CYCLIC PRODUCTION OF MONTEREY SHALE: BREATHING FRACTURES AND LOW-GRADE RESERVOIRS

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ABSTRACT

The Monterey Formation is the source for much of the hydrocarbon in oil and gas fields of Miocene and younger age in Southern California. It is also a reservoir formation for some of these oil fields. Oil or gas shows are encountered in the Monterey practically everywhere it is tested. Many Monterey fractured shale reservoirs are tabular, the boundaries of which parallel the axial plane of folds. Monterey fractured shale reservoirs are fragile and easily damaged. Many marginal quality fractured reservoirs have been and continue to be destroyed during drilling. What is done to these reservoirs in the first few minutes of drilling affects their behavior and producibility for several years. The permeability of many reservoirs is too low to sustain economic production rates using traditional techniques for more than a few months. Artificial fracturing and acidization improves the production rates of marginal quality Monterey fracture reservoirs, but only for a short period of time. Because of the plastic behavior of shale at depth, it is theoretically possible to produce some Monterey fractured reservoirs cyclically. Average production rates of three to 40 barrels of oil per day for several years can be expected from marginal quality Monterey fractured reservoirs which have traditionally been abandoned. The cyclic production of Monterey fractured reservoirs will significantly increase the recoverable hydrocarbon from this formation. Drilling practices and production procedures must protect the fragile and easily damaged Monterey reservoirs. These practices are different from those used to explore for hydrocarbon accumulations in the turbidite or beach sand facies.

MONTEREY FRACTURED RESERVOIRS

The Monterey has several facies as discussed by Williams and Graham (1982), Williams and Graham (1985) and Wilkerson (this publication). In this article, only the hydrocarbon potential in the argillaceous facies of the Monterey will be addressed. This facies is the most common and widespread facies in the Monterey. Potential reservoirs within this facies can be modeled as tabular zones 500 to 1,000 feet wide (perpendicular to the axial plane), 1 to 3 miles long and 500 to 1,000 feet in axial plane thickness (see Figure 2 in companion article, "Hydrocarbon potential of the Monterey Formation as a function of sedimentation, digenesis, and tectonic history" in this publication). The vein-like geometry of these reservoirs is due to the presence of non-penetrative extension fractures at the crest of folds. These reservoirs parallel the axial planes of both synclines and anticlines. An idealized Monterey fractured shale reservoir may have dimensions of 500 x 5,000 x 1,000 feet representing a volume of 2,500 million cubic feet. If 3% of this volume is oil, this represents 13.5 million barrels of oil in place. Currently, productive Monterey fractured reservoirs have dimensions (and reserves) much smaller than those given above. This is because current production is only from the "high grade" portions of the fractured reservoirs. The "low grade" portions of the reservoirs have typically been damaged while they were drilled. The damaged reservoirs are abandoned because recovery rates from them were too low to sustain economic production.

SIGNIFICANCE OF "SHOWS" IN THE MONTEREY

The Monterey Formation is difficult to evaluate because just about everywhere it is tested it will have a show of oil or gas recorded on the lithologic ("mud") log. The resistivity logs, by comparison, seldom suggest any hydrocarbon presence. This circumstance indicates that the reservoir was damaged between the time the drill bit cut into the formation and when the electric logs were run. Invasion of drilling fluid into the fractures as shown in Figure 2. Once the fractures are contaminated, it is very difficult to clean them out again. Acidization and fracturing may clean some of the fractures, but not all of them. Production is permanently crippled. In many instances the damage is, apparently, irreversible. This sequence of events has, sadly, been repeated thousands of times throughout the oil-bearing basins of southern California.

THE HAMES VALLEY HYDROCARBON OCCURRENCE

An example of a low-quality Monterey fractured reservoir which was tested and abandoned is in the Hames Valley of Monterey County, California. A structural contour map of this area is given in Figure 3. The wells that tested the Monterey in this area had initial production rates of up to 360

