are common; indeed in about 67 percent of wells, Cottage Grove Sandstone is overlain directly by 200 feet or more of clayey shale. In only about 12 percent of wells is the shale thinner than 150 feet.

Figure 35 shows the extent and thickness of cumulative shale above the Cottage Grove interval. Throughout the study area the Cottage Grove interval is covered directly or indirectly by a substantial thickness of confining shales; altogether, cumulative shale is in the range of about 175 feet to about 600 feet.

Figure 36 illustrates the areas where multiple layers of confining shale -- 20 feet thick or thicker -- overlie the Cottage Grove interval. Based upon the assumption that a stratigraphic unit of shale 20 feet thick or thicker should also be laterally extensive, this map should be valuable in estimating the sealing-potential of shales.

Figure 37 simply shows areas where possible injection-reservoirs are above the Cottage Grove Sandstone and below the Pawhuska Limestone. However, few of these horizons are as thick and extensive as the Cottage Grove.

Conclusions

Based upon results of this part of the study, the conclusion is drawn that development of a computer data base permits construction of various maps that would be helpful in quick and general assessments of confining bed integrity. Some of the advantages are:

1. A geologist of limited experience can examine wireline logs, correlate formation tops and record the thicknesses and numbers of shale units, thus freeing more experienced geologists for more difficult tasks.
2. A person with even limited experience in entering data into a personal computer can be employed to compile the data base.
3. The computer-mapping program used in this study is simple enough that a person with limited experience can manipulate it confidently to generate the desired maps.

4. Using the mapping program described here, scale-of-map is only one of the many options available to the user.

5. Maps can be made relatively quickly and easily, thus allowing for examination of a large sample of maps; therefore more time is available to hand-draw detailed maps where necessary.

6. Information from these maps can be combined with other data relatively easily.

Estimation of Confining Bed Integrity Using Subsurface-mapping Techniques to Recognize Fracture Trends

Methods and Procedures

Estimation of confining-bed integrity in Burbank Field involved the following subsurface and surface geological techniques:

1. Subsurface mapping to test the validity of fracture trends in the major producing reservoir in Burbank oil Field (Plates 4 and 5).

2. Comparison of fracture-trends inferred from subsurface mapping to fracture-trends at the surface, in order to map probable zones of weakness that could be conduits for vertical migration of injected fluids.

Maps of the Subsurface

Initial investigation of geologic data pertaining to Burbank Field and available to the public indicated that three subsurface-mapping techniques would be valuable in determining probable fracture-trends in the reservoir: (1) a structural contour map on a stratigraphic marker bed closely above the Burbank Sandstone horizon (Plate 3), (2) an isopotential map of wells drilled early in development of Burbank Field (Puckette, 1989) (Plate 4, APPENDIX C), and (3) an effective-reservoir thickness map of the Burbank Sandstone (Puckette, 1989) (Plate 5, APPENDIX C). Isoproduction maps were considered not to be beneficial, for the following reasons. Most leasehold blocks in the Burbank Field are 160 acres or more, and all oil production would have been measured at a common tank battery. Because most fracture-trends are believed to be quite narrow, the large production of wells affected by such fractures could have been offset by small production from nonfractured wells on the 160-acre tract. This production-monitoring problem was exacerbated by the historical formation of secondary-recovery units within boundaries of Burbank Field, which makes the establishment of cumulative-production values for individual wells nearly impossible. Moreover, no satisfactory method was found for discounting the effects of

Structural geologic maps, Burbank Field. Structural contour maps are published and copyrighted by the Osage Tribe of Native Americans. These maps were reviewed, but no significant evidence of structural folding or faulting was recognized in Burbank Field. Electrical-log surveys are scarce over large areas of the field; this fact makes the search for missing stratigraphic section on logs quite difficult. Such omissions of strata commonly indicate normal faults of small throw, which would not be manifested in ordinary structural mapping. Considering the availability of published data and paucity of electrical-log data in some areas of the field, the decision was made not to make a subsurface structural contour map on the same scale as the isopotential and reservoir-thickness maps (Plates 4 and 5).

Conclusions

Study of the Burbank reservoir by subsurface-mapping methods and testing for recognition and delineation of fracture-trends had the following results.

1. Abrupt changes in thickness, and the general linear geometry of the Burbank channel-fill sandstone reservoir make the mapping of fracture-trends by ordinary subsurface geologic methods an endeavor of small reward.
2. Fracture-trends may be identifiable in some sandstone reservoirs where isopotential-trends or

isoproduction-trends are "normal" to reservoir thickness trends, or are otherwise conspicuously detectable.

3. In Burbank Field, where relatively large leases with many wells are available for study, isopotential maps are valuable for mapping trends of highly productive rock, but isoproduction maps cannot be used effectively.

4. The likelihood of operator-introduced bias in reporting initial-production rates seems to justify reserved judgment about the validity of large initial-production trends along lease lines that separated different operators.

5. In the Burbank Field, quality of reservoir penetrated by drilling and exposed for production had more influence on initial production rates than total thickness of reservoir drilled.

6. Effects on initial potential of reservoir-pressure depletion and hydraulic-fracturing techniques were eliminated in the Burbank Field study by using wells drilled early in development of the field.

7. Explosion-fracturing of the Burbank reservoir had greater impact on initial productions of wells with small natural-production rates than on wells with large natural-flowing rates.

8. Based on study of the Burbank reservoir, abrupt changes in thickness and geometry make most

channel-fill sandstone reservoirs generally unsuitable for use in developing models for subsurface fracture-trend studies; attention should be directed toward sandstone reservoirs of other depositional settings.

Injection-Sensitivity Map

The eastern portion of Burbank Field shows little evidence of actual structural deformation. Comparison of Plates 3 and 5 suggests that the Pink Lime marker has been folded by differential compaction over the Burbank "shoestring" sandstones. This area also has high confining-bed potential with thick, extensive sections of Pennsylvanian shale. Techniques used in an attempt to detect faulting revealed no strong evidence of such faulting. However, other workers (for example Hagen, 1972) have shown formidable evidence of water movement through individual beds of sandstone, presumably through open fractures.

Examination of lineaments evident on satellite imagery led to delineation of regions of possible sensitivity to fluid injection. This mapping is based on working assumptions, believed to be worthy of use in conservative judgment of injection-potential: (1) Systematic joints are in the Burbank Sandstone, and are in the strata next above (Hagen, 1972; Dickey, 1979). (2) Under overpressured conditions, this network of fractures is a conduit for fluids. (3) Anomalously dense and extensive concentrations of lineaments suggest the possibility of through-going or incipiently through-going fractures in the sedimentary-rock column. Areas within these elliptical or amoeboid patterns (Figure 38) should be suitable for some Class II injection wells but not for Class I wells. It is recommended that in these areas fluid be injected into the producing horizon at pressures less than the original bottom-hole pressure at the locality. Detailed studies of the subsurface by Hagen (1972) and Trantham and others (1980) indicated that slight overpressuring of the Burbank reservoir opened fractures and caused lateral migration of fluid through the reservoir and through naturally fractured sandy shales that overlie the reservoir.

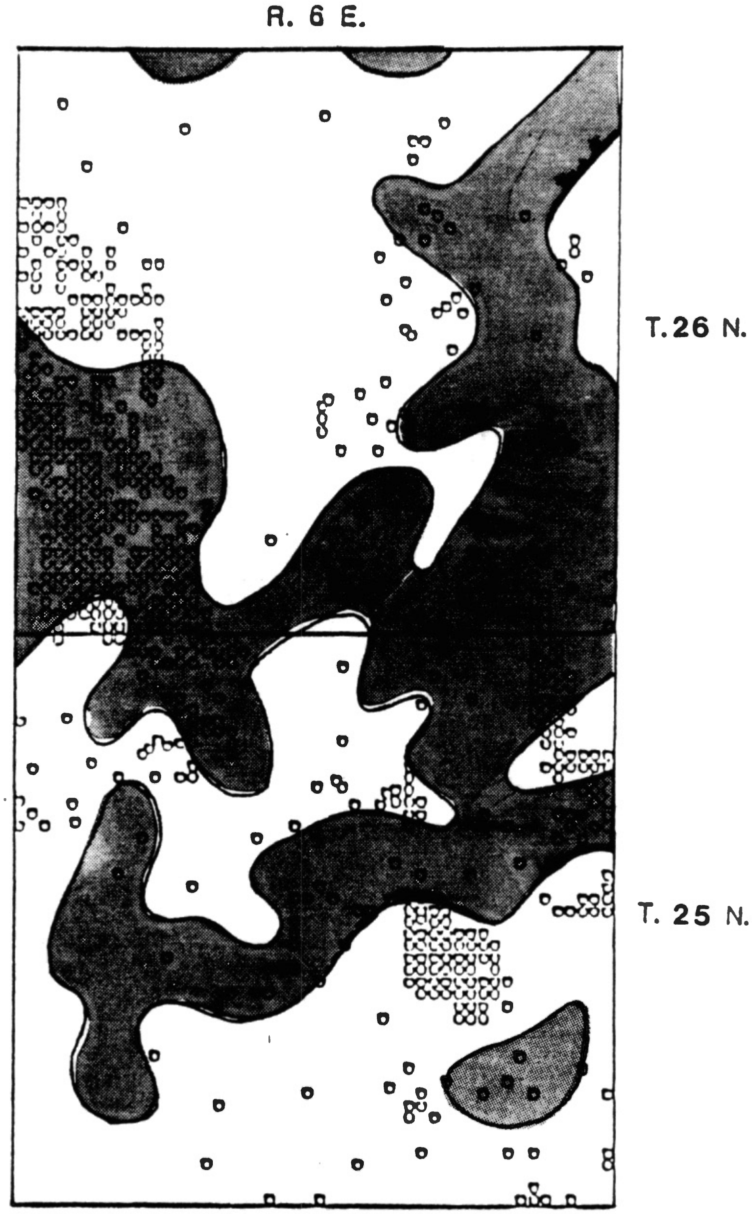


Figure 38: Injection-sensitivity map, Burbank Field. Shaded area outlines Zones of Caution, areas within which lineaments and joint clusters are suggestive of faulted rocks in the subsurface. In Zones of Caution, geologic evidence should accumulate to show that risks associated with injection of fluid are acceptable. (Scale: Width of diagram is 6 miles.)

CHAPTER V

SUMMARY

Attributes of confining beds were explored using techniques applicable for surface and subsurface geologic work. Outcrops where shale is underlain or overlain by jointed or fractured competent beds were examined. Where shale is clayey and ductile, joints in adjacent competent beds tend to end abruptly at the contact with shale. However, silty shales tend to be jointed in a fashion similar to nearby competent strata. Remote-sensing imagery, including satellite imagery and topographic maps, provided information for recognition of potential fracture-trends. Areal geological maps are invaluable in determining the susceptibility of rock types to localized jointing, specific erosional or weathering patterns, and/or major fracture trends.

Burbank Field provided a special opportunity to test fracture-delineation techniques. Additionally, this study provided an opportunity to test computer-mapping techniques to approximate structural configurations, thicknesses of beds, and areal extents of confining units and potential storage beds.

The use of isopotential or isoproduction maps to delineate suspected trends of fractures in the Burbank reservoir rock met with little success. Large lease and production unit sizes made isoproduction maps effectively useless, whereas methods of reporting initial flow rates and operator-introduced bias reduced confidence in mapping from initial-flow potentials. The most significant factor in use of isopotential maps for fracture-delineation was the overall character of the reservoir rock and the abrupt changes in reservoir quality associated with narrow, channel-fill sandstones. Although the isopotential study did identify several possible east-west fracture trends, there is reasonable doubt these trends are fracture-controlled.

Building a computer data base of part of Burbank Field allowed quick generation of various maps, including structural contour maps, interval-thickness maps, and cumulative-thickness maps of confining beds and potential storage units. Routine use of data bases and mapping software would allow geologists with limited experience in subsurface geology to collect, enter and manipulate data to generate a large variety of maps. This method would free experienced geologists for generation of maps which would be more definitive for judgment about injection-sensitivity of specific areas.

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APPENDIXES

APPENDIX A

LIMITATIONS OF COMPUTER-GENERATED MAPS

In general, the computer based maps are potentially very helpful. However, the limitations should be realized by anyone examining them. The Jupiter Mapping System uses a process referred to as neighborhood-based interpolation. The computer examines each data point and compares it to its neighbors, to interpolate the slope of values that surround the data point. (For a better explanation of neighborhood-based interpolation, see Watson and Philip, 1987). In places where no data exist, the computer will extrapolate the slope to a maximal or minimal value. While examining the computer-generated maps in this report, it is important to keep these facts in mind. Further, the system follows contouring rules that are somewhat different than those commonly followed by most geologists.

Examine Figures 38 and 39. In the southwestern corner of the map few data points were available to support the construction of the closed syncline. Also, the closed syncline near the southeastern corner may be attributable to bad data. Otherwise, this map compares favorably with a map that might be constructed by a geologist using standard contouring and drafting techniques.

With reference to Figure 40: Knowing limitations of the mapping system, it was hoped that the well locations and values of the data points could be plotted, along with contour lines. Even at a scale of 1 inch: 1 mile it is evident that addition of well locations and data point values to the contours would result in a map too cluttered to be of value.

Figure 42 shows thickness of the interval between the top of the Pink Lime and the top of the Cottage Grove interval. Contour lines show negative values because of the direction of subtraction of the two data sets. For the same reason, one should interpret closed "thicks" for closed "thins" and visa versa. Regardless of the direction of subtraction, absolute values of differences are meaningful.

Figure 43 shows thickness of the Cottage Grove interval. It also demonstrates a divergence from standard contouring procedures. If the 100-foot contour is followed from where it enters the map from the north in T. 26 N., R. 6 E., it can be seen to form two connecting loops with an "x" where the two loops join. Further, the closed "thin" approximately in Sec. 15, T. 26 N., R. 6 E., has few data points to substantiate it. The above statement also could be applied to the closed "thin" approximately in Sec. 9, T. 25 N., R. 6 E., and to the closed "thick" approximately in Sec. 19, T. 25 N., R. 6 E..

