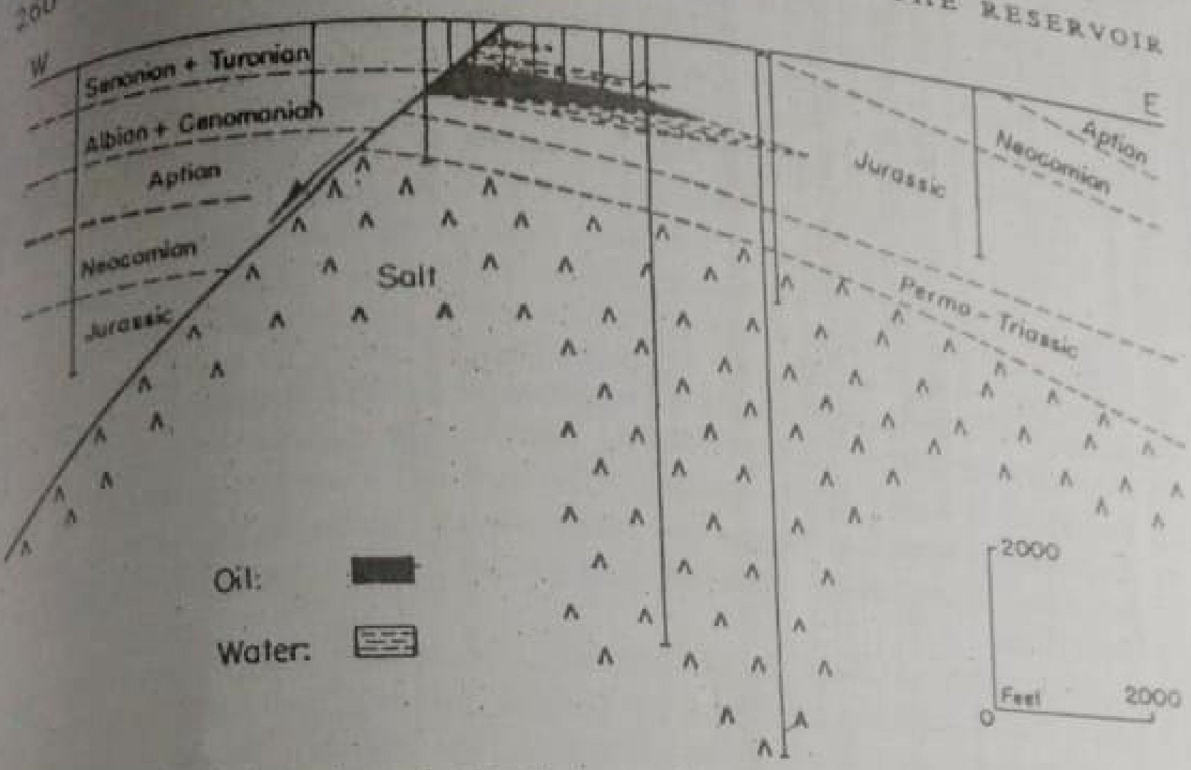


FIGURE 6-28 *Section through the Dossor oil pool in the Emba province of the USSR. Petroleum is trapped in a faulted Jurassic sand above a thick, folded salt mass. There is no evidence of intrusion of the salt. One well, at a depth of 750 feet, produced over 75,000 barrels of oil in 30 hours in 1911. [Redrawn from T. Jeremenko,* Neftyonoye Khozyaystro (Petroleum Economy), *Moscow (1939), and C. W. Sanders, Bull. Amer. Assoc. Petrol. Geol., Vol. 23 (1939), p. 505.]*

Traps Caused by Faulting

Normal, or gravity, faults and reverse and thrust faults[30] in the reservoir rock have wholly or partly formed the trap for many oil and gas pools; most pools found in structural traps, in fact, are modified by faults. Faulting may be the sole cause of the formation of a trap, but more commonly faults form traps in combination with other structural features, such as folding, tilting, and arching of the strata, or with variations in the stratigraphy or permeability. Faulting has been a minor trap-forming element in many pools, where it modifies the trap and causes local variations in the production characteristics.

Seepages of oil and gas are often associated with fault outcrops. Thus faults are commonly thought of as vertical channels permitting migration between reservoirs and to the surface. The presence of seepages at the surface suggests that the potentiometric surface of the aquifer is above the level of the ground. Lack of seepage, on the other hand, may indicate that the potentiometric surface is below the level of the ground. Many faults form the boundary plane of a pool of oil and gas, and this may be due to the fact that the fault is tightly sealed and holds the petroleum from further migration; or it probably more commonly is due to higher fluid potentials within the fault channels and up-dip across the fault which act as an added barrier to the up-dip movement of petroleum. The combination of the fault and the hydrodynamic conditions forms a trap that holds a pool.

Normal Faulting. Normal, or gravity, faulting, combined with a regional homoclinal dip, may form traps. There may be a single curved fault, as in Figure 6-23 (A), the intersection of two faults (B), or a combination of several faults (C). Normal faulting, combined with low folding, forms many pools, as in Figure 6-24 (A). As the folding becomes more acute, the trap becomes more definite (B); traps such as these are common on many elongated anticlines and domes.

The Round Mountain field, Kern County, California, contains pools trapped by the intersection of curved faults with a homoclinal regional dip. (See Fig. 6-25.) The West Edison field, nearby, contains traps formed by the intersection of normal faults with a homoclinal regional dip. (See Fig. 6-26.)

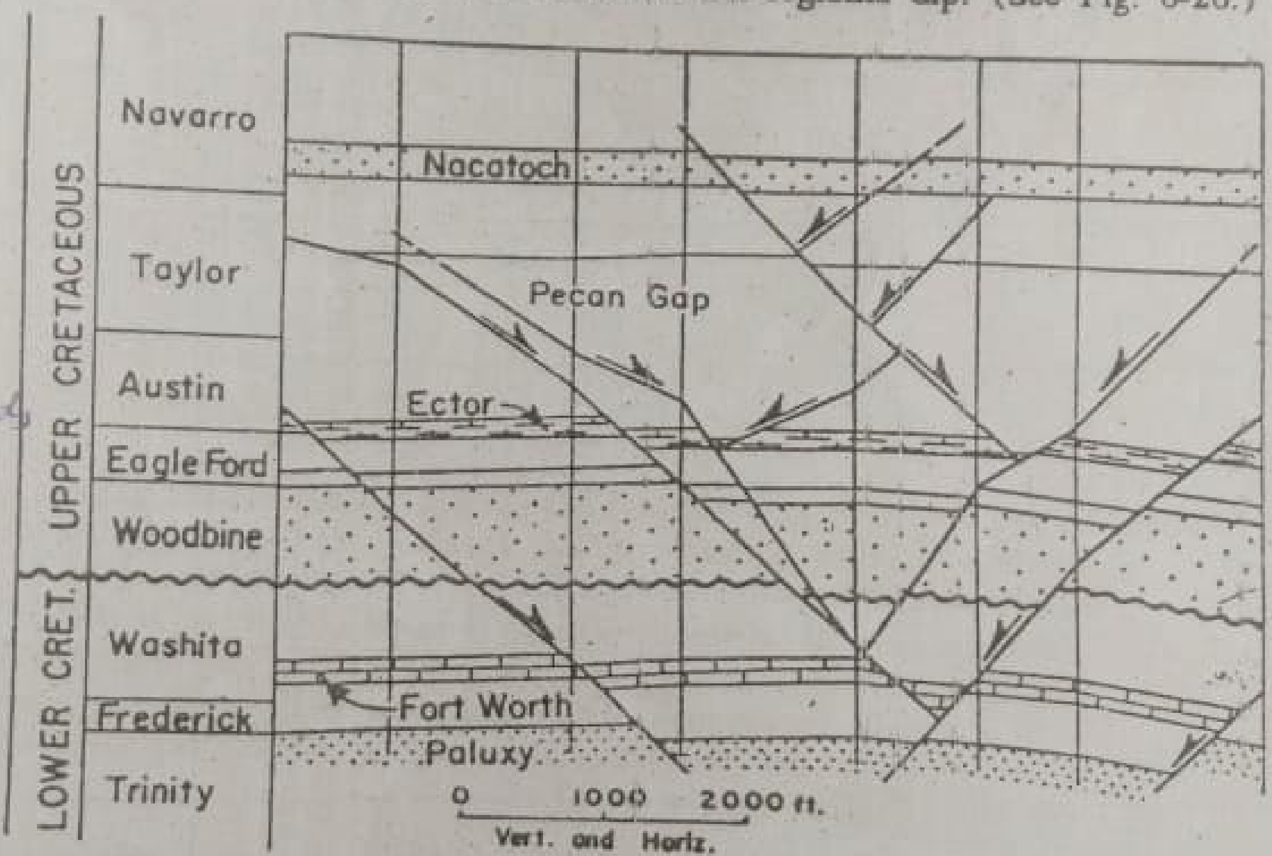
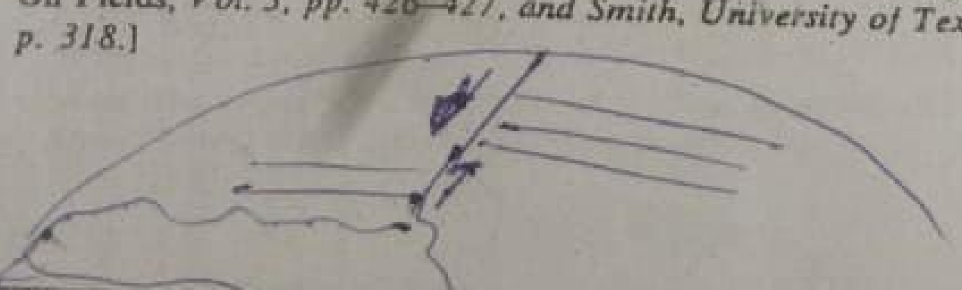


FIGURE 6-29 *Section across the top of the Quitman field, Wood County, Texas. An example of a complex fault pattern developed along the crest of an elongate anticline. The Eagle Ford and Paluxy sands are productive in the high portion of nearly every fault block. The Woodbine sand is productive in one fault block. The oil-water contact is 104 feet higher in one Paluxy producing fault block than in the others, suggesting some post-accumulation faulting.* [*Redrawn from Scott, in* The Structure of Typical American Oil Fields, *Vol. 3, pp. 426–427, and Smith, University of Texas Pub. 5116, p. 318.*]



