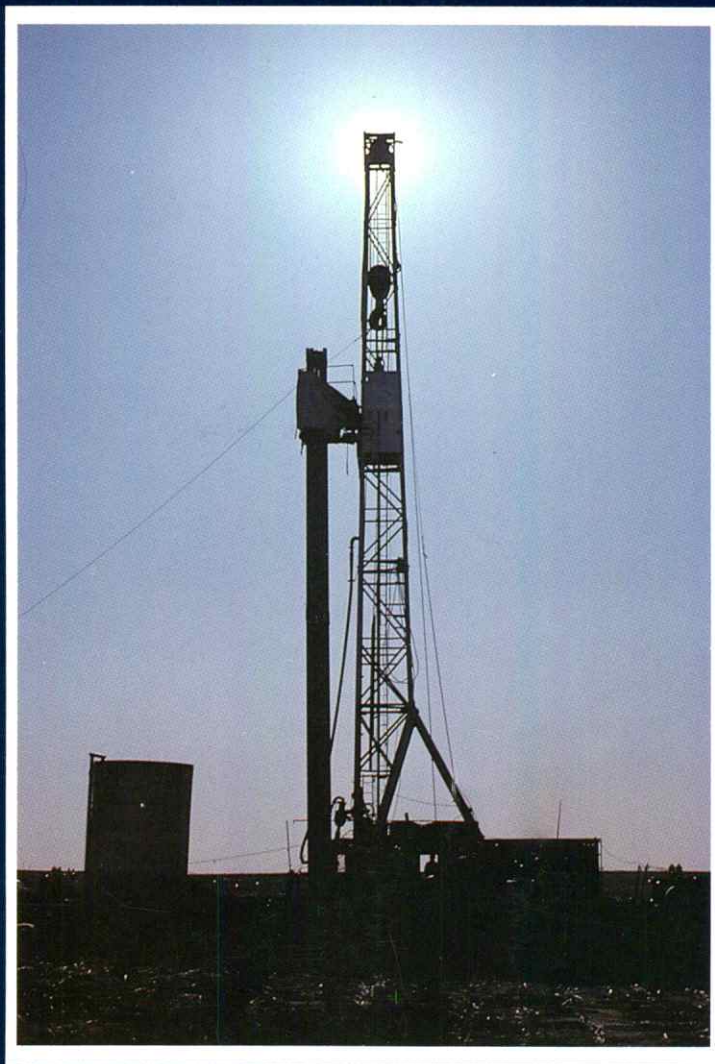


Educational Series 7

Petroleum:
a primer for Kansas



D. L. Baars, W. Lynn Watney, Don Steeples
and
Erling A. Brostuen

Other publications of interest available from the Kansas Geological Survey:

- A geologic history of Kansas*, by D. F. Merriam, 1963, Bulletin 162, 317 p.
- Aeromagnetic map of Kansas*, by H. Yarger, R. Robertson, J. Martin, K. Ng, R. Sooby, and R. Wentland, 1981, scale 1:500,000, Map 16
- Geologic map of Kansas*, 1964, scale 1:500,000, Map 1
- Oil and gas fields in Kansas*, by S. E. Paul, J. A. Ross, M. K.-W. Wong, R. K.-W. Wong, C. G. Ross, and D. L. Beene, 1988, scale 1:500,000 (multi-color), Map 18
- Oil and gas in eastern Kansas: a 25-year update*, by M. O. Oros, 1979, Energy Resources Series 13, 30 p.
- Oil and gas shows in the Salina basin*, by K. D. Newell, 1988, Subsurface Geology Series 10, 36 p.
- Stratigraphic and spatial distribution of oil and gas production in Kansas*, by K. D. Newell, W. L. Watney, S. Cheng, and R. Brownrigg, 1987, Subsurface Geology Series 9, 90 p.
- Subsurface structural maps over the CNARS with discussion*, P. Berendsen and K. Blair, 1986, Subsurface Geology Series 8, 20 p.
- The stratigraphic succession in Kansas*, ed. by D. E. Zeller, 1968, Bulletin 189, 81 p.

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Petroleum:
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State of New Mexico

Kansas Geological Survey
University of Kansas
Lawrence, Kansas 1989

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Preface

Petroleum: a primer for Kansas is the story behind the techniques, philosophies, and struggles of finding oil and gas in Kansas. It is written in non-technical language for those who have interests in the petroleum industry in one way or another, but who have had little or no training in the technical fields involved.

Dr. Lee C. Gerhard, State Geologist and Director of the Kansas Geological Survey, suggested this project. This book is based on a similar publication of the North Dakota Geological Survey by Erling Brostuen, published when Dr. Gerhard was State Geologist of North Dakota. The North Dakota Geological Survey kindly gave permission to excerpt portions of that book. The sections on petroleum, geology of petroleum, exploration, and subsurface geology were written by D. L. Baars; the section on petroleum geology of Kansas was written by W. Lynn Watney; and the sections on geophysical exploration were written by Don W. Steeples, all of the Kansas Geological Survey. The sections on mineral rights and leasing, drilling the well, and production are only slightly modified from Erling Brostuen's book.

Others helped prepare this book. Bryan Stephens made the high-quality thin sections for fig. 2A–D and assisted with fig. 9. John French assisted with the data analysis for figs. 10 and 11, and Jan Chung Wong generated the maps using Surface III. K. David Newell allowed us to use fig. 14. John C. Davis took the cover photograph of a drilling rig in Rawlins County. Jennifer Sims designed the cover of the book and drafted some of the figures. Fred Terry edited the manuscript and designed the page layout.

Most importantly, Dr. Gerhard has patiently and helpfully supported the compilation and production of this book and has contributed many excellent suggestions.

Introduction

The petroleum industry is a major contributor to the economy of Kansas. More than 350,000 wells have been drilled within the state in the search for oil and gas, and they have produced more than **5 billion** barrels of oil, with an estimated **11 billion** barrels of oil remaining underground. Yet most lay people in the state of Kansas know very little about how petroleum occurs, how it is discovered, or how it is produced once found. The purpose of this book is to describe the many complex processes involved in the formation of oil and gas pools, exploration and drilling methods used to find them, and the production of petroleum that has been found, in understandable language.

The Kansas Geological Survey is a repository for many types of data obtained in the process of petroleum exploration and production. We store drill cuttings and cores

from thousands of wells, we file various well logs obtained from boreholes, and we compile the voluminous data accumulated through more than 100 years of drilling. Computer data bases are maintained for industry study and research. Data are evaluated, interpreted, and published as free or inexpensive information for the public. Extensive libraries of publications, including technical reports and maps, are available at the Kansas Geological Survey, and at the University of Kansas, Kansas State University, Wichita State University, Fort Hays State University, and Emporia State University.

Further information may be obtained from the Kansas Geological Survey, 1930 Constant Avenue, Campus West, Lawrence, KS 66046-2598 or the Kansas Geological Survey, 103 Colorado Derby Building, 202 West First Street, Wichita, KS 67202-1212.

Petroleum

Petroleum is a substance, usually liquid or gas, consisting of organic molecules composed of hydrogen and carbon atoms. Thus the general name “hydrocarbons” is often used. The possible variations in the construction of the molecules and mixtures of different molecules to form naturally occurring oil (crude oil) are virtually limitless. No two crude oils are identical. Because these complex mixtures of organic matter are found in rock, they are called “petroleum,” a word derived from the Latin words for rock (petra) and for oil (oleum).

Most petroleum is formed from organic matter, tiny particles of plant and animal debris that accumulated with mud deposited in stagnant bodies of water. The original organic material was mostly microscopic marine plants and animals that lived in open seas, but much of it may have been derived from land plants and carried by streams to the site of deposition (fig. 1a). Despite stories you might have heard, dinosaurs did not contribute to the original soup. Organic material is easily destroyed by exposure to air. Deposition of the material must be rapid in waters containing little or no oxygen due to water stagnation. Where water is oxygen deficient and chemical reactions take oxygen atoms away from molecules it is said to be a “reducing” condition, a requirement for the preservation of organic matter. Also, low-oxygen environments greatly decrease the number of scavengers that might otherwise consume and destroy the organic morsels. Usually the proper conditions occur in quiet marine basins, lagoons, and rapidly buried delta deposits, but similar conditions prevail in some lakes.

Once the fragile organic matter is preserved from oxidation and scavengers, it must be buried to considerable depths, usually more than 5,000 ft (1,524 m), by more sediments (fig. 1b). Compaction from the weight of the overburden changes the deposits to rock (shale) by compressing the clay and organic particles and expelling the contained water. Bacterial and chemical actions, aided by

elevated temperatures, begin the long, complicated process of transforming the organic material to hydrocarbons. No one thoroughly understands the complexities involved, but great heat and pressure from deep burial over millions of years are required to complete the process.

The beds of sedimentary rock in which the petroleum is formed are called the “source rocks.” They are usually dark gray or black shales, but limestone is a source under some conditions. Shale has an abundance of pore space between the clay particles which can contain liquid, but the pores are much too tiny to allow the movement of fluids under normal conditions. In other words, shales are not “permeable.” However, the pressure produced by the processes of petroleum generation expels the fluid, and petroleum has to move from the source rock at some stage of development to become economically producible. The event is called “primary migration.” Once departed from the source bed, the oil or gas will enter any nearby porous and permeable rock, such as sandstone or limestone.

Oil and natural gas are less dense than water and, for all practical purposes, are insoluble in water. If the fluids are mixed, oil and gas rise to the surface of the water. Rocks beneath the water table are, by definition, saturated with water. Petroleum leaving the source rock enters a water-wet rock and must try to rise to the top of the porous layer. If the porous rock is also “permeable,” that is, fluids can pass from one tiny pore to another or “flow” through these tiny channelways in the rock, the petroleum will rise until it reaches impermeable rock above. Keep in mind that pores in most rocks consist of tiny spaces between the sand grains or crystals. The pores must be interconnected for fluids to pass from one pore to the next, and the connecting opening must be larger than a hydrocarbon globule for movement to occur. Such movement of petroleum after leaving the source rock is called “secondary migration.”

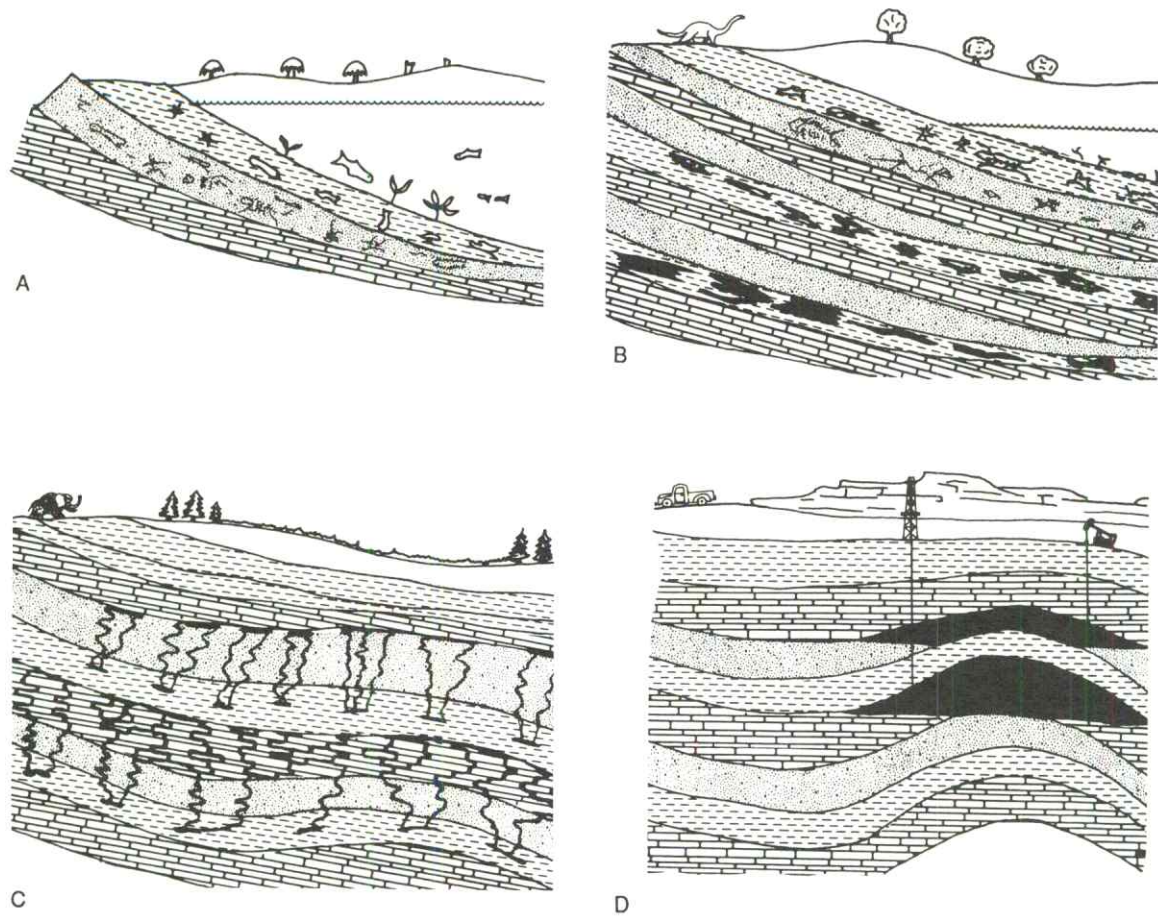


FIGURE 1—DIAGRAMS SHOWING THE ORIGIN OF PETROLEUM. A) Shows life existing in an ancient sea hundreds of millions of years ago and the death and burial of organic matter in the sediments. B) Millions of years later, life still exists in a shallow sea and the sediments have increased in thickness. The organic matter is being altered into petroleum. C) The sea no longer exists. Petroleum is migrating from the source rocks into porous rocks. D) The rocks have been folded forming an anticline. The petroleum is trapped at the crest of the anticline.

Threads and tiny globules of oil or bubbles of natural gas collect at the top of the porous-permeable rock layer (fig. 1c). Such accumulations are usually too small to be recovered practically from a well. However, if the rocks are tilted somehow, the petroleum will continue to migrate up the sloping top of the bed until it reaches the surface or an impermeable barrier to its flow (fig. 1d). The measured inclination of a rock layer is said to be the “dip” of the rock. If the petroleum reaches the surface of the earth at an “outcrop” of the rock layer, it flows onto the surface as an oil or gas “seep.” This is how oil was first discovered in Kansas, in Miami County in 1860, shortly after the Drake discovery in Pennsylvania. If the petroleum rises to an impermeable limit, it is said to be trapped. An “oil trap” is any natural barrier to the up-dip migration of petroleum; and huge amounts of oil and/or natural gas may accumulate, such as at the El Dorado oil field northeast of Wichita and in the Hugoton gas area of southwestern Kansas.

Geology of petroleum

Sedimentary rocks

Petroleum may occur in any porous rock, but it is usually found in sedimentary rocks such as sandstone or limestone. Sedimentary rocks are grouped into three major classes: clastic, carbonate, and evaporitic.

Clastic rocks are those that are formed by the accumulation and cementation of sedimentary particles derived from weathered fragments of preexisting rocks. Weathering processes, such as freezing and thawing, rain, wind, and other similar events, break down the parent rock into small particles that can then be transported by wind and rain runoff. Streams carry the mud, sand, and gravel from the source area down to its final resting place, be that a stream channel, floodplain, lake, or ultimately the sea. There it accumulates, is buried and compacted by later-arriving sediments, and cemented to form sedimentary

rocks. The mud compacts to shale or mudstone, the sands are cemented by silica or calcite to form sandstones, and the gravels become conglomerates. Sandstones, because of the inherent porosity between their grains, often become excellent reservoirs for oil or natural gas. In oil-field terminology, any potentially productive sandstone is called a "sand" (fig. 2a).

Carbonate rocks are limestones and dolomites. They usually form in warm seawater at shallow depths, ankle deep to about 20 ft (6 m), where various plants and animals thrive. The hard, usually calcareous parts of the organisms pile up on the seafloor over time, forming beds of lime particles. Algae, simple plants, are one of the greatest contributors of lime particles, but any shelled animal may contribute whole or fragmented shells to the pile. Reefs, banks of lime mud, and lime sand bars are commonly found preserved in rocks (figs. 2b and c).

Carbonate sediments are subject to many processes in becoming a rock. If lime mud is exposed to the air, it simply dries out and almost overnight becomes a natural "concrete," and lime sands become cemented by the evaporation of lime-rich seawater to form "beach rock." Rainwater, however, begins to destroy the rock and forms porosity in the process. If not exposed to the air, lime sediments continue to accumulate, perhaps to great thicknesses. Under these conditions, they compact under the weight of new sediments and eventually are cemented to form limestone. These rocks are rarely porous unless other processes become involved.

Limestone is composed of calcium carbonate (calcite or aragonite), thus the general rock term "carbonate" is used. Magnesium, a common element in seawater, can replace some of the calcium within the crystal structure of calcite. This often happens by various processes that are not fully understood; the resulting rock is known as "dolomite" (calcium-magnesium carbonate). The process of changing limestone to dolomite produces somewhat smaller crystals, so the resulting rock has tiny pores between the new crystals. This kind of porosity, much like that in sandstone, often contains oil and natural gas (fig. 2d).

Evaporites are formed by the direct precipitation of minerals by evaporation of seawater. Resulting rocks are ordinary salt (halite-sodium chloride), gypsum (calcium sulfate with some water), and various forms of potash salts. When gypsum is buried to considerable depths, the water is expelled from the crystals and "anhydrite" (meaning simply "without water"), a harder crystalline rock, results. Evaporites are not porous, although they are readily dissolved by water and are not source rocks for petroleum. However, they may be formed in highly stagnant water where black mud, rich in organic matter, may also be deposited, and so are commonly associated with good source rocks. Because they are impermeable, evaporites often form seals on other reservoir rocks. Evaporites of the Sumner Group form the upper seal of Chase Group carbonate reservoirs in the giant Hugoton gas area in southwestern Kansas.

Layered rocks

Geologic time is nearly incomprehensible to the human mind. We usually think in terms of a few tens of years, since that measures a lifetime. Hundreds or thousands of years are considered ancient history. But in geology, we must think in time spans of millions of years, hundreds of millions of years, even of billions of years. Geologists measure such tremendous spans of geologic time in a relative sense, that is, one event occurred after another and prior to a third event. In that sense, a geologic time scale was developed in the 1800's to make handy "boxes" of relative time periods in order to think of events in an understandable manner. "Periods" and "eras" were named to designate varying intervals of time that then seemed to be useful. The geologic time scale is shown in fig. 3.

The actual time in years, "absolute time," is more difficult to determine. Geologists are now able to calculate time from the decay rates of radioactive elements, such as uranium and potassium. Radioactive minerals are required for this exercise, and these only occur in certain rocks, usually igneous rocks such as granite. Thus sedimentary rocks can only be dated relative to the occurrence of related igneous events, usually with the aid of fossils that fit into evolutionary sequences. As one might guess, dates in years for sedimentary rocks are still relative, and uncertain at best.

There are many reasons to believe that the Earth formed about **4.5 billion** years ago. However, it was not until the beginning of Cambrian time, about 570 million years ago, that sedimentary rocks containing fossils became abundant. The first four billion years of Earth history, lumped by geologists into the Precambrian Era, can only be dated where radioactive minerals are available.

During the remaining half-billion years, the area that is now Kansas was covered repeatedly by shallow seas. Sea level fluctuated hundreds of times, at least relative to the nearly level landscape, and shorelines waxed and waned accordingly. Layered sedimentary rocks accumulated to thicknesses up to 9,500 ft (2,895 m). Remember, though, that there was plenty of time—more than 400 million years! During times of high sea level, limestones were deposited in the shallow, perhaps knee-deep, seas; clastic sediments, sands and mud, were carried to the shorelines by streams that drained the lands. When sea level dropped and the marine deposits were exposed, sediments that had accumulated were subjected to erosion and some were carried back to the sea by streams. The shorelines and their related environments traveled hundreds of miles, back and forth, producing complex rock relationships as the waters deepened or shallowed with time. The study of the sequences and variations in sedimentary rocks is called "stratigraphy."

Depositional edges (pinch-outs) of shoreline sandstones and local build-ups of reefs and carbonate mud banks are numerous in the rocks beneath Kansas. The resulting changes in rock type, and related rock porosity and permeability, formed traps for oil and gas. This kind of barrier to the underground flow of petroleum is called a "stratigraphic trap" (fig. 4). Many of the oil and natural gas fields in Kansas produce from these localized sedimentary variations that recur throughout the hundreds and



FIGURE 2A—A GREATLY MAGNIFIED IMAGE OF A SANDSTONE AS SEEN IN A THIN SECTION OF THE ROCK UNDER THE MICROSCOPE. The scale is equal to one millimeter. The rock sample was injected with blue-colored epoxy that is seen here filling pores which are interconnected (permeable). After plastic is injected and solidified, the rock sample is cut and polished on a glass slide to a thickness of 35 thousandths-of-an inch. The "thin section" of the rock is thin enough to permit light to be transmitted through it as in this photomicrograph.

This particular sandstone contains grains of quartz (white), calcite, and feldspar (shades of brown). The grains originally came from other rocks that had been eroded. The sample is exceedingly porous and permeable. The grains are loosely packed and there is very little cement filling the space between the grains. The arrow indicates possible pathways for fluid movement.



FIGURE 2B—A THIN SECTION PHOTOMICROGRAPH OF A PENNSYLVANIAN LIMESTONE taken from a core sample of a producing zone in Victory field, Haskell County, Kansas. This particular sample comes from an interval that is not a good reservoir rock. Circular grains composed of calcite (finely crystalline, reddish-stained areas in a grain) and dolomite (clear, coarse crystals) are completely cemented by medium crystalline calcite. No porosity is visible.