The main discrepancy in Figure 44 is the "thick" area in Sec. 12, T. 26 N., R. 6 E. This is the result of extrapolation in the absence of data. The reverse is true for the closed "thin" in the north part of Sec. 24, T. 26 N., R. 6 E., where less than 10 feet of sandstone is shown within the Cottage Grove interval. By examining the table in Appendix B, it may be seen that no less than 17 feet of sandstone were recorded anywhere in the studied area.

Figure 45, a thickness map, shows the amount of shale in the Cottage Grove interval. Values used to construct this map were obtained by drawing vertical lines on electric logs through points of 50 mv of deflection of the spontaneous potential curve from the shale base line. Rock to the right of this vertical line was interpreted as shale, whereas rock represented by the spontaneous potential curve to the left of this vertical line was interpreted as sandstone. The number of feet of shale within the interval was accumulated as a data point with which to construct this map. Although logs of some wells showed no shale, as defined by this method, one should keep in mind the tendency of the software to extrapolate in absence or sparsity of data.

Figure 47 shows the confining shale for the Cottage Grove interval. Whereas thickness of this confining bed was highly varied over the study area, some shale overlies the Cottage Grove interval throughout. Again, as this figure demonstrates in the southwestern and northwestern corners, the computer extrapolates toward a maximal or minimal value.

Cumulative shale above the Cottage Grove interval is shown in Figure 48, including the confining bed directly above the interval. Because the emphasis here was on the rock as a confining bed, a more rigorous definition of "shale" was used. Here, only rock with a spontaneous potential signature on or to the right of the shale base line was considered to be shale of confining potential. Two areas on this map that show conspicuously low amounts of confining potential are both unsupported by data. The more obvious is in Sec. 2, T. 26 N., R. 6 E., the other is approximately in Sec. 20, T. 26 N., R. 6 E..

Figure 49 shows the number of intervals of shale (as defined above) that are 20 feet or more thick. False "thins" are in Sec. 2 and 20, T. 26 N., R. 6 E. Also, the "thick" in the southwestern corner of the map is unsubstantiated.

Figure 50 illustrates the number of intervals above the Cottage Grove interval and below the top of the Pawhuska Limestone that are regarded as having potential for injection of fluids. The large numbers recorded in Sec. 5, T. 26 N., R. 6 E., and in Sec. 18, T. 25 N., R. 6 E., along with the small numbers recorded in Sec. 2, T. 26 N., R. 6 E. are not supported by the data collected.

APPENDIX B

COMPUTER DATA BASE

The following data base was used to construct computer-generated maps included in this report. Key to abbreviations:

WELL: Index number of log used.

SEC: Section number in which the well is located.

TWP: Township in which the well is located, with respect to the Oklahoma Base Line.

RGE: Range in which the well is located, with respect to the Indian Meridian.

S4 S3 S2 S1: Well location in quarter sections, to 2.5-acre tracts. Individually, S4, S3, S2, and S1 represent the quarter number as they would appear on a legal description (according to the Bureau of Land Management's subdivision of a 1-square-mile section).

ELEV: Elevation corresponding to zero feet in depth on wireline log -- generally, elevation of the Kelly Bushing.

COTTG: Elevation of the top of Cottage Grove Sandstone, relative to sea level.

COTHK: Total thickness of Cottage Grove.

COT%S: Percentage of sandstone within Cottage Grove interval.

FSDAC: Thickness of shale (thickness of confining bed) directly above Cottage Grove interval.

CFSAC: Cumulative thickness of shale above Cottage Grove (including that amount of shale represented by FSDAC).

NSBAC: Number of shale breaks of thickness greater than or equal to 20 feet that lie between the Cottage Grove Sandstone and surface casings of wells.

NPIAC: Number of possible injection sites above Cottage Grove interval.

COTFS: Thickness of shale within Cottage Grove interval.

COTNS: Thickness of sand within Cottage Grove interval.

PNKLM: Elevation of top of Pink Lime, relative to sea level.

Blank spaces show where data were not available.

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
68	2	26	6		SW	SW	SW	1122	-891	96	11	
253	2	26	6				SW					220
255	3	26	6		SW	NW	SW	1047	-906	103	14	210
255.7	3	26	6		SE	SE	SE	1138	-895	92	13	
256	5	26	6		NE	SW	SE	1028	-1057	98	11	270
257	6	26	6		NE	NE	SW	992	-1044	107	40	272
258	7	26	6		SE	NW	NE	1019	-989	106	47	250
259	7	26	6		NE	NE	SW	1089	-1011	103	30	238
260	7	26	6		NW	NE	SW	1061	-1019	110	46	210
261	7	26	6		SE	NE	SW	1088	-1020	92	17	214
262	7	26	6		NE	NW	SW	1044	-1024	106	49	215
263	7	26	6		NW	NW	SW	1043	-1029	108	22	217
264	7	26	6		SE	NW	SW	1063	-1018	117	38	223
265	7	26	6		NE	SW	SW	1051	-1035	93	34	242
266	7	26	6		NW	SW	SW	1029	-1041	100	14	200
267	7	26	6		SE	SW	SW	1030	-1038	100	20	210
268	7	26	6		NE	SE	SW	1085	-1029	94	26	227
269	7	26	6		NW	SE	SW	1086	-1027	97	24	230
270	7	26	6		SE	SE	SW	1048	-1032	97	29	247
271	7	26	6		SW	SW	SE	1051	-1029	100	36	237
272	8	26	6		NW	SW	SW	1058	-1008	98	36	271
274	10	26	6		E2	NE	NE	1122	-898	105	11	112
275	10	26	6		SW	SE	SE	1128	-903	117	8	217
276	11	26	6		W2	NW	SW	1090	-879	115	30	134
280	11	26	6		SE	NW	SW	1096	-894	96	8	200
278	11	26	6		SW	SW	SW	1132	-900	96	8	220
277	11	26	6		NW	SE	SW	1098	-859	121	31	200
280.72	12	26	6		SW	NW	SW	1146	-846	104	18	
280.74	12	26	6		SW	SW	SE	1160	-834	96	16	
281	13	26	6		NW	NW	NE	1164	-840	98	70	164
282	13	26	6		NE	SW	NE	1175	-833	91	52	236
283	13	26	6		SE	NE	NW	1149	-828	107	29	168
283.78	13	26	6		SE	SW	SW	1203	-868	25	12	
284	14	26	6		SW	SW	NE	1156	-864	98	5	157
286	14	26	6	N2	N2	NE	SW	1149	-859	96	9	160
290	14	26	6	W2	W2	NE	SW	1149				
291	14	26	6		SE	NE	SW	1207	-855	96	3	160
288	14	26	6		SE	NW	SW	1176	-865	99	17	160
294	15	26	6			NW	NE	1131	-909	94	4	242
292	15	26	6			SE	NE	1161	-902	95	3	233
298	15	26	6		NE	NW	SE	1159	-905	96	4	117
297	15	26	6			SE	SE	1200	-880	96	5	160
299	15	26	6		SE	SE	SE	1154	-902	91	3	220
301	17	26	6		SW	NE	NW	1083	-996	94	22	283
302	17	26	6		SE	NE	NW	1116	-954	126	29	236
303	17	26	6		SW	SE	NW	1070	-999	91	35	258
304	17	26	6		NE	NE	SW	1115	-973	112	34	110
305	17	26	6		NW	NE	SW	1078	-991	96	18	103
309	17	26	6		NE	NW	SW	1056	-1001	93	19	236
306	17	26	6		NW	NW	SW	1043	-1001	95	15	263
307	17	26	6		SW	NW	SW	1036	-998	99	55	234
310	17	26	6		SW	SW	SW	1064	-997	104	74	107
311	17	26	6		SE	SW	SW	1041	-991	116	60	117

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
312	17	26	6		NE	SE	SW	1056	-976	115	32	130
313	17	25	6		SW	SE	SW	1067	-1006	87	60	126
314	17	26	6		SE	SE	SW	1102	-1010	88	68	123
315	18	26	6		NE	NE	NE	1068	-995	116	54	233
316	18	26	6		SE	NE	NE	1068	-994	108	47	246
318	18	26	6		NE	NW	NE	1058	-1017	98	30	245
317	18	26	6		SW	NW	NE	1044	-1003	96	18	237
319	18	26	6		SE	NW	NE	1027	-1020	100	35	246
320	18	26	6		NE	SW	NE	1026	-1020	93	34	230
321	18	26	6		NW	SE	NE	1029	-1011	95	38	233
322	18	26	6		SE	SE	NE	1032	-976	122	28	237
323	18	26	6		NE	NE	NW	1033	-1034	99	26	182
324	18	26	6		NW	NE	NW	1026	-1042	94	26	210
325	18	26	6		SE	NE	NW	1026	-1021	113	39	224
326	18	26	6		NW	NW	NW	1020	-1050	94	23	220
327	18	26	6		SE	NW	NW	1014	-1046	98	35	227
328	18	26	6		NE	SW	NW	1014	-1039	95	34	236
329	18	26	6		NW	SW	NW	1014	-1049	90	31	240
330	18	26	6		SE	SW	NW	1025	-1034	89	31	244
331	18	26	6		NE	SE	NW	1018	-1014	108	41	234
332	18	26	6		SE	SE	NW	1028	-1010	106	47	227
333	18	26	6		SW	NE	SW	1024	-1003	111	83	258
334	18	26	6		SE	NE	SW	1012	-1002	116	85	253
335	18	26	6		SW	NW	SW	1031	-1029	107	63	252
336	18	26	6		SE	NW	SW	1031	-1040	79	76	252
337	18	26	6		NE	SW	SW	1026	-1008	108	76	241
338	18	26	6		NW	SW	SW	1011	-1017	109	71	256
339	18	26	6		SW	SW	SW	999	-1015	110	71	245
339.5	18	26	6		SE	SW	SW	1012	-1020	106	77	245
340	18	26	6		NE	SE	SW	1008	-1004	116	76	248
341	18	26	6		NW	SE	SW	1007	-1010	111	80	224
342	18	26	6		SW	SE	SW	1003	-1003	102	76	234
343	18	26	6		SE	SE	SW	1000	-1013	107	79	260
344	18	26	6		NE	NE	SE	1024	-980	116	13	259
345	18	26	6		NW	NE	SE	1022	-982	114	56	240
346	18	26	6		SW	NE	SE	1024	-987	113	69	249
347	18	26	6		SE	NE	SE	1030	-988	112	71	250
348	18	26	6		NE	NW	SE	1012	-994	103	49	244
349	18	26	6		NW	NW	SE	1024	-996	104	41	247
350	18	26	6		SE	NW	SE	1018	-987	113	58	252
351	18	26	6		NE	SW	SE	1020	-995	123	61	261
352	18	26	6		SW	SW	SE	1014	-1008	107	65	258
353	18	26	6		SE	SW	SE	1027	-1003	105	76	278
354	18	26	6		NE	SE	SE	1051	-996	108	49	257
355	18	26	6		NW	SE	SE	1040	-990	116	69	258
356	18	26	6		SW	SE	SE	1043	-997	110	70	272
356.86	19	26	6		SW	SW	NE	1032	-1023	107	16	
356.88	19	26	6		SW	SE	NE	1068	-1026	98	47	
356.89	19	26	6		SE	SE	NE	1114	-1023	107	52	
356.91	19	26	6		NW	NW	NW	1000	-1017	94	43	
356.93	19	26	6		SE	NW	NW	991	-1024	95	33	
356.92	19	26	6			SW	NW	1002	-1037	91	5	
356.94	19	26	6		NE	SW	NW	994	-1020	113	25	

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
356.95	19	26	6		SW	SW	NW	1019	-1025	109	31	
356.96	19	26	6		SE	SW	NW	1007	-1023	130	39	
356.97	19	26	6		NW	SE	NW	1002	-1018	105	46	
357	19	26	6		SE	SE	NW	1015	-1015	109	33	130
358	19	26	6		NE	NE	SW	1058	-1015	116	29	143
359	19	26	6		NW	NE	SW	1041	-1031	128	20	134
360	19	26	6		SW	NE	SW	1068	-1017	141	23	140
361	19	26	6		SE	NE	SW	1092	-1014	92	13	162
362	19	26	6		NE	NW	SW	1036	-1034	128	28	140
363	19	26	6		NW	NW	SW	1098	-1042	125	9	113
364	19	26	6		SW	NW	SW	1085	-1045	118	8	143
365	19	26	6		SE	NW	SW	1062	-1038	120	9	115
368	19	26	6			SW	SW	1035	-1015	113	29	175
366	19	26	6		NE	SW	SW	1045	-1021	112	21	147
367	19	26	6		NW	SW	SW	1083	-1035	108	16	120
369	19	26	6		SW	SW	SW	1036	-1027	98	13	150
370	19	26	6		SE	SW	SW	1058	-1014	106	18	170
371	19	26	6		NE	SE	SW	1079	-1009	132	40	155
372	19	26	6		NW	SE	SW	1091	-1011	131	27	126
373	19	26	6		SW	SE	SW	1046	-1012	108	33	180
374	19	26	6		SE	SE	SW	1045	-1017	118	26	170
375	19	26	6		NW	NE	SE	1107	-1021	102	27	122
376	19	26	6		SW	NE	SE	1078	-1004	108	19	130
377	19	26	6		SE	NW	SE					
378	19	26	6		NE	SE	SE	1087	1006	105	16	125
379	19	26	6		NW	SE	SE	1095	-1010	105	15	127
380	19	26	6		SE	SE	SE	1067	-1005	98	22	126
381	20	26	6		NE	NE	NW	1086	-1011	91	46	140
382	20	26	6		NW	NE	NW	1067	-1011	90	39	136
383	20	26	6		SW	NE	NW	1076	-996	101	70	134
384	20	26	6		SE	NE	NW	1089	-1004	89	58	129
386	20	26	6		NE	SE	NW	1090	-998	91	60	133
387	20	26	6		NW	SE	NW	1117	-991	101	59	161
388	20	26	6		SW	SE	NW	1140	-994	103	77	183
389	20	26	6		SE	SE	NW	1123	-987	103	47	180
389.102	20	26	6			NE	SW	1138	-989	83	66	
389.101	20	26	6		NW	NE	SW	1134	-1005	88	61	180
385	20	26	6		SW	NW	SW	1124	-1006	99	21	191
389.104	20	26	6		NE	SW	SW	1095	-998	100	15	170
389.105	20	26	6		SE	SW	SW	1090	-988	95	13	126
390	22	26	6		SE	SW	NE	1192	-873	107	0	186
399	22	26	6		NE	NE	SW	1209	-853	120	34	182
395	22	26	6			NW	SW	1180	-908	109	24	160
393	22	26	6		SW	NW	SW	1175	-905	117	14	165
392	22	26	6		NW	SW	SW	1156	-890	129	39	170
394	22	26	6		SW	SW	SW	1185	-879	134	36	166
400	22	26	6			S2	SE	1198	-842	135	37	194
401	22	26	6			E2	SE	1206	-864	123	31	180
398	22	26	6		NW	SW	SE	1216	-837	143	36	209
396	22	26	6		NE	SE	SE	1213	-820	135	36	182
397	22	26	6		SE	SE	SE	1187	-815	138	53	200
402	23	26	6	SE	NW	NE	NW	1203	-865	91	14	182
403	23	26	6			W2	SE	1179	-787	144	64	210

