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CALIFORNIA OIL, GAS, AND GEOTHERMAL RESOURCES

AN INTRODUCTION

DEPARTMENT OF CONSERVATION

THE RESOURCES AGENCY
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CALIFORNIA OIL, GAS, AND GEOTHERMAL RESOURCES

AN INTRODUCTION

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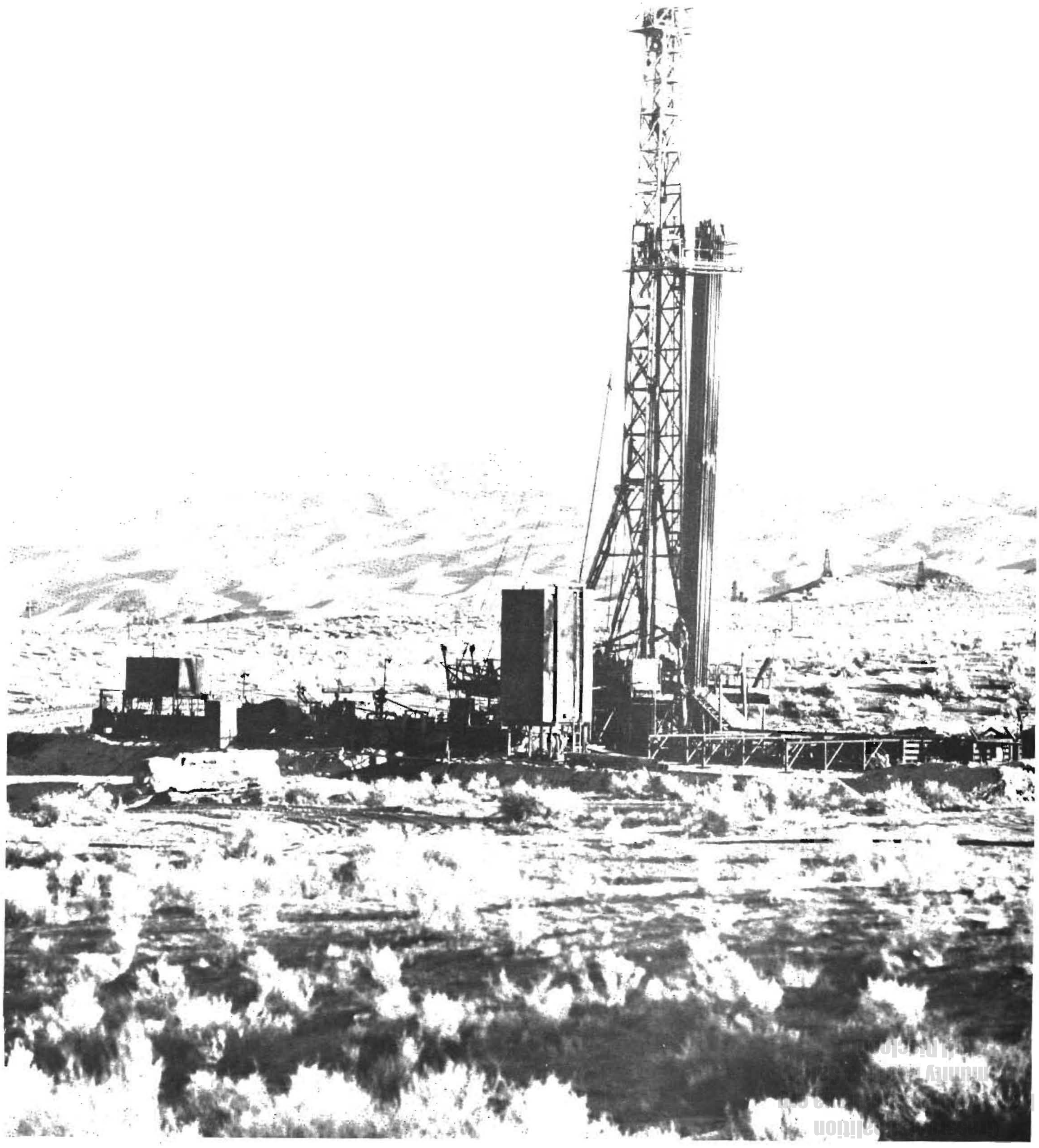
FOREWORD

As we rush through our lives, we may sometimes take a moment to admire the beauty of nature—a peaceful cove—a grove of redwood trees—the majestic mountains. But seldom do we stop and think how blessed the State of California is, not only in beauty, but in all the resources that enrich us.

Unfortunately, petroleum, geothermal, and other natural resources are not unlimited. It is only by understanding our resources that we can learn to conserve them and use them wisely. To this end, the present volume has been prepared.



CHAPTER 1
CALIFORNIA'S ENERGY RESOURCES

OIL AND GAS

Oil and gas are by far the largest sources of energy found and used in California. In 1980, oil and gas provided about 91 percent of the **total energy** consumed in California, with hydropower supplying 4 percent; coal, 2 percent; nuclear energy, 1.0 percent; geothermal energy, 1.0 percent; and other sources, 1.0 percent.

Even though California is an exceptionally large producer of oil and gas (only Texas, Alaska, and Louisiana produce more oil), statewide consumption of these resources still exceeds production. About 357 million barrels* of oil and 317 billion cubic feet of gas were produced in the state in 1980. Even with this vast production, about 52 percent of the oil and about 82 percent of the gas used in the state in 1980 had to be imported from other states and foreign countries.

Proved oil and gas reserves are the petroleum resources extractable under current economic and technological conditions. As of December 31, 1980, California's proved oil and gas reserves equaled about 5.2 billion barrels of crude oil (excluding ultraheavy and unconventional oil deposits) and about 4 trillion cubic feet of natural gas. (These reserve estimates exclude federal offshore fields.)

With present energy demands so great, California fields may never again produce enough oil and gas to fill the state's need. The only known, large, conventional oil and gas fields in the entire West Coast area remaining to be developed are off California's coast, as are the most favorable areas to explore for new oil and gas fields.

The state's unconventional oil resources, such as diatomaceous oil shales and tar sands, are other petroleum resources that will become more important under more favorable economic and technological conditions.

* One barrel equals 42 gallons.

The production of oil and gas is an essential part of California's economy. In 1980, about 32,800 people earned their living from oil and gas production, and about 24,400 people earned their living from petroleum refining.** Furthermore, the value of oil and gas produced in the state during 1980 is estimated to be 10.1 billion dollars.

GEOTHERMAL

Geothermal resources are important sources of energy in California. High-temperature geothermal resources (320°F or 160°C, and above) from which electricity can be generated, occur as dry steam and hot water reservoirs. The Geysers Geothermal field, about 65 miles northeast of San Francisco, is the largest known commercial, dry steam, geothermal reservoir in the world (2 other steam reservoirs are in Italy, and 1 is in Japan). In 1980, 15 power plants operating at The Geysers generated 908 megawatts of electricity, enough electricity for a city of about 908,000 people.[a]

High-temperature hot water geothermal reservoirs are much more common than dry steam reservoirs. In the Imperial Valley, investigations into the possibilities of commercially producing electricity from valley hot water reservoirs have been underway since the 1920's. The greatest stumbling block to electrical generation there has been the high mineralization of geothermal waters. This is a hindrance because, when the water temperature or pressure is reduced during production, the minerals are deposited as scale on well casing, pipelines, and other equipment with which they come into contact, making constant maintenance necessary.

Several pilot power plants are operating to determine if the scaling problem can be solved. As of this time, operators are optimistic that reliable commercial, geothermal electrical production from the Imperial Valley is possible.

[a] All such estimates are based on a ratio of 1 kilowatt to 1 person in a residential area. (1 megawatt equals 1,000 kilowatts)

** Excludes employees of oilfield service contractors and other service and supply companies, and foreign operation employees.

Low-temperature resources [65°F (16°C) to 320°F (160°C)][b], are the state's most prevalent geothermal resource. Found throughout Calfornia, low-temperature waters are used in an increasing variety of heating cooling, agricultural, and aquacultural projects.

HYDROPOWER

Water power, in some form, has been exploited for centuries. In early-day America, water power was most often used for turning water wheels, which, in turn, supplied power for grinding grain and running textile mills.

Hydroelectric power has been a source of energy in California since 1887. In that year, a hydroelectric power plant was built at Highgrove, near Riverside. At the present time, about 150 hydroelectric power plants are operating in California, and additional small hydroelectric plants are scheduled to be built. In December 1980, total hydroelectrical generating capacity in California was about 8,700 MWe,* enough for the electrical needs of about 8,700,000 people.

NUCLEAR

Although there is no commercial production of uranium in California, two nuclear-powered electrical generating plants operate in the state, San Onofre and Rancho Seco. Together, in December 1980, they had an operating capacity of 1,344 MWe of electricity, enough for a community of 1,344,000 people. A third nuclear power plant, the Humboldt Bay Plant, has been deactivated, and a fourth, the Diablo Canyon Nuclear Plant, has not begun operation.

WIND AND SUNLIGHT

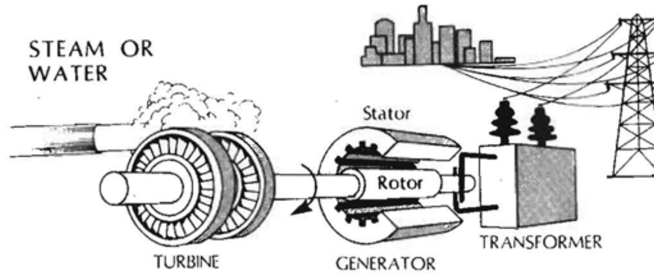
Although commercial, electrical generating plants operated with wind and sunlight are new to California, several such plants are in the planning or testing stages throughout the state. Development of these plants is encouraged by increasing demands for energy, rising energy costs, and the nonrenewable nature of most of the more traditional energy sources.

Many California areas have winds of sufficient velocity and constancy for windmills to generate electricity. Here, windmills, some in the form of wind turbine generators, are being built, singly or in groups called *wind farms.*

Sunlight is used in several ways to generate electricity. Sometimes, mirrors reflect sunlight onto containers of fluid that serve as steam generating systems, such as at a pilot project called *Solar One* Near Daggett, California (*see* photo).

A different use of sunlight occurs at a photovoltaic plant, such as the 1 megawatt plant to be built by the Sacramento Municipal Utility District on the grounds of the Rancho Seco Nuclear Power Plant. A photovoltaic plant converts sunlight directly into electricity. A plant inverter changes the electricity from DC to AC current, which is fed directly into a utility's electrical gridwork.

HOW ELECTRICAL POWER PLANTS WORK



When you flick on a switch and a lamp lights up, somewhere behind that glow is a power plant generating a flow of electricity.

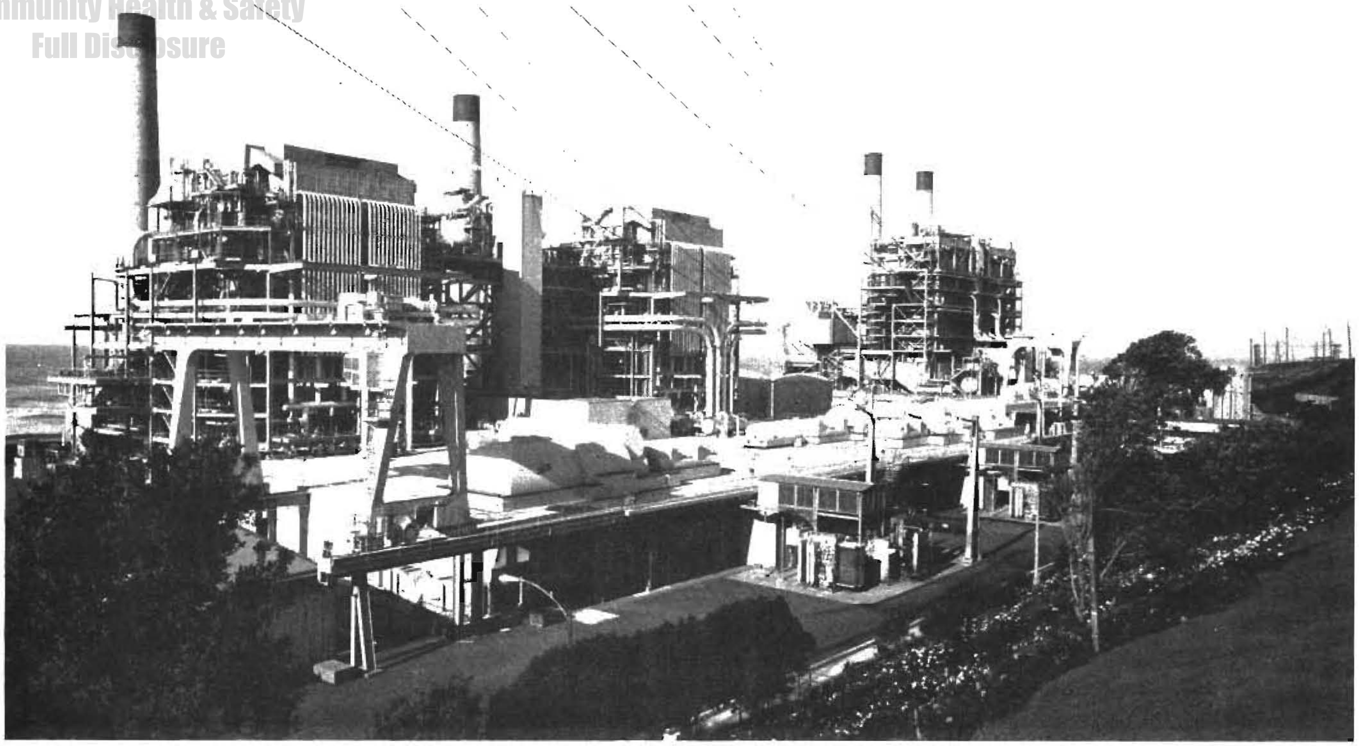
Commercial electricity in California is produced from a generator composed of a *rotor,* spinning inside a stationary field coil, called a *stator.* A series of bladed wheels, called a turbine, is fastened to the same shaft as the rotor. As the turbine is turned, the moving magnetic field sets electrons in motion, and electricity is generated.

It takes power to turn a turbine. In California plants, that force comes from jets of steam (steam-powered generating plants) or from falling water (hydroelectric generating plants). Windmills provide the power to turn the rotor in wind-powered generating plants.

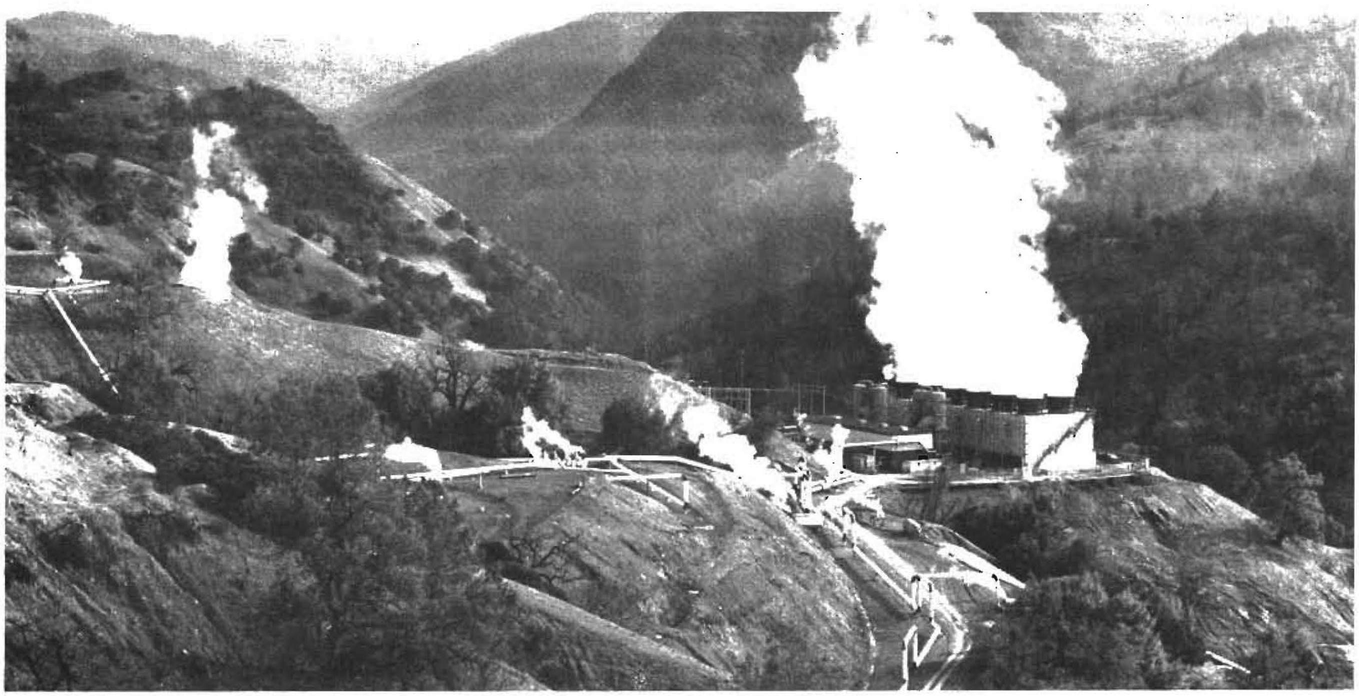
Power plant steam is usually produced by heating water with fuels such as gas, oil, coal (not in California), by nuclear fission (in nuclear power plants), or by sunlight (just beginning to be used in California). At The Geysers Geothermal field, steam occurring naturally in the earth is extracted from wells and piped directly to power plants to turn the turbines.

[b] The temperatures are based on technical data. Legally, low-temperture geothermal resources in California have a temperature no higher than the boiling point of water at the altitude of occurrence.

*MWe—megawatts of electricity.



Fossil fuel power plant near El Segundo, California. At full capacity, the plant burns 10 million cubic feet of natural gas per hour or 40,000 barrels (42 gallons per barrel) of fuel oil per 24-hour period. The plant produces 1,020 megawatts of electricity, enough for the electrical needs of about 1,020,000 people. *Photo courtesy of Southern California Edison Company.*



Power plant Units 3 and 4, The Geysers Geothermal field, Northern California. Steam produced from wells passes through the insulated pipeline network to the power plant units.

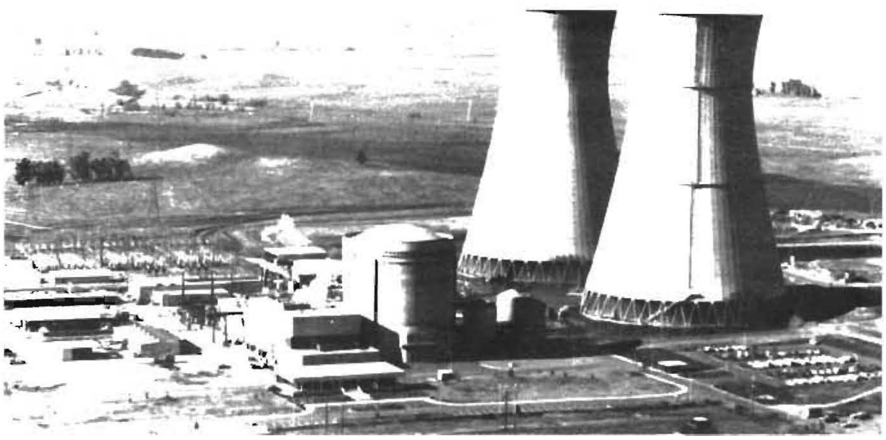
At the power plants, the steam turns turbine generators that produce 54 megawatts of electricity.

The turbines are in the building to the left of the cooling towers. Here, after passing through the turbines, the steam is converted to hot water in the condensor. Then, the hot water is pumped to the towers for cooling. Most of the water from the condensation process will be reused, but about 20 percent is excess water that must be injected back into the steam reservoir. Water vapor rising from the cooling towers is lost to the atmosphere.

Lake Oroville and Oroville Dam, the tallest and one of the largest dams in the United States, rises 770 feet above the stream bed of the Feather River in Northern California. The earth-filled dam contains enough embankment material to pave a two-lane highway around the world.

At the base of the dam, photo right, are the electricial transmission lines connected to the Edward Hyatt Power Plant. The hydroelectric plant, itself, is underground in a cavern blasted from bedrock and as large as a football field. The water flows from the shoreline down to the turbines of the power plant through two underground passageways, in back and to the right of the dam.

Water leaving Lake Oroville or the power plant flows downstream through another hydroelectric power plant, the Thermalito Power Plant, where additional electricity is generated. Together, the two power plants generate about 800 megawatts of electricity, enough for the electrical needs of a city of about 800,000 people. *Photo courtesy of the California Department of Water Resources.*



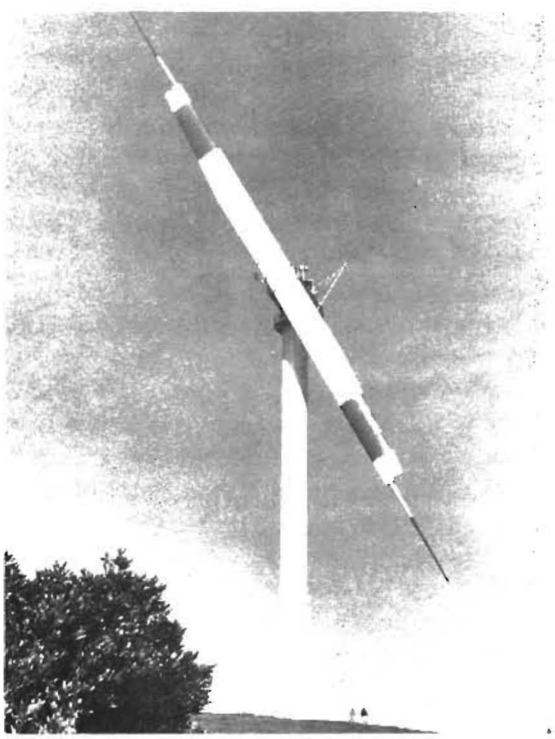
Rancho Seco Nuclear Power Plant, about 25 miles southeast of Sacramento, California. The plant has a generating capacity of 914 megawatts of electricity.

At Rancho Seco, heat is created inside a nuclear reactor through a process called nuclear fission. The amount of fission heat created is carefully controlled and used to heat water.

The Rancho Seco Plant has three water systems. Water in the first system, called primary water, is heated directly to 610°F. (Primary fuel water is never mixed with water from the other two systems.) Primary water is kept under high pressure and circulated through a steam generator, where it heats to steam the water in the secondary water system. The steam is used to spin turbine blades, generating electricity. Water from a third water system cools the steam in a condenser and two cooling towers. *Photo courtesy of the Sacramento Municipal Utility District.*

A pilot 10 megawatt solar electric plant, Solar One, receives sunlight from 1,818 mirrored collectors arranged on 130 acres in the Mojave Desert near Daggett, California. The collectors track the sun as it moves across the sky, focusing the rays on a cylindrical boiler-receiver on top of the power plant. The boiler panels produce superheated steam that is piped to a turbine generator below to generate electricity.

The U.S. Department of Energy (D.O.E.) funded the unique solar parts of the plant. Southern California Edison Company, a partner with D.O.E. in the project, is the operator of Solar One, providing the site and all conventional generating equipment along with the Los Angeles Water and Power Company. Other California solar electric plants are planned. *Photo courtesy of the Sandia National Laboratories of Livermore.*



A wind-powered generator at a site 30 miles northeast of San Francisco, on a low hill between Vallejo and Fairfield. Built by Boeing Engineering and Construction Company for Pacific Gas and Electric Company, the generator is one of several wind-powered electrical generation projects being tested in California.

The tower is 200 feet high, with one 300-foot-long steel blade weighing 99 tons. The generator and drive train are inside the box-like structure on top of the tower. The power plant can generate 2.5 megawatts of electricity in winds of 27½ miles per hour. *Photo courtesy of Pacific Gas and Electric Company.*

CHAPTER 2
OIL AND GAS PRODUCTION HISTORY IN CALIFORNIA

OIL

California oil was a valued commodity even before the early settlers arrived. When Spanish explorers landed in California in the 1500's, they found Indians using asphaltum (*very* thick oil) gathered from natural seeps. The asphaltum was used to make baskets and jars, to fasten arrowpoints to shafts, and for ornaments. The explorers, in turn, used asphaltum to seal seams in their ships.

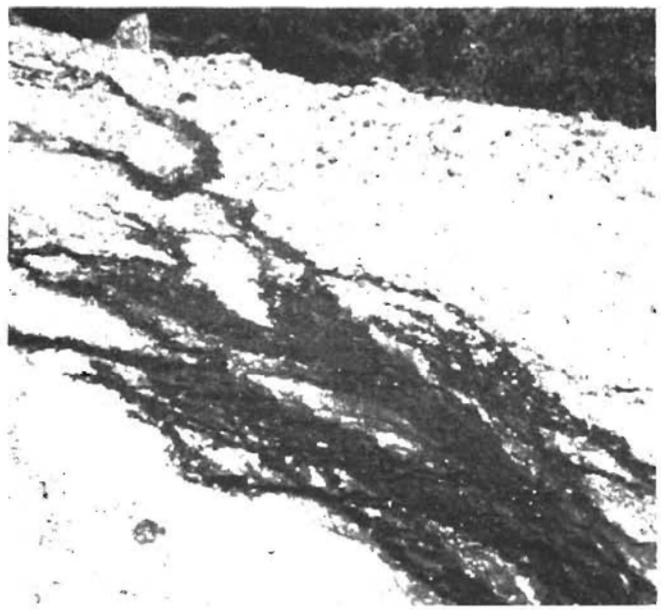
Later, settlers found many uses for thick asphaltum, including sealing roofs on their houses. As pioneers continued to arrive and settle, the number of oil seeps discovered in California continued to increase.

In Northern California, people were interested in the oil seeps in Humboldt, Colusa, Santa Clara, and San Mateo Counties , and in the asphaltum seeps and bituminous residues in Mendocino, Marin, Contra Costa, Santa Clara, and Santa Cruz Counties. Oil taken from a Humboldt County seep was sold in 1855, 4 years before Colonel Drake drilled America's first oil well in Pennsylvania.[4]

In Southern California, large seeps in Ventura, Santa Barbara, Kern, and Los Angeles Counties received the most attention. Interest in oil and gas seeps was stirred in the 1850's and 1860's, perhaps partly because one of California's oldest and most-used roads passed along nearly all the seep areas on the west side of the San Joaquin Valley. As early as 1849, these seeps were used by people moving along the route, who would pause to lubricate their wagon wheels with oil.

Interest in oil seeps became widespread after the 1859 discovery of oil in Pennsylvania, when the value of kerosene as an illuminant became generally known, although it appears a number of California settlers distilled oil taken from the seeps to make *lamp oil* prior to the Pennsylvania activity. The first person recorded as doing so was Andreas Pico. In 1850, Pico obtained oil from seeps found in Pico Canyon, near Newhall, and distilled the oil for use as an illuminant at the San Fernando Mission.[8] In 1854, oil was collected from seeps and excavations at Sulphur Mountain, in Ventura County, and refined in stills for home use. Complete records of the operations are not available, but it is reported that as early as 1856, a company organized in San Francisco began working the tar pits at La Brea Ranch, near Los Angeles, distilling some oil.[2]

[4]Superior figures refer to references at the end of the chapter.



A natural tar seep in Ventura County. Seeps are transitory features, appearing and disappearing through the years on no apparent schedule. Over 500 onshore seeps are documented in the division publication *Onshore Oil and Gas Seeps in California.*

Other sources state that a G. S. Gilbert was refining oil on a commercial basis as early as 1857, if not before. In 1861, Gilbert set up a larger plant near Ventura to refine asphaltum gathered from seeps on the Ojai Ranch. That plant produced about 300 to 400 gallons of refined oil each week for several years.

Shortly thereafter, oil was obtained from pits dug in seep areas throughout California. Among the most important were those at McKittrick, in Kern County, which were worked from 1864 to 1867, and seeps at Sargent Ranch, in Santa Clara County, worked in 1864 and 1865.

In the early 1860's, tunnels were dug in Sulphur Mountain near Santa Paula in Ventura County. Josiah Stanford, a mining engineer, dug about 30 tunnels into the mountain, slanting them upwards so oil flowed out to the entrances. Some tunnels reportedly produced as much as 20 barrels of oil per day. As oil flowed steadily from the tunnels, Stanford became one of the top oil producers of the 1860's. Today, a few of these tunnels are still producing oil.

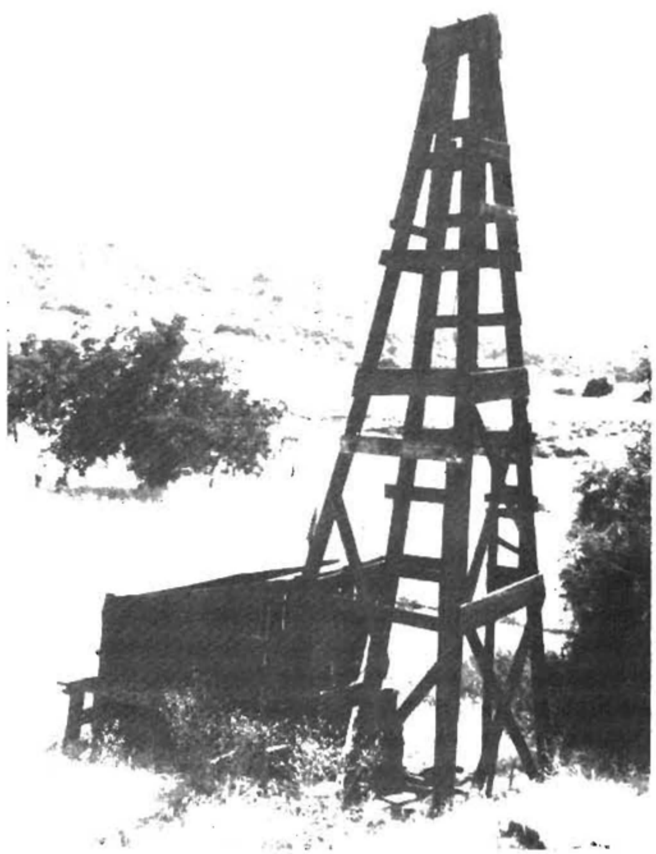
In most instances, distances from markets and relatively high operating costs limited seep operations to occasional short periods when circumstances made the work profitable. Such operations became sporadic as the practice of drilling oil wells grew.

In 1861, the first well drilled in California for oil production was drilled in Humboldt County.[9] The well was unsuccessful, as were numerous other wells drilled in Humboldt County between 1861 and 1864.

Drilling activity began in earnest in 1865 and 1866, as wells were drilled from Humboldt County southward to Ventura. H.G. Hanks[9] states that there were 65 companies drilling for oil in the state in 1865.

The Boardinghouse Tunnel in the Adams Canyon area of Santa Paula oil field, dug over 100 years ago and photographed in February 1980. The tunnel is one of 26 Adams Canyon oil tunnels dug by Union Oil Company (or by companies that eventually merged to form a part of Union Oil).

Such tunnels took advantage of natural oil seepage in the area. Water and a little oil still flow from this tunnel through a pipeline that is buried in the slumped-in dirt and rock at the tunnel entrance. The water and oil are collected in tanks by Union Oil Company. *Photo by John Hardoin, CDOG.*



Remnants of the activity of California's early oil pioneers still dot the landscape. Natural oil seeps abound in this region of central Ventura County.

Another California oil well, the Union Mattole Oil Company well in Humboldt County, was completed in the summer of 1865. The well was not commercial, although it produced some oil for a time. No records of its initial production are available. Reports conflict as to the exact month of completion and the amount of the first oil shipment, but Hanks[9] states: "Thirty barrels of oil were shipped to San Francisco. 'Six, 20 gallon casks of crude oil', by another statement, was the first shipment of oil received from the north."

Walter Stalder[9] writes that the Stanford Brothers refined and sold the first shipment of oil from the Mattole well, the first oil produced and refined from a California well. Reportedly, the refined "burning oil" sold for $1.40 per gallon.

In 1866, Thomas R. Bard drilled several wells on the Rancho Ojai, near Ventura. The most successful of these was "Ojai" 6, which produced from 15 to 20 barrels of oil per day from a depth of 550 feet. This was the best well to date, and would be considered as the first oil well in California to produce on a commercial basis, except that a record of whether the well produced continually or intermittently is not available.

Sespe Canyon, painted in 1911 by California artist Hanson Duvall Puthuff (1875-1972). The painting was part of an exhibition by the Oakland Museum entitled Impressionism, The California View.

Sespe oil field, in Sespe Canyon, is one of California's oldest oil fields. Discovered in the late 1880's, it spans the history of the oil industry, from early cable-tool drilling to present-day rotary drilling methods.

The field was discovered by two Pennsylvania oil operators who moved to California to try their luck. The men, Lyman Stewart and Wallace L. Hardison, drilled the first productive well in Sespe oil field in 1887. In 1890, Hardison and Stewart, along with Thomas R. Bard and others, formed Union Oil Company.

Painting reproduced by permission of Gary Breitweiser. Caption information from Sespe Oil Field by Murray W. Dosch. Photo by Rafael Maldonado.

Also in 1866, according to Hanks,[9] a number of stills were built to refine oil: the Charles Stott still on Santa Paula Creek in Ventura County; the Hayward and Coleman still, and the Stanford Brothers' still, both in San Francisco; the Buena Vista Petroleum Company still, near the present town of McKittrick; and the Polhemus still in Los Angeles.

By 1867, drilling activity had declined. Many California wells capable of producing oil were idled because overproduction in Pennsylvania brought Pennsylvania oil to San Francisco at a price lower than California operators could meet. However, some activity continued, the most important being in Pico Canyon near Newhall. Here, in 1876, well "Pico" 4 was completed, producing 30 barrels of oil a day from a depth of 300 feet. This well proved to be the first truly commercial oil well in the state, and has been so designated by the placement of a state historical monument. The site is California Registered Landmark 516.

The same year, the first true oil refinery in the state was built at Newhall to take care of the new production. The refinery had a daily capacity of 20 barrels (*see* Chapter 11). This is about the time in California history of the change from candle to kerosene lamp.

In 1878, well "Pico" 4, was deepened to 610 feet and produced as much as 150 barrels of oil per day for a short period—spectacular production for that time. In the same year, the Newhall refinery was dismantled and the equipment moved to a new location 1/2 mile east of Newhall near the Southern Pacific Railroad. The refinery, called the Pioneer Oil Refinery, is still standing and open to the public as California Registered Landmark 172 (*see* Chapter 11). In 1879, the first oil pipeline in California, a 2-inch line, was laid from Pico Canyon to this new refinery east of Newhall, a distance of about 5 miles.

By 1880, although a number of wells had been drilled in Pico and Wiley Canyons near Newhall, the greatest interest was focused at Moody Gulch in Santa Clara County. Moody Gulch wells were from 800 to 1,600 feet deep, and some initially produced as much as 100 barrels of oil a day. However, the production from these wells declined rapidly. Soon, further prospects at Moody Gulch looked poor, and interest returned to canyons near Newhall where increased drilling brought the area's oil production up to approximately 500 barrels a day.

In 1885, development began in Adams Canyon, near Santa Paula, greatly increasing the production in the Ventura area and boosting the total state oil production—which was almost entirely from the Ventura County and Newhall fields—to 325,000 barrels for the year.

Most of the oil from the Ventura County and Newhall fields was shipped to the San Francisco area, the most populous region in the state. Railroad rates were high, so the companies looked for cheaper ways to ship the oil. To this end, a pipeline was laid from Newhall to the waterfront at Ventura in 1886. In 1888, two wooden steamers equipped with steel tanks were constructed in San Francisco and were soon transporting oil from Ventura to San Francisco at greatly reduced costs.

In 1890, the discoveries of the Sunset Area of Midway-Sunset field in Kern County, and the Coalinga field in Fresno County opened large, potential areas for exploration. However, since the discovery wells were small producers, no large-scale development of these fields occurred at that time, and statewide production for the year dropped to 307,000 barrels of oil.

Then, in February 1892, California saw its first oil gusher. While being drilled in Adams Canyon near Santa Paula, Union Oil Company's well No. 28 hit oil and blew out of control, flowing an estimated 1,500 barrels of oil per day. This was the first truly big well in the state. Unfortunately, no storage facilities were available for such amounts of oil. The oil ran down Adams Canyon into the Santa Clara River, and on to the ocean. The well produced about 40,000 barrels of oil before the flow was controlled, but no lasting damage occurred.

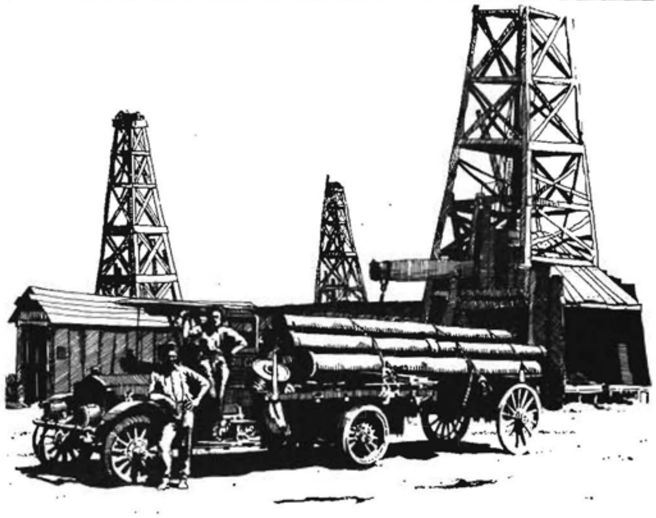
In 1893, Los Angeles City field was discovered and soon led the state in production. Shortly thereafter, overproduction became so acute that the price of oil dropped to 25 cents a barrel. In 1895, Los Angeles City field produced approximately 750,000 barrels of the 1.2 million barrels produced in the state.