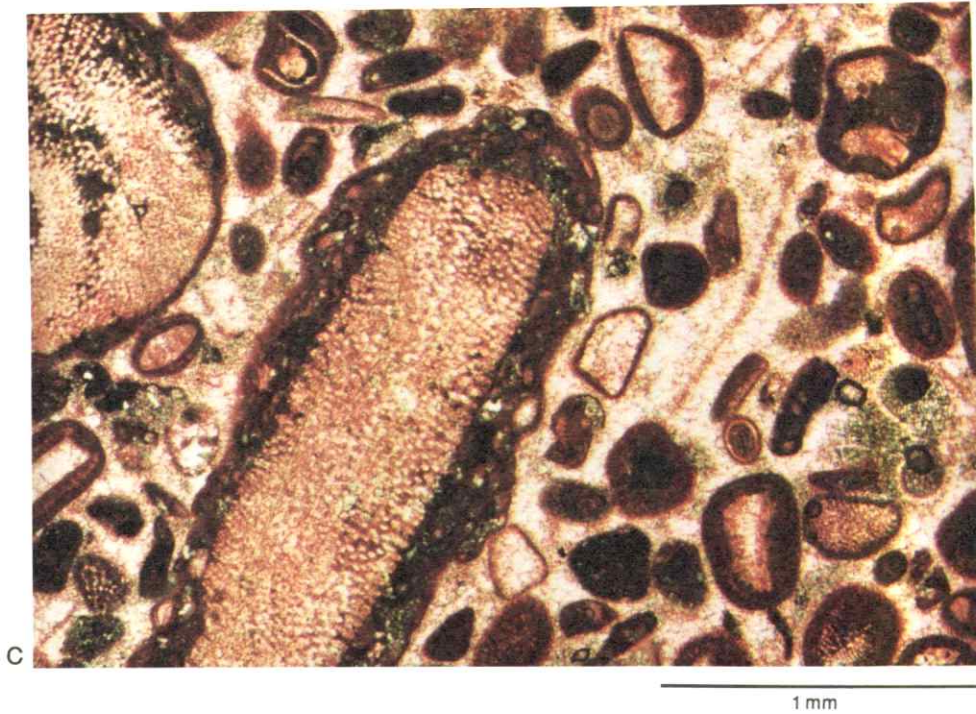


FIGURE 2C—A THIN SECTION PHOTOMICROGRAPH OF A PENNSYLVANIAN LIMESTONE. The scale bar equals one millimeter. These well-rounded carbonate grains consist of broken shells and other skeletal remains of marine organisms. The rounding is produced by coatings of dense, dark, finely crystalline calcite which formed rims around the particles as they were agitated by current action in a shallow marine setting. The rounded particles are completely cemented together with finely crystalline calcium carbonate (calcite), and consequently no porosity is present.

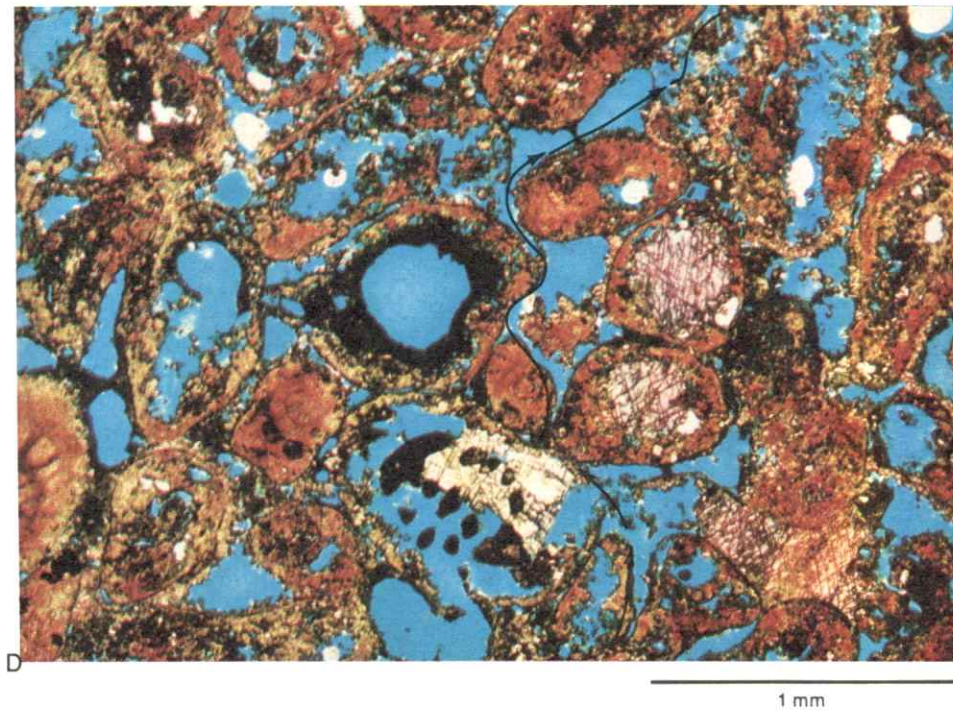
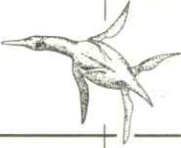

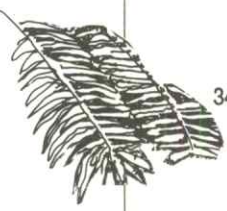




FIGURE 2D—THIS THIN SECTION PHOTOMICROGRAPH CAME FROM A SAMPLE OF A CORE TAKEN 1 ft (.3 m) BELOW THE ONE SHOWN IN FIG. 2b. The scale bar equals one millimeter. This sample is representative of an excellent carbonate reservoir rock with pore space contributing nearly one-third of the total volume of the rock. In fact, this zone is one of the main reservoirs of Victory field. The carbonate grains artificially stained red on this thin section are poorly preserved remains of coated fossil fragments. Permeable porosity (indicated again by the blue epoxy) occurs within these particles as well as between them. The arrows trace possible avenues of migration for fluid such as oil and gas that now are found in this reservoir rock.

KANSAS GEOLOGIC TIMETABLE

(Not scaled for geologic time or thickness of deposits)

ERAS	PERIODS	EPOCHS	EST. LENGTH (YEARS) *	DESCRIPTION	
CENOZOIC	QUATERNARY	HOLOCENE	10,000+	Early, the land was stable with some erosion. Glaciers moved into the northeast at least twice. Later the climate was dry. Sand dunes were formed by wind in the west. Volcanic ash was blown in from California, New Mexico, and Wyoming.	1.6
		PLEISTOCENE	1,590,000		
	TERTIARY	PLIOCENE	3,700,000	Rocks found are part of the Ogallala Formation (sand, gravel, and porous rock), which contains a large quantity of ground water and occurs only in the western third of the state. No rocks were formed in eastern Kansas.	66.4
		MIOCENE	18,400,000		
		OLIGOCENE	12,900,000		
		EOCENE	21,200,000		
PALEOCENE		8,600,000			
MESOZOIC	CRETACEOUS		77,600,000	Much of the western half was covered by seas. Limestone, sandstone, and chalk formed from sea deposits. Fossils can be found in these rocks, which crop out in central and western Kansas.	144
	JURASSIC		64,000,000	Most rock in Kansas is underground in the west. A few small outcrops are found in the southwest corner.	208
	TRIASSIC		37,000,000	No rocks have been found in Kansas.	245
PALEOZOIC	PERMIAN		41,000,000	Much of Kansas was covered by several seas. As they rose and fell, limestone, shale, and chert were deposited. The Flint Hills were formed. When the seas dried up, salt and gypsum were left behind. Salt, now underground, is mined in central Kansas. The Red Hills were formed from deposits of shale, siltstone, sandstone, gypsum, and dolomite.	286
	PENNSYLVANIAN		34,000,000	For much of the period the land was flat. Seas and swamps came and went; coal formed in swamps from dead plants. Shale, limestone, sandstone, chert, and conglomerates were deposited. Two ridges of hills, the Nemaha uplift and the Central Kansas uplift, appeared; both are now buried. Pennsylvanian rocks are found at the surface in eastern Kansas.	320
	MISSISSIPPIAN		40,000,000	Repeated layers of limestone, shale, and sandstone indicate that seas rose and fell. Mississippian rocks are the oldest found at the surface and are in the southeast corner; elsewhere these rocks are only underground.	360
	DEVONIAN		48,000,000	Seas covered Kansas during much of the period. Limestone, shale, and sandstone deposits are only underground.	408
	SILURIAN		30,000,000	Land was uplifted and seas disappeared. Limestone deposits are found only underground.	438
	ORDOVICIAN		67,000,000	Seas covered parts of Kansas during much of the period. Dolomite and sandstone are only underground.	505
	CAMBRIAN		65,000,000	Early, the climate was dry and many rocks eroded. Later, parts of Kansas were covered by seas. Dolomite, sandstone, limestone, and shale are now underground.	570
PRECAMBRIAN		3,930,000,000	These rocks are the oldest on earth. In Kansas, they are only found deep below the surface and not much is known about them. Many are igneous and metamorphic and have gone through many changes.	4,500?	

Eons not shown

* Decade of North American Geology 1983 Geology Time Scale, Geological Society of America

FIGURE 3—GEOLOGIC TIME SCALE SHOWING GEOLOGICAL ERAS AND PERIODS RECOGNIZED IN NORTH AMERICA from oldest to youngest in ascending order. Length of time of each period and million years before present are rough estimates based on radiometric dating of rocks and relative rock relationships. Earliest humans did not appear until about the beginning of the Pleistocene Epoch some two million years ago.

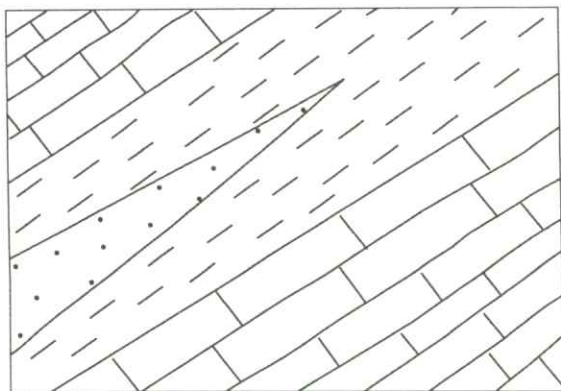


FIGURE 4A—A SANDSTONE BED IS SHOWN THINNING TO A PINCHOUT IN A DIRECTION UP THE DIP OF INCLINED STRATA. Fluids moving up along the tilted porous and permeable sandstone will be trapped where the sandstone terminates in impermeable shale beds.

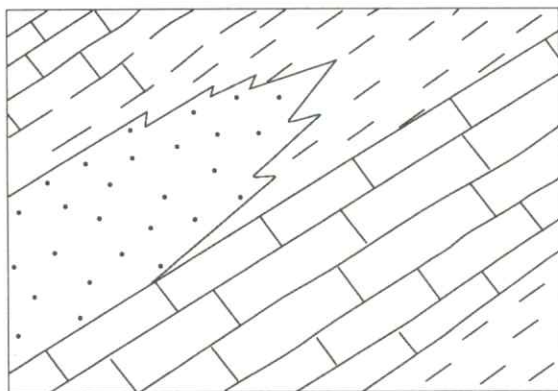


FIGURE 4B—PERMEABLE BEDS, SUCH AS BEACH SANDSTONES, OFTEN CHANGE Laterally TO OTHER ROCK TYPES, SUCH AS SHALE AS SHOWN IN THIS EXAMPLE. Such a change in rock type is called a "facies change." Petroleum migrating up the inclined permeable strata is trapped when it encounters impermeable shale beds, and an oil/gas field is created.

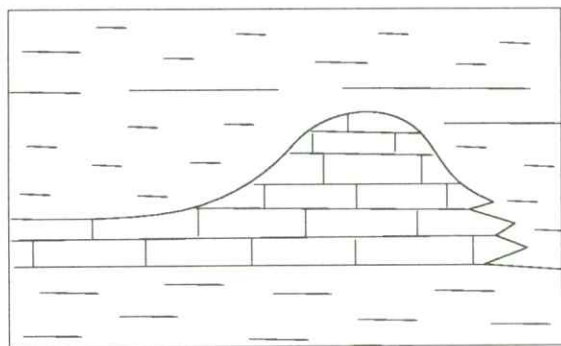


FIGURE 4C—REEFS AND OTHER THICKENED ACCUMULATIONS OF ORGANIC DEBRIS OFTEN FORM POROUS AND PERMEABLE LIMESTONES. Where these change laterally to impermeable rock types, a permeability barrier is formed and petroleum can accumulate.

thousands of feet of sedimentary rock. Gas in the large Hugoton gas area is trapped because porous carbonate reservoirs change laterally to impermeable shales and siltstones.

Structure

Once formed, sedimentary rocks are subject to various kinds of deformation, such as folding and faulting. Three general types of folds are anticlines, synclines, and monoclines.

Folds

Anticlines are **upfolds** in the layered rocks. They are usually long, high wrinkles in the rocks that may extend for hundreds of feet, but normally they are miles or tens of miles long and may have numerous prominences. Anticlines are much like the "up-wrinkles" produced in a rug or sheet of paper when pushed or squeezed from side to side and are formed in much the same way as the Earth's crust was compressed or shortened by lateral forces. Circular upfolds in the rocks are called "domes." Anticlines are important types of "structural traps" in petroleum geology, as petroleum migrating up the dip along a flank of the fold is trapped at the crest. It can't rise any farther up the tilted strata and can't go back down the other flank, at least until the fold is full of oil and/or gas. A good example in Kansas is the El Dorado anticline that is a major producing oil field. The Central Kansas uplift is a large "antiform" with numerous smaller anticlines that collectively have produced in excess of 2.5 billion barrels of oil.

Synclines are the opposite of anticlines. A syncline is a **downfold**, usually occurring between two anticlines. Every upfold on our wrinkled rug or sheet of paper has one or two adjacent downfolds. Synclines, like their associated structures the anticlines, are elongate, perhaps extending for many miles. More or less circular depressions in the layered rocks are called "basins," but that term is usually reserved for very large depressions, tens or hundreds of miles wide, in the Earth's crust. Such large basins are natural centers for thick accumulations of sedimentary rocks. Unlike anticlines, synclines only form structural traps for petroleum when the depressed strata occur above the water table in dry rocks and oil gathers in the bottom by gravity flow. Such synclinal oil fields are rare, although the first oil produced west of the Mississippi River was from a syncline at the Florence-Canyon City field in central Colorado (fig. 5).

Faults

Faults are breaks, or **fractures**, in rocks along which one side has **moved** relative to the other side. There are many kinds of faults, some of which are important as structural traps for petroleum in Kansas. Faulting, for example, is important to entrapment and migration of oil at Salina-Lindsborg fields in Saline County. The most common type of fault is the "normal fault" (fig. 6a). In

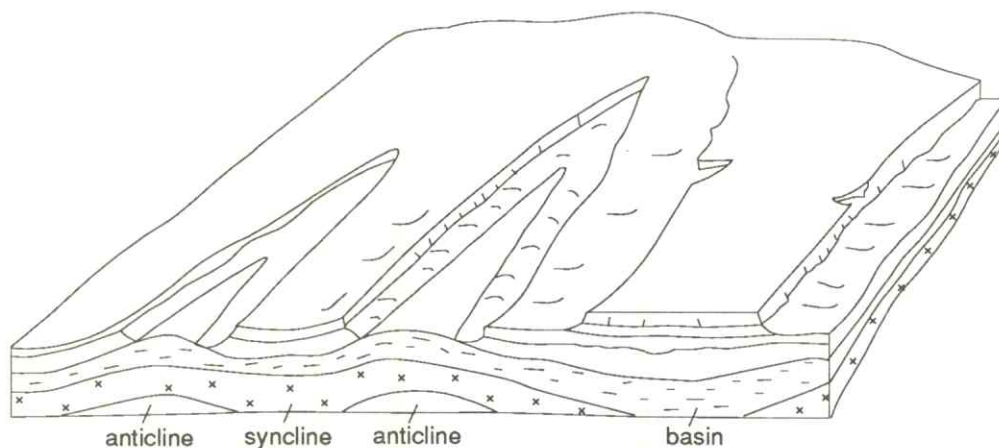


FIGURE 5—LAYERED ROCKS OF THE EARTH'S CRUST ARE OFTEN FOLDED WHEN THE CRUST IS SHORTENED BY INTENSE COMPRESSIONAL FORCES. UPFOLDS ARE CALLED "ANTICLINES," DOWNFOLDS ARE CALLED "SYNCLINES," AND BROAD DOWNFOLDED AREAS ARE KNOWN AS "BASINS."

this case, rocks along one side of the break simply drop down relative to the other side. An example is the Humboldt fault zone, a series of normal faults which can be traced from Nebraska southwestward across the state of Kansas along the east side of the Nemaha ridge. This happens when the Earth's crust is stretched.

Another kind of fault occurs when one block of rock is faulted upward and over another. If the plane of the fault is steep, it is called a "reverse fault" (fig. 6b) and if it is low angle, it is called a "thrust fault" (fig. 6c). The fault at Salina-Lindsborg fields is a reverse fault, and the Humboldt fault zone includes some reverse faults. Reverse and thrust faults occur when the Earth's crust is compressed, or shortened. When this occurs, folds usually form first, only to break into thrust faults when the strength of the strata involved is exceeded by the compressional forces.

We are only now learning that the most important kind of faulting is when one block of the Earth's crust is forced to move **laterally** (horizontally) in relation to the other side. Such faults, known technically as "strike-slip faults," and rather colloquially as "wrench faults," form when lateral stresses (twisting in the horizontal plane) act on large expanses of the Earth. Wrench faults usually form in broad bands, or swarms of many faults, that may be tens of miles wide and hundreds of miles long. Such extreme friction occurs that the rocks literally are shattered along a wide path and movement occurs along dozens or perhaps hundreds of individual faults and drag folds. The many faults that are active today in southern California, the San Andreas and related faults, constitute a wrench-fault zone. In that case, the western, or seaward, block is moving northward relative to the eastern, or continental side along hundreds of active faults. Geologists are now finding numerous wrench-fault zones, especially in rocks of younger Precambrian age, on every continent, and the midcontinent of North America is no exception. Structures associated with the Central Kansas uplift occur in patterns and trends which resemble those involved in wrench-fault zones. The Midcontinent Rift System that traverses from northeast to southwest across eastern Kansas is believed by some geologists to be an ancient,

billion-year-old, wrench-fault zone.

Basically, faulting of any kind makes structural traps for petroleum. Porous layers are commonly faulted against rocks with low porosity and permeability, stopping the updip migration of oil or natural gas; huge accumulations may result. The inherent complexities of wrench-fault zones may localize dozens or hundreds of oil or gas fields in large linear trends. Southern California is a well-known example; some geologists think that the Central Kansas uplift may be another.

Fractures in otherwise tight, nonporous rocks can themselves be open, providing "fracture porosity" that may contain petroleum. Thus a shale or dense limestone may be fractured and contain oil, forming another type of structural trap. Fractures commonly break through porous rocks and increase the permeability greatly by providing pathways that interconnect rock pores. Fracturing may be much more important in forming reservoirs in Kansas than we realize. Recent research on porosity and permeability development in shallow Pennsylvanian sandstones of southeastern Kansas and northeastern Oklahoma indicates a clear link between production and fracture patterns as mapped at the surface. Fracture porosity is also a component of the pore space in reservoirs in the Hugoton gas area. Ancient weathering along fractures has enhanced reservoir development in fields producing from the Arbuckle Group in the midcontinent.

An important characteristic of all structures, but of wrench-fault zones in particular, is that once a fold or fault begins to move, it is a zone of weakness for all remaining geologic time. Movement will recur each time properly oriented stresses are generated in the crust of the Earth for whatever reason. Consequently, structures originating in Precambrian basement rocks may have been rejuvenated repeatedly throughout geologic history. Each time there is renewed movement on a structure, be it ever so slight, overlying rocks are shuffled up or down, perhaps only by inches or a few feet. Every foot of topographic relief on the seafloor affects the nature of the sediments being deposited, especially in the case of carbonate sediments. Consequently, shoals may develop on the seafloor on and

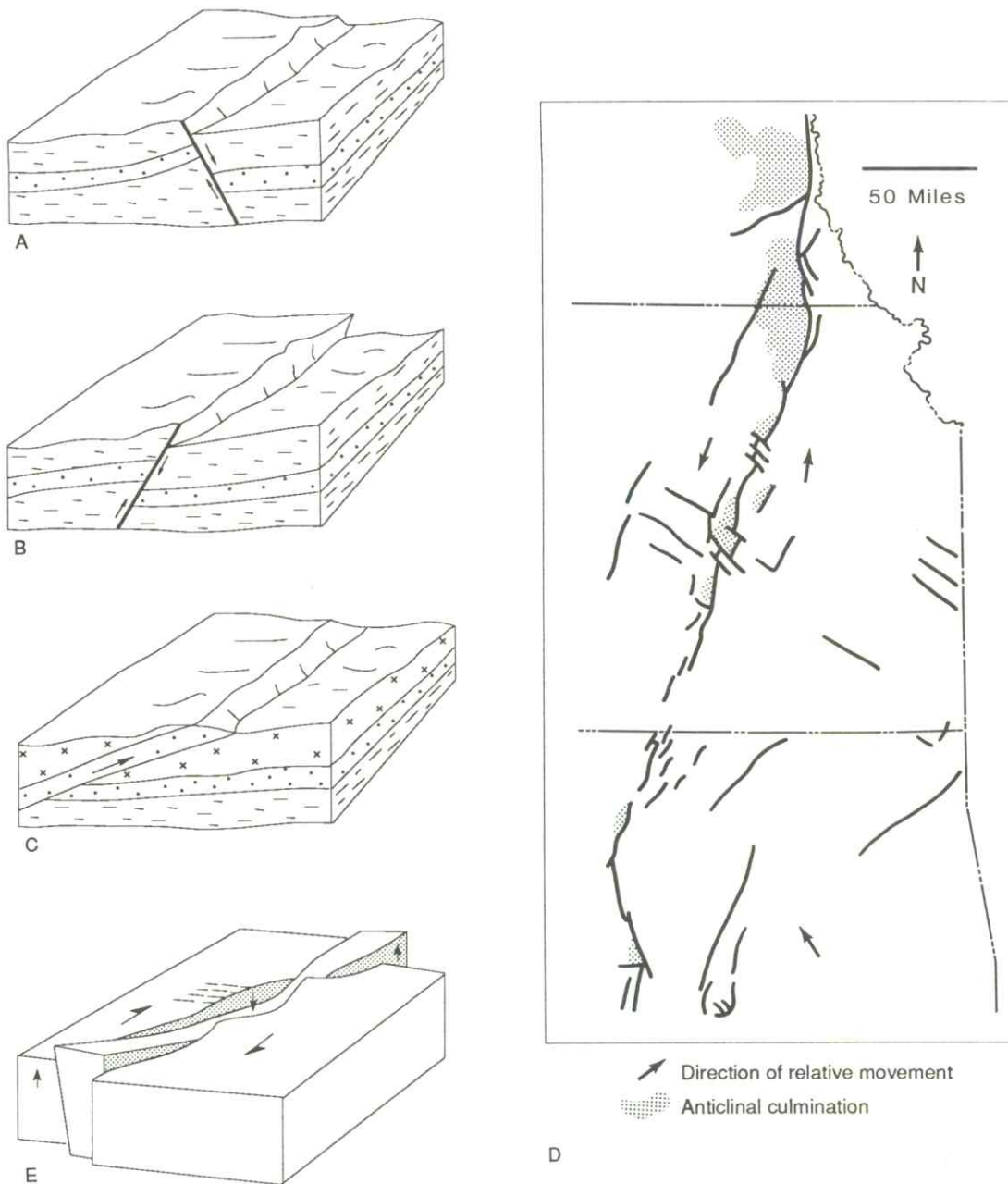


FIGURE 6—FRACTURES IN THE EARTH'S CRUST ALONG WHICH MOVEMENT HAS TAKEN PLACE ARE CALLED "FAULTS." A) Where one side of the fault is dropped down by gravity relative to the other side, it is a "normal fault." B) Where one side of a fault is pushed up and over the opposite side of the fault along a steep fracture, it is called a "reverse fault." C) A "thrust fault" occurs where a sheet of rock is forced up and over the opposite side of the fault along a low-angle break. Rocks are sometimes displaced many miles along large thrust faults. D) "Wrench faults" occur where one side of the fault moves along several, often sinuous faults, such as shown here along the Nemaha or Humboldt fault zone in eastern Kansas. E) This block diagram of a wrench-fault zone shows that vertical movement is often very complex. Faults may appear to be normal or reverse along the fault zone, and fault reversals and scissoring are common; horizontal displacement is greater than these vertical complications.

around high structures, and structural depressions become sedimentary basins. Either situation changes the environment of deposition to a degree.