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
404	25	26	6		NW	NW	NE	1173	-772	155	65	240
405	25	26	6		NE	NW	SW	1146	-797	147	35	240
406	25	26	6		SE	SW	SW	1138	-787	155	35	278
407	26	26	6		S2	SW	SE	1131	-816	133	55	282
408	27	26	6			NW	NE	1178	-830	148	74	210
409	27	26	6			N2	NW	1161	-831	148	65	217
410	29	26	6		SW	SW	NE	1043	-971	112	20	152
411	29	26	6		SW	NE	NW	1127	-965	114	25	147
412	29	26	6		NE	NW	NW	1088	-985	96	16	223
413	29	26	6		NW	NW	NW	1088	-992	95	13	195
414	29	26	6		SW	NW	NW	1101	-976	113	25	199
416	29	26	6	S2	SW	NW	NW	1109	-963	116	20	140
415	29	26	6		SE	NW	NW	1128	-984	98	12	196
416.54	29	26	6		NE	SW	NW	1120	-966	118	18	142
417	29	26	6		NW	SW	NW	1124	-966	128	21	135
418	29	26	6		SW	SW	NW	1117	-975	114	11	150
419	29	26	6		SE	SW	NW	1134	-964	115	27	146
420	29	26	6		NE	SE	NW	1100	-952	125	22	147
421	29	26	6		NW	SE	NW	1135	-955	120	21	142
422	29	26	6		SW	SE	NW	1116	-951	123	25	143
423	29	26	6		SE	SE	NW	1069	-978	97	14	147
424	29	26	6		NW	NE	SW	1118	-959	113	27	144
425	29	26	6		SW	NW	SW	1103	-974	113	20	140
426	29	26	6		SE	NW	SW	1078	-954	126	15	142
428	29	26	6		NE	SW	SW	1130	-955	123	16	146
429	29	26	6		NW	SW	SW	1124	-958	128	13	137
430	29	26	6		SE	SW	SW	1103	-960	121	17	149
431	29	26	6		NE	SE	SW	1029	-958	116	22	155
432	29	26	6		NW	SE	SW	1075	-945	130	16	153
433	29	26	6		SE	SE	SW	1014	-964	107	43	168
434	29	26	6		SE	NE	SE	1081	-956	93	63	170
435	29	26	6		NE	NW	SE	1064	-956	118	23	156
436	29	26	6		NW	NW	SE	1041	-964	116	30	150
437	29	26	6		NE	SW	SE	1046	-973	91	59	177
438	29	26	6		NW	SW	SE	1047	-956	115	63	163
439	29	26	6		SE	SW	SE	1061	-963	107	39	167
440	29	26	6		NE	SE	SE	1076	-947	113	62	183
441	29	26	6		SW	SE	SE	1062	-959	99	64	182
442	30	26	6		NE	NE	NE	1056	-1003	101	26	190
443	30	26	6		SW	NE	NE	1087	-993	107	19	134
444	30	26	6		NE	NW	NE	1043	-1009	95	22	178
445	30	26	6		NW	NW	NE	1035	-1013	101	17	177
446	30	26	6		SW	NW	NE	1101	-1002	104	17	186
447	30	26	6		SE	NW	NE	1092	-1003	92	20	181
448	30	26	6		NE	SW	NE	1105	-995	108	28	189
449	30	26	6		NW	SW	NE	1073	-999	103	19	207
450	30	26	6		SW	SW	NE	1108	-986	116	15	204
451	30	26	6		SE	SW	NE	1094	-984	112	18	200
452	30	26	6		NW	SE	NE	1115	-990	105	19	198
453	30	26	6		SW	SE	NE	1112	-972	116	30	190
454	30	26	6		NE	NE	NW	1025	-1015	108	27	190
455	30	26	6		NW	NE	NW	1018	-1024	94	29	183
456	30	26	6		SW	NE	NW	1092	-1005	103	9	170

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
457	30	26	6		SE	NE	NW	1096	-1008	103	17	178
458	30	26	6		NE	NW	NW	1013	-1027	93	13	164
459	30	26	6		NW	NW	NW	1012	-1035	88	22	150
460	30	26	6		SE	NW	NW	1081	-1019	98	20	169
461	30	26	6		NE	SW	NW	1025	-1030	95	17	182
462	30	26	6		NW	SE	NW	1044	-1016	97	14	182
463	30	26	6		SW	SE	NW	1051	-1012	115	18	173
464	30	26	6		SE	SE	NW	1094	-996	110	16	180
465	30	26	6		NE	NE	SW	1072	-990	125	14	185
466	30	26	6		SW	NE	SW	1052	-985	131	19	173
467	30	26	6		SE	NE	SW	1096	-978	136	21	183
468	30	26	6		NE	NW	SW	1079	-1003	126	19	188
469	30	26	6		NE	SE	SW	1074	-986	129	19	180
470	30	26	6		SE	SE	SW	1102	-984	128	25	188
471	30	26	6		NE	NE	SE	1115	-962	123	29	194
472	30	26	6		NW	NE	SE	1111	-961	125	35	139
473	30	26	6		SW	NE	SE	1104	-980	116	19	134
474	30	26	6		SE	NE	SE	1088	-978	112	27	140
475	30	26	6		NE	NW	SE	1086	-971	123	35	189
476	30	26	6		NW	NW	SE	1067	-983	120	26	230
477	30	26	6		SW	NW	SE	1104	-979	124	15	216
478	30	26	6		SE	NW	SE	1114	-969	127	19	134
479	30	26	6		NE	SW	SE	1112	-975	121	19	133
480	30	26	6		NW	SW	SE	1091	-979	126	21	174
481	30	26	6		SW	SW	SE	1099	-981	128	34	136
482	30	26	6		SE	SW	SE	1102	-974	130	24	136
483	30	26	6		NE	SE	SE	1098	-991	101	12	172
483.143	30	26	6		NW	SE	SE	1079	-966	129	24	133
484	30	26	6		SW	SE	SE	1065	-971	124	25	140
485	30	26	6		SE	SE	SE	1072	-964	129	16	144
486	31	26	6		NW	NE	NE	1054	-989	110	24	180
487	31	26	6		SW	NE	NE	1105	-988	107	23	183
488	31	26	6		SE	NE	NE	1110	-991	99	15	193
489	31	26	6		NE	NW	NE	1056	-976	131	29	122
490	31	26	6		NW	NW	NE	1058	-985	127	17	134
491	31	26	6		SW	NW	NE	1033	-1007	103	14	171
492	31	26	6		SE	NW	NE	1054	-1006	98	15	150
497	31	26	6			SW	NE	1031	-989	113	17	154
493	31	26	6		NE	SW	NE					
494	31	26	6		NW	SW	NE	1034	-1008	99	10	150
495	31	26	6		SW	SW	NE	1030	-990	118	33	155
496	31	26	6		SE	SW	NE	1054	-986	120	21	160
498	31	26	6		NE	SE	NE	1107	-976	115	44	164
499	31	26	6		NW	SE	NE	1054	-993	101	34	162
500	31	26	6		SW	SE	NE	1094	-976	100	63	170
501	31	26	6		SE	SE	NE	1092	-970	104	76	176
502	31	26	6		NE	NE	NW	1058	-1010	115	12	135
503	31	26	6		NW	NE	NW	1075	-998	130	22	190
504	31	26	6		SW	NE	NW	1078	-992	130	21	130
505	31	26	6		SE	NE	NW	1032	-992	126	10	140
506	31	26	6		NE	SE	NW	1014	-990	132	20	136
507	31	26	6		NW	SE	NW	1069	-1007	108	35	142
508	31	26	6		SW	SE	NW	1022	-1014	99	40	148

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
509	31	26	6		SE	SE	NW	999	-991	119	42	143
510	31	26	6		NE	NE	SW	1013	-981	124	30	144
511	31	26	6		NW	NE	SW	1001	-981	120	34	144
512	31	26	6		SW	NE	SW	990	-987	119	29	152
513	31	26	6		NE	NW	SW	1016	-992	120	53	193
514	31	26	6		NE	SE	SW	1014	-1007	97	81	176
515	31	26	6		NW	SE	SW	1004	-1001	105	37	160
516	31	26	6		SE	SE	SW	1027	-993	103	68	177
517	31	26	6		NE	NE	SE	1109	-981	94	62	188
518	31	26	6		NW	NE	SE	1069	-972	106	63	177
519	31	26	6		SW	NE	SE	1112	-995	78	76	185
520	31	26	6		SE	NE	SE	1128	-983	99	86	190
521	31	26	6		NE	NW	SE	1054	-978	118	59	168
522	31	26	6		NW	NW	SE	1033	-987	110	40	160
523	31	26	6		SW	NW	SE	1075	-988	105	51	171
524	31	26	6		SE	NW	SE	1064	-996	98	80	184
525	31	26	6		NE	SW	SE	1047	-1003	78	82	186
526	31	26	6		NW	SW	SE	1022	-988	113	79	180
527	31	26	6		NE	SE	SE	1113	-957	113	87	200
528	31	26	6		NW	SE	SE	1068	-993	93	87	187
529	31	26	6		SW	SE	SE	1083	-971	116	77	204
530	31	26	6		SE	SE	SE	1117	-956	115	62	216
531	32	26	6		SW	NE	NE	1082	-937	113	46	200
532	32	26	6		NE	NW	NE	1048	-946	114	77	190
533	32	26	6		NW	NW	NE	1046	-957	96	42	200
534	32	26	6		SW	NW	NE	1046	-951	101	77	186
535	32	26	6		SE	NW	NE	1063	-941	114	61	193
536	32	26	6		NE	SW	NE	1086	-934	113	49	204
537	32	26	6		NW	SW	NE	1065	-941	112	58	188
538	32	26	6		SW	SW	NE	1056	-936	110	50	
539	32	26	6		SE	SW	NE	1059	-929	106	40	220
540	32	26	6		NW	SE	NE	1087	-929	116	42	211
541	32	26	6		SW	SE	NE	1086	-924	114	40	224
542	32	26	6		NE	NE	NW	1023	-963	104	56	174
543	32	26	6		SW	NE	NW	1038	-959	96	64	177
545	32	26	6		SE	NE	NW	1011	-953	105	53	183
546	32	26	6		NW	NW	NW	1123	-971	120	25	152
547	32	26	6	E2	SE	NW	NW	1063	-969	108	75	175
548	32	26	6		NE	SW	NW	1068	-961	100	52	176
549	32	26	6		SE	SW	NW	1047	-962	109	50	185
544	32	26	6		NE	SE	NW	1022	-948	118	43	188
550	32	26	6		NW	SE	NW	1033	-951	103	74	188
551	32	26	6		SW	SE	NW	1022	-950	111	55	190
552	32	26	6		SE	SE	NW	990	-952	105	62	190
553	32	26	6		NW	NE	SW	1015	-947	111	67	197
554	32	26	6		SW	NE	SW	980	-930	113	57	220
555	32	26	6		SE	NE	SW	1025	-940	105	50	228
556	32	26	6		NE	NW	SW	1058	-955	109	48	200
557	32	26	6		NW	NW	SW	1099	-964	110	48	180
558	32	26	6		SW	NW	SW	1087	-954	116	12	193
562	32	26	6		NE	SW	SW	1038	-943	99	54	227
560	32	26	6		NW	SW	SW	1060	-955	105	61	211
561	32	26	6		SW	SW	SW	1071	-953	112	39	224