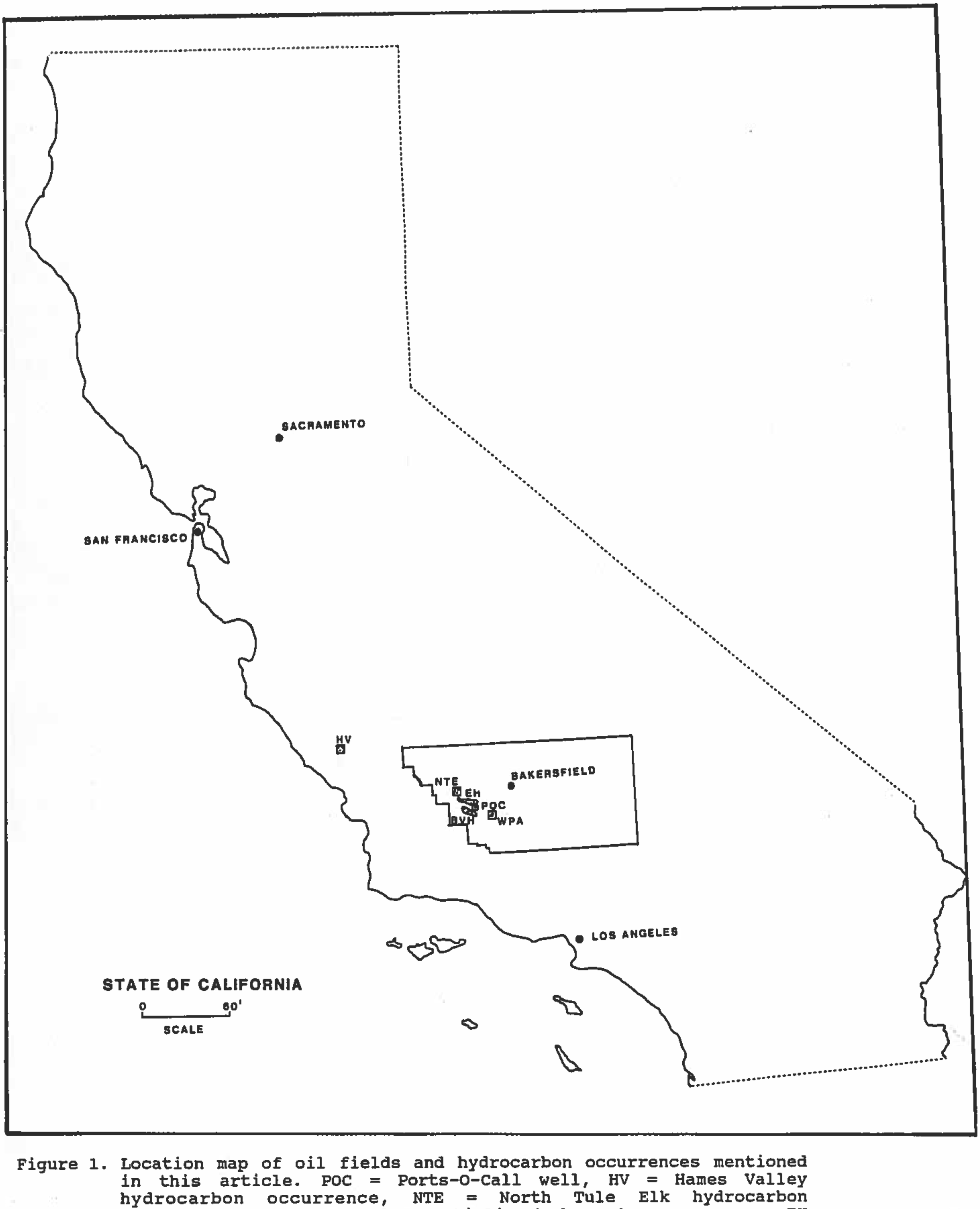

Figure 1. Location map of oil fields and hydrocarbon occurrences mentioned in this article. POC = Ports-O-Call well, HV = Hames Valley hydrocarbon occurrence, NTE = North Tule Elk hydrocarbon occurrence, WPA = West Paloma Anticline hydrocarbon occurrence, EH = Elk Hills oil field, BVH = Buena Vista Hills oil field.

barrels per day (Moore, 1987). The wells rapidly watered out. Acidization and fracturing were attempted. These efforts met with moderate success and the play was abandoned. One very interesting well in this area was the Pleyto Oil Company #2 (Sec 26, T.24S., R.10E.). The operators failed to abandon the well. Several years later, on hot summer days, oil would ooze out of the casing and spread over the nearby road (Kilkenny, 1963).

THE NORTH TULE ELK HYDROCARBON OCCURRENCE

A structural contour map of the North Tule Elk ("NTE") hydrocarbon occurrence is given in Figure 4. Several wells tested this structure the center of which is located 2 miles north of the Tule Elk oil pool of the Elk Hills oil field, and 5 miles southeast of the Cal Canal Gas Field (Land and Mitchell, 1983). The wells were drilled in search of turbidite sand reservoirs. Only distal turbidite sands and siliceous and argillaceous shale were encountered. The Monterey has less and less sand northward from the productive Stevens turbidite sand in the Tule Elk field. Initial production tests for the NTE structure yielded only a few dozen barrels of oil per day. The wells rapidly watered out, and were all eventually abandoned.

THE WEST PALOMA HYDROCARBON OCCURRENCE

The West Paloma Anticlines a southeast plunging structure between the Paloma Anticline (Peirce, 1949), the southeastern part of the Midway-Sunset oil field, and the Yolumne oil field (Land and Bright, 1981). The anticline, like all others around it are bounded by wrench faults. Several wells have tested this structure. The Tenneco "B-N Minerals" #1-13 (Sec 13, T.32S, R.25E) reported a core sample having 31% oil with low permeability. No economic rates of production were obtained, and all the wells were abandoned.

