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Geology of the Gladys McCall Geopressured-Geothermal Prospect, Cameron Parish, Louisiana

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The Gladys McCall prospect lies at the western edge of the Rockefeller Wildlife Refuge about 88 km (55 mi) southeast of Lake Charles in Cameron Parish, Louisiana. The test well is 4825 m (15,831 ft) deep and was drilled in 1981 under the U.S. Department of Energy geopressured-geothermal research program. The well was shut in at the end of October 1987 after it had produced over 27 million barrels of brine and 676 MMscf gas, without any significant pressure decline. The stratigraphic section seen in this test well consists of alternating sandstones and shales with about 350 m (1150 ft) of net sand between 4393 m (14,412 ft) and 4974 m (16,320 ft). The producing reservoir is bounded on the north and south by faults. The east-west dimension is poorly defined due to lack of deep well control. Eleven prospective production zones have been identified. The pressure maintenance and the continuous high brine yield from the reservoir may be due to laterally overlapping and connected sandstones, communication between overlying and/or underlying reservoirs, growth faults acting as passageways for brine, shale dewatering, or possible communication of zones behind the casing.

Introduction

The existence of subsurface regions having abnormally high formation pressures in many areas around the world has been known for a long time. Numerous methods have been proposed for the recognition, evaluation, and prediction of abnormal pressures (Fertl, 1976). Three pressure regimes have been defined in terms of pressure-depth gradients: (*a*) normal pressure (0.465 psi/ft); (*b*) soft overpressure (0.465–0.70 psi/ft); and (*c*) hard overpressure (>0.70 psi/ft). The typical pressure gradient in the Gulf Coast area is 0.465 psi/ft, which is equivalent to 9.0 lb/gal drilling mud weight (Harkins and Baugher, 1969; Loucks et al., 1979); higher pressures are considered abnormal.

The generation of abnormal pressure has been variously attributed to (*a*) continuous rapid loading and incomplete gravitational compaction of sediments combined with faulting, and (*b*) clay mineral diagenesis during compaction, whereby water is expelled from clay minerals as a result of heat and chemical alteration (typically of montmorillonite to illite) (Barker, 1972; Burst, 1969; Dickinson, 1953; Flanigan, 1981). Conditions produced within abnormally pressured formations include higher-than-normal temperatures, lower-than-normal salinites, decreased permeability, and comparatively higher porosity.

The northern Gulf of Mexico basin, along the coasts of Louisiana and Texas, is one of the most intensely studied areas containing potential geopressured-geothermal energy resources. The abnormally pressured Cenozoic sedimentary formations in this area generally lie at depths greater than 3048 m (10,000 ft) and have temperatures above 107°C (225°F) (Matthews, 1980). Production of oil and gas from geopressured zones is generally accompanied by geopressured brine. However, while all geopressured reservoirs contain brine, not all have hydrocarbons. It is those reservoirs with brine containing dissolved natural gas, mostly methane, that are the object of current evaluation by the U.S. Department of Energy (DOE) under its geopressured-geothermal program begun in 1975. The Technadril-Fenix and Scisson-DOE-Gladys McCall No. 1 well was drilled under this program. It is located east of the town of Grand Chenier (Fig. 1) in sec. 27, T. 15 S., R. 5 W. and is 3.7 km (2.3 mi) into the marsh south of Highway 82. It was drilled in 1981 to a depth of 5032 m (16,510 ft) and plugged back to 4825 m (15,831 ft). The nearby brine disposal well was first drilled in 1965 as a hydrocarbon prospect to a depth of 4754 m (15,598 ft), and was later reentered and completed at 1071 m (3514 ft).

Regional Trends

The structure and history of the Gulf Coast geosyncline has been well documented (Bornhauser, 1958; Caughey, 1975; Rainwater, 1967, 1968; Williamson, 1959; Woodbury, 1973). Since early Tertiary time the Gulf Coast basin has been the repository for large volumes of terrigenous clastic sediments transported in by large river systems. The cumulative