In 1896, the first offshore wells in the United States were drilled as an extension to Summerland oil field in Santa Barbara County. For more information, *see* Chapter 9.

After a few relatively quiet years, excitement returned when large gushers began to flow in the Oil City Area of Coalinga field. One famous gusher, Home Oil Company well No. 3, sometimes known as "Blue Goose", was completed at a depth of 1,400 feet in 1898. The well flowed initially at a rate in excess of 1,000 barrels of oil per day.

Then McKittrick field was discovered in 1898, Kern River field in 1899, and the Midway Area of Midway-Sunset field in 1900, and another oil boom was on. By 1900, wells from Los Angeles, Coalinga, and Kern River fields were the leading producers, and the annual state oil production had risen to 4.3 million barrels.

In 1904, the first gusher in Santa Maria field was brought in. Union Oil Company's well "Hartnell" 1 flowed an estimated 12,000 barrels of oil per day for about 3 months before the flow diminished. During the 2-year period when the well flowed, about 3 million barrels of oil was produced.



A truck hauling well casing to a Kern County well site in the early 1900's, *from Kern County Museum photo.*

Summerland oil field, Santa Barbara County, around 1900. Onshore drilling started here in 1886. As field development continued, operators realized the oil sands extended under the ocean. To reach the offshore sands, piers were built over the water to support drilling and production machinery.

Close-up of piers around 1900, Summerland oil field.

Production continued to rise until, by 1905, the annual state oil production was 34 million barrels, with Kern River, the largest field, producing 15 million barrels.

New fields were discovered and new gushers occurred with surprising regularity. Finally, in March 1910, well "Lakeview" 1 came in, the greatest gusher of them all. Drilling was started on January 1, 1909, by Lakeview Oil Company in Midway-Sunset field, about 2 miles north of the Town of Maricopa. The company completely exhausted its finances after drilling the well to a depth of 1,655 feet, and the controlling interest was acquired by Union Oil Company of California. Drilling operations were carried on intermittently until a depth of 2,225 feet was reached.

The well suddenly started flowing about dawn on March 15, 1910, and soon was completely out of control. Estimates of the first 24 hours of oil production varied from 15,000 to 125,000 barrels; and 2 months later the well's production was estimated to be from 68,000 to 90,000 barrels of oil per day. The well continued to flow out of control for 18 months, finally stopping on September 9, 1911, after having produced an estimated 8.2 million barrels of oil. No well comparable to the *Lakeview Gusher* has been drilled in the United States to this day.

By 1910, state production had reached 77.7 million barrels. The years 1910 and 1911 also saw the discovery of three very important fields: Elk Hills, Lost Hills, and South Belridge, all in Kern County. However, because the United States Government withdrew the Elk Hills land to form Naval Petroleum Reserve No. 1, the field was not produced until 1919.

Kern Front oil field, Kern County, discovered in 1914.

Signal Hill, a part of the Long Beach oil field, was a prolific oil producer. The Long Beach field reached its production peak of 68 million barrels in only 2 years after discovery.

large field in the southern part of the Salinas Valley, and oil was found in 1949 in the Cuyama Valley at Russell Ranch field. In 1950, even with fewer discoveries, California oil production increased to an unprecedented total of 331 million barrels.

No large onshore fields were found between 1950 and 1960. Discoveries were limited to small fields and to the development of extensions or deeper zones in existing fields. However, during this decade, the first persistent exploration of offshore lands was undertaken, and two large oil fields were found: Summerland Offshore (where onshore drilling began in 1896) in 1957, and Conception Offshore, discovered in 1958 – both in Santa Barbara County. Total 1960 state oil production was 305.3 million barrels. More oil was produced in California between 1950 and 1960 than in any other decade.

Although less oil was produced between 1960 and 1970 than in the prior decade, a new high in yearly oil production was reached in the 1960's. During the peak year—1968—a total of 375.4 million barrels of oil was produced, an average of more than one million barrels per day. By December 1980, annual state oil production was down to 357 million barrels, although California ranked as the fourth largest oil-producing state in the United States.

From 1960 to 1970, the only large oil discoveries were offshore fields, both in Santa Barbara County. Carpinteria Offshore oil field, lying in both federal waters and state tidelands, was discovered in 1966; and Dos Cuadras, in federal waters, was found in 1968.

A blowout in the federally-regulated Dos Cuadras field occurred in January 1969, during the drilling of the field's fifth well. This historic blowout caused a large spill, resulting in an outcry against offshore drilling. Shortly thereafter, the state placed a moratorium on offshore drilling on lands under state control until tighter and better controls could be instigated.

Between 1970 and 1980, onshore oil production never again reached the 1968, peak-year production level. In 1974, Yowlumne oil field was discovered in Kern County and by 1979 was the 9th largest producer in the state. By 1980, although no longer on the list of the 10 largest oil producers, Yowlumne field was the 3rd largest California producer of associated (oil zone) natural gas.

The Arab oil embargo of 1973 led to the federal government opening Elk Hills oil field (Naval Petroleum Reserve No. 1) to full development and production in 1976. By 1977, Elk Hills field had jumped to second place in the amount of oil produced from a California field. By 1979 (and again in 1980), Elk Hills production had moved to first place for both oil and associated gas production.

During the 1970's, other fields moved up the ranks of the leading California oil producers. The refinement of steam-injection techniques, the expansion of steam-injection projects and oil price increases led to record amounts of heavy-oil production. One barrel of crude oil from Kern River field, which sold for $2.15 in 1970, sold for $24.30 in 1980.

GAS

A water well was drilled in the City of Stockton (San Joaquin County) between 1854 and 1858 to a depth of 1,002 feet, and natural gas was produced with the water. The gas was burned at the Stockton courthouse for many years, even before Drake drilled his Pennsylvania oil well.

Many other water wells drilled in San Joaquin County produced gas as well; however, little use was made of the gas until 1885 when Standard Gaslight and Fuel Company was incorporated to develop natural gas in the San Joaquin Valley. In 1886, the California Well Company was organized in Stockton for the same purpose.

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STATE MINING BUREAU
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LOS ANGELES OFFICE

CALIFORNIA STATE MINING BUREAU

Department of Petroleum and Gas

Notice of Intention to Drill New Well

This notice must be given before drilling begins

Long Beach Cal. Mar. 23 1921

Mr. M. H. Soyster

Deputy State Oil and Gas Supervisor

Los Angeles, Calif Cal.

DEAR SIR:

In compliance with Section 17, Chapter 718, Statutes of 1915, notice is hereby given that it is our intention to commence the work of drilling well number 1 Section 29 T. 4 R. 12 W, SBM B. & M., Signal Hill Oil Field, Los Angeles County.

The well is 31 feet N. ~~or S.~~, and 32 feet E. ~~or W.~~ from S.W. Cor Alamitos Land Co Farm Lot 6 Cor. Hill & Temple Sts.
(Give location in distance from section corners or other corners of legal subdivision)

The elevation of the derrick floor above sea level is 228 feet.

We propose to use the following strings of casing either cementing or landing them as here indicated:

Size of Casing, Inches	Weight, Lbs. Per Foot	New or Second Hand	Depth	Landed or Cemented
20" S.P.	70#	new	200'	landed
10"	45#	new	±3000'	cemented

It is understood that if changes in this plan become necessary we are to notify you if possible before cementing or landing the casing.

We estimate that productive oil or gas formation should be encountered at a depth of about 3500' feet, more or less.

Respectfully yours,

Shell Co. of California
(Name of Company or Operator)

By J. W. Paulsen Jr.

Reference to file of data:

Maps	Model	Cross Section	Cards	Forms 114	Forms 121

Address notice to Deputy State Oil and Gas Supervisor in charge of district where well is located

Early division record for "Alamitos" 1, the discovery well of the famous Long Beach oil field at Signal Hill.

STATE MINING BUREAU
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AUG 10 1921
LOS ANGELES OFFICE

Form 103. 6415 10-20 10M

CALIFORNIA STATE MINING BUREAU

HISTORY OF OIL OR GAS WELL

Field LOS ANGELES Company SHELL COMPANY OF CALIFORNIA

Township 4 *Range* 11-W *Section* 29 *Number of well* 1 Alamitos

Signed SHELL COMPANY OF CALIFORNIA (President, Secretary or Agent)

Date Title Agent

It is of the greatest importance to have a complete history of the well. Please state in detail the dates of redrilling, together with the reasons for the work and its results. If there were any changes made in the casing, state fully, and if any casing was "sidetracked" or left in the well, give its size and location. If the well has been dynamited, give date, size, position, and number of shots. If plugs or bridges were put in to test for water, state kind of material used, position, and results of pumping or bailing.

Spudded in March 23, 1921.
Drilled 23" rotary hole 0- 380', 15" hole 380-2765'
Landed 70# DBX. at 380' in Blue Clay -March 28
Bridged back from 2765' to 2725'.
Landed and cemented 10" 45# new DBX. casing at 2724' - 10", with 150 sacks Special Riverside Portland Oil Well cement, by Perkin's method.
Final pressure 400#, May 6, 1921.
Stood 17 days.
Bailed to 1500' for casing test and found O.K. Drilled 2' pocket to 2727' and bailed water level to 1050'. Stood 13 hours with 50' OIL and no water entering hole.
W.S.O. passed by Deputy State Oil & Gas Supervisor May 24, 1921.
Drilled with Cable Tools from 2725' to 3114' and landed 8¼" 32# DBX. at 3114' on June 23rd. with 385' of Shop Perferated on bottom, 5 rows, 3/8" holes, 10" centers staggered.

The following formation cores were taken from:

2086 - 2087 Fine Gray Sandy Shale
2369 - 2370 Shale with streaks sand
2517 - 2518 Clay, streaks sand.
2738 - 2742 Sand, streaks of Clay - OIL.
2764 - 2765 Sand, streaks Clay - OIL
3083 - 3083' - 6", Sand - OIL
3105 - 3105' - 6" Sand - OIL

Well started flowing June 25th. through 8¼" casing.
Tubed with 3" at 2236' on July 12th. with 6" Bell Nipple on bottom.

The *History of Oil or Gas Well* for the discovery well of Long Beach oil field was received in August 1921. NOTE: *Spudded in* is oilfield jargon for the time drilling began. Notations such as *70# DBX* refer to a type and weight of well casing (pipe). *W.S.O.* stands for Water Shutoff Test. *Shop Perforated* means the casing through the oil zone was perforated when it was manufactured, rather than after it was placed in the well.

In 1887, the City of Stockton granted the California Well Company the right to lay pipelines throughout the city and distribute natural gas; thus, Stockton became the first California city to be supplied with natural gas. However, the first utility company with an adequate supply of natural gas was the Santa Maria Gas Company, which began service to its customers in 1907.During this era,the importance of natural gas was realized.

In 1910, the City of Bakersfield in Kern County was supplied with natural gas delivered through a pipeline laid from the Midway-Sunset oil field, 40 miles away. In 1913, another pipeline from the same source was laid to supply the Los Angeles area. By 1915, gas from local fields was available in the Los Angeles area, and, by 1927, most of the communities in Southern California had gas service. The San Francisco Bay region was supplied with gas through a pipeline laid from Kettleman Hills oil field in 1929.

Most of the gas originated as *associated gas* (gas produced with oil). However, some *nonassociated gas* (gas produced from gas fields) reached the market as early as 1910, the year after the first gas zone in the state was found in the Buena Vista Hills Area of Midway-Sunset field (now called Buena Vista field).

During the 1920's, the supply of natural gas in Southern California greatly exceeded the demand. Many large oil fields were discovered in the Los Angeles area during the decade, and the large quantity of gas that accompanied the prolific oil production from these fields caused a great gas surplus. This gas was blown to air and wasted, and, as gas pressure declined in the reservoirs, oil production was lost as well. In response to the situation, conservation laws were enacted in 1929 prohibiting the waste of natural gas. The California Division of Oil and Gas was mandated to enforce these laws and, over the years, has obtained several injunctions to reduce gas wastage.

The first important nonassociated gas zone found outside an oil field was discovered in 1926 near Buttonwillow, in Kern County. Gas was not in great demand at that time, thus the discovery did not stimulate new activity. The first intensive effort to find nonassociated gas accumulations occurred in the last half of the 1930's. In 1936, McDonald Island Gas field in San Joaquin County and Rio Vista Gas field (the largest in the state) in Sacramento, Solano, and Contra Costa Counties were discovered. These large fields are near the San Francisco Bay area, where additional gas was sorely needed. With these discoveries, enthusiasm to find additional gas fields increased.

Gas exploration increased appreciably during the 1940's, and assumed even greater proportions in the 1950's. In the 1950's, more than 30 gas fields were found, most of them in the Sacramento Valley. Also, Gaviota Offshore, the first gas field found in offshore waters, was found in Santa Barbara County.

The search for gas continued throughout the 1970's, and 44 gas fields were found from 1970 to 1980. As in the 1950's, most of the new fields were in the Sacramento Valley. With the exception of the decade of the 1930's, the 1960's were the most successful years in finding nonassociated gas reserves in the state.

Prior to the 1940's, there was a gas surplus in California. Since that time, the situation has changed to one of inadequate supply because of the tremendous growth in population and industry. Thus, California must import gas every year. Since 1947, when gas was first brought into California through pipelines from Texas and New Mexico, more gas has been needed. By the end of 1980, about 82 percent of the gas used in California was from sources outside of the state.

Although fields in Texas and New Mexico remain major California suppliers, large amounts are shipped from fields in Oklahoma, Kansas, Utah, and Colorado. Since late 1961, large quantities of gas have been transported through pipelines from fields in Canada.

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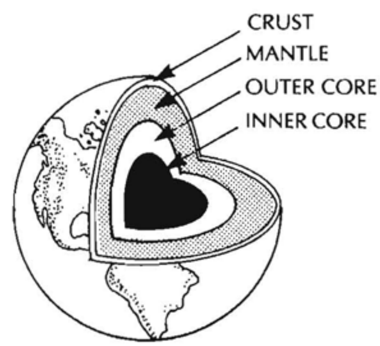
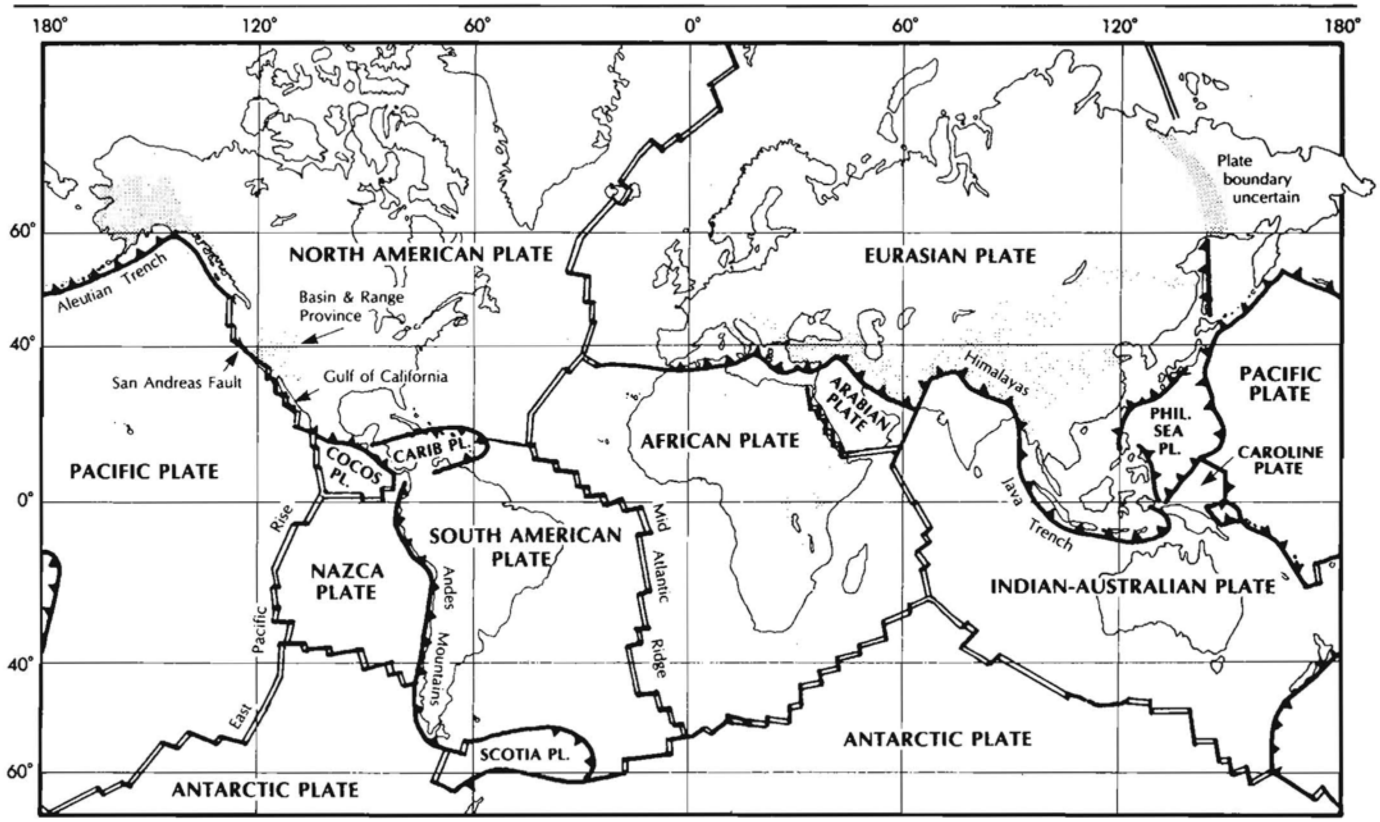
CHAPTER 3
OIL AND GAS ORIGIN AND ACCUMULATION

THE EARTH'S CRUST



The outer zone of the earth, known as the crust, is naturally the part of the earth we know best. Most of what we have learned about the earth has been from the study of crustal materials. It is in the shallower depths of the crust (from the surface to about 30,000 feet) where oil, gas, and geothermal resources have been found.

The earth's crust is composed of many large and small plates, all moving relative to each other at rates sometimes approaching 7 inches per year. The plates pull apart here, slip past one another there, slide one



Lithosphere (or crustal) plates of the world, showing boundaries that are presently active. *Double line:* zone of spreading, from which plates are moving apart. *Line with bars:* zone of underthrusting (subduction), where one plate is sliding beneath another (barbs on overriding plate). *Single line:* strike-slip fault, along which plates are sliding past one another. *Stippled area:* part of a continent, exclusive of that along a plate boundary, which is undergoing active extensional, compressional, or strike-slip faulting. Compiled and adapted from many sources; much simplified in complex areas. *Reprinted with permission from California Geology, October 1978.*

beneath another somewhere else, and, in other places, collide slowly, building spectacular mountain ranges. There are seven very large plates and a dozen or more smaller plates (not all illustrated). The movement of these plates is called *continental drift.*

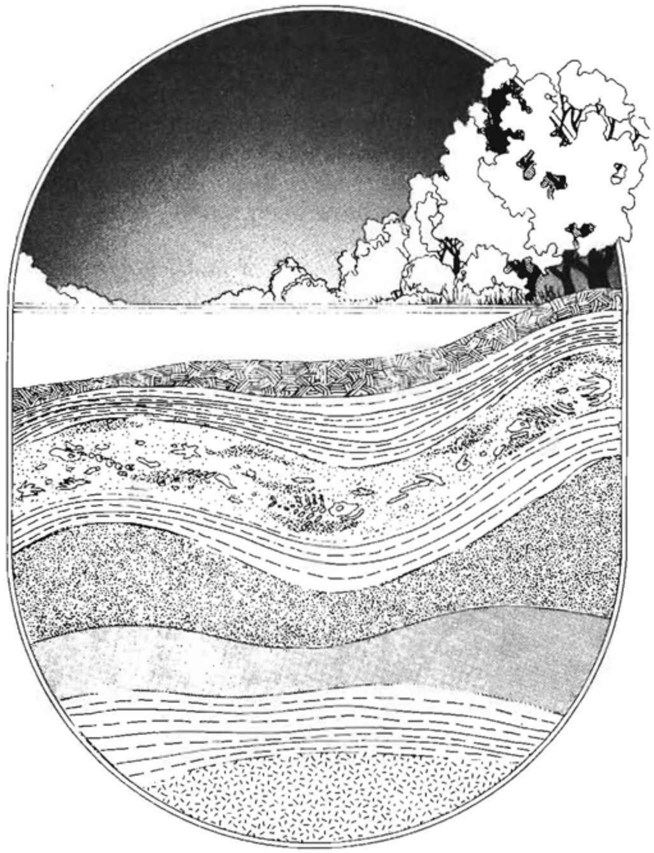
Changes in the earth's surface occur so slowly that they are scarcely noticeable during the lifetime of an individual. However, over hundreds of millions of years, the geologic record shows that the processes of uplift and erosion have been repeated again and again in many areas.

People think in five generations—two ahead, two behind—with heavy concentration on the one in the middle. Possibly that is tragic, and possibly there is no choice. The human mind may not have evolved enough to be able to comprehend deep time. It may only be able to measure it. **From Basin and Range by John McPhee.**

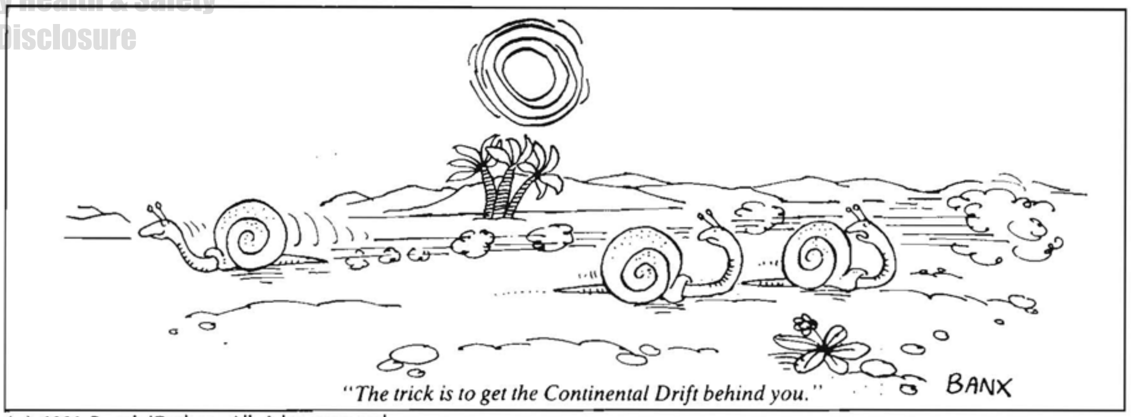
Most of North America has been submerged beneath the waters of ancient seas—not all at once, but parts at one

Most California oil comes from the decay of dead organic matter laid down in the relatively recent Miocene epoch. Such oil is less desirable than older oils because it contains 1) a great deal of hydrogen sulfide gas that must be removed during refining, and 2) a high carbon-to-hydrogen ratio, making it heavier and more viscous than older oils, thus more difficult to produce, transport, and refine.

Plant and animal remains are deposited in aquatic, depositional basins where they decay and are covered with sediments. Especially important in the formation of California's oil have been the deposits of diatoms, which are microscopic, single-celled, silica-secreting plants. Enormous numbers of diatoms lived in California marine and lake waters. Beds of diatomaceous shale up to 7,000 feet thick are in the upper Miocene - lower Pliocene Coast Ranges. (Enlarged drawings are of diatoms and of single-celled animals called foraminifera.)



With the passage of millions of years, the dead organic matter is buried under successive sedimentary layers and subjected to increased heat, pressure, and tectonic forces. The strata are often folded and faulted.



"The trick is to get the Continental Drift behind you."

Eventually, some of the sediments are converted into minute oil droplets. These droplets usually migrate out of their beds of origin and through other rocks. The droplets are stopped (trapped) somewhere by an impervious cap rock.

time and parts at another. For example, the area now occupied by the Rocky Mountains was once an ancient sea floor, as were sections of California. Today, it seems strange to find sea shells and other fossilized marine organisms on high mountain tops, buried in clays, silts, and sands.

WHAT ARE OIL AND GAS?

Oil and natural gas are naturally occurring mixtures of predominately hydrogen and carbon compounds. In its primary state in the earth, oil often contains a large volume of gas. The gas may have been formed at the same time as the oil, or at a later date from chemical changes in the oil. However, natural gas can be formed from sources other than those from which oil is derived, such as peat deposits or coal fields. Thus, gas deposits are often found by themselves, unassociated with oil.

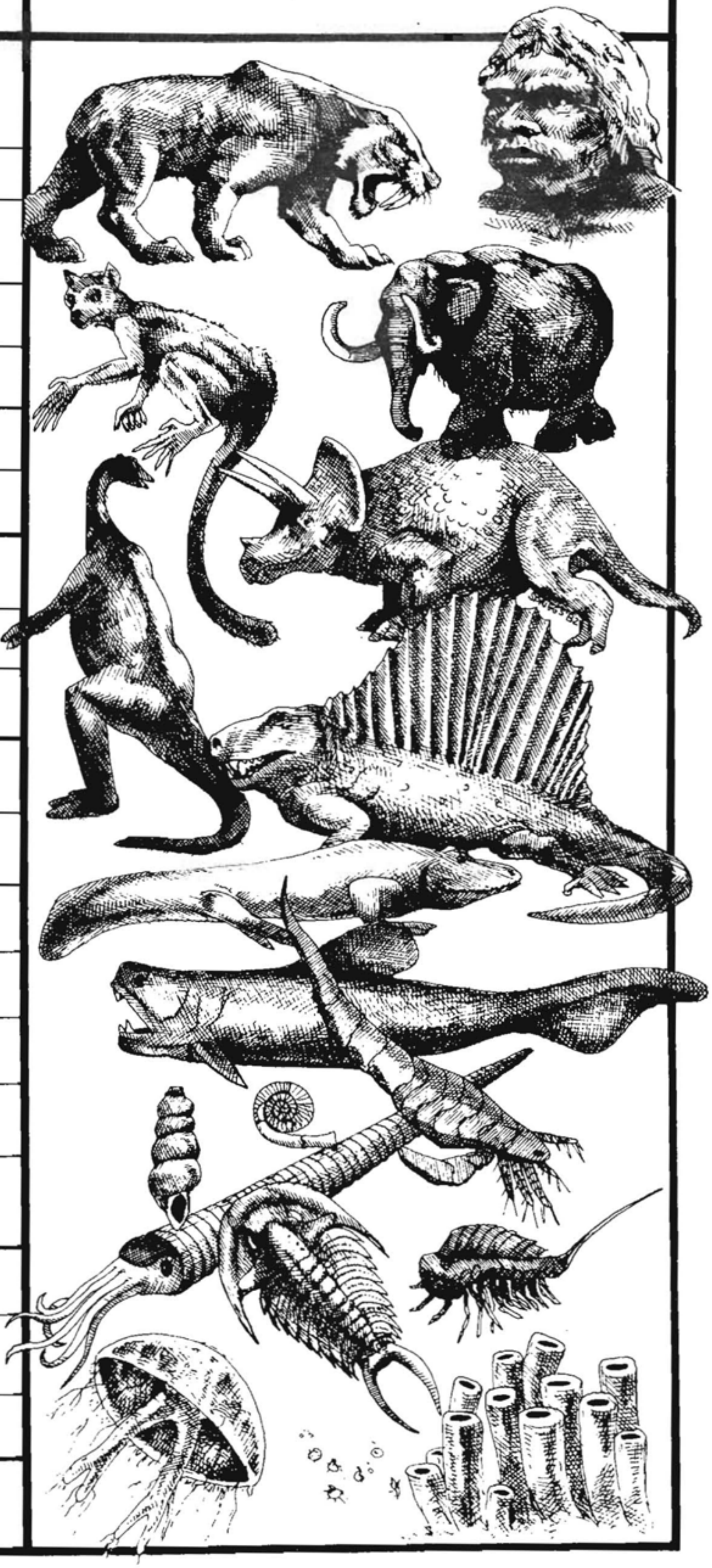
Heavy Oil

Heavy oil, not as desirable as lighter oil, has been described as crude oil with a consistency similar to cold molasses. About 32- to 42-billion barrels of the state's crude oil-in-place is considered to be heavy oil. Clearly, heavy oil is the most important petroleum resource in the state. (Federal offshore areas are excluded from this estimate.)

Heavy oil is very viscous, with an API (American Petroleum Institute) gravity ranging from 10° to 20°. The high

Light oil, photo left, with an API (American Petroleum Institute) gravity of 25°. Heavy oil, photo right,—Kern River crude oil with an API gravity of 12.6°. Ultraheavy oils, with an API gravity of 10° or less, are even more viscous.

ERAS	PERIODS, EPOCHS	MILLIONS OF YEARS AGO	LIFE ON THE EARTH
CENOZOIC	Quaternary Holocene		
		0.01	
	Pleistocene		
		1.8	
	Tertiary Pliocene		
		5.0	
	Miocene		
		22.5	
	Oligocene		
		37.5	
	Eocene		
		53.5	
	Paleocene		
		65	
MESOZOIC	Cretaceous		
		136	
	Jurassic		
		190-195	
	Triassic		
		225	
PALEOZOIC	Permian		
		280	
	Pennsylvanian		
		320	
	Mississippian		
		345	
	Devonian		
		395	
	Silurian		
		430-440	
	Ordovician		
		500	
	Cambrian		
		570	
PRECAMBRIAN	Proterozoic z		
		800	
	Proterozoic y		
		1600	
	Proterozoic x		
		2500	
Crust of the earth solidified about 4 billion years ago			
		4500	



viscosity of heavy oil causes major production and handling problems, such as getting the oil to flow from the formation into wells, pumping the oil from wells, treating the oil, and shipping the oil. In addition, without special refinery equipment, heavy oil (as opposed to lighter, less viscous oil) yields a higher percentage of less-valuable refinery products, such as residual fuel oil and asphalt.

Because of these problems, interest in heavy oil production was limited in the years when petroleum prices were low. At that time, heavy oil was generally left in the ground. However, after 1973, when economic and world oil-supply conditions changed, heavy oil production became more profitable. Today, increasing importance is placed on extracting the large domestic reserves of heavy crude oil.

For further information, *see* division publication TR28, *Heavy Oil in California,* by William F. Guerard, Jr.

Ultraheavy Oil, Tar Sands, and Diatomaceous Oil Shale

With oil price deregulation and world market escalation in the late 1970's, interest has increased in the development of what are commonly called California's unconventional petroleum resources. In California, unconventional petroleum resources include ultraheavy oil, tar sands, and diatomaceous oil shale. Ultraheavy oil and tar sand oil (bitumen) generally refer to deposits of crude oil of less than 10° API gravity.

Currently, diatomaceous oil shale attracts considerable interest in California, especially at McKittrick and South Belridge oil fields. Getty Oil Company has undertaken a pilot, open-pit mining project in the oil-saturated diatomite at McKittrick field. Oil will be extracted from the mined diatomite by both solvent and retort methods in a test to determine which method is more economical. Two pilot plants for the tests were completed in 1981.

According to Getty Oil, about 380 million barrels of oil could be recovered over a 48-year period should either or both of the methods prove economically feasible. Evaluation of both processes should be completed in 1983.

For further information, *see* division publication TR25, *Unconventional Petroleum Resources in California,* by Fred O. Hallmark.

SOURCE OF OIL AND GAS

Marine sediments, such as clay, silt, and sand,* along with the remains of plant and animal life, are deposited in many types of aquatic, depositional basins.** The deposits sometimes reach thousands of feet in thickness and the plant and animal remains, especially those of microscopic one-celled organisms, are thought to be the materials from which oil and gas are made. It is believed that some time after these remains collect in the sediments, parts of them are converted into minute oil droplets. The exact process by which the organic material becomes oil is not known, but bacteria, heat, and pressure are all believed to play important parts.

* Clay, silt, and sand are erosional particles defined by grain size. Of the three, clay grains are the smallest and sand grains the largest.

**A sedimentary basin is most likely to become an oil source basin if the sediments are marine, present in great volume, varied, and are not significantly altered (metamorphosed) by heat and pressure.

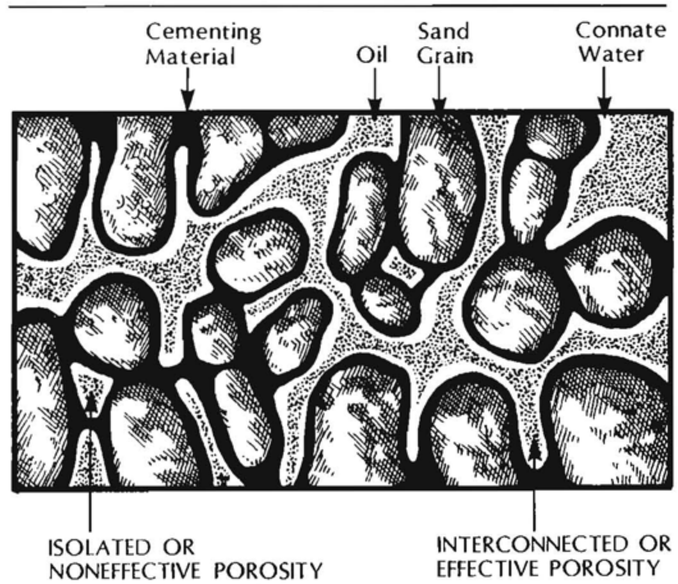
MIGRATION AND ACCUMULATION

Heat and compaction caused by the increased overlying weight gradually harden the deeply buried layers of sediments. The clays and silts become shale in this process, and the sand becomes sandstone. Sedimentary layers are called beds or strata, and shales and sandstones are types of sedimentary rocks.

Depending upon composition and degree of bedding, there may be many gradations of shale, such as sandy shales, or silty shales, or claystones, all of which may be grouped under the general heading of shale. Sands and sandstones also may show many gradations: there may be shaly sands or silty sands, or sands so cemented by mineral deposits between the grains that the sandstones are as hard as concrete.

Any rock with internal open spaces is porous and said to have porosity. Shales and sandstones are composed of grains of materials pressed together, but with open spaces between them. In sandstone, these pore spaces are most often occupied by water, but sometimes contain oil or gas.

In sandstone, pore spaces may account for as much as 30 percent or more of the total volume, while in other types



Enlarged view of sand grains in sandstone. Only interconnected pores or *effective porosity* is of real significance in commercial oil and gas recovery operations. It is through the interconnected pores that fluids move in a reservoir rock.

of sedimentary rocks, the pore spaces may equal only a small percentage of the total volume.

Permeability is defined as the ease with which fluid can move through the interconnected pore spaces of a rock. In a sandstone, the pore spaces may be interconnected so that liquid or gas is free to move from one pore space to another in any direction. The pore spaces in shale between the clay and silt grains are not interconnected; therefore, the fluid in the rock is trapped inside individual pore spaces and cannot move. When shale is a reservoir rock, the oil and gas are contained in fractures and in films along bedding planes.

The compaction of organic muds causes some of the fluid present—either oil droplets that may have been formed in the muds, or water—to be squeezed into the sands where more pore spaces are available. Undoubtedly, other forces also play a part in moving the oil droplets from the muds into the sands, but compaction is considered the most important factor.

Migration is the movement of oil droplets through pore spaces. How oil droplets migrate with accumulations is not fully known, but migration may occur through the following combination of forces and actions:

1. *Gravity.* Oil, lighter than water, will rise through water until an obstruction is encountered, prohibiting additional upward progress. Oil may move a considerable distance laterally at the same time it is moving upward.
2. *Water currents.* Movement of the water through sands may push oil along for considerable distances.
3. *Crustal movements.* Beds bending and folding undoubtedly play an important part in the migration of oil. Tilting strata that have been lying relatively flat accelerate the separation of oil and water, concentrating the oil in the highest accessible place.

Oil pools are formed when the proper combination of conditions are present. Oil and gas migrate until they reach a trap past which they cannot move. At this point, they accumulate, forming an oil or gas reservoir. Three basic conditions must be met for the creation of an oil or gas reservoir. There must be:

1. *Source beds* containing material from which oil can be formed;
2. *A bed of porous rock* to serve as a reservoir rock;
3. *A trap* to confine the oil to the reservoir.

OIL AND GAS TRAPS

When forces within the earth raise or compress segments of the earth's crust, they may uplift them only a small amount—perhaps by a few feet—or high enough to form large mountains. At the same time the segments of the earth's crust are upraised, they may be folded, buckled, or faulted. Thus, the beds of sandstone and shale once comprising a flat sea floor may be formed into upfolds, called anticlines, or numerous other structures that can serve to trap oil or gas.

Anticlines

Of the many types of structural features present in the upper layers of the earth's crust that can trap oil, the most important is the anticline—the type of structure from which the greater part of the world's oil has been produced.

Anticlines are upfolds of beds in the earth's crust, and, when the proper conditions are present, oil accumulates within the closure of these folds. Anticlinal structures account for many of the largest oil fields in California, such as Long Beach, Wilmington, Ventura, Elk Hills, and Kettleman Hills. Many smaller fields have an anticlinal structure, as well.

