

Eugene Herrin

Tom Goforth

# Environmental Problems Associated with Power Production from Geopressured Reservoirs

*Eugene Herrin is professor of Geological Sciences at Southern Methodist University.*

*Tom Goforth is senior research geophysicist at Southern Methodist University.*

## INTRODUCTION

This paper is concerned with various environmental problems that may arise in the exploration for and exploitation of geopressured reservoirs. A particular reservoir in northwest Cameron County, Texas, was used as a model. Pertinent parameters are as follows:

Depth of sand	14,300-15,000 ft
Thickness	700 ft
Temperature	320°F
Reservoir pressure (ave.)	12,000 psi
Total salinity	2,000-6,000 ppm
Permeability	0.10-0.14 Darcy
Porosity	0.25
Area of reservoir	300 mi <sup>2</sup> or more
Well-head pressure	5,000 psi or more

Environmental studies were based upon the properties and location of this model reservoir.

## ENVIRONMENTAL IMPACT

The National Environment Policy Act (NEPA) of 1970 requires each federal agency to prepare an environmental impact statement (EIS) prior to the initiation of any major action that may significantly affect the quality of the human environment. By court ruling, NEPA has been extended to any project for which a significant fraction of the funding is provided by the federal government. In anticipation of the eventual need for an EIS, agencies now are asked to prepare environmental impact assessments during the planning of any project in which the human environment may be seriously affected.

A group from the Department of Geological Sciences, Southern Methodist University, made an environmental assessment of a Gulf Coast geothermal test facility in northwest Cameron County, Texas, as part of a feasibility study (Herrin, Goforth, and Pheasant, 1973). Two outstanding problems were found to be unique to this type of project.

1. Disposal of water brought to the surface from the geopressured reservoirs; whether accidentally because of a blow-out or purposefully as in a flow test
2. Environmental changes brought about by the removal of vast amounts of high-pressure, subsurface water and the subsequent decrease in reservoir pressures

An environmentally acceptable method for water disposal, probably by injection into normally pressured reservoirs, must be worked out before significant tests of a geopressured reservoir can be undertaken. An environmental impact statement will surely be required prior to the construction of semi-permanent surface facilities and the commencement of any long-term flow tests. Such a statement must address the problems listed above.

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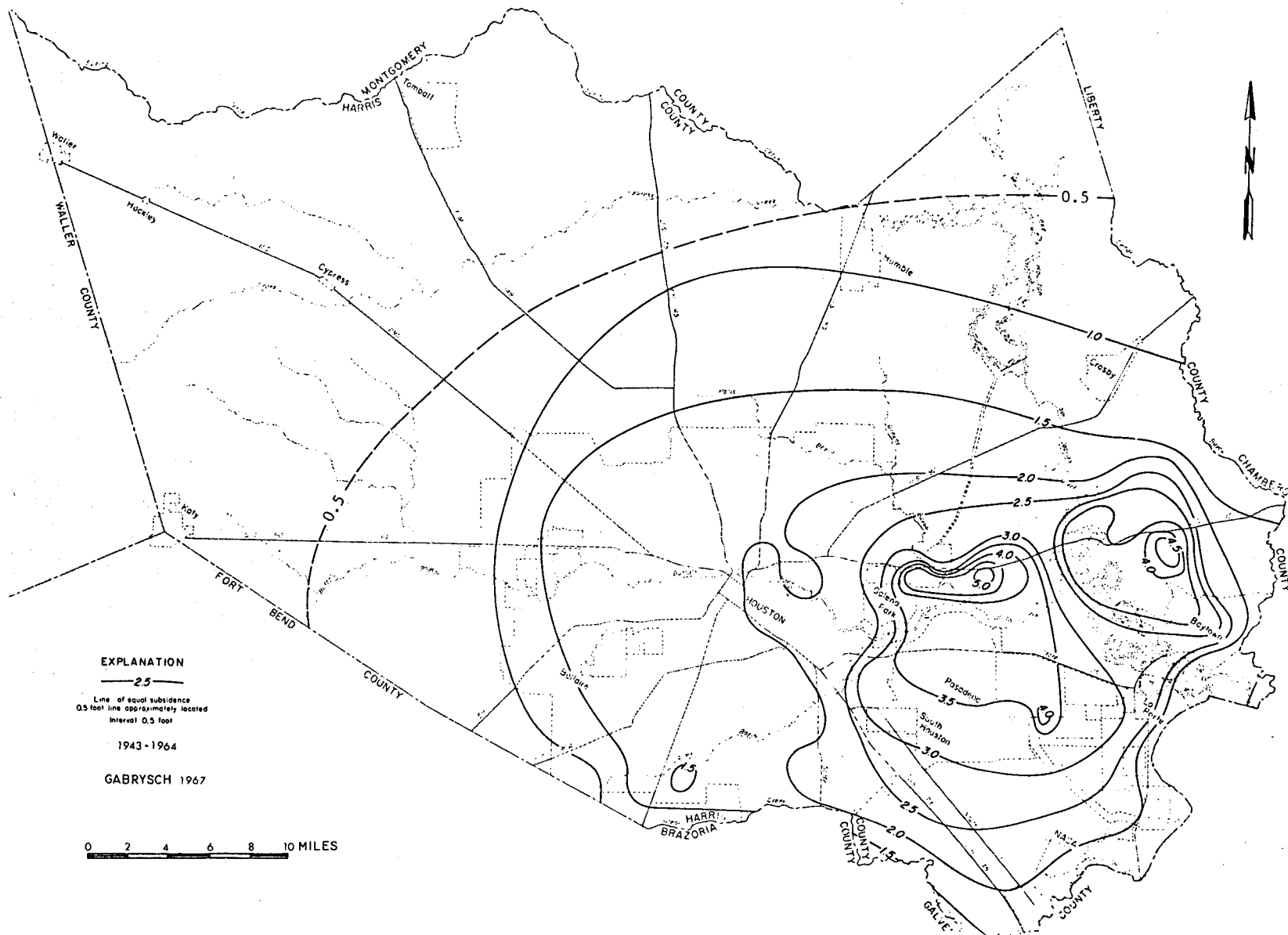


