Chapter 29
Petroleum Reservoir Traps

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Introduction

A reservoir trap is a combination of physical conditions that will cause hydrocarbon liquids and/or gases and water to accumulate in porous and permeable rock and prevent them from escaping either laterally or vertically because of differences in specific gravity, pressure, fluid/gas characteristics, and/or lithology. It has the capability of collecting, holding, and yielding hydrocarbon fluids and water.

The portion of the trap that contains oil and/or gas accumulations is the petroleum reservoir. It generally occupies a limited portion of the trap capacity, the remainder being occupied by formation waters that underlie and are interspersed within the petroleum accumulation.

Traps are formed by an infinite variety of structural and stratigraphic conditions of rock formations combined with pressure differentials among the various fluids within the reservoir rock. A trap consists of an impervious cover or roof rock overlying a porous and permeable rock. Reservoir pressure gradients and fluid flow within the reservoir rock can create traps that do not have structural closure. The boundary between oil and water or between gas and water need not be flat or level when these pressure gradients are present. Generally, however, traps do have structural closure, and as viewed from below, the impervious cover is concave, preventing the oil and gas, if present, from escaping vertically or laterally. The water underlying the oil and gas exerts a buoyant force on the oil/water boundary or contact, lifting and holding the oil and gas to the crest of the structure or area of minimum hydrostatic pressure.

Trap Classification

Classification of traps logically falls into three broad general groups: (1) structural, (2) stratigraphic, and (3) combination. More detailed classifications have been made by geologists attempting to include all factors and conditions that account for petroleum reservoirs. Many reservoirs have unique features that cause the oil to accumulate at a given location. The purpose of this chapter is to illustrate the more common geological conditions that cause traps and to point out a few of the infinite variety of minor variations that help create and hold petroleum accumulations in place.

Structural Traps

Structure implies some form of rock deformation, commonly expressed as a positive uplift, which may result in four-way dip closure. With the proper stratigraphy, structural traps may be present. Domes, anticlines, and folds are common structures. Fault-related features also may be classified as structural traps if closure is present. Structural traps are the easiest to locate by surface and subsurface geological and geophysical studies. They are the most numerous among traps and have received a greater amount of attention in the search for oil than all other types of traps. In new areas of exploration the prime search is for potential reservoir rock, source beds for hydrocarbons, and structural deformation. This structural deformation provides opportunities for several types of structural traps.

Domes, Anticlines, and Folds. Domes, anticlines, and folds in general must have structural closure to become effective traps. The reservoir rock must dip away in all directions from the crest of the structure. If there is not dip in all directions away from the crest but hydrocarbons are present, there are other contributing physical factors that helped complete the trap.

Domes, anticlines, and folds caused by structural deformation of sedimentary rocks generally create many potential traps because the deformation extends vertically through potential reservoirs. Thus a single well can reveal many possible pay zones when drilled on the crest of a domal structure.

*Fred L. Oliver wrote the original chapter on this topic in the 1962 edition.

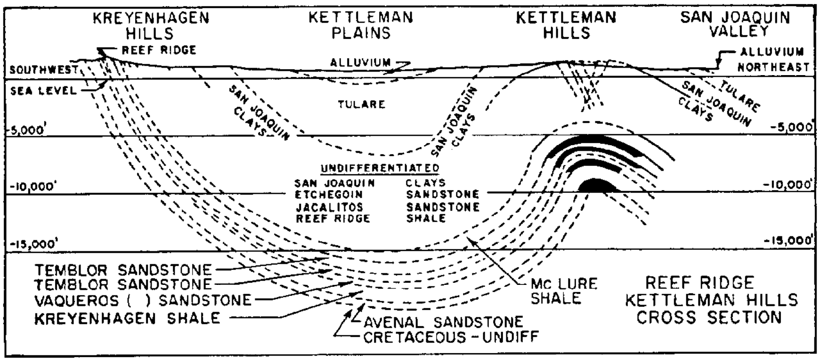

Fig. 29.1—Example of anticlinal folds creating structural traps; Kettleman Hills field.

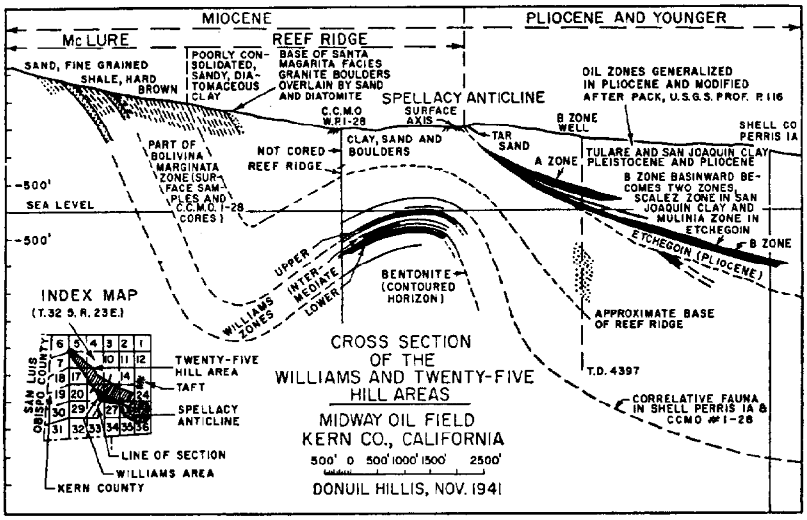

Fig. 29.2—Example of anticlinal folds creating structural and stratographic traps; Midway oilfield.