Faults

A fault is a break resulting in a displacement in the earth's crust. Often, movement along a fault places an impermeable bed opposite a sandstone bed, sealing off the sandstone bed. At other times, the *gouge* in the fault zone forms a seal. (Gouge is the broken, crushed material formed by the movement of the rocks against one another along a fault). In such instances, oil may travel up a sandstone bed until it reaches the fault and then can go no farther. In this way, faults often provide an updip seal for inclined sandstone beds, and form what are known as fault traps.

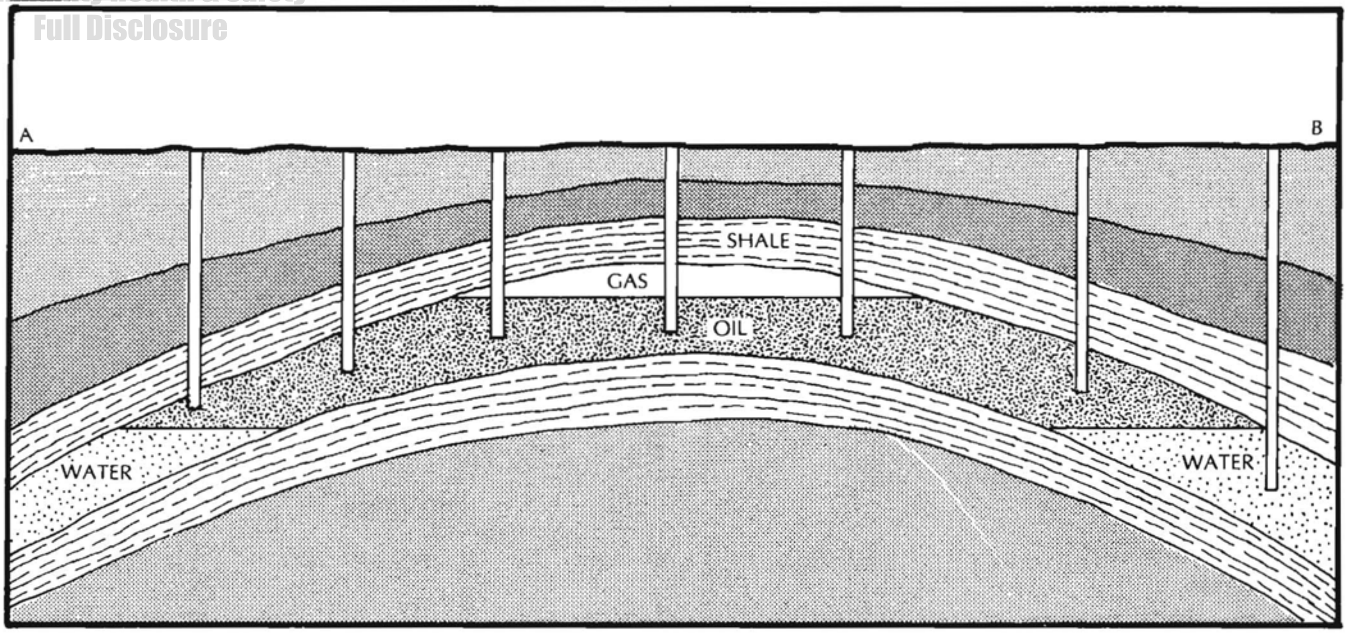
Stratigraphic

Sediments are deposited under so many different conditions that sedimentary beds vary greatly in thickness, texture, and pore space. Such variations often result in beds that are suitable for trapping oil. In instances where this occurs, the beds are said to form stratigraphic traps.

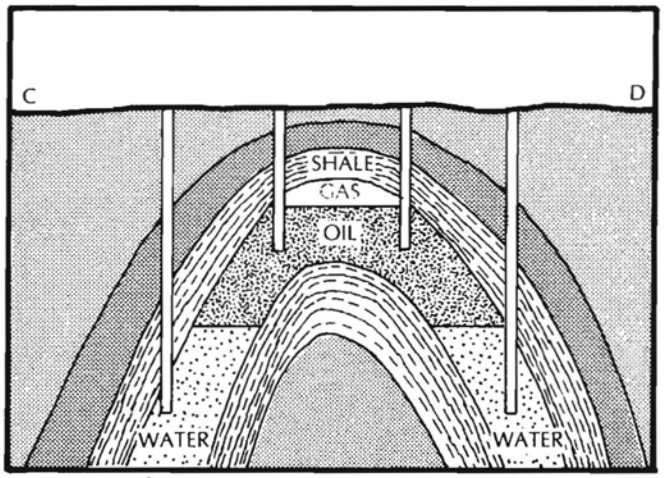
For example, an inclined sand bed that was laid down as a beach or near-shore deposit may *pinch out* updip between converging shale beds. The sandstone bed provides a suitable oil reservoir. A number of oil pools in the southern San Joaquin Valley occur in reservoirs formed in this manner.

A variation of this type of trap occurs when sand is deposited as a lens surrounded by clay. Some of the oil sands in South Mountain oil field, Ventura County, are lenses of this type.

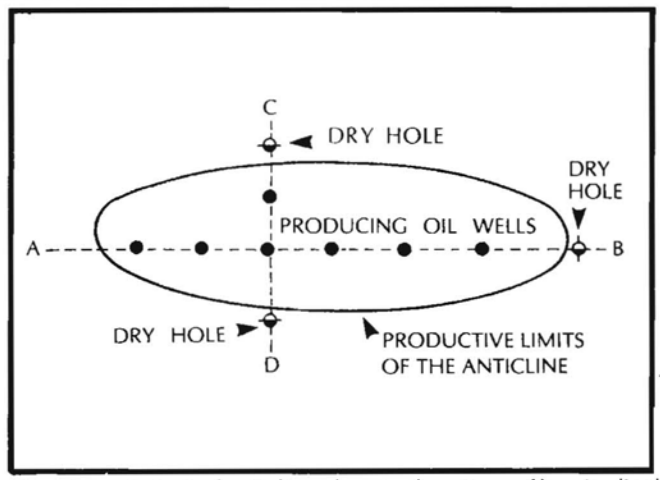
Changes in sedimentation may cause part of a sandstone bed to become very silty or tightly cemented, sealing the connected pore spaces and thereby reducing the permeability in that part of the bed. Oil may be trapped by the



Longitudinal view of a typical anticline. The oil cannot escape upward because of the impervious shale bed above the oil sand; neither can it travel downward because of the water that is associated with an accumulation of this type.



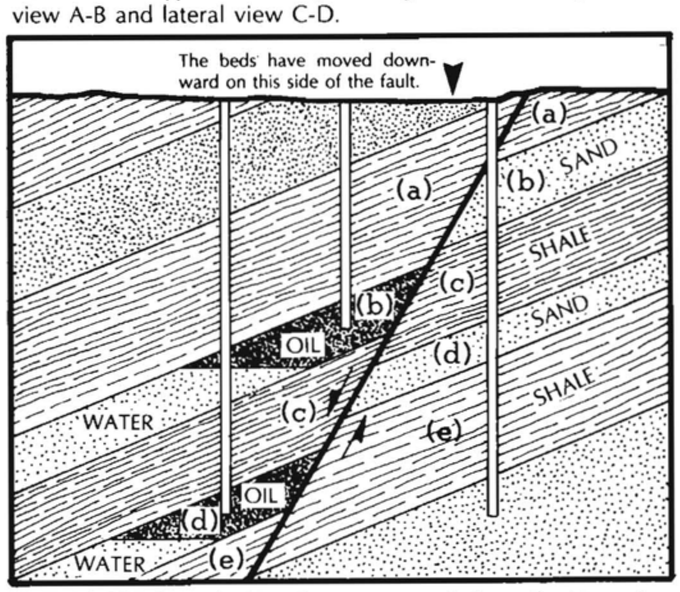
Lateral, or end view, of a typical anticline.



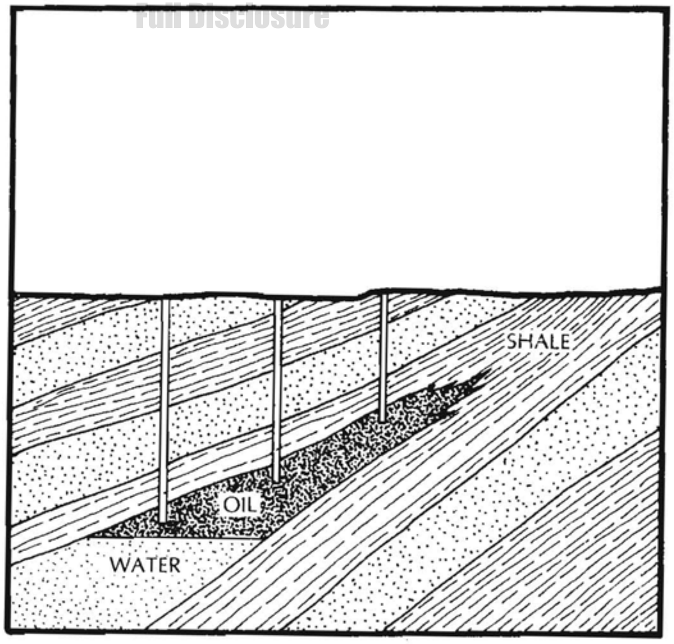
Plan view of a typical anticline, showing locations of longitudinal view A-B and lateral view C-D.

impermeable part of an inclined bed and prevented from migrating farther updip. This type of stratigraphic seal is often referred to as a *permeability barrier.* As an example, certain oil pools in the Midway- Sunset field, Kern County, occur in reservoirs with this type of seal.

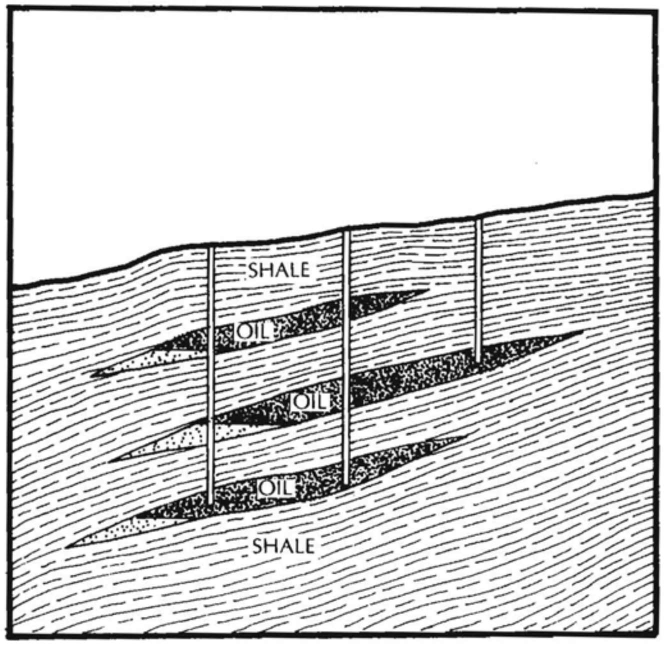
Many California oil fields consist of several individual oil pools. For example, Midway-Sunset oil field in Kern County is comprised of a large number of oil accumulations collected in each type of trap described.



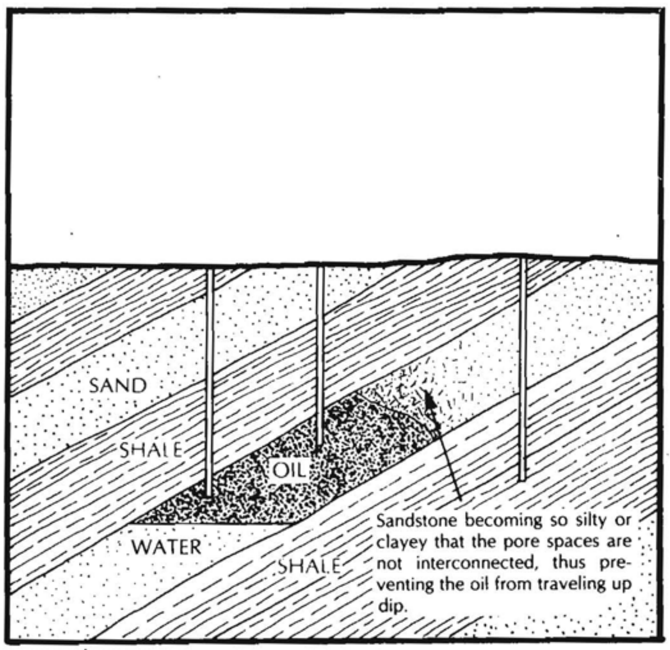
An oil field where faulting has entrapped the oil. Note the impervious beds now opposite the oil zones.



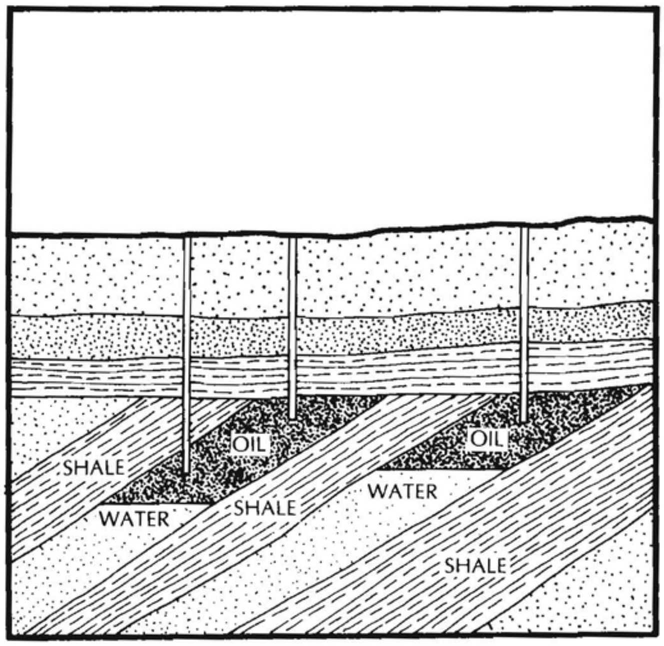
An example of a stratigraphic trap where the oil zone *pinches out.*



A stratigraphic trap where *sand lenses* are interspersed in a shale bed. The shale acts as a permeability barrier.



A stratigraphic trap where *changes in sedimentation* act as a permeability barrier.



An *angular unconformity* as an oil trap. The flat-lying shale bed above the oil zones acts as a permeability barrier.

OIL AND GAS PROVINCES IN CALIFORNIA

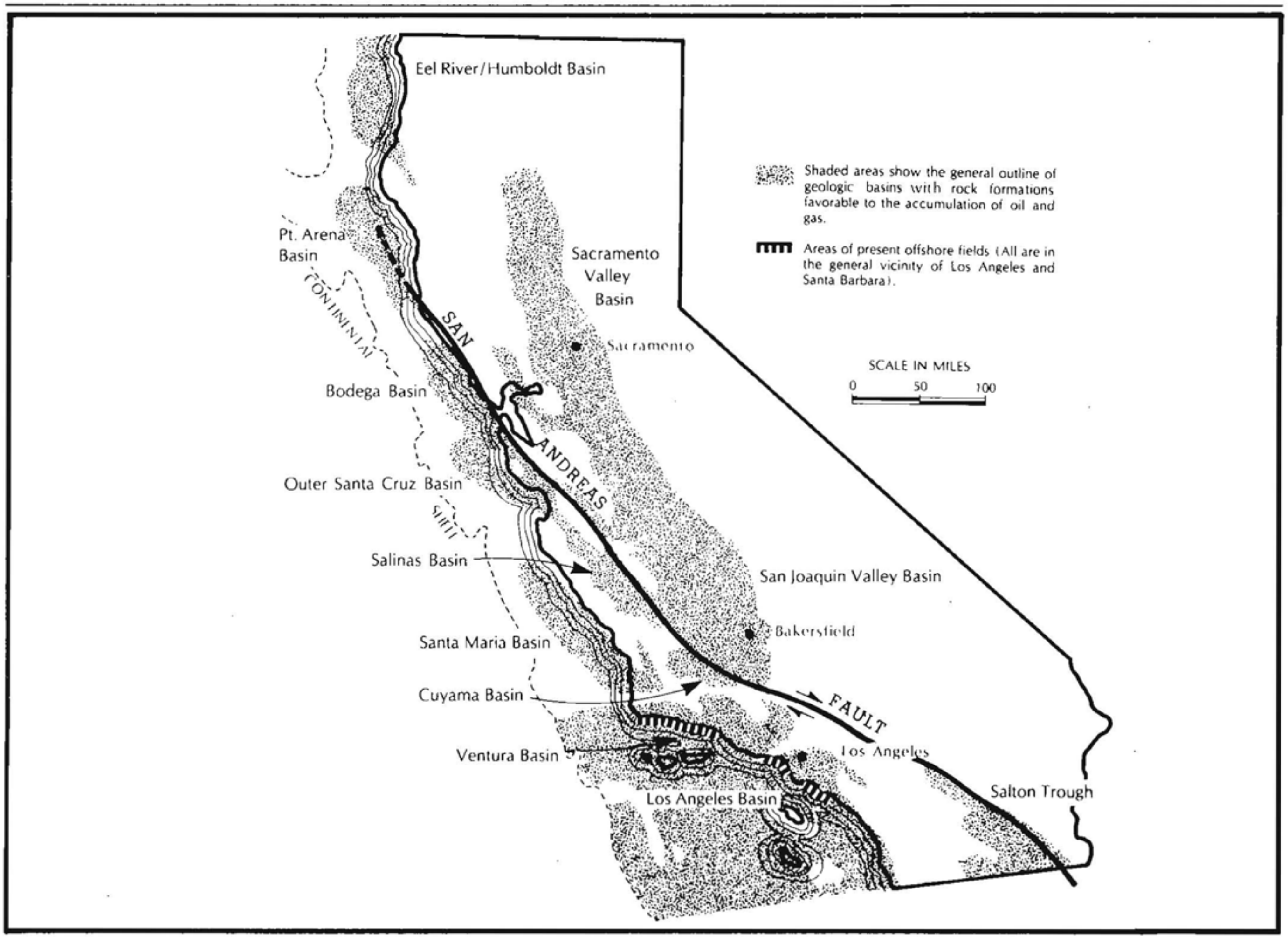
In California, oil and gas are found in the parts of the state that, for the last 100 million years or so, have been alternately dry land and shallow sea bottoms. These areas constitute only a small part of the state's total acreage, thus limiting the areas in which oil and gas may be found.

The areas of the state with ancient marine sedimentary basins are outlined below. Many of these old sea basins extend beneath present-day oceanic waters and, of course, are the areas in which offshore oil fields are situated. Large parts of the potentially productive offshore areas have not been completely explored.

In relation to its size, the most prolific oil province in the state, and probably the world, is the relatively small, Los Angeles Basin. It is also the area of the state where the greatest number of people choose to live. With such a large population, the surface value of the land has increased, resulting in a conflict with oil and gas operations.

These factors may preclude the recovery of all of the oil and gas that would otherwise be extracted from this petroleum-rich basin.

Thus, a California paradox: the greatly expanding population—which creates the need for ever-increasing amounts of oil and gas—becomes a major constraint to oil and gas exploration and production.



California sedimentary basins, onshore and offshore.

CHAPTER 4
OIL AND GAS EXPLORATION METHODS

Early-day prospecting was based on natural oil seeps. Since very little was known about petroleum deposits, surface evidence of oil was the only indication early prospectors had that oil and gas might be present underground.

As more wells were drilled, more facts about petroleum geology were learned. However, even now, no direct means is known for detecting accumulations of oil. Therefore, the modern oil geologist searches not only for a petroleum environment, itself, but also for structures in which oil may be trapped. The search occurs in the sedimentary deposits of ancient seas or in adjacent beds. Geologists combine subsurface and surface geological data to develop a theory of probable hydrocarbon accumulations. From these data, locations for exploratory drilling are chosen. Of the many exploratory methods used, the following are the most common.

SURFACE GEOLOGY

The oldest scientific method of exploration is one that infers what lies below from what is seen at the surface. The exact positions of beds exposed at the surface are plotted on maps. The ages, compositions, and any other pertinent information concerning the beds, together with any *fossils** present, are noted on the map. Aerial or satellite photographs of the region under investigation may be used to aid in selecting contacts between different beds and other physical features. The geologist uses all data to interpret the probable subsurface structural features.

A vast amount of oil has been found with surface geological exploration. However, the accuracy of the method depends upon the extent to which the beds are exposed at the surface.

In areas where the beds are not exposed, or are only partially exposed, surface geological studies are of minor value. In such cases, after securing all information possible from the surface features, the geologist must turn to subsurface geological studies, or to geophysical methods, or to a combination of both to learn further details about subsurface structures.

SUBSURFACE GEOLOGY

Subsurface geological studies are carried on continuously by most oil companies to find new fields and develop fields already discovered. The studies depend upon information obtained from wells drilled in the vicinity. Therefore, in areas where only part or none of the beds are exposed at the surface, and where few, if any, wells have been drilled, a number of carefully spaced holes may be cored, usually at selected intervals, to depths of several thousand feet.

Core Drilling

When a hole is drilled with a type of bit that retrieves a sample of the penetrated beds, the hole is said to have been cored, and the sample is called a core. This practice is followed not only in the special type of well known as a core hole, but sometimes while drilling oil and gas wells.

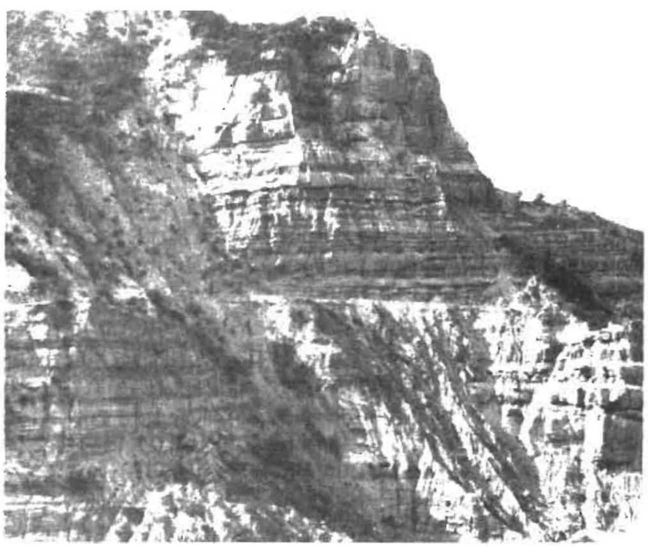
Core holes drilled for structural information only are often cored to a predetermined point, such as to a definite bed known to be present in the area. The depth at which this *key* or *marker* bed is found will be plotted on a map. (Also, an electrical device will be run in the core hole to obtain an electric log of the strata to further aid in the correlation.) Any consistent bed or marker that appears in most of the wells may be used as a key bed correlation point. By correlating these key beds, or strata, in the different wells, the geologist develops theories of subsurface structural conditions.

Electric Logs

A special electrical instrument can be lowered into a well to measure electrical characteristics, such as resistivity

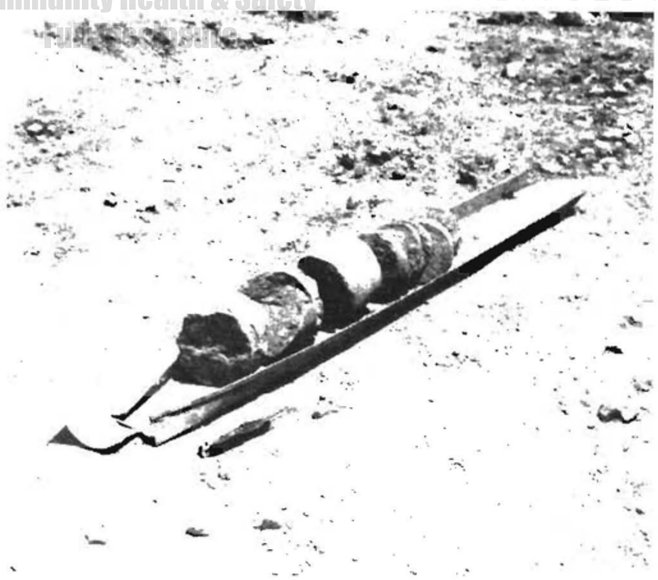
* Fossils are ancient plant or animal traces or remains preserved in the earth's crust.

Tools of a field exploration crew from left to right: a geodetic gravity meter, cords and geophones for seismic surveying equipment, a geologist's pick, core samples, a pocket transit (a compass commonly used by geologists), aerial photos (in the case), a topographic map, and surveying equipment.



Exposed strata help the geologist to interpret geology.

This well core was obtained with a diamond core-drilling bit. The core provides a sample of the subsurface rock strata for the geologist to test and examine. Notice the porosity in the rocks.

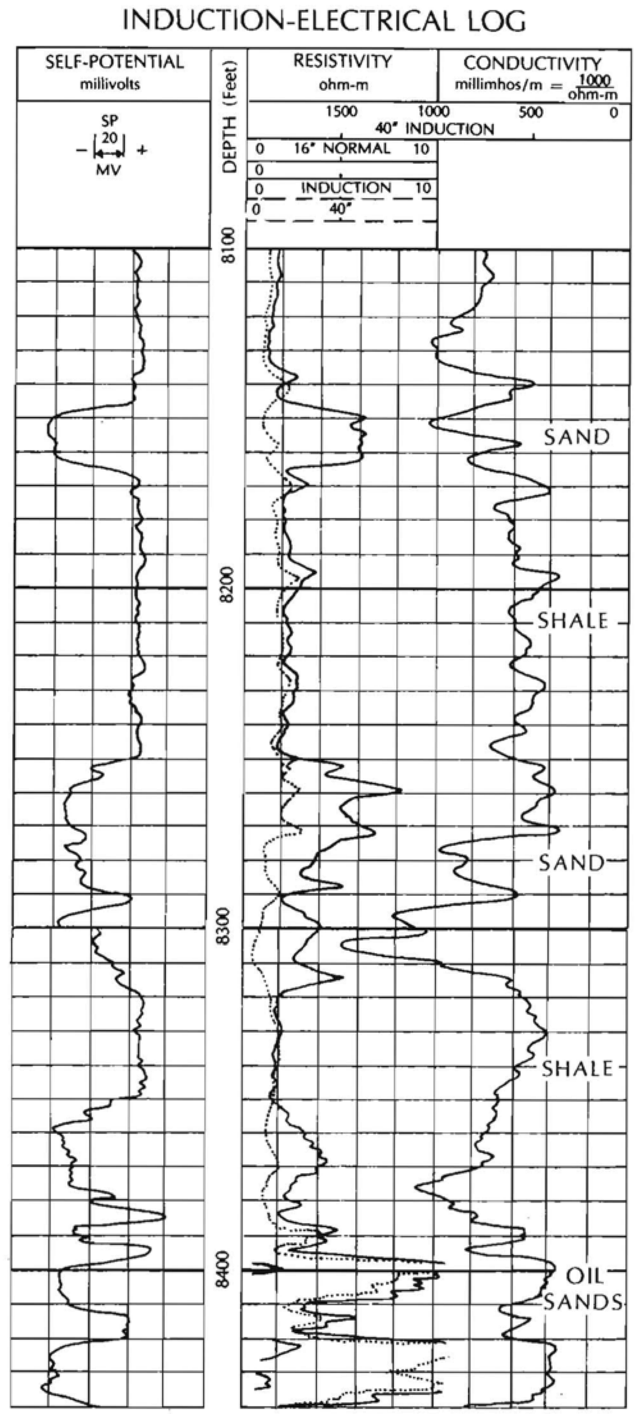


Sometimes the cored rock strata are broken along natural bedding planes when they are removed from the core barrel, as this example shows.

and spontaneous potential, of downhole strata. This important geologic tool, developed in the early 1930's, is used to create an electric well log. The log data are recorded with depth markings corresponding to the well depths where the readings were taken. The electric log helps geologists identify potentially productive sands. Usually, each bed has a unique profile on the electric log, enabling the different strata to be correlated in an area. Again, as with data received in core drilling, the correlation of marker beds is of great assistance in determining subsurface structural features.

Another important use of the electric log is to identify the fluid content of strata penetrated by the well, to learn which contain oil and which contain water. The use of the electric log is critical, especially in the parts of wells where no cores are taken. As a result, upon the discovery of a new field, the productive interval usually is cored in the discovery well and in the first few wells. For subsequent wells, the electric log is used to differentiate between oil-bearing strata and water-bearing strata.

Although other valuable data are secured from an electric log, strata correlation and fluid content identification are its most important uses. Other logs, such as sonic and radioactivity logs, may be used to determine other formation properties.

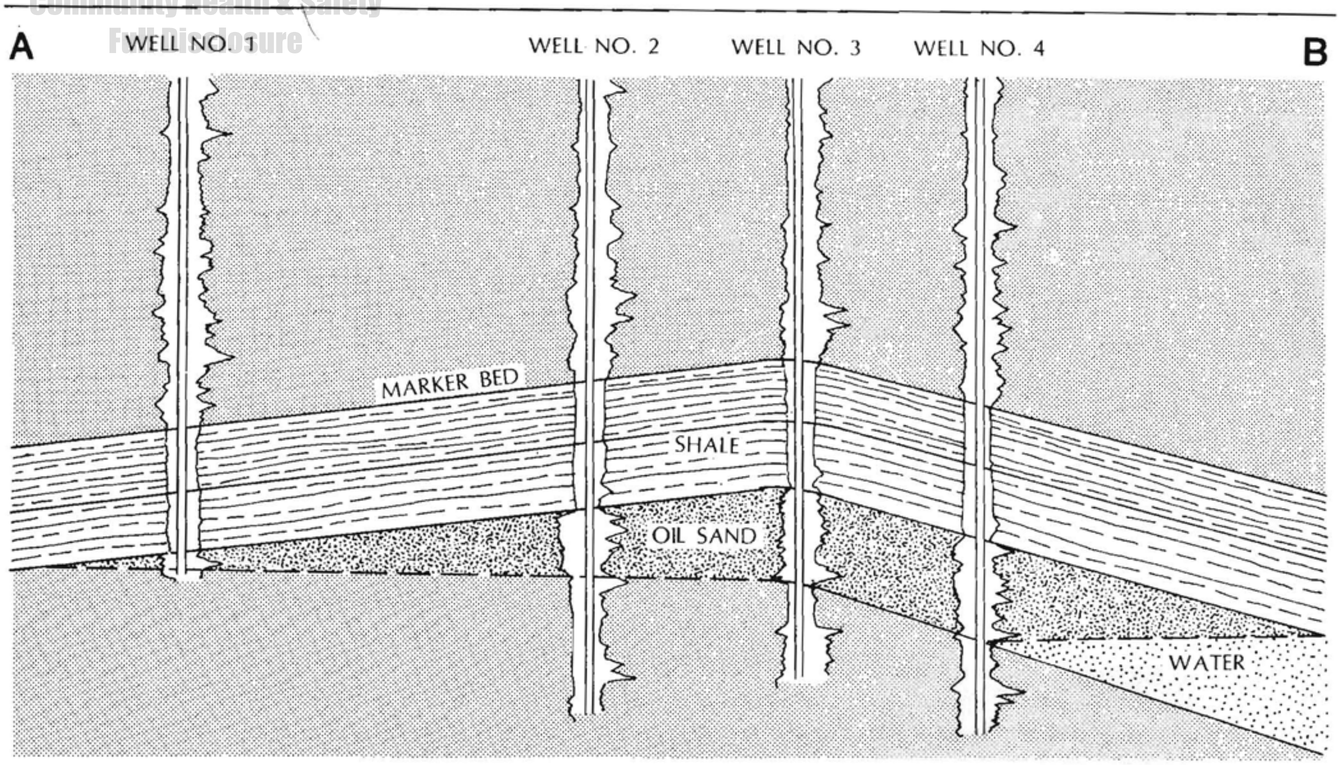


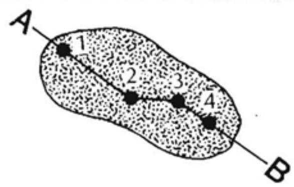
An electric well log, used to determine rock and fluid types. The shales and sandstones measured by this log are from 8,100 feet to 8,440 feet deep.

Fossils

In both surface and subsurface geologic studies, the identification of fossils, especially microfossils, is very important. Usually, the geologic ages of strata can be determined by knowing which fossils are present.

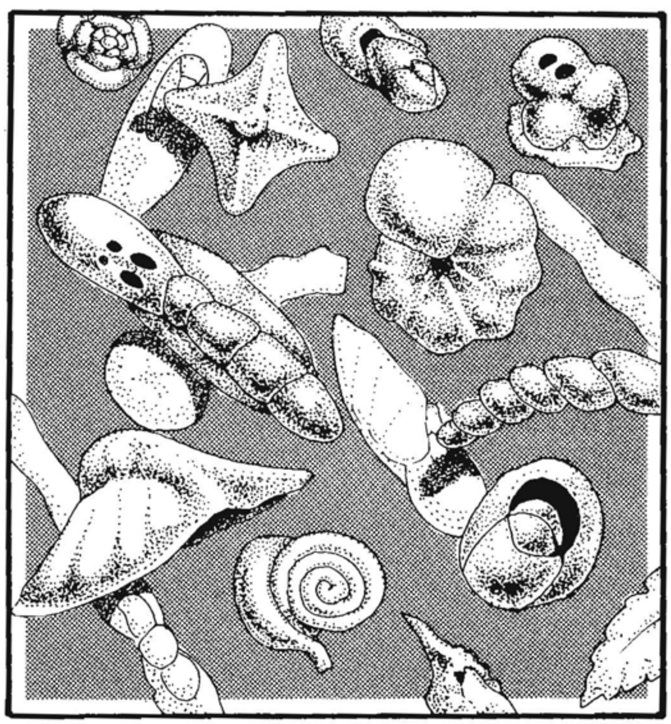
For geologic correlation purposes, foraminifera are the most important and most widely used of these fossils. Foraminifera are microscopic, single-celled animals that develop a shell (most forms are visible only with the aid of a microscope). When the animals die, their shells are buried in the sediments. There are many species, each with a characteristic shell. Some species lived only in certain geologic times. Thus, when certain shells, or assemblages of shells are found, the geologic age of the formation is known, and correlation is possible. Very often, correlation of beds penetrated by different wells





A simplified cross section showing how electric logs are used to correlate subsurface strata. The electric logs for each well are drawn first, then the common strata are identified. The small, plan view (right) indicates where the wells were drilled. A geologist must learn to think three-dimensionally and imagine the shapes of underground strata.

Trucks such as this contain logging equipment used to run electric logs, or other logs, on oil, gas, and geothermal wells.

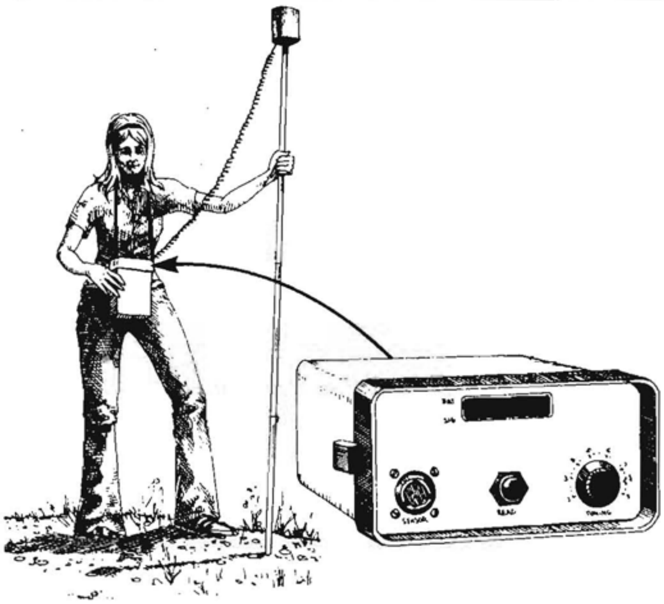


Enlarged microscopic foraminifera fossils.

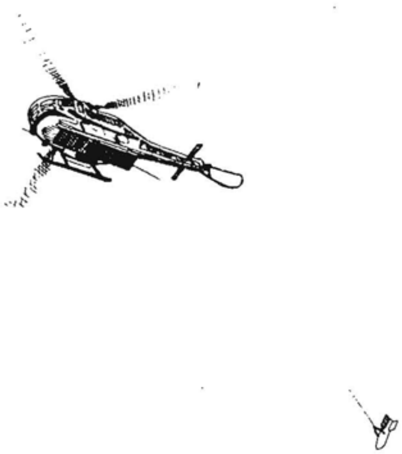
is possible only because of the identification of foraminifera shells in the strata.

Magnetometer

A magnetometer is a geophysical tool used to measure the magnetic intensity of the earth immediately beneath the magnetometer itself. Magnetic methods are most useful in reflecting basement-rock features that may control the overlying sedimentary structure. Magnetometers have been used for many years in the petroleum industry as reconnaissance exploration tools, and have been a valuable aid in finding many oil fields in the Mid-Continental section of the United States.



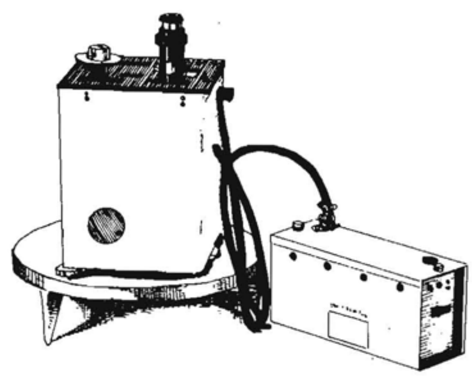
A magnetometer is used to measure the magnetic field of the earth. The proton-precession magnetometer consists of a magnetic sensor (on top of pole) that is connected by cables to an electronic console.