Process known as basin inversion

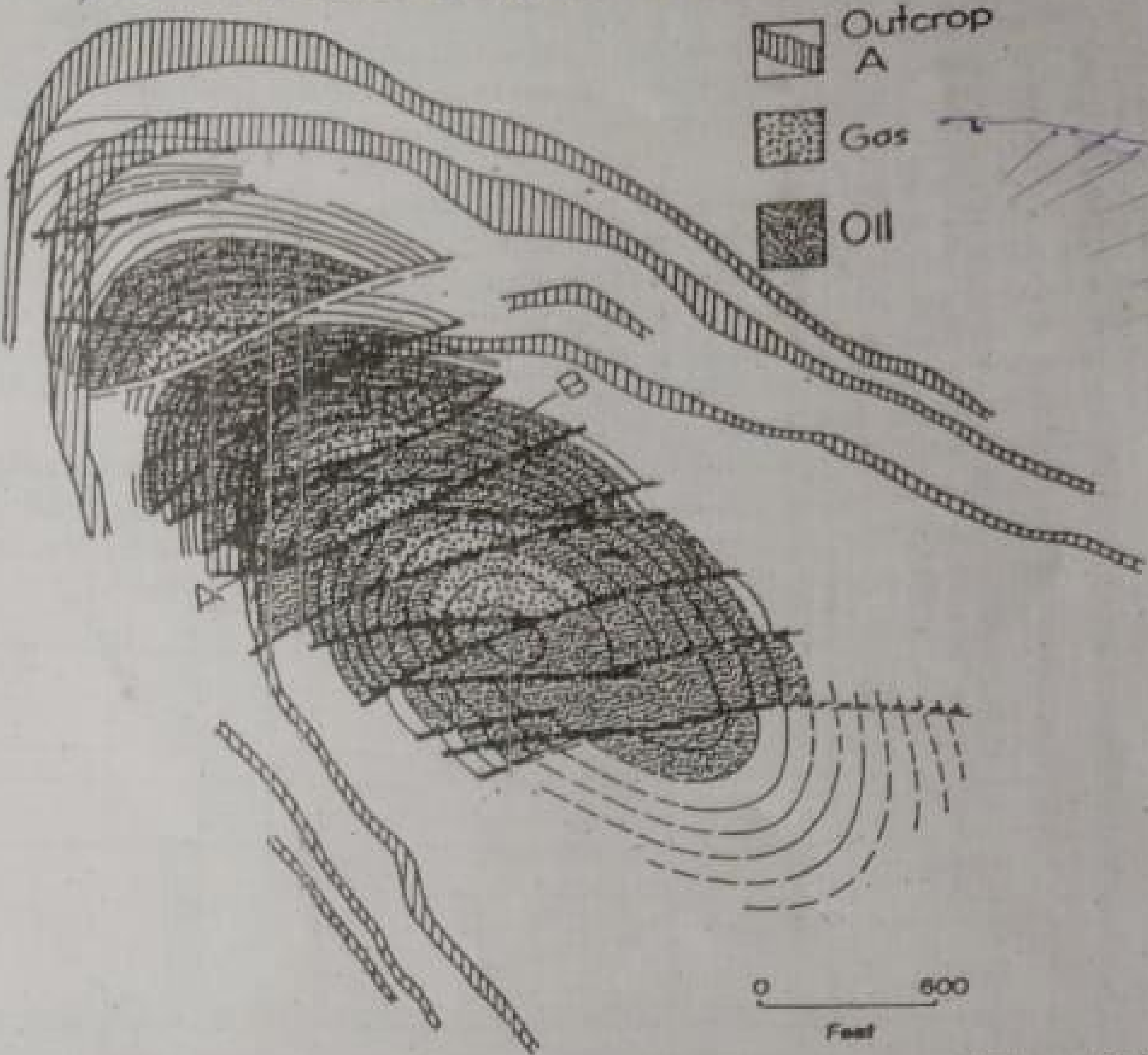


FIGURE 6-30 *Structure of the Kala oil and gas field, Azizbekovo Oil Trust, Baku region, Apsheron Peninsula, USSR. (See Fig. 2-3, p. 21, for location.) The contour interval is 10 meters (33 feet). The distribution of the oil and gas in the Sabunchi series (Productive formation, Pliocene) is shown. The cross faults form separate pools along the axis of the fold. The Kala fold is one of the simpler folds of the great Baku producing province. [Redrawn from "Oil Deposits of Azerbaidjan," XVIIth Int. Geol. Cong., Moscow (1937), Vol. 4, p. 116.]*

Many pools in this part of California are trapped, in large part, by normal faults.

The Richland pool, in Navarro County, Texas, is one of a great many pools trapped by a normal fault cutting across an arch or low fold in the reservoir rock.[31] A structural map and section of the reservoir are seen in Figure 6-27, which shows not only the trace of the fault at the surface but its intersection with the producing sand. In the Dossor oil field, in the Emba province of the USSR,[32] shown in Figure 6-28, production is obtained from Jurassic sands that are arched and faulted; here, as in the Richland pool, the fault plane forms one side of the reservoir.

Faulting often breaks up a field into separate pools; where that happens, the fault planes may become the boundary of a pool and tightly seal it off. The Quitman field, in Wood County, Texas, is one among many in which an anticlinal dome fold is broken into a number of fault blocks, each containing a trap in which oil and gas have accumulated. A section across the field is shown in Figure 6-29. Another is the Kala field, in the Baku district of the USSR, a structural map of which forms Figure 6-30. This combination of folding and faulting is common to many anticlinal traps. In some the transverse faults are not large enough to separate the pools; but in others, as in the Kala fold, many of the faults form boundaries of separate pools, distinguished by their differing oil-water contacts. Thrust faulting combines with anticlinal folding to form the traps in some of the prolific Cretaceous limestone reservoirs of western Venezuela. A section across the Mara field is shown in Figure 6-31 and shows the thrust horst along the axial part of the fold, a characteristic of several of these fields.

The Inglewood field, in California, is an example of a trap composed of a dome that has been modified by normal faulting and forming several pools. A structural map of the reservoir and two sections across it are shown in Figure 6-32.

The Creole field, in the Gulf of Mexico off the coast of Louisiana, consists of four separate pools trapped by normal faults associated with a dome fold caused by a deep-seated salt plug. The field is also of interest for another reason: it was all drilled from a single off-shore platform by means of directed drilling.[33] The traces of the drill holes and their relations to the faults are

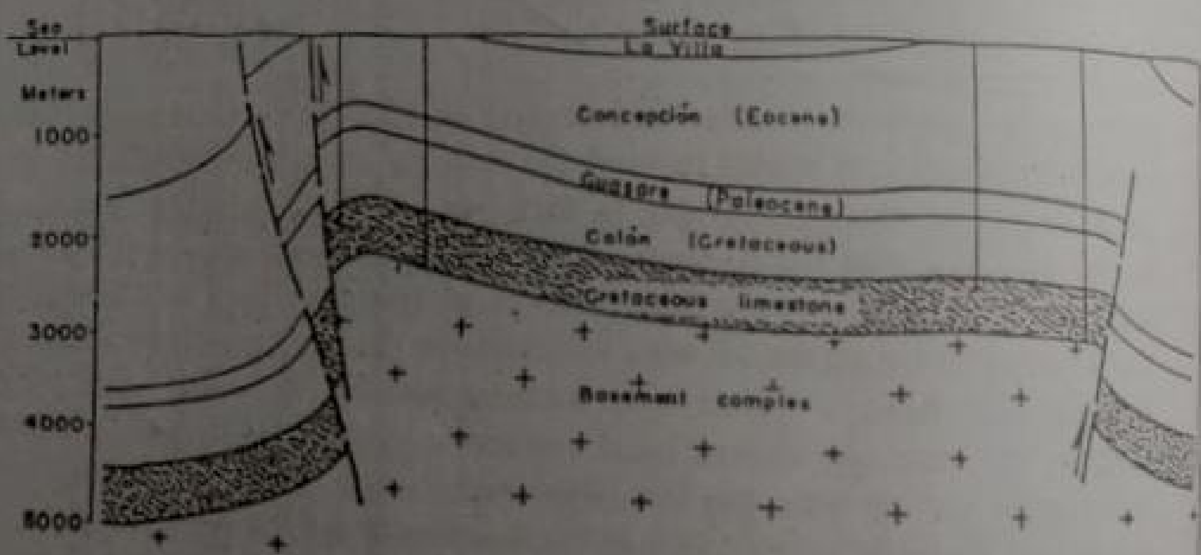


FIGURE 6-31 *Section across the Mara field, western Venezuela. Large production occurs from the Cretaceous limestone and from the fractured granites of the basement complex. Length of section about six miles. [Redrawn from Mencher et al., Bull. Amer. Assoc. Petrol. Geol., Vol. 37, p. 725, Fig. 3.]*