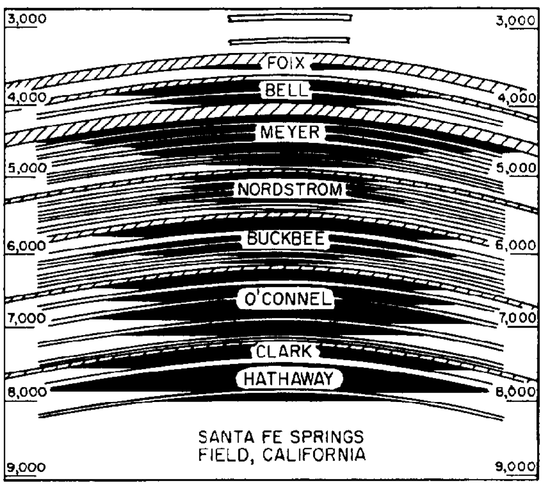

Fig. 29.3—Example of anticlinal folds creating many separate reservoirs; Santa Fe Springs field.

Figs. 29.1, 29.2, and 29.3 are cross sections of Kettleman Hills, Midway, and Santa Fe Springs fields, CA.[1] These are examples of single folds creating many separate accumulations. The separation between the various reservoirs is demonstrated in each case by different oil/water and gas/oil contacts in most reservoirs. The Midway field also illustrates stratigraphic traps formed on the flanks of the anticlinal fold.

Folds, anticlines, and domes are the easiest to interpret in subsurface studies. They vary in size from a few acres to several thousand acres. Folds and anticlines were created by compressional or tensional forces in the earth's crust or by differential compaction of the sediments. Asymmetrical anticlines, overturned anticlines, thrust faulting, and fracturing generally indicate areas of compression. Symmetrical folds and anticlines, low-angle normal faulting, monoclines, homoclines, and low-relief domal structures generally indicate areas of tensional forces or compaction.

Mountainous areas usually result from compressional forces. Torsion and shearing help cause local complex structures but are generally forces resulting from the more regional compressional forces of the earth's crust.

Stable areas or areas of subsidence are the counterpart to mountain-building compressional areas. They are areas where structures are caused by differential

Fig. 29.4—Examples of fault traps: normal or gravity faults.

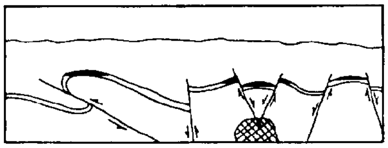

Fig. 29.5—Examples of fault traps: reverse or thrust faults.

downwarping, as in the midcontinent area of the U.S. and areas where structures are created by the lengthening of the earth's crust, such as the gulf coast of Texas and Louisiana. This lengthening causes regional horizontal tensional forces that create simple and more predictable local structures. The many prolific structural and stratigraphic oil trends that parallel the U.S. gulf coast today are the result of regional downwarping and tensional forces.

Fault Traps. Fault traps are classified as structural traps where closure is effected in one or more directions by faulting or where faulting has caused definite changes in the reservoir configuration (such as along strike-slip faults). Many structures are faulted without being limited by the faults or without changing the reservoir configuration. Fault traps can occur in both the up- and downthrown blocks. Closure against the fault can result from faults striking across regional dip or across anticlines or domes. Horsts and grabens and other closed fault blocks can result in traps with relatively no structural closure.

Normal or gravity faults (Fig. 29.4) occur as a result of tensional or gravitational forces. The angle of the fault plane with the horizontal generally ranges between 25 and 60°. Normal faults involve horizontal lengthening of the earth's crust and are recognized in the subsurface by loss of stratigraphic section in wells drilled through the fault plane. Geophysically, they are recognized by interruptions in the continuity of reflective interfaces.

Two common types of normal fault-related traps are: (1) fault closures and (2) rollover fault closures. Any structural nosing cut at right angles by a fault results in a fault closure. The direction of throw on the fault is not important but the closure created by the fault is. For example, a south-plunging structural nose cut at right angles by a fault will result in a potential trap. The fault throw may be in either direction. A trap will result if the fault acts as a seal or if the potential reservoir is thrown against a shale or other impermeable member on the opposite side of the fault.

Gravity-type faulting commonly occurs in areas of tension and over the crests of domes and anticlines because of the stresses involved. Fault traps are common in such an environment, and hydrocarbon accumulations may occur on either the up- or downthrown blocks, in horsts, and/or in grabens.

Rollover fault closures are common in sedimentary basins receiving great quantities of sediments. Closure is created on the downthrown block by contemporaneous sedimentation and fault movement. Through this interaction, more deposition takes place next to the active fault plane, resulting in a "downbending" of the deposits into the fault. This "downbending" creates a reversal in dip and this results in closure. This type of trap is extremely common in the Cenozoic formations of the U.S. gulf coast.

Reverse or thrust faults (Fig. 29.5) result from compressional forces and involve horizontal shortening of the earth's crust. The angle of the fault plane with a horizontal plane can vary from a few degrees to 90° and can be recognized in the subsurface by repetition of stratigraphic section in wells drilled through the fault plane. Structural traps of this nature are common on both the east and west coasts of North America. The occurrence of a trap against a fault depends on the fault plane sealing the porous reservoir rock and preventing migration across or along the fault plane.