Figure 1. Subsidence of the Land Surface in the Houston, Texas, Area.

## **SUBSIDENCE EFFECTS**

There is evidence that surface subsidence resulting from the removal of large quantities of water from the sedimentary section must be considered as a major environmental hazard. Figure 1 shows subsidence of the land surface in the Houston, Texas, area caused by large-scale withdrawal of fresh water from shallow, normally pressured aquifers. According to Winslow and Wood (1959), the subsiding region comprises about 7,200 square miles (mi<sup>2</sup>) of the Gulf Coastal Plain and includes all or parts of the following counties: Harris, Fort Bend, Waller, Brazoria, Galveston, Liberty, Chambers, Orange, and Jefferson. Topographic relief in this region is low, ranging from sea level at the Gulf of Mexico to 300 feet (ft) or more in northwestern Harris County.

In the upper Gulf Coast region of Texas, which embraces the most heavily populated and industrialized parts of the state, the industrial and municipal water supply is obtained chiefly from wells. The largest center of groundwater withdrawal is the Houston-Baytown area, where about 200 million gallons per day (mgd) were pumped in 1956 for municipal and industrial use. Other large centers of groundwater withdrawal include the Alta Loma sector and the heavily industrialized Texas City area in Galveston County, where about 23 mgd were pumped in 1956. In the Freeport area in Brazoria County about 6 mgd were pumped in 1956 for city and industrial supply (Winslow and Wood, 1959).

A large area of subsidence is centered in the Houston-Baytown district, where the maximum recorded is about 5.0 ft. between 1943 and 1964 (fig. 1). Subsidence in this area as a whole has been on a rather broad scale; in only a few localities do great variations occur within short distances. For this reason there is little visible surface evidence. In several places, however, particularly in the industrial section, certain features can be attributed to subsidence. In some instances deep-set well casings protrude from the ground where the land surface has subsided. In others there is surface evidence of faulting that may be related to subsidence.

The Texas City area has experienced more local subsidence than the Houston-Baytown vicinity. Differential subsidence has had visible results in the immediate vicinity of Texas City including protruding well casings, clogged sewers, and broken pipelines. Another adverse effect of subsidence has been the lowering of land near the coastline. Part of the Baytown district once used for grazing is now tideland. In the Texas City area some of the land formerly believed to be high enough above sea level to be safe during high tides is now subject to inundation during hurricanes (Winslow and Wood, 1959).