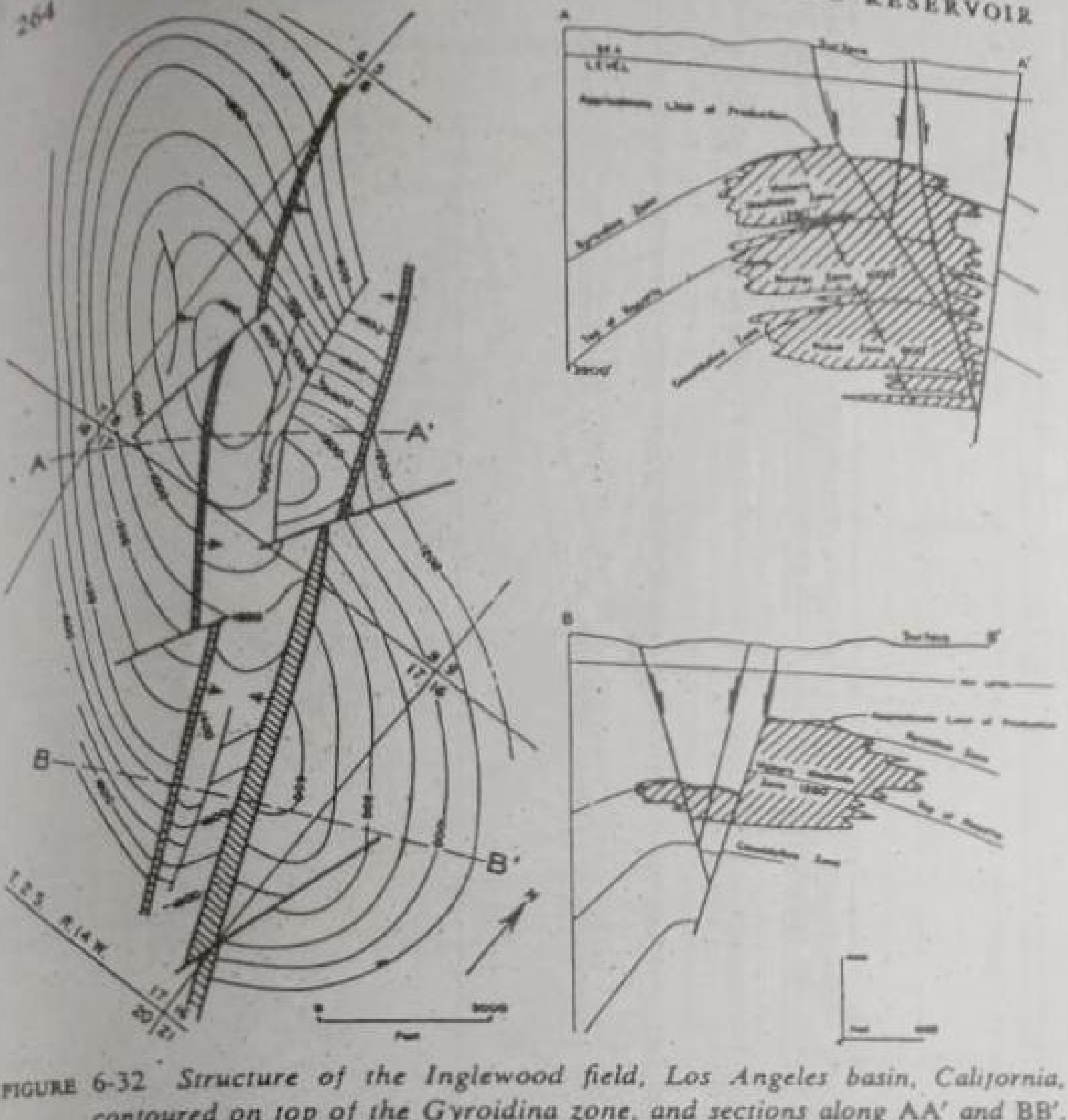


FIGURE 6-32 *Structure of the Inglewood field, Los Angeles basin, California, contoured on top of the Gyroidina zone, and sections along AA′ and BB′. Movement along the main fault is chiefly horizontal, the movement being south along the east side (right lateral). The distribution of the oil is shown as hatching in the sections.* [*Redrawn from Driver, Bull. 118, Calif. Div. Mines (1943), p. 307.*]

shown in Figure 6-33. The distribution of the gas, oil, and water in the deeper pools is shown in Figure 6-34, and a section through the pool in Figure 6-35. The structure of the producing Woodbine formation (Upper Cretaceous), in the Van field, northeastern Texas, is shown in Figure 6-36. Two separate pools, *A* and *B*, are trapped by a fault superimposed on a dome fold. A section from northeast to southwest across the field is shown in Figure 5-4, page 150, where an analysis is made of the time the accumulation occurred.

Minor faulting may in some cases follow incipient fracturing and the shallow effect of subsurface stresses related to the folding; as erosion and removal

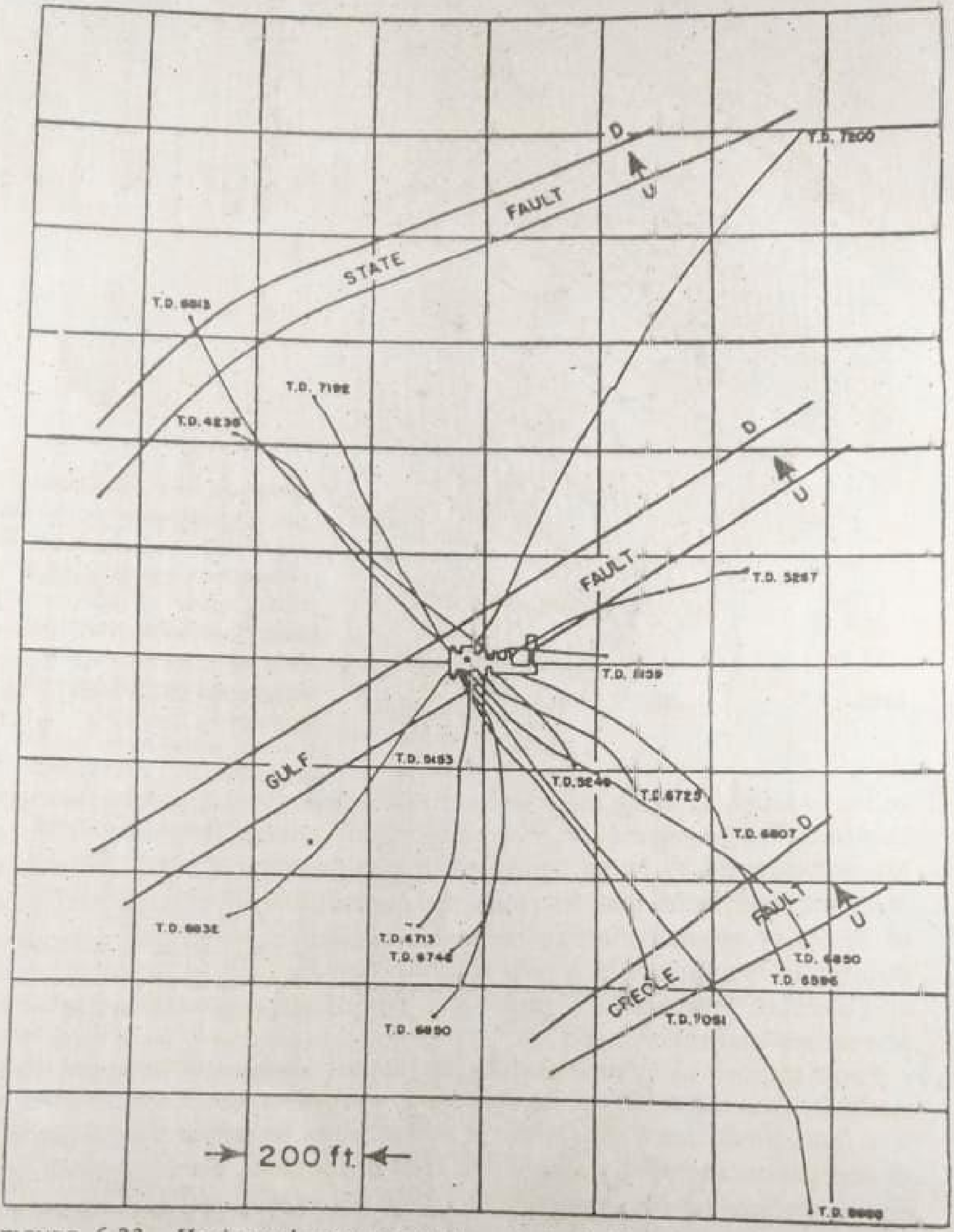


FIGURE 6-33 *Horizontal traces of nineteen holes drilled from one offshore drilling platform in the Creole oil field, Louisiana, Gulf of Mexico. The structural conditions encountered are shown in Figures 6-34 and 6-35.* [*Redrawn from Wasson, in* The Structure of Typical American Oil Fields, *Vol. 3, Amer. Assoc. Petrol. Geol.* (1948), *p.* 288, *Fig.* 5.]

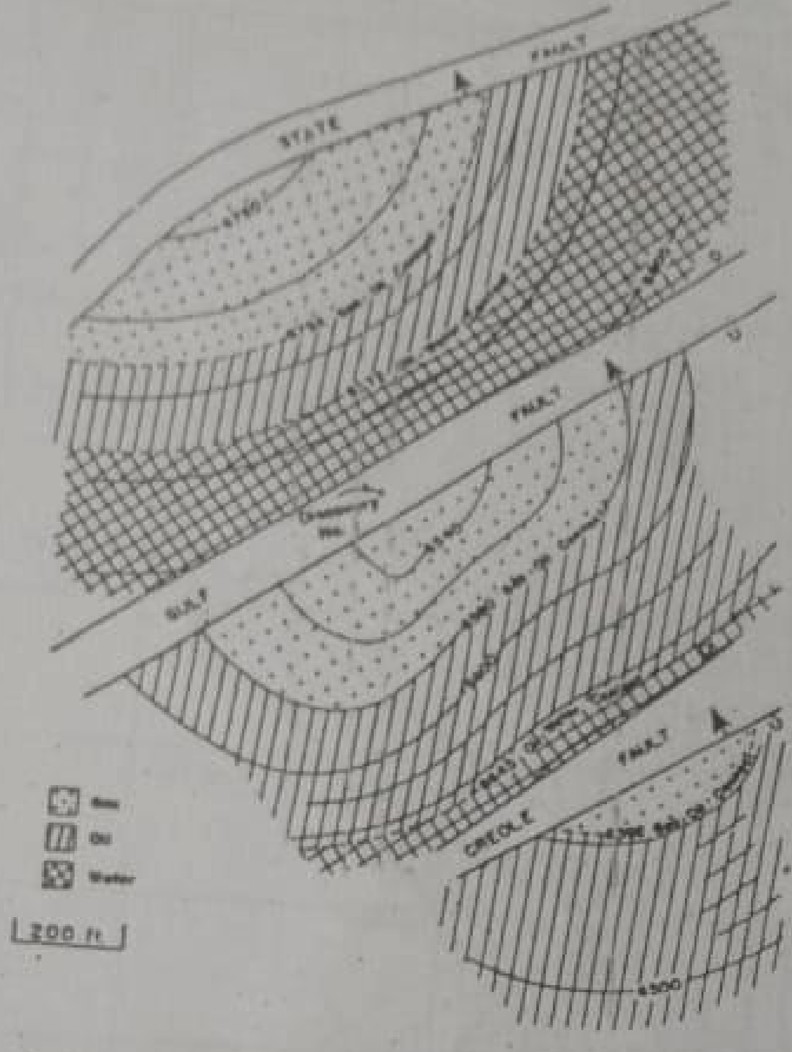


FIGURE 6-34

Structure and distribution of gas, oil, and water in the chief producing sand, the Gulf sand (Miocene), of the Creole oil field, found at about 6,700 feet. [Redrawn from Wasson, in The Structure of Typical American Oil Fields, *Vol. 3 (1948); p. 292, Fig. 7.]*

of the overburden bring these stressed rocks closer to the surface, the stress caused by the folding may be relieved by minor faulting. Thus many fold traps are accompanied by minor faults, which may or may not reach down to the reservoir, and faults that do reach the reservoir merely change the outline of the pool without affecting the water-oil contact, which remains planar throughout the pool. Such a pool is in the Petrólea field, in the Barco region of Colombia,[34] shown in Figure 6-37. The minor shallow faulting is both of a normal and a thrust type.