THE PORTS-O-CALL WELL

Two of the giant oil fields of the southern San Joaquin valley are the Buena Vista Hills and Elk Hills oil fields. These oil fields are fault-bounded en-echelon anticlines. Between them is the Dustin Acres Syncline. In the Elk Hills oil field Monterey production is from the turbidite facies while the argillaceous (Antelope 555 pool) facies is productive at Buena Vista Hills. At the axis of the syncline between these two fields the Ustan-Ports-O-Call 1-22 ("Ports-O-Call") well was drilled. A structural contour map of this area is shown in Figure 6.

The history of the Ports-O-Call well is as follows: Ports-O-Call Company drilled the well and completion testing was performed. Initial recovery rates of 6 and 20 barrels per day were reported. Production after a gel fracturing program was reported at 40 barrels per day after 30 days from 13,392 to 13,420 feet in "Stevens Sand". The Ports-O Call Company then filed for bankruptcy. The well was shut in for six months while the state reclamation bond was attached by the Bureau of Land management which then issued a contract to have the well abandoned. When the well was entered for abandonment, there was 6,000 psi at the well head. The well head, located in the back of a residential yard, was flooded and gas bubbles were issuing up through the water. During abandonment, all perforated zones where cemented. After a cavity shot at @ 6150 feet, the well began to flow oil. It did so for one or two hours, recovering 150 barrels of oil (Hal Bopk, personal communication, 1985). This would have been equivalent to production of 1,800 to 3,600 barrels per day. The flow was forcibly stopped and abandonment completed. It is not known how long this rate of production might have been sustained had it not been interrupted.

BREATHING FRACTURES

The behavior of the Ports-O-Call well can be explained by a theory of "breathing fractures" (Figure 7). The rock in the argillaceous facies is plastic at depths below 5,000 feet. Tectonic forces create the fractures, and hydraulic (pore) pressure enlarges them. The hydraulic fluid supporting the fractures is a mixture of oil and water. Over time, a segregation of fluids takes place, and oil migrates toward the top of the fracture reservoir. When penetrated by a drill bit, the oil and water flow into the well bore. The pressure then decreases, the fractures collapse, and permeability is reduced. The capillary pressure difference between oil and water allows for both fluids to flow from the formation when the fractures are large. As the fractures collapse, only water can flow from the fractures. This explains why many Monterey tests have "flush" production which rapidly waters out. If testing continued after all oil was produced, water production would drop off rapidly too. In the case of the Ports-O-Call well, an extended period of time elapsed between final testing and well abandonment. This is something that typically does not occur for most Monterey wells. During the time that the well was idle, pressures within the reservoir began to increase. The fractures were enlarged hydraulically with oil and water. Since the well was washed out during gel fracturing, a conduit for oil migration existed outside the casing. When the cavity shot was conducted, an escape route was provided for the over pressurized fluids surrounding the well bore. As a result, the well flowed. The phenomena of breathing fractures, as described above, leads to the hypothesis that cyclic production of "low grade" Monterey fractured reservoirs may be economically viable.

LIMITATIONS OF CYCLIC PRODUCTION

If the physics of fracture behavior in the argillaceous facies of the Monterey Formation as described above is correct, then what factors are likely to limit cyclic production? These reservoirs may be modeled