Fractured formations usually are caused by local deformation, faulting and folding, reduction in overburden permitting expansion of the underlying rock, and differential compaction. Brittle rocks are more commonly affected because of their inelasticity. In many cases minor joints, fractures, and fissures are modified by solution and combine with primary and secondary porosity to give a greater effective reservoir porosity and permeability. Fractures in reservoirs increase the wellbore radius and permit extremely tight and impermeable areas to bleed into the fractures over a wide area and thus be connected with channels leading to the wellbore.

Production is sometimes obtained from igneous and metamorphosed rock as a result of fracturing. The fractures provide the reservoir space as well as the permeability to permit oil and gas migration, accumulation, and production from the reservoir.

For a trap to occur in a fractured formation, it must be overlain by a more pliable or less brittle rock that has not been fractured by the deformation. Otherwise, migration would occur up through the fractures and there would be no trap.

Where faulting caused the fracturing, production is limited to a narrow band along the fault. When folding or other deformation has caused the fracturing, the reservoir can become very complex in shape and unpredictable in production performance. Generally, the areas of greatest deformation have the greater number of fractures, which results in better well performance and recovery of more oil or gas.

Stratigraphic Traps

Traps created by changes in stratigraphy have the same physical requirements as structural traps. There is an updip limitation or termination of the reservoir rock, creating an area of minimum hydrodynamic potential or concave closure. In case of structural limitations, this is

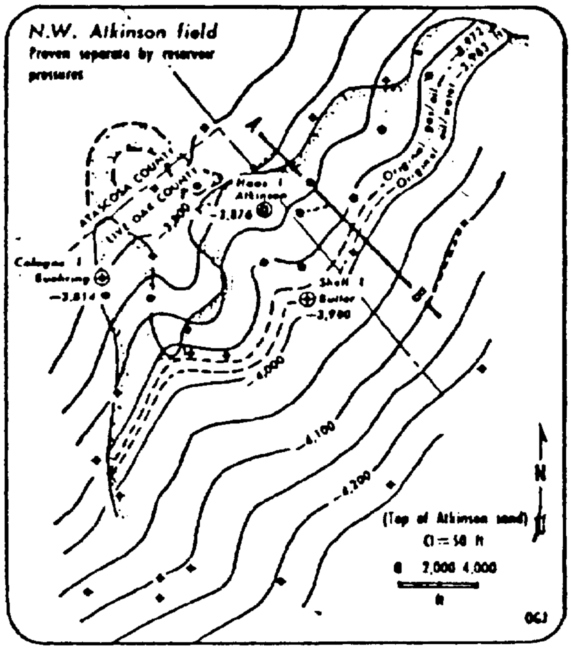

Fig. 29.6—Structural/stratigraphic interpretation; Northwest Atkinson field, TX.

obtained by faulting or a turnover of the reservoir rock. In stratigraphic traps, this limitation is accomplished by changes in porosity and permeability, which result from nondeposition, erosion and overlap, facies, and lithological changes caused by depositional variations, truncation, and differential compaction.

Stratigraphic traps can be classified as primary or secondary. Primary traps are those formed during sedimentary deposition: lenses, facies changes, shoestring sands, offshore sandbars, reefs, and detrital limestone or dolomite reservoirs can be classified as primary. Secondary traps are those resulting from later causes such as solution, cementation, erosion, fracturing, and chemical alteration or replacement.

Primary Stratigraphic Traps. These traps result from deposition of clastic or chemical materials. Shoestring sands, lenses, sand patches, bars, channel fillings, facies changes, strand-line (shoreline) deposits, coquinas, and weathered or reworked igneous materials are classified as clastic sedimentary deposits and can result in stratigraphic traps. Fig. 29.6 is a structural/stratigraphic interpretation of the northwest Atkinson field in Live Oak County, TX.[2] An ancient sand-filled stream channel meander has cut into older south-dipping shales and created a perfect stratigraphic trap. Fig. 29.7 is a cross section[3] across the Yoakum Channel in Lavaca County, TX. This is an example of a channel filled with shale. The shale plug served as the seal for reservoirs within a west-plunging structural nose. Hydrocarbons are trapped in the truncated updip portions of the reservoirs.

Organic reefs or bioherms and biostromes are the primary chemical stratigraphic traps; they are built by organisms and are foreign bodies to the surrounding deposits. A cross section of Scurry field in Scurry County, TX (Fig. 29.8) gives an example of a primary chemical stratigraphic trap.[4] The Strawn and Cisco-Canyon series are limestone reefs that have had younger sediments deposited on the flanks and eventually over the crest of the reef deposits. The shale serves as the seal. Differential compaction of the thicker shales on the