Pools trapped by normal faulting are almost always on the upper side of the fault. One might expect, on looking at a cross section, that the lower side of a fault would form a trap, but it seldom does so, apparently because the oil and gas escape up-dip around the ends of the fault. Pools in which petroleum is trapped on the lower side of a fault are exceptional and are generally to be explained by a combination of minor faulting, permeability variations, hydrodynamic forces directed down-dip folding along the lower side, and truncation of the reservoir by the lower side of the fault. Many of the pools along the Gulf Coast of southern Texas and Louisiana, however, lie on the lower side of normal faults. These pools are found immediately to the south of a series of

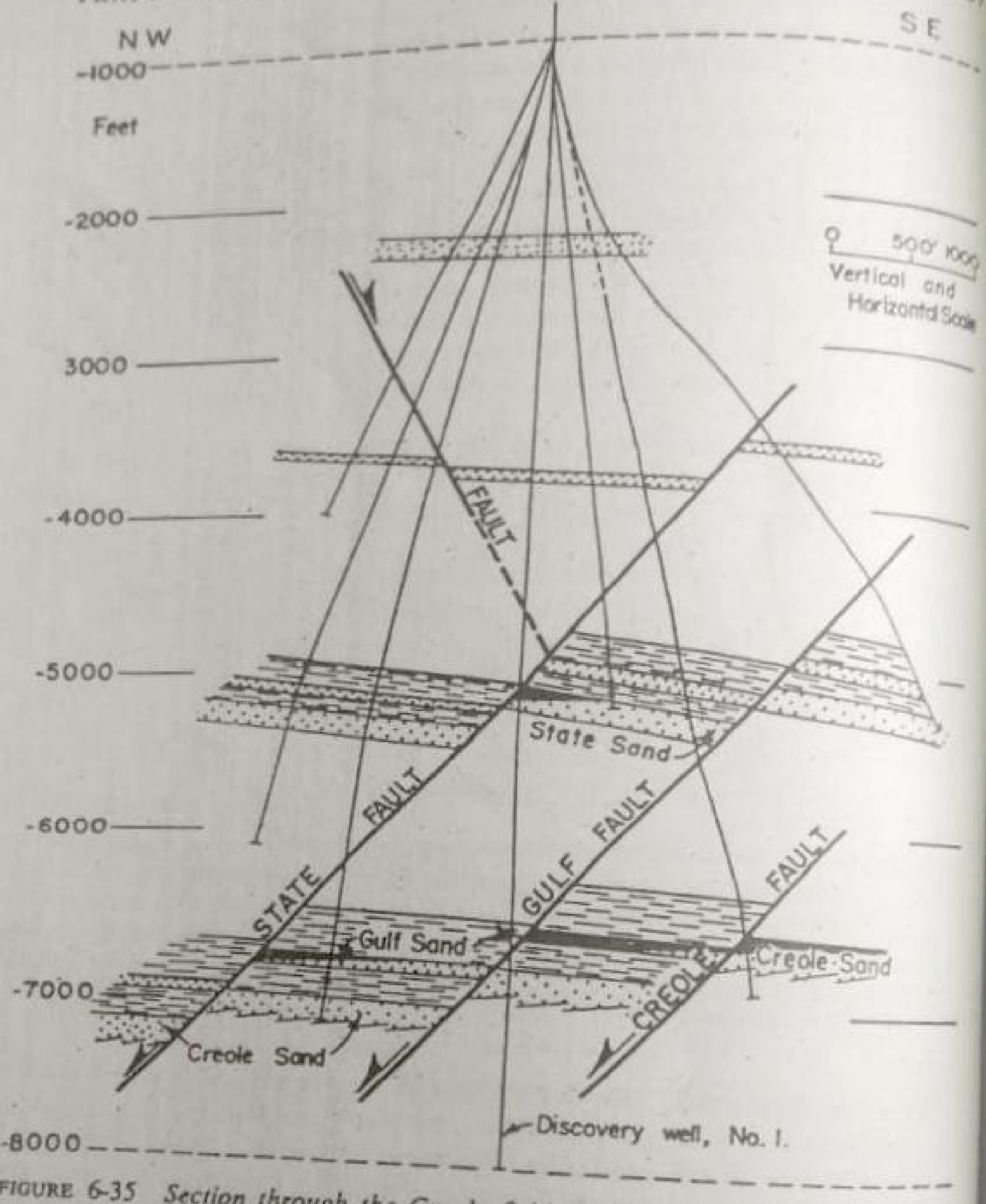


FIGURE 6-35 *Section through the Creole field showing the manner in which the field was developed by directed drilling from one platform standing in the Gulf of Mexico. While the overall structure is a dome fold over a deeply buried salt intrusion, the separate pools are defined by normal faulting associated with the fold. [Redrawn from Wasson, in* The Structure of Typical American Oil Fields, *Vol. 3 (1948), p. 286, Fig. 4.]*

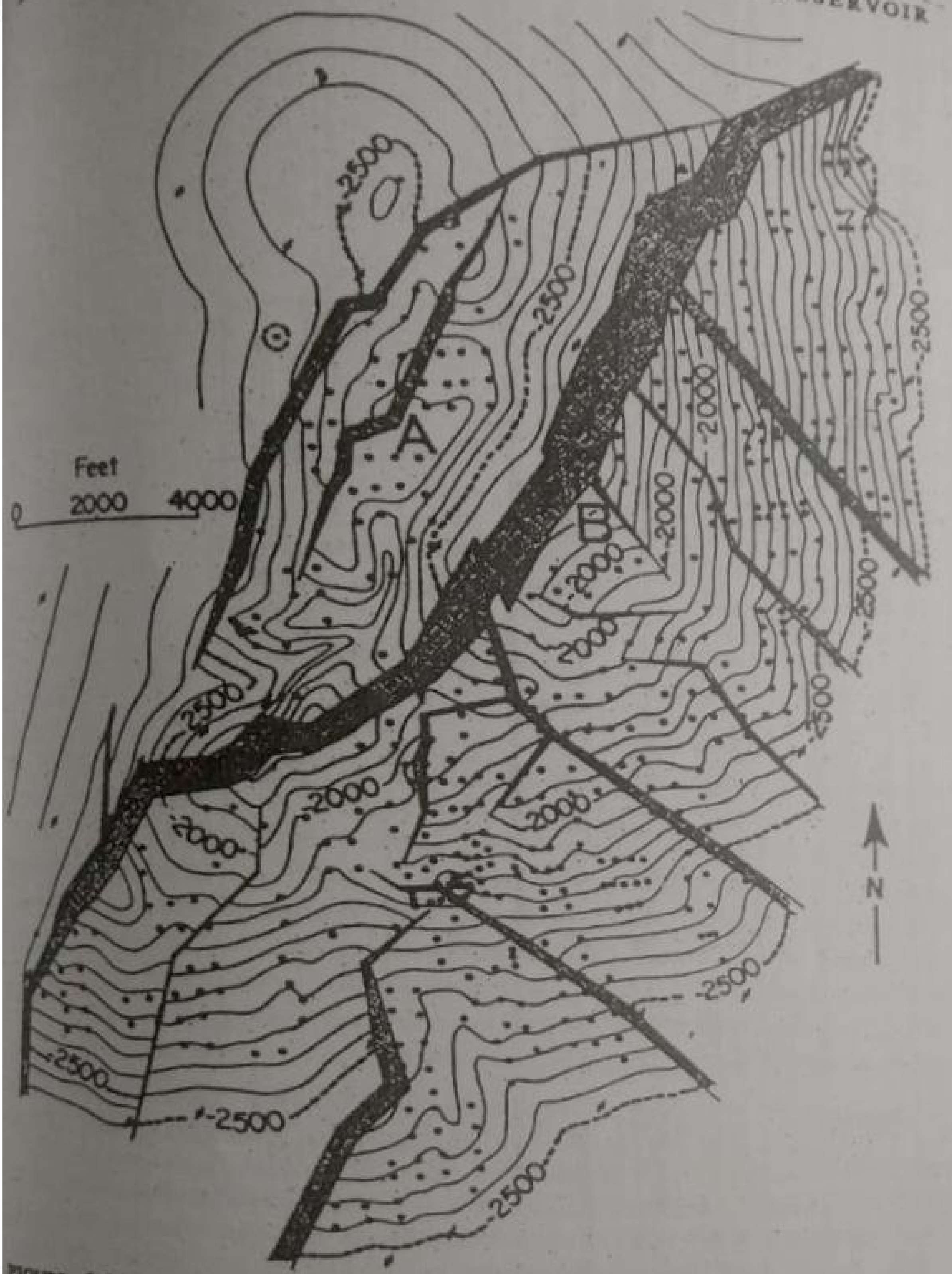


FIGURE 6-36 *Structure of the top of the productive Woodbine sand (Cretaceous) in the Van field, Van Zandt County, Texas. The shaded areas show where the top of the Woodbine sand is absent because of faulting. The dashed line marks the boundaries of the pool. A section across the field is shown in Figure 5-4, page 150. The Van field, it is estimated, will ultimately produce 400 million barrels of oil. It is typical of faulted folds caused by the deep intrusion of salt masses. (See Chap. 8.) [Redrawn from Liddle, University of Texas Bull. 3601, Fig. 19, and Betts, University of Texas Bull. 5116, p. 401.]*