The lithology of the deep geopressured reservoirs is very similar to the alternating clays and sands that constitute the shallow groundwater regime in the Texas Gulf Coast. The clear correlation between rapid subsidence and excessive groundwater removal makes it imperative that any large-scale removal of geopressured water be accompanied by continuous monitoring of both surface and subsurface effects.

Tectonic movement may also be a cause of subsidence, since obvious displacement has been noted along some of the many small faults known to exist in the Gulf Coast region. It is not clear, however, whether the displacement is the result of strictly tectonic movements or whether the faulting is related to subsidence.

## **TECTONIC ACTIVITY**

The Gulf Coast of Texas is a tectonically active area and has been for at least 50 million years as evidenced by the thick accumulation of shallow-water, tertiary sediments in the Gulf Coast geosyncline. As shown in figure 2, a large number of major faults, called "growth faults," exist in this area. These faults

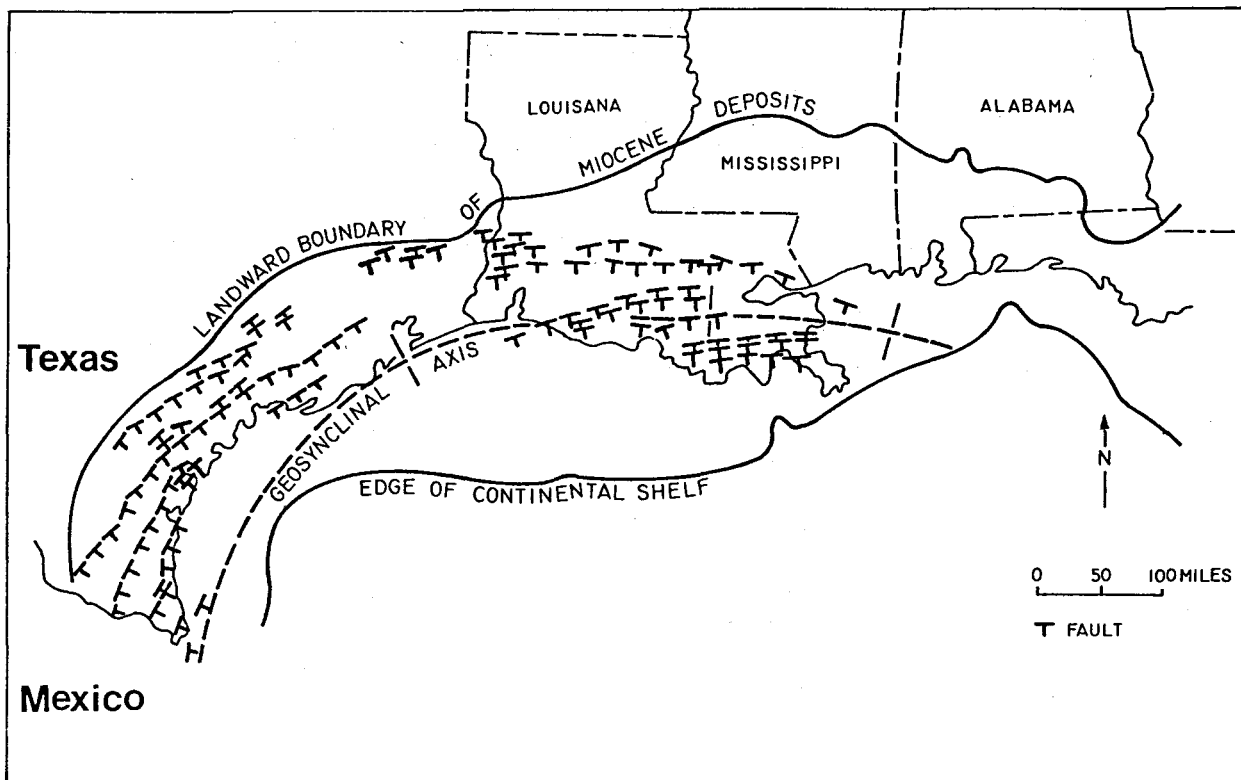


Figure 2. Principal Regional Normal Faults and Landward Boundary of Miocene Deposits, Northern Gulf of Mexico Basin (after Murray, 1961).

are and have been active throughout Tertiary and Quaternary time; however, there is no historical record of major earthquakes in this region. The growth faults cut the geopressed zone and contain overpressured water. The presence of this water, along with the inherently low strength of the sedimentary rocks in the region, may allow slow movement along the faults without strain accumulations and the sudden strain release that initiates an earthquake.