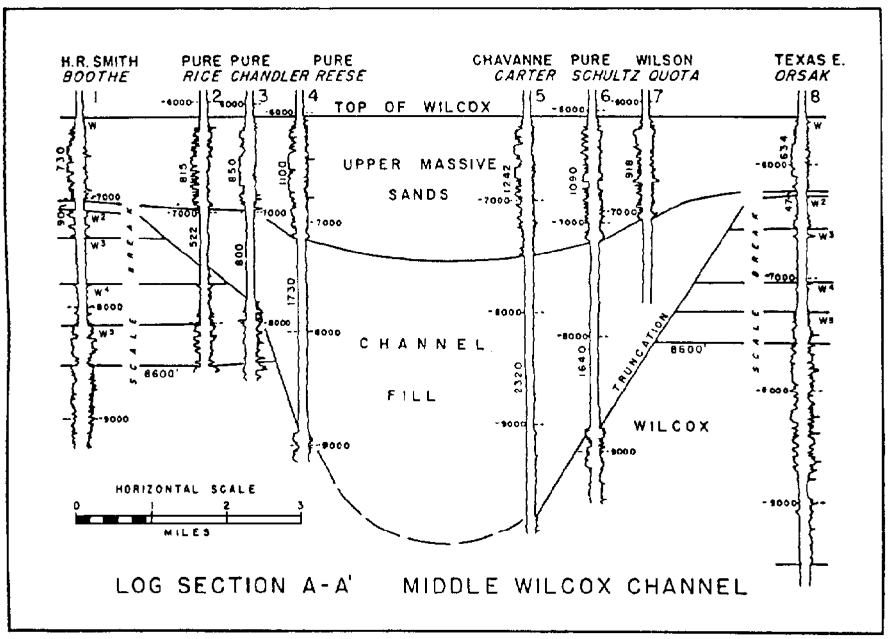

Fig. 29.7—Cross section showing stratigraphic position of upper Wilcox Yoakum channel.

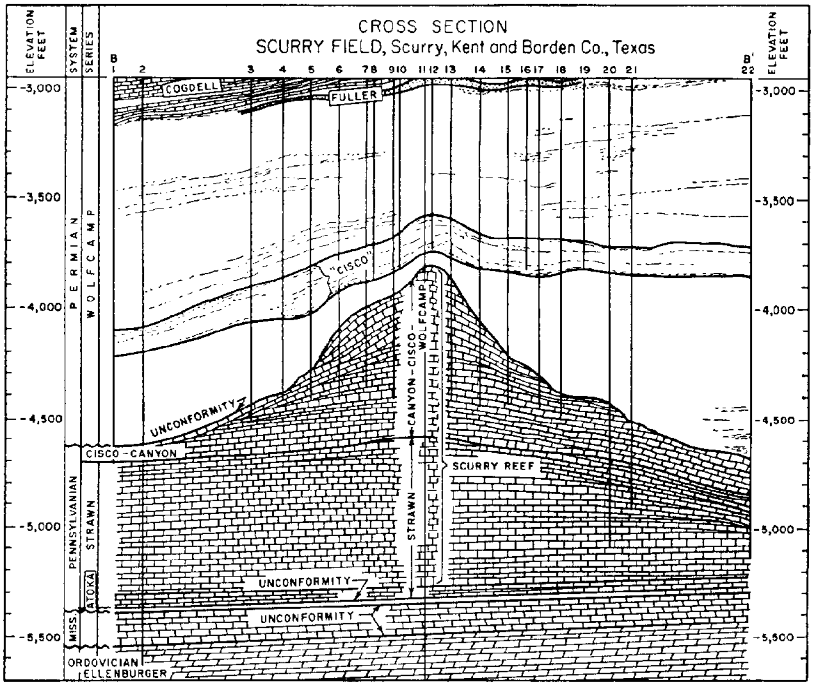

Fig. 29.8—Example of a stratigraphic reef field; structure and cross section of Scurry field.

flanks of the reef as compared with the thinner shale at the crest has created structural closure in younger overlying formations. Hydrocarbon accumulations have occurred in the Cisco and Fuller formations as a result of this differential compaction. Additional traps in other reservoirs are the result of updip permeability and porosity barriers and are either primary or secondary stratigraphic traps.

Secondary Stratigraphic Traps. Traps of this type were formed after the deposition of the reservoir rock by erosion and/or alteration of a portion of the reservoir rock through solution or chemical replacement.

Secondary stratigraphic traps actually should fall into the combination-trap classification because most are associated with or are the result of structural relief during some stage of development of porosity and permeability or limitation of the reservoir rock. However, many of the so-called typical "stratigraphic traps" fall into this category, and it is felt that it would be impossible to change the historical usage of this term. Therefore, secondary stratigraphic traps are defined for this discussion as those traps created after deposition and having limitations caused by lithology changes.

Erosion creates a major part of these through truncation of the reservoir rock. On-lap deposition (when the water is encroaching landward), off-lap deposition (when the water is regressing), and the chemical alteration of limestone result in many secondary stratigraphic traps.

The East Texas field (Figs. 29.9 and 29.10) is perhaps the most famous field in this classification. It is a truncation of the Woodbine formation as it approaches the regional Sabine uplift.[5] A certain amount of leaching of the cementing material by waters over the unconformity has resulted in increased porosity and permeability in the field as compared with similar Woodbine sands in the deeper portions of the East Texas basin.

Combination Traps

Combination traps are structural closures or deformations in which the reservoir rock covers only part of the structure. Both structural and stratigraphic changes are essential to the creation of this type of trap. Traps of this nature are dependent on stratigraphic changes to limit permeability and structure to create closure and complete the trap. Updip shale-outs, strand-lines, and facies changes on anticlines, domes, or other structural features causing dip of the reservoir rock create many combination traps. Unconformities, overlap of porous rocks, and truncation are equally important in forming combination traps. Faulting is also a controlling factor in many of these traps. Asphalt seals and other secondary plugging agents may assist in creating traps.

Salt Domes. These structures are of enough importance to justify a separate classification. However, sometimes they are difficult to identify, and many of the traps result from both stratigraphic variations and structural deformation.