As we have seen, different types of sediments eventually produce different porosity/permeability relationships in the rocks. If the rock type varies due to water depth that is controlled by structural movement during deposition, local variations in porosity/permeability will result. Thus a definite relationship exists between geologic structure and the kind of sedimentary rock that is produced, and stratigraphic traps result.

Petroleum reservoirs produced by structural growth during deposition of sediments are common in Kansas. The myriad oil/gas reservoirs in Pennsylvanian rocks of the Central Kansas uplift are examples, and more are being discovered by drilling every day. A prominent anticline, formed over deep-seated faulting in Haskell County, exhibits recurrent growth which helped develop a series of major oil and gas fields along this structure. The Cahoj field in Rawlins County in northwest Kansas was a topographic high during deposition of the Lansing-Kansas City reservoirs leading, in part, to the stacking of 11 reservoir units in that field. It is still high today. McClain field in Nemaha County produces from Simpson and Viola reservoirs. Both were influenced by ancient topography similar to present-day structure. Other Viola fields along the Pratt anticline in south-central Kansas exhibit early structural growth of this anticline which extends southward from the Central Kansas uplift.

Unconformities

Whenever the sea withdraws and the landscape is exposed to the elements, erosional processes take com-

mand. Physical weathering, such as rainfall, the resulting runoff as streams, wind action, and perhaps glacial scouring, work to lower and level the lands. Chemical processes form soils and dissolve soluble rocks such as limestones and evaporites. Structurally formed topography can be beveled to a near plain, exposing the eroded edges of formations that may have been tilted in the process. When the sea returns and new sediments are deposited on the old eroded land surface, the surface of contact is called an "unconformity" (fig. 7). If the old rocks have been tilted and beveled before burial by near-horizontal beds, the surface is called an "angular unconformity."

The presence of an unconformity in the layered sequence of rocks indicates that some increment of time is missing in the rock record. It is estimated that the sedimentary rocks deposited in Kansas represent only a small part of geologic time. The remaining time is incorporated in the unconformities. These gaps in the record are at least as important as the rocks and markedly affect their distribution.

Oil and gas migrating upward along inclined rock layers may be trapped at an unconformity if the beds overlying the eroded surface are impermeable. Oil and gas may also have migrated along the unconformity. The major uplifts of Kansas, and some smaller folds and faults, have been elevated, and the resulting tilted strata beveled by erosion at different times during the geologic past. Excellent unconformity traps have resulted, notably along the flanks of the Central Kansas and Nemaha uplifts. Mississippian limestones along the western flank of the Central Kansas uplift contain vast amounts of petroleum beneath the Pennsylvanian/Mississippian unconformity.

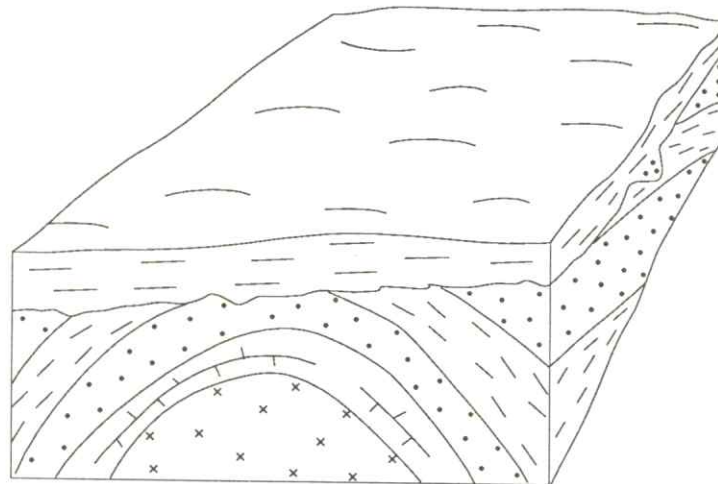


FIGURE 7—UNCONFORMITY IS A SURFACE BETWEEN ROCK LAYERS that shows the effects of a period of erosion or nondeposition. In this case, the rocks below the wavy line (unconformity) were deposited, folded to form an anticline, and then eroded to a plain before the rocks above the unconformity were deposited. Petroleum migrating along any permeable bed may be trapped when it rises to the eroded surface.

Exploration

Three conditions must be present for an oil or gas field to exist: 1) a source rock, such as shale, that is rich in organic material; 2) a reservoir rock, such as porous and permeable limestone, dolomite, or sandstone; and 3) a trapping mechanism, such as an anticline, faulted strata, or any of the myriad kinds of stratigraphic traps. Petroleum geologists must do everything possible to search for areas where all of these conditions are met. The task is very much like that of the private detective in a murder mystery. One must gather as many clues as possible (there are never really enough), the clues must be studied and interpreted individually, and then with a great deal of data compilation and imagination a recommendation to explore can be made. Usually patterns will develop, everything falls into place at an unexpected time, and the "drilling prospect" is ready to sell to management or investors. Yet the very best prospect in the world, where everything seems to be perfect, is suspect and risky until it is actually drilled. The cost of drilling and completing a well can be in excess of a million dollars, and the probability of success in a wildcat well is only about one in nine.

There are as many ways to search for oil as there are petroleum geologists. Usually a geologist begins by searching for an area with a thick section of sedimentary rocks. The more layers of rock present, the better the opportunities for porous and permeable rocks to exist; the source rocks must be deeply buried for long periods of time for hydrocarbons to be generated from organic matter. Thickness of the rock column can be determined by studying rock exposures in stream gullies and roadcuts (fig. 8). Wells drilled for water, or previously drilled oil

and gas wells also provide information. In Kansas, where more than 350,000 wells have been drilled in search of petroleum, the amount of available data is staggering. At the same time geologists are studying rock thickness, they are also searching for organic-rich shales (source rocks) and porous sandstones or carbonate rocks (reservoir rock). If a thick sequence of sedimentary rocks with possible source and reservoir rocks is found, the search for traps begins. In most parts of the world, answers to these questions have already been determined by previous studies, and one needs only to visit a technical library to find the answers. In Kansas, the source rocks are relatively well known; the most prolific are the Chattanooga Shale, a Late Devonian–Early Mississippian black, organic-rich shale; the Middle Ordovician Simpson Group containing algal-rich brown, waxy, shales; and where they are more deeply buried, dark shales of Pennsylvanian age.

Locating traps is not easy, but structural traps are the most obvious kind. The easiest and least expensive method is to map the location and attitude of rocks exposed at the surface. Folds and faults can often be detected in surface exposures, and aerial photos and satellite images may give clues to the presence of structures too large or too obscure to be noticeable at the surface. In eastern Kansas, much of the oil discovered early was found by studying structures exposed at the surface; the El Dorado oil field is a good example. However, most of these more obvious structures have been previously mapped and drilled. Consequently, other techniques must be used to find structures beneath the surface of the earth that cannot be seen at the surface.

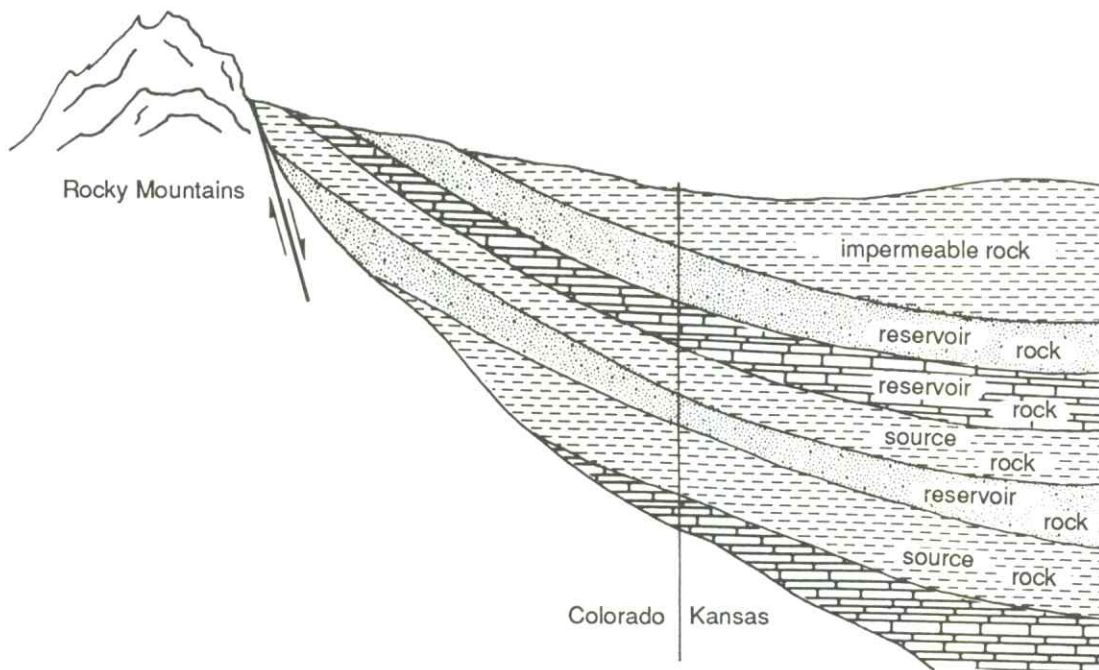


FIGURE 8—GEOLOGIC FORMATIONS THAT UNDERLIE PARTS OF KANSAS MAY BE EXPOSED AT THE SURFACE ELSEWHERE. Geologists study the rocks where they are exposed for information that may aid in the discovery of oil and gas in Kansas.

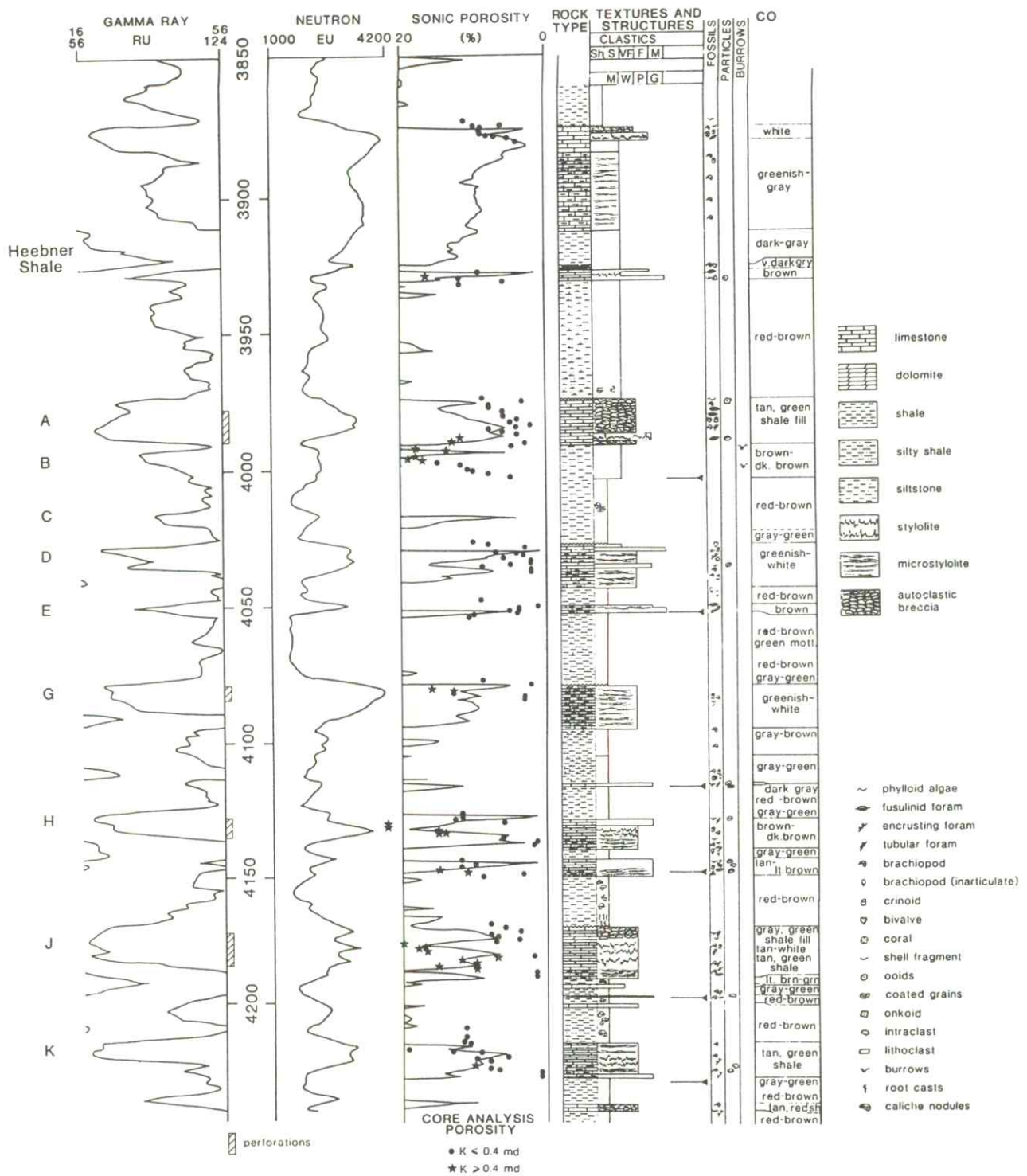


FIGURE 9—WELL LOGS, SUCH AS GAMMA RAY-NEUTRON AND SONIC LOGS, ARE RECORDED ON STRIP GRAPHS THAT ARE KEYED TO DEPTHS IN THE WELL. THESE LOGS CAN BE USED TO DETERMINE ROCK TYPES AT GIVEN DEPTHS, AND TO INDICATE ZONES OF POROUS ROCK. THIS IS AN ACTUAL EXAMPLE OF COMBINED WELL LOGS AND ROCK DATA FROM A WELL DRILLED IN CAHOJ FIELD, RAWLINS COUNTY, KANSAS.

Subsurface geology

When a well is drilled in the search for petroleum, samples of the rock layers encountered are saved. Studying these “drill cuttings” (chips of rock produced by the drill bit) and “cores” (continuous columns of rock cut during drilling; see the section on cores, page 28) allows petroleum geologists to identify the rock layers present in that locality and their natural sequence. Geologists can also see the nature of any porosity and can detect the presence of oil in the rock. A continuous graphic and written record (strip log) of the observed rocks is made for future use.

When a hole reaches its projected depth (“total depth”), geophysical logs are run in the hole to measure different properties of the rocks encountered. “Electric logs” measure naturally existing electrical currents and how the rocks transmit induced electrical currents. These logs detect porous zones and the nature of the contained fluids. Saltwater is a good conductor of electricity, while freshwater and hydrocarbons are not, thus the presence of saltwater (most deep underground waters are saline) can be determined and distinguished from petroleum. Oil-field waters in Kansas are highly variable in salinity, ranging from near freshwater to concentrated brines.

“Gamma ray-neutron logs” are records of the presence of naturally occurring radioactive minerals, even in minute quantities and show how the rocks respond to induced radioactive particles (fig. 9). Shale is more radioactive than sandstone or limestone and is thus distinguishable from them. When the rock is bombarded with neutrons, any hydrogen present in the rocks absorbs the radioactive particles. As any naturally occurring fluids, either hydrocarbons or waters, contain hydrogen, their presence is indicated and an indirect measurement of the rock porosity is recorded.

“Sonic logs” are made by bombarding the rocks in the borehole with sonic (sound) waves and recording their rate of travel within the rock. Sonic waves travel more rapidly through solid rock, scatter, and are thus detained in open pores. This provides another means of determining the porosity of the rocks drilled.

Many other types of logs are occasionally run in wells, and new types are devised continually. These, however, are the most commonly run geophysical logs. “Subsurface geologists” use any or all of these data to determine exactly what rocks were drilled and to decide where to

drill the next hole. They compare the logs of one well to others drilled in the vicinity (correlation) to determine the structure of the rock layers, as well as thickness and sedimentary-rock types present in each individual layer. From these data, maps are drawn.

Maps

Subsurface geologic maps are used extensively to determine the distribution of rock layers, their thickness variations, and their attitudes (structure).

The elevation at the top of each bed is determined by subtracting the depth of the layer in the hole from the elevation at the surface of the hole. A value is calculated and plotted on a map along with similar values from all other holes drilled in the area of interest. The elevation values are contoured, much the way surface elevations are contoured on a topographic map, and the resulting “structural contour map” of a specific layer of rock results. In this way anticlines, synclines, and faults may be located and their size and orientations determined (fig. 10).

Thickness (“isopach”) maps are made by subtracting the depth in a hole of the top of a rock layer from the depth of the base of the layer (fig. 11). The value is again plotted on a map along with thickness calculations of the particular layer from all other wells in the area, and the data are contoured. The resulting thickness map displays trends of thickening and thinning of each layer and, thus, indicates the locations of possible stratigraphic traps.

There are as many kinds of subsurface stratigraphic maps as there are conditions to map. “Facies maps” show the distribution of rock types within a specific rock layer, as well as potential stratigraphic traps. “Paleogeologic maps” or “subcrop maps” show the areal distribution of rock layers exposed at ancient erosional surfaces (unconformities), now buried by younger rocks. These maps show where the old structures were located at the time of the erosional surface and where to look for eroded edges of the various formations, as they may form traps for petroleum. Almost any geologic situation can be studied and displayed with maps. Of course, the data are stored, sorted, calculated, retrieved, and the maps plotted and contoured with the aid of computers. But the subsurface geologist must interpret the maps to decide where to drill next for the ever-elusive petroleum.

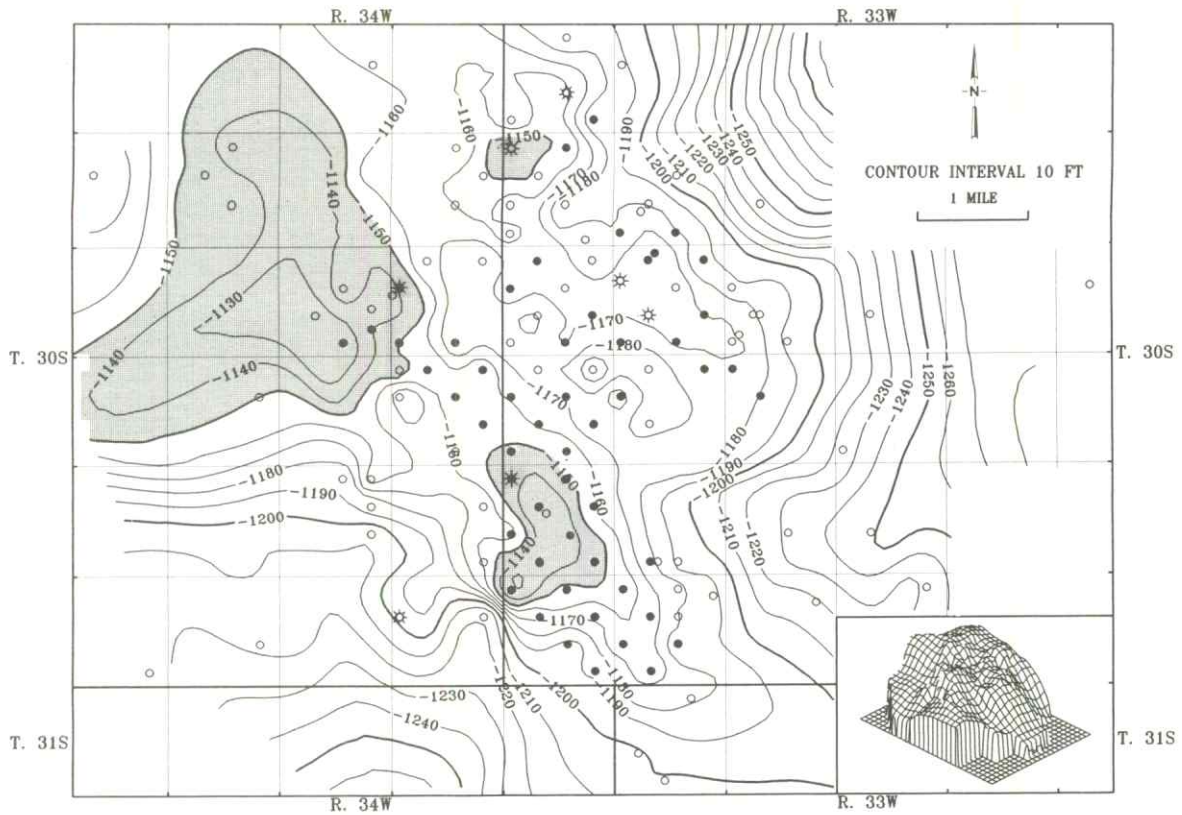


FIGURE 10—A STRUCTURAL CONTOUR MAP, SUCH AS THIS MAP ON ROCKS AT THE TOP OF THE LANSING GROUP in the Victory field in Kansas, show the structure (variations in elevation on a rock layer relative to sea level) with contours, much like a topographic map. Petroleum rises to the highest occurrences of the rock layer, thus a structural contour map is a tool in locating oil/gas fields. Solid circles represent oil wells, barbed circles are gas wells, and open circles are dry holes.