In April, 1964, four earthquakes were felt near the town of Hemphill in East Texas near the landward boundary of Miocene deposits (fig. 2). The earthquakes ranged from unified magnitude 3.4 to 4.4, the latter being comparable to the shock from a buried nuclear explosion with the yield of the Hiroshima bomb. The epicenters of the four earthquakes are shown in figure 3 along with the locations of known faults in the area. Considering the expected statistical scatter in epicenter computations, it is considered likely that the foci of at least three of the shocks were located on the faults.

The geophysics group from Southern Methodist University participated in the establishment of seismic stations near and east of Hemphill in the late spring of 1964. Hundreds of earthquakes, too small to be felt, were detected by the instruments. About six months after installation of the seismographs, the number of shocks decreased and after another month no more microearthquakes were recorded. We concluded that the faults in the area were active, but that the motion was usually more or less continuous and without sudden release of strain. For some reason one or more of the faults appeared to "lock-up" for a time leading to strain accumulations and sudden releases of seismic energy.

The entire Gulf Coast region of Texas is in a similar tectonic setting to that of the Hemphill area. It is not known just how much movement is presently taking place along the major growth faults in the coastal region (fig. 2) or whether microearthquakes are occurring in association with these movements. It would be very useful to make background measurements of tectonic activity in areas