Intrusion of rocks into overlying sediments may result in many different types of traps. Salt intrusions are more commonly associated with petroleum traps, although some igneous intrusions have also resulted in the formation of petroleum traps.

Salt domes are classified as piercement, intermediate, and deep-seated domes. Salt plugs or masses have moved up from greater depths through overlying sediments, forming traps in the sediments that have not been penetrated by the salt. Most salt intrusions took

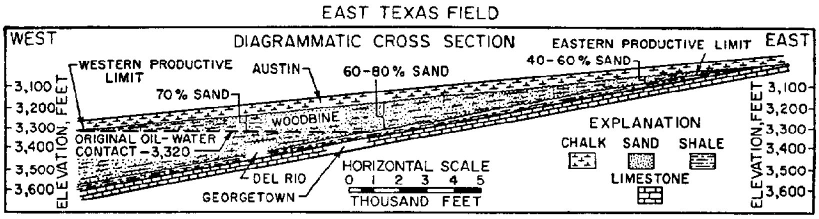

Fig. 29.9—Example of a secondary stratigraphic trap: structure and cross section of East Texas field.

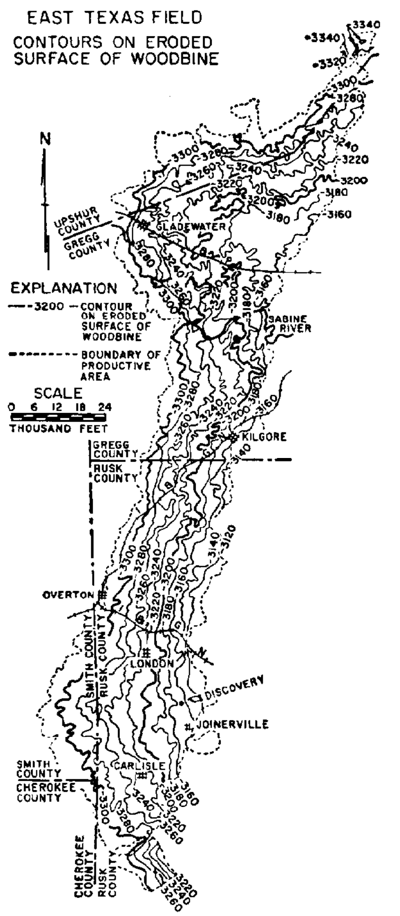

Fig. 29.10—Example of a secondary stratigraphic trap: structure and cross section of East Texas field.

considerable geologic time to reach their current position in the crust of the earth. Some are still growing, and apparently all have grown intermittently, allowing sands to be deposited over the crest of the structure at certain times and limiting deposition to the flanks of the structure at other times. The movement of the salt mass up through the surrounding rock creates many complex structures and sedimentary variations. Radial and peripheral faulting provide the avenue for the salt pushing up through overlying sediments. At times, the overlying formations were competent enough to stop or delay the growth of the salt plug. At other times, the salt apparently grew steadily and contemporaneously with the deposition. Many times the salt masses of some domes must have reached the surface or near surface, where groundwaters could act on the intrusive salt mass. Some of the domes are very near the surface of the ground. Some have reached the surface and are currently extruding salt. In areas of very low rainfall, such as southwest Iran, salt has reached a height of 5,000 ft above the surrounding terrain.

Deep-seated salt domes are normally those at considerable depths where the salt may not have been penetrated by drilling. These can be identified by the overlying characteristic structure or by geophysical data, which help prove salt is present at depths of 12,000 ft or more and can be assumed to have caused the overlying complex structure. Intermediate domes can be defined arbitrarily as those where the salt is deeper than 2,500 ft but has been penetrated by drilling at depths less than 12,000 ft.

Traps occur on the flanks of salt domes where sands have been faulted and deformed or terminate against the salt mass and where facies changes have resulted because of the associated uplift. These conditions are illustrated in Fig. 29.11.[6] Traps occur in the caprock, which consists of calcite, anhydrite, and limestone. Caprock is the insoluble residue on top of the plug that results from the dissolution of the salt from the crest of the plug. Porosity and permeability in the caprock result from fracturing, solution, chemical alteration, or any combination of these and are generally restricted to the calcite or limestone portions of the caprock.

Traps also overlie the salt mass and may result entirely from structural closure, faulting, differential compaction, or stratigraphic variations combined with the deformation, as indicated in Fig. 29.12.[7]

Characteristics of Reservoir Rocks

Classification of reservoirs* can be made on the basis of the texture, composition, and origin of the containing rock or the geometric configuration of the reservoir trap. Classification of reservoirs on the basis of rock texture and composition can assist in the prediction of reservoir performance. Variations in the mineralogy of reservoir rocks can be as important in reservoir performance as structural configuration or areal extent of the reservoir rock.

Sedimentary reservoir rocks can be divided into two groups: chemical and detrital. Sedimentary rocks are created by the weathering, disintegration, erosion, reworking, and deposition of material from older rocks.

*For more detailed coverage of this subject, refer to Refs. 8 and 9.