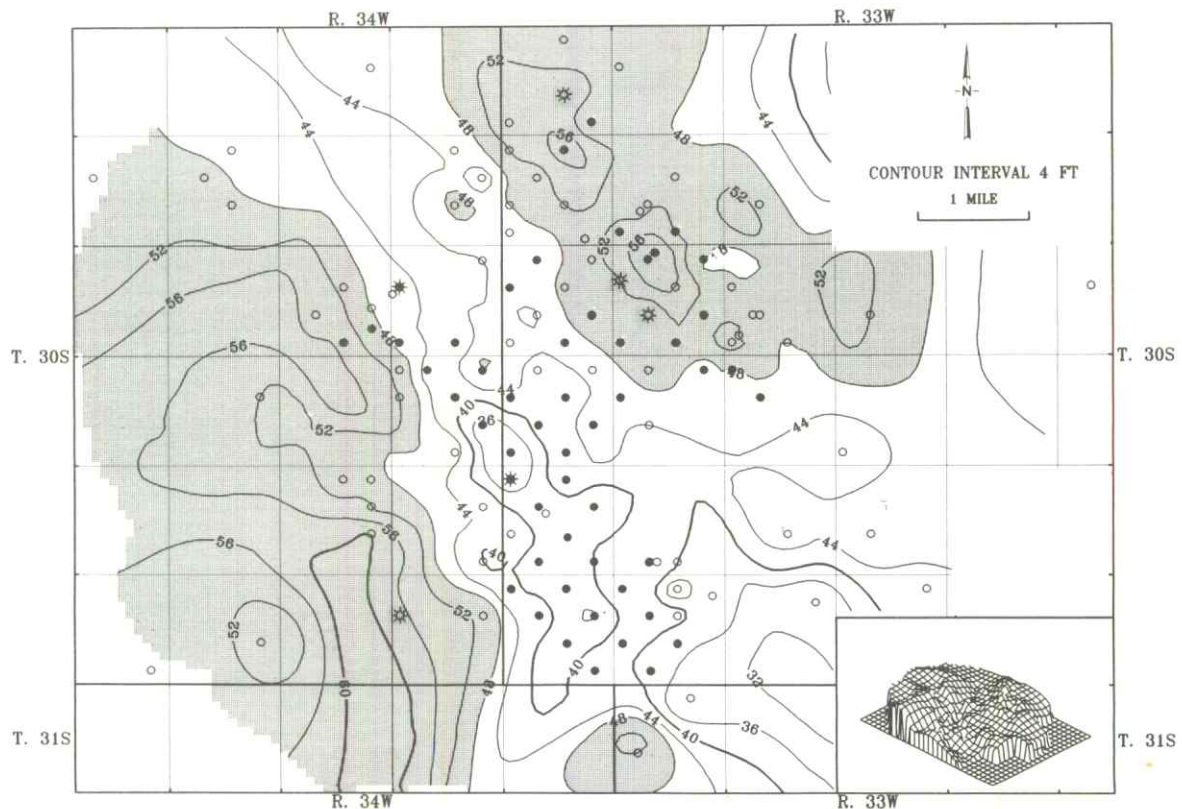


FIGURE 11—ISOPACH MAPS, SUCH AS THIS ONE OF THE SAME ROCK LAYER in the LANSING GROUP mapped in fig. 10, show thickness of the rock containing petroleum by contours that connect points of equal thickness. The thicker areas of the rock unit are shaded, and the unit thins noticeably over the crest of the structure. Fig. 2D illustrates the porosity in this rock unit.

Petroleum geology of Kansas

The surface geologic map of Kansas shows a relatively simple pattern of bedrock strata cropping out at the Earth's surface (fig. 12). Paleozoic rocks dip very gently to the west and northwest from the structurally high Ozark dome centered in southeastern Missouri and north-central Arkansas. The oldest rocks are Mississippian limestones that occur in the most southeastern corner of the state. Broadly curved bands of Pennsylvanian and then Permian strata overlie Mississippian rocks and are exposed over the eastern third of Kansas. Sedimentary rocks of Cretaceous and Tertiary age blanket the Paleozoic rocks in western Kansas. This simplistic surface geology masks much more complex relationships known to occur deep underground from examination of drill holes and geophysical studies. The following discussion should be regarded as only a thumbnail sketch of the petroleum geology of Kansas. Detailed descriptions and discussions would fill a library. Summary accounts have already produced several books. A good example is *Stratigraphic and spatial distribution of oil and gas production in Kansas* by K. D. Newell et al. published by the Kansas Geological Survey in 1987 as Subsurface Geology Series 9.

Deep beneath the surface, Kansas is divided into portions of five basins separated by uplifts (fig. 13). Basins are areas having thicker sections of sedimentary rocks than found on the uplifts. The western third of the state is underlain by the Hugoton embayment of the Anadarko basin, a very deep (around 40,000 ft [12,192 m]) basin centered in Oklahoma. A major structurally high trend—the Central Kansas uplift, and its southern extension the Pratt anticline—separate the Hugoton embayment from the Salina and Sedgwick basins of central Kansas. A complexly folded and faulted east-northeast-trending basement high in east-central Kansas, the so-called Nemaha ridge, separates the Salina and Sedgwick basins from the Forest City and Cherokee basins of eastern Kansas. The Forest City and Cherokee basins are divided by the Bourbon arch.

These uplifts are fascinating. Both the northwest-trending Central Kansas uplift and the northeasterly Nemaha ridge are associated with broad bands of complex folding and faulting. Faults of the late Paleozoic-age Nemaha uplift (Humboldt fault zone) parallel the Precambrian Midcontinent Rift System. Although structural growth on these two features is separated by 700 million years, the later structure may be a reactivated portion of the rift. The Central Kansas uplift appears to transect the Midcontinent Rift System. Its relation to a rift or wrench fault system has not been established.

Sauk Sequence

Rocks of early Paleozoic age thicken regionally toward the south and east across Kansas, suggesting that the surface at the top of the Precambrian basement was sagging slowly southward toward Oklahoma in Late Cambrian and Early Ordovician time. These sedimentary

rocks represent the early burial of the southern margin of the old core of the continent, known generally as the "craton." This cycle of sedimentary rocks, consisting of a basal nearshore sandstone (Lamotte and Reagan) overlain by a vast sheet of dolomite deposited on extensive tidal flats (Arbuckle), represents the first major advance and retreat of Paleozoic seas (fig. 14). Such major cycles of deposition were named "sequences" by L. L. Sloss; this one is the Sauk Sequence of Cambrian and Lower Ordovician age. Vast amounts of oil have been produced from these strata, mostly from structural traps (fig. 15).

Tippecanoe Sequence

The Tippecanoe Sequence (Middle Ordovician to Lower Devonian) succeeds the Sauk Sequence with similar kinds of rocks. The sea level rose again covering Kansas and many adjoining areas of the midcontinent. Sandstones and shales of the Simpson Group were deposited as the shoreline advanced inland onto the craton. As water depths increased and as sources of mud and sand were buried, marine lime sediments of the Viola Limestone and Hunton group were deposited. These rocks are thickest in southern and north-central Kansas and serve as good petroleum reservoirs in these areas.

Sea level dropped and uplift of the region began after the sequence was deposited. Erosion began stripping the deposits from the higher lands, especially on the Chautauqua arch in southeastern Kansas and large parts of the Central Kansas uplift. Petroleum accumulation has been notable where these broadly upturned and beveled strata are covered by younger rocks at the overlying erosional unconformity. Accumulation is focused along the unconformity because: 1) the porosity of the limestones is greater along the weathered surface, 2) the unconformity terminates the porous limestone against nonporous rock, and 3) the unconformity apparently acts as a porous carrier of petroleum to the site of accumulation.

Shales of the Simpson Group contain an abundance of oil-prone organic matter. These shales have generated much of the oil produced from reservoirs in northeastern, central, and south-central Kansas.

Kaskaskia Sequence

The Kaskaskia Sequence (Devonian through Mississippian time) succeeded the Tippecanoe Sequence and represents another inundation of the continent. Near the base of the sequence the Chattanooga Shale was deposited. It is rich in organic matter in southern Kansas and Oklahoma and is the most significant source rock for oil and gas in the midcontinent.

A series of moderately thick limestones follows the Chattanooga Shale. The limestones accumulated on a broad, tropical, shallow marine shelf that extended across

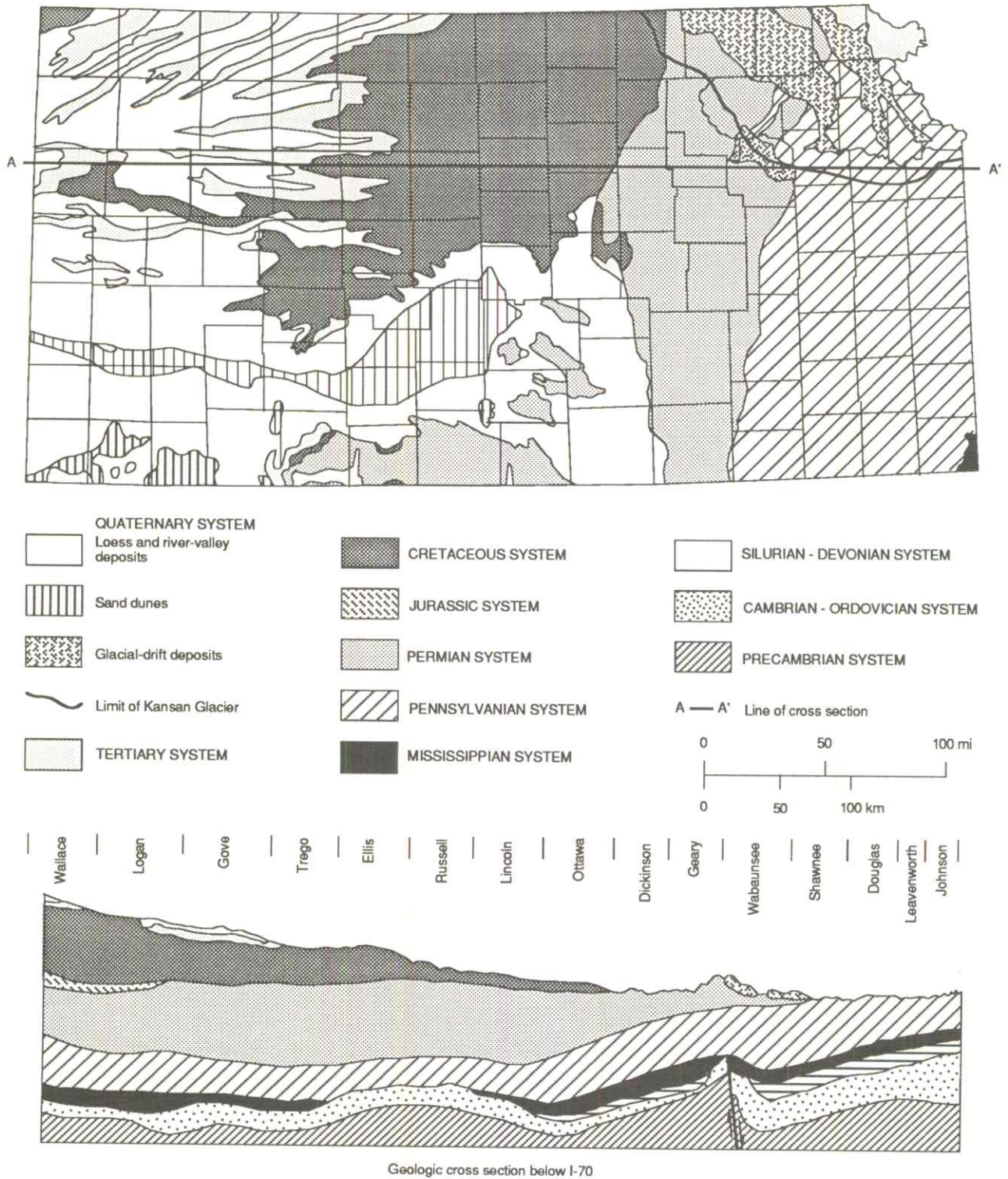


FIGURE 12—A HIGHLY GENERALIZED GEOLOGIC MAP OF KANSAS, showing areas where rocks of different ages are exposed at the surface. The cross section at the bottom of the illustration shows an interpretation of rock layers at considerable depths beneath the Interstate-70.

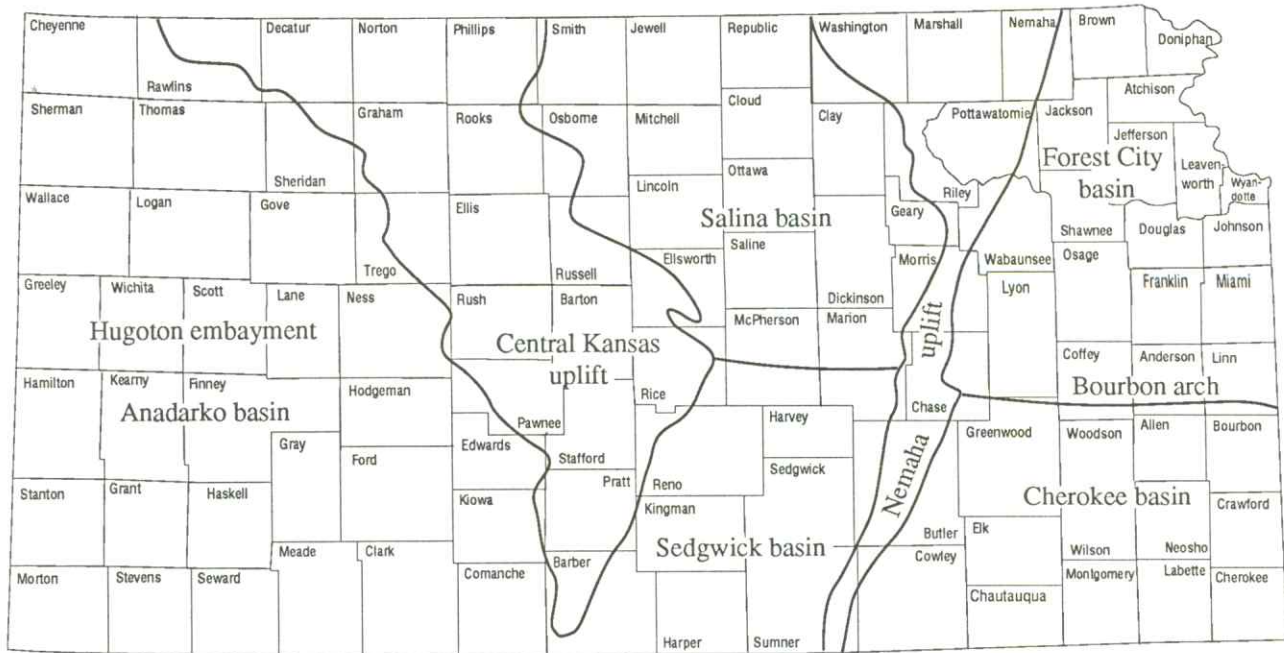


FIGURE 13— MAP SHOWING THE RELATIVE LOCATIONS OF BASINS AND UPLIFTS DEEP BENEATH THE SURFACE OF KANSAS. These large structures are discussed in the text.

much of the United States. Mississippian limestones are divided into several formations which reflect changing depositional settings afforded by minor changes in sea level. These units provide many opportunities for oil and gas accumulation amounting to more than 20% of the original oil in place in Kansas. Later uplift and concomitant lowering of sea level led to tilting and erosion of these deposits. Notably, the Mississippian was removed over the Central Kansas uplift. Prolific oil and gas fields were produced from adjoining flanks along belts or fairways where upturned and beveled Mississippian carbonates intersect the overlying unconformity at the top of the Kaskaskia Sequence. Oil apparently filled these reservoirs as it migrated along the unconformity surface.

Mississippian limestones contain abundant chert in southern Kansas. As these limestones weathered along the unconformity, a residual chert, called "chat," was produced. The chat is thickest along the southern flanks of the Central Kansas uplift bordering an area where the Mississippian strata were removed.

Absaroka Sequence (Pennsylvanian through Triassic)

By Early Pennsylvanian time, erosion was stripping the older rocks from parts of the uplifts, permitting Pennsylvanian rocks to eventually rest directly on the upturned eroded edges of all older formations. Upper Pennsylvanian strata rest directly on the Precambrian surface in local areas on the Central Kansas and Nemaha uplifts. Then the entire region began subsiding, but the basins were sagging much faster than the faulted uplifts. Sedimentary rocks of Middle and Late Pennsylvanian and Early Permian age

(Absaroka Sequence) are much thicker in the basins and thicken southward as well. As the regional basins were developing, individual structures on the uplifts were being jostled about, causing variations in depositional patterns. Complex structural and stratigraphic traps resulted.

Early Pennsylvanian through Early Permian time was a period of great structural unrest, apparently brought on by collision between North American and South American–African continental plates. The situation was greatly complicated by simultaneous cycles of fluctuating sea levels, caused by episodes of continental glaciation in the polar regions. Sea levels rose and fell repeatedly; each time the shoreline would migrate inland several hundred miles, only to fall back during times of lowering sea level. Although each cycle of sedimentary rocks can be traced over thousands of square miles in the subsurface, variations in sedimentary facies caused by shorelines wandering about over growing faults and folds created untold hundreds of stratigraphic and structural traps. Many of these are found on the Central Kansas uplift, one of the most densely drilled targets in North America, but others are scattered over central and western parts of the state. Some of the most prolific reservoirs occur in the Lansing–Kansas City groups of Upper Pennsylvanian age. The Hugoton gas field, the largest accumulation of natural gas in North America, produces from Lower Permian cyclical dolomites in the Hugoton embayment of southwestern Kansas.

Rocks of Cretaceous age rest directly on Permian strata over most of the state. Triassic red beds are found only in a tiny area of southwestern Kansas, and the latest Jurassic rocks are known to occur in northwestern Kansas. Otherwise there are no rocks to represent the two geologic periods in the state. Chalks of Cretaceous age produce a little gas in northwesternmost Kansas.

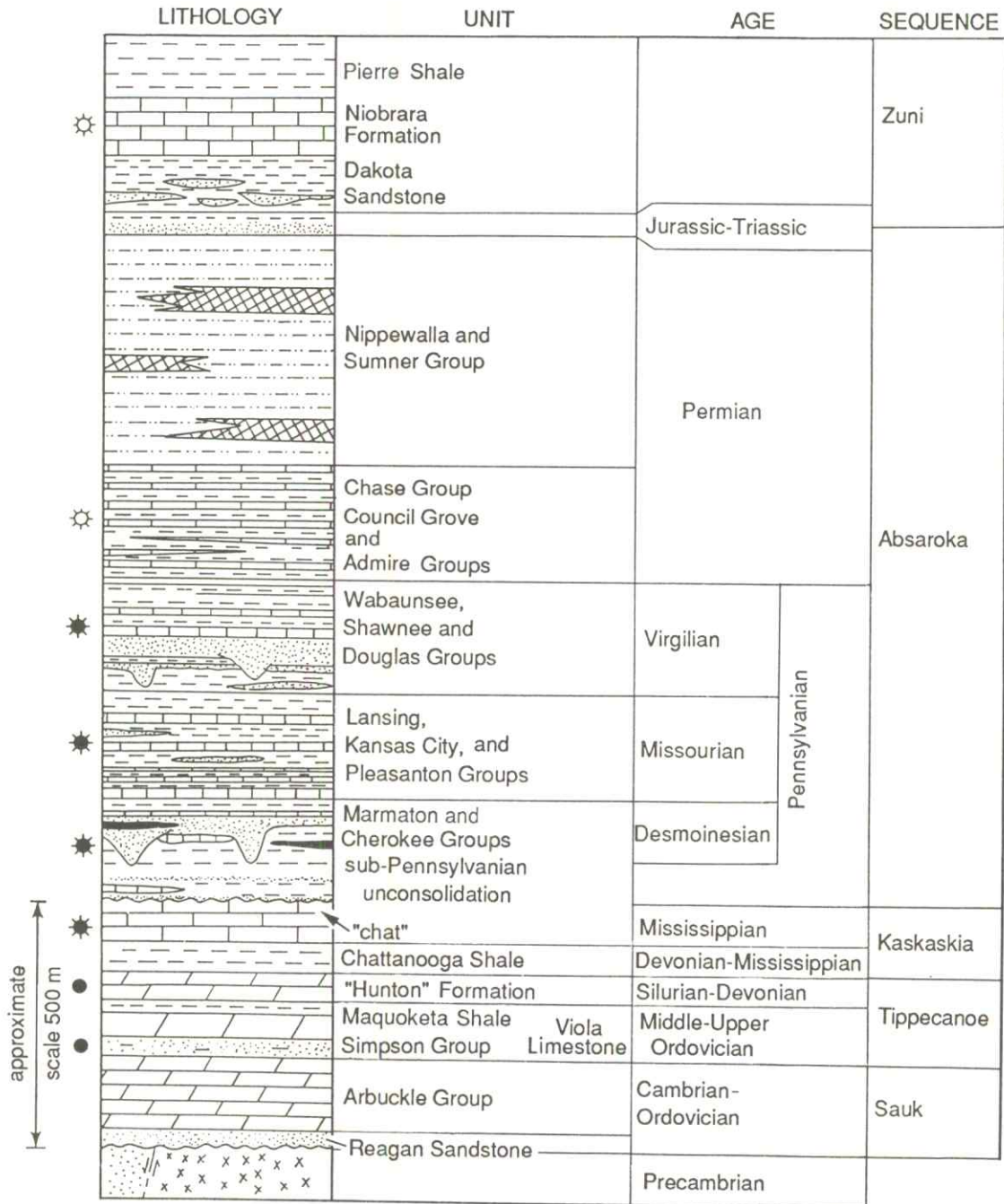


FIGURE 14—DIAGRAM SHOWING THE SEQUENCE AND AGE OF ROCK STRATA FOUND AT AND BENEATH THE SURFACE OF KANSAS. The nature of these rock layers is discussed in the text.