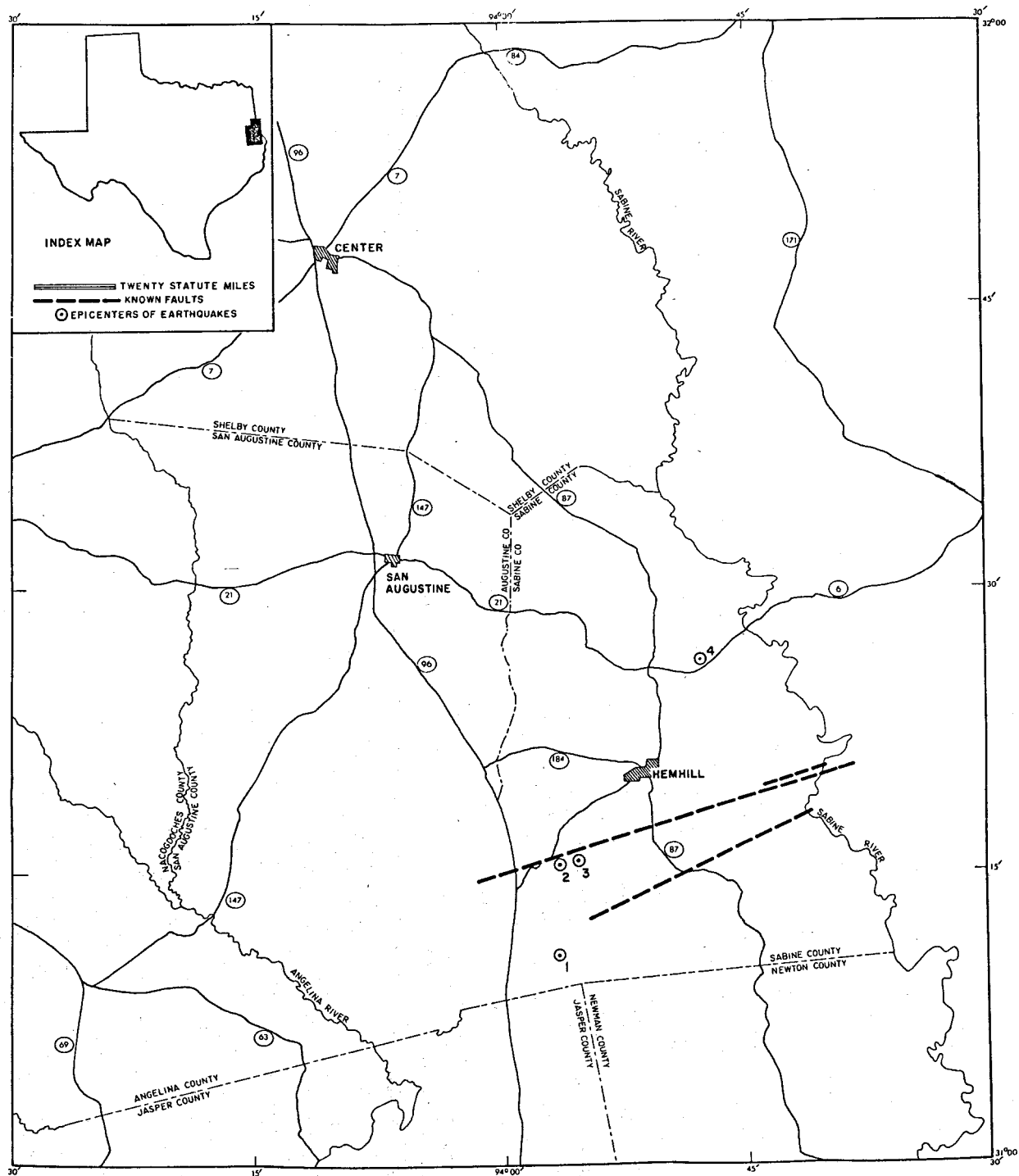


Figure 3. Earthquake locations, Hemphill Area of East Texas.

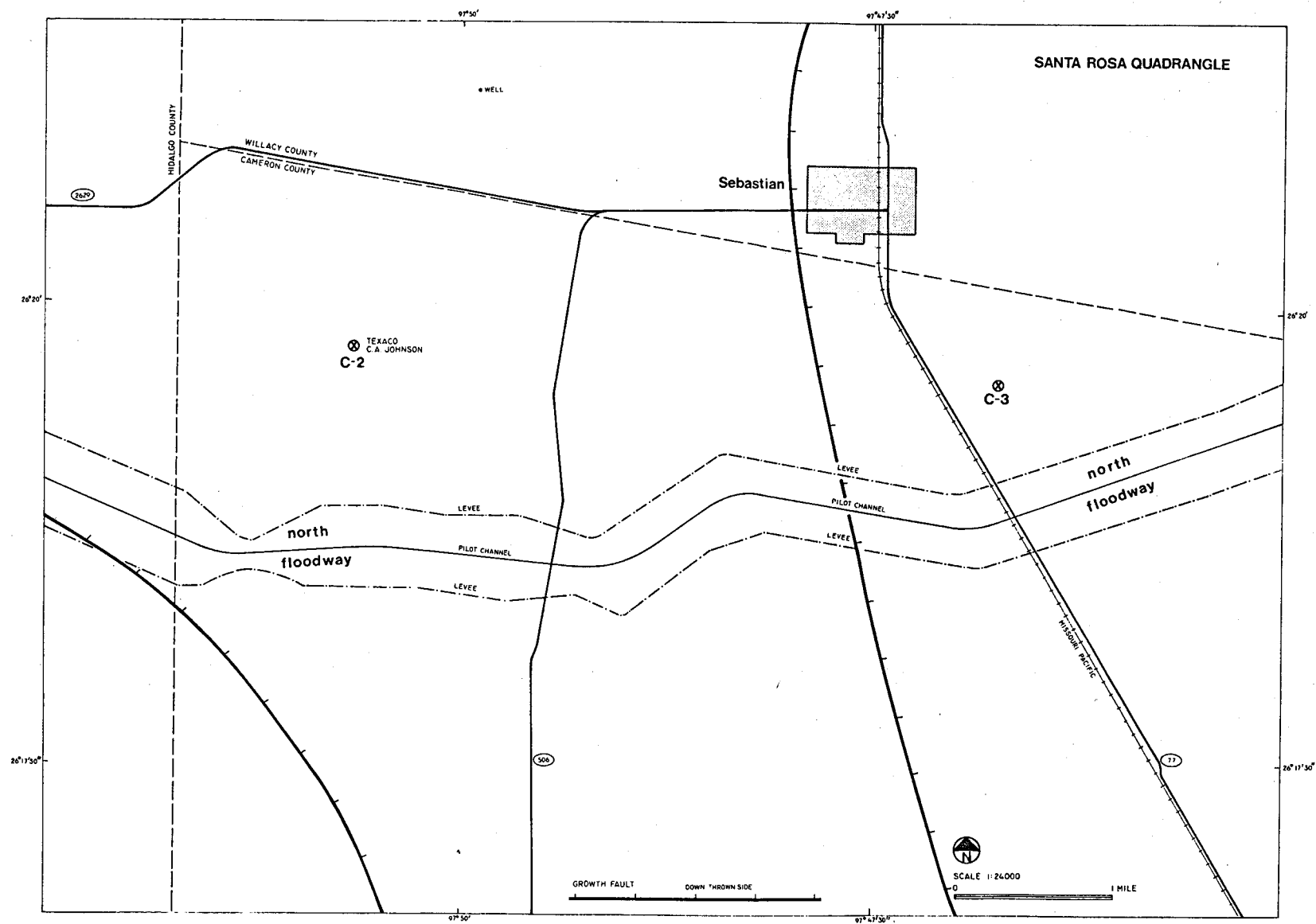


Figure 4. Location of Texaco, C. A. Johnson, well in Cameron County, Texas.