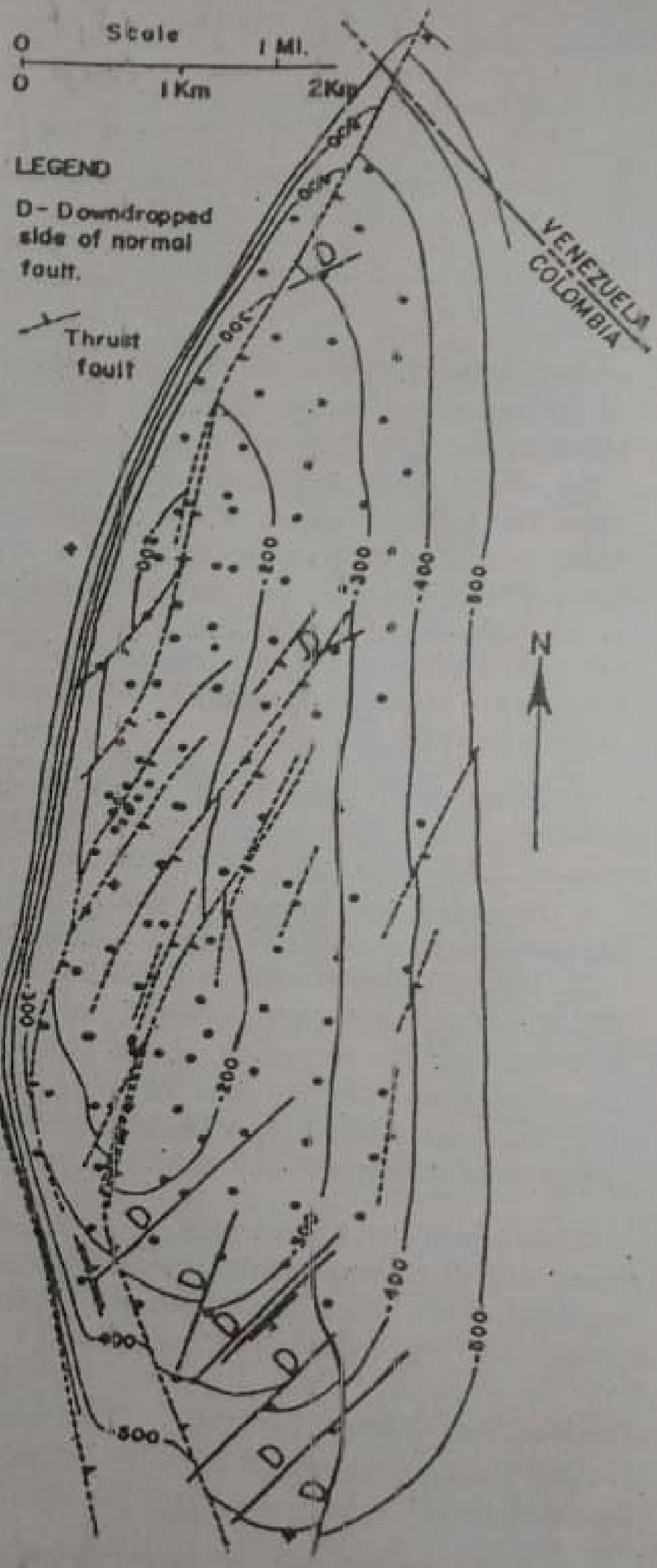


FIGURE 6-37

Structure of the Petrólea North Dome oil field, Barco Concession, northern Colombia, contoured on the productive Zone 3 (Cretaceous). Contour interval is 100 meters (328 feet). This trap is a dome fold with steep or overturned beds on the west flank, numerous thrust faults, and some normal faults. Oil seepages are common at the surface, and prolific oil production has been found at the shallow depths of 26–513 meters (about 85–1700 feet). (See Fig. 14-12 for location.) [Redrawn from Notestein, Hubman, and Bowler, Bull. Geol. Soc. Amer., Vol. 55 (1944), p. 1208, Pl. 6.]

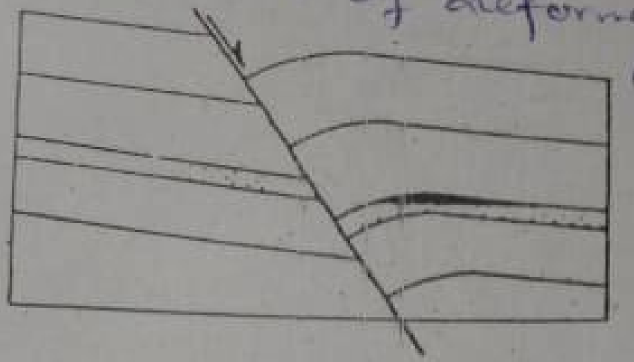


FIGURE 6-38

Diagrammatic section through down-dropped fault and fold, characteristic of many traps along the Gulf Coast of Texas and Louisiana.

south-dipping normal faults parallel to the Gulf, and dipping, as the rocks of the region do, toward the Gulf. When these pools are examined more closely, however, it is found that they are nearly all trapped by closed anticlines, which occur along and parallel to the lower or down-dropped side of these faults. The situation is diagrammatically shown in Figure 6-38. The north closure of the trap is in the north dip into the fault plane, which in itself is very unusual, and the fault seldom has anything to do with the actual bounding of the pool; the trap is formed by the anticline. The faulting, however, must be genetically related to the folding, and a number of theories have been advanced to explain the unusual relationship. Some of these explanations are:

1. Subsidence of the basement along hinge lines parallel to the coast, causing an abruptly steeper dip, along which the overlying incompetent formations were pulled apart.
2. Slipping of the formations toward the coast along bedding planes, causing breaks to form, into which the lower-side beds dip.
3. Deeply buried salt ridges paralleling the coast, which plastically intruded the overlying formations, causing normal faults.[35] The mechanics of the intrusion and the formation of the faults are similar to those believed to cause the graben faulting over salt plugs, which is discussed on pages 361–363. These fault breaks may be, in fact, the incipient up-slope edge of future great landslides into the Gulf of Mexico.

The trap in the Amelia field, in Jefferson County, Texas, is a fold on the lower side of a normal fault. A map of the structure on the Langham producing sand (Frio formation, Oligocene) is shown in Figure 6-39, and a section through the field is shown in Figure 6-40.

Reverse and Thrust Faulting. Traps associated with thrust and reverse faulting* may form either above or below the fault plane. The trap may be bounded on one side by the fault, but more often it is formed by folding asso-

* When the hanging wall has apparently moved up with respect to the footwall, a fault is termed a *reverse fault* if the fault plane makes a high angle (above 45°) with the horizontal, a *thrust fault* if the fault plane makes a low angle (less than 45°) with the horizontal.

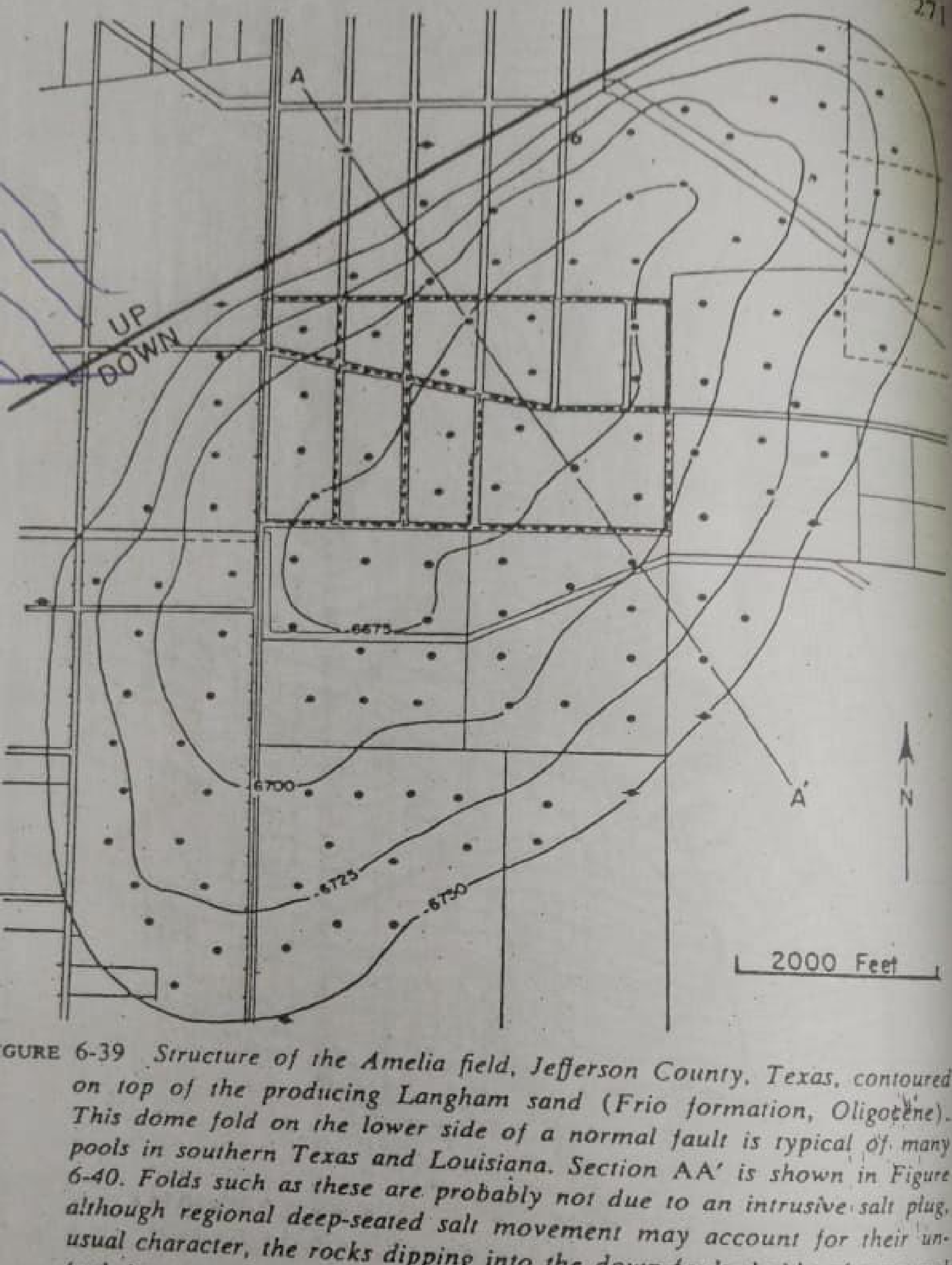


FIGURE 6-39 *Structure of the Amelia field, Jefferson County, Texas, contoured on top of the producing Langham sand (Frio formation, Oligocene). This dome fold on the lower side of a normal fault is typical of many pools in southern Texas and Louisiana. Section AA' is shown in Figure 6-40. Folds such as these are probably not due to an intrusive salt plug, although regional deep-seated salt movement may account for their unusual character, the rocks dipping into the down-faulted side of a normal fault in a way that is not found in most faulting.* [*Redrawn from Hamner, Bull. Amer. Assoc. Petrol. Geol., Vol. 23, p. 1646, Fig. 3.*]

ciated with the thrust faulting. Some traps characteristically associated with thrust faults are diagrammatically shown in Figure 6-41.

The Talang Akar pool, in Sumatra, is trapped in an overthrust elongated fold. Maps and sections are shown in Figure 6-42. The South Mountain field,

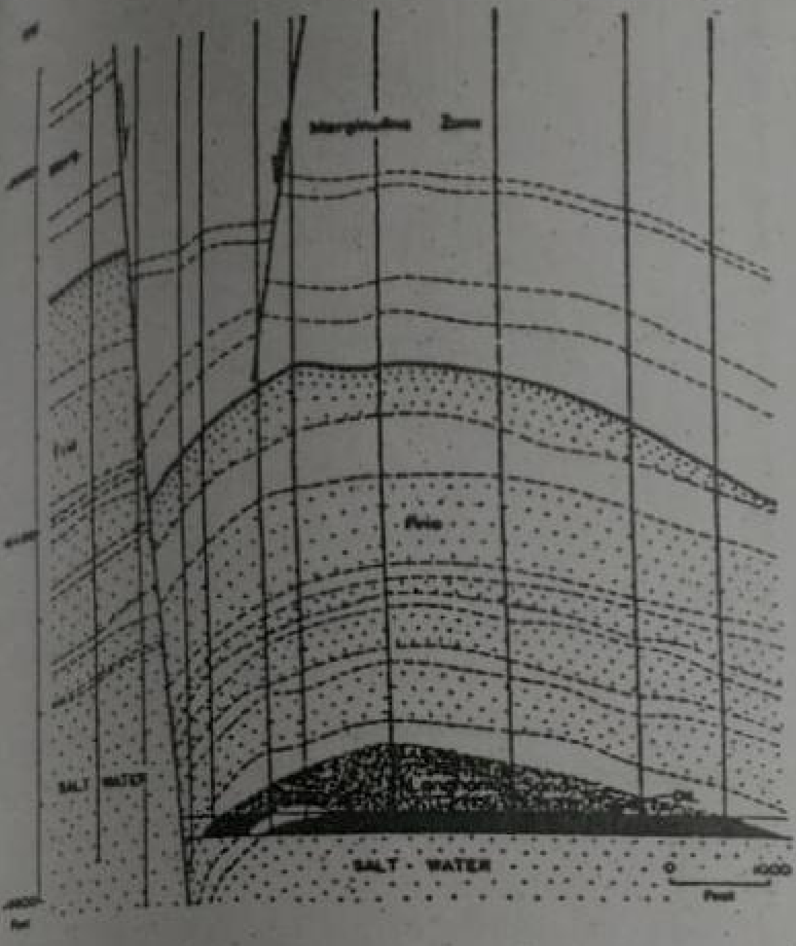


FIGURE 6-40

Section through the Amelia field, Texas, showing the relations between the dome fold and the fault. The dip into the down side of the fault is contrary to most faulting, except in the system of faults parallel to the Gulf Coast in Louisiana and Texas, of which this is an example. The discordance in dip between the two upper members in the section and the Frio formation suggests an intervening period of deformation. [Redrawn from Hamner, Bull. Amer. Assoc. Petrol. Geol., Vol. 23, p. 1647, Fig. 4.]

in Ventura County, California, is also found in folded sandstone reservoir rocks, which have been thrust up over the underlying formations along the South Mountain thrust fault. A short distance away, several pools occur below the thrust plane of the Timber Canyon overthrust fault, which acts as a trap boundary. A section through these two areas may be seen in Figure 6-43.