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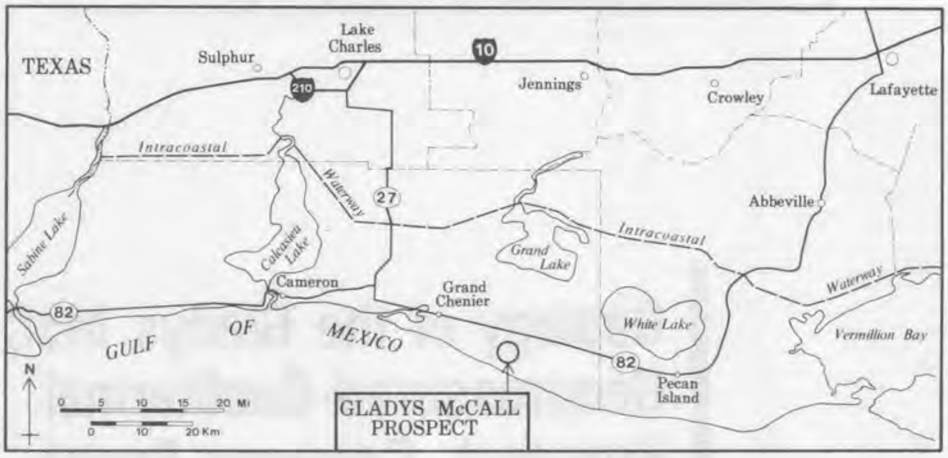

Fig. 1 Location of the Gladys McCall prospect in Cameron Parish, Louisiana

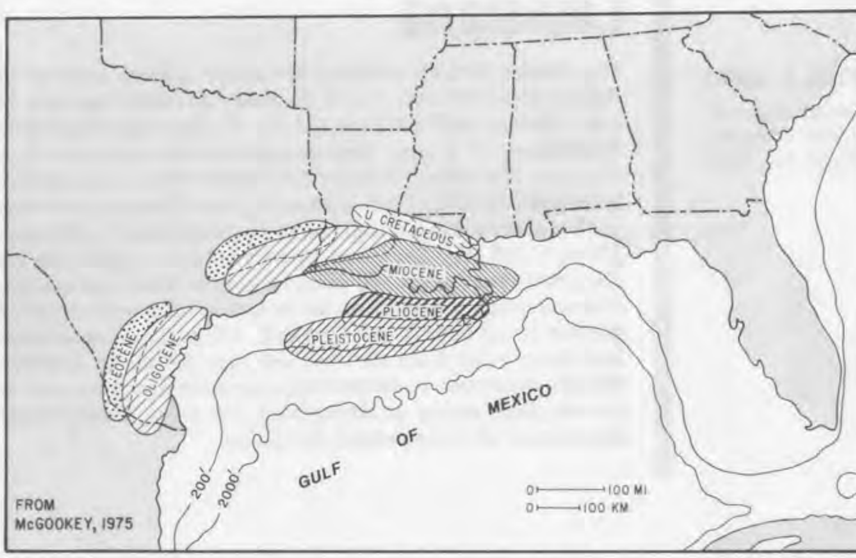

Fig. 2 Location of major sedimentation sites in the northern Gulf of Mexico area during Late Cretaceous and Tertiary time (modified from Bebout, 1982, p. 52)

thickness of sediments in this basin is estimated to be over 10 km (6.2 mi) (Rice, 1980). These major river systems shifted their sand deposition sites through geologic time depending upon the prevailing paleoclimate, tectonics, and sediment supply. The locations of these depocenters during the Tertiary in the northern Gulf of Mexico area are shown in Fig. 2 (Bebout, 1981; McGookey, 1975). Rapid sedimentation caused subsidence and was accompanied by growth faulting, resulting in thickening of beds on the downthrown side (Ocamb, 1961). The oldest growth-faulted and geopressured sediments were first deposited seaward of the buried Lower Cretaceous shelf margin (Bebout, 1981). The geopressured zone along the Texas and Louisiana coast seaward of the lower Cretaceous shelf margin is shown in Fig. 3.

Based on sandstone percentages, which in turn depend on depositional environment, three main facies have been recognized in the Tertiary and Quaternary sedimentary sequences of the Gulf Coast basin (Norwood and Holland, 1974; Thorsen, 1964): (*a*) massive sandstone facies, where sandstone volume is 50 percent or more of the total volume; (*b*) alternating sandstone and shale facies, where sandstone comprises 15–35 percent of section; (*c*) massive shale facies, in which 15 percent or less of the section is sandstone. This sequence is usually found from the coastline seaward. It overlies or underlies another similar sequence depending upon the extent of the transgressive or regressive episode.

Information about the patterns of regional sandstone distribution, subsurface temperatures, porosity, permeability, formation pressures, salinity, and subsurface structure are essential for the successful identification and exploration of potential geopressured-geothermal reservoirs. Regional geologic studies were conducted at the Louisiana Geological Survey by D. G. Bebout and others (Bebout et al., 1982; Bebout and Gutierrez, 1981; Wallace, 1982), identifying potential areas of suitable geopressured-geothermal reservoirs. Figure 4 shows the distribution and depth of Tertiary geopressured sandstones in south Louisiana (McCulloh et al., 1984). These regional studies also demonstrated that the top of geopressure is shallower along the Texas Gulf Coast (2133–3657 m 7000–12,000 ft) and deeper to the northeast into Louisiana (2743–5486 m or 9000–18,000 ft). Porosity generally decreases uniformly with depth (Loucks et al., 1979), although wide variations in porosity at any particular depth occur due to differences in original sand composition, diagenesis, geopressure, fluid composition and movement. Subsurface temperatures of 148°C (300°F) in the geopressured zone are found at depths of 3962–4572 m (13,000–15,000 ft) in the Texas Gulf Coast and west Louisiana, and 4572–5486 m (15,000–18,000 ft) in east Louisiana. Permeability trends showed wide variation and hence were difficult to predict. Salinity generally increased with depth being highest just above the geopressured zone (100,000 ppm or greater). In the