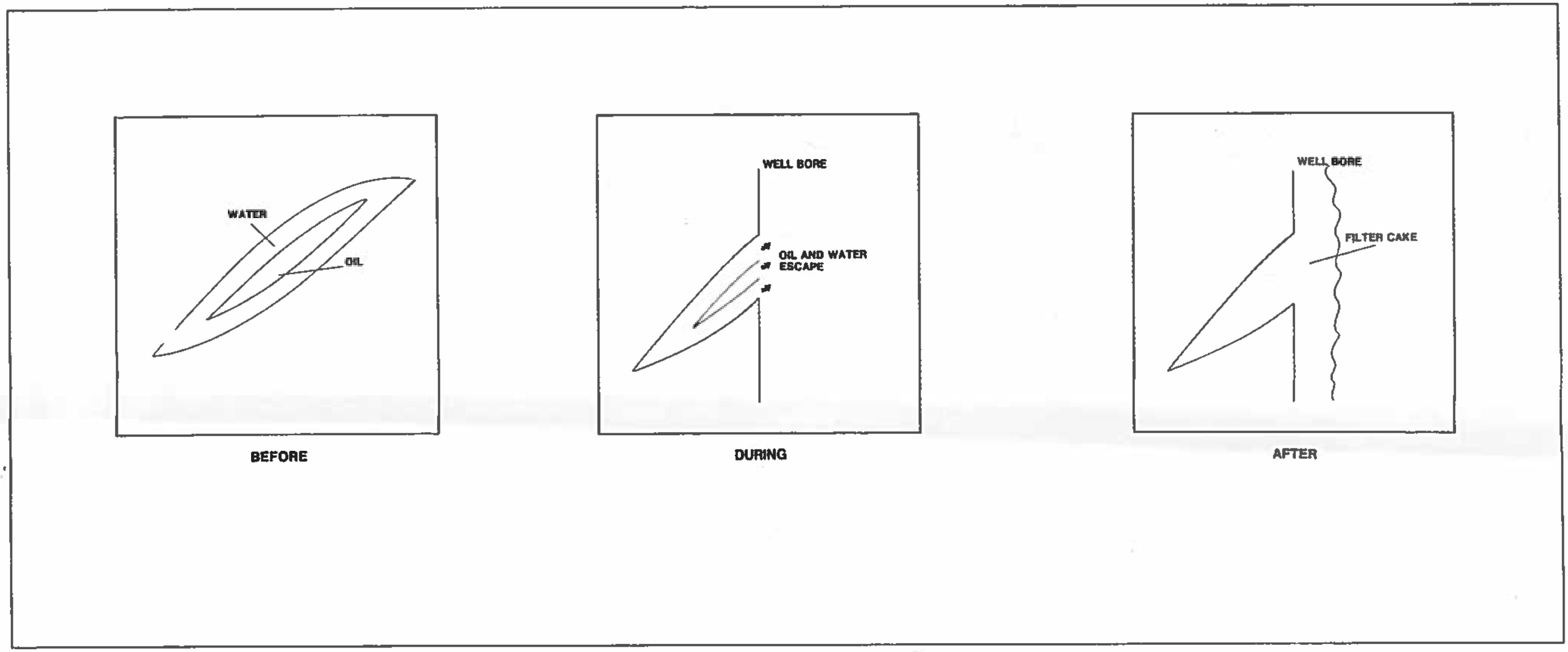

Figure 2. Destruction of fractured reservoirs during drilling.

as tabular zones having predictable dimensions, and reserves. The number of cycles of production that can take place before all recoverable oil is extracted is dependent on the amount of oil existing in the microfractures as well as the number of times the shale can be stretched and compressed before it looses its plasticity (theoretically, this quality would never be lost). Such factors, in theory, could be determined from analysis of pressurized core samples. From the limited data, it appears that the pressure conditions required to allow plastic deformation and cyclic production in the Monterey occurs at subsea depths below 5,000 feet.

Using the Ports-O-Call well as a measure of the potential for cyclic production, expected annual oil recovery is estimated as follows: Assuming that the well would have had an initial production of 1,000 barrels a day and that it would decline to 0 barrels a day within 30 days, gives a value of about 14,000 barrels for the first cycle of production. This represents an average daily rate of 20 barrels of oil per day, assuming the second cycle of production commenced 11 months later.

Above I described a "typical" low-grade Monterey reservoir as having 13.5 million barrels of oil in place. Assuming that only 10% of this could be produced cyclically, that still leaves 1.3 million barrels that could be recovered.

DRILLING PRACTICES

When exploring for fractured reservoirs in the Monterey, care must be taken to protect the reservoir from damage by drilling fluid. Use of air would is the best method. At depths where air drilling is not possible, use of foam and very light mud is recommended. Muds must be as "clean" as possible with a minimum of suspended solids. Conventional drilling practices could be used until one reaches Monterey rocks and, then air or light muds could be used.

CONCLUSION

The Monterey Formation possesses many low-grade fractured reservoirs. These are easily damaged by drilling, and many of them have been tested and inadvertently abandoned. The plastic behavior of the argillaceous facies of the Monterey at subsea depths below 5,000 feet leads to the phenomena of breathing fractures. Cyclic production from these breathing fractures may be possible for low-grade fractured reservoirs.