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
563	32	26	6		SE	SW	SW	1036	-944	114	54	241
564	32	26	6		NE	SE	SW	1019	-935	112	42	244
565	32	26	6		NW	SE	SW	998	-944	105	45	227
566	32	26	6		SW	SE	SW	971	-937	112	35	252
567	32	26	6		SE	SE	SW	1017	-932	73	48	252
568	32	26	6		NW	NE	SE	1077	-919	112	50	234
569	32	26	6		SW	NE	SE	1078	-920	107	50	247
570	32	26	6		NE	NW	SE	1077	-923	110	43	230
571	32	26	6		NW	NW	SE	1040	-930	110	41	223
572	32	26	6		SW	NW	SE	1073	-930	115	44	237
573	32	26	6		SE	NW	SE	1079	-931	100	49	246
574	32	26	6		NE	SW	SE	1082	-929	112	35	252
575	32	26	6		NW	SW	SE	1049	-934	107	39	251
576	32	26	6		SW	SW	SE	1059	-933	108	29	253
577	32	26	6		SE	SW	SE	1045	-920	107	39	257
580	32	26	6		NE	SE	SE	1050	-917	125	29	253
578	32	26	6		NW	SE	SE	1061	-929	110	25	250
579	32	26	6		SW	SE	SE	1044	-914	118	32	256
581	32	26	6		SE	SE	SE	1038	-908	126	27	252
582	33	26	6		NW	NW	NE	1148	-909	121	38	234
583	33	26	6		NE	SE	NE	1108	-899	125	41	259
585	34	26	6		NE	SE	NW	1128	-854	130	37	250
585.147	34	26	6		NW	SE	NW	1092	-867	134	43	
584	34	26	6		NE	NW	SW	1086	-866	154	32	262
586	35	26	6		SW	NW	NE	1124	-824	129	46	247
587	35	26	6		NE	SW	NE	1105	-832	126	46	280
588	35	26	6		SW	SE	NE	1115	-839	116	38	270
589	35	26	6		SE	SE	NE	1086	-824	127	48	277
590	35	26	6	S2	NE	NE	SW	1129	-839	133	44	254
592	35	26	6		NE	NE	SE	1113	-814	140	39	289
594	35	26	6		NW	NE	SE	1135	-819	136	33	277
593	35	26	6		SW	NE	SE	1130	-813	135	32	270
591	35	26	6		NE	SW	SE	1115	-835	143	36	270
612	35	26	6		NE	SE	SE	1075	-811	127	46	283
595	36	26	6		SE	SE	NE	1028	-734	120	24	292
596	36	26	6		SE	NW	NW	1079	-791	150	25	268
597	36	26	6		NW	SW	NW	1063	-806	144	27	275
598	36	26	6		SW	SW	NW	1041	-807	136	47	295
599	36	26	6		SE	SW	NW	1076	-788	136	21	263
600	36	26	6		NW	SE	NW	1128	-784	144	25	265
601	36	26	6		SE	SE	NW	1062	-761	134	25	263
601.61	36	26	6		W2	NE	SW	1045	-775	134	31	278
602	36	26	6		NE	NW	SW	1054	-786	134	31	274
603	36	26	6		NW	NW	SW	1036	-804	134	54	276
604	36	26	6		SE	NW	SW	1041	-795	123	60	280
605	36	26	6		NE	SW	SW	1026	-790	111	64	297
606	36	26	6		NW	SW	SW	1034	-799	127	50	283
607	36	26	6		SE	SW	SW	1029	-790	115	39	307
608	36	26	6		NW	SE	SW	1034	-786	96	63	310
609	36	26	6		SW	SE	SW	1020	-782	106	63	311
610	36	26	6		SE	NE	SE	1027	-703	104	16	299
611	36	26	6		NW	NW	SE	1048	-728	126	25	285
613	36	26	6		SE	SE	SE	1024	-696	116	23	312

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
653	1	25	6		SW	SW	NE	1062	-814	81	44	261
654	1	25	6		NE	NE	NW	1026	-767	109	62	322
655	1	25	6		NW	NE	NW	1014	-778	106	59	312
656	1	25	6		SW	NE	NW	1010	-812	80	39	328
657	1	25	6		SE	NE	NW	1010	-801	99	41	340
658	1	25	6		NE	NW	NW	1043	-780	116	6	313
659	1	25	6		SE	NW	NW	1021	-819	94	46	321
660	1	25	6		NE	SW	NW	1011	-822	94	43	334
661	1	25	6		SE	SW	NW	999	-832	89	64	272
662	1	25	6		NE	SE	NW	998	-804	100	43	271
663	1	25	6		NW	SE	NW	1000	-820	86	47	273
664	1	25	6		SW	SE	NW	998	-838	82	45	268
665	1	25	6		SE	SE	NW	1032	-814	97	47	274
666	1	25	6		NE	NE	SW	1037	-820	97	37	232
667	1	25	6		SW	NE	SW	1042	-829	87	48	250
668	1	25	6		SE	NE	SW	1032	-820	90	46	260
669	1	25	6		NE	NW	SW	1025	-831	88	45	269
670	1	25	6		SE	NW	SW	1050	-830	93	41	267
671	1	25	6		NE	SW	SW	1019	-824	107	29	267
672	1	25	6		SE	SW	SW	1028	-804	115	45	245
672.5	1	25	6		NE	SE	SW	1032	-804	122	36	260
673	1	25	6		NW	SE	SW	1012	-822	111	37	264
674	1	25	6		SW	SE	SW	1023	-790	127	50	245
675	1	25	6		SE	SE	SW	1021	-779	138	44	240
676	1	25	6		NW	NW	SE	1045	-813	89	49	261
677	1	25	6		SW	NW	SE	1035	-811	97	54	256
678	1	25	6		NW	SW	SE	1031	-784	123	45	235
679	2	25	6		NE	NE	NE	1039	-816	113	43	306
680	2	25	6		SW	NE	NW	1116	-851	120	37	287
681	2	25	6		SE	SW	NW	1110	-860	110	33	305
682	2	25	6		W2	W2	SW	1080	-854	106	21	298
683	2	25	6		SW	NW	SE	1032	-849	102	25	271
684	3	25	6	SW	NW	SE	NW	1089	-871	117	14	294
685	4	25	6		SW	NE	NW	1063	-899	113	28	234
686	4	25	6		NE	NW	NW	1013	-900	134	30	267
687	4	25	6		NW	NW	NW	1011	-894	138	36	275
688	4	25	6		SW	NW	NW	1048	-905	117	27	290
689	4	25	6		SE	NW	NW	1074	-899	113	24	280
690	4	25	6		NE	SW	NW	1077	-903	98	17	282
691	4	25	6		NW	SW	NW	1070	-912	104	13	262
692	4	25	6		SW	NW	SW	1092	-864	119	29	277
693	4	25	6		SW	SW	SW	1073	-865	114	33	312
694	5	25	6		NE	NE	NE	977	-906	125	30	264
695	5	25	6		NW	NE	NE	972	-911	125	27	258
696	5	25	6		SW	NE	NE	1038	-904	132	29	270
697	5	25	6		SE	NE	NE	1044	-908	115	30	283
698	5	25	6		NW	NW	NE	1008	-917	131	32	252
699	5	25	6		SE	NW	NE	1027	-915	136	24	261
700	5	25	6		NE	SW	NE	1037	-910	122	22	277
701	5	25	6		NW	SW	NE	1019	-908	126	26	263
702	5	25	6		NW	SE	NE	1051	-915	121	26	281
703	5	25	6		NW	NE	NW	1008	-940	115	28	257
704	5	25	6		SW	NE	NW	964	-932	122	32	257

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
705	5	25	6		SE	NE	NW	950	-920	134	27	253
706	5	25	6		NE	NW	NW	1050	-946	117	26	253
707	5	25	6		NW	NW	NW	1051	-951	118	37	248
708	5	25	6		SE	NW	NW	1012	-942	114	29	258
709	5	25	6		NE	SE	NW	954	-919	133	29	268
710	5	25	6		SW	SE	NW	940	-931	123	24	273
711	5	25	6		NE	NE	SE	1066	-901	103	17	265
712	5	25	6		SW	NW	SE	1047	-919	94	18	254
713	5	25	6		SE	NW	SE	1044	-912	94	11	261
714	5	25	6		NE	SW	SE	1067	-905	95	15	270
715	5	25	6		NW	SE	SE	1077	-893	91	16	267
716	5	25	6		SW	SE	SE	1075	-883	92	35	280
717	5	25	6		SE	SE	SE	1067	-877	96	27	292
718	6	25	6		NE	NE	NE	1085	-955	120	31	234
719	6	25	6		NE	NE	NW	1019	-991	108	69	184
720	6	25	6		SW	SW	SW	911	-991	94	73	258
721	6	25	6	NW	SW	SW	SE	1012	-978	123	24	280
722	7	25	6	NW	SW	SE	NE	1008	-962	123	24	300
723	7	25	6	S2	SE	SW	NW	1001	-999	116	34	274
724	7	25	6		NW	SW	SW	987	-1028	95	51	307
725	7	25	6		SE	SW	SW	976	-1017	108	40	301
726	7	25	6	SE	NW	SW	SE	899	-989	109	33	281
727	8	25	6		NE	NE	NE	1080	-857	98	42	287
728	8	25	6		NW	NE	NE	1080	-863	97	41	304
729	8	25	6		SW	NE	NE	1063	-859	103	34	312
730	8	25	6	S2	SW	NW	NE	1067	-873	97	32	295
731	8	25	6		SE	NW	NE	1076	-868	95	44	307
735	8	25	6		SW	SE	NE	956	-886	108	46	302
735.732	8	25	6	NE	SE	NE	NW	1040	-901	89	25	283
739	8	25	6			E2	NW	1044	-902	81	22	307
739.733	8	25	6		NW	SE	NW	1018	-913	107	45	295
741.72	8	25	6		NE	NE	SW	980	-913	115	24	307
741	8	25	6		NW	NW	SW	926	-936	108	14	310
741.73	8	25	6		NW	NE	SE	946	-906	112	14	314
742	8	25	6		NE	NW	SE	957	-919	90	24	310
742.73	9	25	6		NE	NW	NW	1005	-868	105	31	300
742.73	9	25	6		NW	NW	NW	997	-853	107	43	291
742.73	9	25	6		SE	NW	NW	972	-870	108	38	317
742.74	9	25	6		NE	SW	NW	945	-875	100	22	303
743	10	25	6		SE	SE	NE	987	-835	126	60	250
745	10	25	6	NW	SW	NE	NW	969	-865	106	11	266
748	10	25	6	NW	SW	NE	SW	1079	-853	115	57	265
749	10	25	6	SE	NE	NW	SW	1104	-828	106	68	247
746	10	25	6	NW	SW	NW	SW	1105	-842	106	51	257
747	10	25	6	SW	NE	SE	SW	1107	-834	127	39	239
750	10	25	6		NE	NE	SE	1107	-829	119	42	246
751	10	25	6		SW	NE	SE	1119	-824	117	66	247
752	10	25	6		SE	NE	SE	1108	-825	117	41	250
753	10	25	6	SE	SE	NW	SE	1041	-831	125	79	243
754	10	25	6	SW	NE	SW	SE	1117	-826	127	48	240
755	10	25	6		NE	SE	SE	1133	-808	129	42	255
756	10	25	6		NW	SE	SE	1126	-821	125	38	234
757	10	25	6		SE	SE	SE	1130	-810	137	34	236

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
758	11	25	6		NW	SW	SW	1051	-807	137	39	244
759	11	25	6		SW	SW	SW	1114	-811	87	54	240
760	11	25	6		SE	SW	SE	1024	-788	146	40	237
761	12	25	6		NW	NW	NE	1027	-778	121	43	236
762	12	25	6		NE	SW	NE	1070	-766	130	65	237
763	12	25	6		NW	SW	NE	1055	-773	134	54	236
764	12	25	6		SW	SW	NE	1138	-765	145	56	240
765	12	25	6		SE	SW	NE	1115	-765	136	48	240
766	12	25	6		NE	SE	NE	1100	-722	156	44	238
767	12	25	6		NW	SE	NE	1085	-747	144	58	238
768	12	25	6		SW	SE	NE	1090	-760	134	61	236
769	12	25	6		SE	SE	NE	1097	-723	165	39	236
769.789	12	25	6		S2	SE	NE	1108	-732	160	56	243
770	12	25	6		NE	NE	NW	1038	-772	138	59	238
771	12	25	6		NW	NE	NW	1045	-777	128	63	242
772	12	25	6		SW	NE	NW	1117	-783	126	62	240
773	12	25	6		SE	NE	NW	1062	-776	132	65	248
774	12	25	6		NE	SE	NW	1150	-777	141	72	238
775	12	25	6		SW	SE	NW	1150	-787	133	56	237
776	12	25	6		SE	SE	NW	1134	-782	127	57	236
777	12	25	6		NE	NE	SW	1100	-782	128	52	243
778	12	25	6		SE	SE	SW	1073	-744	167	68	247
779	12	25	6		NE	NE	SE	1150	-760	117	43	240
780	12	25	6		NW	NE	SE	1160	-770	118	42	239
781	12	25	6		SW	NE	SE	1096	-738	153	64	241
782	12	25	6		SE	NE	SE	1099				
783	12	25	6		SE	NW	SE	1108	-742	160	55	247
784	12	25	6		SW	SW	SE	1174	-760	136	55	247
785	12	25	6		SE	SW	SE	1093	-737	170	75	246
786	12	25	6		NE	SE	SE	1127	-725	182	48	247
787	12	25	6		NW	SE	SE	1095	-720	169	66	245
788	12	25	6		SE	SE	SE	1105	-777	116	48	302
790	13	25	6		NE	NE	NE	1084	-733	149	46	268
791	13	25	6		NW	NE	NE	1073	-730	161	48	245
792	13	25	6		NW	NW	NE	1055	-750	155	60	257
793	13	25	6		SE	NW	NE	1051	-719	180	58	242
794	13	25	6		SE	NE	NW	1038	-758	153	56	266
795	13	25	6		SW	SW	NW	1157	-756	165	44	263
796	13	25	6		NW	SE	SW	1108	-776	152	31	290
797	13	25	6		SE	SE	SW	1156	-778	119	34	313
798	13	25	6		NE	NE	SE	1143	-735	152	33	288
799	13	25	6		SE	NE	SE	1162	-736	149	29	296
800	13	25	6		NE	SW	SE	1165	-759	136	50	296
801	13	25	6		SW	SW	SE	1161	-755	144	44	168
802	13	25	6		SE	SW	SE	1127	-763	139	47	290
803	13	25	6		NE	SE	SE	1180	-736	144	35	291
804	13	25	6		NW	SE	SE	1180	-741	142	46	299
805	13	25	6		SW	SE	SE	1166	-747	127	36	307
806	13	25	6		SE	SE	SE	1180	-760	124	34	320
807	14	25	6		NE	NE	NE	1088	-759	160	48	240
808	14	25	6		NW	NW	SW	1079	-826	145	42	261
809	14	25	6		NW	SW	SW	1100	-820	134	40	281
810	14	25	6		SW	SW	SW	1044	-806	154	46	274