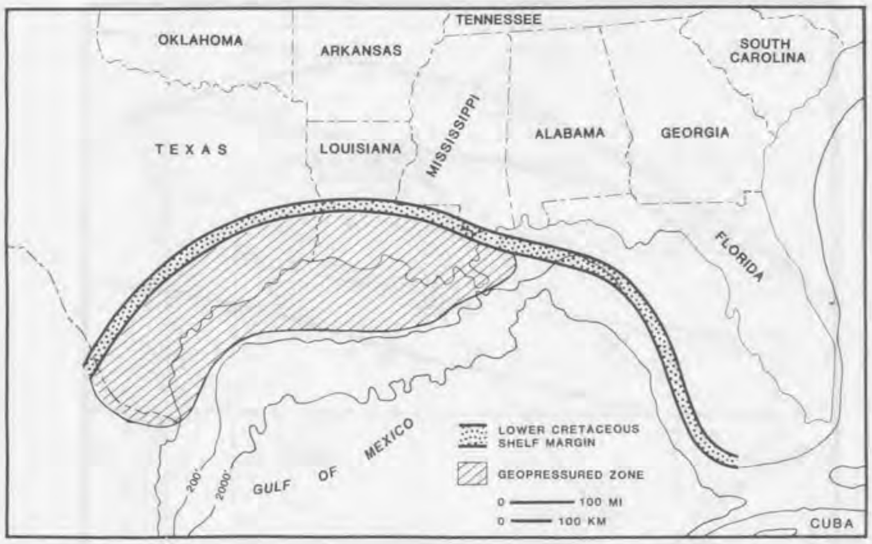

Fig. 3 Trend of the Lower Cretaceous shelf margin and the geopressured zone in the northern Gulf of Mexico area (modified from Bebout, 1982, p. 50)