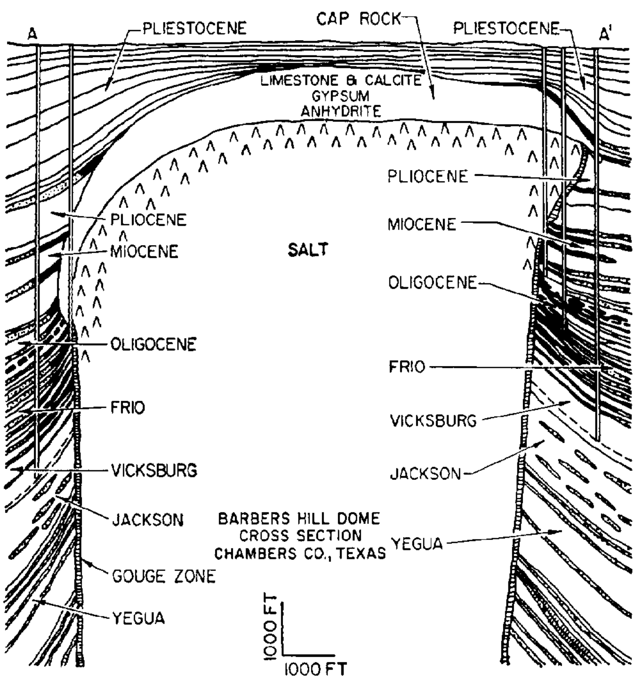

Fig. 29.11—Example of piercement-type dome showing termination of sands on the flanks of the salt plug and the resultant reservoir traps.

Clastic or detrital rocks are created from fragments transported by wind or water and allowed to settle out of suspension when the weight of the fragments is sufficient to exceed the carrying capacity of the transporting agent (wind or water). Chemical rocks are the result of precipitation of materials out of aqueous solution by organic growth and deposition or evaporation of seawater in closed basins, which precipitates salt and other evaporites. A list of reservoir rocks is given in Table 29.1.

Detrital Reservoirs

Clastic or Detrital Granular Reservoirs. These reservoirs can be classified according to rock types, depending on variations in source rock, transport distance, and depositional environment.

Quartzose-Type. Quartzose-type sediments occur in periods of geologic quiescence, with relatively flat coastal plains bordered by shallow seas. Weathering and chemical decay are at a maximum and erosion is at a minimum. Only stable minerals remain, and these are well sorted and generally uniform in texture and composition. Blanket sands and shales over extensive areas are general factors and the sandstones demonstrate high vertical as well as horizontal permeability. Waterdrive reservoir mechanisms can be expected and high recoveries by primary methods of production are the general rule because of the homogeneity of the reservoir rock. The coastal plains, embayments, and continental shelf along the Gulf of Mexico from Texas to Florida are typical of the physical requirements for this type of deposition.

Graywacke Sediments. These sediments occur in periods of moderate geologic disturbances. The coastal region is moderately uplifted and the depositional basins are somewhat deeper with a shorter continental shelf. More rapid erosion and shorter distances of transportation prevent the complete weathering and chemical decay of the sediments, and some of the more unstable minerals are able to remain. The land and adjacent basin areas are unstable, and minor isostatic adjustments occur from time to time, causing abrupt changes in the sediments being deposited. This causes poor sorting, lenticularity, irregular porosity and permeability variations, and heterogeneous deposition. Vertical permeability is poor, limiting water drive and gravity drainage. Production is normally gas-depletion drive, and the opportunities for secondary recovery operations are excellent. The New England coast is typical of the environment necessary for these types of deposits.

Arkose Sediments. Arkose sediments result from deposition during periods of intense orogenic movements. Certain land areas are sharply elevated above other land areas and/or the shoreline. Faulting and major isostatic adjustments occur frequently. The con-

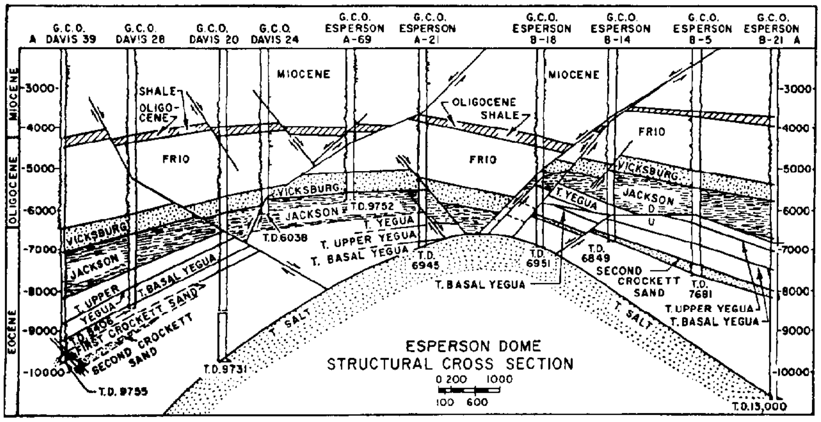

Fig. 29.12—Example of traps caused by a combination of structural and stratigraphic variations and of the complex faulting occurring above an intrusive salt mass.