Magnetic measurements can be made on land, at sea, or in the air. On a ship or aircraft, the magnetic sensor must be removed as far as possible from interference caused by iron or steel objects or electrical currents. Thus, on a ship, the sensor is usually towed several hundred feet behind the vessel. On an aircraft, the sensor either is placed in a rigid extension from the wingtip or tail, or is towed 100 feet to 150 feet below the aircraft.

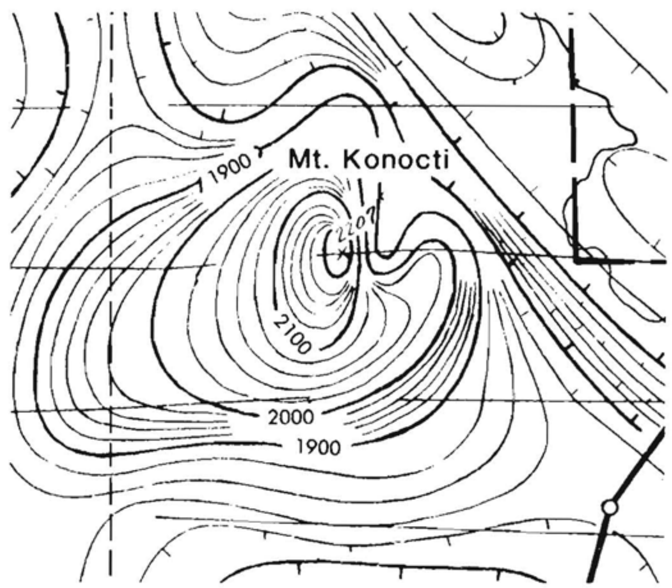
Gravity

Gravity surveys are a widely used reconnaissance geophysical method of petroleum exploration. In a gravity survey, a gravity meter measures the gravitational pull of rocks up to several miles below the earth's surface. Any



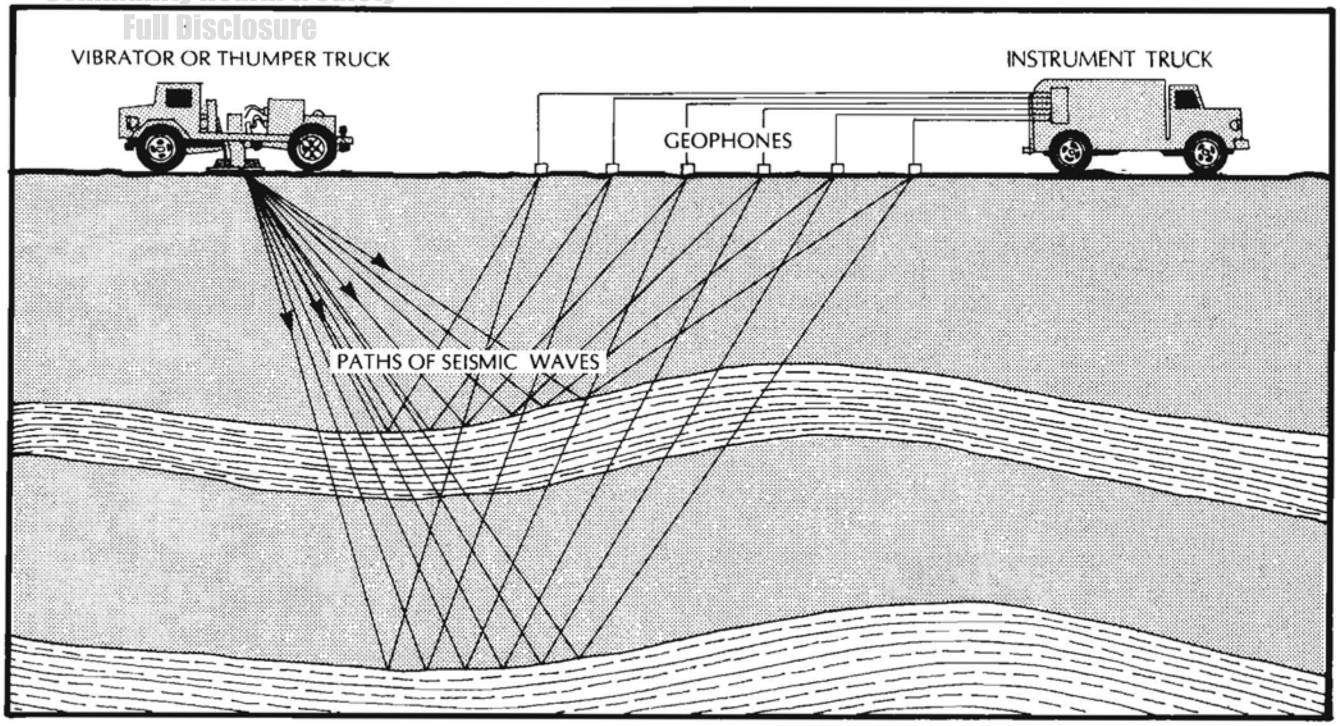
A geodetic gravity meter (on the left) measures the force of the earth's gravity. This force varies from place to place, in part because of changes in geology. Thus, gravitational differences between sites are used to help determine the natures of subsurface structures.

A cable connects the meter to a battery that provides temperature compensation.



Portion of an aerial magnetic survey of The Geysers Geothermal field in Northern California. Contours that are close together or show closures indicate areas with unusual magnetism.

Geophysical caption information by Rodger H. Chapman, California Division of Mines and Geology.



To learn the nature of subsurface strata, a vibrating mechanism such as a thumper truck is used to create shock waves. The shock waves are reflected by subsurface strata and picked up at the surface by geophones. The geophones carry the reflected shock wave signals to a nearby receiver in the van, where a seismogram is produced. By studying the seismogram, interpretations of the subsurface strata can be made.

up-arching of rock material means a gravitational force different from that of the surrounding sediments will be measured and evaluated as a possible oil or gas reservoir.

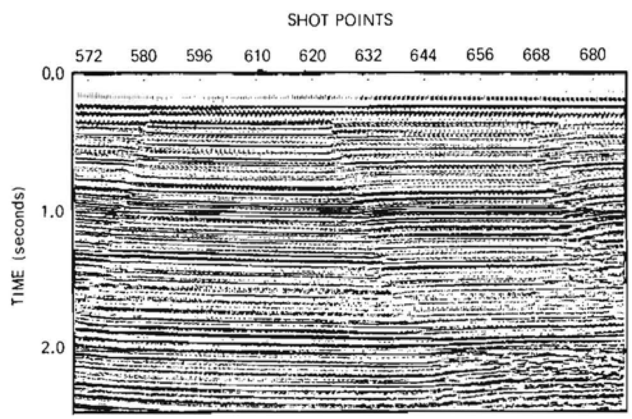
Gravity surveys are more valuable exploration tools in the Mid-Continental area of the United States than on the West Coast.

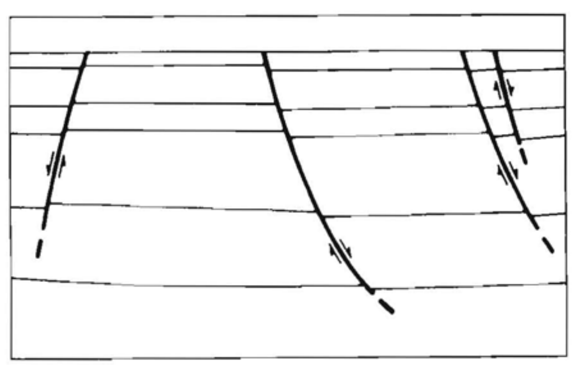
Reflection Seismic Technique

Reflection seismographic exploration has been a most successful geophysical exploration tool. It is used to obtain a subsurface structural picture. Many anticlines and other types of structural features containing large oil accumulations have been found with this method where no surface indications of the structure exist.

In the past, explosive charges were used to generate shock waves for seismic exploration. Today, however, explosives have generally been replaced by a newer method of seismic exploration that includes a truck with a heavy metal plate beneath it. When the truck reaches a predetermined location, the plate is lowered to the ground and vibrated. Seismic detectors (geophones), which have been placed on the ground at various points, pick up the shock waves reflected from the different rock beds below, and the information is recorded at an instrument truck.

This procedure is repeated at each location in a predetermined pattern. The depth of a particular rock stratum is determined at each detector station by the length of





Seismogram (above) and a simplified interpretation. By looking carefully at the seismogram, the faults, indicated by the lines, can be seen.

time required for the shock waves to return to the surface. Seismic profiles are made in several directions across the area being investigated. From this record, the depth and dip of the beds can be determined and the type of structure deduced.

Bright Spot Technique

Today, the use of an enhanced seismic survey to indicate *bright spots* often helps to pinpoint hydrocarbon reservoirs. Geophysicists using the bright spot technique study the white bands, or bright spots, on seismograms. (Many such bands appear on the sample seismogram in this chapter.) The bands indicate abnormal velocity changes in the reflected sound waves. The bright spots may indicate porous rocks with hydrocarbon accumulations. However, mistakes can occur with exclusive use of the bright spot technique, because not all bright spots represent areas with hydrocarbons, and not all areas with hydrocarbons show up as bright spots.

DRILLING COSTS AND RISKS

Costs

Oil or gas exploration and development is expensive. A considerable sum of money is spent on geological and geophysical work even before drilling operations are begun. If geological and geophysical interpretations indicate that oil or gas may occur in an area, the oil and gas mineral rights will be leased and the well site prepared. Such predrilling activities usually cost thousands of dollars.

Drilling an oil or gas well costs from several thousand to several million dollars, depending on well depth, location, and problems encountered. For example, in 1981, the average cost in California to drill an onshore oil well was $25,000 a day. A 5,000 foot oil well takes about 30 days to drill *and* complete. Completion includes casing the well, and the installation of production equipment, tanks to hold the oil, and a myriad of other equipment. In general, it costs about the same amount to complete a well to production as to drill it, exclusive of lease equipment.

Offshore oil wells are much more costly to drill than onshore wells. In California, the cost of drilling an offshore exploratory well from the larger movable or fixed drilling platforms is about $50,000 a day. The drilling costs of a relatively shallow exploratory well drilled from a drilling ship are about $100,000 a day. Wells drilled from a jackup rig cost about $70,000 a day. (For further information on offshore wells, *see* Chapter 9.)

In 1981, the average cost of drilling a gas well in the Sacramento Valley was $175,000. (Completion costs are not included in that figure.)

The average cost of drilling a geothermal well at The Geysers Geothermal field was about $1.5 million in 1981, including completion costs. Hard rock strata, high temperatures, directionally drilled wells, special well completion practices, and complex well siting requirements all contribute to the high cost of drilling geothermal wells.

Success Ratio

A well that is drilled in the search for oil or gas outside a known oil or gas field is called a prospect, exploratory, or wildcat well. In California, 410 prospect oil wells were drilled in 1980, and about 33 percent, or 1 in 3, was successful. This was much higher than the national average, which was about one in seven. The 1980 success ratio of prospect wells in finding new gas accumulations in the Sacramento Valley was about 30 percent or 3 in 10.

CHAPTER 5
DRILLING

Wells may be drilled using the cable-tool or rotary method. The cable-tool method depends upon repeatedly dropping a heavy piece of sharpened steel suspended on a cable so that the impact crushes and breaks rock strata. With the rotary method, a drilling bit bores a hole in the earth, much like a carpenter's bit drilling a hole in a piece of wood. In both cases, power machinery and a derrick are used for handling the tools, and pipe. Today, almost all California wells are drilled with the rotary method.

CABLE-TOOL DRILLING

The cable-tool drilling method was used at least 2,000 years ago by the Chinese, who drilled wells for brine from which salt was extracted by evaporation. These wells were reportedly drilled as deep as 3,000 feet. A spring pole was used to lift and drop the bit. The springpole method of cable-tool drilling is still common in the more remote areas of the world.

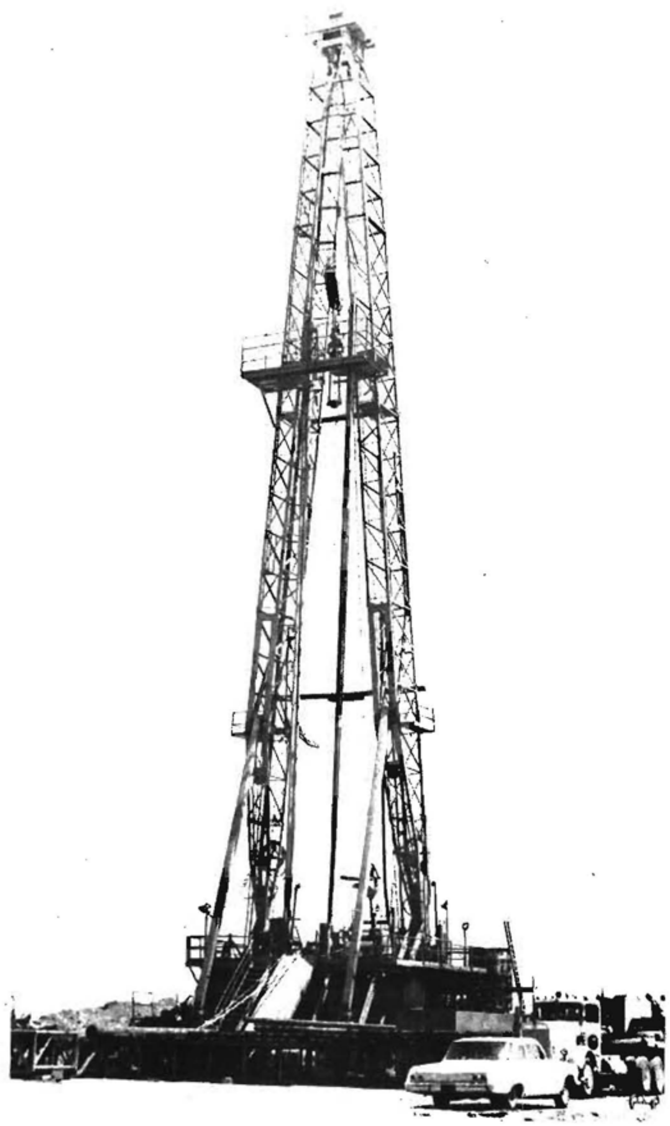
ROTARY DRILLING

Records indicate that the rotary method of drilling came into use some time prior to 1900. The method had many disadvantages in those early years of development and was slow to be accepted. However, as the difficulties were overcome, rotary drilling became more popular. By the early 1920's, the rotary method had largely replaced the cable-tool method.

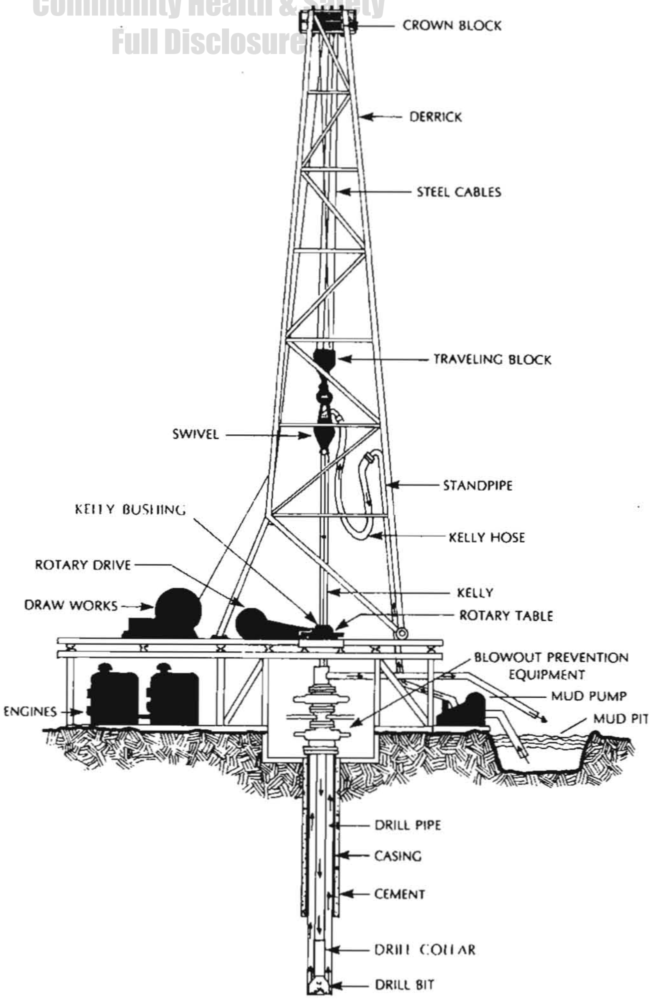
Equipment and Procedures

The rotary method of drilling requires the use of a large amount of expensive equipment, only part of which will be described. The equipment includes a derrick, draw works, crown and traveling blocks, steel cables, mud pumps, rotary table , drill pipe, drill collar, and drilling bit (*see* illustrations).

Before drilling a well, the drill pipe, drill collar, and drilling bit are attached to a square or hexagonal pipe called the



A rotary rig.

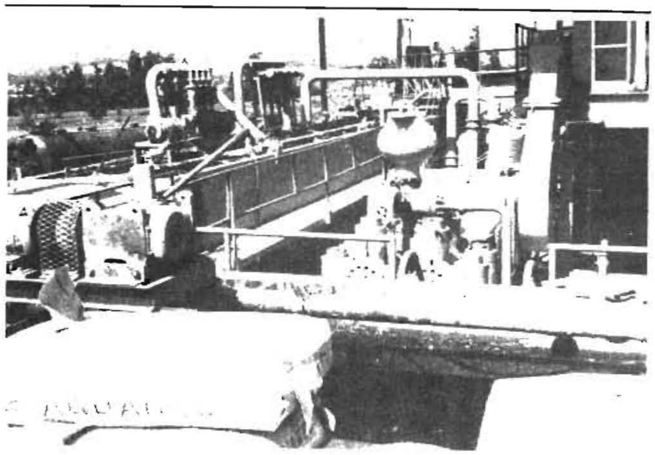


kelly, which passes through the kelly bushing. During drilling, the kelly bushing sits in and is turned by the rotary table. Lengths of drill pipe are added as the hole is deepened.

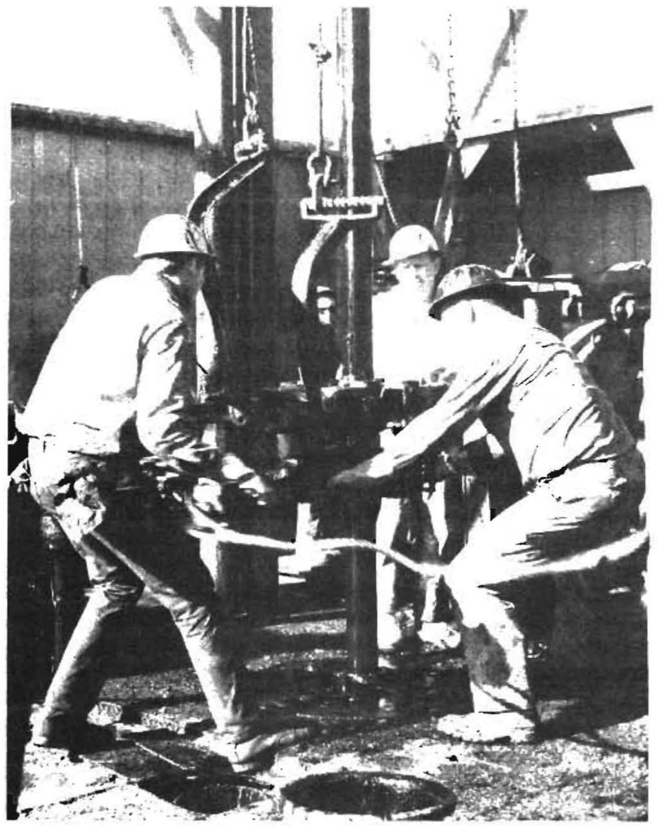
During the drilling operation, drilling mud (generally a mixture of clay and water especially chosen for physical and chemical properties) is pumped down the drill pipe and out through the drilling bit. The mud cools the drilling bit and, after jetting through holes in the bit, picks up the rock cuttings and returns to the surface through the space between the drill pipe and the wall of the hole. Upon reaching the surface, the mud travels through a screen that removes the cuttings and into a mud pit from which it is pumped and circulated back down the drill pipe to pick up more cuttings.

Simultaneously, a mud cake forms on the wall of the hole. The mud cake prevents mud fluid from flowing into porous rock and, together with the weight of the column of mud, prevents the hole from caving in. The weight of the column of drilling mud also prevents high-pressure gas, oil, or salt water from flowing into the hole.

Mud weight is controlled by using special weighting material, such as barite. (Depending upon conditions en-



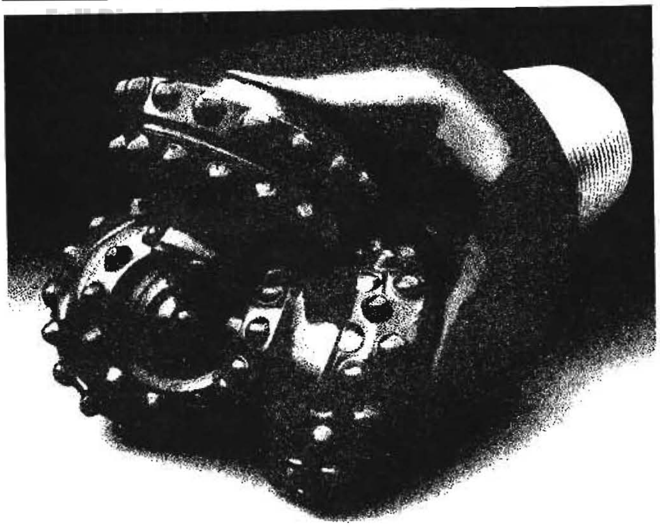
Mud equipment used with a rotary rig. In the foreground are bags of *dry mud* to be placed in *mud mixing tanks,* to the left, as more mud is needed. In the center is the mud pump that forces mud down the drill pipe.



Drilling a well requires a crew capable of good teamwork.

countered while drilling , a mud weight between 65 lb. and 130 lb. per cubic foot is normally maintained). Different chemicals may be added to the mud from time to time to achieve desired mud properties.

Occasionally, in areas where formations do not cave in easily and formation pressures are not very high, air is used as the circulating medium instead of mud. When this is done, several huge air compressors are used to supply the volume of air needed to keep the bit cool and to remove the cuttings from the hole. In California, this



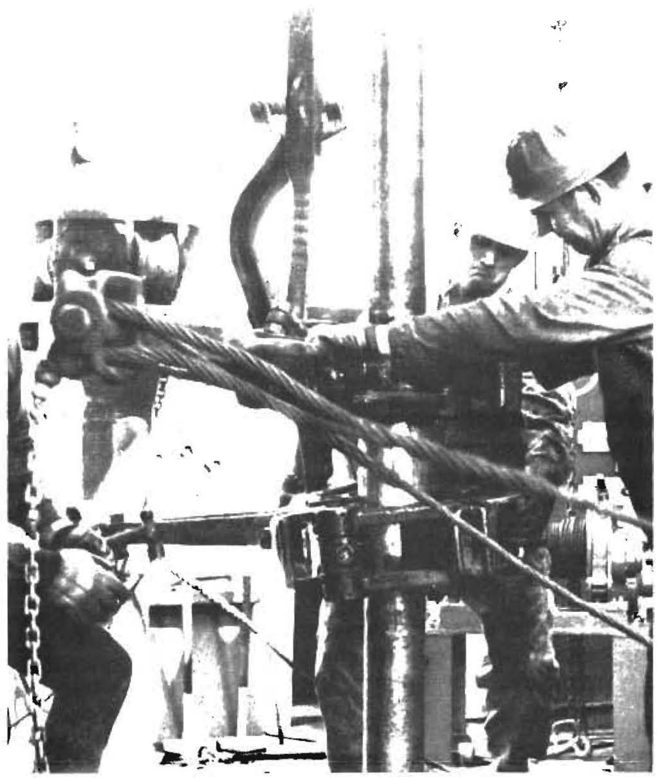
A typical drilling bit used with a rotary rig. The bit is threaded so it can be screwed into a drill collar, which is connected to the drill pipe. Mud enters the well bore after passing down the drill pipe and through the holes between the conical cutters, called jet nozzles.

A drilling crew is preparing to place a *whipstock* in the well to directionally drill a well. (*See* offshore chapter for drawing of a directionally drilled well.)

method is used mainly for drilling geothermal wells in The Geysers Geothermal field.

When a drilling bit becomes dull, all drill pipe must be removed from the hole so the bit can be changed, a process called *tripping.* As drill pipe is tripped, it is stacked vertically against the derrick, usually in lengths of 60 or 90 feet, depending upon the derrick size. Once the bit is replaced, the drill pipe is run back into the hole, and drilling is resumed.

Drilling crew at work. As a drilling bit, turned by powerful engines, grinds down into the earth, the crew adds lengths of steel drill pipe. When the bit gets dull and must be replaced, the pipe is pulled from the hole (as in this photo) and broken down into shorter lengths. When the old bit is brought to the surface and replaced, the pipe is screwed back together as it is run back into the well bore, often over 2 miles deep. This process occurs many times as a well is drilled.



The crew is unscrewing the drill pipe as it is brought out of the hole. The tongs they use are like huge pipe wrenches, operated mechanically with steel cables connected to a part of the drawworks.

Sometimes, it is impossible to install drilling equipment over the desired location. This occurs when the desired bottom-hole site is under a large building, residential property, a river, or when a group of wells must all be drilled from one location. At such times, wells are directionally drilled from an accessible surface location to the underground target. Some wells are directionally drilled with deviations as much as 80 degrees from vertical, and may be bottomed as much as a mile from the surface location.

BLOWOUT PREVENTION

Old-Time Gushers

Many early wells blew out of control because drillers lacked the necessary equipment and drilling mud technology to prevent blowouts. Gushers were looked on as natural indicators of discoveries. Often, such flows could not be stopped until reservoir pressures declined. Thus, not only were great quantities of oil and gas lost at the surface, but much oil was left unrecoverable in the reservoir because much of the reservoir energy was lost.

Modern Wells

Today, the California Division of Oil and Gas requires the installation of blowout prevention equipment on wells during drilling operations to prevent blowouts. Before such equipment can be installed, pipe called surface casing must be cemented in the hole to anchor the equipment. The amount of surface casing used depends upon factors such as expected well pressures, the depth of fresh water, and the competence of the strata in which the well casing will be cemented. Thus, surface casing may be cemented at depths as shallow as 200 feet or as deep as 1,500 feet.

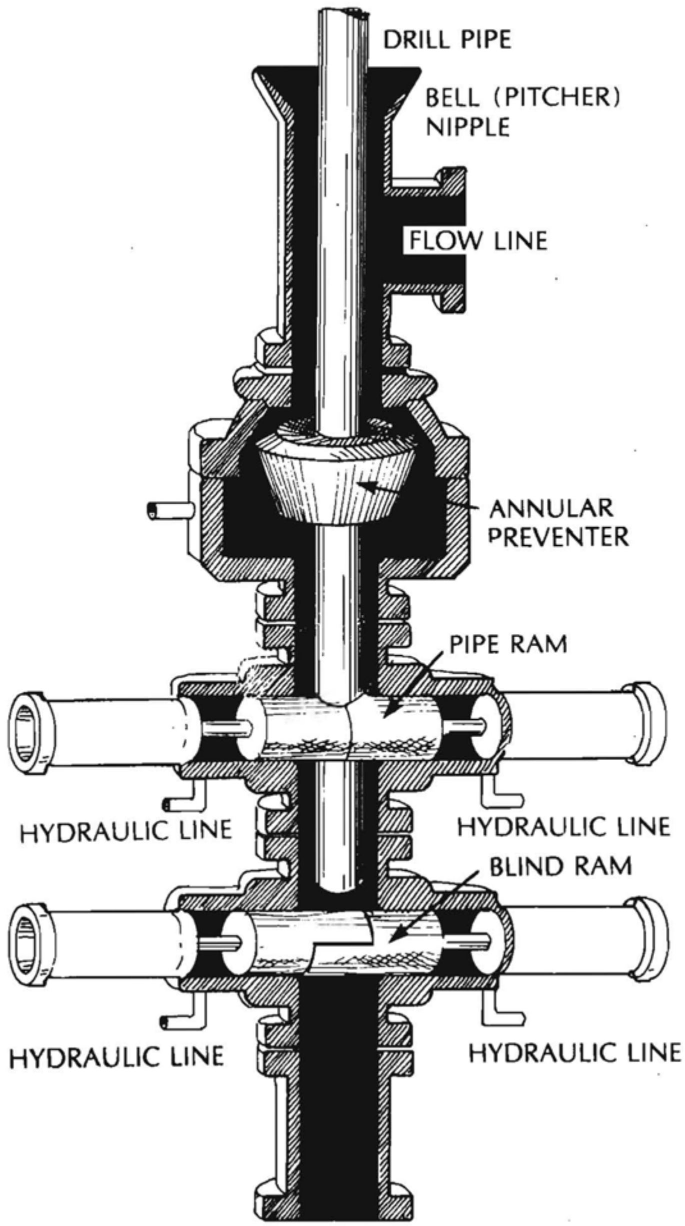
Blowout prevention equipment is bolted to the surface casing. All successive drilling occurs through the blowout prevention equipment, which can be operated to control well pressures at any time.

For exploratory wells or high-pressure development wells, blowout prevention equipment usually consists of two ram-type preventers and an annular preventer. One ram-type preventer will be full closing—for use when the drill pipe is out of the hole—and the second ram-type preventer will fit around the drill pipe so the preventer can be closed when drill pipe is in the hole. The annular preventer can be closed around any object or fully closed when no drill pipe is in the hole.

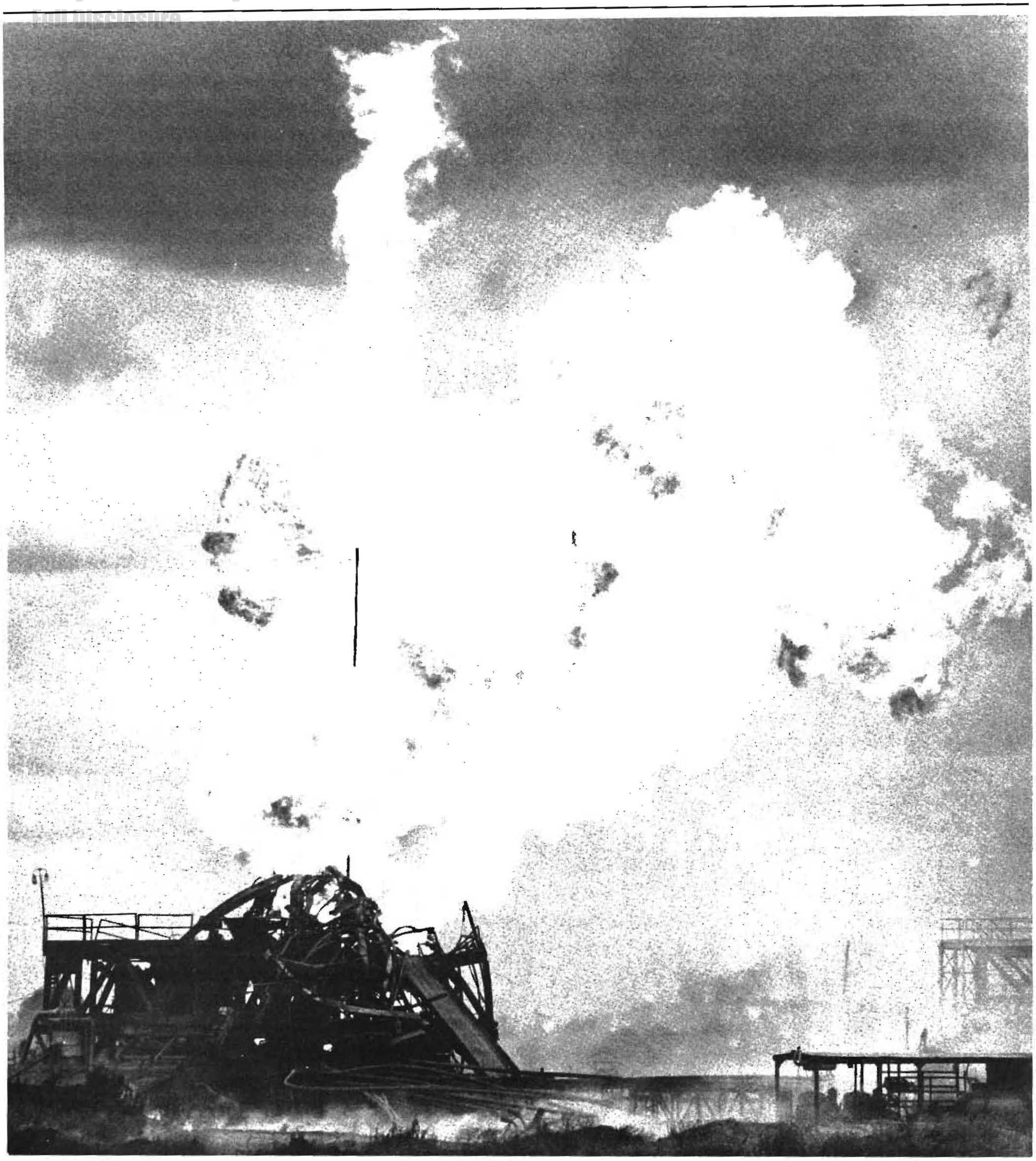
All three preventers are operated hydraulically with the touch of a switch. Division inspectors witness the installation and operation of blowout prevention equipment to ensure operational readiness and integrity. Thus, if a well should start to blow out, the proper preventers can be closed in a matter of seconds.

Today, because of well control practices and excellent blowout prevention equipment, blowouts are rare. Of the 48,961 oil and gas wells drilled in California (excluding federal offshore wells) from 1961 through 1980, only 31 blowouts have occurred. The blowouts were almost always the result of human error, and most were brought under control in a matter of hours.

Further information on blowout prevention procedures is in division publication M07, *Oil and Gas Well Blowout Prevention in California*. A videotape titled *Blowout Prevention Equipment Inspection Procedures of the California Division of Oil and Gas* is also available.



A simplified, cutaway view of a blowout preventer stack. A version of this stack, modified for each well, is placed on oil, gas, and geothermal wells drilled in California.



In May 1974, a well being drilled for gas storage, "Whisky Slough" 14-W, blew out of control, caught fire, and burned for 19 days at McDonald Island Gas storage field. The fire was extinguished and the well brought under control after a relief well was drilled nearby. *Photo courtesy of Pacific Gas and Electric Company.*

CHAPTER 6
WELL COMPLETION AND PRODUCTION METHODS

Before penetrating oil or gas reservoirs, most wells pass through freshwater and saline aquifers. For their mutual protecton, aquifer and reservoir fluids must not be allowed to migrate outside the casing and infiltrate other strata. Such intermingling can destroy aquifer quality and impair well production.

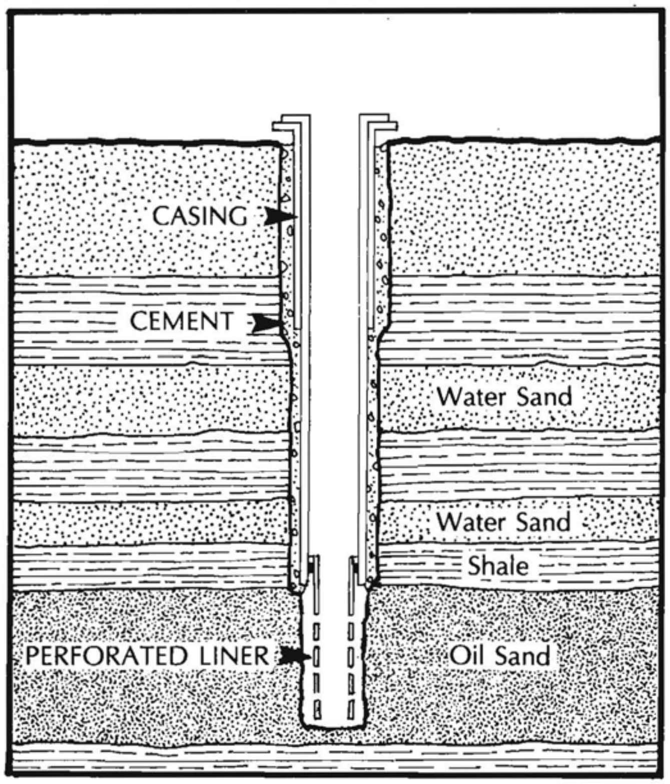
Therefore, once a well has penetrated oil or gas sands, pipe, called casing, is used to segregate these zones from water zones. The casing is placed in the well, usually from the top of the productive oil or gas sand to the surface. To secure the casing, cement is pumped through the casing down the well bore, out the bottom of the casing, and up between the casing and the well wall. In California, such casing is called a *water string.*

After the water string is cemented and the cement has set, the well is drilled to the bottom of the oil zone and completed. (The oil zone may include a number of oil sand layers separated by beds of shale).