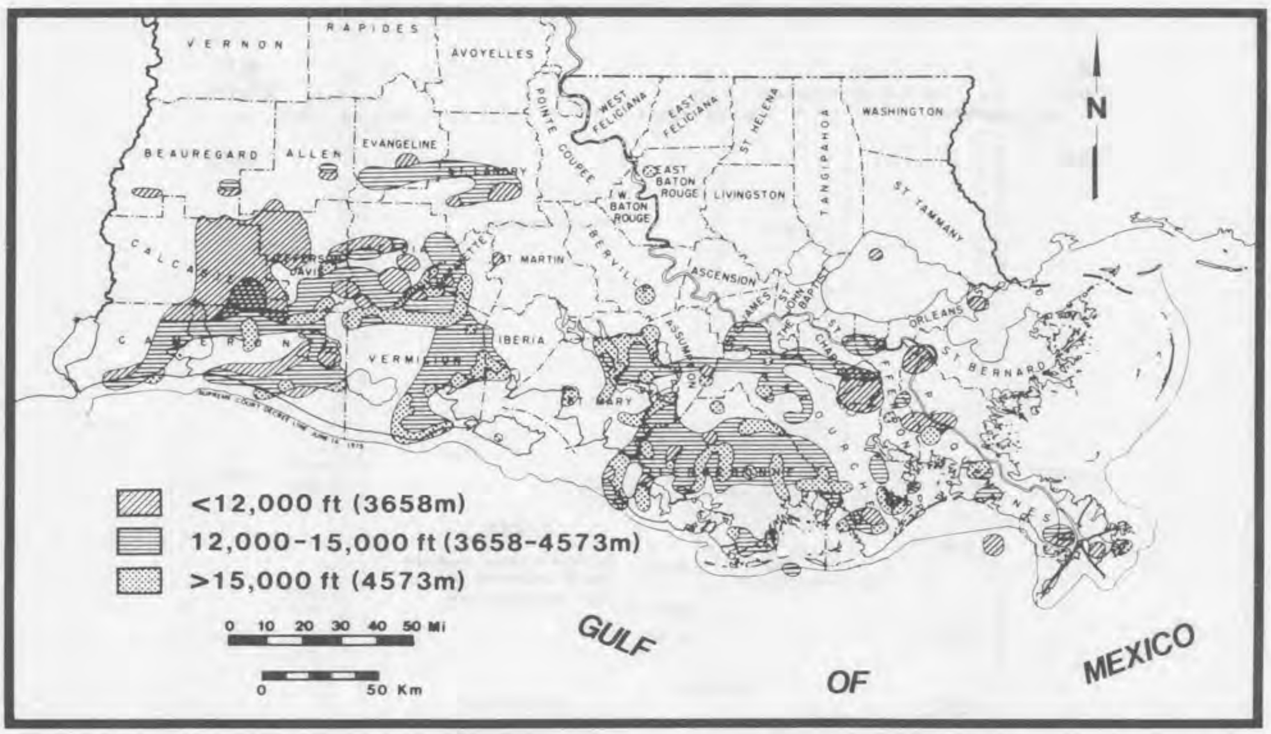

Fig. 4 Distribution and depths to Tertiary geopressured sandstones in south Louisiana (modified from McCulloh et al., 1982)

geopressured zones, salinities were found to be highly variable, ranging from more than 100,000 ppm to less than 20,000 ppm (Bebout and Gutierrez, 1981).

Prospect Site Geology

Preliminary studies of the geology and structure of the area were carried out by D. G. Bebout (Louisiana Geological Survey) and Magma Gulf Company (Bebout, 1982; Brunhild, 1984). The Technadril-Fenix and Scisson-Department of Energy (TF&S-DOE) No. 1 Gladys McCall well was drilled in 1981 to a total depth of 5032 m (16,510 ft) and plugged back to 4825 m (15,831 ft). The well lies in the Miocene geopressured-geothermal trend. Wells in this area have penetrated some of the thickest geopressured sand sections in Louisiana or Texas (Bebout, 1982). This fact is contrary to that predicted by regional studies which indicated a predominance of shale in this area. The anomalous sand thickness may be due to local variations in sand supply and deposition combined with subsidence and growth faulting. Regional geological work by Brunhild (1984) suggested that a fluvio-deltaic clastic regression across the shelf slope break contemporaneous with growth faulting and antithetic faulting could account for the greater thickness of sandstones in this area.

The test well penetrated upper (1219–1828 m or 4000–6000 ft), middle (1828–3352 m or 6000–11,000 ft), lower Miocene (3352 m or 11,000 ft-T.D.) sections with the section below 4389 m (14,400 ft) being geopressured. Approximately 350 m (1150 ft) of net sand was seen in this well from 4392 to 4974 m (14,412 to 16,320 ft). A generalized structure map of the pros-

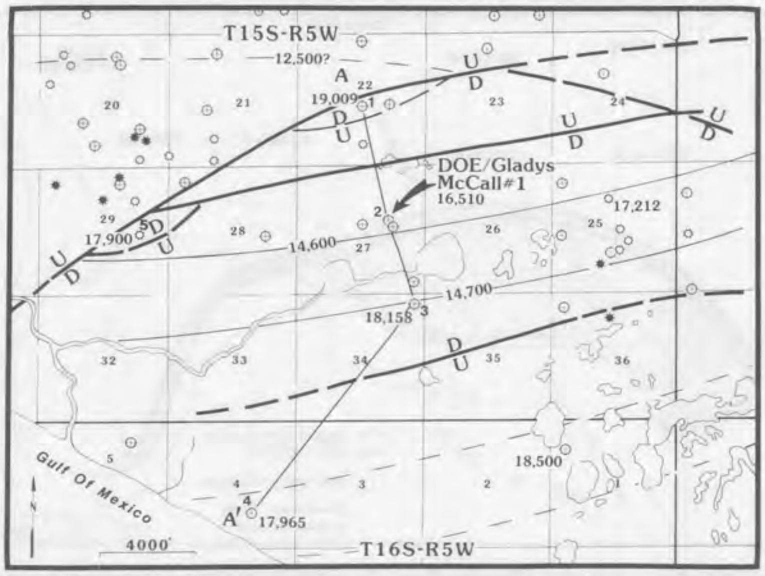

Fig. 5 Structure of the Gladys McCall prospect area, contoured at the 14,560ft sand in the T-F&S/DOE Gladys McCall No. 1 well by Magma Gulf Company (adapted from Technadril-Fenix and Scisson, 1982, pp. 4-10). (See Fig. 6 for well identification.)