where geopressed reservoirs are known to exist. Such baseline measurements could be made, for instance, north of Harlingen, Texas, in Willacy and Cameron Counties on the South Texas Coastal Plain. Figure 4 is a large-scale map of the area showing growth faults and the location of the Texaco, C. A. Johnson, well (C-2), which penetrated several thousand feet into the geopressed zone. Down-hole systems can be used to record seismic background and the data telemetered to a central site for on-line computer analysis and location of any microearthquakes that may be detected. A close-in network of bench-marks should be established so that periodic resurveys can be used to determine any tilts due to differential motion across the faults and possible elevation changes caused by tectonically induced subsidence.

Prior to the initiation of any long-term flow tests of geopressed reservoirs, similar baseline studies are essential to provide the background information required for an adequate environmental impact statement.

## **INDUCED ACTIVITY**

The production of power from geopressed reservoirs will require the removal and disposal of very large quantities of hot, somewhat saline, water. Calculations by Sid Kaufman (personal communication, 1971) for a typical reservoir on the South Texas coast give an average production of about  $5 \times 10^{10}$  gallon per year or more than 130 mgd. The level of production is comparable to the withdrawal figures previously quoted for the Houston area; thus we can expect potentially serious subsidence to be associated with the exploitation of geopressed reservoirs. The possible mitigating effects of reinjection must be carefully studied; however, no adequate model now exists for use in predicting the subsidence pattern that might be expected over a geopressed reservoir after a significant period of production.

The geopressed reservoirs are generally bounded on one to three sides by growth faults of the type shown in figure 2. These faults contain geopressed water (Paul Jones, personal communication, 1975) and act as conduits for the slow migration of this water from the geopressed reservoirs to upper-level sands and to the surface. This migration of saline water and its replacement by fresh water from clay minerals accounts for the fact that water in the geopressed reservoirs may be relatively fresh. As discussed earlier, the growth faults are active today; however, the movement is slow, without sudden relaxations that give rise to destructive earthquakes.

The efficient production of a geopressed reservoir should be planned so as to essentially exhaust the available resource in a finite length of time. That is, the production level should be held as nearly constant as possible until the reservoir pressure drops to the point where continued production is no longer economically feasible. During production the pressure will drop along the growth faults. Pressure changes in fault zones are known to be causally related to the frequency and intensity of earthquakes (Denver and Rangle, Colorado), but the mechanism is not well understood at this time. It is possible that large changes in water pressure in the fault zones beneath the Texas Gulf Coast could cause the faults to lock-up, as was the case at Hemphill, Texas. Earthquakes with potentially dangerous magnitudes might result from this sequence of events.

The Texas and Louisiana Gulf Coast are now considered to be aseismic; therefore, no consideration of seismic risk has been made in land utilization and construction in the region. It is probable that any noticeable level of earthquake activity induced by production from geopressed reservoirs would be considered environmentally unacceptable and would result in the premature closing of a production facility.

## **CONCLUSIONS**

A study of the environmental effects of power production from geopressed reservoirs reveals two important problems that cannot be adequately evaluated at this time: surfaces subsidence and the possible inducement of earthquakes, which could result from the efficient production of power over the lifetime of a reservoir. These effects must be considered in any environmental impact statement and must be monitored over the entire lifetime of a production facility.

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## Discussion

**Dorfman** Gene, I don't want to argue with your particular ideas on subsidence. I happen to agree with you and also about the need for this type of experimentation. But I do think it is important to point out for those who might be frightened by the idea of microearthquakes that we do have a vast amount of experience in the withdrawal of large volumes of fluid along the Gulf Coast.

There are fields associated with growth faults that have produced literally hundreds of millions of barrels of oil and even more water. We haven't had any buildings fall down and we haven't had any interchanges come down.