Perforated casing, called a liner, is placed in the hole throughout the oil zone. Its purpose is to prevent the oil sand from caving into the hole while the oil enters the well through the perforations. The top of the liner usually extends only a short distance up inside the water string.

Another common type of completion in California is to cement an unperforated string of casing through the oil zone, with cement extending through and above all possible productive intervals. After the cement has set, the casing is perforated at the appropriate point(s) in the oil or gas zone. Perforating is accomplished by lowering a perforating gun to the desired depth in the hole and firing a special type of shaped charge (jet) through the casing.

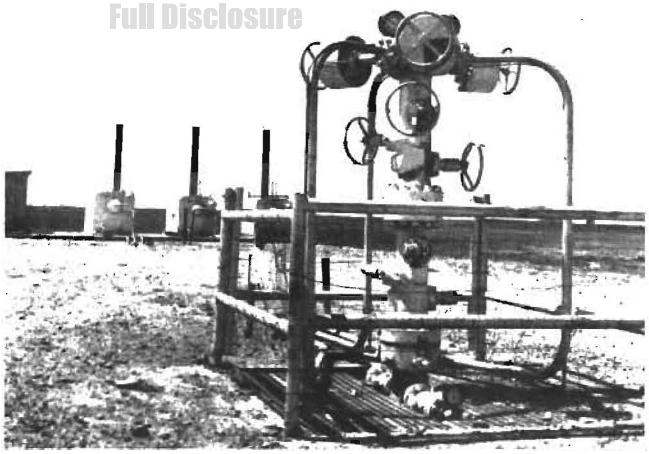
After the liner is run or the casing is perforated, tubing, usually 2-to-3-1/2 inches in diameter, is suspended from the surface with the lower end a short distance above the top perforations. Oil or gas is produced through the tubing.



Casing cemented at the top of a productive oil sand.

If the zone has sufficient pressure to be produced without pumping, a series of valves called a Christmas tree will be attached to the tubing and casing at the surface. The rate of oil and gas flow can be regulated by the valves on the Christmas tree.

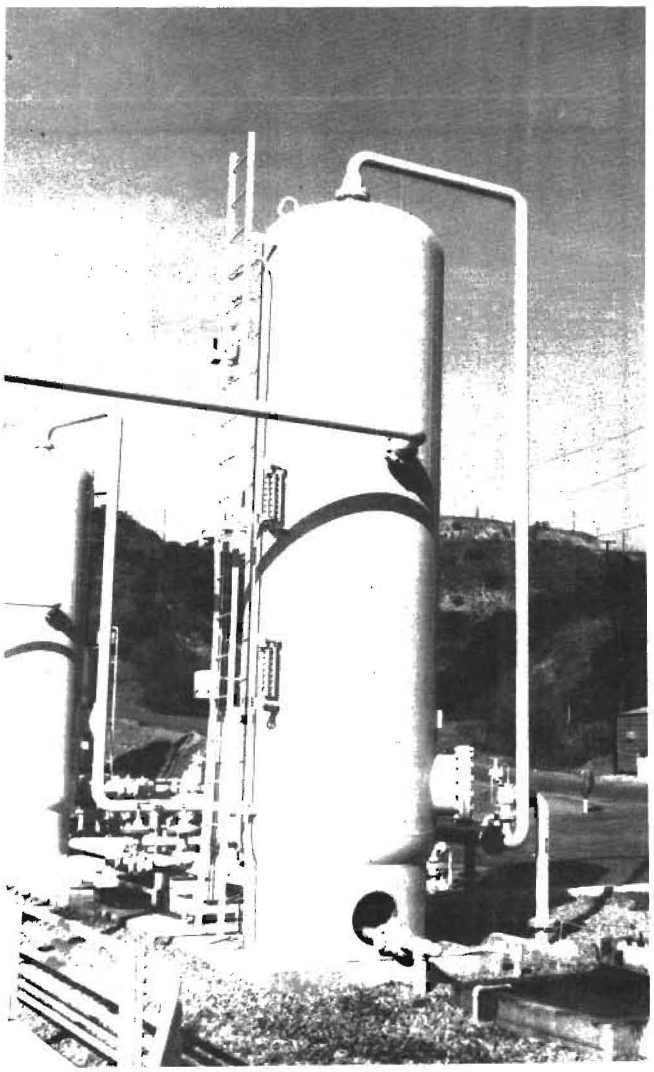
The oil and gas leave the well through a pipeline attached to a device known as a separator, where the gas is separated from the oil and water, and the sediment and water are separated from the oil. The oil is stored in stock tanks, and the gas is routed into a line leading to a gas plant where the so-called wet fractions are removed. (Natural



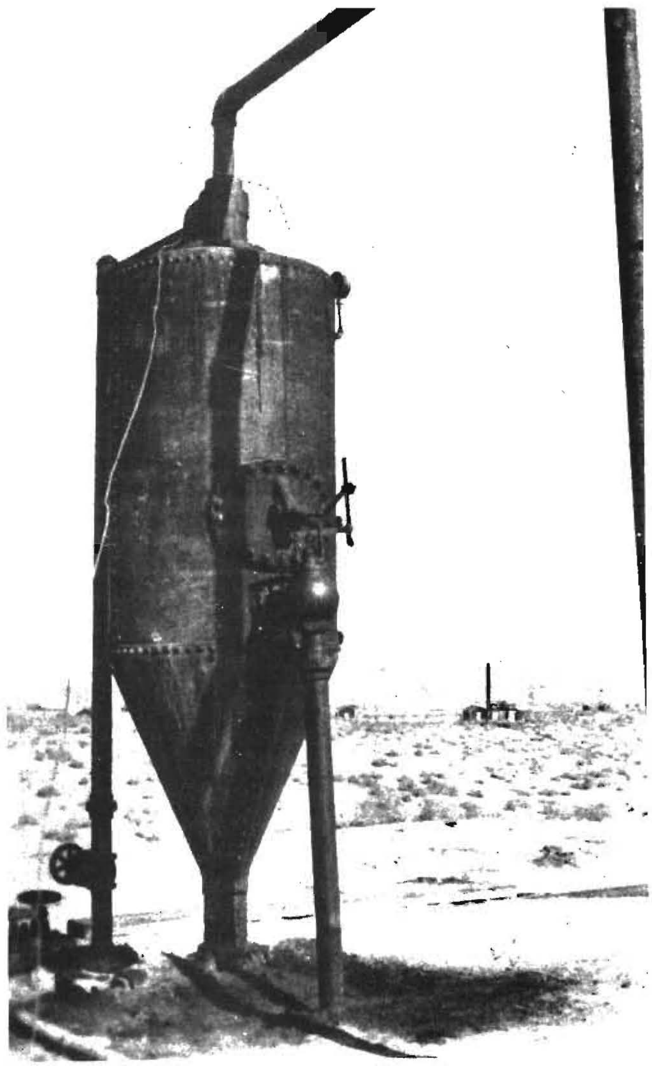
A series of valves, flanges, and gauges (called a Christmas tree) on top of a gas well in Lindsey Slough Gas field, Solano County.

gasoline, butane, and propane are the three most important wet fractions). The butane and propane constitute the fuel called liquid petroleum gas (LPG) that is used in the petrochemical industry and certain types of stoves and heaters. Once the wet fractions are removed, the dry gas goes into the commercial gas lines, where it is sold for industrial and domestic use.

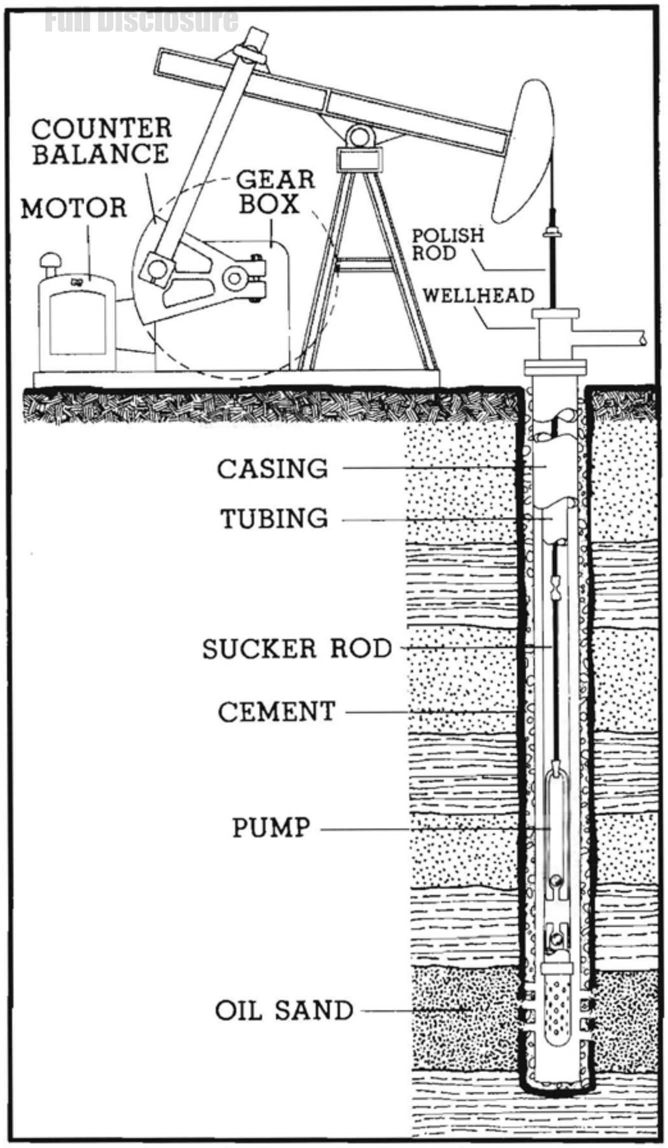
When reservoir pressures are too low to raise the oil to the surface, some artificial means of lifting the oil must be employed. The most common method is to use a rod pump at the bottom of the tubing. The pump is actuated by rods extending up the center of the tubing to the surface. At the surface, the rods are fastened to the beam of the pumping unit. The pumping unit has a motor and gears that move the beam and the attached rods up and down, operating the pump. The oil is pumped up the tubing to the surface, through a separator, and into a tank, following the same route as for a flowing well.



A separator used with a well that produces both oil and gas. The oil and gas enter the separator, in this instance at the center of the tank. Gas leaves the separator at the top, and oil leaves it at the bottom.



An early gas separator at an oil recovery plant near Taft, California, in the early 1920's. The separator works on the same principle as a modern unit. *Photo courtesy of E. H. Musser.*



An oilwell rod pump.

At times, operators choose to use other types of pumps such as those actuated by fluid or those with electric motors at the bottom of the tubing. No rods or beam-type surface units are used with these pumps. Such pumps are especially desirable for use in directionally drilled holes. Also, natural gas may be used in a gas lift system to force oil up the production tubing.

In a fluid-actuated pump, a string of small tubing is run inside or outside of the regular tubing and attached to the special pump at the bottom of the production tubing. Power fluid is pumped down one string of tubing to actuate the pump, which forces the oil entering the wellbore up the production tubing to the surface.

In a submersible, electric pump, an electric motor and multistage centrifugal pump are fastened to the bottom of the tubing. A special type of electric cable extends from the motor, up the side of the tubing, to the surface. The oil is pumped up the tubing to the surface, as in the other types of installations. Extra-large volumes of fluid can be handled with this type of pump.

Almost all oil wells are pumped at some time during their productive lives. Even a well that flows naturally for a long period of time eventually will lack sufficient pressure to raise the oil to the surface.

CHAPTER 7
OIL RESERVOIRS

RESERVOIR VARIATIONS

Oil reservoirs differ in size, shape, porosity and permeability, depth (from several miles deep to very near the surface), and pressure (from very high to almost none at all). Oil reservoirs contain differing quantities of water and gas. In addition, oil, gas, and water from various reservoirs differ greatly in physical and chemical characteristics.

PRODUCING MECHANISMS

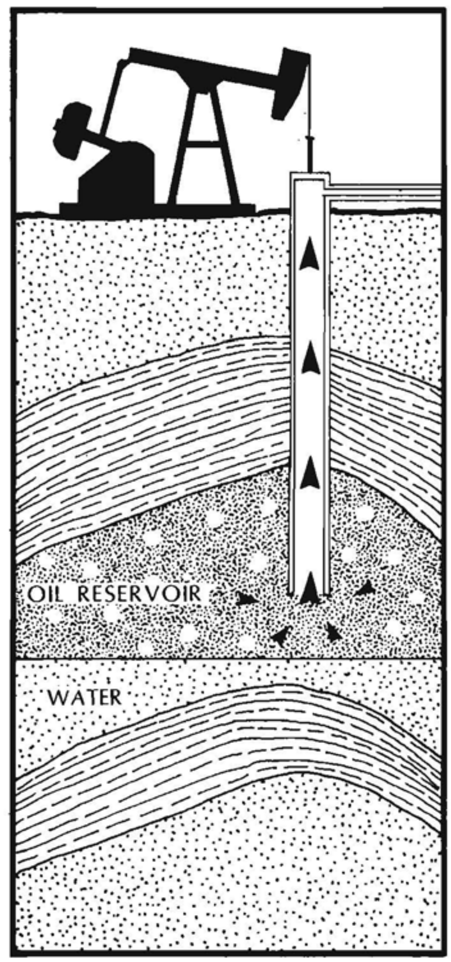
Oil in a reservoir does not have any inherent energy. Energy to drive oil from a reservoir to a well must come from some other source. This energy comes from: gas dissolved in oil, a gas cap above the oil, encroaching water (water drive), or gravitational force.

Although all of these forces may be at work as a reservoir is first developed, one generally dominates. During the later stages of reservoir development, if gas and water pressure are depleted, gravity becomes the dominating force.

The first three figures in the chapter illustrate three of these mechanisms. The final three figures depict the life of an oil reservoir that it is acted upon by the same three mechanisms. The fourth mechanism, gravitational force, may be at work in this reservoir, as well.

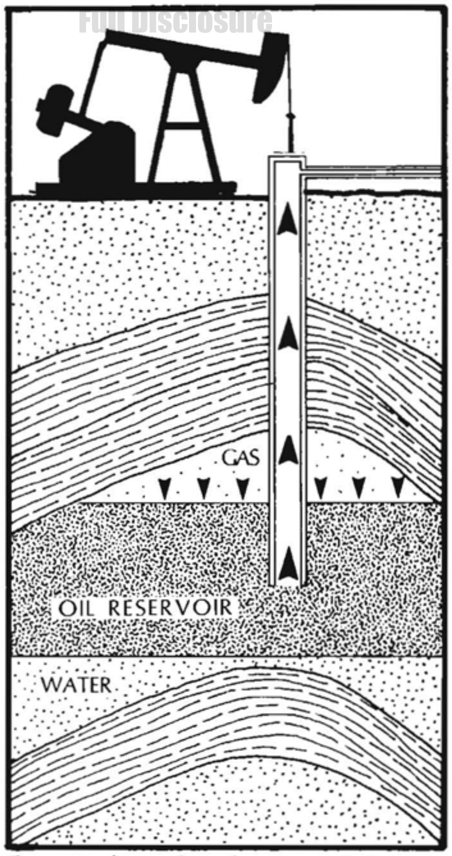
Gas Dissolved in Oil

Usually, some gas is dissolved in the oil. Sometimes the amount is very large and sometimes it is under great pressure. After a well is completed in such a reservoir and production begins, the reservoir pressure is reduced and free gas emerges from solution and expands. The expanding gas provides more energy to move the oil to the well bore and, in the case of a flowing well, up the well to the surface.

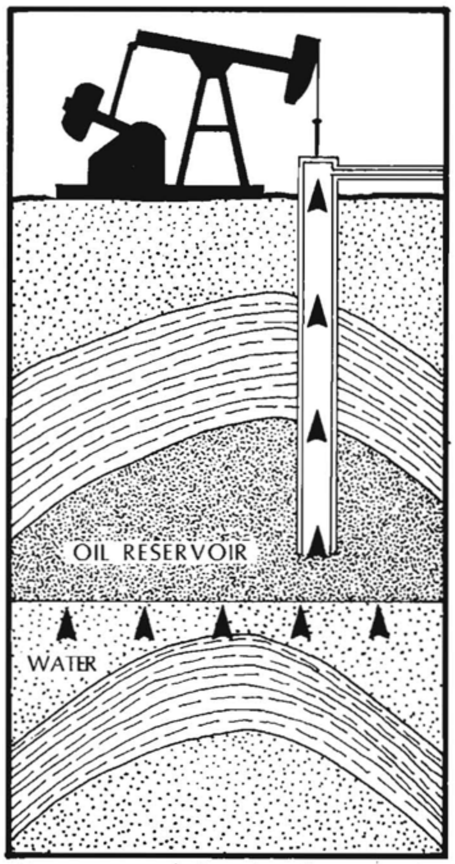


Gas dissolved in oil as a producing mechanism.

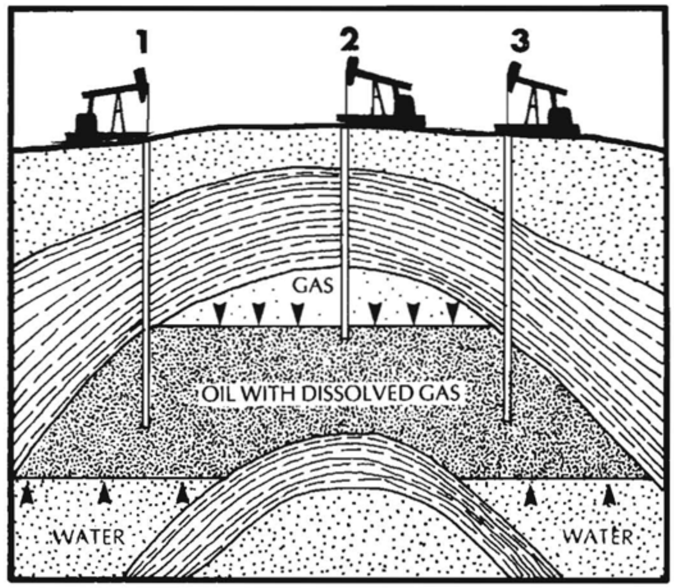
A drop in reservoir pressure as oil is produced is characteristic of most reservoirs; however, in a dissolved-gas drive reservoir, the rate of pressure drop per barrel of produced oil is rapid. Therefore, total oil recovery from such a reservoir is comparatively low because, after the



Gas cap above the oil as a producing mechanism.



Water pressure below the oil as a producing mechanism.



Productive life of an oil pool, early stage. During this stage, the gas dissolved in the oil, the gas-cap, and the water are all exerting force on the oil, driving it to the wells.

Although producing large volumes of oil and gas, the wells can be produced at low gas-oil ratios (gas-oil ratio is volume of gas compared to volume of oil). Reservoir pressure is high and all wells are capable of producing large amounts of oil. Wells 1, 2, and 3 are producing oil and dissolved gas.

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gas is withdrawn, insufficient energy is left to move the remaining oil to the well bore. As little as 5 percent of the oil originally in this type of reservoir may be produced if no enhanced recovery methods are employed.

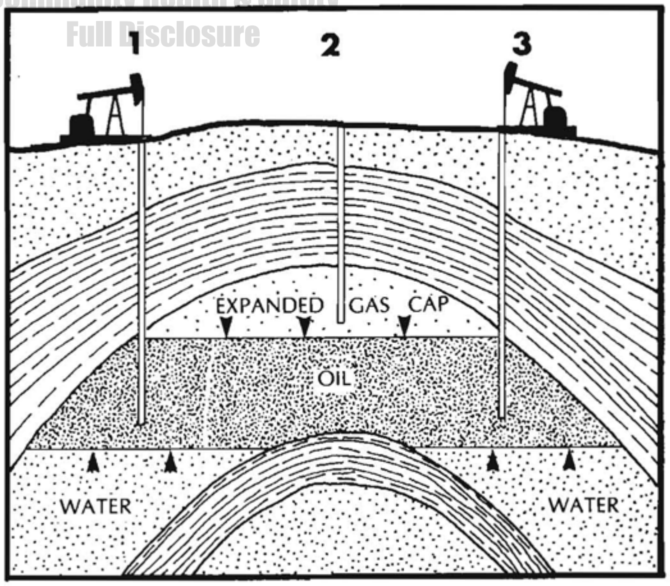
Gas Cap Above the Oil

In a reservoir with more gas than can be dissolved in the oil, a gas cap forms above the oil. With proper production methods, the gas cap will expand as oil below the gas cap is produced. The expansion exerts a continuous pressure against the oil, forcing it into the wells.

Because of the additional amount of natural energy, a much higher percentage of oil will be recovered from a gas-cap drive reservoir than from a reservoir with only a dissolved-gas drive.

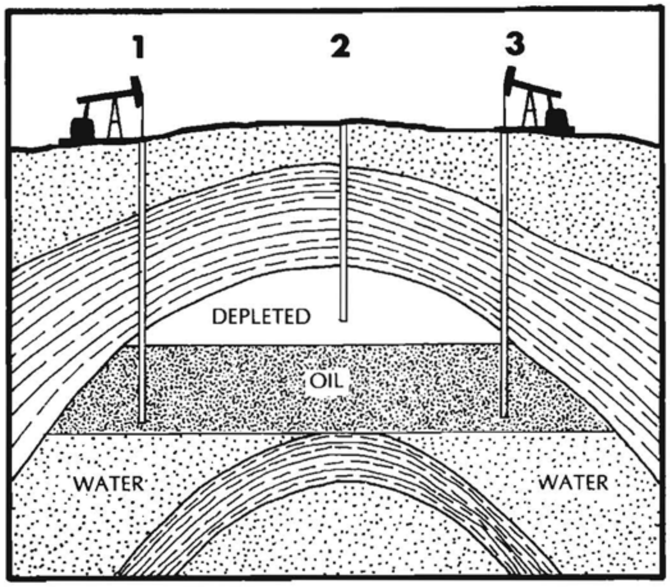
Water Pressure Below the Oil

In California, large quantities of salt water usually lie under oil in the reservoir. This water is usually under pressure, which, in turn, is exerted against the overlying oil. As oil is produced from such a reservoir, the water follows the oil through the sand, continuing to force the oil ahead of it. Total oil recovery is usually much greater from a water-drive type of reservoir than from either a dissolved-gas drive or gas-cap drive type of reservoir.



Productive life of an oil pool, middle stage. A considerable amount of oil has been produced from the pool and the individual wells produce a smaller volume of oil and gas than initially. However, the gas-oil ratios will have increased and the wells on the crest of the structure will have such excessively high gas-oil ratios that they will have to be shut in to prevent waste of reservoir pressure. In the diagram, wells 1 and 3 are producing oil and dissolved gas, while well 2 is shut in to conserve gas, thereby conserving reservoir pressure. At this stage, part of the gas originally in solution has been produced and, because of the drop in reservoir pressure, part has come out of solution and entered the gas-cap.

The gas-cap has lost much of its original high pressure because part of the gas has been removed by the wells high on the structure, and also because it is occupying a much larger space. The water still may retain much of its original driving force. However, unless this is an exceptionally strong water-drive, the pressure on the remaining oil will be much less because of the reduced force of the other two drive mechanisms. If gas is to be injected into the zone to help maintain reservoir pressure, it will be done before, or at this stage, and will be injected in well 2 (gas cap) of this diagram to drive the oil to wells 1 and 3.



Productive life of an oil pool, late stage. At this stage, inasmuch as both the dissolved-gas drive and gas-cap drive are largely expended, the only remaining natural forces being exerted on the oil are from the water drive and gravity.

Now, unless the natural water drive is still strong, gravity may be the dominant force moving the oil to the wells. Gravity will cause the oil to travel down dip and accumulate in the reservoir immediately above the water, so that now, the more productive wells may be those located structurally down dip, a short distance above the water. Because of this greatly reduced reservoir pressure, the oil will have to be raised to the surface by artifical means—probably by pumping.

In the diagram, well 2 is uneconomical to produce because of insufficent oil or gas remaining in the structurally higher portion of the reservoir; wells 1 and 3 are producing oil. Note that water has moved into and is now occupying the lower part of the reservoir, formerly occupied by oil.

Gravitational Force

In some reservoirs, the force of gravity is the only energy source that moves oil to the well bore. The drive mechanism, gravity drainage, is most effective in reservoirs where the strata are very permeable and dip steeply. Gravity drainage is most noticeable in the later life of an oil pool, after the dissolved gas and gas cap are depleted.

CHAPTER 8
ENHANCED OIL RECOVERY METHODS

During the early stages of oil production, called primary production, a reservoir's natural producing mechanisms (*see* Chapter 7) move the oil through the reservoir into the producing wells. However, only about 5 to 30 percent of the original oil-in-place can be produced from California fields with primary production methods. For additional production, enhanced oil recovery (EOR) methods must be used to add energy to the reservoir.

Enhanced oil recovery methods add energy in the form of pressure, heat, and chemicals, alone or in combination, to overcome the natural forces that impede oil recovery. EOR methods include waterflooding, natural gas injection, steam injection, in situ combustion, chemical injection (augmented waterflooding), and gas flooding.

The most important EOR method used in California is steam injection, because of the state's abundance of heavy crude oil. Basically, the heat from the steam lowers the viscosity of the heavy crude so it will flow, just as heating molasses increases its ability to flow. In 1980, steam injection accounted for 30 percent or about 104 million barrels of the state's total oil production.

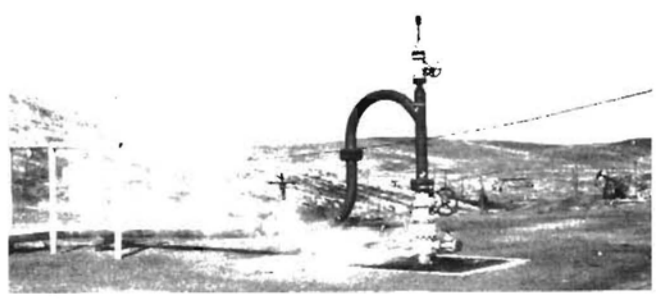
Steam is injected on either a continuous (flood) or an intermittent (cyclic) basis. Cyclic stimulation, also known as steam soak or huff-and-puff, is carried out by injecting steam into a producing well for a short period of time. After each steaming cycle, the well is returned to production. Continuous steaming, commonly known as steam flooding or steam drive, is carried out by injecting steam into a reservoir through injection wells and producing the oil from nearby production wells.

Waterflooding, the second-most prevalent stimulation method used in California, involves injecting water into an oil reservoir through injection wells. The injected water increases or maintains the reservoir pressure, pushing the oil through the reservoir to the producing wells in a manner similar to natural water drive.

Natural gas injection, commonly known as pressure maintenance, is another method of enhanced recovery in which gas is injected into the producing zone to prevent or slow the natural pressure decline that occurs as dissolved gas is produced with the oil. Pressure maintenance projects are usually employed relatively early in the life of an oil pool, before an appreciable reservoir pressure decline begins.

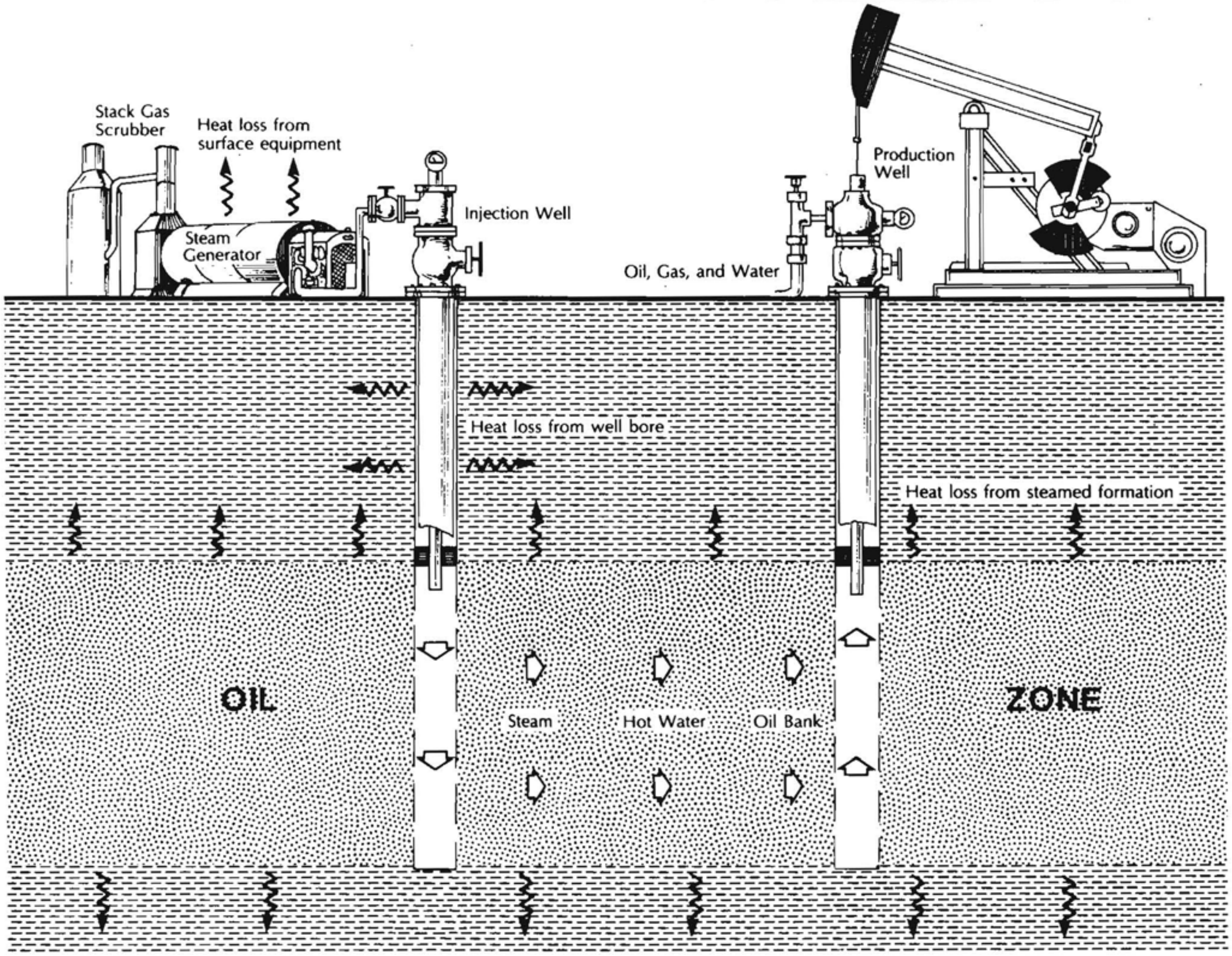
In situ combustion, or fireflooding, is a thermal EOR technique. Rather than using steam to transfer heat to an oil reservoir, this method generates reservoir heat and pressure when air is pumped into injection wells to support combustion, and reservoir hydrocarbons are actually burned. Sometimes, water is injected with the air to create a steam zone ahead of the combustion front, thereby increasing the efficiency of the combustion process.

Chemical flood methods combine special chemicals (e.g., polymers and surfactants) with the basic waterflooding principle. Chemicals can be mixed with the injected water or injected in slugs and followed by water. Depending on the specific reservoir characteristics, chemical flooding serves to reduce the capillary forces that have trapped residual oil or to thicken the injected water so its viscosity more closely matches that of the oil it is displacing.



Steam injection well, Mount Poso oil field, Kern County. *Photo by Hal Bopp, CDOG.*

Gas flooding, with either inert or hydrocarbon gases, drives oil to production wells either by entraining oil in the gas steam, swelling residual oil in the reservoir, or developing miscibility (a solvent effect) between the injected gas and oil. One of the most promising gas flooding techniques, carbon dioxide flooding, combines carbon dioxide with water and/or a hydrocarbon gas to achieve the desired results.



How steamflooding works. From *Heavy Oil in California,* published by the California Division of Oil and Gas.

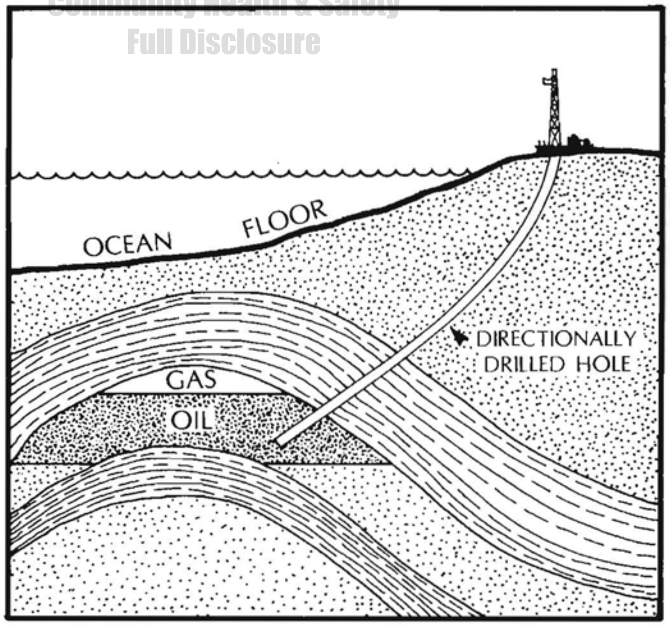
CHAPTER 9
CALIFORNIA'S OFFSHORE FIELDS

California's offshore fields, although beneath the surface of the Pacific Ocean, are on the continental shelf, which is an extension of the adjoining coast. The shelf ranges in width from less than 30 miles at locations north of San Francisco to more than 160 miles at the California-Mexico border.

The State of California receives royalties from offshore oil and gas production in the state tidelands areas. In the 1980-81 fiscal year, this amount equaled $500 million.

The first offshore wells in the United States were drilled in 1896 as an extension to Summerland oil field in Santa

The offshore area of Summerland oil field, late 1890's (now abandoned). The offshore wells were drilled through sections of large casing, called conductor pipe, driven into ocean-bottom sands to shut out sea water. Inside the pipe, cable tools were used to drill the well. The piers often suffered storm damage, collapsing and breaking the conductor pipe below sea level. This allowed water to enter the oil sands. *Drawing by James Spriggs from a photograph in the C. C. Pierce Collection, Title Insurance and Trust Company, reprinted in Spudding In by William Rintoul.*



When a well cannot be economically or physically located over the targeted structure, it is *directionally drilled.* Directionally drilled wells are drilled as precisely as true, vertical holes. Most wells in urban areas are directionally drilled.

These pumping wells along the ocean shore in Wilmington oil field, Los Angeles County, are directionally drilled beneath the ocean.

Barbara County. Here, over 400 wells were drilled from wooden piers extending into the Pacific Ocean, although the average daily oil production per well was only 1 to 2 barrels.

The next offshore discovery was in 1927 when the offshore extension of Rincon field, near Ventura, was found. After this, discoveries of offshore fields were more frequent until, by 1980, a total of 24 oil and gas fields had been located off California's coast. Eight of the fields are extensions of onshore fields.

In 1966, the United States Supreme Court ruled that land within 3 nautical miles of California's coast and island coastlines belongs to the State Government. This has meant that 21 of the offshore fields are under state jurisdiction, and 3 huge oil and gas fields are under federal jurisdiction (as of 1980). The jurisdiction for 1 of the 3 fields is split between federal and state governments. Currently, all California offshore fields are in the offshore portions of the Los Angeles and Ventura geologic basins.

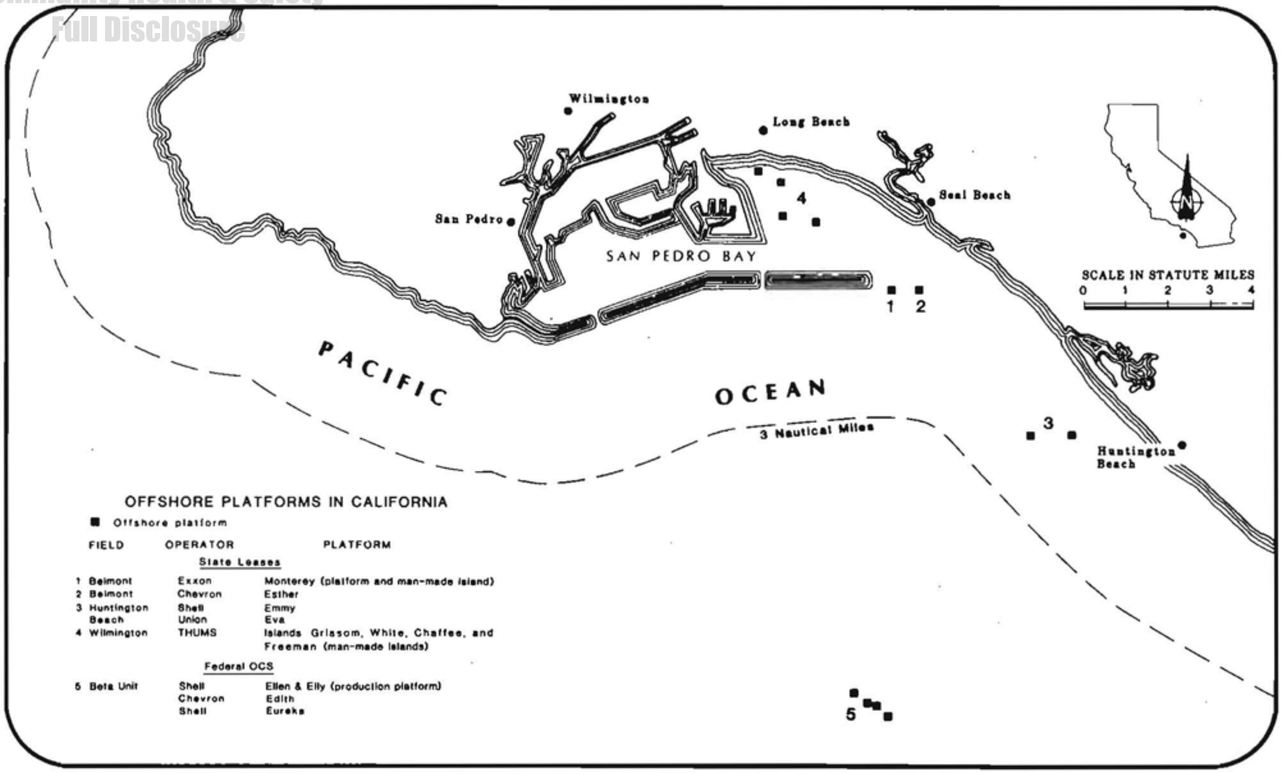
When oil accumulations under the ocean are close to shore, especially in those fields that are extensions of onshore fields, wells may be directionally drilled into the offshore accumulations from onshore locations. Examples of such wells are at Huntington Beach, Wilmington, and Rincon oil fields. Some wells at Huntington Beach are drilled from onshore locations to over a mile offshore, and some have been drilled at angles over 80 degrees from vertical to predetermined bottom hole locations. Most often, offshore oil accumulations are too far offshore to be reached from onshore locations. In such cases, the wells must be drilled from boats, barges, platforms, or man-made islands.