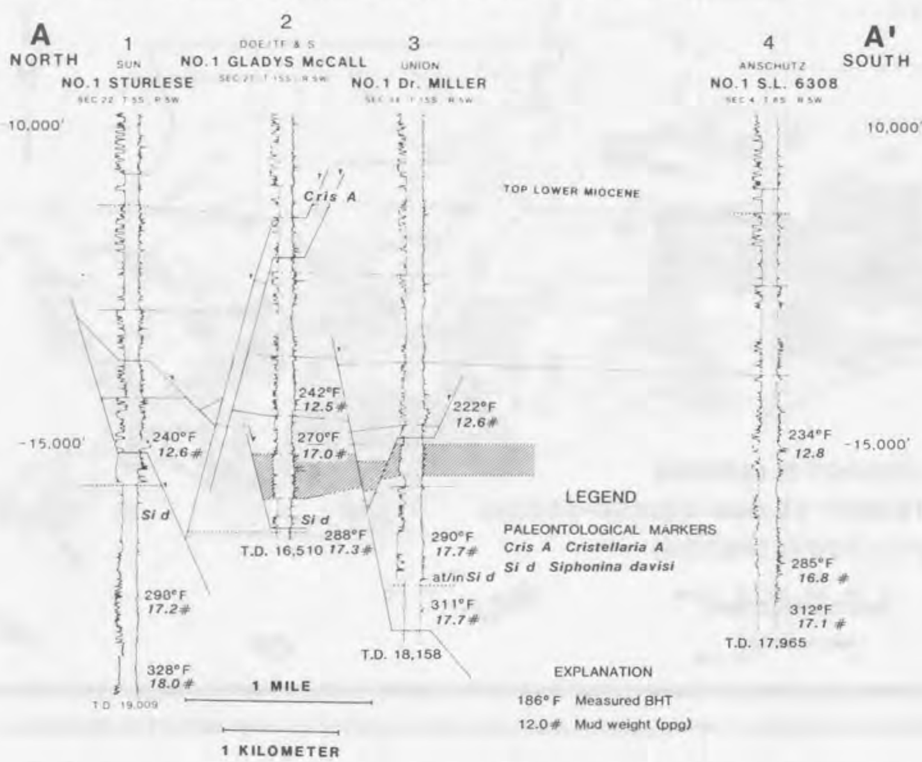

Fig. 6 Dip cross section of the prospect area, showing log correlations, paleontological markers, temperature and mud weights (modified from Bebout et al., 1983, p. 86). (See Fig. 5 for line of cross section.)

pect area is shown in Fig. 5 (Technadril-Fenix and Scisson, 1982). There are a large number of wells in the area, but very few are deep enough to have reached the geopressured reservoir system observed in the test well. Hydrocarbon production in this area is from horizons shallower than the target section at Gladys McCall No. 1. The locations of the faults controlling the north-south extent of the geopressured reservoir were determined using available seismic lines.

A dip (north-south) cross section of the area through the Gladys McCall test well is shown in Fig. 6. Log correlations are relatively straightforward at shallower depths, but tend to get more complex below 4572 m (15,000 ft). Paleontologic analysis has helped to confirm the correlations. The target section lies between two key microfossils, *Cristellaria A* (3384 m or 11,100 ft) and *Siphonina davisi* (4998 m or 16,440 ft). The former marks the outer shelf (ecozone-3) environment while the latter is characteristic of the upper slope (ecozone-4) environment, indicating that sands constituting the target section were probably deposited in a shelf environment by distributary channel systems.

There is a good correlation between sands seen in the Gladys McCall No. 1 well and the Union of California, Dr. Miller No. 1 well located to the south, but the former well shows a thicker section. Also, *Siphonina davisi* was picked at 5346 m (17,540 ft) in the Miller well compared to 5010 m (16,440 ft) in the Gladys McCall well, indicating a large missing section (ap-