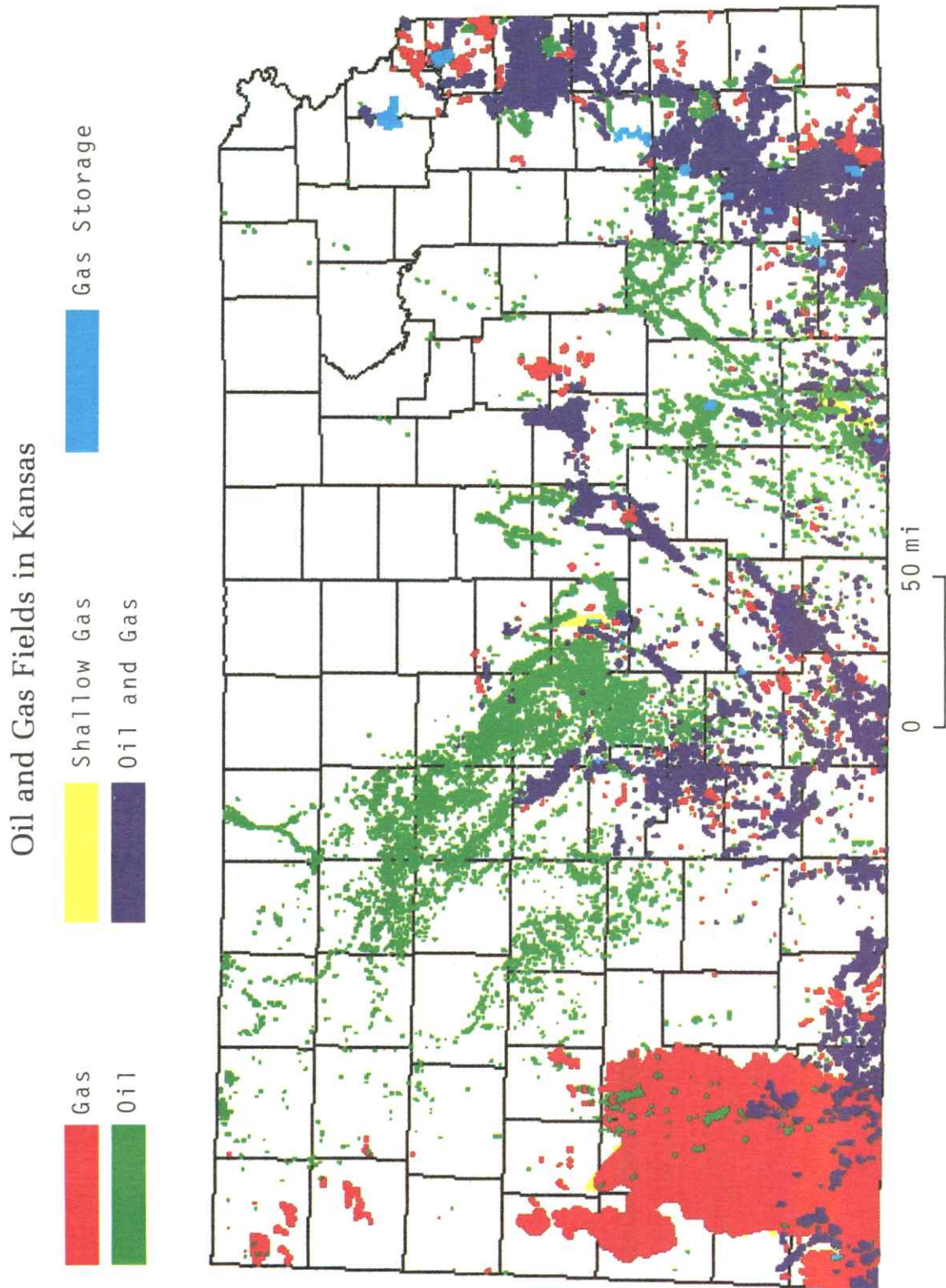


FIGURE 15—MAP SHOWING THE LOCATIONS OF OIL AND GAS FIELDS IN KANSAS. Note the relationships between producing fields and the major deep-seated structures (fig. 13).

Some fundamentals of geophysical exploration

There are several means of exploring the Earth by geophysical methods. Each of these techniques exploits fundamental physical aspects of Earth materials such as electrical, magnetic, acoustical, or gravitational properties. While these techniques do not allow detailed examination of the rocks beneath us, they often enable geologists and geophysicists to infer the most likely properties of large volumes of rocks. The physical fundamentals of various geophysical exploration techniques are discussed in the following paragraphs.

Gravity methods

The Earth's gravitational attraction varies slightly from one place to another on the Earth's surface. Some of this variation occurs because the Earth is not a perfect sphere, and some is related to differences in elevation on the Earth's surface. While these variations in gravity are predictable and can be calculated for each spot on the Earth's surface, other variations in gravity, such as those caused by unknown geologic features are not predictable.

For example, in north-central Kansas, there is an anomaly known as the Midcontinent Gravity High where the Earth's gravity is about 0.006% greater than normal. In other words, it would be slightly more difficult for a track and field athlete to high jump or pole vault in north-central Kansas than in other parts of the state.

Gravity measurements are made with an instrument known as a gravity meter, and maps can be produced that show differences in the pull of gravity across the state.

These variations are useful in locating geologic faults and ancient volcanoes, for example. They can also indicate the presence of geologic basins that are filled with unusually large thicknesses of sedimentary rocks.

Magnetic methods

The Earth's magnetism varies from place to place, much as the gravity varies. The variation in strength of the magnetism is caused primarily by concentrations in rocks of a magnetic mineral called magnetite. Rocks such as granite and sandstone have a high magnetite content relative to such rocks as limestone and shale.

These variations in magnetism have been measured for the state of Kansas by towing an instrument known as a magnetometer behind an airplane. The resulting magnetic maps are useful in finding geologic faults and geologic basins that are filled with unusually large thicknesses of sedimentary rocks or buried mountains that are covered with unusually thin sediments.

Electrical methods

Variations in the electrical properties of Earth materials can be measured at the Earth's surface and within drill holes. These measurements are very often made in holes at the time of drilling, but are not often made at the Earth's surface in Kansas. The presence of oil and gas in rocks in a drill hole is indicated by unusually high electrical resistance.

Concepts of seismic-reflection prospecting

Seismic reflection, a powerful technique for underground exploration, has been used for over 60 years. The purpose of this short discussion and the accompanying figures is to describe basic principles and features of seismic reflection. This discussion is for those who have heard of seismic reflection but do not know how it works. Seismic waves are essentially sound waves that travel underground at velocities of 2 to 4 miles per second (3 to 6 km per second), depending upon the type of rock through which they pass.

Seismic-reflection techniques depend on the existence of distinct and abrupt seismic-velocity and/or mass-density changes in the subsurface. These changes in either density or velocity are known as acoustical contrasts. The measure of acoustical contrast (formally known as acoustic impedance) is the product of mass density and the speed of seismic waves traveling within a material. In many cases, the acoustical contrasts occur at boundaries between geologic layers or formations, although manmade boundaries such as tunnels and mines also represent contrasts.

The simplest case of seismic reflection is shown in fig. 16. A source of seismic waves emits energy into the

ground, commonly by explosion, truck-mounted vibrators, mass drop, or projectile impact. Energy is radiated spherically away from the source. One ray path originating at

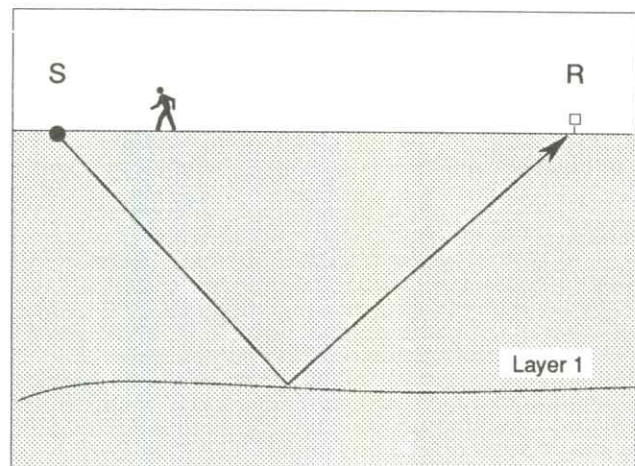


FIGURE 16—REFLECTION FROM ONE LAYER.

the source will pass energy to the subsurface layer and return an echo to the receiver at the surface first. In the case of a single flat-lying layer and a flat topographic surface, the path of least time will be from a reflecting point midway between the source and the receiver with the angle of incidence on the reflecting layer equal to the angle of reflection from the reflecting layer.

The sound receivers at the surface are called geophones and are essentially low-frequency microphones. Signals from the geophones are transmitted by seismic cables to a recording truck, which contains a seismograph. The

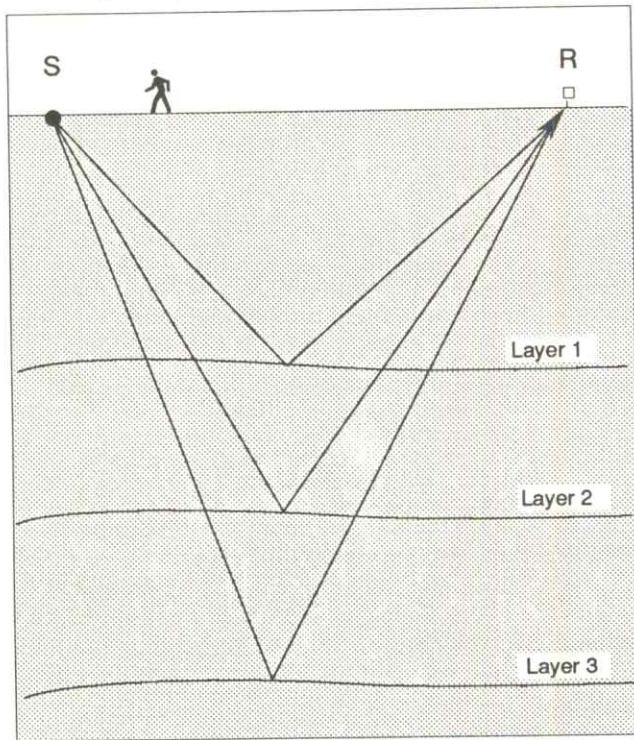


FIGURE 17—REFLECTION FROM THREE LAYERS.

seismograph contains amplifiers that are very much like those on a stereo music system. The sounds returning from the Earth are amplified and then recorded on digital computer tape for later processing and analysis. The purpose of computer processing is to separate echoes from other sounds, to enhance the echoes, and to display them graphically.

In the real world, several layers beneath the Earth's surface are usually within reach of the seismic-reflection technique. Fig. 17 illustrates that concept. Note that echoes from the various layers arrive at the geophone at different times. The deeper the layer, the longer it takes for the echo to arrive at the geophone. Because several layers often contribute echoes to seismograms, the seismic data become more complex.

In the case of a multi-channel seismograph, several geophones detect sound waves almost simultaneously. Each channel has one or more geophones connected to it. Reflections from different points in the subsurface are recorded by various geophones. Note in fig. 18 that the subsurface coverage of the reflection data is exactly half the surface distance across the geophone spread. Hence, the subsurface-sampling interval is exactly half the geophone interval at the surface. For example, if geophones are spaced at 16 m (52 ft) intervals at the Earth's surface, the subsurface reflections will come from locations on the reflector that are centered 8 m (26 ft) apart.

In fig. 19, we have placed source locations and receiver locations in such a way that path S1-R2 reflects from the same location in the subsurface as path S2-R1. This is variously called a common-reflection point (CRP) or a common-depth point (CDP), depending upon the preference of the author. The power of the CDP method is in the multiplicity of data that come from a particular subsurface location. By gathering common midpoint data together and then adding the traces in a computer, the reflection signal is enhanced. Before this addition can take place, however, the data must be corrected for differences in

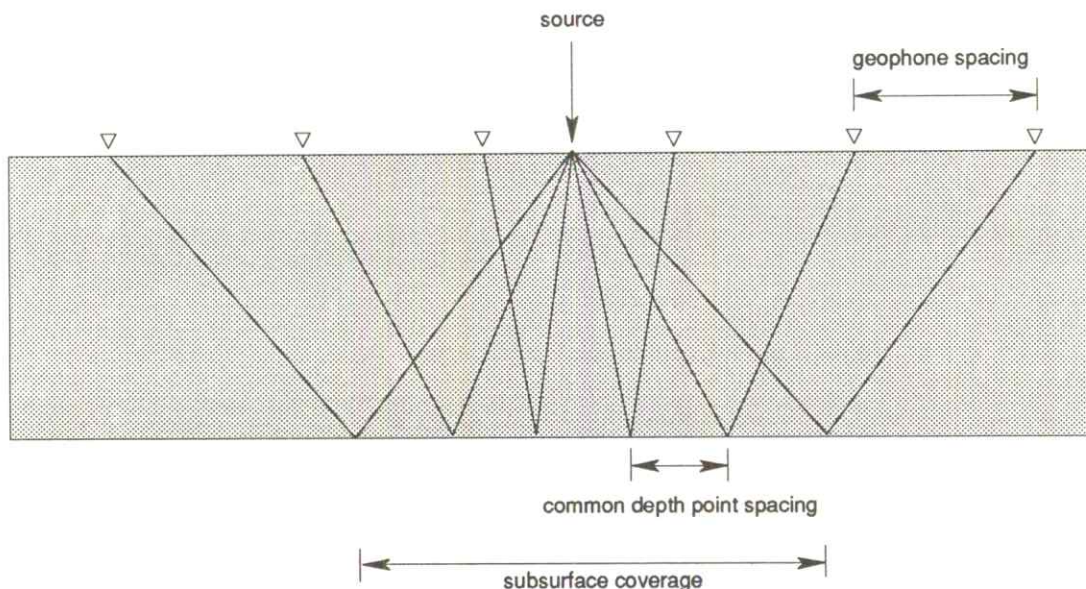


FIGURE 18—SCHEMATIC DRAWING OF SEISMIC-RAY PATHS FOR A SINGLE SHOT WITH A SIX-CHANNEL REFLECTION SEISMOGRAPH.

travel time for the reflected waves caused by the differences in source-to-geophone distance. The degree of multiplicity is called CDP fold. A seismograph with 24 channels, for example, commonly is used to record 12-fold CDP data.

The seismic-reflection method is used to determine the spatial configuration of underground geological formations. Fig. 20 shows conceptually what we are trying to accomplish with such a survey. Note that the peaks of the seismic reflections have been blackened to assist in the interpretation. This example is a very simple version of typical near-surface geology that depicts a buried sand lens in a river valley. The deeper the sand lens below the surface, the more difficult it is to detect, but the physical principles remain the same.

Earlier in this discussion, we touched on the analogy between a seismograph and a stereo music system. A stereo music system has control knobs to enhance high frequencies (like a flute) or low frequencies (like a bass drum). A seismograph has similar capabilities in choosing the sound frequencies that are recorded. A seismologist

selects the frequencies to be enhanced depending on the depth and size of underground geologic features of interest.

To detect small geologic features, it is necessary to use a seismograph that can record and enhance high-frequency sound waves. The use of high-frequency seismic waves in reflection seismology is known as “high-resolution” seismic exploration. As research and instrumentation developments allow recording higher and higher seismic frequencies, it is becoming possible to prospect for progressively smaller geologic targets.

Compressional waves, or P-waves, are the most common type of seismic wave used for reflection prospecting. P-waves propagating through the Earth behave similarly to sound waves propagating in air. P-waves generate echoes (reflections) when they come in contact with an acoustical contrast in the air or under the ground. In the underground environment, however, the situation is more complex because energy that comes in contact with a solid acoustical interface can be transmitted across the interface or converted into refractions and/or shear waves as well as reflected waves.

Seismic reflection is sensitive to the physical properties of Earth materials and is relatively insensitive to chemical makeup of both Earth materials and their contained fluids. The seismic-reflection technique involves no assumptions about layering or seismic velocity. However, no seismic energy will be reflected back for analysis unless acoustic impedance contrasts are present within the depth range of the equipment and procedures used. This is identical to the observation that sound waves in air do not echo back to an observer unless the sound wave hits something solid that causes an echo. The classic use of seismic reflections involves identifying the boundaries of layered geologic units. It is important to note that the technique can also be used to search for anomalies such as isolated sand or clay lenses and cavities.

Fig. 21 depicts a single explosive charge fired in a drilled hole to provide a source of seismic waves for a

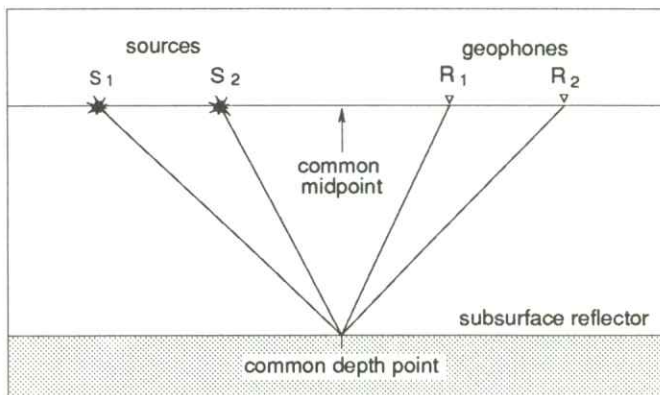


FIGURE 19—THE CONCEPT OF COMMON DEPTH POINT (CDP). Note that ray paths from two different shots (S1 and S2) reflect from a common point in the subsurface.

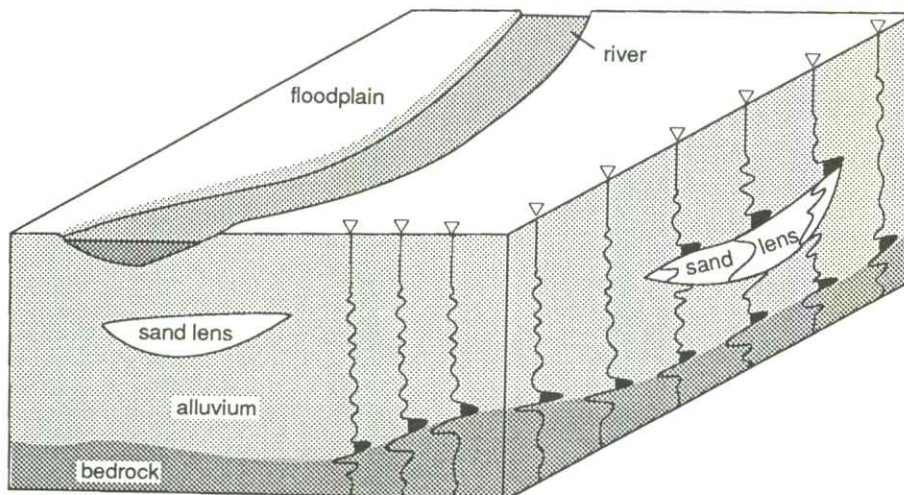


FIGURE 20—SCHEMATIC SHOWING A SEISMIC SECTION RELATING TO REAL-WORLD GEOLOGY.

seismic-reflection survey. The seismic waves (which are really sound waves) echo from underground rock layers. These echos are then detected at the Earth's surface by geophones (which are really low-frequency microphones). The signals are transmitted to the recording truck via cables. The seismograph in the recording truck is much like a multi-channel stereo music system. The seismograph's amplifiers condition and amplify the data and send

the data to a digital tape recorder. After the data are placed on computer tape by the recorder, they are ready for processing. The signals are processed in a computer to produce a final display called a seismic section. The seismic section displayed here shows echos from rock units a few hundred feet below the Earth's surface (the Lawrence, Stanton, and Wyandotte formations).

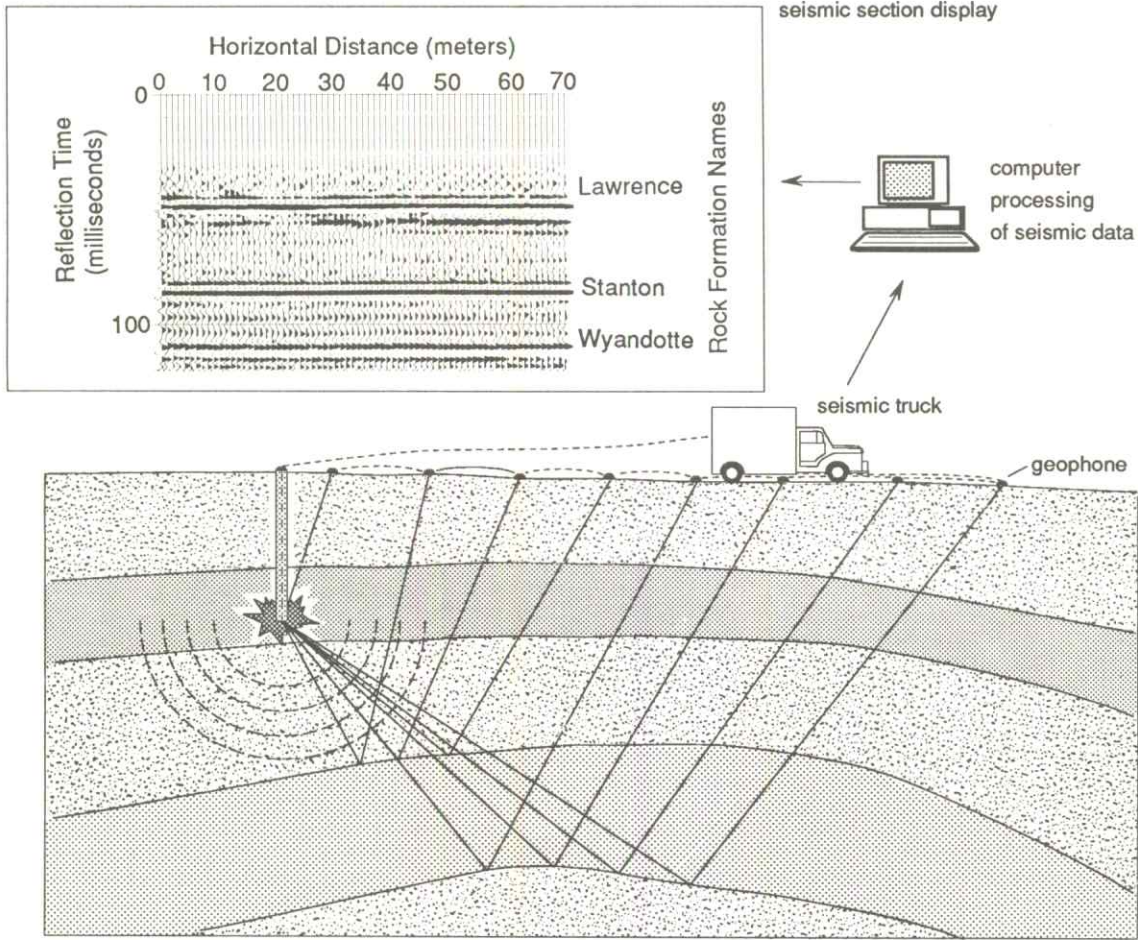


FIGURE 21—SCHEMATIC CROSS SECTION OF GEOLOGY, SEISMIC-RAY PATHS, AND PROCESSED SEISMIC DATA.

Mineral rights and leasing

The ownership of minerals underlying the surface must be determined prior to their leasing for oil and gas exploration. In many cases, the minerals are owned by the surface owner, but sometimes the minerals have been severed, or separated, from the surface ownership. In this section we will discuss minerals, mineral rights, and leasing.

Minerals

The term **minerals**, as it is used in the discussion of mineral rights, has been defined to include some substances of organic origin such as oil, gas, and lignite as well as substances of inorganic origin such as sulfur, bentonite, and potash.

Mineral rights

Mineral rights may be defined as the right of ownership of the mineral resources which underlie a tract of land. With the right of mineral ownership is the right to explore for, develop, and produce the mineral resources.

Because most minerals are found below the land surface, it is convenient to refer to mineral rights as subsurface rights to distinguish them from surface rights, such as land ownership and the right to use the surface for agricultural purposes, urban development, etc. Mineral rights are also sometimes referred to as the mineral estate, and surface rights as the surface estate.

Severed mineral rights

Mineral rights may be severed or separated from surface rights by mineral deed or by mineral reservation.

Severance by mineral deed occurs when a party owning both surface rights and mineral rights sells or grants by deed all or a portion of the mineral rights underlying his/her property. This deed, known as a mineral deed, is registered with the county register of deeds and will become a part of the abstract of title to the land involved.

Severance by mineral reservation occurs when a party owning both surface rights and mineral rights sells or grants by deed the surface rights of his property, but retains all or a portion of the mineral rights. Severance of minerals by mineral reservation has been widely practiced by federal and state governments, land-grant railroads, and lending institutions, as well as by individuals. Mineral reservations are recorded with the county register of deeds and are included in any abstract of title to the land involved.