TABLE 29.1—RESERVOIR ROCKS

Clastic and Detrital Porosity
1. Sand, conglomeratic sand, and gravel (clean, argillaceous, silty, lignitic, etc.)
2. Porous calcareous sandstone and siliceous sandstone (incomplete cementation)
3. Arkosic (feldspathic) sand, arkose, arkosic conglomerate (granite wash)
4. Detrital limestone and dolomite, oolitic and pisolitic limestone, coquina, and shell breccia

Fractured Porosity
1. Fractured sandstone and conglomerate
2. Fractured limestone, shale, and chert

Crystalline Porosity
1. Crystalline limestone and dolomite
2. Sugary dolomite "saccharoidal" porosity

Solution Porosity
1. Crystalline limestone and dolomite
2. Cavernous limestone and dolomite
3. Porous caprock
4. Honeycombed anhydrite
5. Ooliclastic limestone

TABLE 29.2—TYPES OF RESERVOIRS

Shale Reservoirs

Sometimes present in brittle, siliceous fractured shales

Anhydrite Evaporites

Develop porosity from leaching by circulating waters

Igneous or Metamorphic Rock
1. Very uncommon
2. Sometimes contain oil when secondary porosity is developed by fracturing or weathering
3. Best-known igneous reservoirs are the serpentine plugs of Bastrop and Caldwell counties, Texas

tinental shelf is extremely narrow or nonexistent. Maximum erosion and the short distance of transportation virtually eliminate chemical decay and weathering. Sediments are deposited and covered over by younger sediments before any appreciable sorting and weathering can take place. Unstable minerals are present in the thick heterogeneous deposits. Highly porous stratigraphic traps are developed by lensing, pinchouts, and unconformities. Depletion-drive reservoirs are the general rule and recoveries are usually low. Much of the California coast is typical of the depositional environment for the deposition of arkosic sediments.

Chemical Reservoirs

Limestones and Dolomites. Limestones and dolomites also are deposited in quiescent geologic environments. Deposition of limy deposits is occurring along the west coast of Florida and some of the Bahama Islands while clastic sediments are being deposited in other nearby local areas.

Carbonate Reservoirs. Carbonate reservoirs include reefs, clastic limestones, chemical limestones, and dolomite. Porosity may be intercrystalline, intergranular, oolitic or ooliclastic, vuggy fractured, fossiliferous, cavernous, or saccharoidal. Production characteristics are highly variable in carbonate reservoirs, depending almost entirely on the type of porosity and fracturing developed and the resultant permeability.

Other types of reservoirs are given in Table 29.2.

Glossary of Terms

Bioherm: A moundlike, domelike, lenslike, or reeflike mass of rock built by sedentary organisms (such as corals, algae, foraminifers, mollusks, and gastropods), composed almost exclusively of their calcareous remains and enclosed or surrounded by rock of different lithology.

Biostrom: A distinctly bedded and widely extensive or broadly lenticular, blanketlike mass of rock built by and composed mainly of the remains of sedentary organisms and not swelling into a moundlike or lenslike form. As an organic layer, such as a bed of shells, crinoids, or corals or a modern reef in the course of formation.

Breccia: A coarse-grained clastic rock composed of angular broken fragments held together by a mineral cement or in a fine-grained matrix.

Closure: In a subsurface fold, dome, or other structural trap, the vertical distance between the structure's highest point and its lowest closed structure contour. Four-way dip is determined by in-line and cross-line right angle control demonstrating dip in four directions away from the crest of the closure.

Coquina: A detrital limestone composed wholly or chiefly of mechanically sorted fossil debris that experienced abrasion and transport before reaching the deposition site, and weakly to moderately cemented but not completely endurated.

Detrital: Pertaining to or formed from detritus of rocks, minerals, and sediments. The term may indicate a source outside or inside the depositional basin.

Facies: The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin; especially as differentiating the unit from adjacent or associated units.

Graben: An elongate, relatively depressed crustal unit or block that is bounded by faults on its long sides.

Horst: An elongate, relatively uplifted crustal unit or block that is bounded by faults on its long sides.

Minimum hydrodynamic potential: As used here, a geologic position or condition due to impermeability in the reservoir rock where the dynamic action of fluid movement is abated.

Minor isostatic adjustment: The minor adjustment of the lithosphere of the earth to maintain equilibrium among units of varying mass and density; excess mass above is balanced by a deficit of density below and vice versa.

Normal fault: A fault in which the hanging wall appears to have moved downward relative to the foot wall. The angle of the fault is usually 45 to 90°. A low-angle normal fault is a normal fault with the angle of the fault less than 45°.

Off-lap deposition: The progressive offshore regression of the updip terminations of the sedimentary units within a comformable sequence of rocks in which each successively younger unit leaves exposed a portion of the older unit on which it lies. The successive contraction in the lateral extent of strata (as seen in an upward sequence) resulting from their being deposited in a shrinking sea or on the margin of a rising land mass.

On-lap deposition: The regular and progressive pinching out toward the margins or shores of a depositional basin of the sedimentary units within a conformable sequence of rocks in which the boundary of each unit is transgressed by the next overlying unit and each unit, in turn, terminates farther from the point of reference.

Oolicast: One of the small, subspherical openings found in an oolitic rock, produced by the selective solution of ooliths without destruction of the matrix.

Oolicastic porosity: The porosity produced in an oolitic rock by removal of the ooids and formation of oolicasts.

Oolith: One of the small round or oval accretionary bodies in a sedimentary rock resembling the roe of fish, usually formed of calcium carbonate and having a diameter of 0.25 to 2 mm.

Pisolith: One of the small, round or ellipsoidal accretionary bodies in a sedimentary rock, resembling a pea in size and shape, and constituting one of the grains that make up a pisolite. It is often formed of calcium carbonate and some are thought to have been produced by a biochemical algae-encrustation process. A pisolith is larger and less regular in form than an oolith.

Pisolitic: Pertaining to pisolite or to the texture of a rock made up of pisoliths or pealike grains.