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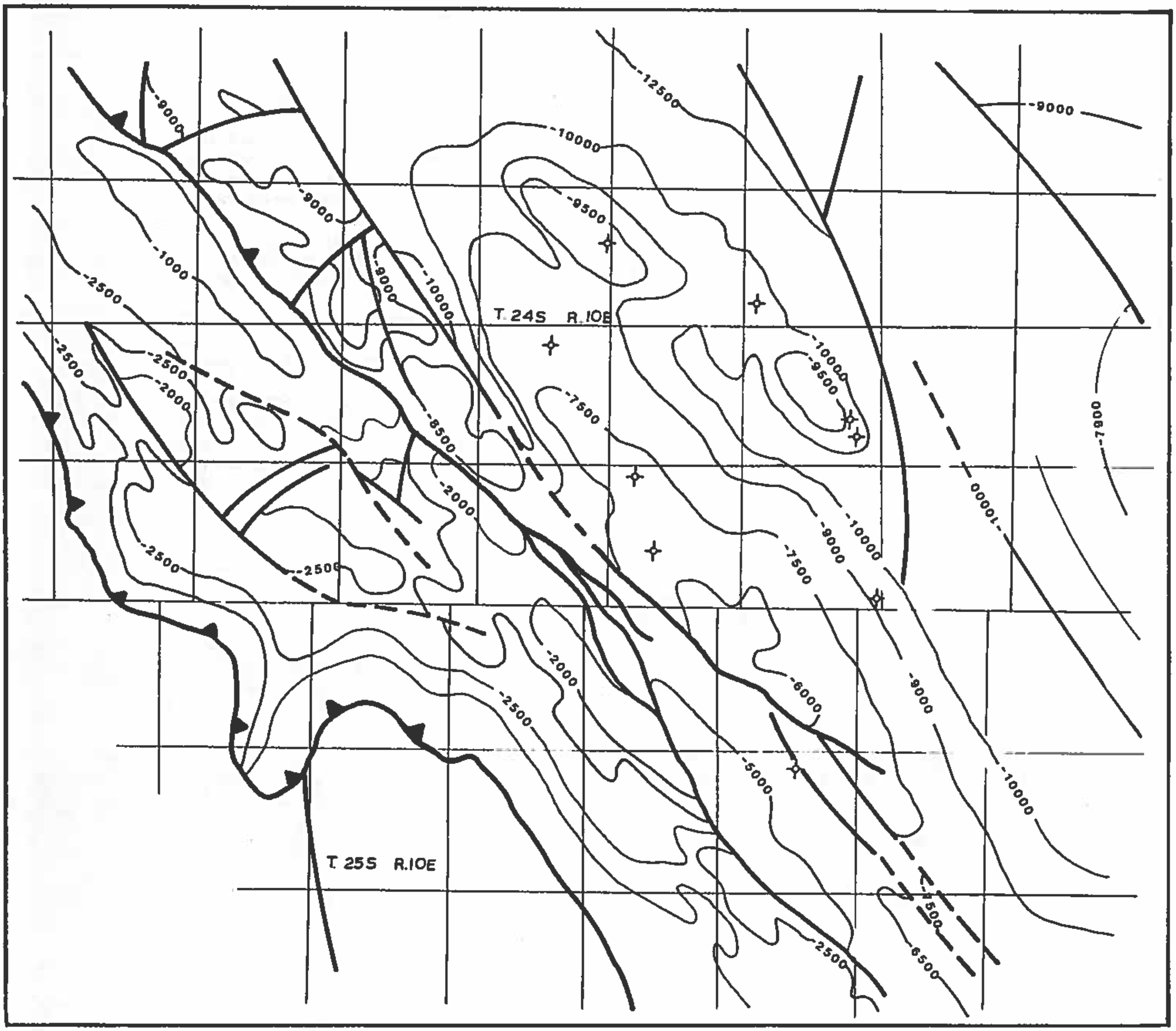


Figure 3. Structural contour map of the Hames Valley hydrocarbon occurrence (modified from MJ systems microfiche, 1987).