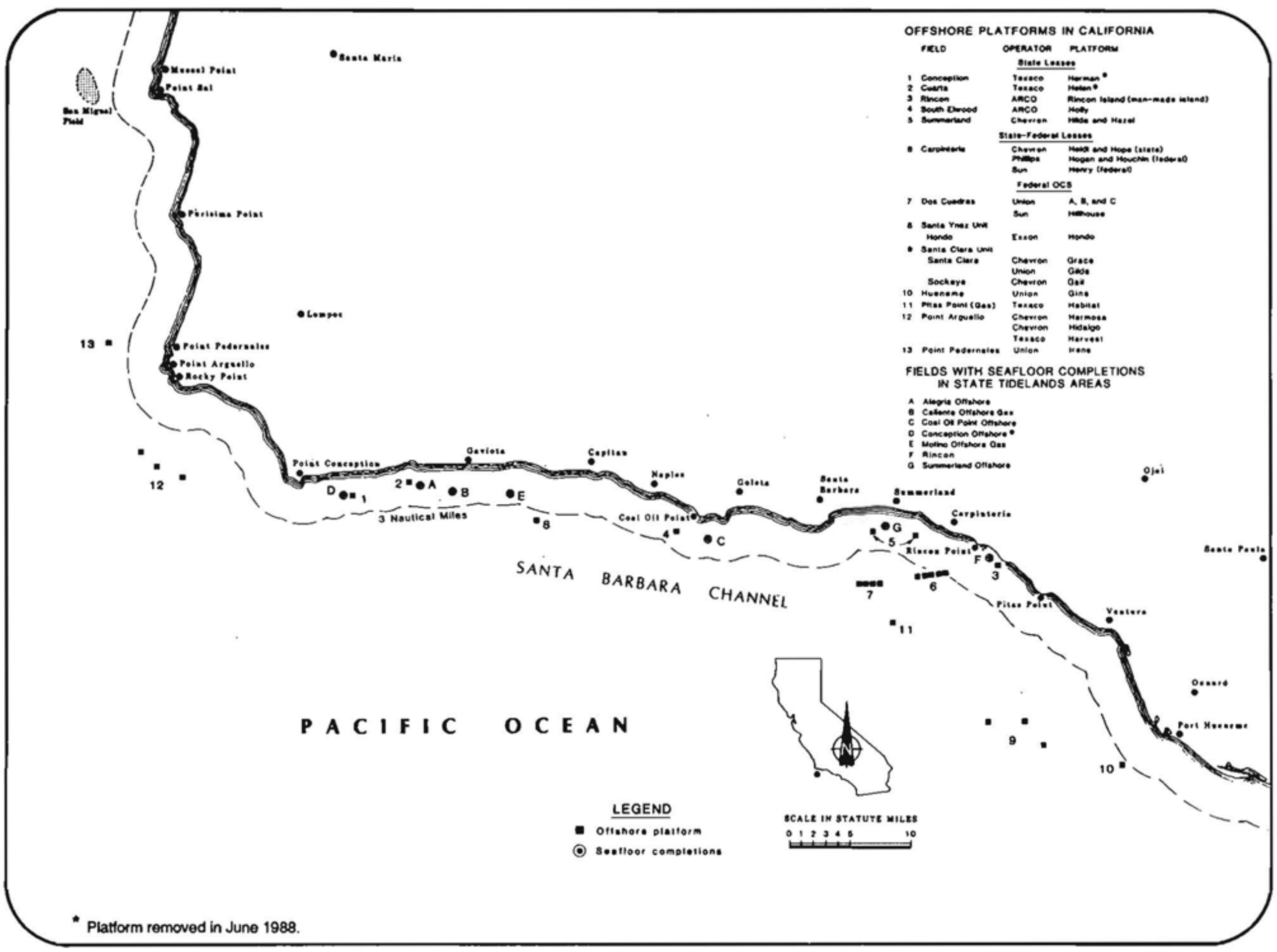
If commercial quantities of oil or gas are discovered with an offshore exploratory well, a permanent platform may be built and placed over the most suitable location for drilling and producing the new field. Drilling equipment will be removed from the platform as soon as all the necessary wells are drilled, and only the production equipment will remain. Space is not provided on the platforms for oil storage, so production generally flows through large pipelines to onshore facilities. Present platforms under California jurisdiction are in water no deeper than about 200 feet. However, Platform Hondo, in federal waters off California, is one of the tallest platforms in the world and is set in 850 feet of water.

If the water depth is not too great, instead of a platform, an earth and rock-fill island may be built from which wells can be drilled and produced. Examples are the islands in the Wilmington field, near Long Beach, those near Seal Beach, and the one at Rincon, near Ventura. Most islands have been landscaped to help make them aesthetically appealing.

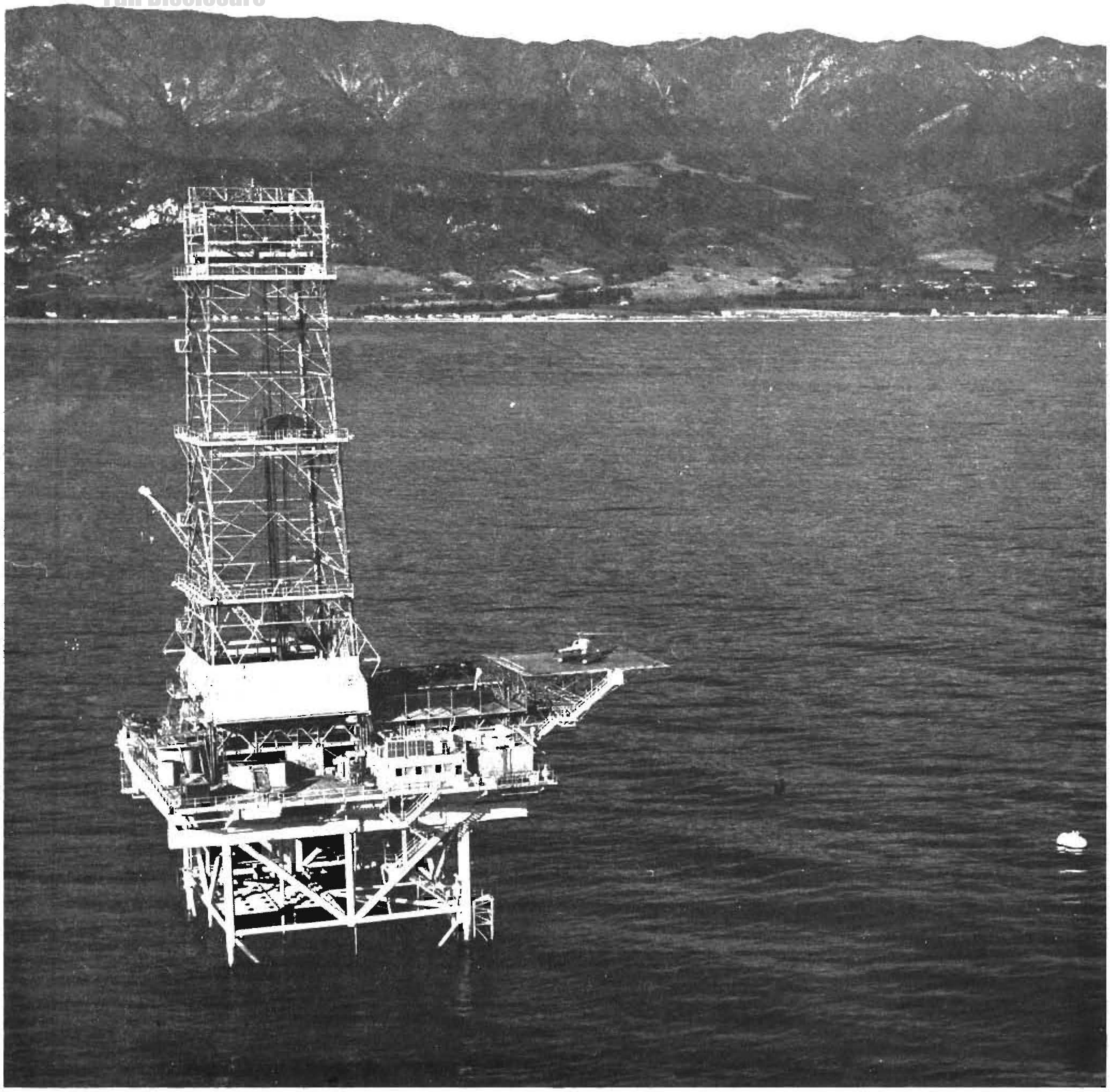
In some offshore fields, wells are completed on the ocean floor; that is, the control valves at the wellhead are at the ocean floor. No platforms or structures of any kind show at the surface. Flow lines run directly from the wells to the shore or to an offshore structure.

For ocean-floor completions, divers or remote-control equipment must be used to open or close valves; any remedial work needed on a well must be done from a drilling boat or barge. As might be surmised, wells that are completed on the ocean floor are more costly to maintain than those drilled from a fixed platform or island. However, there is new equipment for ocean-floor completions





California offshore oil platforms and islands in state and federal waters.

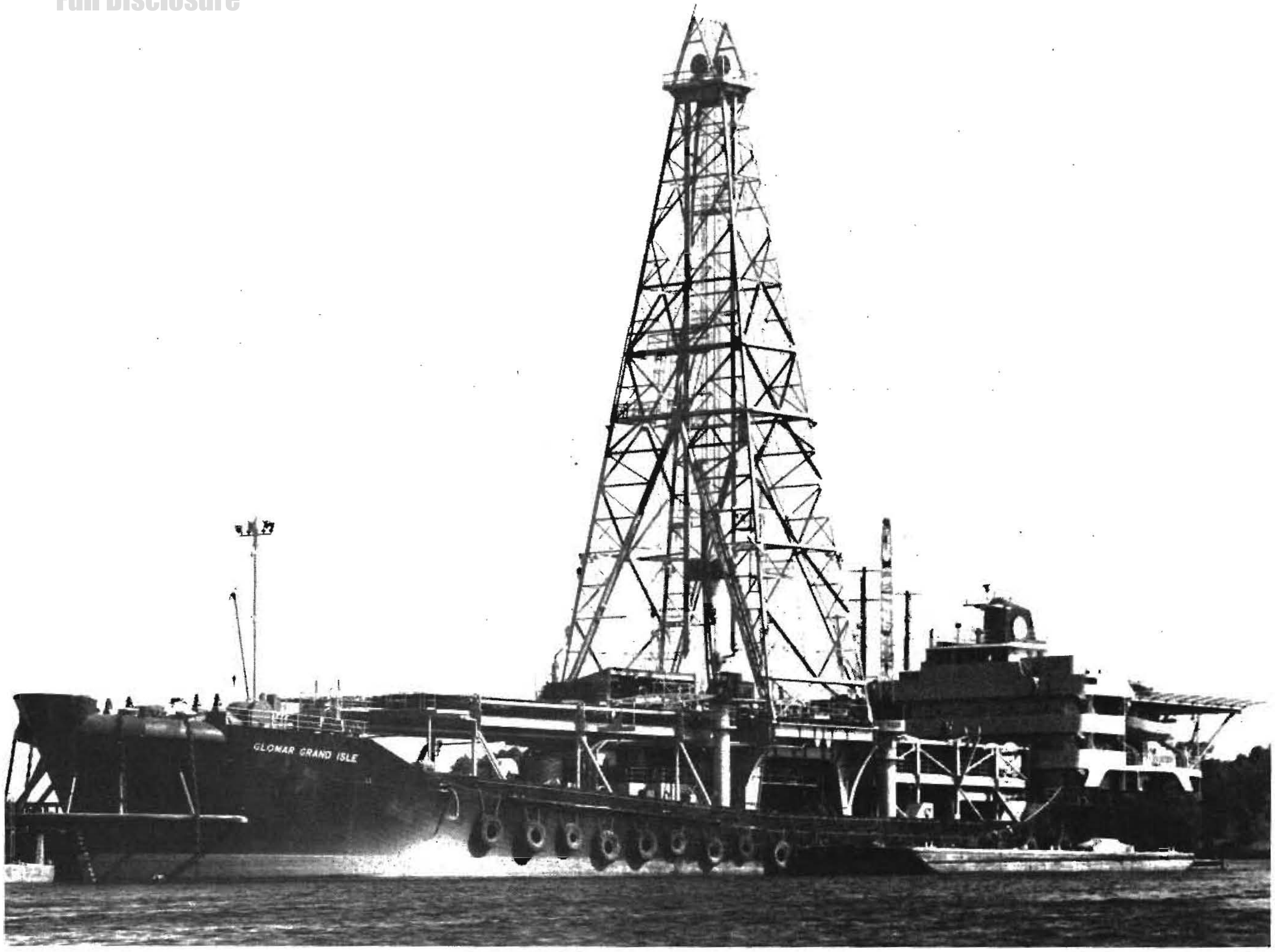


Platform Hazel, a permanent platform in use since 1958, was the first major offshore platform in the Pacific. It is located off Summerland, Santa Barbara County, in Summerland Offshore oil field.

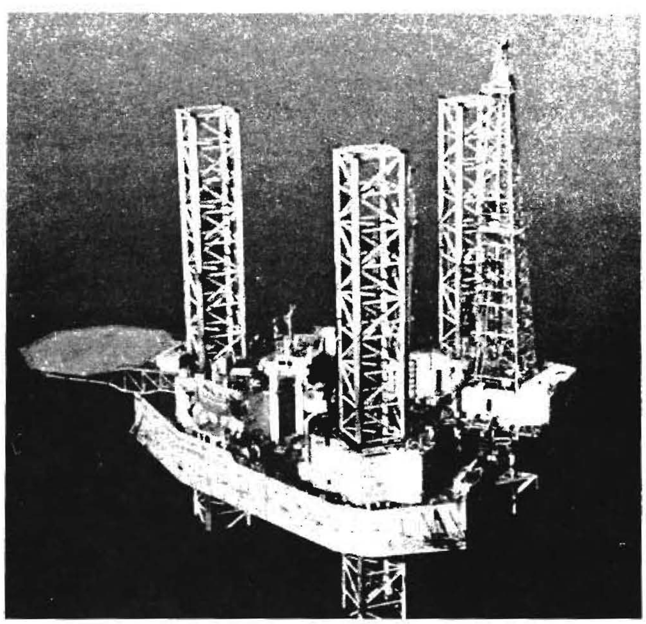
that may make this type of completion preferable, even in areas where fixed platforms once were used.

In 1980, there were nearly 1,500 producing wells in state offshore fields and 227 producing wells in federal offshore fields. Almost 40 million barrels of oil and 13 billion cubic feet of natural gas were extracted from the state fields, and 10 million barrels of oil and 6 billion cubic feet of natural gas from the federal fields during the year. State offshore oil production was about 13 percent of the total state oil production of 1980, even with the limited drilling permitted in the state-owned tideland areas. (A partial drilling moratorium has been in effect in most state offshore areas since the 1969 blowout in federal waters in the Santa Barbara Channel. Drilling has continued from some existing facilities.)

While offshore exploration and production have lagged in some areas of the United States, other parts of the world are developing offshore fields at a greatly expanding rate. Recently, many important oil and gas discoveries have been made in the offshore areas of Great Britain, Norway, Mexico, and Africa.



Drillship Glomar Grand Isle drilling for Sun Oil Company on the western edge of Carpinteria Offshore oil field. The rig can drill to 25,000 feet in 600 feet of water. Anchor lines extend from either end of the vessel to stabilize the ship.



A jack-up platform, the Bergston Dolphin, drilling for Shell Oil Company on Tract 247 in San Pedro Bay adjacent to state waters. The rig can drill to 30,000 feet in 300 feet of water.

The platform area may be raised or lowered along the three legs. When moving to another location, the platform is lowered to float on the water and the legs raised from the ocean floor.

Two of four man-made drilling islands off Long Beach. The tall structures are camouflaged drilling rigs, and the island perimeter is landscaped. The drilling rigs are moved from well site to well site along tracks.

CHAPTER 10
TRANSPORTING AND STORING OIL AND GAS

OIL

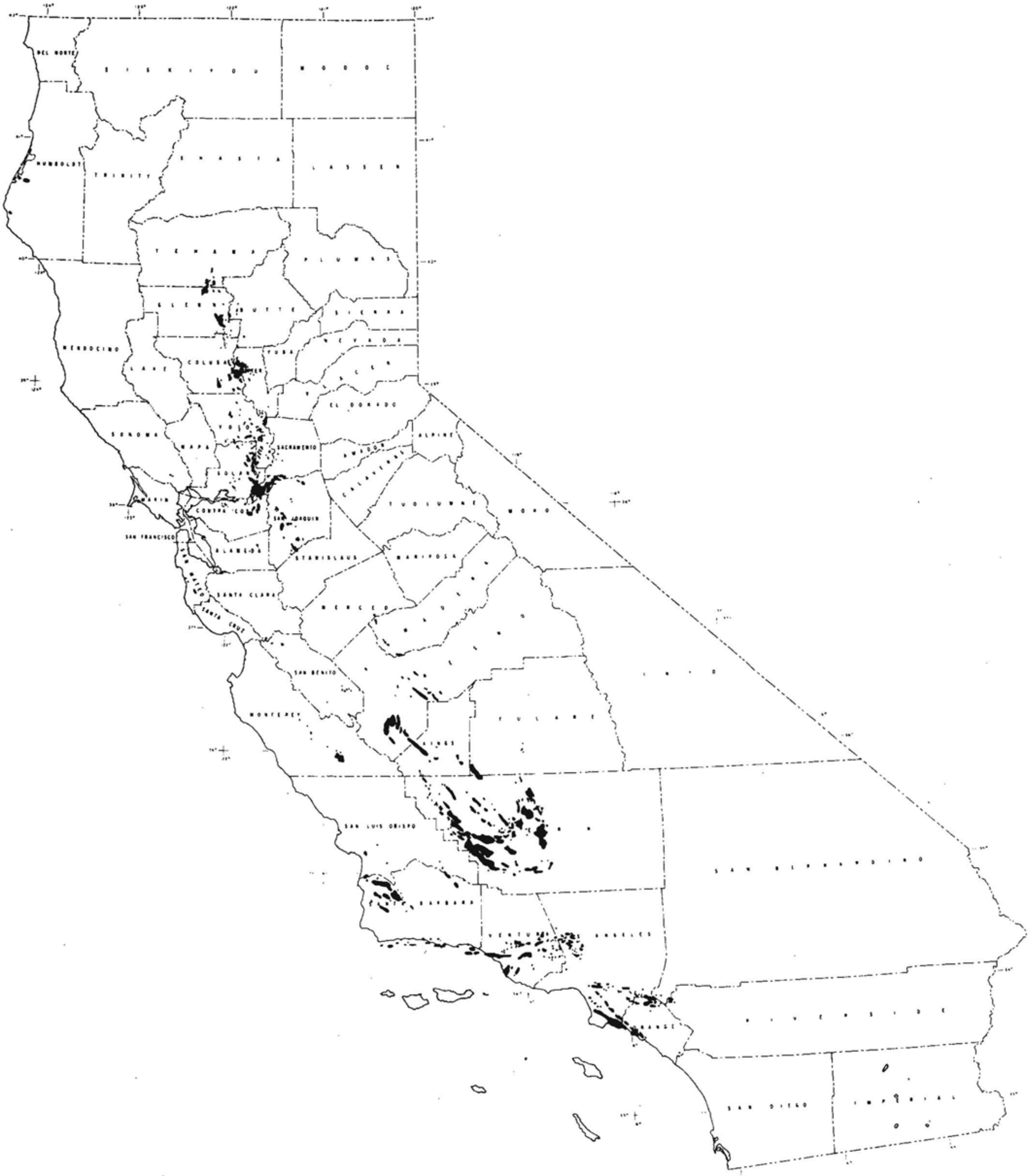
From the time oil leaves the underground reservoir until it reaches the consumer, it can be moved via pipelines, tank trucks, railroad tank cars, oil barges, and large ocean tankers.

At the start of the journey, the oil is passed from the well into field storage tanks through a pipeline about 2 inches in diameter. Pipelines carry most oil from the field storage tanks to the refineries, where many petroleum products are made. In California, these pipelines have diameters up to 36 inches, and are laid in the most direct route from the fields to the refining centers through all types of terrain. Usually, the pipelines are buried. Pumps move the oil through the pipelines from pumping stations placed at intervals along the pipeline route. (See map S-2, the *Energy Map of California,* for much of the state's oil and gas pipeline network).

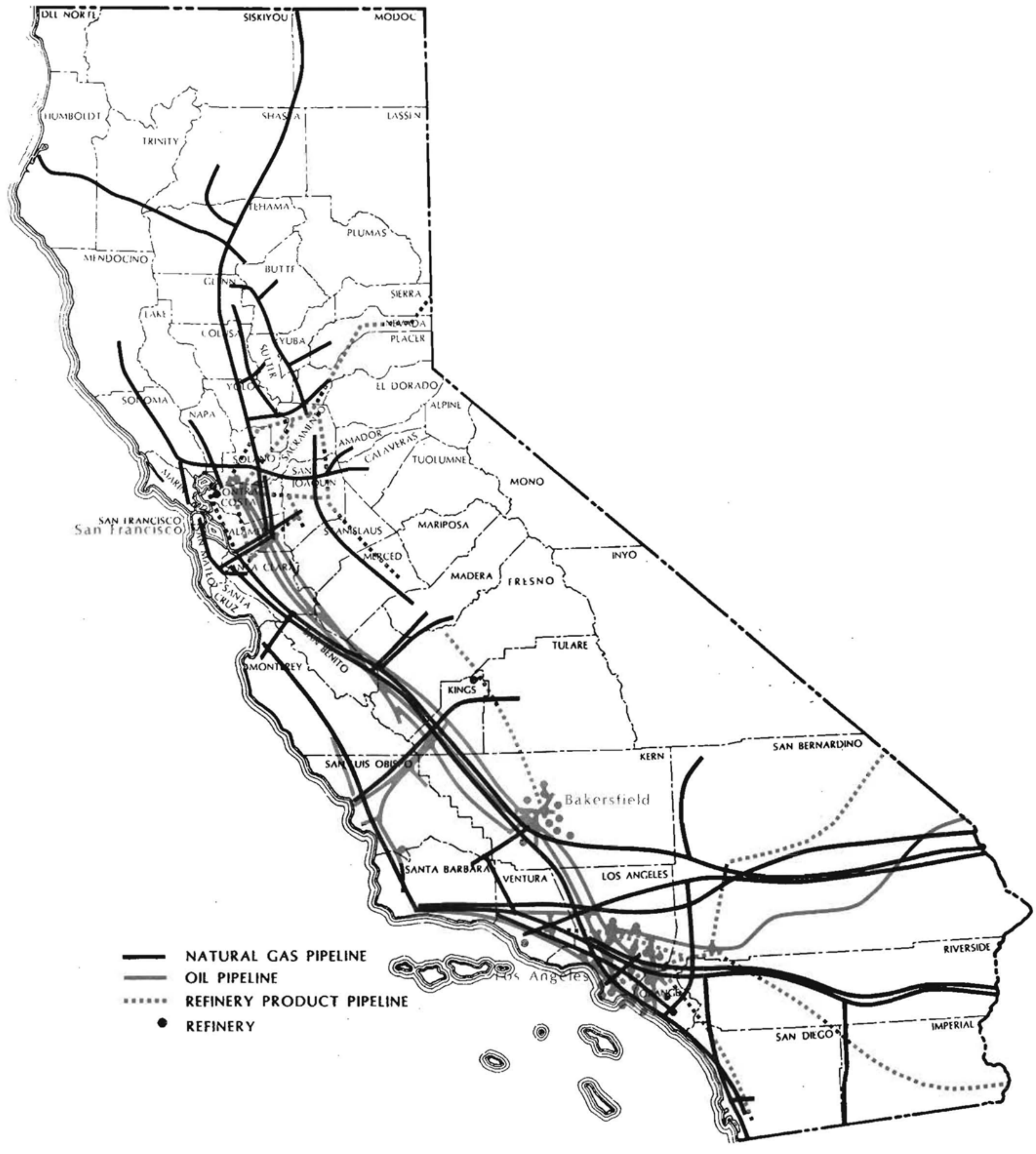
Usually, a tank truck carries refined products from the refinery to filling stations, farms, homes, and factories. Also, tank trucks are used to carry some crude oil from wells to refineries. In some areas of the United States,

A Chevron U.S.A. Inc. oil train hauling gas-oil, a petroleum distillate, to Richmond, California, from Utah. Two 70-car trains of jumbo oil tankers are always in use.

Gas-oil is kept in a liquid state throughout the journey in the insulated tanker cars, heated with steam coils. *Photo courtesy of Chevron U.S.A. Inc.*

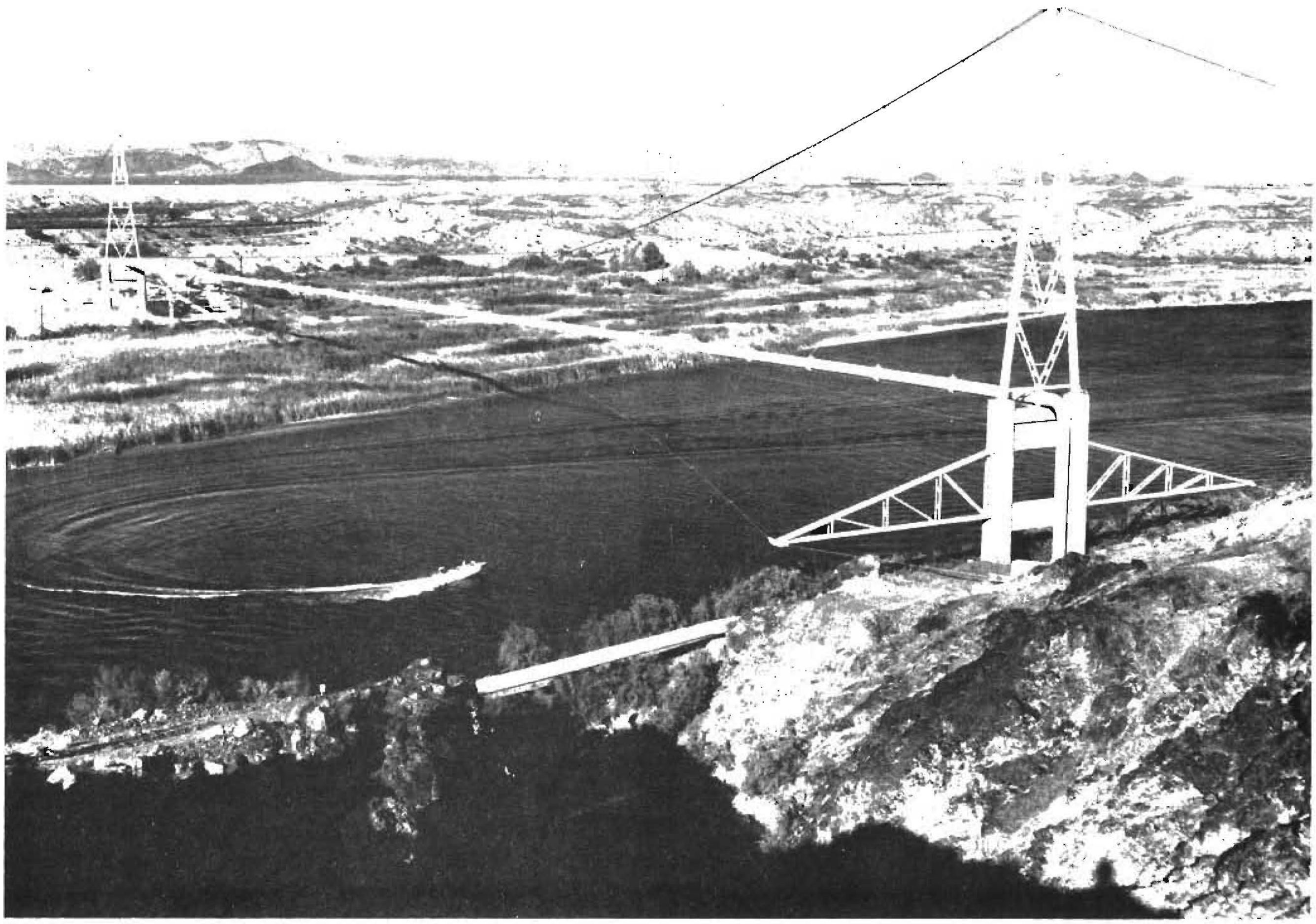


California oil and gas fields. From these fields, the transportation process begins.

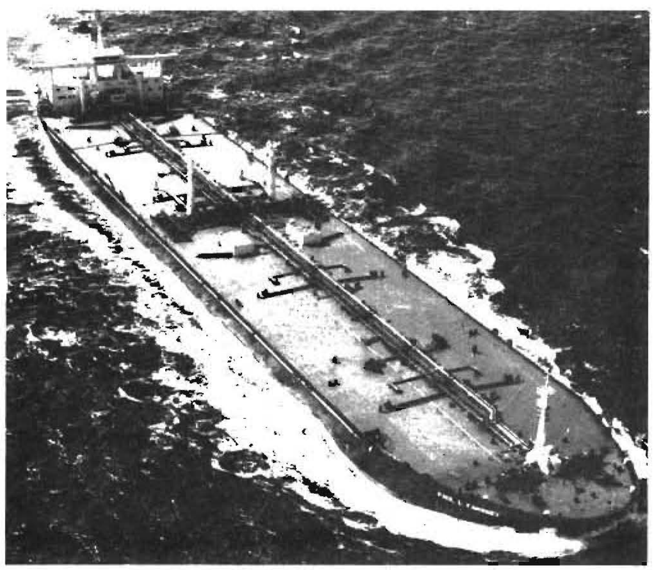


Major oil, gas, and refinery product pipelines in California. Some refineries shown.

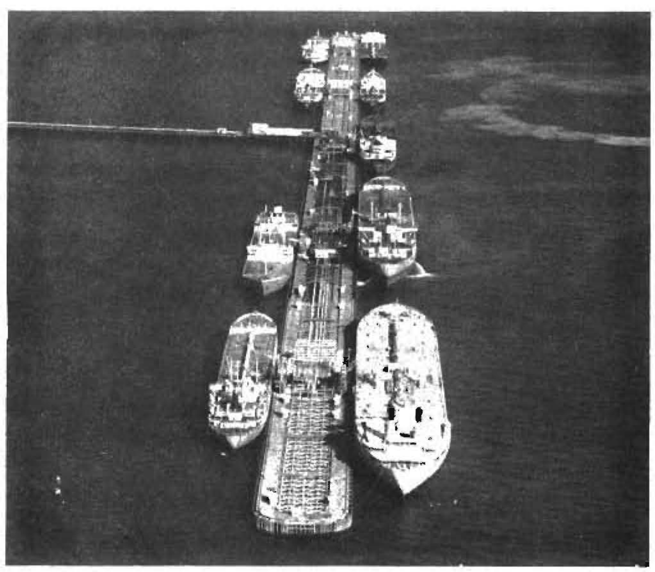
For more detailed information, see California Division of Oil and Gas Map S-2, *Energy Map of California.*



Natural gas is brought into Southern California from Texas and New Mexico via this 34-inch pipeline, shown here crossing the Colorado River from Topock, Arizona, into San Bernardino County, California. *Photo courtesy of Southern California Gas Company.*



This supertanker is capable of carrying 1.33 million barrels of oil. Tankers such as this play a vital role in providing for the energy needs of the world.



Tankers loading oil in the Middle East. *Photo courtesy of Chevron U.S.A. Inc.*

large quantities of oil are moved in railroad tank cars. In California, the amount carried in this manner is small compared with the amount moved by pipelines and tank trucks. However, regular shipments of crude oil from Utah are made to the Chevron U.S.A. Inc. refinery at Richmond, California by train.

A large amount of oil is moved by ocean tankers in coastal and transoceanic shipping lanes. Once, when California was an oil-exporting state, ocean tankers moved large quantities of oil from California ports to foreign lands; however, in recent years, the tankers have brought foreign and domestic crude oil into California. The amount of oil moved throughout the world by ocean tankers is tremendous, as many, large oil-producing countries ship almost all of their oil to foreign ports. In worldwide terms, approximately 58 percent of all oil shipments are by water.

GAS

In California, natural gas is transported entirely through pipelines. Some reservoirs contain only gas, called *nonassociated gas.* When nonassociated gas is produced, it is dehydrated and routed directly from wells into a utility company's collecting line.

When gas occurs with crude oil, it is called *associated gas.* When associated gas is produced, the oil-gas mixture is routed through a separator, or trap, which separates the gas from the oil. From the trap, the gas flows through a pipeline to a gas plant where other liquid hydrocarbons are removed.

The gas then flows from the gas plant to the utility company facilities (*see* Chapter 11). Here, chemicals called *mercaptans* are added to natural gas to provide it with an odor, for safety reasons. (Natural gas generally has no odor.) Then, the gas is sold.

GAS STORAGE PROJECTS

To meet peak demands during cold, winter months, utility companies use depleted oil and gas reservoirs for underground storage of large volumes of natural gas. Gas is pumped into the reservoirs during the summer months when the demand for natural gas is low. When the demand increases during the winter months, the gas is withdrawn as needed.

CHAPTER 11
REFINING

Crude oil is not a single chemical compound, such as water. It is a mixture of chemical compounds comprised mostly of hydrogen and carbon atoms. Each compound is called a *fraction.*

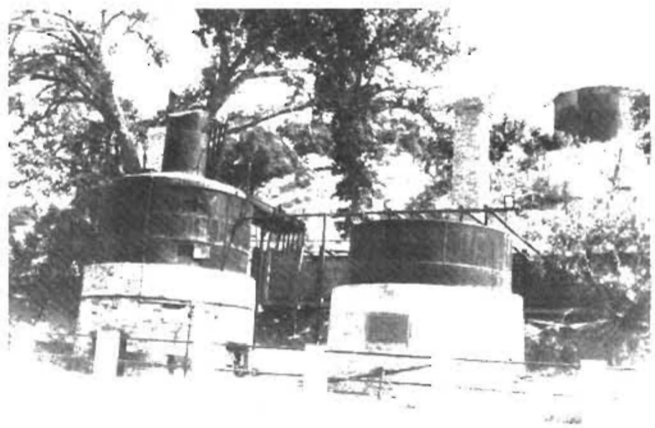
The refining process begins with *fractional distillation,* when crude-oil fractions are separated into *hydrocarbon groups,* which are sets of fractions with boiling points within certain ranges.

Fractional distillation is undertaken by heating crude oil to 600°F, or more, and running it into a fractionating tower. The fractions with the lowest boiling ranges vaporize first and rise highest in the tower before condensing to liquids, which are then withdrawn and kept separated from the other fractions. The fractions with very highest boiling points do not vaporize; they drop to the bottom of the tower and are drawn off. The fractional distillation unit is usually called a *crude distillation unit,* or an *atmospheric crude unit.*

Cut point temperatures	Fraction
below 90°F	butanes and lighter
90°F to 220°F	gasoline
220°F to 315°F	naphtha
315°F to 450°F	kerosene
450°F to 800°F	gas-oil
800°F and above	residue

Typical crude oil *fractions.* Fractions are generic names for crude oil compounds that boil between any two temperatures, called cut points.

Crude oil compositions vary widely. The heavy crudes, such as California crudes, tend to contain more gas-oil and residua. Gasoline, naphtha, and kerosene can be more easily refined from light crudes.