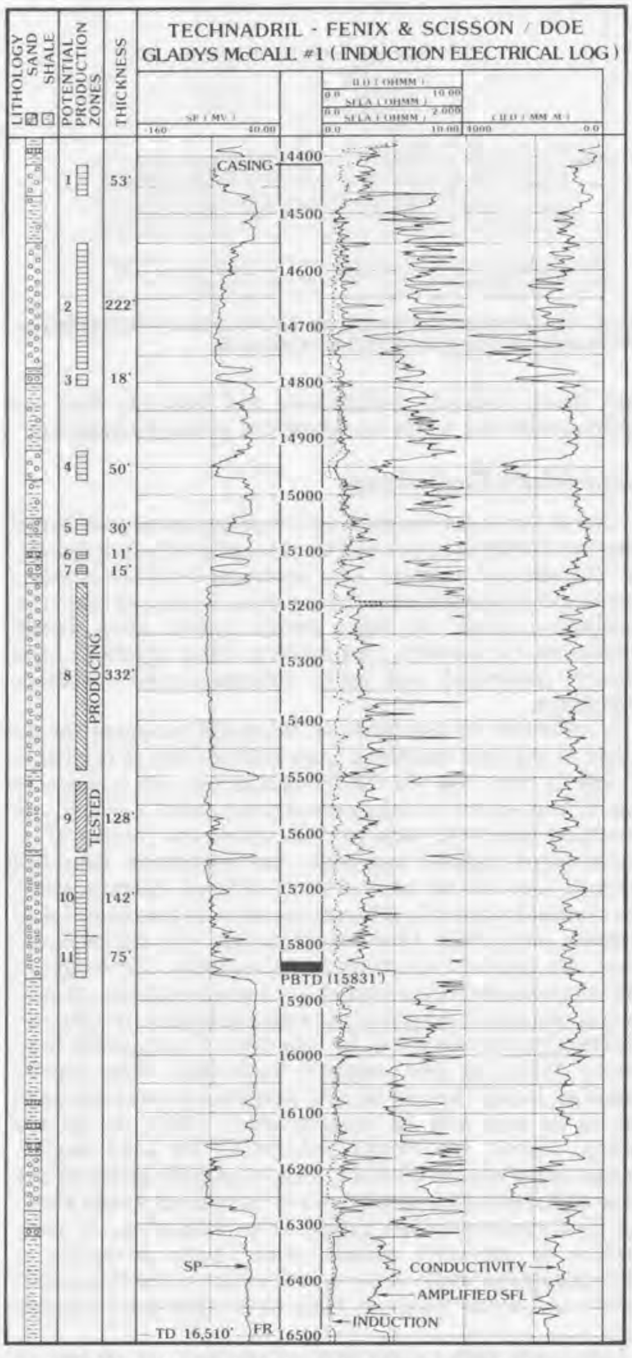

Fig. 7 Electric log, potential production zones, thickness, and generalized lithology of the test well

prox. 365 m or 1200 ft) in the Gladys McCall well and the presence of a large fault cutting the Gladys McCall well. This fault at 4983 m (16,350 ft) in the test well cuts out the lower thick sandstone seen in the Miller well. The dipmeter log also confirms the presence of this fault. This log shows a south dip from 4389–4602 m (14,400–15,100 ft), and a north dip (10–30 deg) from 4602–4983 m (15,100–16,350 ft), where it again changes to the south. The north or reverse dip in the target section indicates a rollover fault. Contemporaneous fault movement and sand deposition with subsidence increase the thickness of the shale and sand section above the fault. The fault to the south of the Gladys McCall well was drawn (see Fig. 5) to explain the absence of *Siphonina davisi* in the Pan Am SL 4079 well (T.D. 5,638 m or 18,500 ft) to the total depth of the well. This microfossil would have been present even if the sand shaled out. Depending upon how far this fault extends upward in the section, it may or may not be a sealing fault relative to the target section.

Lack of deep well control in the east-west direction results in poor definition of the reservoir boundaries. The target sand seen at Gladys McCall is absent in the Cherryville No. 1 Miller well (T.D. 5455 m or 17,900 ft) (well No. 5 in Fig. 5) as both the faults north of the test well merge to the west and cut the Miller well at approximately 4907 m (16,100 ft). An additional fault may be present on the east side as shown by the dashed line in Fig. 5, but its existence cannot be proved definitely because of the lack of deep well and seismic data in this area.

Production Test Summary

Eleven potential production zones, numbered sequentially, have been defined within the geopressured section; the electric log, production zones and generalized lithology are shown in Fig. 7. Three diamond cores were taken in the target sand from 4622 to 4625 m (15,167 to 15,177 ft), 4626 to 4630 m (15,179 to 15,192 ft), and 4678 to 4685 m (15,348 to 15,374 ft). Twenty-eight sidewall cores were shot between 4712 m (15,460 ft) and 5015 m (16,455 ft). The analysis of all these cores showed that the reservoir was made up of fine-grained, well-consolidated and mostly silica-cemented sandstone (Technadril-Fenix and Scisson, 1982). No sand was produced during production tests. Trace quantities of oil were produced during times of high volume (20,000 bbls/day and more), but no oil was observed when daily volume was reduced. It has been postulated that the oil might be originating from nearby shales.

The average Gulf Coast geothermal gradient is approximately 1.5°F/30 m (1.5°F/100 ft). The average gradient at the test site was found to be 1.55°F/30 m (1.55°F/100 ft) and 1.67°F/30 m (1.67°F/100 ft) between 3840 and 4754 m (12,600 and 15,600 ft) (Technadril-Fenix and Scisson, 1985).