Pisolitic limestone: A limestone with pisolitic texture.

Saccharoidal: Said of a granular or crystalline texture resembling sugar.

Shell breccia: A breccia composed of angular broken shell fragments.

Shoestring sands: A shoestring of sand or sandstone usually buried in the midst of mud or shale as in a buried sandbar or channel fill.

Strand line: The ephemeral line or level at which a body of standing water meets the land; the shoreline, especially a former shoreline now elevated above the present water level.

Strike-slip fault: A fault on which the movement is parallel to the fault's strike.

Torsion: The state of stress produced by two force couples of opposite movement acting in different but parallel planes about a common axis. Torsion faults are wrench faults or lateral faults in which the fault surface is more or less vertical.

Truncation: An act or instance of cutting or breaking off the top or end of a geologic structure or land form, as by erosion.

Unconformity: A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as interruption in the continuity of a depositional sequence of sedimentary rocks or a break between eroded igneous rocks and younger sedimentary strata. It results from a change that caused deposition to cease for a considerable span of time, and it normally implies uplift and erosion with loss of the previously formed record.

References

1. Galloway, T.J.: Bull. 118, California Division of Mines, Sacramento (Aug. 1957).
2. Sams, H.: "Atkinson Field; Good Example of "Subtle Stratigraphic Trap," *Oil and Gas J.* (Aug. 12, 1974), 145-63.
3. Hoyt, W.V.: "Erosional Channel in the Middle Wilcox Near Yoakum, Lavaca County, Texas," *Trans.*, Gulf Coast Assn. of Geological Societies (Nov. 1959) **9**, 41-50.
4. "Occurrence of Oil and Gas in West Texas," F.A. Herald (ed.) Bureau of Economic Geology and West Texas Geological Soc. (Aug. 1957).
5. "Occurrence of Oil and Gas in Northeast Texas," F.A. Herald (ed.) Bureau of Economic Geology and East Texas Geological Soc. (April 1951).
6. *An Introduction to Gulf Coast Oil Fields*, Houston Geological Soc. (1941).
7. *A Guide Book*, Houston Geological Soc. (1953).
8. Pirson, S.J.: *Oil Reservoir Engineering*, second edition, McGraw-Hill Book Co. Inc., New York City (1958).
9. Krynine, P.D.: "The Megascopic Study and Field Classification of Sedimentary Rocks," *J. Geol.*, **56**, No. 2.

General References

Aguilera R.: *Natural Fractured Reservoirs*, Petroleum Publishing Co., Tulsa (1980).

Bates, R.L. and Jackson, J.A.: *Glossary of Geology*, second edition, American Geological Inst. (1980).

Beebe, Warren B.: "Natural Gases of North America, Vols. 1 and 2," Memoir 9, AAPG (1968).

Bouma, H., Moore, G.T., and Coleman, J.M.: "Framework, Facies and Oil Trapping Characteristics of the Upper Continental Margin," AAPG (1978) Studies No. 7.

Braunstein, J.: "North American Oil and Gas Fields," AAPG (1976) Memoir 24.

Busch, D.A.: "Stratigraphic Traps in Sandstone," AAPG (1974) Memoir 21.

"Geologic Formation and Economic Development of Oil and Gas Fields of California," California Department of Natural Resources, Sacramento (1943).

Halbouty, M.T.: "Giant Oil and Gas Fields of the Decade 1968–1978," AAPG (1980) Memoir 30.

Halbouty, M.T.: "Salt Domes, Gulf Region, United States and Mexico," second edition, Gulf Publishing Co., Houston (1979).

Halbouty, M.T.: "The Deliberate Search for the Subtle Trap," AAPG (1982) Memoir 32.

Hanna, M.A.: "Gulf Coast Salt Domes," *Problems in Petroleum Geology*, AAPG (1934).

Hubbert, M.K.: "Entrapment of Petroleum under Hydrodynamic Conditions," *Bull.*, AAPG (Aug. 1953) **37**, 1954-2026.

King, R.E.: "Stratigraphic Oil and Gas Fields: Classification, Exploration Methods and Case Histories," AAPG (1972) Memoir 16, S.E.G. Special Publication No. 10.

Levorsen, A.I.: *Geology of Petroleum*, W.H. Freeman and Co., San Francisco (1954).

Mazzullo, S.J.: "Stratigraphic Traps in Carbonate Rocks," AAPG (1980) Reprint 23.

Payton, E.: "Seismic Stratigraphy—Applications to Hydrocarbon Exploration," AAPG (1977) Memoir 26.

Russel, W.L.: *Structural Geology for Petroleum Geologists*, McGraw-Hill Book Co. Inc., New York City (1955).

Scholle, P.A., Bebout, D.G., and Moore, C.H.: "Carbonate Depositional Environments, AAPG (1983).

"Structure of Typical American Oil Fields," *Bull.*, AAPG (1929).

Weeks, L.G.: "Habitat of Oil," AAPG (1958).

Wilhelm, O.: "Classification of Petroleum Reservoirs," *Bull.*, AAPG (Nov. 1945) **29**, 1537-79.

Woodland, A.W.: *Petroleum and the Continental Shelf of Northwest Europe, Vol. 1, Geology*, John Wiley Sons Inc., New York City (1975).

Young, A. and Galley, J.E.: "Fluids in Subsurface Environments," AAPG (1965) Memoir 4.