Several pools producing gas from the Oriskany sand (Lower Devonian), in northern Pennsylvania and southern New York, occur in folds associated with reverse faulting. One such field consists of the Woodhall and Tuscarora[36] pools, in southern New York, of which a structural map is shown in Figure 6-44 and a section in Figure 6-45.

An overthrust field is found in the Turner Valley gas and oil field, in Alberta, Canada, where oil and gas accumulated within the overthrust mass and were later carried forward by the overriding rocks.[37] During the thrust movement the folding was intensified, and the anticline was overturned in the

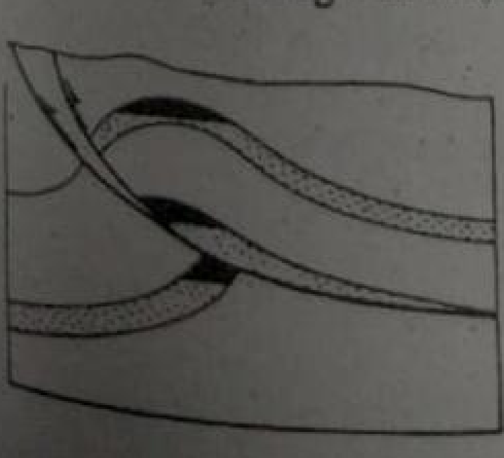


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FIGURE 6-41

Diagrammatic section showing characteristic positions of traps associated with thrust faulting.

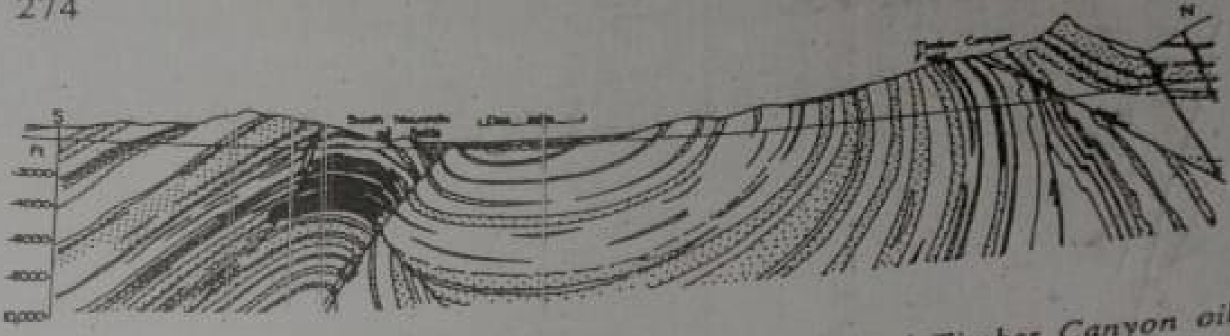


FIGURE 6-43 *Structural section across South Mountain and Timber Canyon oil fields, Ventura County, California. The trap in the South Mountain field is an overthrust fold and reverse fault, and the trap in the Timber Canyon field is formed by the faulted edges of the reservoir rocks where they are overridden and sealed by an overthrust fault. This section shows examples of accumulations both above and below thrust-fault planes.* [*Redrawn from Bailey,* AAPG Guidebook (1952), *Los Angeles, p. 68.*]

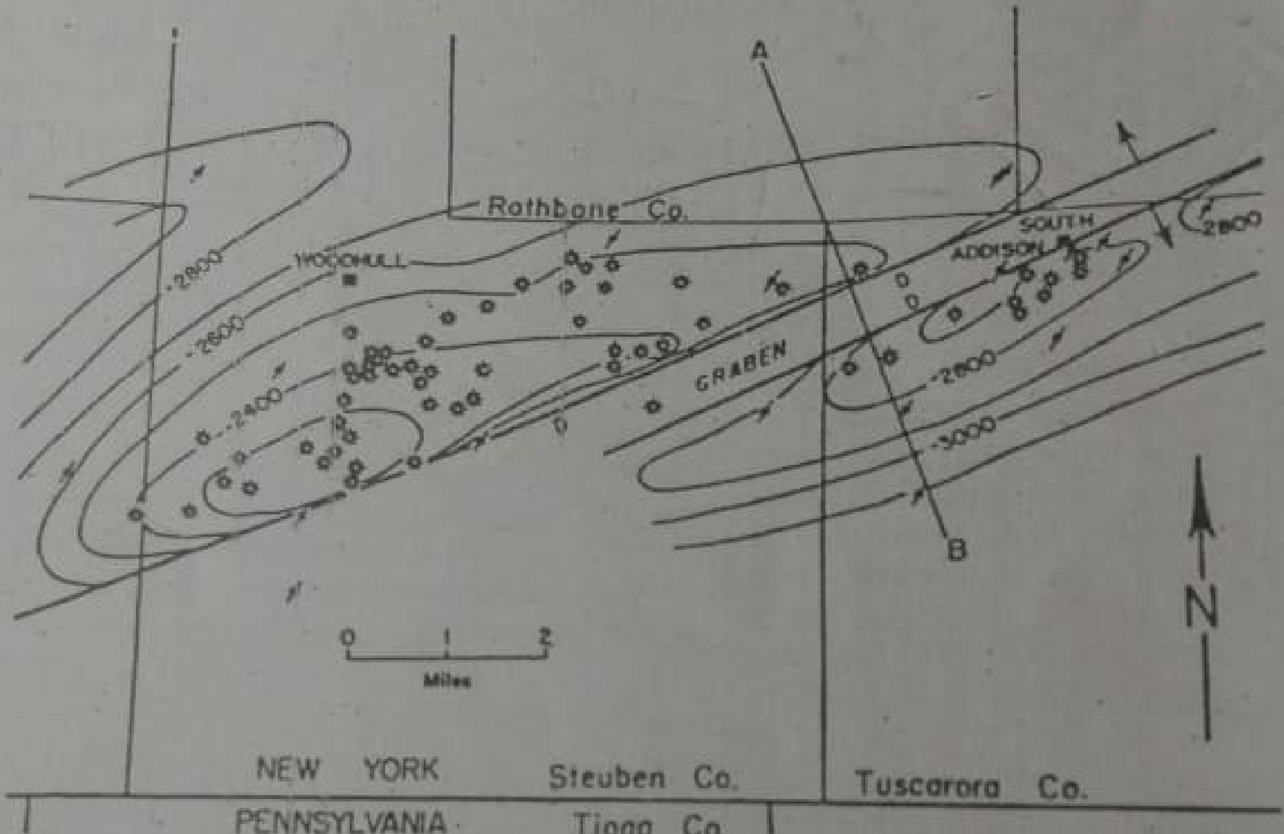


FIGURE 6-44 *Structural map (contour interval 50 feet) of the gas-producing Oriskany sandstone (Lower Devonian) in the Woodhull and Tuscarora gas pools of southern New York State. The traps are associated with reverse faulting, which is common to the traps of gas pools in this region. Fault blocks, such as shown in Figure 6-45, seem to be necessary for commercial production, possibly because of the porosity and permeability developed by the intense shattering and fracturing of the brittle Oriskany sandstone. (See Finn, Bull. Amer. Assoc. Petrol. Geol., Vol. 35, p. 306.)* [*Redrawn from Finn, Bull. Amer. Assoc. Petrol. Geol., Vol. 33, p. 332, Fig. 14.*]

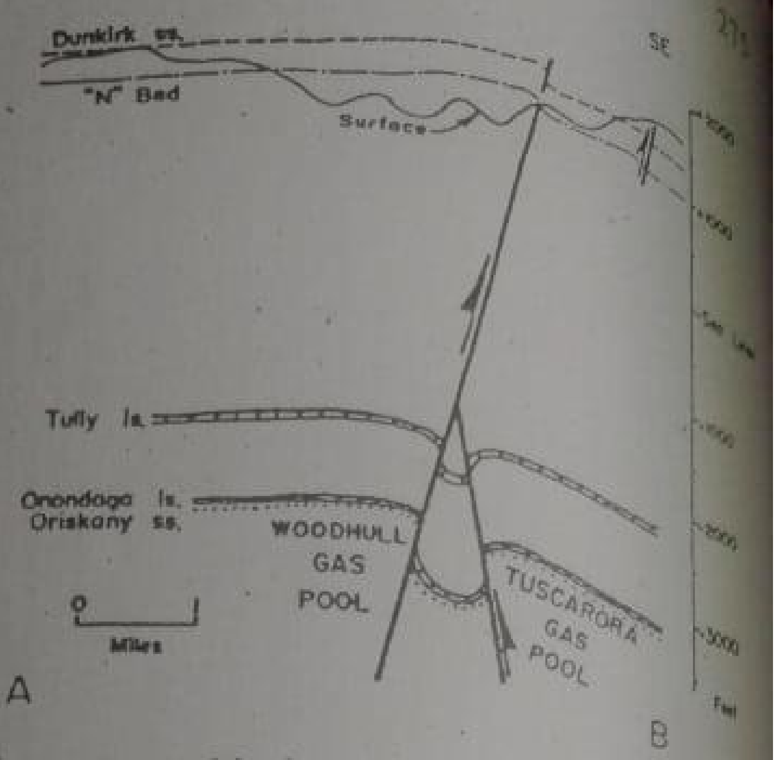


FIGURE 6-45

Section through the Woodhull-Tuscarora gas pools (AB in Fig. 6-44). Reverse faults such as these are common in the Oriskany gas region of Pennsylvania and New York, where they either modify or form the boundaries of a number of gas pools. [Redrawn from Finn, Bull. Amer. Assoc. Petrol. Geol., Vol. 33, p. 333, Fig. 15.]

direction of movement. A section across this feature is shown in Figure 6-46. (See also Fig. 14-14, p. 651, for an account of the development of the fold and the pool.) Traps defined by reverse faults occur in the Circle Ridge field, Fremont County, Wyoming, where the Permian has been thrust over the Triassic to form traps, in which several pools occur,[38] both above and below the overthrust fault plane. The relations are shown in the structural map and section of Figure 6-47. In the Aliso Canyon field, in California, traps associated with overthrust faults contain oil pools. A map of the surface relations is shown in Figure 6-48 and a section across the area in Figure 6-49. The oil in the Achi-Su field, in the Caucasus region of the USSR, which is typical of several fields in the Grozny area, is found in an elongated fold associated with an overthrust fault. A structural map and sections are shown in Figure 6-50.