Only zones 8 and 9 have been flow tested. Zone 9 was perforated between 4726 and 4765 m (15,508 and 15,636 ft) and tested for a short time. Total production from this zone was 119,000 bbls of brine and 3.4 MMscf gas. Average porosity for zone 9 was 24 percent, permeability 90 md, brine temperature 148°C (298°F), and original reservoir pressure 12,936 psi. The brine contained approximately 32 SCF/STB of solution natural gas. The brine had total dissolved solids of 95,500 ppm. After zone 9 was plugged, the long-term testing of zone 8 (perforating between 4620 and 4721 m (15,158 and 15,490 ft)) began in December 1983 and continued until the end of October 1987 when the well was shut in. Initial testing of zone 8 showed porosity of 22 percent, permeability 130 md, brine temperature 142°C (288°F), original reservoir pressure 12,821 psi and total dissolved solid content of 94,000 ppm. The brine contained approximately 31 SCF/STB of solution natural gas (Technadril-Fenix and Scisson, 1985). During this long-term testing of zone 8, the well was flowed at various rates (36,500–5000 bbls/day) for different lengths of time, averaging approximately 20,000 bbls of brine per day. When the well was shut in, it had produced over 27 million bbls of brine and 676 MMscf gas without any significant change in bottom hole pressure. The well is believed to be capable of producing approximately 19,000 bbls of brine per day while maintaining constant pressure. A higher volume production tended to reduce pressure while a lower volume production tended to increase the pressure (Featherstone and Meahl, 1987).

After gas separation, the brine was disposed of by injecting it into a nearby disposal well. The brine disposal well, originally the Getty-Buttes No. 1 well, was drilled in 1965 as a hydrocarbon prospect well to 4754 m (15,598 ft). It was re-entered and completed as a disposal well at 1071 m (3514 ft). Figure 8 shows the electric log, disposal zones, and the

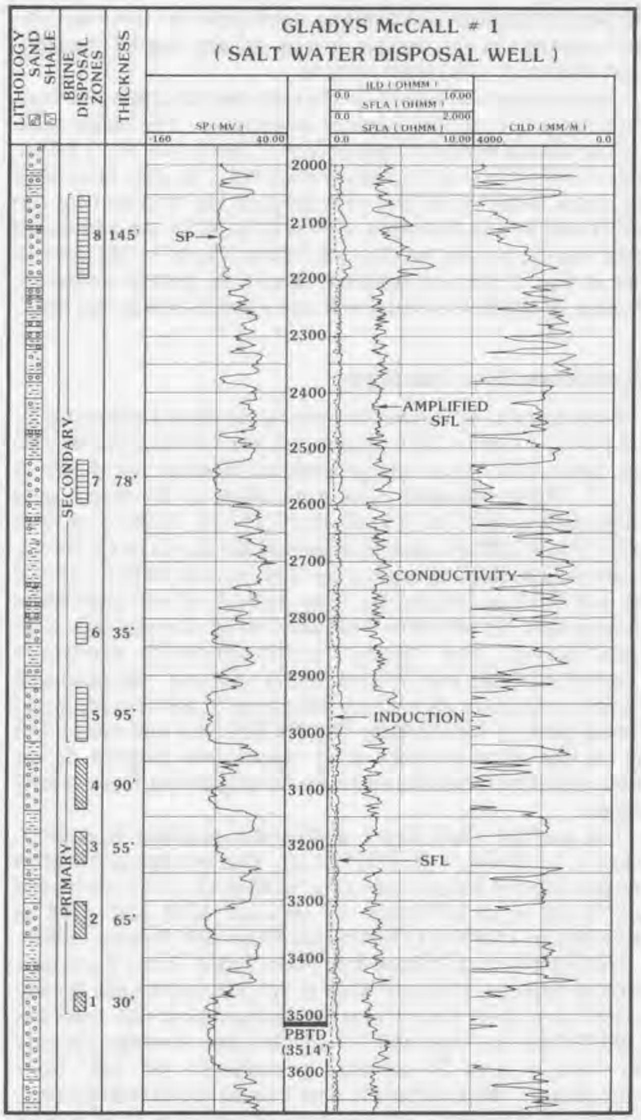

Fig. 8 Electric log, brine injection zones, thickness, and generalized lithology of the brine disposal well

generalized lithology of the brine disposal well. The well log shows Pliocene sandstones that are thick and porous and hence suitable for brine disposal. Major fault displacement is unlikely at these depths and hence and sandstones will have good lateral continuity. A possible practical benefit of this information may be the use of brine in aiding secondary production. No detrimental environment aid effects have yet been attributed to testing and brine disposal (Van Sickle et al., 1988).