Leases and leasing

In most cases the expense of exploring for and developing oil and gas resources by the individual mineral rights owner is prohibitive. A single well may cost over a

million dollars for drilling and well-completion operations. As a result, most exploration and development is undertaken by companies or individuals having sufficient capital to finance such ventures.

Before companies can begin an exploration program, they must obtain valid leases to the oil and gas rights within the area in which they wish to explore. This activity is called leasing.

Leasing is conducted by oil-company landmen or by lease brokers. An oil-company landman is a person in the employ of the company who is engaged in the negotiating of lease agreements with mineral-rights owners. A lease broker is a person or a company which negotiates lease agreements on behalf of a company or individual. The lease broker may acquire leases in the name of the oil company or may acquire them in his/her own name and later assign them to the company that has retained his/her services.

An oil and gas lease agreement is a legal instrument which provides for the granting by the mineral rights owner (lessor) to the oil company (lessee) the right to explore for and develop the oil and gas resources which may underlie the area described in the lease. A lease agreement contains a number of stipulations usually including but not necessarily limited to

1. A legal description of the area included in the lease and the number of acres involved.
2. An effective date of the lease agreement and the anniversary date for the lease on or before which annual lease rental payments must be paid to keep the lease in force.
3. A statement as to the primary term of the lease. This may be of any mutually agreed to period of time, but is usually for five or 10 years.
4. A provision for the payment of annual lease rentals by the lessee to the lessor. These rentals are paid in order to maintain the lease in effect throughout the primary term and are paid in lieu of royalty payments. In the event that oil or gas production is found, the lease will remain in effect so long as production continues, even beyond the primary term of the lease.
5. A royalty clause, which indicates the share of oil and gas production that is reserved to the mineral rights owner. Royalty is usually indicated as a fraction or percentage of the oil or gas that is produced. It may be any amount mutually agreed to between the lessor and the lessee but is usually 1/8 (12 1/2%) and is stated on the lease. Royalty may be received in kind, that is, the lessor may take physical possession of the oil or gas, but usually the oil or gas is sold to a refiner and the lessor receives payment for his/her share.

Drilling the well

Drill-site preparation

All of the efforts of the petroleum landmen, geologists, and geophysicists, and everyone else involved in leasing and exploration activities up to this point must culminate in a decision by the management of the petroleum company to either drill or not drill a well. If the exploration activities conducted thus far have not found encouraging indications for the accumulation of petroleum in the area being explored, the leases held in the area will likely be dropped. If exploration activities have been encouraging, however, a decision will likely be made to drill an exploratory well. Such a decision may require the commitment of hundreds of thousands or even millions of dollars for the drilling program. In this section we will discuss the activities related to the drilling of an exploratory well. State regulations regarding drilling, development, and production will be discussed in a subsequent section.

Drill-site selection

The selection of the drill site is based largely on the geological evidence indicating the possible accumulation of petroleum. The exploration company will want to drill the well at the most advantageous location for the discovery of oil or gas. Surface conditions, however, must also be taken into consideration when selecting the drill site. There must be a nearly level area of sufficient size on which to erect the drilling rig, excavate reserve pits, and provide storage for all of the materials and equipment that will be required for the drilling program. All of the required legal matters need to have been attended to, such as acquiring a drilling permit, surveying of the drill site, and so on. When all of these matters have been resolved, the work on site preparation will begin.

Once the drill site has been selected and surveyed, a contractor or contractors will move in with equipment to prepare the location. If necessary, the site will be cleared and leveled. A large pit will be constructed to contain water for drilling operations and for the disposal of drill cuttings and other waste. A small drilling rig, referred to as a dry-hole digger, will be used to start the main hole. A large-diameter hole will be drilled to a shallow depth and lined with conductor pipe. Sometimes a large, rectangular cellar is excavated around the main bore hole and lined with wood. A smaller-diameter hole called a "rat hole" is drilled near the main bore hole. The rat hole is lined with pipe and is used for the temporary storage of a piece of drilling equipment called the "kelly." When all of this work has been completed, the drilling contractor will move in with the large drilling rig and all the equipment required for the drilling of the well.

Rigging up

The components of the drilling rig and all necessary equipment are moved onto the location with large, specially equipped trucks. The substructure of the rig is located and leveled over the main bore hole (fig. 22). The mast or derrick is raised over the substructure and the other equipment such as engines, pumps, and rotating and hoisting equipment are aligned and connected. The drill pipe and drill collars are laid out on racks convenient to the rig floor so that they may be hoisted up when needed and connected to the drill bit or added to the drill string. Water and fuel tanks are filled. Additives for the drilling fluid (drilling mud) are stored on location. When all these

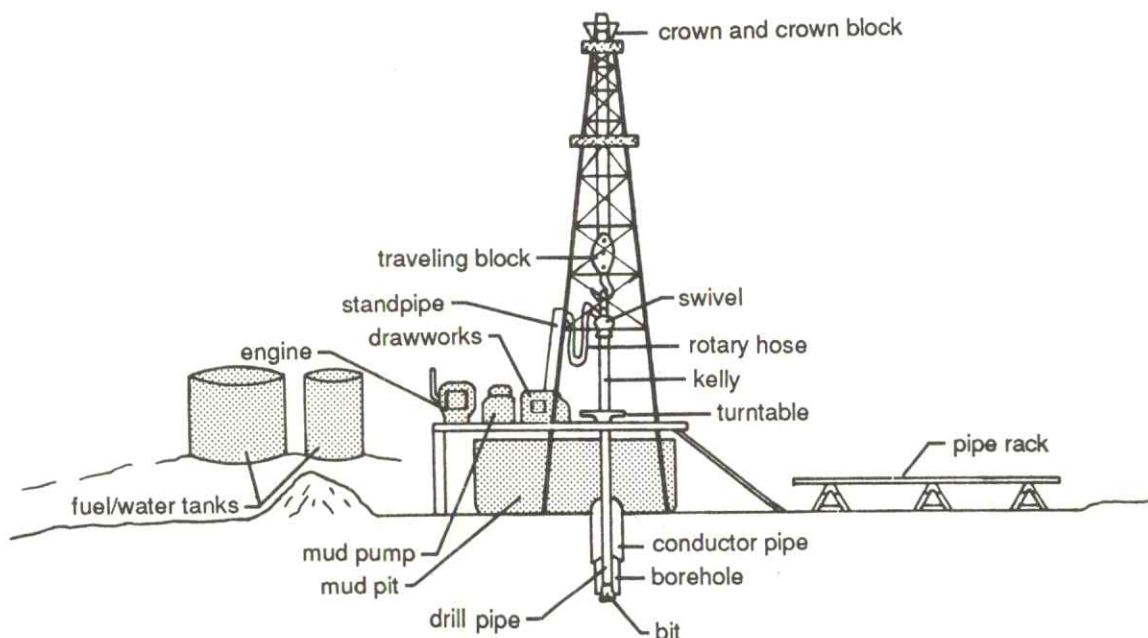


FIGURE 22—A DRILLING RIG WITH ITS MAJOR COMPONENTS AND RELATED EQUIPMENT.

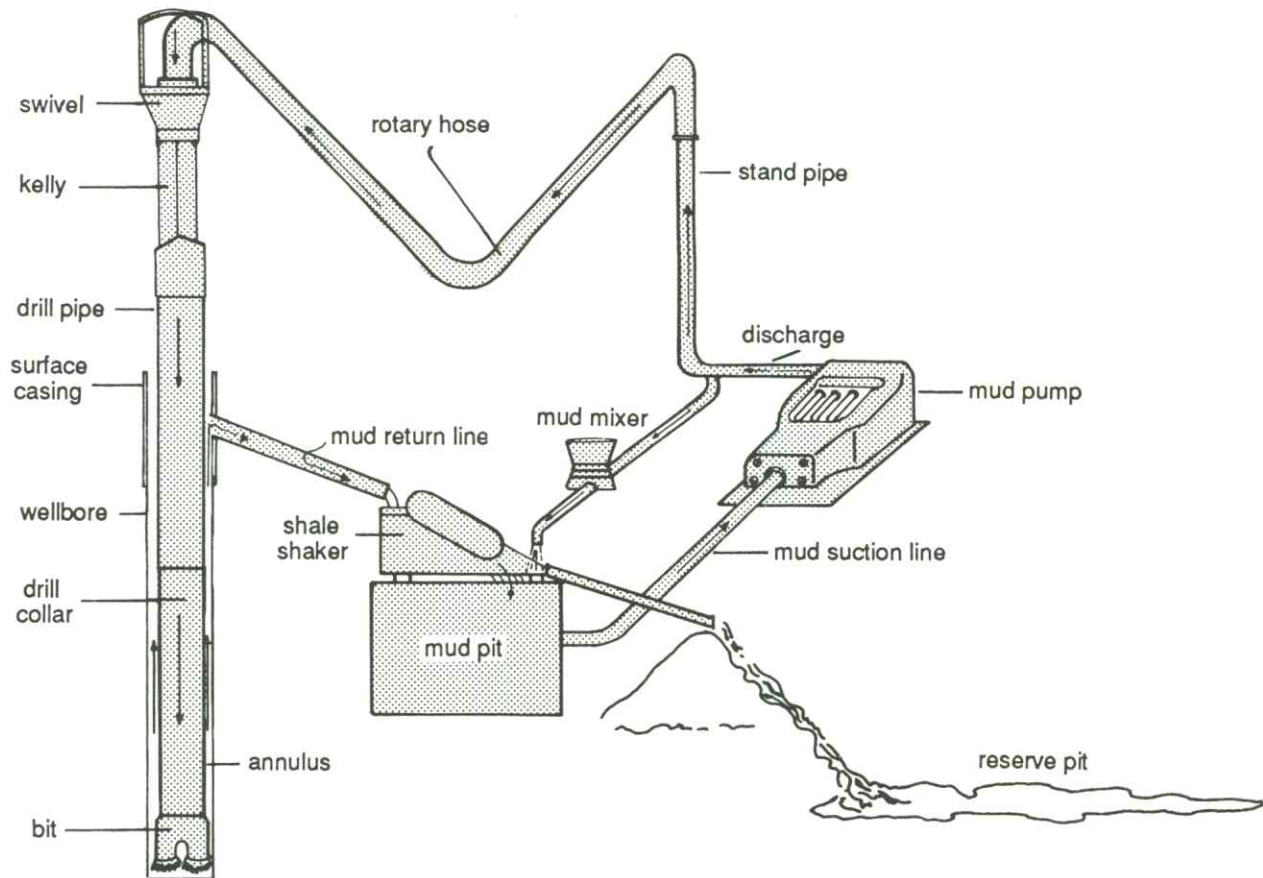


FIGURE 23—DIAGRAM ILLUSTRATING THE DRILLING-FLUID (DRILLING-MUD) SYSTEM AND THE FLOW OF FLUIDS THROUGH THE SYSTEM.

matters have been attended to, the drilling contractor is ready to begin drilling operations (spud the well).

Spudding in

“Spudding in,” or to “spud” a well, means to begin drilling operations. The drill string, consisting of a drill bit, drill collars, drill pipe, and kelly, is assembled and lowered into the conductor pipe. Drilling fluid, better known as drilling mud, is circulated through the kelly and the drill string by means of pipes and flexible hose connecting the drilling fluid or mud pumps and a swivel device attached to the upper end of the kelly. The swivel device enables drilling mud to be circulated while the kelly and drill string are rotated. The mud pump draws fluid from mud tanks or pits located nearby. The drilling mud passes through the kelly, drill pipe, drill collars, and drill bit. It is returned to the surface by means of the well bore and the conductor pipe where it is directed to a device called a shale shaker. The shale shaker separates the drill cuttings and solids from the drilling mud, which is returned to the mud tanks to be circulated again (fig. 23). As the drill string is rotated in the well bore, the drill bit cuts into the rock. The drilling mud lubricates and cools the drill bit and drill string and carries the drill cuttings to the surface (fig. 23).

Drilling the surface hole

When a well is spudded in, a large-diameter drill bit is used to drill to a predetermined depth. This is for the purpose of drilling the surface hole. The surface hole is lined with casing. The casing protects aquifers which may contain freshwater, provides a mounting place for the blowout preventer, and serves as the support for the production casing that will be placed in the well bore if the drilling program is successful. The surface hole may be several hundred or several thousand feet deep. When the predetermined depth is reached, the drill string will be removed from the well bore. Steel casing of the proper diameter is inserted. Sufficient cement is pumped down the surface casing to fill the space between the outside of the casing and the well bore all the way to the surface. This is to insure the protection of freshwater aquifers and the security of the surface casing (fig. 24). The casing and the cement are tested under pressure for a period of 12 hours before drilling operations may be resumed. A piece of equipment known as a blowout preventer is attached at the top of the surface casing. This device is required to control the well in the event that abnormal pressures are encountered in the bore hole that cannot be controlled with drilling fluid. If high-pressure gas or liquid blows the drilling fluid out of the well bore, the blowout preventer can be closed to confine the gas and fluids to the well bore.

Drilling to total depth

After the surface casing has been tested and the blowout preventer installed, drilling operations are resumed. They will continue until the well has been drilled to the total depth decided upon. Usually, the only interruptions to drilling operations will be to remove the drill string from the well bore for the replacement of the drill bit, a procedure known as tripping, and for the testing of formations for possible occurrences of oil or gas, known as drill-stem testing. Other interruptions may be due to problems incurred while drilling, such as the shearing off of the drill string (known as "twisting off"), and the loss of drill-bit parts in the well bore, known as "junk in the hole."

As drilling operations continue, a geologist constantly examines drill cuttings for signs of oil and gas. Sometimes special equipment known as a mud logger is used to detect the presence of oil or gas in the drill cuttings or drilling fluid. By examining the drill cuttings, the geologist determines the type of rock that the drill bit is penetrating and the geologic formation from which the cuttings are originating.

Today's conventional drill bit utilizes three revolving cones containing teeth or hardened inserts which cut into the rock as the bit is revolved (fig. 25). The teeth or inserts chip off fragments of the rock which are carried to the surface with the drilling fluid. The fragments or chips, while they are representative of the rock being drilled, do not present a clear and total picture of the formation being drilled or the characteristics of the rock being penetrated as to porosity and permeability. For this purpose, a larger sample of the rock is required. Such a sample is acquired by using a diamond coring bit and a core barrel. The diamond core bit is essentially a cylinder with industrial diamonds set into one end. The other end is threaded so that it may be connected to a core barrel, a device which contains equipment for holding the core as it is cut. As the drill stem and coring bit are turned, the diamonds cut the rock and a cylindrical core of the rock is cut. The core passes upward into the core barrel where it is held until the drill string can be extracted from the well bore. At the surface the core is removed from the core barrel where it is examined by the geologist. The core is usually sent to a laboratory for core analysis and testing.

Drill-stem testing

If the geologist detects the presence of oil or gas in the drill cuttings, a drill-stem test is frequently performed to evaluate the formation or zone from which the oil show was observed. Drill-stem tests may also be performed when the driller observes a decrease in the time required to drill a foot of rock, known as a "drilling break." Since porous rock may be drilled easier than nonporous or less porous rock, a drilling break indicates the presence of porosity, one of the qualities of reservoir rock. A drill-stem test enables the exploration company to obtain a sample of the fluids and gases contained in the formation or interval being tested as well as pressure information, which is determined by special gauges within the test tool.

Drill-stem testing is accomplished by removing the drill string from the bore hole. The drill bit is removed and a drill-stem test tool with a packer is attached. The test tool, packer, and drill string are inserted back into the bore hole to the desired depth. The packer, which is an expandable device, is set and expanded at the predetermined depth to isolate the zone to be tested. The test tool contains a valve which may be opened and closed to allow formation fluids to enter the test tool and drill string. If there is sufficient fluid and pressure within the zone being tested, the formation fluid (oil, gas, water) may rise to the surface and flow into special test tanks used for that purpose. If gas is present, it is burned at the surface as a flare. By analyzing the rate of flow or the amount of formation fluid recovered in the drill string and the formation pressures recorded, obtaining a good indication of reservoir characteristics such as porosity, permeability, and the nature of the fluids or gas contained therein is possible.

Well logging

Drilling operations continue until the predetermined total depth of the well is reached. A logging company is then called to the well site. The drill string is removed from the well bore to allow the insertion of logging tools, which are lowered all the way to the bottom of the hole by means of a special cable. This cable contains numerous electrical circuits. The tools are reeled slowly back to the surface. Specific properties of the formations are measured as the tools are retrieved. Signals detected by the tools are recorded in a recording truck at the surface by means of the electrical circuits contained in the cable.

Electrical logs measure the natural electric potential and the effect of induced electricity on the formations. Radioactivity logs measure the natural radioactivity and the effect of induced radioactivity on the formations. Sonic logs measure the velocity of sound waves in the formations. By analyzing these logs, experienced geologists and engineers can determine the depth from the surface to various formations and intervals, formation characteristics such as rock type and porosity, and indications of the presence of oil or gas and quantity.

Completing the well

When drill-stem testing and well-logging operations have been completed and the results have been analyzed, the company management must decide whether to complete the well as a producing well or to plug it as a dry hole. If the evidence indicates that no oil or gas are present, or they are not present in sufficient quantity to allow for the recovery of drilling, completion, and production costs and provide a profit on investment, the well will probably be plugged and abandoned as a dry hole. If, on the other hand, evidence indicates the presence of oil or gas in sufficient quantity to allow the recovery of these costs and provide a profit to the company, an attempt will be made to complete the well as a producer.

If the well is to be plugged and abandoned as a dry hole, a cementing company is called to the drill site. The

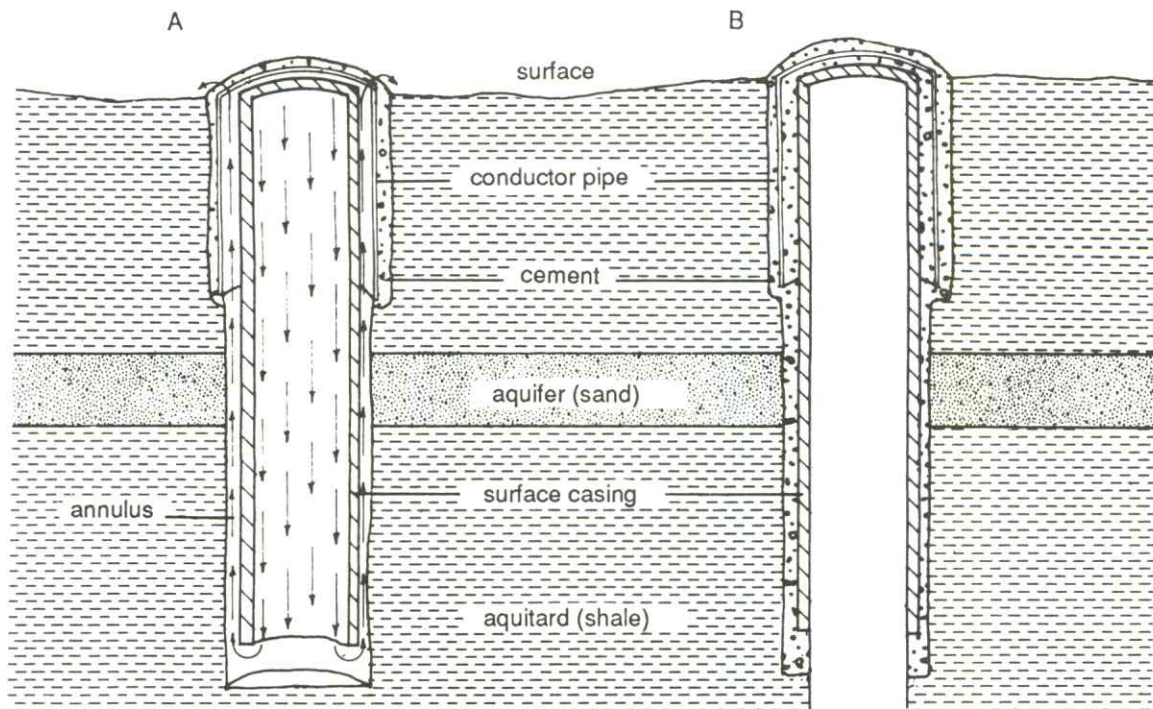


FIGURE 24—A CASING IS INSTALLED IN THE SURFACE HOLE TO PREVENT THE CONTAMINATION OF FRESHWATER ZONES AND TO SUPPORT THE PRODUCTION CASING. A) The conductor pipe has been cemented into place. A predetermined amount of casing has been inserted into the well bore below the deepest freshwater zone. Cement is pumped down the inside of the casing until cement flows to the surface through the annulus. B) The cement in the bottom of the casing has been drilled out so that drilling can be resumed.

well bore is filled with drilling fluid, which contains additives which give it special properties that prevent its movement from the well bore into the surrounding rock. Cement plugs are required within the well bore at intervals where porosity has been detected to isolate these porosity zones and prevent the movement of formation fluids from one formation to another. The cement is pumped into the well bore through the drill string. The cement is mixed at the surface in special trucks which are equipped with high-volume pumps. The pumps are connected to the drill string which has been inserted into the well bore to a predetermined depth. A quantity of cement is pumped into the well bore through the drill string and displaced out of the bottom of the drill string with drilling fluid. The drill string is then pulled up to the next interval that is to be cemented. This process is repeated until all the required plugs have been set. A cement plug is also set at the base of the surface casing, which remains in the hole, and another plug is set at the surface. In cultivated areas the surface casing is cut off below plow depth. A steel plate is welded at the top of the surface casing. All drilling equipment and materials are removed from the drill site. The pits are allowed to dry up and are backfilled and the site is restored as nearly as possible to its original condition.

If a decision is made to attempt to complete the well as a producer, casing is delivered to the site and a cementing company is called. The well bore is filled with drilling

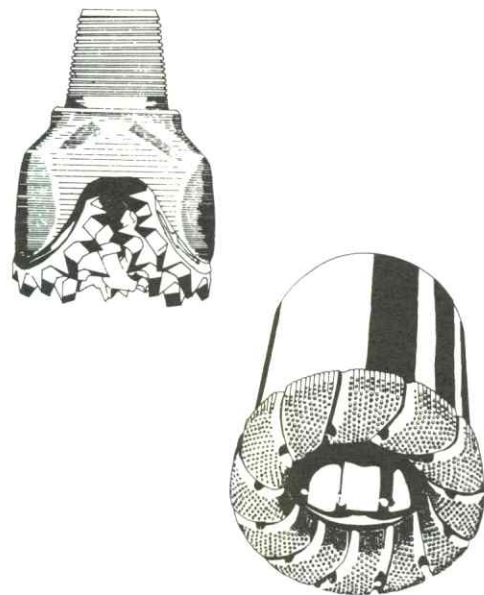


FIGURE 25—AT THE TOP IS A CONVENTIONAL ROCK, OR CONE, BIT. As the bit rotates, the teeth on the cones turn and bite into the rock and chip off fragments. Drilling fluid passes through the bit to cool and lubricate it and to carry the rock chips to the surface. The diamond bit, below, is used in conjunction with a core barrel for cutting a core out of the rock. The bit is hollow so that as it cuts into the rock, a core of rock is cut which passes through the bit and into the core barrel.