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
811	14	25	6		SE	SW	SW	1055	-813	138	36	276
812	14	25	6		SW	SE	SW	1107	-804	139	33	278
813	14	25	6		NW	NW	SE	1116	-797	154	27	266
814	15	25	6		NE	NE	NE	1126	-791	161	44	239
815	15	25	6		SW	SE	NE	1095	-798	164	45	238
817	15	25	6		SW	NW	SW	1001	-839	168	33	250
816	15	25	6		NE	SW	SW	998	-839	160	35	250
818	15	25	6		SE	SE	SW	975	-822	188	34	268
819	15	25	6		SW	SW	SE	989	-801	192	52	256
820	15	25	6		NE	SE	SE	1057	-806	157	41	265
821	15	25	6		SE	SE	SE	1012	-824	146	37	277
822	16	25	6		NW	NE	NE	1059	-861	137	44	244
823	16	25	6		SE	NE	NW	1049	-876	145	46	296
824	16	25	6		NE	SE	SE	1059	-845	156	49	259
825	16	25	6		NW	SE	SE	1045	-847	161	48	244
826	17	25	6		SW	NE	NW	1011	-930	134	24	307
827	17	25	6		NW	NW	SW	943	-917	160	37	295
828	17	25	6		SW	NE	SE	1044	-910	135	61	290
829	18	25	6	N2	N2	NW	NE	923	-977	117	47	298
830	18	25	6		NW	NE	NW	885	-995	125	76	308
831	18	25	6		NW	NW	NW	958	-1033	89	63	304
832	20	25	6		SW	SW	NE	918	-852	190	60	220
833	21	25	6		NW	NE	NE	1020	-840	155	39	270
834	21	25	6		SW	NE	NE	1002	-840	157	45	272
835	21	25	6		NW	SE	NE	953	-837	147	53	280
837	21	25	6		NE	SW	SW	1000	-847	148	48	280
838	21	25	6		SW	SW	SW	978	-844	138	43	275
836	21	25	6		NE	SE	SW	944	-869	109	50	323
839	21	25	6		NW	NE	SE	936	-837	135	50	290
840	21	25	6		NE	NW	SE	953	-842	130	46	298
841	21	25	6		NW	NW	SE	948	-838	147	48	285
842	21	25	6		NW	SW	SE	940				
843	22	25	6		NE	NE	NE	1015	-808	137	27	276
844	22	25	6		SE	NE	NE	1096	-809	141	43	286
845	22	25	6		NE	SE	NE	1054	-796	142	51	286
846	22	25	6		SE	SE	NE	1018	-806	144	41	304
847	22	25	6		NW	SE	NW	995	-835	136	42	280
848	22	25	6		SW	NW	SW	977	-853	137	41	314
849	22	25	6		NE	NE	SE	1007	-807	138	36	304
850	22	25	6		SE	NE	SE	1042	-808	147	35	310
851	23	25	6		SW	NW	NE	1048	-792	143	27	312
852	23	25	6		SE	NW	NE	1054	-787	159	43	302
853	23	25	6		NE	SW	NE	1096	-785	143	36	307
854	23	25	6		NW	SW	NE	1074	-789	147	39	304
855	23	25	6		SW	SW	NE	1134	-778	155	27	303
856	23	25	6		SE	SW	NE	1092	-778	150	28	307
857	23	25	6		NW	SE	NE	1088	-782	138	41	307
858	23	25	6		SW	SE	NE	1148	-775	137	36	308
859	23	25	6		NW	NE	NW	1045	-796	156	44	289
860	23	25	6		SW	NE	NW	1032	-796	144	44	288
861	23	25	6		SE	NE	NW	1040	-795	133	35	295
862	23	25	6		NE	NW	NW	1026	-784	163	44	273
863	23	25	6	N2	NW	NW	NW	1027	-816	139	32	280

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
864	23	25	6		SW	NW	NW	1109	-791	146	24	282
865	23	25	6		SE	NW	NW	1070	-782	154	42	280
867	23	25	6		NE	SW	NW	1110	-784	146	44	290
868	23	25	6		NW	SW	NW	1050	-795	147	47	287
869	23	25	6		SW	SW	NW	1040	-792	130	43	302
870	23	25	6		SE	SW	NW	1053	-790	147	33	303
871	23	25	6		NE	SE	NW	1085	-792	140		311
872	23	25	6		NW	SE	NW	1084	-797	133	27	302
873	23	25	6		SW	SE	NW	1098	-787	147	31	306
874	23	25	6		SE	SE	NW	1126	-798	143	29	307
875	23	25	6		NE	NE	SW	1079	-789	135	35	316
876	23	25	6		NW	NE	SW	1063	-790	137	32	310
877	23	25	6		SW	NE	SW	1082	-798	132	34	320
878	23	25	6		SE	NE	SW	1068	-789	138	28	320
879	23	25	6		NE	NW	SW	1041	-799	123	43	314
880	23	25	6		NW	NW	SW	1029	-797	144	36	307
881	23	25	6		SW	NW	SW	1104	-801	142	34	315
882	23	25	6		SE	NW	SW	1092	-801	137	36	317
883	23	25	6		NE	SW	SW	1042	-806	132	32	325
884	23	25	6		NW	SW	SW	1041	-809	140	31	318
885	23	25	6		NE	SE	SW	1050	-792	128	26	416
886	23	25	6		NW	SE	SW	1040	-801	125	30	420
887	23	25	6		SE	SE	SW	1031	-802	117	21	427
890	23	25	6		NW	NE	SE	1098	-784	128	29	415
888	23	25	6		SW	NE	SE	1073	-797	117	18	430
889	23	25	6		SE	NE	SE	1092	-791	115	20	432
891	23	25	6		NW	NW	SE	1109	-771	145	19	400
892	23	25	6		SW	NW	SE	1057	-783	133	22	413
893	23	25	6		SE	NW	SE	1063	-780	141	28	413
894	23	25	6		NE	SW	SE	1064	-789	127	22	425
895	23	25	6		NW	SW	SE	1056	-807	107	24	420
896	23	25	6		SW	SW	SE	1037	-806	111	23	430
897	23	25	6		SE	SW	SE	1043	-789	125	23	430
898	23	25	6		NW	SE	SE	1068	-795	124	21	430
899	23	25	6		SE	SE	SE	1047	-779	134	35	426
904	26	25	6		NE	NW	NE	1069	-788	125	20	427
905	26	25	6		NW	NW	NE	1060	-806	114	19	436
906	26	25	6		NE	NE	NW	1065	-805	118	21	423
900	25	25	6		SW	SW	NW	1097	-763	130	38	130
907	26	25	6		SW	NE	SW	1033	-829	98	44	
901	25	25	6		NE	SW	SW	1039	-751	143	36	190
908	26	25	6		NW	SW	SW	1141	-819	123	50	130
908.46	26	25	6		SW	SW	SW	1148	-814	131	29	
909	26	25	6		SE	NE	SE	1041	-859	133	50	183
902	25	25	6		NE	NW	SE	1030	-717	143	40	145
910	26	25	6		NE	SW	SE	1147	-773	140	40	174
903	25	25	6		NE	SE	SE	1020	-689	169	69	142
911	27	25	6		NE	NW	NE	1053	-827	123	63	328
913	27	25	6				SE	1111	-841	105	62	270
912	27	25	6		NE	NE	SE	1016	-835	102	19	246
914	27	25	6		SE	SE	SE	1132	-818	128	38	150
915	28	25	6		SW	SW	SW	942	-928	98	80	240
916	28	25	6		NE	SE	SE	1013	-879	118	64	253

WELL	SEC	TWP	RGE	S4	S3	S2	S1	ELEV	COTTG	COTHK	COT%S	FSDAC
917	29	25	6		SE	SE	NW	972	-926	134	51	340
918	32	25	6		NE	NE	SE	948	-909	125	28	433
920	33	25	6		SW	SW	SE	968	-842	137	28	180
921	34	25	6		NE	NE	NE	1112	-813	145	33	164
922	34	25	6		NE	NE	SW	1102	-803	163	22	174
923	34	25	6		SW	SW	SW	968	-802	188	38	190
924	35	25	6		SE	SE	NE	1014	-718	188	74	134
925	35	25	6		NE	NW	NW	1141	-806	143	50	177
926	35	25	6		SW	SW	NW	1071	-764	181	29	184
927	36	25	6		SE	SE	NE	1013	-705	132	47	210
928	36	25	6		SE	SW	NW	1015	-765	134	37	240
929	36	25	6		NE	SW	SW	984	-746	146	53	240
930	36	25	6		SW	SW	SW	984	-736	160	28	233
931	36	25	6		SE	SW	SW	979	-743	146	58	200
932	36	25	6		SW	SE	SW	984	-730	162	80	200
933	36	25	6		NE	NE	SE	998	-702	147	42	210
934	36	25	6		SW	SW	SE	970	-727	160	68	217

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
68	197	2	6	11	85	-1670
253						-1704
255	531	10	8	14	89	-1686
255.7	246	2	7	12	80	-1688
256	512	9	12	11	87	
257	556	5	9	43	64	-1784
258	397	6	6	50	56	-1777
259	413	6	9	31	72	-1790
260	501	12	11	51	59	-1795
261	471	8	9	16	76	-1791
262	348	7	12	52	54	-1804
263	423	8	10	24	84	-1812
264	309	5	11	45	72	-1803
265	509	11	11	32	61	-1801
266	328	7	8	14	86	-1806
267	458	10	11	20	80	-1803
268	462	9	7	24	70	-1788
269	648	7	7	23	74	-1792
270	489	5	9	28	69	-1795
271	419	8	7	36	64	-1797
272	344	7	6	35	63	-1772
274	417	6	8	12	93	-1698
275	501	8	6	9	108	
276	297	4	9	34	81	-1674
280	384	8	4	8	88	-1717
278	344	5	6	8	88	-1692
277	371	6	7	37	84	-1659
280.72	502	11	8	19	85	-1645
280.74	272	4	8	15	81	-1626
281	350	4	7	69	29	-1628
282	332	4	6	47	44	-1641
283	275	4	8	31	76	-1630
283.78				3	22	-1662
284	246	3	8	5	93	-1664
286	243	4	9	9	87	-1641
290						-1658
291	330	6	7	3	93	-1659
288	409	7	7	17	82	-1666
294	481	8	7	4	90	-1697
292	452	7	6	3	93	-1692
298	348	5	8	4	92	-1695
297	320	4	6	5	91	-1676
299	416	6	7	3	88	-1689
301	419	7	6	21	73	-1771
302	363	6	6	37	89	-1758
303	369	6	4	32	59	-1774
304	292	7	6	38	74	-1772
305	298	4	7	17	79	-1770
309	317	4	5	18	75	-1778
306	328	7	6	14	81	-1782
307	310	5	7	54	45	-1789
310	356	5	6	77	27	-1784
311	239	3	7	70	46	-1789

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
312	253	3	8	37	78	
313	275	3	8	52	35	-1777
314	288	4	8	60	28	-1782
315	317	6	5	63	53	-1782
316	381	7	7	51	57	-1779
318	482	7	9	29	69	-1781
317	433	7	7	17	79	-1785
319	447	7	8	35	65	-1801
320	400	7	8	32	61	-1799
321	476	7	8	36	59	-1788
322	407	7	7	34	88	-1783
323	395	7	9	26	73	-1799
324	460	6	8	24	70	-1801
325	396	8	8	44	69	
326	434	8	8	22	72	-1810
327	308	7	7	34	64	-1806
328	457	8	9	32	63	-1811
329	523	7	9	28	62	-1814
330	441	8	9	28	61	-1805
331	321	6	9	44	64	-1809
332	381	6	9	50	56	-1805
333	463	7	9	92	19	-1796
334	418	7	9	99	17	-1804
335	402	6	7	67	40	-1811
336	354	7	9	60	19	-1801
337	460	7	9	82	26	-1797
338	409	7	8	77	32	-1810
339	368	5	7	78	32	-1807
339.5	416	7	9	82	24	-1802
340	437	6	10	88	28	-1807
341	422	8	9	89	22	-1802
342	466	7	9	78	24	-1791
343	415	9	9	84	23	-1799
344	276	6	6	15	101	-1781
345	361	8	8	64	50	-1781
346	357	7	9	78	35	-1779
347	399	9	8	79	33	-1784
348	442	8	8	50	53	-1773
349	417	8	9	43	61	-1780
350	486	9	8	65	48	-1780
351	455	7	8	75	48	-1788
352	397	8	10	70	37	-1803
353	541	8	8	80	25	-1791
354	328	5	8	53	55	-1790
355	335	5	8	80	36	-1789
356	399	6	9	77	33	-1794
356.86				17	90	-1815
356.88				46	52	-1804
356.89				56	51	-1806
356.91				40	54	-1809
356.93				31	64	-1814
356.92				5	86	-1815
356.94				28	85	-1812

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
356.95				34	75	-1821
356.96				51	79	-1814
356.97				48	57	
357	376	7	10	36	73	-1803
358	391	7	9	34	82	-1804
359	384	5	10	26	102	-1815
360	432	7	9	33	108	-1816
361	362	6	10	12	80	-1808
362	373	6	10	36	92	
363	430	8	7	11	114	-1828
364	358	6	9	9	109	-1822
365	384	6	9	11	109	-1818
368	277	5	8	33	80	
366	415	8	9	24	88	-1817
367	433	6	8	17	91	-1815
369	364	7	9	13	85	-1817
370	311	3	9	19	87	-1814
371	416	9	7	53	79	-1810
372	355	7	8	36	95	-1816
373	395	6	9	36	72	-1814
374	370	6	10	31	87	-1810
375	403	7	9	28	74	-1806
376	401	8	9	21	87	-1804
377						-1809
378	351	7	9	17	88	-1796
379	410	8	8	16	89	-1811
380	393	9	9	22	76	-1801
381	343	7	8	42	49	-1786
382	214	4	7	35	55	-1778
383	410	7	9	71	30	-1782
384	396	8	9	52	37	-1777
386	434	9	7	55	36	-1770
387	365	7	8	60	41	-1774
388	354	7	9	79	24	-1786
389	351	7	9	48	55	-1775
389.10	174	1	7	55	28	-1771
389.10	487	9	7	54	34	-1793
385	349	6	8	21	78	-1798
389.10	305	6	8	15	85	-1800
389.10	296	6	10	12	83	
390	400	5	9	0	107	-1688
399	471	7	4	41	79	-1695
395	362	6	6	26	83	
393	392	7	8	16	101	-1721
392	412	6	7	50	79	-1719
394	299	4	7	48	86	-1736
400	517	7	6	50	85	-1686
401	506	7	6	38	85	-1686
398	483	7	6	51	92	-1728
396	318	3	7	49	86	-1670
397				73	65	-1669
402	347	5	6	13	78	-1652
403	341	5	5	92	52	-1656