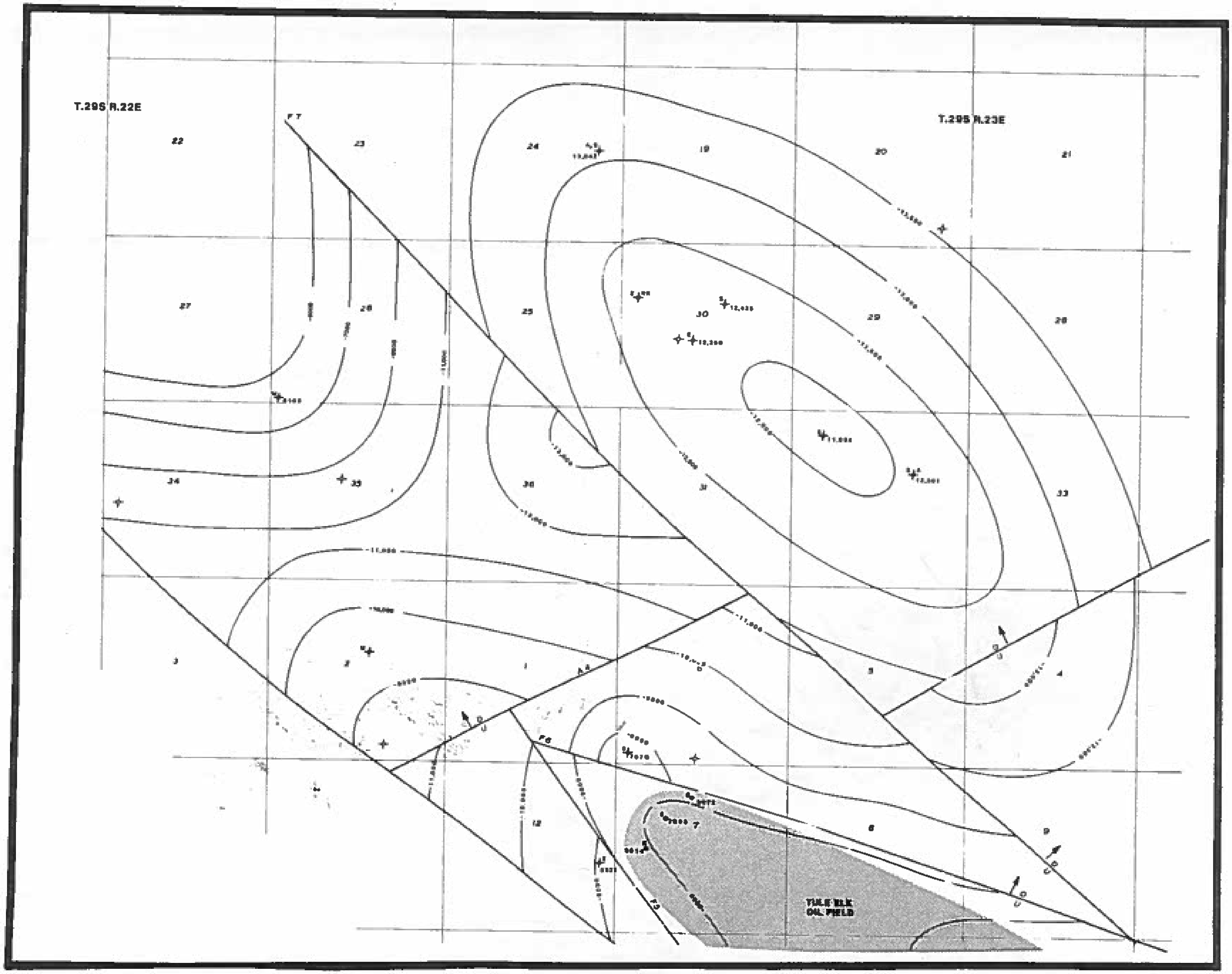


Figure 4. Structural contour map of the North Tule Elk hydrocarbon occurrence. Contours on top of Monterey Formation. "Shows" in the following formations indicated by: A = Antelope Shale, S = Stevens Sand, E = Etchegoin Sand, M = Monterey. Modified from Wilkerson (1986a).