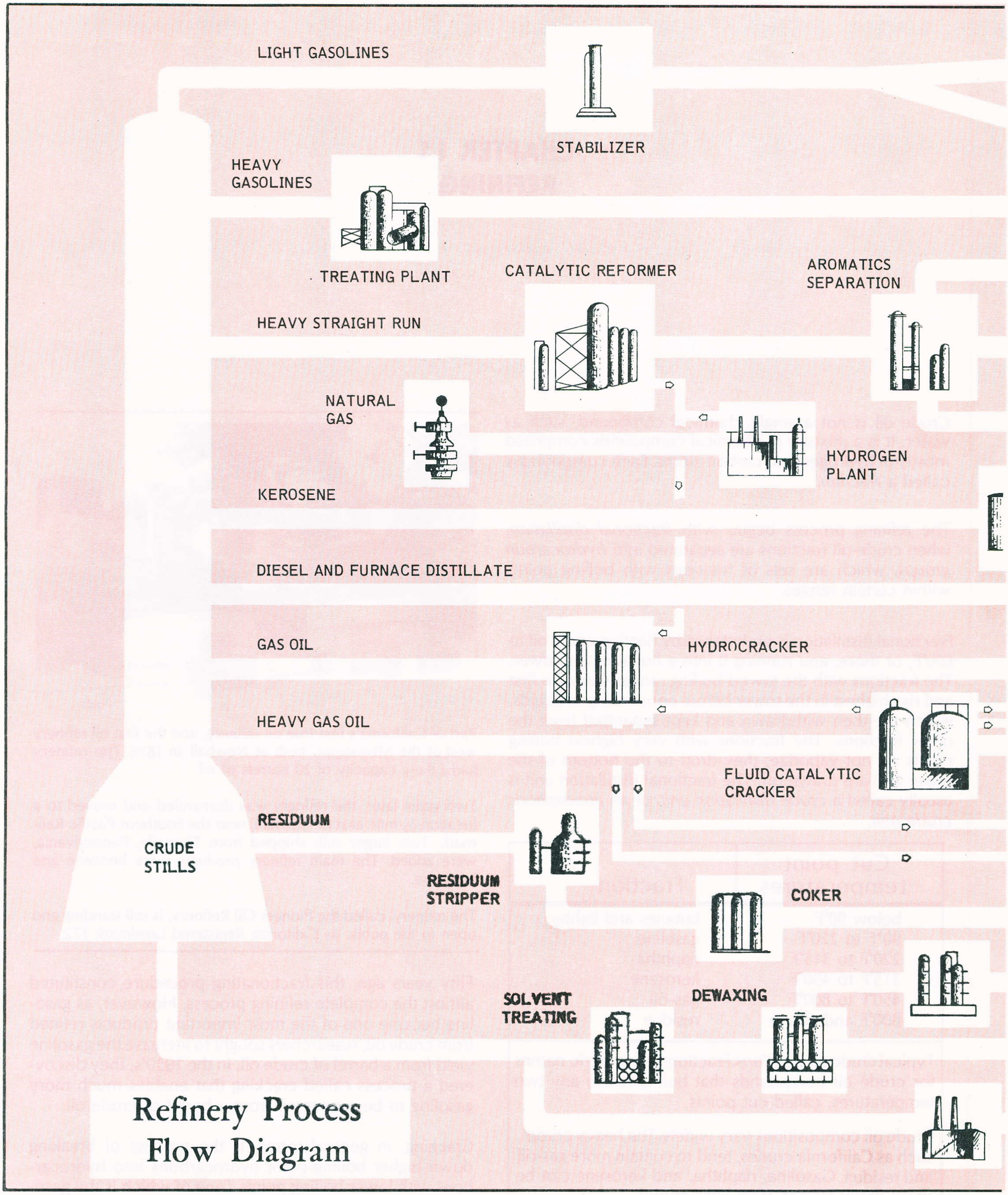
Part of California's first true oil refinery, and the first oil refinery west of the Mississippi, built at Newhall in 1876. The refinery had a daily capacity of 20 barrels of oil.

Two years later, the refinery was dismantled and moved to a location ½ mile east of Newhall, near the Southern Pacific Railroad. Two larger stills shipped from Titusville, Pennsylvania, were added. The main refinery products were benzene and kerosene.

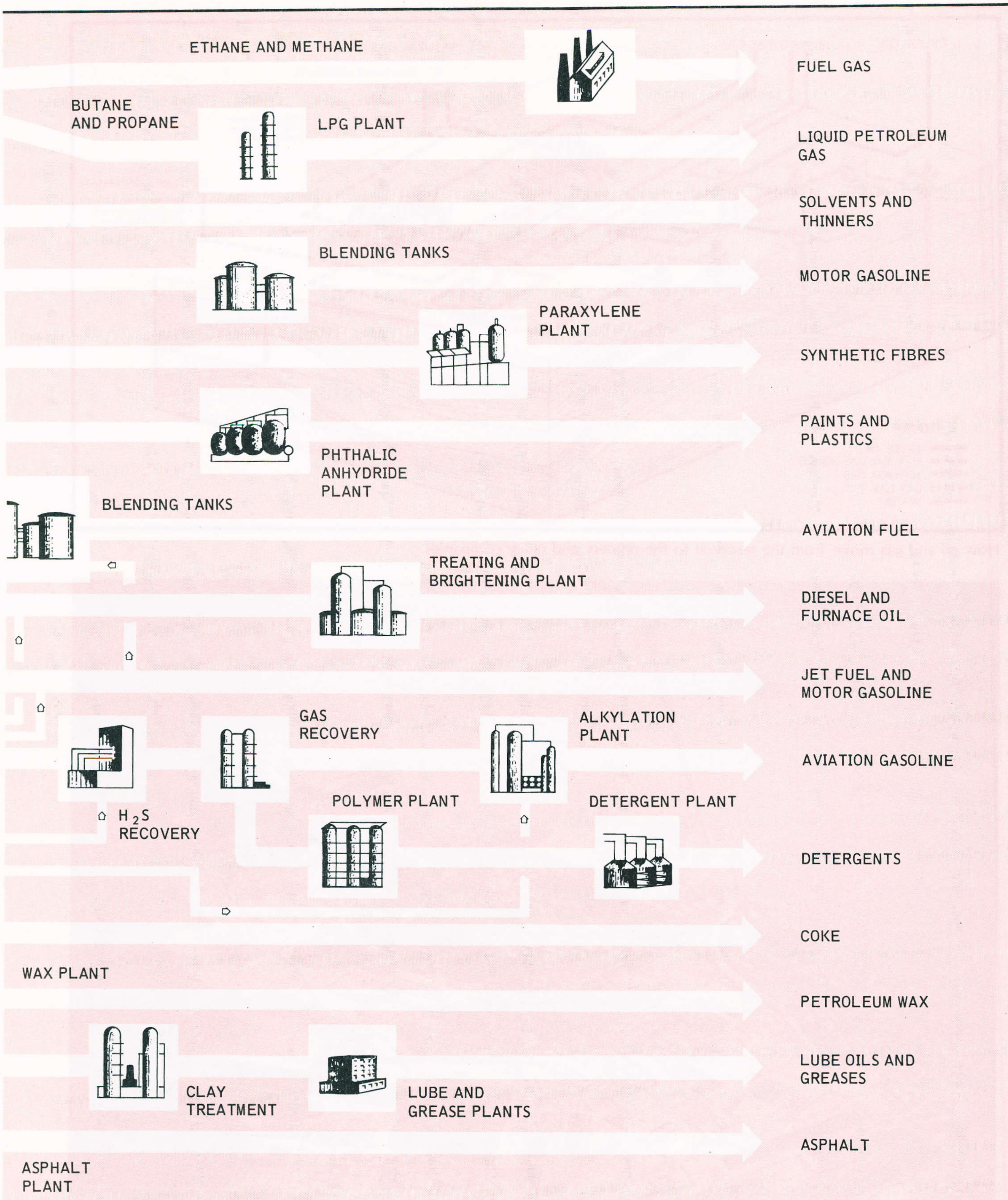
The refinery, called the Pioneer Oil Refinery, is still standing and open to the public as California Registered Landmark 172.

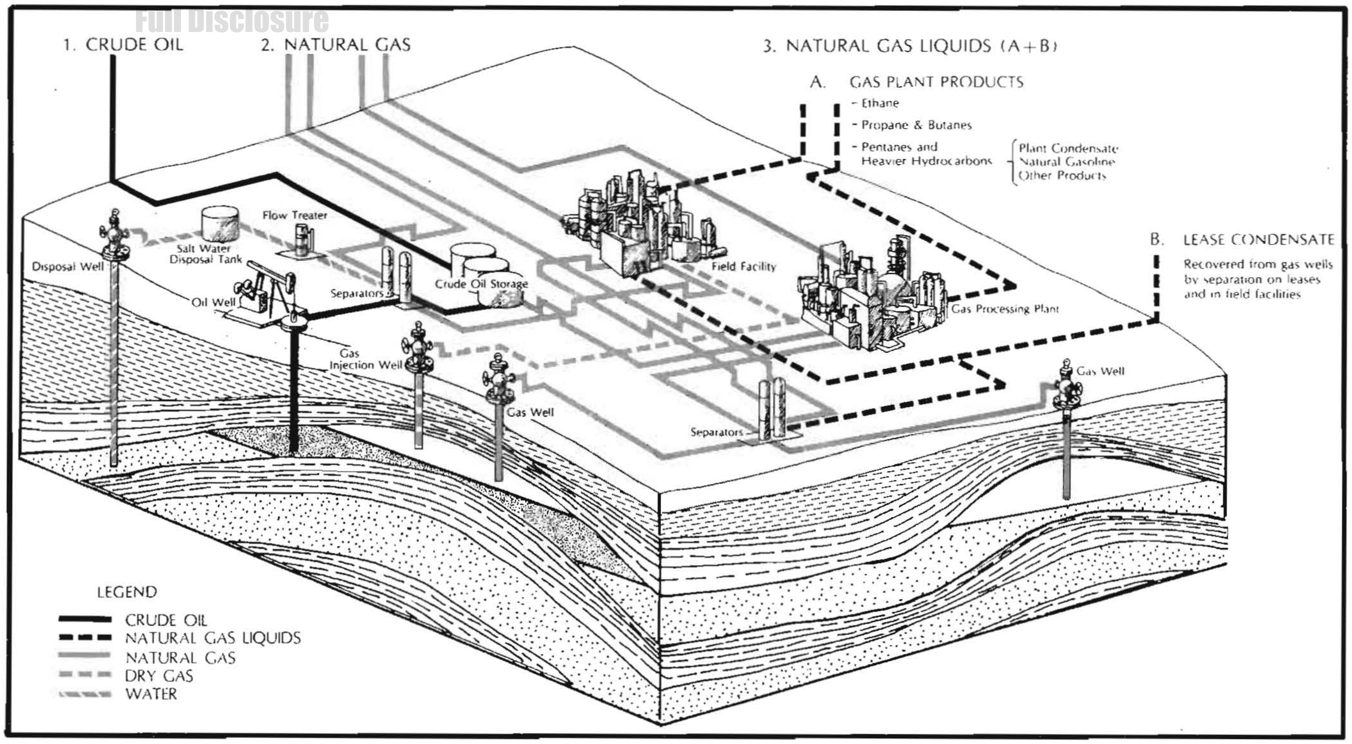
Fifty years ago, this fractionating procedure constituted almost the complete refining process. However, as gasoline became one of the most important products refined from crude oil, researchers sought to increase the gasoline yield from a barrel of crude oil. In the 1930's, they discovered a process called cracking that enables much more gasoline to be recovered from a barrel of crude oil.

Cracking, in general terms, is the process of breaking down higher boiling-point hydrocarbons into hydrocarbons with lower boiling points (one of which is the gasoline fraction). This is accomplished by subjecting certain

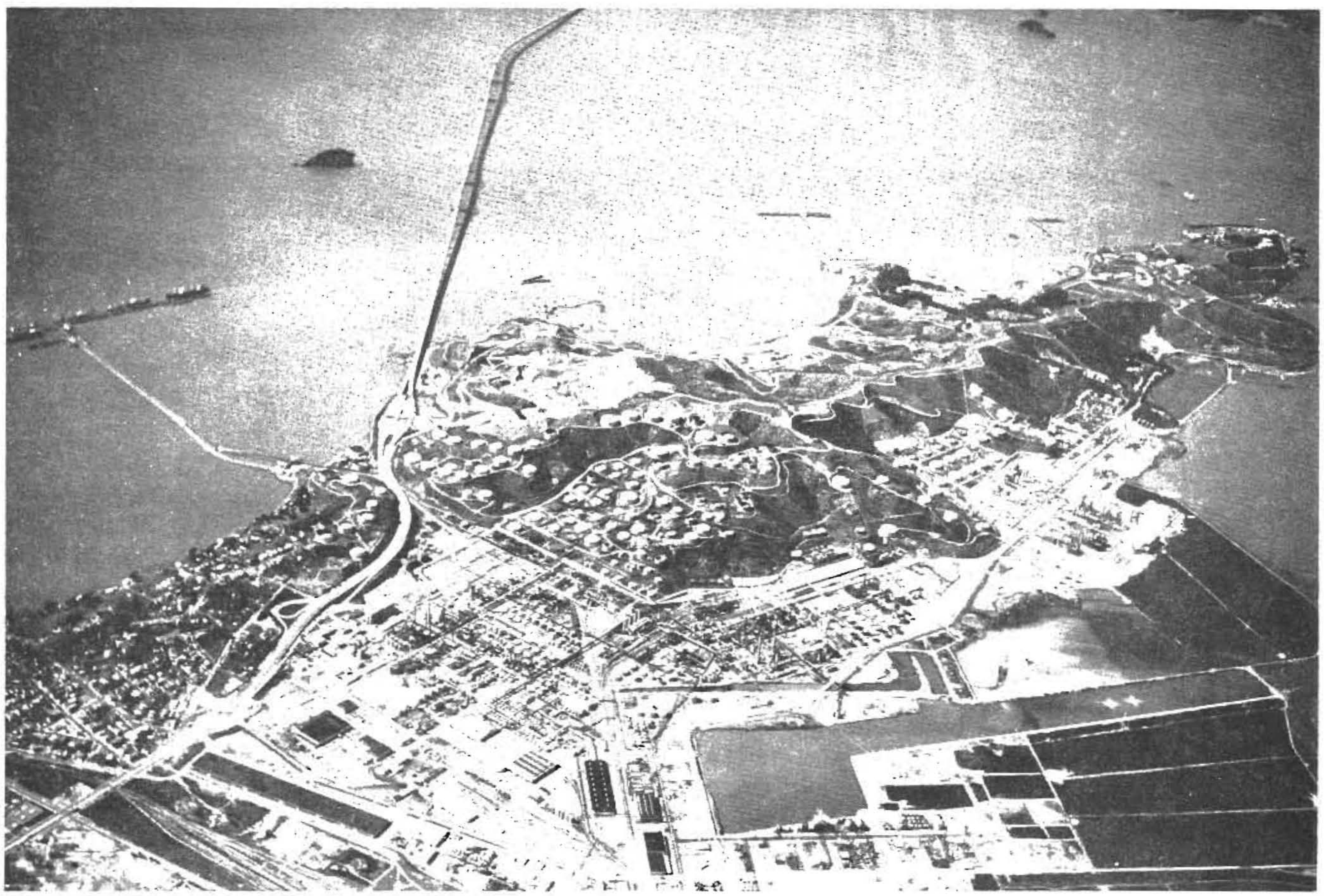


Refinery Process Flow Diagram

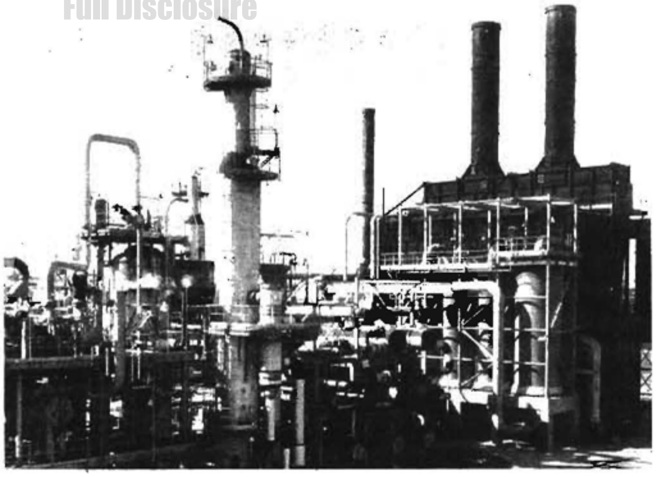

ETHANE AND METHANE
FUEL GAS
BUTANE AND PROPANE
LPG PLANT
LIQUID PETROLEUM GAS
SOLVENTS AND THINNERS
BLENDING TANKS
MOTOR GASOLINE
PARAXYLENE PLANT
SYNTHETIC FIBRES
PAINTS AND PLASTICS
PHTHALIC ANHYDRIDE PLANT
BLENDING TANKS
AVIATION FUEL
TREATING AND BRIGHTENING PLANT
DIESEL AND FURNACE OIL
JET FUEL AND MOTOR GASOLINE
GAS RECOVERY
ALKYLATION PLANT
AVIATION GASOLINE
H_2S RECOVERY
POLYMER PLANT
DETERGENT PLANT
DETERGENTS
COKE
WAX PLANT
PETROLEUM WAX
LUBE OILS AND GREASES
CLAY TREATMENT
LUBE AND GREASE PLANTS
ASPHALT
ASPHALT PLANT



How oil and gas move from the reservoir to the refinery and utility companies.



An aerial view of a modern refinery, the Chevron U.S.A. Inc. refinery at Richmond, California. Tanker mooring sites are in photo upper left. Refinery capacity is 365,000 barrels of oil a day. *Photo courtesy of Chevron U.S.A. Inc.*



Heavy gasolines from crude oil are fed to this catalytic reformer unit. The resulting xylenes are later processed into synthetic fibers, paints, and plastics.

Gas-oil feedstock is fed to this fluid catalytic cracker, in which the molecular structure of the petroleum is changed, forming smaller molecules such as gasolines and other light fractions.

fractions obtained from the initial distillation to extreme heat and pressure.

In the 1940's, the cracking process was improved by using a catalyst. (Catalysts are agents that cause chemical changes in other substances while remaining unchanged themselves). Since then, improvements in cracking and in catalysts have continued. Without the continual research leading to these improvements, we would not have today's high-quality gasolines.

Perhaps one of the greatest advances in the refining process occurred in the 1960's. This was development of the *hydrocracker,* a unit in which feed oil is cracked in the presence of both a catalyst and an excess of hydrogen. With the aid of the hydrocracker unit, modern refineries can recover still more gasoline from a barrel of crude oil.

Of greater value is the versatility of the hydrocracker. The refiner can now turn feedstock into whatever product is wanted, with a wide latitude in producing the quantities of gasoline, diesel, or jet fuel required to meet seasonal changes in market demand.

We all know that gasoline and oil used to run our cars comes from a refinery, but seldom do we realize how many other petroleum-based products we use.

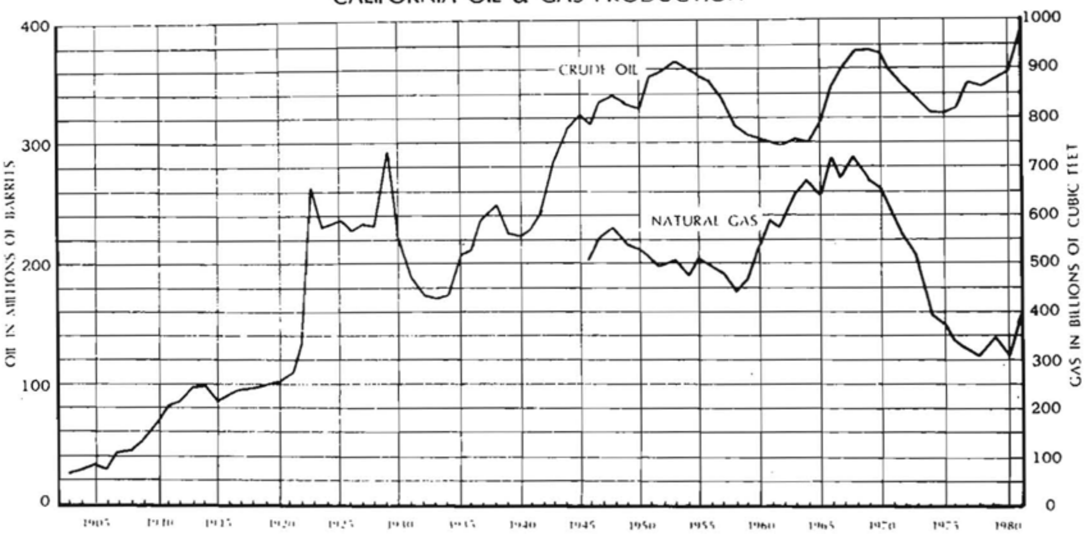
A group of refinery products developed from petrochemicals merits special attention. The group forms the basic material from which a vast array of products is produced, such as synthetic fibers and rubber, plastics, paints, fertilizers, and insecticides.

REFERENCE

Leffler, William L., 1979, Petroleum refining for the non-technical person: Tulsa, Okla. Pennwell Books, P.O. Box 21288, Tulsa, Oklahoma 74121.

CHAPTER 12
OIL AND GAS STATISTICS

CALIFORNIA OIL & GAS PRODUCTION



LARGEST CALIFORNIA FIELDS - 1987

OIL

FIELD	DISCOVERY DATE	OIL PRODUCTION (bbl)	CUMULATIVE OIL PRODUCTION (Mbbl)	ESTIMATED RESERVES (Mbbl) (Dec. 31, 1987)
1. Belridge, South (1)*	1911	63,562,322	616,000	494,942
2. Midway-Sunset (2)	1894	57,760,967	1,821,712	430,645
3. Kern River (3)	1899	45,667,201	1,158,042	789,674
4. Elk Hills (4)	1911	40,571,779	854,146	618,999
5. Wilmington (5)	1932	32,108,856	2,261,472	526,686
6. Coalinga (6)	1890	10,383,841	743,996	162,399
7. Hondo Offshore (7)	1969	9,586,621	79,378	122,522
8. Yowlumne (8)	1974	7,945,583	74,721	33,750
9. Ventura (10)	1919	7,278,869	887,658	103,367
10. Mount Poso (9)	1926	7,094,087	256,653	85,869

ASSOCIATED GAS
(OIL ZONE)

FIELD	DISCOVERY DATE	NET GAS PRODUCTION (Mcf)	CUMULATIVE GAS PRODUCTION (MMcf)	ESTIMATED RESERVES (MMcf) (Dec. 31, 1987)
1. Elk Hills (1)*	1911	59,743,471	648,985	1,162,876
2. Belridge, South (2)	1911	30,750,790	184,856	155,142
3. Lost Hills (3)	1910	18,797,179	268,353	136,457
4. Hondo Offshore (6)	1969	11,334,533	39,111	110,932
5. Belridge, North (4)	1912	11,031,271	589,802	124,380
6. Coles Levee, South (5)	1928	10,477,226	369,408	159,629
7. Buena Vista (8)	1909	5,797,839	1,007,847	127,446
8. Wilmington (7)	1932	5,730,071	1,107,648	85,036
9. Yowlumne (10)	1974	3,422,013	77,227	15,376
10. Santa Clara Offshore (NA)	1975	3,411,554	26,816	15,722

NONASSOCIATED GAS

FIELD	DISCOVERY DATE	NET GAS PRODUCTION (Mcf)	CUMULATIVE GAS PRODUCTION (MMcf)	ESTIMATED RESERVES (MMcf) (Dec. 31, 1987)
1. Rio Vista Gas (2)*	1936	25,162,803	3,302,076	197,861
2. Grimes Gas (1)	1960	24,061,059	514,548	146,381
3. Pitas Point Offshore Gas (3)	1978	20,738,828	92,513	65,598
4. Union Island Gas (5)	1972	11,635,711	177,928	83,662
5. Lindsey Slough Gas (4)	1962	10,847,200	242,553	36,733
6. Elk Hills-Gas Zone (7)	1911	7,185,625	148,367	171,132
7. Malton-Black Butte Gas (8)	1964	5,358,113	103,927	28,998
8. Millar Gas (NA)	1944	5,120,223	135,595	28,963
9. Lathrop Gas (6)	1961	4,942,861	333,679	24,615
10. Putah Sink Gas (NA)	1973	3,615,845	35,035	6,588

* Numbers in parentheses indicate 1986 field rankings.

CALIFORNIA OIL AND GAS FACTS 1987

GENERAL STATISTICS

Total land area of California	101,563,520 acres
Total land area productive as of 12/31/87	417,746 acres (or) 0.42%
Counties with oil and/or gas production	30
First year of commercial production	1876

CRUDE OIL PRODUCTION

Counties producing crude oil *(see county table)*	17
Active oil fields	242 †
Wells producing crude oil in Dec. 87	46,516*
Average daily production of crude oil per well on 12/31/87	23.2 bbl
Year of greatest crude oil production	1985
Crude oil produced in record year	423.9 million bbl‡
Crude oil produced in 1987	397.0 million bbl‡
Cumulative crude oil production as of 12/31/87	21.7 billion bbl‡

† Includes 7 active federal OCS fields. Carpinteria Offshore field is situated in both state and federal waters.
* Includes 362 federal OCS producing wells.
‡ Includes federal OCS production.

NATURAL GAS PRODUCTION

Active dry gas fields	103 †
Dry gas wells producing in Dec. '87	1,294*
Year of greatest natural gas production (total gas)	1968
Natural gas produced in record year	714.9 Bcf ‡
Natural gas produced in 1987	427.4 Bcf**
Cumulative natural gas production as of 12/31/87	32.1 Tcf**

† Includes 1 active federal OCS field.
* Includes 18 federal OCS producing wells.
‡ Includes both associated and nonassociated gas. Includes federal OCS production, which was 1.6 Bcf.
** Includes federal OCS production.

PROVED RESERVES

Estimated oil reserves as of December 31, 1987	5.2 billion bbl
Estimated gas reserves as of December 31, 1987	4.5 Tcf

OFFSHORE (STATE AND FEDERAL)

Percent of total state crude oil production	15.5%
State offshore production	30.3 million bbl
Federal offshore production (OCS)	31.1 million bbl
Total	61.4 million bbl
Percent of total state natural gas production	13.6%
State offshore production	13.0 Bcf
Federal offshore production (OCS)	45.1 Bcf
Total	58.1 Bcf

EXPLORATION AND DEVELOPMENT

Onshore

Deepest well:
Total depth: 24,426 feet (Stevens)
Year drilled: 1987
County: Kern (Sec. 29, T.30S., R.23E.)
Operator: Bechtel Petroleum Operations, Inc.
Well name: 934-29R

Deepest oil well (not producing):
Total depth: 18,876 feet
Year completed: 1975
Producing interval: 17,610-18,060 feet (Vedder) (abandoned-1977)
Field: Semitropic
County: Kern (Sec. 3, T.27S., R.22E.)
Operator: Tenneco Oil Company
Well name: "Tenneco-Union-GBR et al" 66X

Deepest gas well (not producing):
Total depth: 11,402 feet
Year completed: 1966
Producing interval: 11,064-11,144 feet (Forbes) (abandoned-1974)
Field: Clarksburg Gas
County: Yolo (Proj. Sec. 32, T.7N., R.4E.)
Operator: Occidental Petroleum Corporation
Well name: "Sherman Unit" 5

Deepest oil well (producing in 1987):
Total depth: 14,680 feet
Year completed: 1982
Producing interval: 14,528-14,540 feet (Stevens)
Field: Rio Viejo
County: Kern (Sec. 2, T.11N., R.21W.)
Operator: Koch Exploration Company
Well name: "Rio Viejo" 12X-2

Deepest gas well (producing in 1987):
Total depth: 12,576 feet
Year completed: 1978
Producing interval: 10,800-12,574 feet (Stevens)
Field: Cal Canal Gas
County: Kern (Sec. 31, T.28S., R.22E.)
Operator: Oxy Petroleum, Inc.
Well name: "Chevron" 88-31

State Offshore

Deepest dry hole:
Total depth: 17,180 feet (TVD† -16,666 feet)*
Year drilled: 1966
County: Ventura (Proj. Sec. 22, T.3N., R.24W.)
Operator: Chevron U.S.A. Inc.
Well name: "State 3403" 1

Deepest oil well:
Total depth: 14,236 feet (TVD-about 13,240 feet)*
Year completed: 1956
Producing interval: 12,551-13,927 (Colonia)
Field: West Montalvo, Offshore Area
County: Ventura (Proj. Sec. 35, T.2N., R.23W.)
Operator: Chevron U.S.A. Inc.
Well name: "State" C-5

Deepest gas well:
Total depth: 12,589 feet (TVD-about 12,200 feet)
Year completed: 1985
Producing interval: 11,135-11,365 (at intervals) Matilija**
Field: Molino Offshore Gas
County: Santa Barbara (Proj. Sec. 18, T.4N., R.31W.)
Operator: Shell Western E&P, Inc.
Well name: "SSMS 2920"8

† True vertical depth.
* Drilled from an onshore location.
** Seafloor completion.

ECONOMIC IMPORTANCE OF THE WEST COAST OIL INDUSTRY – 1981 †

TABLE I Original Investments in Physical Assets *
(In Thousands of Dollars - 000's Omitted)

Phase of Operations	Alaska	Arizona	California	Nevada	Oregon	Washington	Six-State Total
Exploration & Production	$ 8,000,000	$ 29,000	$ 20,354,000	$ 48,000	$ 15,000	$ 25,000	$ 28,471,000
Manufacturing	700,000	3,500	6,776,000	1,000	50,000	875,000	8,405,500
Marketing	95,000	130,000	1,891,000	65,000	210,000	285,000	2,676,000
All Other Assets /1	10,000,000	135,000	3,212,000	29,000	35,000	100,000	13,511,000
Total Investments	$ 18,795,000	$ 297,500	$ 32,233,000	$ 143,000	$ 310,000	$ 1,285,000	$ 53,063,500

TABLE II Employee and Salary Statistics - 1981 /2

Category	Alaska	Arizona	California	Nevada	Oregon	Washington	Six-State Total
Company Employees**	11,000	1,200	87,000	900	1,500	4,300	105,900
Employees' Salaries	$288,000,000	$25,000,000	$2,100,000,000	$22,000,000	$29,000,000	$102,000,000	$2,566,000,000
Average Salary Per Employee	$ 26,200	$ 20,833	$ 24,137	$ 24,444	$ 19,333	$ 23,721	$ 24,230
Investment Per Employee	$ 1,709,000	$ 247,000	$ 370,000	$ 159,000	$ 206,700	$ 298,000	$ 501,070
Total Industry Personnel***	15,000	13,000	345,600	4,960	13,760	24,000	$ 416,320

TABLE III Materials and Services Purchased /2 /3

Alaska	Arizona	California	Nevada	Oregon	Washington	Six-State Total
$ 640,000,000	$65,000,000	$4,400,000,000	$15,000,000	$101,000,000	$106,000,000	$5,327,000,000

TABLE IV Bonuses, Rents and Royalties To Federal and /2
State and Local and Private Companies or Individuals

Alaska	Arizona	California	Nevada	Oregon	Washington	Six-State Total
$ 500,000,000	$30,000,000	$2,900,000,000	$15,000,000	$ 12,000,000	$ 15,000,000	$3,472,000,000

TABLE V Direct Taxes Paid to State and Local Governments /2

Type of Tax	Alaska	Arizona	California	Nevada	Oregon	Washington	Six-State Total
Property	$170,000,000	$12,000,000	$355,000,000	$4,000,000	$ 6,200,000	$12,500,000	$ 559,700,000
Other	2,186,000,000	30,000,000	621,000,000	650,000	6,600,000	35,000,000	2,879,250,000
TOTAL	$2,356,000,000	$42,000,000	$976,000,000	$4,650,000	$12,800,000	$47,500,000	$ 3,438,950,000

* Excludes Investments in physical assets and employee data of oil field service contractors, supply companies and foreign operations. Figures are in total dollars.

** Direct oil company employees only.

*** Also includes lessee operations, consignees, commission agents, dealers and their employees. EXCLUDES oil field service contractors and other service and supply companies and their employees as well as foreign operations employees. (Figures are average of annual personnel employed during 1981.) (Includes Alyeska Pipeline contractor employees.)

/1 Includes Pipeline and Transportation Assets.

/2 Figures are in actual dollars.

/3 Expenditures are for purchased materials and services for 1981: Includes allocations for tanker ships, trucks and other such moveable items. Excludes crude oil and other petroleum product purchases and exchanges.

† Prepared by the Tax and Statistics Department, Western Oil and Gas Association, December 1, 1982.

CHAPTER 13
GEOTHERMAL ENERGY

Geothermal energy is natural heat generated deep inside the earth. Generally, such heat is not usable unless it occurs near the earth's surface and heats rocks and underground water.

Water temperature, pressure, volume, and mineralization determine how geothermal heat, once captured, can be used.

DRY STEAM

Dry steam geothermal resources are rare and valuable, as dry steam contains a relatively small amount of water and, therefore, relatively few mineral impurities. This is important for geothermal operations because, typically, minerals in geothermal fluids are deposited on well and power plant equipment. This can cause well and plant damage and shutdown.

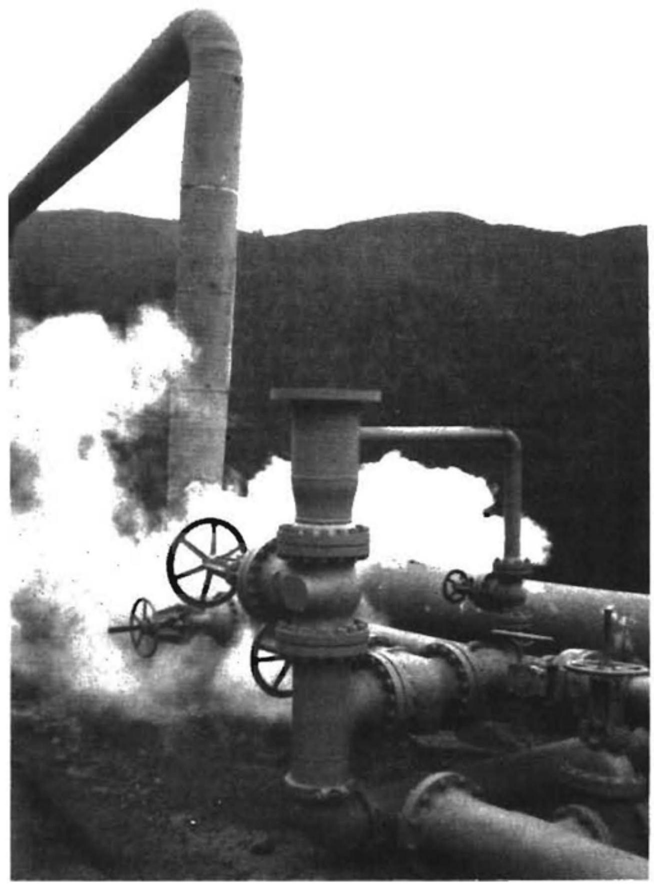
Geothermal fluids exist mostly as dry steam at The Geysers Geothermal field in Northern California. In The Geysers reservoir, groundwater is heated as it descends through faults and fractures. After sufficient heating, the water flashes to steam. Normally, overlying, impermeable rocks prevent the steam from rising to the surface. Geothermal production wells are drilled into the more permeable, steam-bearing fracture zones to tap the resource.

Once the steam is brought to the surface, it flows through above-ground pipelines to geothermal power plants. Here, it passes directly through a turbine generator to produce electricity.

HOT WATER

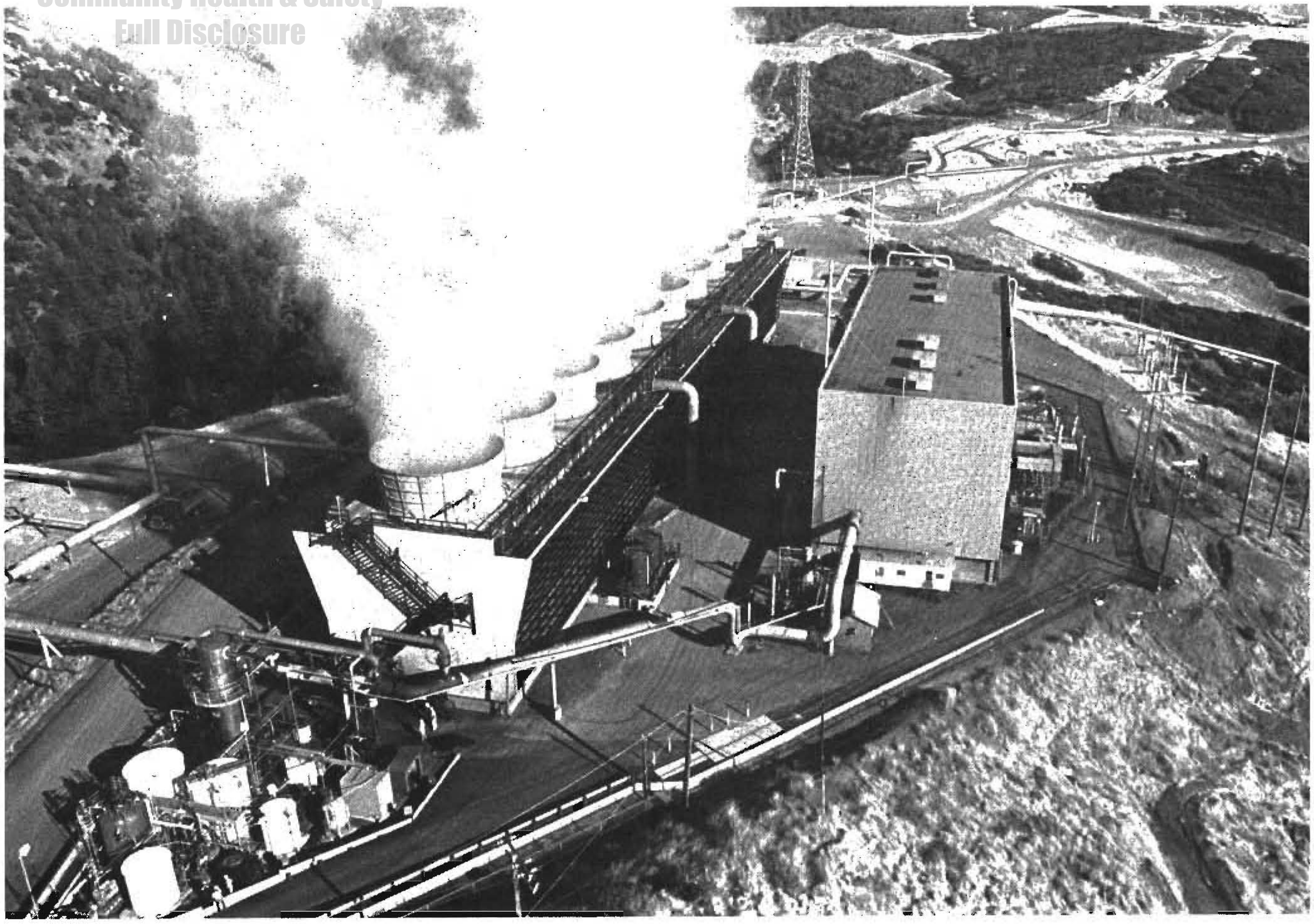
High Temperature

Hot water geothermal resources, such as those in the Imperial Valley, are more common and more difficult to develop than dry steam resources. Special processes are being developed to cope not only with highly mineralized geothermal water, but also with the disposal of spent geothermal water. Developing technology to handle the highly mineralized water has delayed the onset of large-scale electrical power generation from geothermal energy in these areas.