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
404	437	7	6	101	54	-1637
405	466	6	4	52	95	-1658
406	530	8	2	55	100	-1644
407	517	6	4	73	60	-1668
408	463	7	7	109	39	-1677
409	468	5	7	96	52	-1681
410	405	7	7	22	90	-1793
411	428	5	7	29	85	-1779
412	473	9	8	15	81	-1789
413	308	5	8	12	83	-1795
414	309	5	6	28	85	-1793
416	336	4	8	23	93	-1799
415	316	5	7	12	86	-1786
416.54	374	7	9	21	97	-1789
417	307	5	7	27	101	-1782
418	225	3	8	12	102	-1799
419	333	6	6	31	84	-1785
420	347	6	7	28	97	-1784
421	333		5	25	95	-1782
422	333	5	6	31	92	-1778
423	424	5	5	14	83	-1782
424	313	6	7	31	82	-1778
425	270	2	7	23	90	-1793
426	342	4	6	19	107	-1782
428	374	7	6	20	103	-1790
429	285	3	8	16	112	-1796
430	359	7	8	21	100	-1784
431	295	5	5	26	90	-1781
432	347	6	6	21	109	-1784
433	426	6	4	46	61	-1784
434	428	7	6	59	34	
435	293	5	5	27	91	-1786
436	492	7	7	35	81	-1789
437	344	5	5	54	37	-1796
438	419	6	5	73	42	-1780
439	368	6	6	42	65	-1780
440	461	7	6	70	43	-1773
441	329	4	6	63	36	-1790
442	327	7	7	26	75	-1803
443	306	5	7	20	87	-1799
444	324	7	6	21	74	-1806
445	315	5	7	17	84	-1808
446	346	5	5	18	86	-1799
447	379	7	8	18	74	-1804
448	315	4	7	30	78	-1808
449	350	7	5	20	83	-1806
450	337	5	6	17	99	-1806
451	311	6	8	20	92	-1803
452	304	6	8	20	85	-1791
453	280	4	8	35	81	-1795
454	377	7	4	29	79	-1805
455	403	8	6	27	67	-1820
456	351	6	6	9	94	-1807

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
457	442	8	6	17	86	-1809
458	393	7	6	12	81	-1819
459	322	5	5	19	69	-1824
460	317	7	5	20	78	-1822
461	383	6	7	16	79	-1826
462	449	9	7	14	83	-1822
463	389	7	7	21	94	-1825
464	400	7	7	18	92	-1812
465	348	6	9	18	107	-1820
466	338	7	7	25	106	-1824
467	296	5	6	29	107	-1817
468	308	5	7	24	102	
469	323	7	9	25	104	-1820
470	355	6	8	32	96	-1817
471	319	5	7	36	87	-1799
472	336	5	8	44	81	-1796
473	355	6	9	22	94	-1796
474	328	6	8	30	82	-1795
475	276	5	9	43	80	-1804
476	291	6	8	31	89	-1811
477	293	4	7	19	105	-1812
478	285	4	7	24	103	-1805
479	264	3	7	23	98	-1808
480	314	5	8	26	100	-1813
481	340	6	8	43	85	-1816
482	315	4	7	31	99	-1813
483	455	7	8	12	89	-1794
483.14	366	7	7	31	98	-1801
484	367	6	6	31	93	-1803
485	367	6	6	21	108	-1784
486	328	7	7	26	84	-1808
487	443	8	7	25	82	-1805
488	431	6	7	15	84	-1798
489	390	7	8	38	93	-1812
490	339	6	9	21	106	-1820
491	344	6	7	14	89	-1820
492	397	8	7	15	83	-1816
497	425	7	5	19	94	-1813
493						-1821
494	337	7	6	10	89	-1821
495	388	7	6	39	79	-1816
496	389	6	6	25	95	-1814
498	355	5	6	51	64	-1801
499	445	7	7	34	67	-1808
500	355	4	6	63	37	-1805
501	421	6	7	79	25	-1793
502	383	6	6	14	101	-1833
503	360	5	8	29	101	-1834
504	373	6	6	27	103	-1834
505	385	7	6	13	113	-1830
506	423	7	5	27	105	-1830
507	398	8	6	38	70	-1834
508	429	7	7	40	59	-1833

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
509	415	7	6	50	69	-1830
510	370	7	5	37	87	-1819
511	322	6	6	41	79	-1824
512	378	7	6	34	85	-1831
513	380	7	6	64	56	-1836
514	346	5	5	79	18	-1824
515	406	5	6	39	66	-1830
516	418	8	5	70	33	-1827
517	374	4	7	58	36	-1797
518	430	8	7	67	39	-1798
519	316	3	6	59	19	-1794
520	384	6	7	85	14	-1792
521	409	7	7	70	48	-1808
522	384	7	7	44	66	-1817
523	432	7	8	54	51	-1813
524	395	6	7	78	20	-1797
525	389	6	8	64	14	-1819
526	360	5	6	89	24	-1821
527	426	5	7	98	15	-1784
528	373	6	7	81	12	-1796
529	430	7	6	89	27	-1795
530	440	6	7	71	44	-1787
531	606	8	6	52	61	-1768
532	464	7	6	88	26	-1775
533	449	8	8	40	56	-1776
534	399	6	6	78	23	-1773
535	387	6	7	69	45	-1767
536	560	11	6	55	58	-1760
537	410	7	6	65	47	-1761
538	330	4	7	55	55	-1754
539	387	6	7	42	64	-1748
540	449	7	6	49	67	-1760
541	425	6	7	46	68	-1748
542	426	6	6	58	46	-1779
543	482	6	8	61	35	-1776
545	390	4	6	56	49	-1775
546	371	6	7	30	90	-1790
547	354	6	6	81	27	-1785
548	382	5	6	52	48	-1780
549	430	8	5	55	54	-1785
544	348	5	7	51	67	-1771
550	452	6	5	76	27	-1773
551	434	7	4	61	50	-1772
552	424	7	5	65	40	-1760
553	388	5	6	74	37	-1771
554	431	7	7	64	49	-1768
555	402	7	5	52	53	-1764
556	399	6	6	52	57	-1778
557	402	7	7	53	57	-1789
558	355	6	7	14	102	-1781
562	351	6	6	53	46	-1768
560	360	6	6	64	41	-1779
561	345	4	7	44	68	-1781

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
563	407	6	7	61	53	-1775
564	394	6	6	47	65	-1766
565	356	5	7	47	58	-1767
566	439	6	5	39	73	-1769
567	438	6	6	35	38	-1767
568	406	6	5	56	56	-1742
569	380	4	5	53	54	-1752
570	449	5	7	47	63	-1755
571	305	3	5	45	65	-1754
572	391	4	5	51	64	-1762
573	352	4	5	49	51	-1765
574	450	5	6	39	73	-1758
575	385	3	5	42	65	-1767
576	402	5	5	31	77	-1764
577	466	5	4	42	65	-1761
580	292	3	4	36	89	-1759
578	461	6	7	28	82	-1761
579	483	7	5	38	80	-1756
581	482	5	4	34	92	-1758
582	440	7	5	46	75	-1741
583	418	5	5	51	74	-1738
585	503	7	3	48	82	-1724
585.14	382	5	6	58	76	-1724
584	436	4	3	49	105	-1724
586	505	6	3	59	70	-1668
587	503	7	3	58	68	-1665
588	414	6	2	44	72	-1659
589	324	4	4	61	66	-1652
590	418	6	3	58	75	-1675
592	393	6	3	55	85	-1652
594	373	5	4	45	91	-1659
593	386	6	4	43	92	-1652
591	423	6	3	51	92	-1681
612	389	5	2	58	69	-1645
595	411	6	3	29	91	-1578
596	416	6	3	37	113	-1642
597	407	5	2	39	105	-1659
598	429	7	1	64	72	-1645
599	406	6	4	29	107	-1631
600	404	6	3	36	108	
601	302	3	3	33	101	-1609
601.61	456	6	3	41	93	-1631
602	282	1	2	42	92	-1627
603	427	6	3	73	61	-1634
604	410	6	2	74	49	-1624
605	449	6	3	71	40	-1619
606	437	5	1	63	64	-1638
607	480	6	2	45	70	-1620
608	429	5	2	60	36	-1617
609	450	5	1	67	39	-1604
610	427	3	1	17	87	-1534
611	435	6	2	31	95	-1585
613	351	2	2	27	89	-1546

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
653	420	6	4	36	45	-1632
654	510	5	2	68	41	-1578
655	503	6	2	63	43	-1610
656	561	7	2	31	49	-1624
657	482	7	2	41	58	
658	464	5	3	7	109	-1615
659	504	6	3	43	51	-1639
660	405	4	2	40	54	-1634
661	456	7	2	57	32	-1644
662	471	6	2	43	57	-1624
663	480	8	2	40	46	-1632
664	454	8	2	37	45	-1637
665	488	5	1	46	51	-1630
666	480	7	2	36	61	-1635
667	497	6	2	42	45	-1647
668	404	6	3	41	49	-1633
669	362	6	2	40	48	-1649
670	344	4	3	38	55	-1652
671	448	8	3	31	76	-1652
672	419	8	3	52	63	-1648
672.5	424	6	3	44	78	-1636
673	488	8	4	41	70	-1650
674	483	8	2	64	63	-1643
675	400	6	3	61	77	-1641
676	418	7	3	44	45	-1635
677	421	6	3	52	45	-1633
678	328	5	3	55	68	-1643
679	401	3	3	49	64	-1653
680	542	8	5	44	76	-1680
681	492	6	4	36	74	-1696
682	519	7	5	22	84	-1682
683	393	4	3	25	77	-1690
684	370	5	5	16	101	-1699
685	438	6	4	32	81	-1745
686	399	5	5	40	94	-1750
687	348	4	4	49	89	-1749
688	429	5	6	32	85	-1746
689	479	7	7	27	86	-1745
690	482	7	6	17	81	-1757
691	417	6	5	14	90	-1755
692	404	5	5	34	85	-1716
693	467	5	6	38	76	-1669
694	467	6	4	37	88	-1749
695	412	6	6	34	91	-1752
696	420	5	4	38	94	-1748
697	420	5	5	35	80	-1750
698	470	6	4	42	89	-1770
699	355	4	5	32	104	-1755
700	407	5	5	27	95	-1751
701	405	5	5	33	93	-1756
702	534	6	5	32	89	-1751
703	365	5	6	32	83	-1784
704	473	7	7	39	83	-1774

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
705	432	6	7	36	98	-1770
706	424	6	6	30	87	-1780
707	481	9	6	44	74	-1790
708	475	7	7	33	81	-1781
709	360	4	6	39	94	-1769
710	567	9	7	29	94	-1775
711	498	7	3	17	86	-1738
712	440	5	4	17	77	-1756
713	403	6	3	10	84	-1754
714	360	4	5	14	81	-1739
715	404	4	4	15	76	-1719
716	384	4	4	32	60	-1696
717	381	3	5	26	70	-1689
718	332	5	7	37	83	-1785
719	338	6	6	74	34	-1824
720	379	6	6	69	25	-1819
721	420	5	5	30	93	-1819
722	447	6	4	29	94	-1828
723	419	6	5	39	77	
724	451	6	6	48	47	-1864
725	457	7	6	43	65	-1847
726	462	6	3	36	73	-1828
727	427	4	5	41	57	-1684
728	423	5	4	40	57	-1691
729	432	8	5	35	68	-1687
730	535	8	3	31	66	-1704
731	414	4	5	42	53	-1692
735	462	4	3	50	58	
735.73	423	7	4	22	67	-1732
739	566	7	4	18	63	-1738
739.73	390	5	3	48	59	-1756
741.7	534	6	6	28	87	-1761
741	486	6	3	15	93	-1780
741.7	451	5	4	16	96	-1753
742	480	4	4	22	68	-1758
742.7	459	4	4	33	72	-1694
742.7	546	7	4	46	61	-1686
742.7	488	4	4	41	67	-1694
742.7	499	5	4	22	78	-1706
743	486	8	5	76	50	-1705
745	472	9	4	12	94	-1695
748	446	8	6	66	49	-1693
749	489	10	2	72	34	-1706
746	416	7	5	54	52	-1685
747	391	6	2	50	77	-1685
750	568	9	4	50	69	-1692
751	506	10	5	77	40	-1684
752	495	7	6	48	69	-1685
753	468	7	3	99	26	-1683
754	404	7	4	61	66	-1673
755	488	9	7	54	75	-1685
756	568	10	5	47	78	-1680
757	465	8	6	47	90	-1686