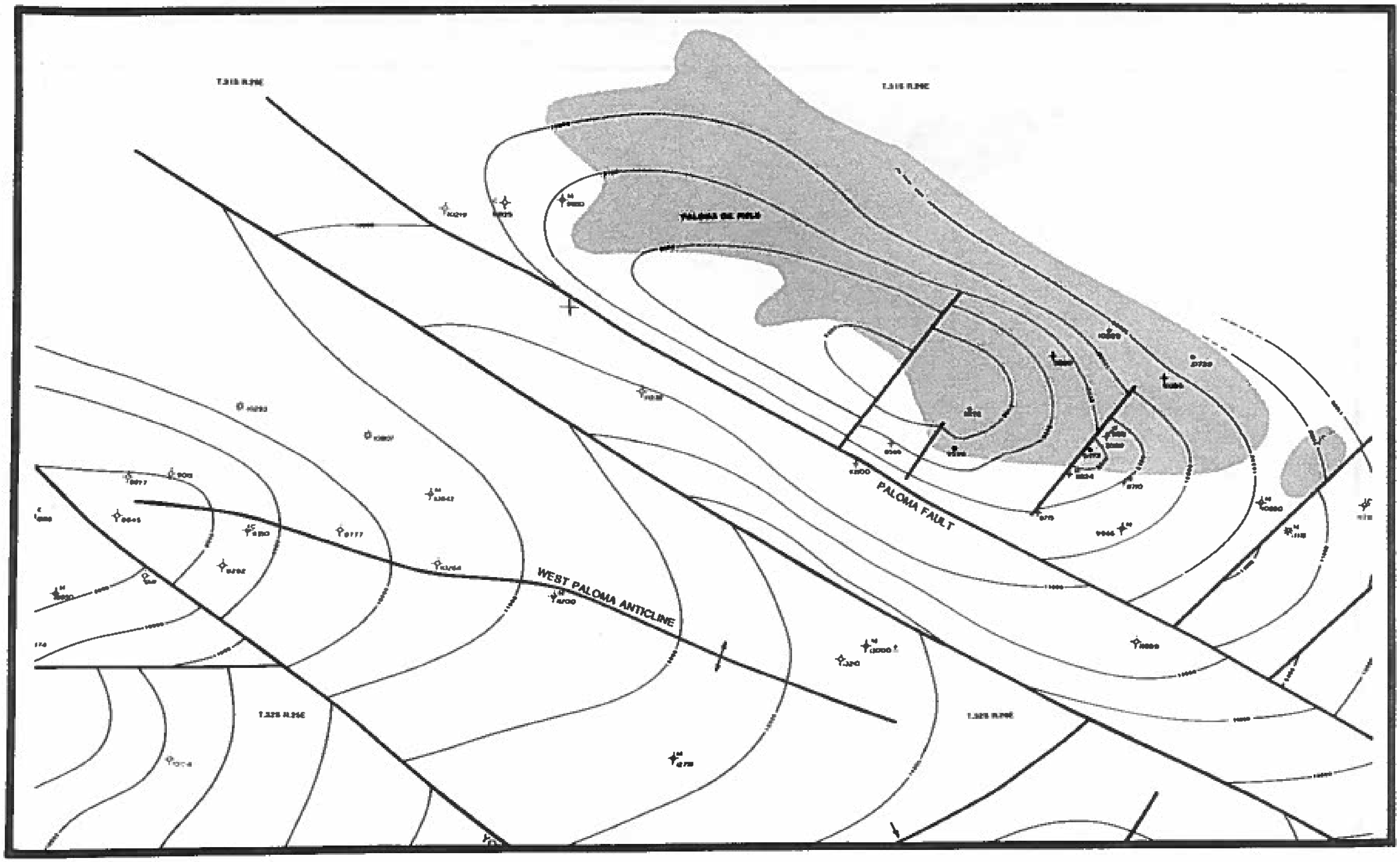


Figure 5. Structural contour map of the West Paloma hydrocarbon occurrence. Compiled from Pierce (1949), Land and Bright (1981), and Wilkerson (1986b). Contours of MM marker. "Shows" in the following zones are indicated as: M = Monterey Shale, S = Steven's ("Paloma") Sand, C = Carneros Sand, T = Tulare Sand, E = Etchegoin Sand.

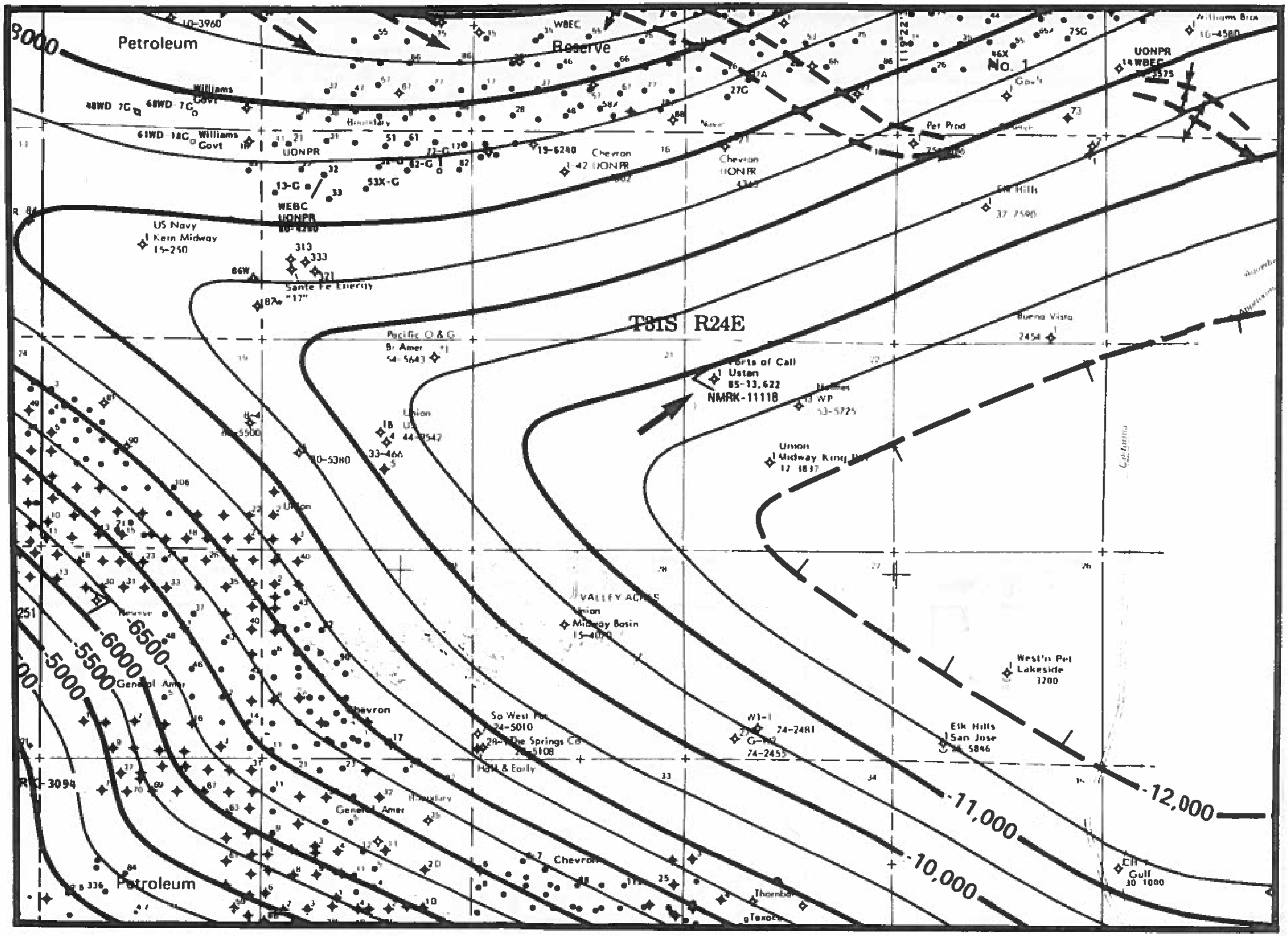
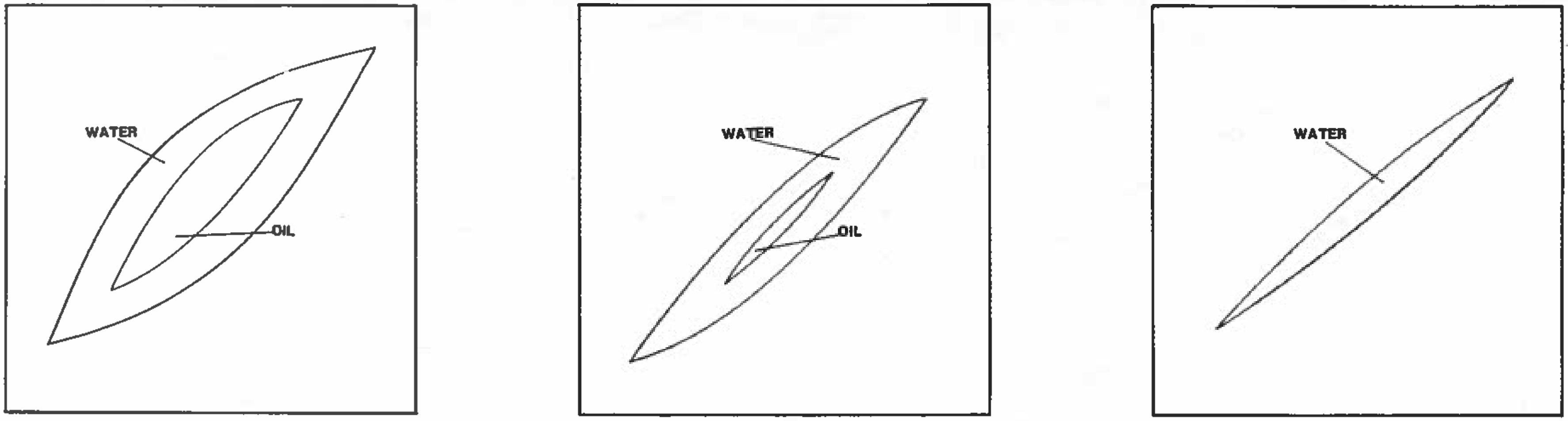