Complex thrust faulting may be associated with incompetent formations, such as soft clays and shales, and with anhydrites and other salts of evaporite rocks. The faulting may be directly responsible for the trap, but more often the faults merely obscure the trap, as shown in a section across the Agha Jari structure in Iran, which is typical of several of the great oil pools of the Near East. (See Fig. 2-2, p. 18.) The oil fields in the Ploesti region of Romania are characterized by traps associated with reverse faulting and salt injection.[21] The section across the Moreni-Bana field, shown in Figure 6-51, is typical of many traps in this region. See Figure 8-11, page 357, for a section through the Mene Grande field. The Bitkow field, in the North Carpathian province of Poland (now in the USSR), is another in which complex folding and thrust faulting combine to form traps.[39] A section across the field is shown in Figure 6-52. Traps such as these are common throughout the entire North Carpathian province.

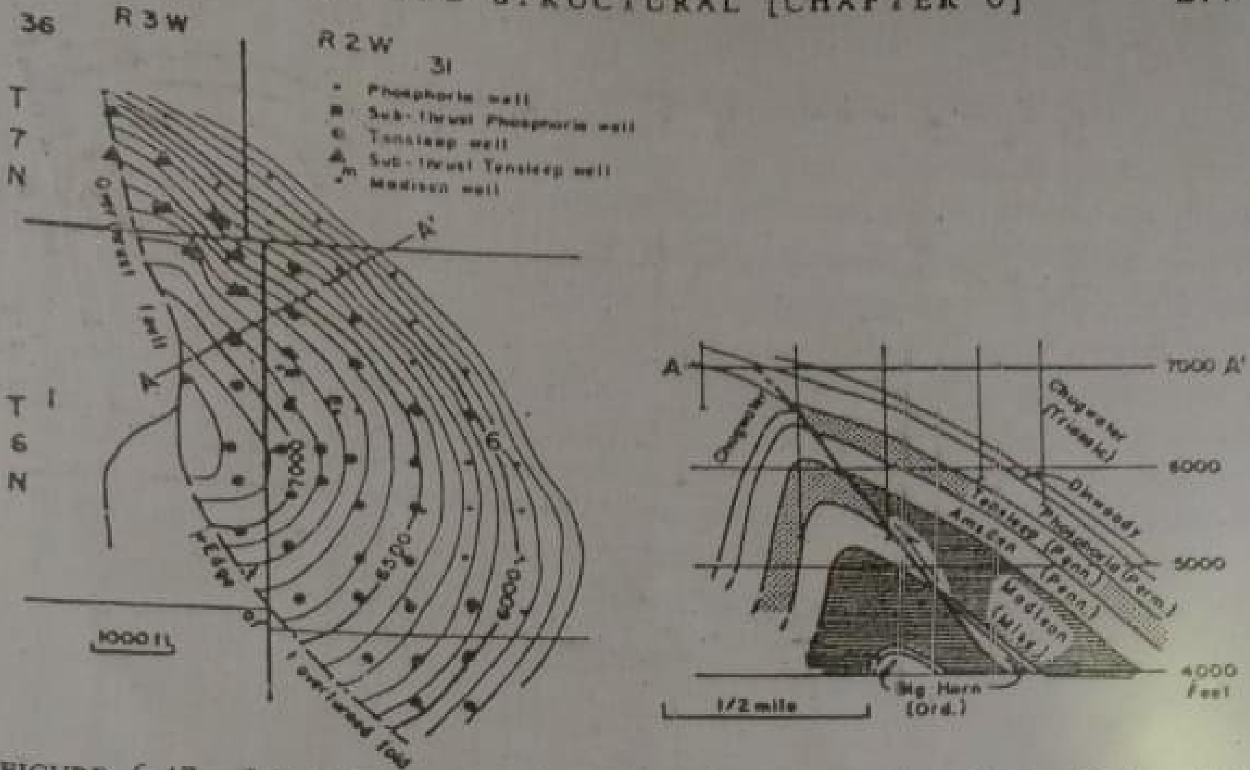
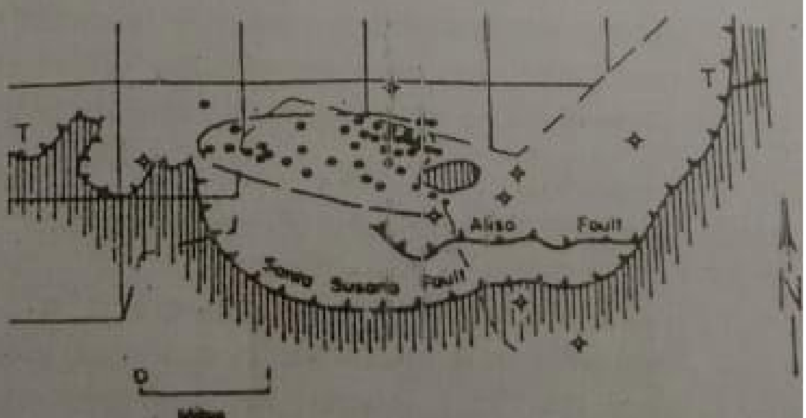


FIGURE 6-47 *Structural map of and section across the Circle Ridge field, Fremont County, Wyoming. Contours on top of the Phosphoria formation (Permian) at an interval of 100 feet. Oil is obtained from several formations both above and below the thrust-fault plane, which merges with an overturned fold to form the traps. [Redrawn from Beebe, O. & G. Jour., Sept. 14, 1953, pp. 110 and 112.]*

FIGURE 6-48

Map showing the Aliso Canyon oil pool and the thrust faults that crop out in the vicinity. The ruled areas show the formation below the Santa Susana fault plane, one area of which is at the east end of the field. See Figure 6-49 for a N-S section through the field. [Redrawn from Leach, in The Structure of Typical American Oil Fields, *Vol. 3 (1948), p. 26, Fig. 2.]*



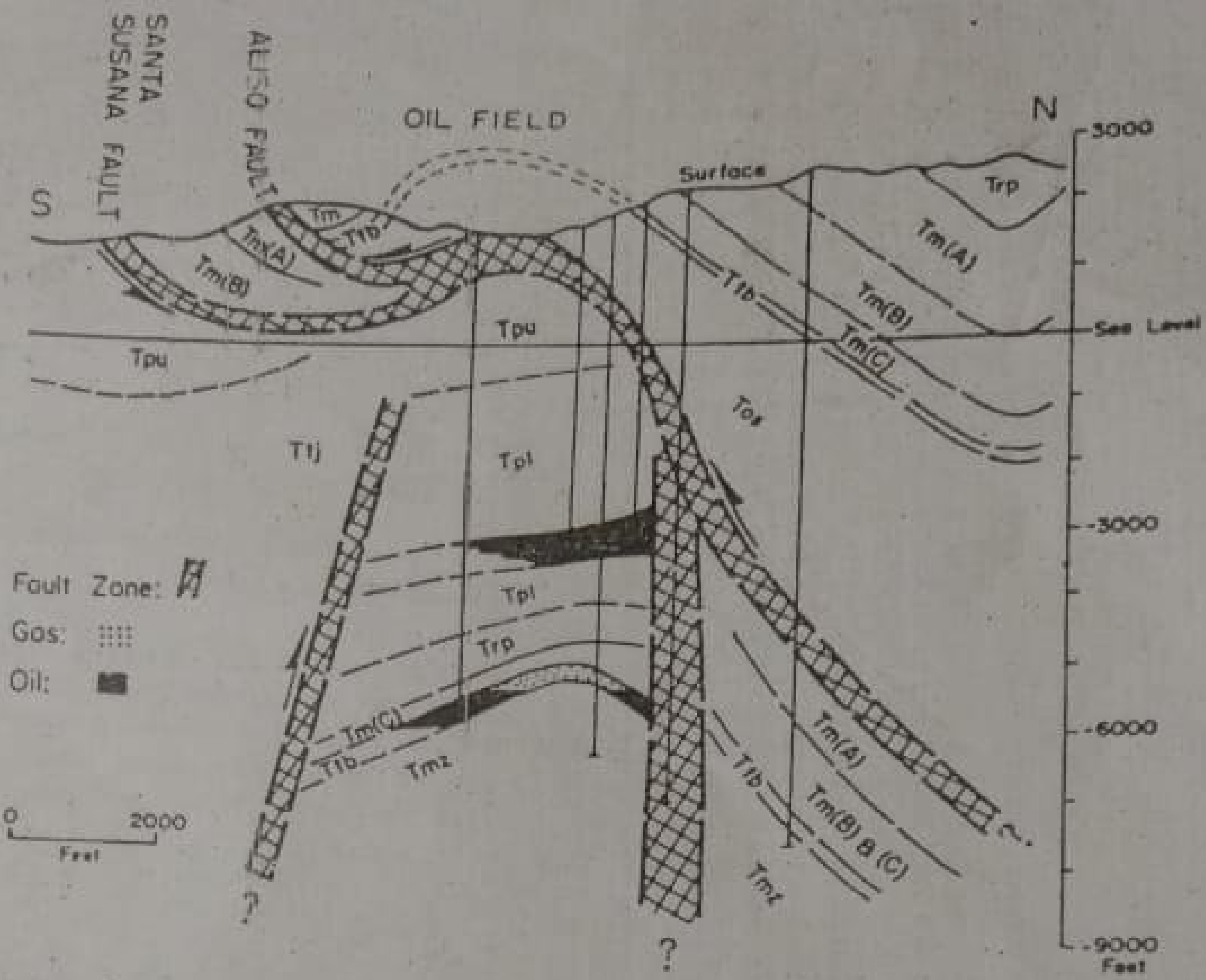
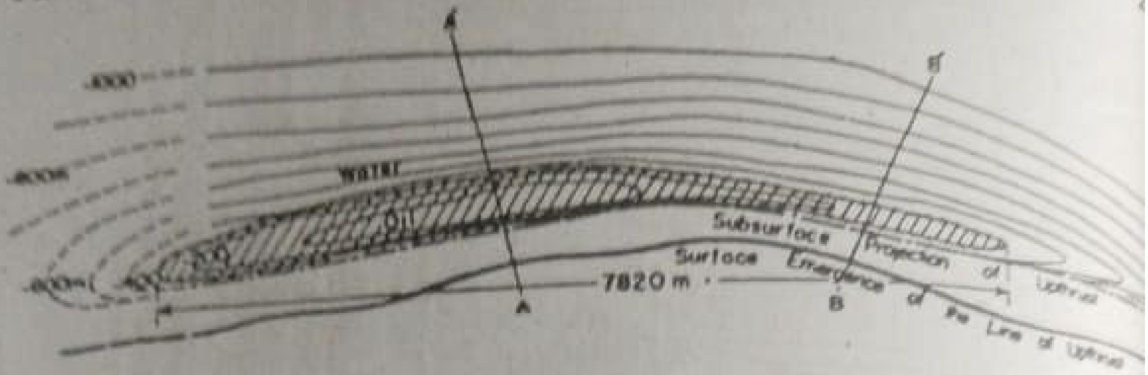