A geothermal wellhead at The Geysers Geothermal field, about 65 miles northeast of San Francisco, California. Until a steam well is connected to a pipeline network leading to a power plant, a small amount of steam is allowed to escape. This is done because once a well is completely closed in, steam will condense in the well bore, thereby quenching the well and making further steam production impossible.

Steam is transported to electrical generating plants in The Geysers Geothermal field through insulated pipelines. The U-joints allow for expansion.



An electrical generating plant at The Geysers Geothermal field. Steam lines approach the plant from several points. Electrical transmission lines are to the right and the rear of the plant.

Two processes are used to convert hot-water geothermal energy into electrical energy. Currently, the most popular method is to bring geothermal water to the surface at high pressure. Then, as the pressure is reduced, part of the water flashes into steam, which is used to turn a turbine generator. This flash process is used at 10 megawatt plants near Brawley and Niland, and at Cerro Prieto Geothermal field, near Mexicali, Mexico. At Cerro Prieto, four turbine generators produce 150 megawatts of electricity.

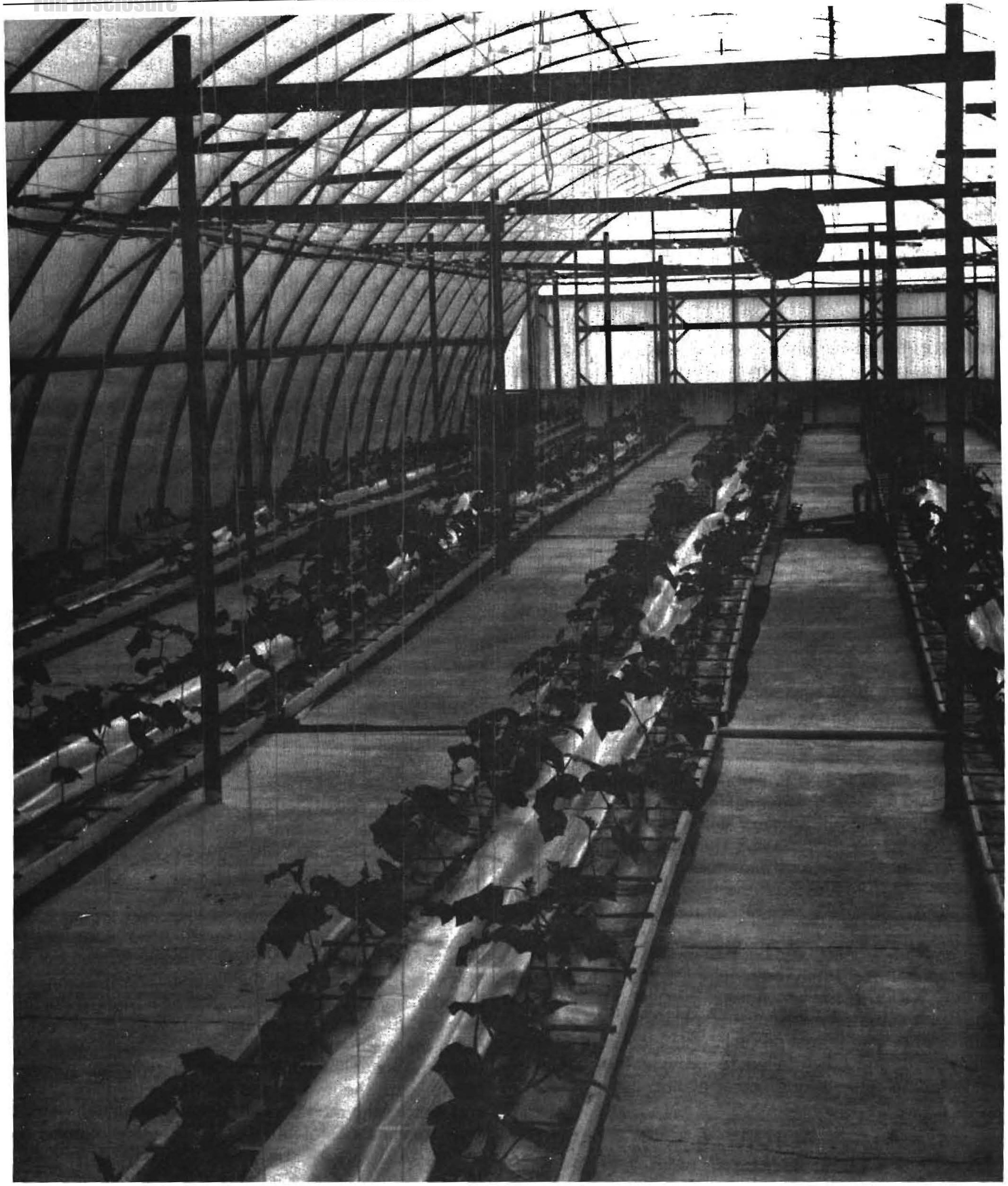
A second method, called the binary process, also uses geothermal water brought to the surface at high pressure. However, to minimize mineral precipitation, the hot water is passed through a heat exchanger and the heat is transferred to a working fluid with a low boiling point. The geothermal water is returned to the reservoir through injection wells, while the vaporized working fluid leaves the heat exchanger and passes through a turbine that turns the electric generator. The binary process is being tested at the East Mesa Geothermal field in the Imperial Valley. A commercial plant is now in the planning stage for the Heber Geothermal field.

Low Temperature

Sometimes geothermal water, although very hot, is too cool to generate electricity. Still, the heat can be used in many ways. People have visited hot springs for centuries for bathing, cooking, and medicinal treatments. Today, well-known California resort areas where hot springs are popular include the Cities of Calistoga and Desert Hot Springs.

Low-temperature geothermal waters also are used for activities such as space heating, aquaculture, snow melting, food processing, and dehydration. Susanville, California, has inaugurated a city-wide, space-heating project with hot water pumped from geothermal wells. Eventually, hot geothermal water will pass through 14 retrofitted public buildings before it is returned underground. The city also plans to provide heat to an industrial park and private homes.

A geothermal space-heating system is planned for the California Correctional Center—Susanville, at Litchfield. The partially cooled geothermal fluids returning from the correctional facility will be used in a nearby industrial park.



Inside a geothermally heated greenhouse near Wendel, California. Hot water (216°F) is pumped from a nearby geothermal well and piped through a distribution system into radiator-fan units suspended at both ends of the greenhouse (photo right of center). Air warmed by the geothermal water is blown through perforated, clear-plastic ducts that extend throughout the greenhouse. The rows of young cucumbers are planted in troughs. *Photo by Dick Thomas, CDOG.*

Near Wendel, California, numerous greenhouses are being heated with geothermal water. In Paso Robles and Mecca, geothermal waters are used for raising catfish and prawns.

EXPLORATION AND DEVELOPMENT

Some of the most promising areas for finding geothermal energy are in a belt circling the Pacific Ocean. The belt, called the *ring of fire,* includes the western coastlines of South, Central, and North America. Geological features characteristic of these areas include active faults, volcanoes, geysers, fumaroles, hot springs, and hot groundwater.

The map in this chapter indicates where geothermal resources have been discovered in California. Geologists begin exploring for geothermal resources by searching for surface geothermal features, such as hot springs, fumaroles, geysers, and areas where snowcover has melted.

After securing the necessary leases and permits in geothermal prospect areas, geophysical studies, such as gravity and magnetic surveys, are made to determine if any unusual geological conditions exist. Such conditions are called *anomalies.*

Once an anomaly is found, temperature observation wells are drilled and temperature profiles run at the anomaly area. Water samples are taken from nearby water wells and analyzed for chemical indicators of heat at depth. In addition, temperature-gradient profiles are run for these wells. If unusually high temperatures are located, an exploratory well may be drilled to determine whether or not a viable geothermal resource exists.

Once a well has been drilled, it is flow tested to measure the extent of the geothermal resource. If the results are satisfactory, the well operator will seek financing to develop and market the resource. The operator may need to drill additional wells and undertake additional reservoir assessments to assure both the financer(s) and user(s) that the geothermal reservoir can meet their needs.

For low-temperature geothermal projects, only 1 or 2 development wells may be required, with, perhaps 1 injection well (if the geothermal water quality is so poor that subsurface disposal is necessary). For high-temperature geothermal projects (electrical generation), many wells must be drilled to provide the resources necessary to operate one power plant.

HISTORY

Use of California geothermal resources started at the hot springs found throughout the state. Here, Indians and later settlers gathered to enjoy the thermal waters. By the late 1800's, some hot springs areas were both well known and commercialized. One such area, The Geysers Resort, was in what today is called The Geysers Geothermal field.

The first attempt to develop the electrical power potential at The Geysers Geothermal field was made in 1921 by J.D. Grant, who formed The Geysers Development Company. At that time, a well was drilled along Big Sulphur Creek in the Big Geysers area, where there are steam vents, fumaroles, and hot springs. By 1925, eight wells had been drilled, the deepest to 487 feet. Finally, development stopped because of poor prospects for marketing energy generated from the steam. The wells were abandoned in 1969 by Union Oil Company, the present operator.

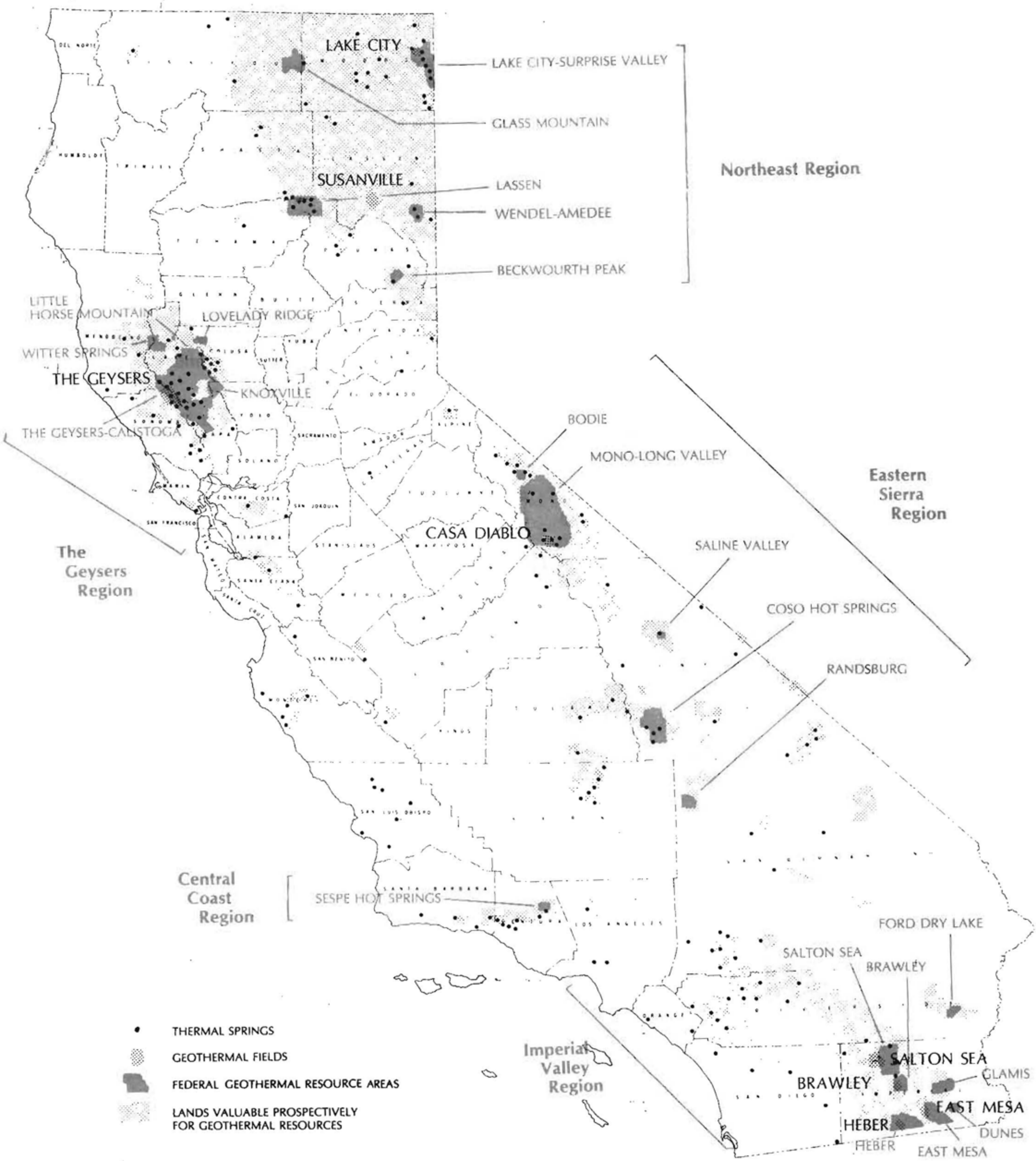
In 1955, development at The Geysers began anew when Magma Power Company obtained a lease from The Geysers Development Company and drilled "Magma" 1, the first modern geothermal well in California. Next, Magma Power Company joined with Thermal Power Company to drill additional wells to test the potential of The Geysers reservoir and to aid in marketing the steam. By the end of 1959, 13 geothermal wells had been drilled. In 1967, Magma and Thermal Power Company merged their holdings at The Geysers with those of Union Oil Company of California. Union was named operator of the steam production phase of the project. In 1981, Magma sold its interest at The Geysers to Natomas Company.

In September 1960, the first power plant at The Geysers was installed, with a generating capacity of 12.5 megawatts of electricity. By September 1980, 15 power plants were operated by the Pacific Gas and Electric Company at The Geysers, with a total installed generating capacity of 930 megawatts of electricity. Steam to drive the electrical-generating facilities is piped to the power plants from about 150 producing wells. Pacific Gas and Electric Company and other organizations plan to build additional power plants in the field. An electical-generating capacity of about 2,000 megawatts is expected by the year 1990.

Surface geothermal phenomena have been noted in the Imperial Valley for many years. In the Salton Sea area, steam fumaroles and boiling mud pots were observed near an extinct volcano now known as Mullet Island.

In 1905, during construction of irrigation works, a mishap occurred that diverted Colorado River water into the Imperial and Coachella Valleys. The river flowed at uncontrolled rates for more than a year, emptying into the Salton basin, and forming the Salton Sea. Most of the mud pots and fumaroles near Mullet Island were covered by the rising waters. They were exposed again for a time when the water level dropped due to evaporation, but, in recent years, the level of the sea has been rising steadily and most of the mud pots are once again under water. A small remnant area of mud pots is still visible in the NW¼ of Sec. 24, T. 11S., R. 13E., about 2½ miles southeast of Mullet Island. The present level of the Salton Sea is maintained by irrigation runoff from the Coachella and Imperial Valleys.

The first attempt to exploit the geothermal resources of the area occurred when three wells were drilled on Mullet Island in 1927 and 1928 by the Pioneer Development



California thermal springs, geothermal fields, Geothermal Resource Areas, and lands valuable prospectively for geothermal resources.

Locations for thermal springs from *U.S. Geological Survey Professional Paper 492 (1965)*. Locations for Geothermal Resource Areas and lands valuable prospectively for geothermal resources from the Jet Propulsion Laboratory report, *Geothermal Energy Resources in California: Status Report for ERCDC (1976)*.

Company as an assessment for the Southern Sierra Power Company. The deepest of these was drilled to 1,473 feet and the drilling fluid reached a maximum temperature of 245°F. All three wells produced steam, hot water, and noncondensible gases; however, steam pressures and volumes were not considered sufficient for commercial operation, and the wells were abandoned.

As these first wells were drilled and tested, it was noted that large amounts of carbon dioxide were produced. This observation led to the formation of the Salton Sea Products Corporation, which began exploring for carbon dioxide gas. In 1932, a well was drilled in this venture, about a mile northeast of Mullet Island, which was the discovery well for the Imperial Carbon Dioxide field. The field was produced commercially from 1933 to 1954, and carbon dioxide was recovered from shallow sands 200- to 700-feet deep. Two processing plants were built in the field to convert the carbon dioxide to dry ice. The field was abandoned in 1954 because of carbon dioxide depletion in the producing sands, the rising waters of the Salton Sea (which covered many of the wells), and the development of modern refrigerated transport systems.

What is generally considered to be the discovery well for the Salton Sea Geothermal field, and the first well in the Imperial Valley to produce substantial amounts of geothermal fluids, was Kent Imperial Corporation well "Sinclair" 1. The well was drilled as an oil prospect in 1957 and 1958 to 4,725 feet. When it was tested, it produced hot water and steam. A small pilot electrical generation plant was installed at the wellhead in 1959. This test facility was operated intermittently for several months until mineral deposition on the equipment caused it to be shut down.

The first well in the Imperial Valley to be drilled expressly for geothermal resources was well Joseph I. O'Neill, Jr. "Sportsman" 1. It was drilled in 1961 to 4,729 feet, about 4 miles northeast of "Sinclair" 1. From 1961 through 1964, 10 more geothermal wells were drilled in the vicinity, 8 of which produced geothermal fluids. The mineral content of brine from these wells was very high, sometimes reaching concentrations of over 300,000 ppm total dissolved solids. The brine was slightly caustic, and production was hampered by severe corrosion and scaling. The Morton Salt Company (Imperial Thermal Products, Inc.) and Union Oil Company erected small pilot plants in an effort to extract minerals from the brine. After a few years of experimentation with brine production and electricity generation, the ventures were terminated as uneconomical.

In 1965, the University of California at Riverside began intensive geothermal investigations of the Imperial Valley that lasted through 1970. This program was later supported by many organizations, including the U.S. Bureau of Reclamation, the National Science Foundation, Standard Oil Company of California, the Chevron Oil Field Research Company, the Imperial Irrigation District, and the United States Department of Energy.

Today, the Imperial Valley has four geothermal fields (Salton Sea, Brawley, Heber, and East Mesa) and about 150 geothermal wells. By the end of 1982, 3 power plants were producing about 27 megawatts of electricity and 6 power plants were in the permitting process.

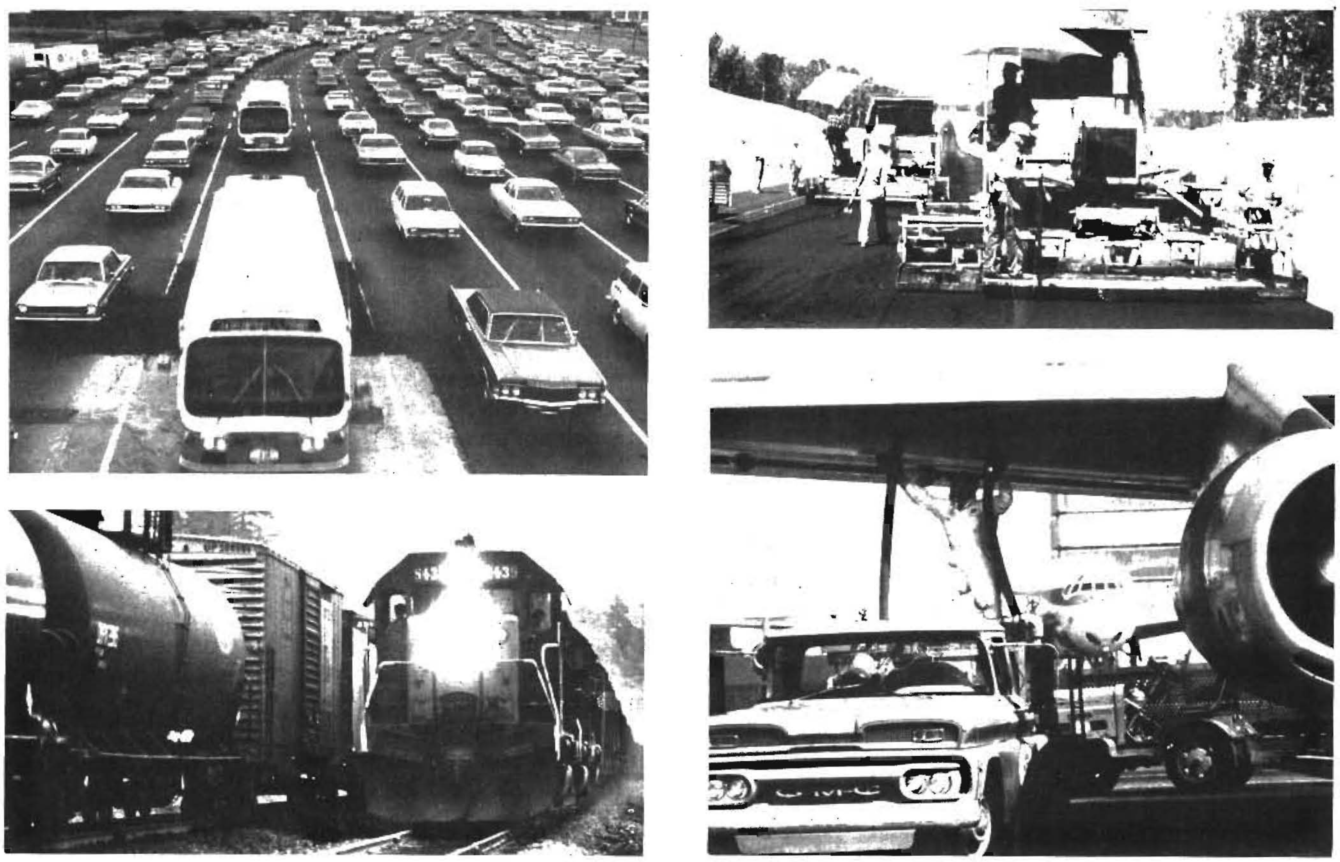
CHAPTER 14
CONSERVATION

WHY CONSERVE?

Edward F. Arn, governor of Kansas from 1951-1955 and former Chairman of the Interstate Oil Compact Commission, once said: "Oil and gas are of great importance to every man, woman, and child in the United States.

"Some of the clothes you wear, the furniture in your home, the equipment in your office, the telephone, nylon, and numerous other articles of common use, are products made from oil and gas. *It is the principal source of the fuel and lubricants necessary for modern machinery.*

"It has truly been said that oil is everybody's business. In time of peace, oil is vital to the whole economy of the country and to our standard of living. It makes our way of life possible. In time of war, it is indispensable for our protection and security, and without it our lives are in jeopardy."



Oil keeps our nation moving.

From transportation to growing and preparing the food we eat; from our clothing to our furniture and much of our heat and electricity——oil, gas, and products made from them form mainstays in our lives. *Photo by James Spriggs, CDOG.*

WHAT IS CONSERVATION?

Conservation is the wise production and use of our resources for the benefit of present and future generations. Conservation is essential to the survival and well-being of mankind.

THE ROLE OF THE DIVISION OF OIL AND GAS

The California Division of Oil and Gas was established in 1915, by act of Legislature, as a branch of the California State Mining Bureau. In 1929, after reorganization, the Division of Oil and Gas became an independent agency in the Department of Natural Resources, now the Department of Conservation.

The Public Resources Code, Division 3, Chapters 1 through 4, governs the regulatory functions of the Division of Oil and Gas. The code charges the division with the responsibility of supervising oil, gas, and geothermal well drilling, operation, maintenance, and abandonment operations to prevent damage to life, health, property, and natural resources. More specifically, the division must:

1. Prevent damage to underground oil, gas, and geothermal deposits;
2. Prevent damage to underground and surface waters suitable for irrigation or domestic use;
3. Prevent other surface environmental damage, including subsidence;
4. Prevent conditions that may be hazardous to life or health; and,
5. Encourage the wise development of oil, gas, and geothermal resources through good conservation and engineering practices.

About 60 division petroleum engineers and geologists in eight district offices work towards these objectives. The division's headquarters is in Sacramento.

The Public Resources Code also gives the division Lead Agency status, under the California Environmental Quality Act, in the environmental review process for geothermal exploratory projects.

The division publishes maps, technical papers, and statistics to aid its professional staff, the public, and industry to better understand the nature of the resources and the problems and trends associated with oil, gas, and geothermal development and conservation.

Oil pumping units in an agricultural area in Southern California exemplify multiple land-use practices.

FUNDING

Funds for the support of the California Division of Oil and Gas are raised by an assessment on the petroleum industry as provided for in Article 7, Division 3, of the Public Resources Code.

The assessment rate is established annually and is based on the projected expenditures of the division. For the 1981-82 fiscal year, the rate of assessment was about 1.6 cents per barrel of oil or per 10,000 cubic feet of natural gas produced. Division geothermal activity is supported, in part, by funds raised from this assessment and by fees levied on applications to drill or redrill geothermal wells.

CHAPTER 15
ENVIRONMENTAL PROTECTION AND ENHANCEMENT

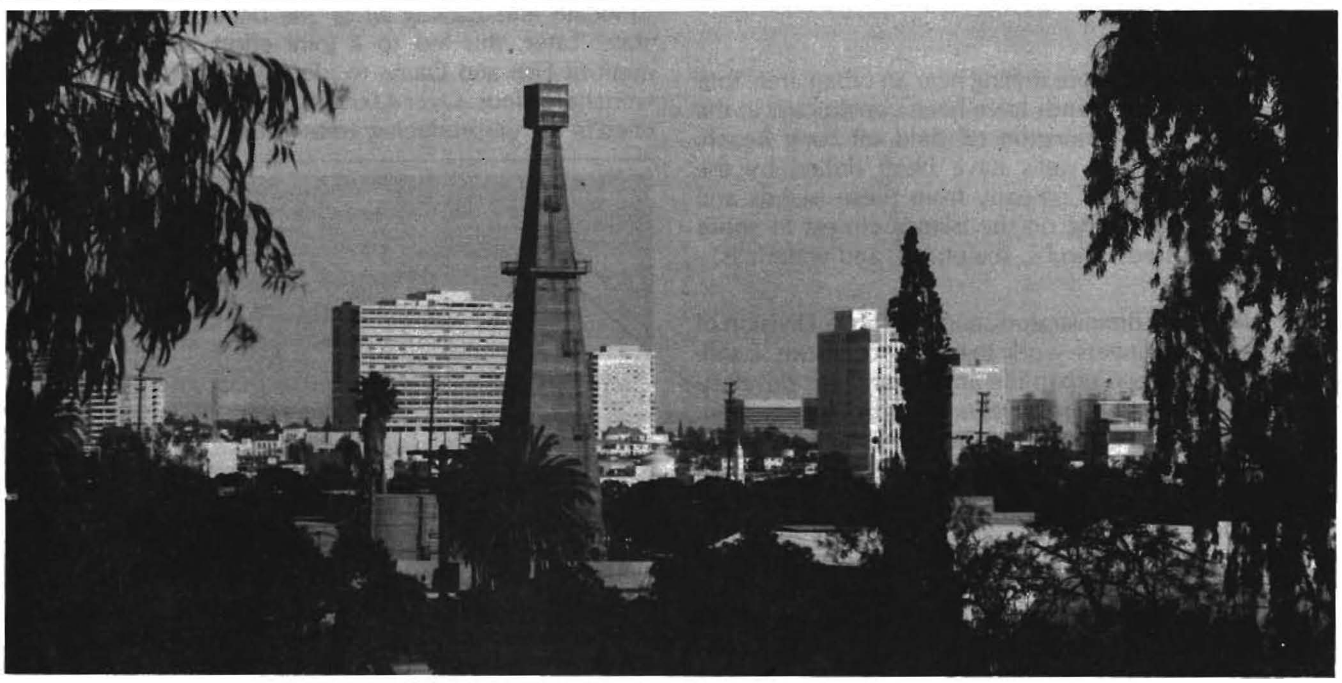
URBAN OIL AND GAS DEVELOPMENT

About one-third or 1.7 billion barrels of California's oil reserves are in urban areas or in areas where residential development is increasing. The Los Angeles Basin both typifies the situation and is the most complex example. Here, a large metropolitan area lies over one of California's major petroleum-producing provinces. Oil production began in downtown Los Angeles in 1893. Since that time, Los Angeles has grown until, in 1980, it had the 4th largest urban population in the world.The L.A.Basin, itself, is judged as holding more oil than any area its size in the world.

These two characteristics have led to conflicts. Urban dwellers and developers have often pushed to end oil and gas production, yet they have increased oil and gas demand by their own lifestyles. Because oil and gas are so fundamental to the United States economy, any recoverable amounts cannot be ignored. Ways have been developed to produce oil and gas safely in urban areas, with minimum negative effects.

As part of this program, urban drill sites often include sound-proofed drilling and producing facilities that, at more permanent sites, are constructed to resemble modern high-rise buildings. Landscaping appropriate to such buildings surrounds the sites.

In urban areas, wells usually can't be drilled from sites directly above desired bottom-hole locations, because



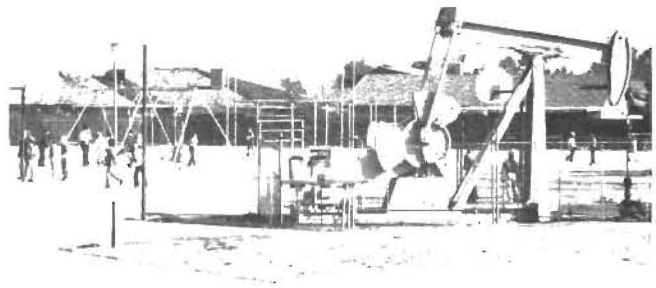
A sound-proofed oil drilling rig in Sawtelle oil field, West Los Angeles. This Occidental Petroleum Corporation drill site is on the hospital grounds of the Veterans Administration Center, and near a residential area.

One of four man-made drilling islands off of Long Beach, California. The tall structures are camouflaged drilling rigs, and wells are directionally drilled from all around the island. People have mistaken the structures for apartment buildings and inquired about rental rates.

buildings, roads, or other facilities usually occupy these areas. Instead, the wells are drilled directionally from nearby locations.

In an example of offshore drilling near an urban area, four 10-acre, man-made islands have been constructed in the East Area of the Wilmington oil field off Long Beach, California. Over 700 wells have been drilled by the THUMS Long Beach Company from these islands and from Pier J. Landscaping on the islands closest to shore includes palm trees, shrubs, sculptures, and waterfalls.

Urban planners, administrators, and California Division of Oil and Gas engineers work together to ensure a safe partnership between urban life and oil and gas development. In 1982, the California Department of Conservation, Division of Oil and Gas and the City of Huntington Beach co-sponsored a workshop on Land Use Planning in Urban Oil-Producing Areas. Planners and administrators from several cities and counties in the Southern California area met to discuss such topics as the importance and value of urban oil resources, problems in oil fields as they face urban encroachment, and strategies for preserving access to this vital resource. Meeting proceedings are available from the division in a publication titled *Land Use Planning in Urban Oil-Producing Areas.*



Oil well in Fruitvale oil field, Kern County. *Photo by Hal Bopp.*

HAZARDOUS AND IDLE-DESERTED WELLS

Numerous old California oil and gas wells, many of which were drilled at the turn of the century, were improperly abandoned. Such wells are often found when they begin to leak oil, natural gas, or water. To protect the environment, the wells must be properly abandoned, an activity financed with monies from the Hazardous and Idle-Deserted Well Abandonment Fund, established by the Legislature in 1976.

The California Division of Oil and Gas was mandated to administer the program, using up to $500,000 a year to abandon or remedy improperly abandoned wells so that dangers to life, health, and natural resources are eliminated. Through 1981, 68 wells have been abandoned under the program.

OILFIELD SUMPS

Oilfield sumps are open depressions commonly used to separate an oil-and water-mixture. Such sumps can be fatal to wildlife that mistake them for water holes. In late 1971, the California Division of Oil and Gas began to locate and catalog all of the oilfield sumps in the state. Later, this led to a joint effort with the Department of Fish and Game to identify which of the sumps were hazardous. Over 4,000 hazardous sumps were identified in the oil-producing areas of the state. Today, these

Cementing operations at Monticello Oil Co. Ltd. well No. 2, classified as hazardous by the California Division of Oil and Gas. The cementing operations are part of a procedure undertaken to properly abandon the well. *Photo by Ed Hickey.*

Screened oilfield sump in Southern California.

sumps have either been eliminated or screened, and are no longer a threat to birds and animals.

LEASE AND FACILITY MAINTENANCE

Eliminating hazardous oilfield sumps has helped to alleviate the problem of oil spills. Often, such spills were caused by sump liquids overflowing into drainage channels, particularly during the rainy season. Other spills occur when tanks or pipelines ruptured in an oil field.

The division requires good housekeeping procedures on oilfield leases. Such practices not only make leases more attractive, but safer and more environmentally compatible.

When operators maintain these leases in an exemplary manner, the division recognizes their efforts through its Outstanding Oilfield Lease and Facility Maintenance Award program.

HYDROGEN SULFIDE GAS

Hydrogen sulfide, a potentially lethal gas, is produced in several California fields, along with the oil, gas, and geothermal resources, and can be hazardous if adequate safety precautions are not taken. H_2S gas may be emitted from geothermal wells and power plants and from oil and gas wells and field facilities.

Many local, state, and federal agencies regulate the amounts of H_2S gas that may be emitted into the air. The California Division of Oil and Gas, as part of its well safety program, encourages the use of safe drilling and operating methods in an H_2S environment. It feels the best protection against H_2S-related accidents is knowing where H_2S is likely to be found and being well informed about H_2S safety practices. To this end, a manual has been prepared entitled *Drilling and Operating Oil, Gas, and Geothermal Wells in an H_2S Environment.* This manual is available from the division.

OFFSHORE OIL SPILLS

California has an excellent safety record for offshore drilling operations. About 2,000 wells have been drilled on state tidelands areas under Division of Oil and Gas supervision without a serious incident. (The Santa Barbara Channel blowout in January 1969 occurred in the federally controlled Dos Cuadras Offshore oil field, about 7 miles southwest of Santa Barbara.)

Stringent regulations, modern technology and personnel training for offshore operations make future major offshore oil spills unlikely. However, private industry and governmental agencies have developed contingency plans for combatting any spill that might occur.

The oil industry has formed nonprofit cooperatives to contain and clean up oil spills. Each of the organizations is responsible for a portion of the California coastline. The co-ops' chief function is to rapidly provide the manpower and equipment to clean up offshore oil spills. The co-ops work under the direction of member companies and state and federal agencies.

Offshore areas where oil production or maritime transport operations are concentrated, such as in the San Francisco Bay, the Santa Barbara Channel, the Los Angeles-Long Beach Harbor, and the Outer Continental Shelf, are areas of principal activity for co-ops. The co-op, *Clean Bay,* is headquartered in San Francisco, *Clean Seas* in Santa Barbara, *Clean Coastal Waters* and *Southern California Petroleum Contingency Organization (SCPCO)* in Los Angeles Harbor.

The California State Interagency Oil Spill Committee has developed an Oil Spill Contingency Plan. The principal objectives of this plan are to (a) provide a coordinated and integrated response to oil spills by the various involved agencies of the state, and (b) to provide local governments, the public, and the news media with accurate and timely information regarding a spill. The plan can function in coordination with, or independent of, the federal government's own contingency plan. Under the state plan, the State Interagency Oil Spill Committee has major responsibilities, while the U.S. Coast Guard has a similar role under the national plan.

GEOTHERMAL ENVIRONMENTAL EVALUATION

When a geothermal exploratory drilling project is proposed on California private or state lands, a review process is undertaken to study environmental, social, and economic issues raised by the project. Designated as Lead Agency under the California Environmental Quality Act, the California Division of Oil and Gas coordinates the review process and prepares the environmental documents. The division ensures that the proper public bodies and agencies participate in the review process, and that a decision on each project is reached within a statutory 135-day time limit.

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