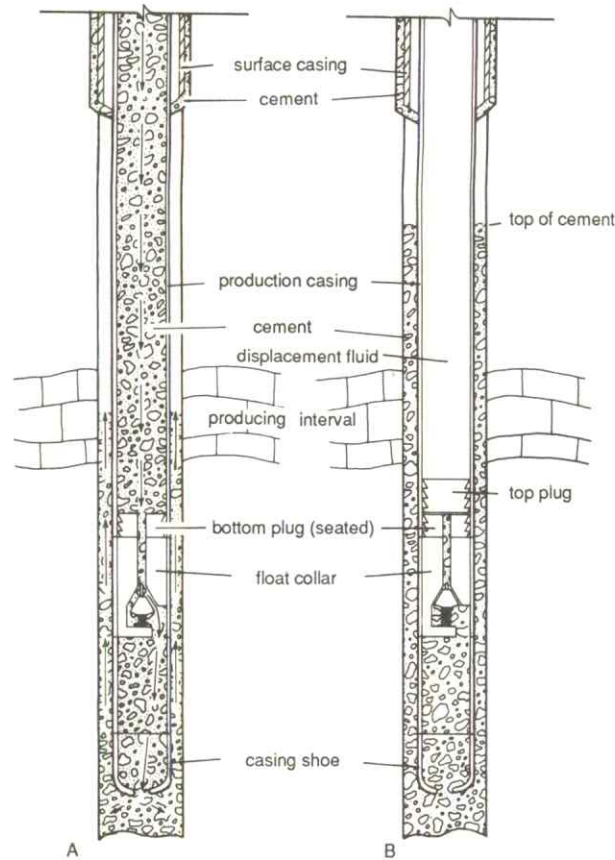


FIGURE 26—CEMENTING THE PRODUCTION CASING IN THE WELL. A) This illustrates how the cement is pumped down the casing. The casing shoe makes it easier to insert the casing into the bore hole. The float collar prevents drilling fluid from entering the casing. The bottom plug precedes the cement down the casing, and the top plug follows the cement and precedes the displacement fluid. B) The production casing when the cementing operation is completed.

fluid that contains additives to prevent corrosion of the casing and to prevent the movement of the fluid from the well bore into the surrounding rock. The casing is threaded together and inserted into the well bore much in the same manner as the drill string. Casing may be inserted to a total depth of the hole or a cement plug may have been set at a specific depth and the casing set on top of it. Cement is mixed at the surface just as if the well were to be plugged. The cement is then pumped down the casing and displaced out of the bottom with drilling fluid or water. The cement then flows up and around the casing, filling the space between the casing and the well bore to a predetermined height. Special tools are sometimes used with the casing which allow the setting of cement between the outside of the casing and the well bore at specific intervals. This is done to protect the casing and to prevent the movement of formation fluids from one formation to another (fig. 26).

After the cementing of the casing has been completed, the drilling rig, equipment, and materials are removed from the drill site. A smaller rig, known as a workover rig or completion rig, is moved over the well bore. The smaller rig is used for the remaining completion operations.

A well-perforating company is then called to the well site. It is necessary to perforate holes in the casing at the proper position to allow the oil and gas to enter the casing.

The perforating company is commonly the same company that has performed the logging of the well. A special perforating tool is inserted into the casing and lowered to the desired position on the end of a cable. The cable contains a number of electrical circuits and is connected to a recording and control truck at the surface. The perforating tool contains a number of shaped charges which are spaced at specific intervals. When the perforating tool has been lowered to the desired position, the shaped charges are fired remotely from the control truck at the surface and jets of high-temperature and velocity gas perforate the casing, the cement, and the surrounding rock for some distance away from the well bore.

A smaller-diameter pipe, called tubing, is then threaded together and inserted into the casing. If it is expected that the oil or gas to be produced will flow to the surface naturally, the tubing is equipped with an expandable packer at the lower end. The tubing is inserted into the casing and the packer is expanded or set at a predetermined point above the perforations. At the surface, a well head is installed which is equipped with valves to control the flow of oil or gas from the well. The well head is known as a "Christmas tree" (fig. 27).

If there is not sufficient reservoir pressure to cause the oil and gas to flow naturally, pumping equipment is installed at the lower end of the tubing. Various types of

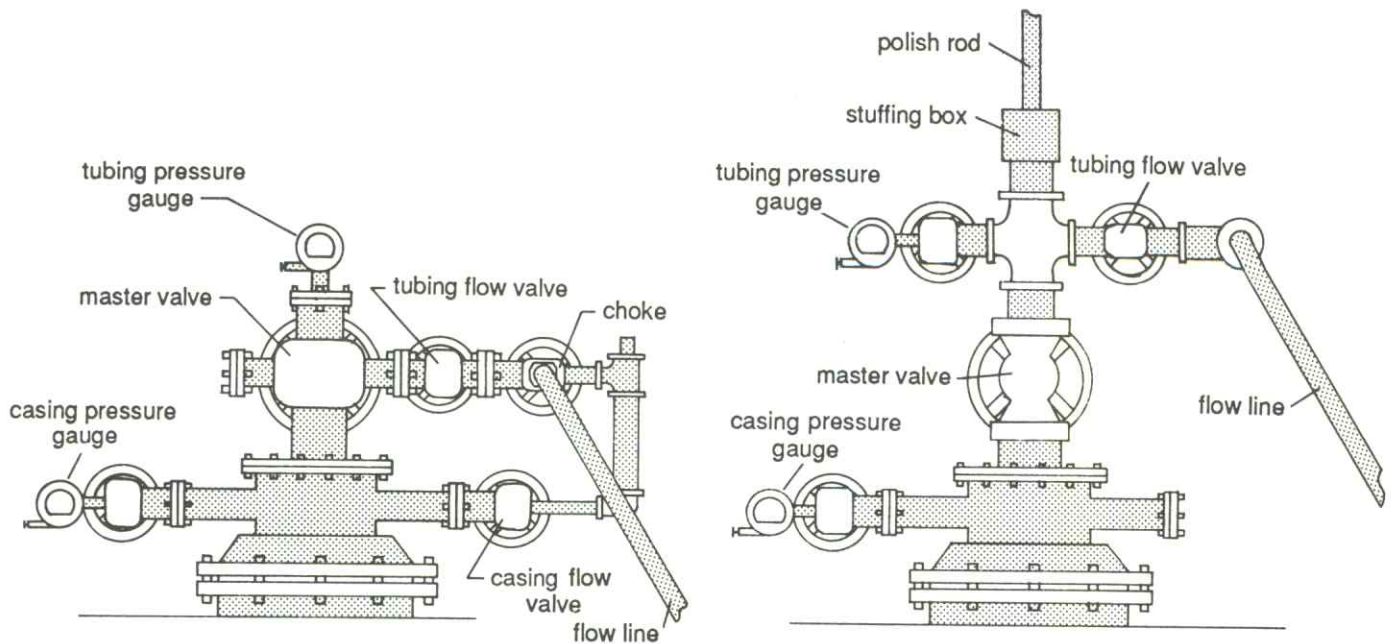


FIGURE 27—THE TWO TYPES OF WELL HEADS OR “CHRISTMAS TREES.” The well head on the left is for a flowing well and the well head on the right is for a pumping well.

pumping equipment are used including piston pumps, submersible pumps, and jet pumps. Power to operate the pump may be supplied by a gas engine or an electrical motor.

During well-completion it is sometimes desirable or necessary to treat or stimulate the producing zone in order to improve the permeability of the rock and increase the flow of oil or gas into the casing. This may be accom-

plished by the use of acid or by the injection of fluid and sand under high pressure in order to fracture the rock. Such a treatment usually improves permeability and facilitates the flow of oil or gas into the casing. At this point, the drilling and completion phase have ended. The well is about to enter the production phase which, hopefully, will continue for many years.

Production

While well-completion operations were taking place, production equipment was being installed on the surface. This usually consists of a separator, a heater treater, storage tanks, circulating pump, and a facility for the storage or disposal of water that is produced with the oil. The various production equipment and the producing well are connected by pipes known as flow line (fig. 28).

After the oil, gas, and water have flowed or have been pumped to the surface, they pass as an emulsion or mixture to the production separator, which separates the gas from the oil and water. The gas may then travel by pipeline to a gas plant for processing into natural gas liquids such as propane and butane and natural gas for residential and commercial use. The oil and water emulsion then goes to the heater treater for the separation of the oil from the water. The oil then is placed in the storage tanks where it remains until it is transported off the site by trucks or by pipeline. The water is either put into a saltwater-handling facility such as a lined pit or tank, or into a flow line to a disposal well where it will be disposed of underground. Before the oil is removed from the storage tanks, it is tested to determine if it still contains an excessive amount

of water. If it does, it is circulated by the circulating pump through the heater treater until the water content is at or below the acceptable level.

The quantities of oil, gas, and water that are produced from the well are measured and recorded. Oil production may be measured with special metering equipment if it is produced into a consolidated tank battery or it may be gauged by measuring the height of the oil level in the storage tanks. When a tank full of oil is delivered to a refiner or crude-oil purchaser by pipeline, truck, or tank car, the oil is measured by gauging the height of oil in the tank. At that time the oil will be tested to determine its gravity (density) because the price paid for crude oil varies with its gravity. The temperature of the oil is determined as well as its content of basic sediment and water. This is done so that the quantity of oil in the tank can be converted into net barrels of oil delivered.

The quantity of gas produced is measured by a meter before it enters the pipeline to the processing facility. The quantity of water produced may be measured by a meter at the heater treater before it enters the saltwater-handling facility or the flow line to the disposal well. Water

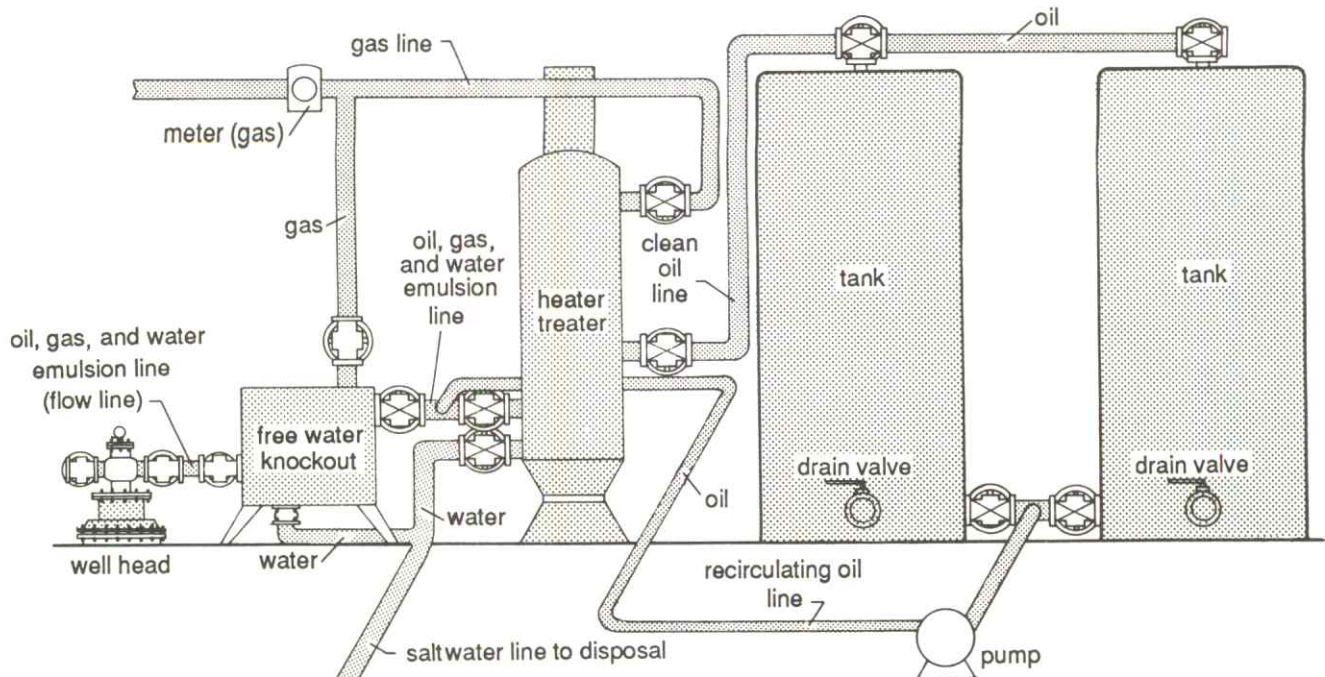


FIGURE 28—SURFACE EQUIPMENT. OIL, GAS, AND WATER, AS AN EMULSION, ENTER THE FREE WATER KNOCKOUT. Some gas and water are separated from the emulsion at this point. The remaining emulsion enters the heater treater where it is heated and the emulsion is separated into oil, gas, and water. The water is drained off and sent to disposal. The gas passes into the gas line, where it is metered and sent to market. The oil passes into the tanks. From there, it may be loaded into trucks from the drain valves or connected to a pipeline. The pump is used for recirculating oil that may have impurities in it back through the heater treater and into the tanks.

production is also determined by periodically testing the oil, gas, and water emulsion before it is separated to determine the percentage of water or "water cut" in the produced fluid.

Reservoir energy

For oil and gas to flow into the casing or well bore, energy is required. This energy may be derived from one or more of the following mechanisms: by dissolved gas in the oil which expands and escapes, driving the oil through the porous and permeable rock toward the well or wells; a gas cap, consisting of a cap of gas overlying the oil, which may expand as the oil is produced, filling the pore spaces occupied by the oil and gas as it is produced; and by water drive resulting from the expansion of water underlying the oil which may expand to fill the reservoir as the oil is produced (fig. 29).

The driving mechanisms discussed above are capable of pushing only a fraction of the oil and gas present in the reservoir rock into the well bore. As soon as the first barrel of oil is produced, reservoir energy begins to decline, and it will continue to decline until insufficient energy exists to force enough oil and gas into the well to warrant continued production. When this occurs, the well must be plugged and abandoned unless the reservoir energy can be restored or replenished in some artificial or secondary way.

Reservoir energy has been replenished in some cases by the injection of gas or fluids into the reservoir. This practice is known as pressure maintenance or secondary recovery. The production of oil and gas without pressure maintenance is known as primary recovery.

Pressure maintenance is not without its problems, however. When gas or liquids are injected into a producing formation or interval, oil and gas are pushed across property lines. A means must be provided to protect the rights of all persons who have royalty or production interests. This is done by unitizing the reservoir. In order to do this, a detailed engineering study of the reservoir or oil pool is conducted to determine the amount of oil that is produced that should be allocated to the various operators and mineral-rights owners. In Kansas, a plan of unitization must be developed which includes specific provisions. The plan must be approved or ratified by the lessees or operators and by the persons owning interests in the production such as royalties, overriding royalties, and production payments. The plan of unitization must also be approved by the Kansas Corporation Commission, which is the state regulatory body governing oil and gas matters.

Pressure maintenance, or secondary recovery, is accomplished by injecting air or water into the producing formation through wells which are located at strategic positions. The injected air or water results in an increase in pressure within the producing formation relative to the pressure in the well bore of the producing wells (fig. 30). Secondary maintenance will not restore reservoir energy to

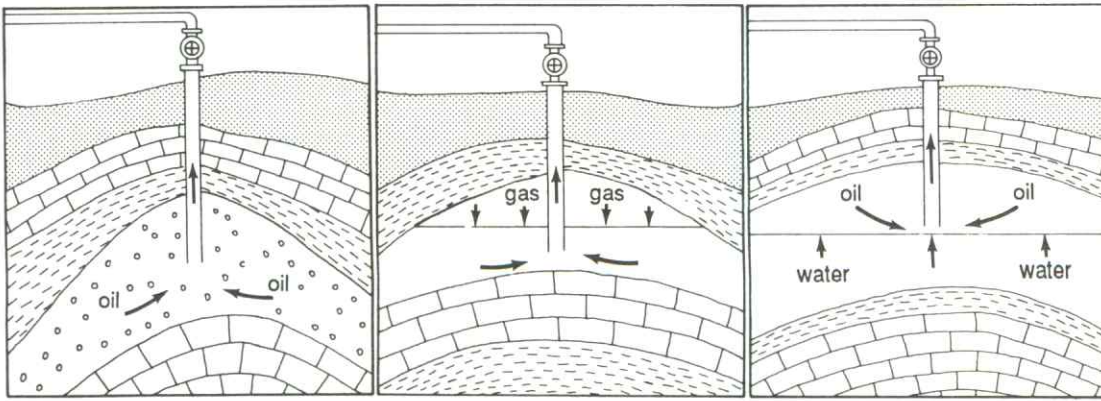


FIGURE 29—RESERVOIR-DRIVE MECHANISMS. Dissolved gas drive is the result of the expansion of gas that is dissolved in the oil. Gas-cap drive is the result of the expansion of gas which is contained in the reservoir above the oil. Water drive is the result of the upward pressure of water, which is under pressure, as it expands and moves into the regions of lowered pressure as oil is produced.

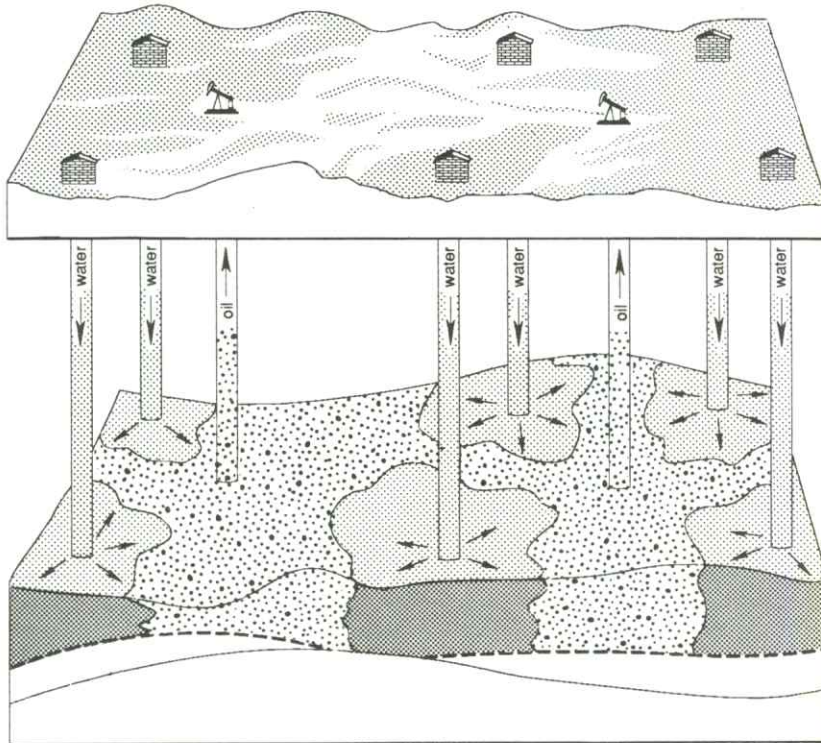


FIGURE 30—WATER FLOOD IS ONE MEANS OF SECONDARY RECOVERY. Water is injected into the producing horizon to increase reservoir pressure and push the oil toward the producing wells. Note that the rocks below the dashed line are less permeable than those above.

its original condition, but it can and does result in a significant increase in the production of oil and gas from a reservoir.

Even after the application of pressure maintenance, a considerable amount of oil may be left in the reservoir.

This is residual oil that cannot be moved into the producing wells by pressure alone. Methods are being developed that will enable much of this residual oil to be flushed from reservoir rock and into the producing wells. This is known as tertiary recovery.

Conclusions

Petroleum is a complex mixture of hydrocarbon molecules derived from organic matter that accumulates with muddy sediments in stagnant environments. After compaction, deep burial, and much time, hydrocarbons are generated from the organic matter and migrate from the source bed into a porous rock that serves as a reservoir for oil and gas. Exploration involves the search for suitable traps, such as anticlines, faults, or permeability pinchouts by constructing a variety of maps from surface rocks, previously drilled wells, and geophysical studies. Suitable conditions for the entrapment of economical petroleum accumulations are widespread in Kansas.

When a potential trap is indicated, mineral rights to the land must be acquired, and a wildcat well is drilled, usually with rotary tools. If reservoir rocks containing shows of hydrocarbons are encountered, the rock is tested to evaluate production potential by conducting a drill-stem test and running geophysical logs. If testing and the well logs indicate that commercial production is possible, casing is cemented in place in the hole, the casing is

perforated, and the reservoir rock is treated to commence or improve production. Control and metering devices and storage tanks are installed at the surface; the oil and/or gas is transported to a market by truck or pipeline. If no commercial production is found, the hole is cemented to protect every possible aquifer and plugged. The entire process of land acquisition, drilling, and completion of the well is regulated by the Kansas Corporation Commission to ensure equitable resource management for all parties. Then the process is started anew to develop the field and/or search for other traps.

Established fields experience a natural decline in production rates as the reservoir energy is depleted. Secondary-recovery methods, such as gas and water injection used widely in Kansas, are designed to maintain pressure in the reservoir and force oil to producing wells. Tertiary-recovery techniques, applied on a more limited basis, offer significant opportunities to recover remaining petroleum resources in existing fields.

Glossary

A

abandon, v: To cease producing oil and gas from a well when it becomes unprofitable. A wildcat well may also be abandoned if it has been proved unproductive.

acidize, v: To treat oil-bearing limestone or dolomite with acid in order to enlarge pore space and improve permeability. Acid is injected under pressure.

adjustable choke, n: Special valve by which the rate of flow from a well may be regulated.

air drilling, n: Method of rotary drilling that uses air under pressure to cool the bit and remove cuttings from the bore hole.

American Petroleum Institute: Founded in 1920, the API is a national trade organization which maintains offices in Washington, D.C., and Dallas, Texas; the leading standardizing organization for the petroleum industry.

angular unconformity, n: Unconformity or break between two series of rock layers such that rocks of the lower series underlie rocks of the upper series at an angle; the two series are not parallel. The lower series was deposited, then tilted and eroded prior to deposition of the upper layers.

annular space (annulus), n: Space surrounding a cylindrical object within a cylinder such as tubing inside of casing or casing inside of a bore hole.

anticline, n: Elongate fold in the rocks in which sides slope downward and away from the crest; an upfold.

API, abbr: American Petroleum Institute.

arkose, n: Sandstone containing a significant proportion of feldspar grains, usually signifying a source area composed of granite or gneiss.