FIGURE 6-49 *Structural section through the Aliso Canyon oil field, in the Ventura basin, California. This field is an example of pools producing from complexly folded and thrust-faulted traps. [Redrawn from Leach, in* The Structure of Typical American Oil Fields, *Vol. 3 (1948), p. 32, Fig. 5.]*

Complex thrust faulting occurs in the Ventura field of California.[40] (See Fig. 9-12, p. 410.) The trap is localized mainly by the Ventura anticline, but at depth it is cut by many large reverse and thrust faults. These separate the field into a number of pools, each contained within a separate fault block of sediments completely or partly bounded by the fault planes. Each pool, when produced, has its own peculiar reservoir pressure and oil and gas content, showing it to be completely separate from the pools in adjacent blocks.

Traps Caused by Fracturing

Fracturing of reservoir rocks is a common cause of porosity and permeability and undoubtedly is an accessory cause in many more pools.[41] (See pp. 119–125.) It may also be regarded as the chief cause of traps in a few instances where special conditions prevail. In the Florence field, in Colorado,[42]



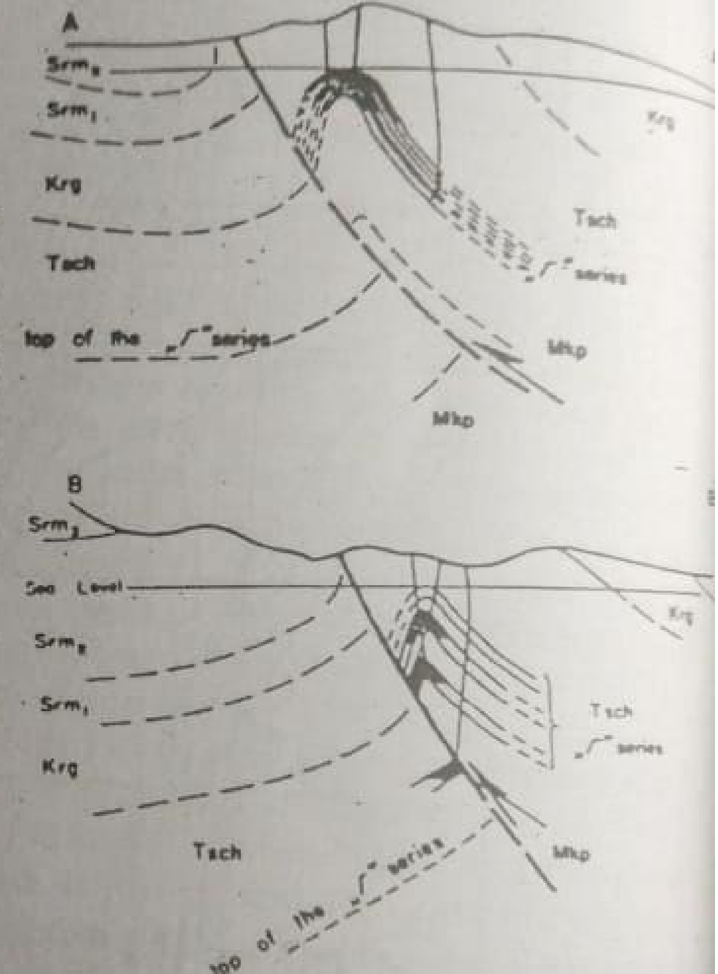


FIGURE 6-50

Structural map and sections of the Achi-Su field, southeast of Grozny, in the northeastern Caucasus, USSR. The chief accumulation is trapped in an elongated, closed, overthrust fold, the reverse fault forming the edge of the trap in some sands. Smaller accumulations are found below the fault in the truncated formations. This type of trap is characteristic of a number of pools in the Old Grozny region of the eastern Caucasus. [Redrawn from I. O. Brod, XVIIth Int. Geol. Cong. (Moscow, 1937), Vol. 4, p. 28, Figs. 3 and 4.]

which was one of the first oil pools discovered in the United States, the oil trapped within the fractured portion of the Pierre shale (Cretaceous), which is nearly flat-lying and of uniform texture over a wide area beyond the field. Apparently fracturing alone is responsible for localizing the trap, for there is no folding or stratigraphic change associated with the pool, and where the fracturing plays out there is no oil accumulation. A section through the pool is shown in Figure 6-53. Production is erratic, and one well is reported to have produced nearly a million and a half barrels of oil.[43]

Similar traps contain the gas found in the Cherokee shales (Pennsylvanian) of eastern Kansas.[44] The gas occurs in a widespread, uniform, black, carbonaceous shale, and salt water is generally produced along with it. The long life and slow decline of these pools are best accounted for by the slow

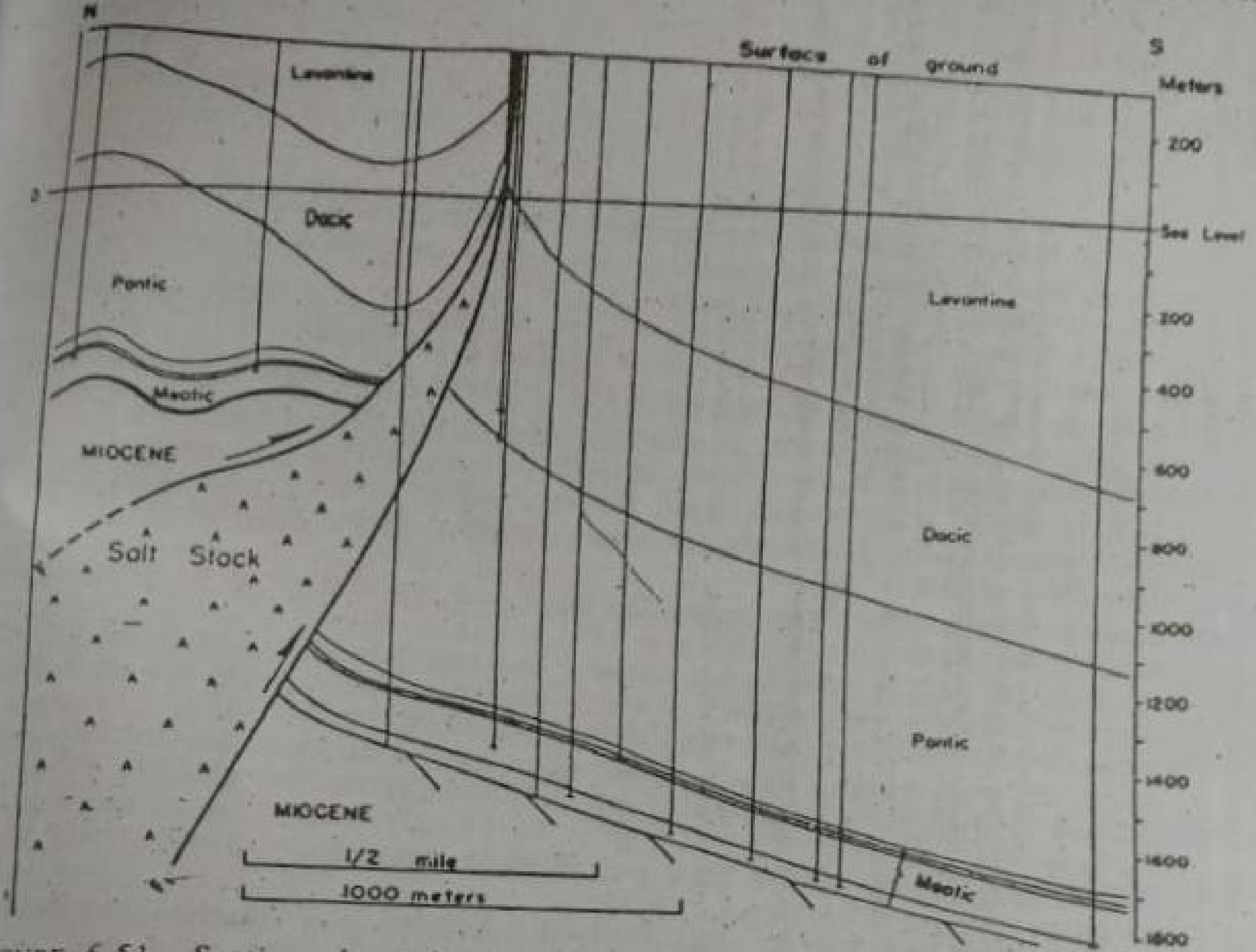


FIGURE 6-51 *Section through the Moreni-Bana oil field in the Ploesti district of southern Rumania. Reverse faulting, associated with incompetent salt formations, makes the deformation in many fields of this area extremely complicated. Presumably the salt in the Moreni-Bana field did not form the trap by intruding, as did the Gulf Coast salt domes, but was squeezed into its present position along a reverse fault plane as a result of the deformation. [Redrawn from Walters, Bull. Amer. Assoc. Petrol. Geol., Vol. 30 (1946), p. 334, Fig. 12.]*

ing of the gas into the wells from fractures, bed partings, laminae, and microscopic pores in the shales. Most of the gas in eastern Kentucky comes from the Black, or Ohio, shale (Devonian and Mississippian?), a fissile, finely laminated, bituminous, black-to-brown shale.[45] While fracturing of the shales is not mentioned by those who have described the pools, it requires shooting with nitroglycerin to obtain production.

In the Mount Calm pool, Hill County, northeastern Texas, the oil is produced from the Austin chalk (upper Cretaceous), from a trap formed by fractures associated with faulting. A section through this pool is shown in Figure 6-54.

If we compare the petroleum found in different pools within a single province, we generally find that the oil in structural traps differs from that in other traps in several respects: it is commonly of higher API gravity, it is