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
758	560	8	5	54	83	-1681
759	353	4	3	47	40	-1688
760	440	6	6	58	88	-1666
761	423	6	3	52	69	-1637
762	397	4	2	85	45	-1624
763	358	4	3	72	62	-1631
764	289	1	6	81	64	-1636
765	339	5	7	65	71	-1627
766	463	7	4	68	88	-1609
767	264	1	4	83	61	-1621
768	427	5	4	82	52	-1616
769	453	7	4	64	101	-1609
769.78	450	8	6	89	71	-1619
770	408	7	4	81	57	-1640
771	397	6	3	80	48	-1642
772	412	5	3	78	48	-1645
773	426	5	4	86	46	-1642
774	401	5	3	101	40	-1649
775	470	6	5	74	59	-1660
776	454	8	5	73	54	-1642
777	409	5	4	67	61	-1645
778	351	4	5	114	53	-1648
779	381	5	3	50	67	-1608
780	347	5	4	49	69	-1614
781	449	6	5	98	55	-1624
782						-1609
783	590	9	5	88	72	-1633
784	450	8	3	75	61	-1646
785	428	5	5	127	43	-1642
786	511	4	5	87	95	-1624
787	461	7	5	112	57	-1617
788	609	8	4	56	60	-1636
790	506	5	3	68	81	-1630
791	577	8	4	77	84	-1634
792	542	6	3	93	62	-1643
793	540	6	4	105	75	-1640
794	501	5	3	85	68	-1652
795	523	8	5	72	93	-1660
796	696	9	5	47	105	-1658
797	360	5	4	40	79	-1648
798	481	7	4	50	102	-1632
799	507	8	4	43	106	-1616
800	464	6	3	68	68	-1645
801	470	6	4	64	80	-1643
802	499	6	4	66	73	-1639
803	392	7	4	51	93	-1613
804	461	6	4	66	76	-1618
805	528	6	4	46	81	-1620
806	548	9	4	42	82	-1618
807	504	6	4	76	84	-1654
808	603	10	5	61	84	-1719
809	479	10	6	54	80	-1696
810	567	9	7	71	83	-1700

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
811	541	9	5	49	89	-1693
812	516	8	5	46	93	-1701
813	481	9	5	42	112	-1677
814	558	9	6	71	90	-1693
815	463	5	4	74	90	-1695
817	551	7	5	56	112	-1739
816	585	7	5	56	104	-1732
818	612	9	5	63	125	-1723
819	490	4	3	99	93	-1713
820	632	9	4	65	92	-1699
821	652	8	5	54	92	-1704
822	497	7	4	60	77	-1738
823	476	5	4	66	79	-1747
824	530	10	5	77	79	-1745
825	576	8	6	77	84	-1747
826	527	6	4	32	102	-1809
827	615	10	4	59	101	-1824
828	506	7	5	82	53	-1780
829	500	9	3	55	62	-1841
830	509	7	5	95	30	-1844
831	605	8	8	56	33	-1866
832	412	5	7	114	76	-1782
833	594	8	6	60	95	-1740
834	502	10	5	71	86	-1740
835	589	7	4	78	69	-1729
837	561	8	4	71	77	-1732
838	646	9	4	60	78	-1723
836	402	5	4	55	54	-1728
839	547	5	5	68	67	-1722
840	696	8	3	60	70	-1717
841	618	7	3	70	77	-1720
842						-1720
843	599	12	4	37	100	-1691
844	567	10	4	61	80	-1688
845	534	7	3	73	69	-1690
846	564	7	4	59	85	-1695
847	632	8	4	57	79	-1713
848	492	8	3	56	81	-1747
849	418	8	6	50	88	
850	513	10	5	52	95	
851	585	7	5	38	105	-1679
852	564	10	5	69	90	-1676
853	537	8	6	51	92	-1676
854	632	10	5	58	89	-1677
855	618	10	5	42	113	-1674
856	553	9	3	42	108	-1678
857	508	8	7	56	82	-1672
858	625	9	5	50	87	-1669
859	575	12	5	69	87	-1695
860	581	10	4	64	80	-1685
861	563	7	5	46	87	-1680
862	582	10	4	72	91	-1688
863	669	10	4	44	95	-1704

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
864	652	9	6	35	111	-1681
865	705	10	5	64	90	-1682
867	715	9	5	64	82	-1682
868	539	10	4	69	78	-1690
869	575	9	5	56	74	-1682
870	647	10	4	53	94	-1680
871	497	9	4	54	86	-1675
872	572	11	5	61	76	-1682
873	758	10	5	46	101	-1685
874	526	8	3	41	102	-1685
875	502	10	4	47	88	-1674
876	590	10	5	44	93	-1679
877	715	12	5	45	87	-1686
878	601	8	3	128	10	-1676
879	540	10	5	53	70	-1689
880	629	9	5	52	92	-1688
881	726	8	4	48	94	-1689
882	677	10	4	49	88	-1692
883	730	10	4	42	90	-1694
884	705	9	4	44	96	-1697
885	524	8	2	33	95	-1684
886	575	9	4	37	88	-1689
887	669	8	2	25	92	-1687
890	563	8	5	37	91	-1671
888	635	9	4	21	96	-1677
889	684	10	5	23	92	-1674
891	571	9	3	27	118	-1667
892	583	8	5	29	104	-1673
893	523	8	4	39	102	-1676
894	574	7	4	28	99	-1678
895	438	7	4	26	81	-1674
896	669	9	4	26	85	-1674
897	645	11	4	29	96	-1675
898	657	8	5	26	98	-1676
899	545	9	5	47	87	-1677
904	656	10	5	25	100	-1676
905	661	10	3	22	92	-1686
906	630	11	2	25	93	-1692
900	506	8	3	50	80	-1658
907	402	7	3	43	55	-1699
901	519	7	4	52	91	-1669
908	513	12	6	62	61	-1713
908.46	597	12	5	38	93	-1709
909	576	6	3	66	67	-1764
902	417	6	4	57	86	-1632
910	539	9	4	56	84	-1689
903	427	5	4	116	53	-1618
911	610	10	3	78	45	-1717
913	562	12	3	65	40	-1715
912	546	10	3	19	83	-1720
914	556	9	6	48	80	-1710
915	606	9	4	78	20	-1800
916	588	11	4	75	43	-1762

WELL	CFSAC	NSBAC	NPIAC	COTFS	COTNS	PNKLM
917	560	10	5	68	66	-1806
918	488	7	5	35	90	-1808
920	449	8	5	38	99	-1772
921	566	11	6	48	97	-1723
922	529	6	4	36	127	-1741
923	416	6	5	72	116	-1752
924	609	11	3	139	49	-1688
925	483	8	6	71	72	-1724
926	414	6	4	52	129	-1717
927	493	9	4	62	70	-1627
928	399	10	3	49	85	-1681
929	455	8	3	78	68	-1677
930	488	8	5	45	115	-1676
931	561	10	6	85	61	-1671
932	580	9	3	130	32	-1682
933	443	6	3	62	85	-1632
934	444	5	3	109	51	-1668

APPENDIX C

DISCUSSION OF PLATES 4 AND 5

Isopotential Map

The isopotential map of wells producing from the Burbank Sandstone (Plate 4) was constructed using data from wells drilled before 1936. For an isopotential map to be an effective tool in fracture-trend study of the Burbank reservoir, these factors, influential on initial potential must be considered.

1. Ages of wells and effects of reservoir-pressure depletion on initial production.
2. Completion techniques, including (a) thickness of reservoir-rock drilled and available for flow into the well bore, and (b) enhancement of reservoir permeability by artificial stimulation.
3. Operator-induced bias in reporting initial-production flow rates.
4. Changes in reservoir character, including total reservoir thickness, lithology, porosity and permeability.

The factor considered first in constructing the isopotential map for the Burbank reservoir was reservoir pressure when record of the initial well-test was filed by the State of Oklahoma. To eliminate the effects of reservoir depletion on initial potential, only initial-potential data for wells drilled in the early stages of Burbank Field were used. In the northern part of the field this included wells drilled before 1930. The field developed southward into the southern part of T. 26 N., R. 6 E. and the northern part of T. 25 N., R. 6 E. in the 1930's. Initial-potential data dated as late as 1936 were used for wells in these areas.

Because of the ages of wells used in the isopotential study, completion techniques for all wells were similar. Most wells were drilled entirely by cable-tool rigs. In some cases only the Burbank reservoir was drilled with cable tools. This basic technique resulted in relatively undamaged reservoir faces in the borehole and hydrostatically unbalanced conditions which allowed oil and gas to flow freely into the borehole. In most wells the reservoir was fractured by nitroglycerin, to enhance flow. Wells with large natural flow rates seem to have been increased in production by only 10 percent to 28 percent as a result of "shooting" with nitroglycerin. On the other hand, wells with very small natural flow rates showed increase of production by as much as 600 percent. Some well-reports did not specify whether an initial flow rate was a "natural" flow test or a test taken after "shooting," but "after-shooting" flow rates were used where available.

Because of the ages of the wells used in the study, no flow rates after hydraulic fracturing were used to map initial-production rates. Most wells in Burbank Field were drilled into the Burbank Sandstone until a satisfactorily large flow of oil and gas was developed or until the entire sandstone section had been exposed. This practice was not followed near the western border of the field because operators recognized an oil-water contact. They drilled into the top part of the reservoir, exposed several feet of rock, and stopped drilling above the oil-water contact. The amount of reservoir exposed by drilling seems not to have had an overriding effect on initial-production rates; very large initial flow-rates were recorded from wells drilled close to the oil-water contact.

Operator-induced bias because of inflation or suppression of initial flow rates for business reasons is not believed to have been a significant factor in most areas of Burbank Field. As was noted earlier, leases in the field covered at least 160 acres; much variation in initial potential can be recognized within the boundaries of a 160-acre tract. However, operator-introduced bias cannot be eliminated entirely and this fact creates doubt about the validity of large initial-potential trends situated along boundaries between leases of different operating companies. Most operating companies reported 24-hour volume. In instances where the operator reported initial-potential volumes for several consecutive days, the largest reported daily volume was used for mapping.

The factor most significant in controlling initial potential of wells in the Burbank Sandstone is change in reservoir quality or thickness. The depositional environment of Burbank Sandstone is believed to have been a deltaic-distributary-channel system. The reservoir is composed of channel-fill units, "stacked" by cut-and-fill. Individual channel-fill, "shoestring" sandstone units or combinations of units were porous, permeable, highly productive reservoirs. However, the uppermost and youngest sandstone unit was an exceptionally good reservoir across the entire field. The uppermost unit commonly is thickest where the total Burbank Sandstone reservoir is thickest. Many wells near the oil-water contact drilled only a few feet of this uppermost sandstone unit, but they produced at larger rates than wells where much thicker sections of sandstone were drilled but the uppermost unit was absent. Wireline logs of recently drilled wells in the Burbank Field show that this highly productive uppermost zone has more porosity and lower resistivity than the underlying, less permeable units. The wireline-log data are confirmed by data from cores. The highly productive uppermost unit has significant impact on reliability of fracture-trend recognition in Burbank Field. Because the uppermost Burbank reservoir generally is closely related to total effective reservoir thickness, the relationship of this uppermost unit to initial potential has been given special attention.

Reservoir-thickness Map

The Burbank Sandstone reservoir-thickness map (Puckette, 1989) (Plate 5) is based on data from all wells in the mapped area that penetrated the Burbank. The reservoir-thickness map indicates that sands were deposited in a southerly flowing deltaic-distributary-channel system. Owing to the stacking of channel-sandstone units, overall thickness greater than 75 feet is common, as is abrupt thinning. Because of lateral shifting of channels during deposition, much of the northern and central portions of Burbank Field are underlain by an apparently continuous thick section of sandstone. As these channels extended southward with time, they diverged and created distinct, separate reservoirs within the overall Burbank section (cf. T. 27 N. and T. 25 N., R. 6 E., Plate 5).

Reservoir thickness and initial potentials of wells are correlated closely in both the northern and southern areas of Burbank Field. As was mentioned previously, large initial-potential rates seem to have been related closely to the uppermost, high-porosity channel-sandstone unit. Based on this close correlation of large initial potential to reservoir thickness, it is necessary to look for anomalously large initial-production rates that are not associated with thick sandstone reservoir. Large production trends that are not closely correlated with thick reservoir may have been influenced by fracture-enhanced porosity and permeability.

The isopotential map (Plate 4) and reservoir-thickness map (Plate 5) indicate that large initial-potential trends and thick reservoir trends are correlated closely over the entire field, except for an area in T. 27 N., R. 5 E. An easterly trend of large initial potential is mapped along the northern boundaries of Sections 22, 23, and 24 of T. 27 N., R. 5 E. This trend appears to be "normal" to the northerly and northwesterly trends of thicker Burbank Sandstone reservoir-rock; it may be evidence of fracture-enhanced initial production. However, in form of a counter-argument, different operating companies drilled wells in Sections 13, 14, and 15 and wells in Sections 22, 23, and 24; operator-introduced bias may have contributed significantly to the large differences in initial-potential rates of wells along the common boundary between these sections.

VITA

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Master of Science

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Biographical:

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Education: Graduated from Morris High School, Morris, Oklahoma in May, 1979; received Bachelor of Science degree in Geology from Oklahoma State University in December, 1984; completed the requirements for Master of Science degree in Geology at Oklahoma State University in December, 1989.

Professional Experience: Graduate Research Assistant, School of Geology, Center for Applications of Remote Sensing, Oklahoma State University, June, 1985 to August, 1989; Part-time Physical Science Instructor, Tulsa Junior College, Southeast Campus, January, 1989 to July, 1989.