The performance of the Gladys McCall test well has far exceeded early predictions based on reservoir engineering studies including reservoir modeling. Various models for the reservoir have been proposed during testing but none of them has been able to accurately predict the actual reservoir performance. It has been difficult to account for the large volume of brine produced from this well. Any predictions dealing with reservoir engineering models have built-in uncertainties associated with a natural geological system. Factors such as the size and geometry of the producing reservoir; fluid flow between overlying, laterally overlapping and/or underlying reservoirs; porosity and permeability changes within a reservoir due to variable compaction rates and cementation; diagenetic effects; shale dewatering with associated effects; and the effects of injected fluids are difficult to quantify accurately. Consequently, reservoir modeling and associated predictions of present

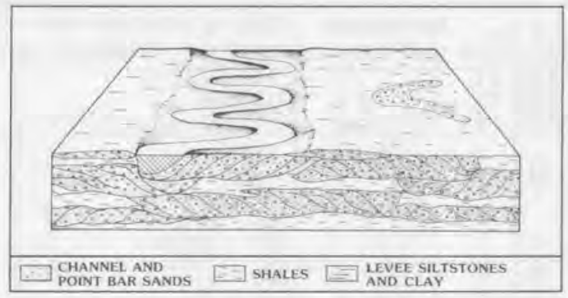

Fig. 9 The formation and mechanism for lateral and vertical extension of connected channel and point bar sandstones

and future reservoir performance and longevity may not always reflect the reality of subsurface geologic conditions.

Depositional Environment

One of the major uncertainties in geopressured-geothermal resource development is reservoir size and production longevity. The size and geometry of a sandstone body are largely a product of the depositional environment. Sandstone reservoirs originating within the same genetic system often exhibit similarities in porosity, permeability, fluid chemistry, and mineral framework and hence undergo similar diagenetic alterations.

A schematic representation of the model proposed for the origin of the sand extending from 4620 to 4834 m (15,160 to 15,860 ft) (Fig. 7) in the Gladys McCall test well is shown in Fig. 9. This section of sand probably represents a genetic unit generated within the same channel system and consists of interconnected channel and point bar sandstones deposited through time. As the main channel migrates laterally within the channel framework, a lateral extension of the channel sand deposits takes place. Contemporaneously with lateral movement, the system is also building up vertically. The weight of the sand being deposited over shale causes subsidence. Depending on the rate of subsidence and the availability of sediment, the resulting sand layer can be quite thick. Faulting may commence. When the sand supply is interrupted, shale may be deposited locally, but the laterally extensive channel and point bar sands may still be interconnected within the genetic system. Hence, the whole thickness of the sand section, though appearing on the electric log as possibly different and separated sandstones, may behave as a single sand body allowing fluid communication during brine production. A transgressive or regressive episode often causes disruption in depositional continuity at the same location within this genetic system and a new system is likely to develop in an adjacent area.

Long-term, high-volume brine production, of the type at Gladys McCall, may cause fractures and subsurface faults within and near the reservoir to accommodate the stresses and volume depletion associated with such production. Surface detection of such effects is unlikely. However, if this phenomenon of fracturing and faulting does take place, it would further aid fluid communication between what may originally have been separate reservoirs.

Summary

When the DOE geopressured-geothermal research and testing program was begun in 1975, very little information was available about the nature and producibility of gas-saturated geopressured-geothermal brine aquifers. Most of the information available at that time was gleaned from the drilling of a large number of wells in the northern Gulf of Mexico in the search for oil and gas, many of which penetrated geopressured sections. Oil companies continue to overlook such reservoirs mainly for economic reasons. Over the past several years the DOE program has obtained vital information about geopressured-gemothermal reservoirs.

The surprisingly successful performance at the Gladys McCall test well has generated a great deal of interest. This well produced over 67 million barrels of brine and 676 MMscf of associated gas during its four-year test. No detrimental environment effects were observed as a result of the production or subsurface disposal of the used brine. Similar large geopressured-geothermal aquifers with long-term production capabilities are likely to exist in the northern Gulf Coast area. The Gladys McCall production has also suggested that the injection of hot, geopressured brine into shallower hydrocarbon-bearing horizons to aid secondary recovery may be economically feasible in hydrocarbon fields where wells penetrate geopressured sands. Depending upon the prevailing local conditions, it may be economically feasible to produce gas from brine after depletion of hydrocarbons.

The geopressured sand section of interest in the Gladys McCall test well represents a genetic unit generated within the same channel environment. This system has migrated laterally and vertically within its framework, and hence sands deposited within this system may be interconnected and in fluid communication. Therefore, to more accurately estimate production capabilities and the life of such reservoirs, the genetic units of sandstones, rather than the individual sands, should be studied and modeled. Fractures and/or subsurface faults may originate within the confines of a genetic reservoir body as a result of high-volume, long-term brine production.

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