B

back off, v: To unscrew one threaded section of pipe from another.

back pressure, n: Pressure resulting from restriction of full natural flow of oil or gas.

barrel, n: Measure of volume for petroleum products. One barrel is the equivalent of 42 U.S. gallons.

basement, n: In geology, the crust of the Earth beneath sedimentary deposits, usually, but not necessarily, consisting of metamorphic and/or igneous rocks of Precambrian age.

basement fault, n: Fault that displaces basement rocks and originated prior to deposition of overlying sedimentary rocks. Such faults may or may not extend upward into overlying strata, depending upon their history of rejuvenation.

bed, n: Specific layer of earth or rock in contrast to other layers of material lying above or below it.

bit, n: Cutting or boring element used in drilling oil and gas wells.

blow out, n: Uncontrolled flow of gas, oil, or other well fluids into the atmosphere.

blowout preventer, n: Equipment installed at the surface on drilling rigs to prevent the escape of pressure from the well during drilling or completion operations.

bore hole, n: Well bore; the hole made by drilling or boring.

bottom-hole pressure, n: Pressure in a well measured at or near the bottom of the hole.

BS or BS&W, abbr: Basic sediment or basic sediment and water; it refers to contaminants in produced crude oil.

C

cable tool, n: Drilling method in which the hole is drilled by dropping a sharply pointed bit on the bottom of the hole. The bit is raised and dropped by means of a cable attached to it.

cap rock, n: Impermeable rock overlying an oil or gas reservoir. It is part of the trapping mechanism.

cased hole, n: Well bore in which casing has been inserted and cemented.

casing, n: Steel pipe placed in a bore hole to prevent the walls from collapsing and to provide a means of extracting oil and gas if the well is productive.

casing head, n: Heavy, flanged steel fitting that connects to the first string of casing and provides a housing for the slips and packing assemblies by which intermediate strings of casings are suspended and the annulus sealed off.

casing-head gas, n: Associated and dissolved gas produced along with crude oil.

casing pressure, n: Gas pressure built up between the casing and tubing.

casing shoe, n: Short, heavy, hollow cylindrical steel section with a rounded bottom, which is placed on the end of the casing string to facilitate the insertion of the casing into the well bore.

catch samples, v: To obtain cuttings made by the drill bit. The cuttings are obtained from the drilling fluid as it emerges from the well bore. The cuttings are examined by geologists to determine the nature of the rock being penetrated and the possible presence of oil or gas.

cellar, n: Pit in the ground to provide additional space between the well head and the rig floor to accommodate the installation of equipment such as blowout preventers, etc.

cement casing, v: To fill the annulus between the casing and bore-hole wall with cement to support the casing and to prevent the migration of fluid between permeable zones.

cementing, n: Application of a liquid slurry of cement and water at various points between the casing and the bore-hole wall.

chert, n: Very dense siliceous rock usually found as nodular or concretionary masses, or as distinct beds, associated with limestones. **Jasper** is red chert containing iron-oxide impurities.

choke, n: Device inserted in a flow line to regulate the rate of flow.

Christmas tree, n: Control valves, pressure gauges, and chokes assembled at the top of a well to control the flow of oil and gas.

circulation, n: Movement of drilling fluid out of the mud pits, down the drill stem, up the annulus, and back to the mud pits.

clastic rocks, n: Deposits consisting of fragments of preexisting rocks; conglomerate, sandstone, and shale are examples.

condensate, n: Hydrocarbons in the gaseous state under reservoir conditions but which become liquid in passage up the hole or at the surface.

conductor pipe, n: Short string of large-diameter pipe or casing that is used to keep the top of the well bore open and to provide a means of conducting the drilling fluid to the mud pit from the well bore.

conglomerate, n: Consolidated equivalent of gravel. The constituent rock and mineral fragments may be of varied composition and range widely in size. The rock fragments are rounded and smoothed from transportation by water.

connate water, n: Water that is inherent to the producing formation; or fossil seawater that was trapped in the pore spaces of sediments during their deposition.

contact, n: Surface, often irregular, which constitutes the junction of two bodies of rock.

continental deposits, n: Deposits laid down on land or in bodies of water not connected with the ocean.

core, n: Cylindrical sample taken from a formation for geological analysis during the drilling of a well.

core analysis, n: Laboratory analysis of a core sample to determine its properties such as porosity, permeability, type of rock, fluid content, and probable productivity.

core barrel, n: Tubular device attached to the bottom of the drill pipe with a core bit on the end to cut a core sample.

correlation, n: Process of determining the position or time of occurrence of one geologic phenomenon in relation to others. Usually it means determining the equivalence of geologic formations in separated areas through a comparison and study of fossils or rock peculiarities.

crown block, n: Assembly of sheaves mounted on the top of the derrick over which the drilling line is reeved.

cuttings, n: Fragments of rock which are dislodged by the drill bit and returned to the surface by the drilling fluid.

D

deadman, n: An anchoring device with a guy line attached to it for bracing a mast or tower.

degasser, n: Equipment used to remove gas from the drilling fluid.

density, n: Weight of a substance per unit volume.

derrick, n: Large, load-bearing structure which rises above the derrick floor on a drill rig, from which the drill pipe is suspended. The derrick is equipped with sheaves and blocks through which the drilling line is threaded.

desander, n: Centrifuge used to remove fine particles of sand from the drilling fluid.

desilter, n: Centrifuge device, much like a desander, used to remove silt-sized particles from the drilling fluid.

development well, n: Well drilled in proven territory to complete a desired pattern of production.

deviation, n: Inclination of the well bore from the vertical.

deviation survey, n: Operation to determine the angle of deviation from the vertical.

diamond bit, n: Steel bit that has a surface of industrial diamonds.

directional drilling, n: Intentional deviation of a well bore from the vertical.

disconformity, n: Break in the orderly sequence of stratified rocks above and below which the beds are parallel. The break is usually indicated by erosional channels, indicating a lapse of time or absence of part of the rock sequence.

displacement fluid, n: In oil-well cementing, the fluid—usually drilling mud or saltwater—that is pumped into the well after the cement to force the cement out of the casing and into the annulus.

dolomite, n: Mineral composed of calcium and magnesium carbonate, or a rock composed chiefly of the mineral dolomite, formed by alteration of limestone.

dome, n: Upfold in which strata dip downward in all directions from a central area; the opposite of a basin.

drawworks, n: Hoisting equipment on a drilling rig. It is essentially a large winch.

drill collar, n: Heavy, thick walled section of pipe that is used between the drill bit and the drill pipe to put weight on the bit.

driller, n: Employee directly in charge of the rig and the drilling crew during a shift or tour. This person is responsible for the drilling rig and the downhole condition of the well.

drilling crew, n: Driller, a derrick-man, and two or more helpers who operate a drilling rig for one tour (pronounced tower) each day.

drilling fluid, n: Circulating fluid used in the drilling of oil and gas wells. Its purpose is to cool and lubricate the drill string and bit, to return the cuttings to the surface, and to confine formation fluids to their respective horizons.

drill pipe, n: Heavy, seamless tubing used to rotate the bit and to circulate the drilling fluid.

drill stem, n: Entire length of tubular pipes composed of the kelly, drill pipe, and drill collars.

drill string, n: The column of drill pipe, not including the drill collars or the kelly.

DST, abbr: Drill-stem test. (see formation testing)

disposal well, n: Well through which water (usually saltwater) is returned to subsurface formations.

dissolved gas, n: Natural gas which is in solution with crude oil in the reservoir.

dry hole, n: Exploratory or development well that contains insufficient amounts of oil or gas to justify completion as an oil or gas well.

E–F

electric well log, n: Record of certain electrical characteristics of formations penetrated by the bore hole, made to identify the formations, determine the porosity, determine the nature and quantity of the fluids that they may contain, and their estimated depth.

eolian, adj: Pertaining to wind. Designates rocks or soils whose constituents have been transported and deposited by wind. Windblown sand and dust (loess) deposits are termed “eolian.”

erosional unconformity, n: Break in the continuity of deposition of a series of rocks caused by an episode of erosion.

facies, n: Generally, the term “facies” refers to a physical aspect or characteristic of a sedimentary rock, as related to adjacent strata. It is usually applied to distinguish different aspects of the sediments in time-equivalent or laterally continuous beds.

fault, n: Break or fracture in rocks, along which there has been movement, one side relative to the other. Displacement along a fault may be vertical (normal or reverse fault) or lateral (strike-slip or “wrench” fault).

field, n: Geographical area in which a number of oil or gas wells produce from one or more oil pools.

fire wall, n: Wall of earth built around an oil tank or other surface equipment to hold the oil if a leak should occur.

fish, n: Object left in the hole during drilling operations. It must be removed before drilling operations can be resumed.

fishing tool, n: Tool designed to recover equipment lost in the well.

float collar, n: Device used in cementing casing. It is attached to several joints above the bottom of the casing and prevents the entry of drilling fluid into the casing as it is inserted into the well bore, allowing the casing to float during its descent, thus decreasing the load on the derrick.

flow by heads, v: Well that flows at irregular intervals.

flowing wells, n: Wells that produce oil or gas without artificial lift.

flow lines, n: Surface pipes through which oil or gas flow from well head to storage.

fluid injection, n: Injection of liquid into a reservoir to force oil toward and into producing wells.

fluid level, n: Distance between the well head and the point to which fluid rises in the well.

formation, n: Fundamental unit in the local classification of layered rocks, consisting of a bed or beds of similar or closely related rock types, and differing from strata above and below. A formation must be readily distinguishable, thick enough to be mappable, and of broad regional extent. A formation may be subdivided into two or more **members**, and/or combined with other closely related formations to form a **group**.

formation fracturing, n: Method of stimulating production of oil or gas by fracturing the rock with a combination of high-pressure, acidic fluid, and propping agents such as sand and glass beads. The purpose is to increase the permeability of the producing formation.

formation pressure, n: Pressure exerted by fluids in a formation.

formation testing, n: Method of determining the potential productivity of a formation or portion of a formation prior to installing casing in the well. By means of drill pipe, packers, and special valving equipment, a sample of the formation fluid can be recovered and analyzed at the surface. Pressure data are also acquired from the formation.

G–H

gas-cut mud, n: Drilling mud that has formation gas entrained in it. The gas must be removed prior to returning the mud or drilling fluid to the well bore.

gas lift, n: Method of producing oil by injecting gas into the casing and allowing it to force the oil to the surface through the tubing.

gas/oil ratio, n: Measurement of the amount of gas produced for a specific quantity of oil. The measurement is given in cubic feet per barrel.

geologic map, n: Map showing the geographic distribution of geologic formations and other geologic features—such as folds, faults, and mineral deposits—by means of color or other appropriate symbols.

granite, n: Intrusive igneous rock with visibly granular, interlocking, crystalline quartz, feldspar, and perhaps other minerals.

gravity-API, n: Specific gravity or density of oil expressed in terms of a scale developed by the American

Petroleum Institute. The formula is:

$$\frac{141.5}{\text{specific gravity of liquid @ } 60^{\circ}\text{F}} - 131.5$$

The lighter the oil, the higher the gravity.

halite, n: Common rock salt (NaCl) precipitates from seawater under conditions of intense evaporation. Occurs as bedded, usually crystalline, white or red rock only in the subsurface; flows plastically under high confining pressure.

hydrocarbons, n: Organic compounds of hydrogen and carbon, whose densities, boiling points, and freezing points increase as their molecular weights increase.

I–K

igneous rock, n: Rocks formed by solidification of molten material (magma), including rocks crystallized from cooling magma at depth (intrusive) and those poured out onto the surface as lavas (extrusive).

impermeable, adj: Preventing the passage of fluid. The absence of connecting channels between pore spaces in rock causes its impermeability.

intermediate casing, n: String of casing that is sometimes inserted into the well bore after the surface casing to prevent caving and further hole problems as drilling continues.

kelly, n: Heavy steel member, four- or six-sided, suspended from the swivel through the rotary table and connected to the topmost joint of the drill string. The kelly turns the drill stem as the rotary table turns.

kelly bushing, n: Device fitted to the rotary table through which the kelly passes and by which the turning motion of the rotary table is transferred to the kelly.

L–M

LACT (“lease automatic custody transfer”), acronym: Automatic measuring equipment that allows for the transfer of oil or gas from lease to pipeline without any manual activity or witnessing.

law of superposition, n: Concept stating that, if undisturbed, any sequence of sedimentary rocks will have the oldest beds at the base and the youngest at the top.

limestone, n: Bedded sedimentary deposit consisting chiefly of calcium carbonate, usually formed from the calcified hard parts of organisms.

location, n: Place at which a well is to be or has been drilled.

log, n: Systematic recording of data, as from a driller's log, electric well log, radioactivity log, mud log, etc.

make a connection, v: To connect another joint of drill pipe to the drill string.

make a trip, v: To withdraw all of the drill pipe, drill collars, and drill bit from the well bore and to insert it back into the well bore again. This is frequently done to change drill bits.

marginal well, n: Well whose production is barely sufficient to pay its operating costs.

metamorphic rock, n: Rocks formed by the alteration of preexisting igneous or sedimentary rocks, usually by intense heat and/or pressure, or mineralizing fluids.

miscible flood, n: Injection of a solvent that lowers the viscosity of the crude oil in a formation which is followed by a displacing fluid.

mouse hole, n: Opening through the rig floor, usually lined with pipe, into which a length of drill pipe is placed temporarily for later connection to the drill string.

mud, n: Drilling fluid circulated during drilling operations. It may consist of water and native mud or may contain many additives that give the mud certain properties.

mud cake, n: Sheath of mud solids that forms on the wall of the bore hole when the liquid from the mud filters into the formation.

mud pit, n: Reservoir or tank, usually made of steel, through which the drilling fluid is circulated. Additives are mixed with the mud in the pit.

mud pump, n: Pump which circulates the drilling fluid throughout the drilling system.

multiple completion, n: Well equipped to produce oil and/or gas separately from more than one reservoir.

N–O

natural gas, n: Mixture of hydrocarbons and varying quantities of nonhydrocarbons that exist either in the gaseous state or in solution with crude oil in natural underground reservoirs.

natural gas liquids, n: Those portions of reservoir gas which are liquified at the surface in lease separators, or gas-processing plants.

offset well, n: Well that is drilled close by another producing well. An offset well is usually only one spacing unit away from a producing well.

oil field, n: Surface area overlying an oil reservoir or reservoirs.

oil pool, n: Accumulation of oil in the pores of sedimentary rock that yields petroleum on drilling.

operator, n: Person or company, either proprietor or lessee, actually operating an oil well or lease.

orogeny, n: Literally, the process of formation of mountains, but practically it refers to the processes by which structures in mountainous regions were formed, including folding, thrusting, and faulting in the outer layers of the crust, and plastic folding, metamorphism, and plutonism (emplacement of magmas) in the inner layers. An episode of structural deformation may be called an orogeny, e.g., the Laramide Orogeny.

P

pay zone, n: Producing formation or interval within a formation.

perforate, v: To pierce the casing wall and cement so as to enable the formation fluids to enter the well bore.

permeability, n: Measure of the ease with which fluids can flow through porous rock.

petroleum, n: Oil or gas obtained from the rocks of the earth.

plug and abandon (P&A), v: To place cement plugs into a dry hole and abandon it.

pore, n: Opening or space within a rock or mass of rock, usually small and often filled with fluid.

porosity, n: State of voids or open spaces existing in rock.

positive choke, n: Choke in which the orifice size must be changed to change the rate of flow through the choke.

potential test, n: Test of the maximum rate at which a well can produce oil.

pressure gradient, n: Scale of pressure differences in which there is a uniform variation of pressure from point to point.

pressure maintenance, n: Repressuring of an oil field to maintain pressure or to slow the decline of reservoir pressure as oil is produced.

R

radioactivity well logging, n: Recording of the natural or induced radioactive characteristics of subsurface formations.

rat hole, n: Hole in the rig floor from 30 to 35 ft (9 to 10 m) deep, lined with casing that projects above the floor. The kelly and swivel are placed in the rat hole when hoisting operations are in progress.

reserve pit, n: Pit in which a supply of drilling fluid is stored.

rig, n: Derrick, drawworks, and other surface equipment of a drilling unit.

rig down, v: To dismantle a drilling rig.

rig up, v: To assemble a drilling rig.

roughneck, n: Worker on a drilling rig, a subordinate to the driller.

round trip, n: To pull out and subsequently run back into the hole a string of drill pipe or tubing.

S–T

samples, n: Well cuttings obtained at designated footage intervals during drilling.

sandstone, n: Consolidated rock composed of sand grains cemented together; usually composed predominantly of quartz, it may contain other sand-sized fragments of rocks and/or minerals.

sedimentary rock, n: Rocks composed of sediments, usually aggregated through processes of water, wind, glacial ice, or organisms, derived from preexisting rocks. In limestones, constituent particles are usually derived from organic processes.

seismograph, n: Device that detects vibrations in the earth, used in prospecting for probable oil-bearing structures.

shale, n: Solidified muds, clays, and silts that are fissile (split like paper) and break along original bedding planes.

shale shaker, n: Device that separates the coarser well cuttings from the drilling fluid when it returns to the surface.

spud in, v: To commence drilling operations.

stratigraphy, n: Definition and interpretation of the layered rocks, the conditions of their formation, their character, arrangements, sequence, age, distribution, and correlation, using fossils and other means.

stripper, n: Well that produces a small quantity of oil, usually less than 10 barrels per day.

swab, n: Device that is inserted into the tubing and lifts oil as it is pulled up.

swab, v: To pull a swab through the tubing in order to lift oil to the surface.

syncline, n: Elongate, troughlike downfold in which the sides dip downward and inward toward the axis.

tectonic, adj: Pertaining to rock structures formed by Earth movements, especially those that are widespread.

trip, n: (see round trip)

U–Z

unconformity, n: Surface of erosion or nondeposition separating sequences of layered rocks.

unitization, n: System of operating a certain oil and condensate reservoir in order to conduct some form of pressure maintenance, repressuring, waterflood, or other cooperative form to increase ultimate recovery.

well bore, n: Bore hole; the hole drilled by the bit.

well completion, n: Activities and methods necessary to prepare a well for the production of oil or gas.

well head, n: Equipment installed at the surface of the well bore.

wildcat, n: Well drilled in an area where no oil or gas production exists.

WOC, abbr: Waiting on cement.

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Collins, David R., *manager, technical information services*
Corcoran, Anna, *word-processing typist*
Cowan, Cora E., *word-processing typist*
Cox, Sharon, *payroll clerk*
Crumet, Juanita, *clerk, business office*
Davidson, Lea Ann, *word-processing typist*
Davis, John C., *chief, advanced projects*
DeGraffenreid, Jo Anne, *research assistant*
Deputy, James O., *systems programmer*
Doveton, John D., *mathematical geologist*
Eberhart, Delbert L., *laborer supervisor, maintenance*
Feldman, Howard R., *adjunct asst. scientist*
Franseen, Evan K., *carbonate sedimentologist/stratigrapher*
Galle, O. Karmie, *geochemist*
Gerhard, Lee C., *Director/ State Geologist*
Goddard, Diane Hoose, *asst. director, budget and planning*
Grisafe, David A., *materials scientist*
Hambleton, William W., *Director emeritus*
Hathaway, Lawrence R., *manager, analytical services*
Healey, John M., *field hydrogeologist*
Heidari, Manoutchehr, *geohydrologist*
Hensiek, Renate, *manager, graphic arts*
Kleinshmidt, Melvin K., *drilling/field operations*
Knapp, Ralph W., *geophysicist*
Macfarlane, P. Allen, *hydrogeologist*
Magnuson, Larry Mike, *geochemist*

Maples, Christopher, *paleontologist*
McCauley, James R., *geologist*
McClain, Thomas J., *acting chief, geohydrology*
McElwee, Carl D., *hydrologist/geophysicist*
Meyers, Joseph K., *engineering technician*
Miller, Richard D., *chief, exploration services*
Moore, Patricia, *computer-operations supervisor*
Newell, K. David, *petroleum geologist/stratigrapher*
Olea, Ricardo, *petroleum engineer*
Paul, Shirley, *petroleum geologist*
Price, Esther L., *word-processing typist*
Reetz, Sonia, *secretary*
Roche, Chris, *admin. asst., technical information services*
Ross, Charles G., *systems analyst*
Ross, Jorgina, *production manager, automated cartography*
Saile, Donna, *administrative secretary*
Sampson, Robert, *systems designer*
Schoneweis, Mark, *graphic designer*
Shaukat, Nadeem, *hydrologic-data manager*
Sheldon, Kathleen, *business-affairs manager*
Sims, Jennifer, *graphic designer/publications*
Song, Yi-Yang, *research assistant*
Sophocleous, Marios, *hydrogeologist*
Sorensen, Janice H., *librarian/archivist*
Spitz, Owen T., *manager, computer services*
Steeple, Don W., *deputy director*
Taylor, Lois, *accountant*
Terry, Fred, *assistant editor*
Townsend, Margaret A., *hydrogeologist*
Watkins, Lila M., *asst. director, personnel management*
Watney, W. Lynn, *chief, petroleum research*
Waugh, Truman C., *chief spectrographer*
Whittemore, Donald O., *environmental geochemist*
Wilson, Frank W., *geologist*
Woods, Cynthia A., *clerk*

Wichita Well Sample Library

Berger, Winifred M., *utility worker*
Catron, Joseph A., *general maintenance technician*
Keener, Barbara, *library assistant*
Skelton, Lawrence H., *geologist/manager*
Wolf, Jessica, *clerk*

Student employees

Alkire, Heather L.	Chu, Tyan-Ming	French, John, Jr.	Kerschner, REXANNE	Shamsnia, Saeed
Anderson, James E.	Chung, Chong-Dae	Grantham, Randie L.	Kessler, Kevin L.	Somanas, Chaturong
Baxter, Carol	Coble, Geoffrey R.	Hamilton, Vince	Kumarajeeva, Dinesh	Steinle, Gary D.
Billar, Christine	Cole, Thomas	Han, Meei-Chyn	Lambert, Michael W.	Voth, Joel D.
Bird, Warren A.	Coyle, W. George, III	Haug, Danny B.	Leonard, Karl W.	Wilson, Matthew E.
Birdie, Tiraz	Daily, Mary E.	Hemmat, Mehrzad	Limesand, Kurt	Wong, Jan-Chung
Blair, Kevin P.	David, Thomas S.	Hoaglund, John	Liu, Wenzhi	Wong, RACKY K.
Bletscher, Katherine K.	Deesilpakij, Paiboon	Hsu, Benedict	McDaneld, Scott	Woods, John J.
Bock, Sabine	Evans, Catherine S.	Huynn, Minh H.	Michnick, Steven M.	Xia, Jianghai
Boyd, Andrea S.	Fesperman, Jeffrey N.	Janisch, Melora J.	Neal, Patrice	Yee, Weng-Liang
Burdick, Diana	Forgey, Brian	Jiang, Xiaosong	Park, Choon Byong	
Cherry, Frank	Foster, Dion W.	Johnson, Ganay M.	Schinkel, Michael J.	



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