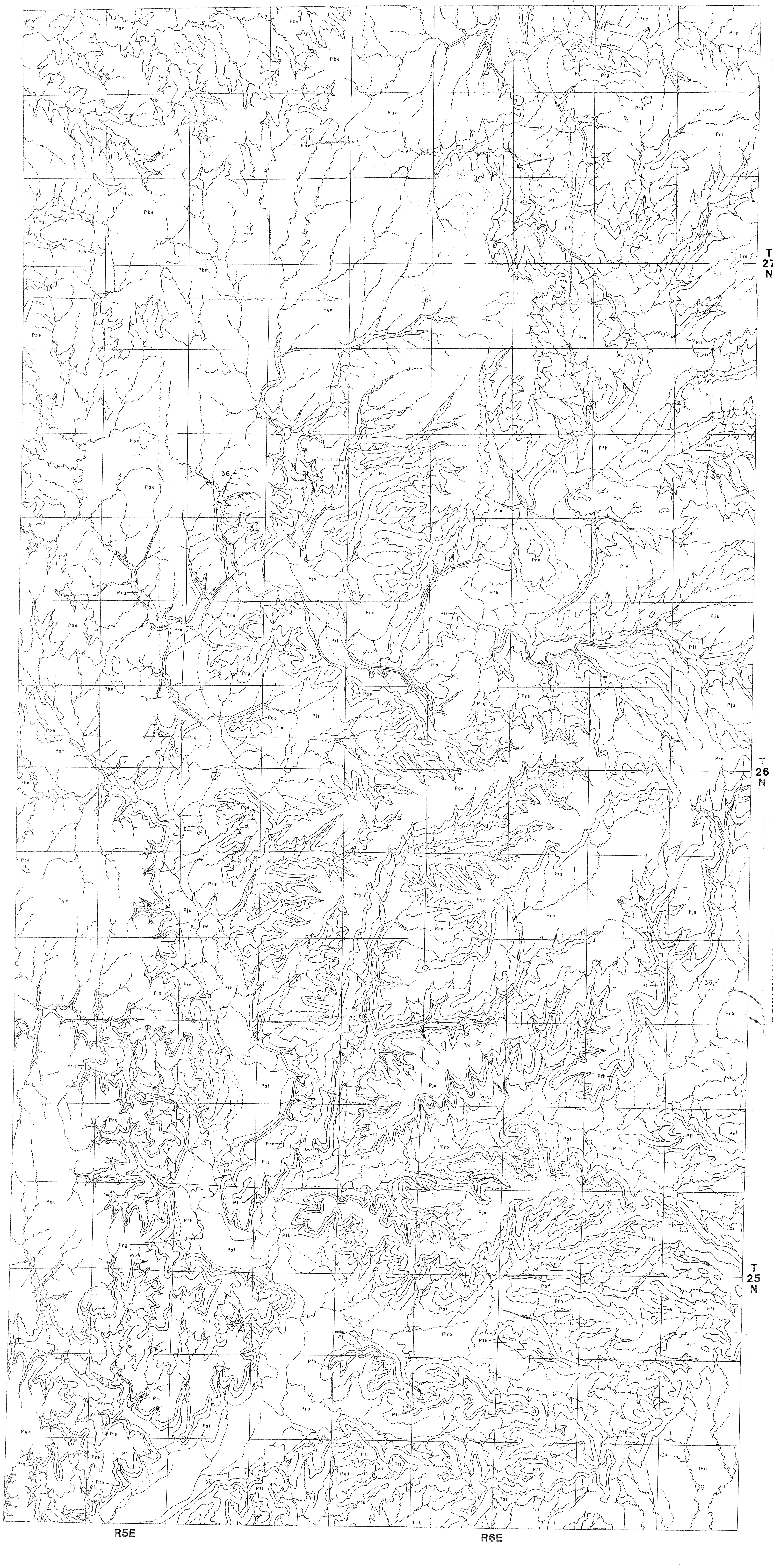
PLATE 1

1350/63

GEOLOGIC MAP-EASTERN PORTION OF

BURBANK FIELD

OSAGE COUNTY, OKLAHOMA



PERMIAN — WOLFCAMPIAN — COUNCIL GROVE GROUP

Pcb BLUE RADIDS SH, CROUSE LM

Pbe EASLY CREEK SH, BADER LM, STEARNS SH

BEATTIE LM: MORRILL LM M, FLORENA SH M, COTTONWOOD LS M

Pge ESKRIDGE SH

GRENOLA LM: NEVA LS M, **Prg** SALEM POINT SH M, BURR LS M, LEGION SH M, SALLYARDS LS M

ROCA SH

RED EAGLE LM: **Pre** HOWE LS M, GLENROCK-BENNETT LS M

Pjs JOHNSON SH

FORAKER LM: **Pfl** LONG CREEK SH M, **Pfh** HUGHES CREEK LM M, **Paf** AMERICUS LM M

ADMIRE GROUP UNDIFFERENTIATED

PENNSYLVANIAN — VIRGILIAN

IPrb BROWNVILLE LM, PONY CREEK SH

EXPLANATION

FORMATION CONTACT

VISIBLE

INFERRED

INTERMITTENT STREAM

POND OR LAKE

NORTH

0 1 2

SCALE IN MILES

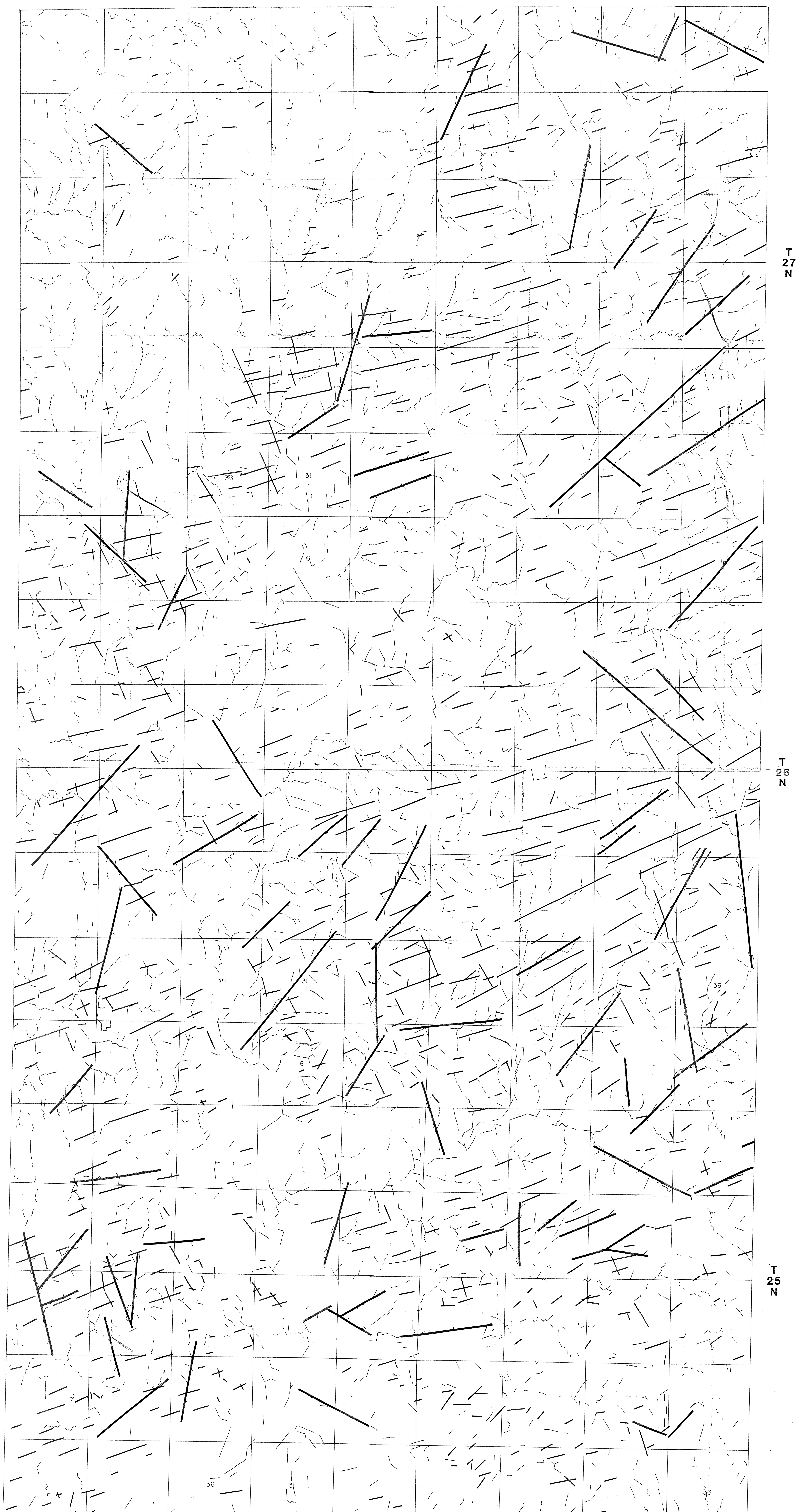
AFTER HAGAN (1972)

PLATE 2

1350163

LINEAMENT MAP - EASTERN PORTION OF BURBANK FIELD

OSAGE COUNTY, OKLAHOMA



EXPLANATION

TOPOGRAPHIC LINEAMENT

JOINT CLUSTER (HAGAN)

SATELLITE IMAGERY LINEAMENT

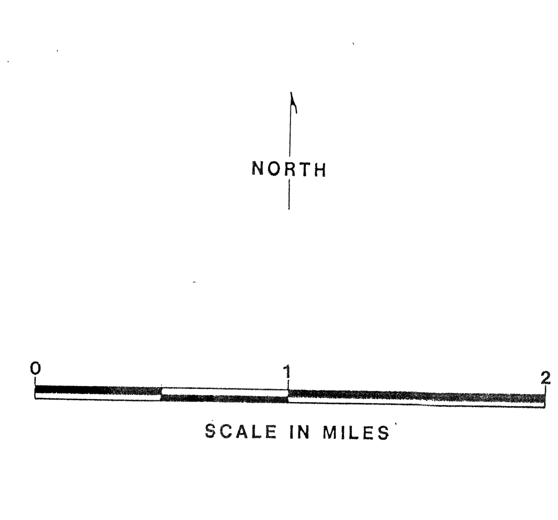
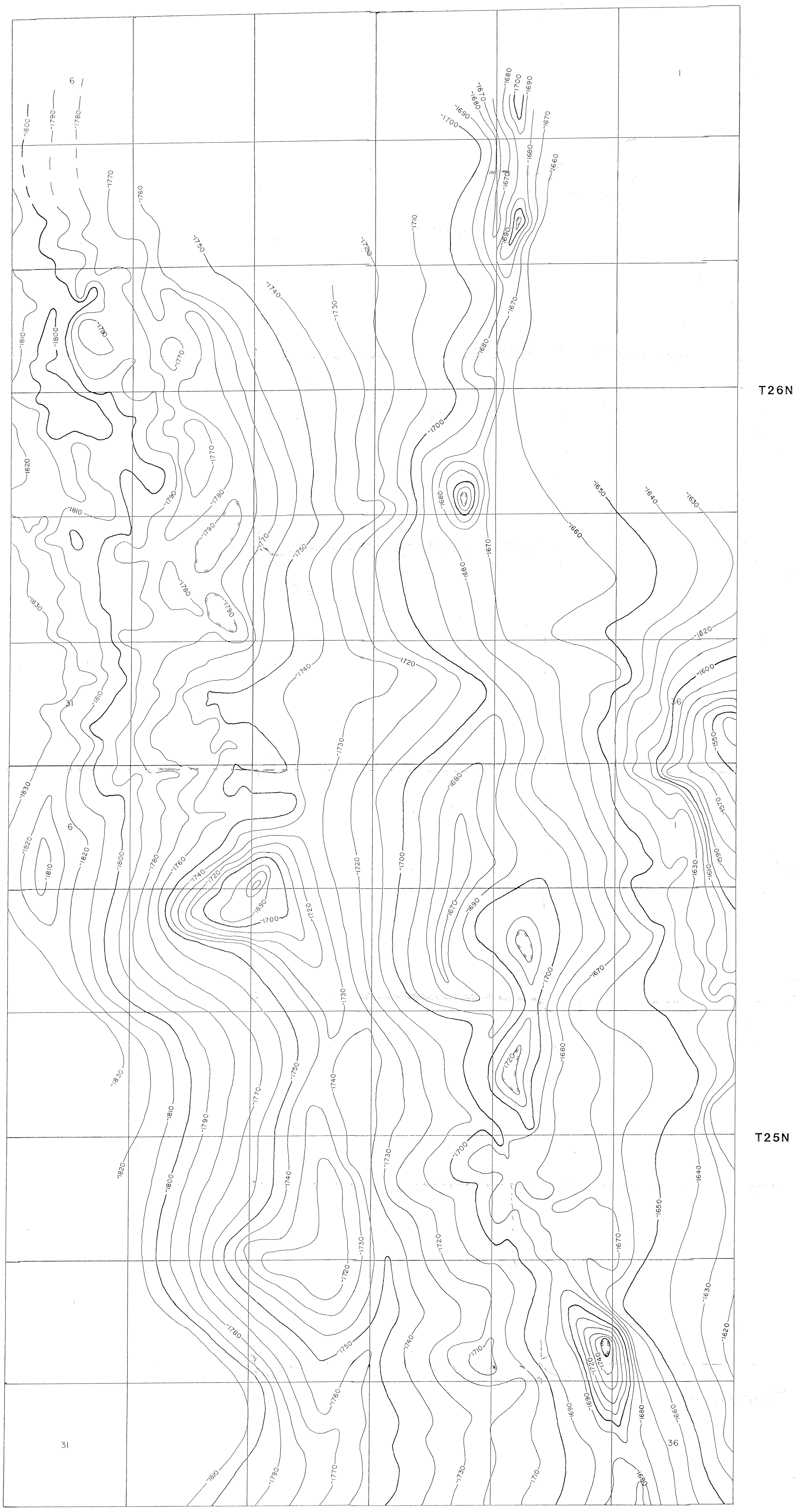


PLATE 3

1350163

PINK LIMESTONE STRUCTURE MAP

C.I. - 10 FEET



LEGEND

10 FOOT CONTOUR

50 FOOT CONTOUR

NORTH

0 1 2

SCALE IN MILES

K. D. Flanagan

LEGEND

WELL INITIAL POTENTIALS IN BOPD

250 - 500
500 - 1000
1000 - 2000
2000 - 4000
4000 +

POSSIBLE FRACTURE TREND

BURBANK SANDSTONE ISOPOTENTIAL MAP

PLATE 4

SCALE: 1 INCH=2000'

N

1350163

J. O. Puckette

LEGEND

BURBANK SANDSTONE THICKNESS IN FEET

ABSENT
0-25
25-50
50-75
75-100
100+

BURBANK SANDSTONE THICKNESS MAP

SCALE: 1 INCH = 2000'

PLATE 5

N

1350168

J. O. Puckette