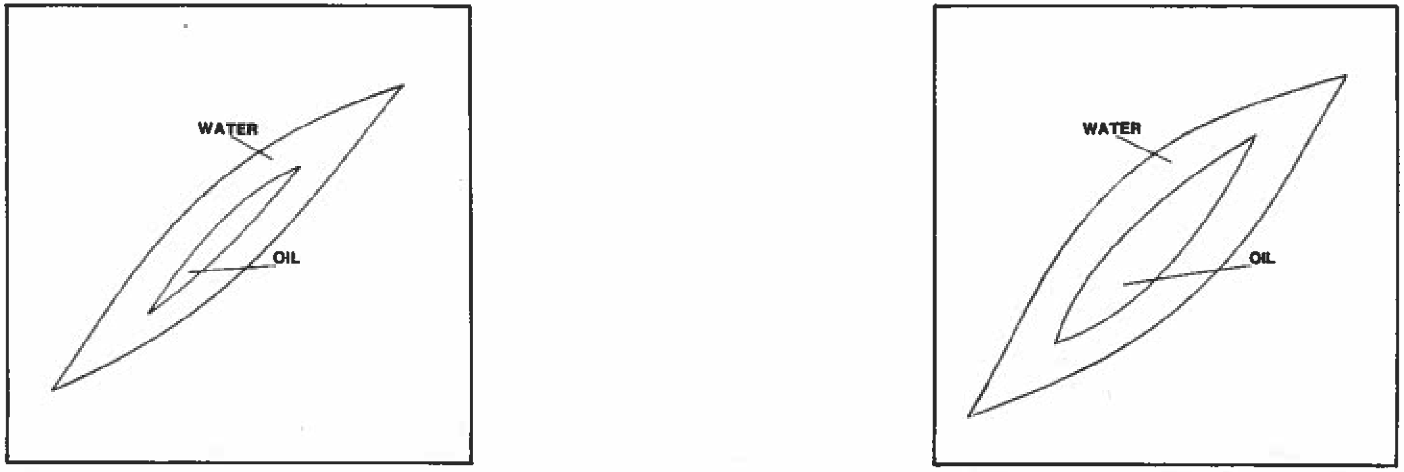
Figure 6. Structural contour map in the area of the Ports-O-Call well. Contours on "N" point marker. From GeoMap Inc, Map No. CAL-133 (1988). Used by permission.



PHASE 1: BEFORE DRILLING.
FRACTURE OPENS UNDER
HYDROSTATIC PRESSURE.

PHASE 2: INITIAL PRODUCTION.
MORE WATER AND LESS OIL
PRODUCED AS FRACTURES CLOSE.

PHASE 3: FRACTURE CLOSES.
WELL SHUT IN, PRESSURES
BEGIN TO INCREASE.



PHASE 4: FRACTURE ENLARGES.
OIL AND WATER OPEN
FRACTURE HYDRAULICALLY.

PHASE 5: FRACTURE RETURNS TO ORIGINAL
PRE-PRODUCTION CONDITION.

Figure 7. Breathing fractures.