Certainly, there is need for this type of geophysical work, but I think it is important to mention the fact that depressuring of reservoirs has occurred.

We have already withdrawn hundreds of millions of barrels of fluids in many cases so this is—

**Herrin** Have you lowered the pressure by 4,000 psi in the geopressed reservoirs?

**Dorfman** Well, I don't have any figures in front of me, but I think you can find some production of geopressed reservoirs where that has occurred.

**Herrin** Has anyone looked at the side effects to see if—

**Dorfman** Not that I know of, but we have not been faced with this catastrophic problem in this region—

**Herrin** Well, I'm not saying that these problems would happen. All I'm saying is that one or two major earthquakes, the size that occurred near the Toledo Bend dam site could turn off a project.

**Barnea**  
**United Nations** The earthquake danger should be very much bigger in other types of geothermal resources, and as far as I know, with all the experience we have now, no geothermal installation was ever damaged by an earthquake.

Moreover though, we use microearthquake in order to find faults because we get hotter water, and we would like to drill into them. I believe, therefore, that if we look at the experience of geothermal fields in volcanic areas, the earthquake dangers should be very much higher.

We have found that it doesn't occur in fields which are being developed and microearthquake indications are probably much more frequent where we have more active faults.

I think, therefore, if we go back over our experience of over 70 years of geothermal development, we have no reason to assume that the danger would be bigger, so far as I see it, or more severe in the case of geopressed zones.

**Herrin** Well, let me say this. First, you are in a tectonically active area. You can look at the level lines which run along the Louisiana and Texas Gulf Coast and you can see how much the land is subsiding naturally.

When you produce this much water and lower the pressure to that extent, you are going to produce subsidence. It is likely that subsidence will be localized, in part, along with growth faults.

The only question is whether or not you will have any earthquakes. The fault is going to move. The question is whether they are going to have earthquakes.

**Baker**  
U.S. Geological Survey

If we do assume that there would be earthquakes associated with production of the resource, then would there not be some advantage to going offshore and developing the resource there and, perhaps, getting away from the detrimental effects of tremors as well as, perhaps, subsidence?

**Herrin**

Well, certainly the cost would be higher, I would think. I haven't seen any of the figures proposed here for offshore development. Economically, it would appear difficult. You are certainly right, that if there were to be small earthquakes, a magnitude of 4 to 5, the type that are being produced in Rangely, Colorado, then you would certainly minimize the hazard.

**Kreitler**  
Bureau of Economic Geology,  
University of Texas at Austin

As to the possibility that it might be happening, I might comment on some of the work we are doing at the Bureau. We have been monitoring the number of faults in the Houston-Galveston area and we have approximately 150 miles worth of active faults in that area now.

These faults are being activated by ground water withdrawal in direct correlation with proximity to the faults. We have very little evidence of any sort of appreciable earthquakes occurring in the Houston-Galveston area.

The faults are very definitely limiting the subsidence in that they are acting as some sort of hydrologic boundary. What we see there is the result of the shallow groundwater production down to 3,000 feet.

We may be looking at a different ball game when we are talking about 10,000- to 15,000-foot depths. However, we have evidenced no subsidence over deep oil fields, 8,000 to 14,000 feet deep where they have had regular oil and gas production and geopressured production of gas, and there have been no earthquakes identified in this area either.

I agree that the subsidence would probably occur on the site of the geopressured production and that it would be limited by the faults, but from the evidence I have seen, there is no reason to expect earthquakes to occur.

**Kleeman**  
General Land Office  
State of Texas

Aside from the earthquake problem, we have been talking about subsidence. That seems to be a particular problem in the Houston-Harris County and Galveston County area.

How much subsidence are you talking about over a 25-year period? It may be the laws that are on the books in that particular area will prevent the problem.

**Herrin**

Well, if you do a tank calculation of this, then you can get anywhere from 4 to 9 feet, but that assumes uniform subsidence over this large area and reduction in the pressure, essentially, to normal pressure in the reservoir.

It's highly unlikely that these things will subside in that simple way. The models are complicated, the faults and the movement of water up and down the faults make it very difficult to predict what the subsidence will be.

If it were a simple subsidence and you were reinjecting in some region, the hazard might not be as great. The problem is that you are talking about water volumes, considerably larger, I think, than these examples.

You are talking about 500,000 barrels a day in just a small field, and that's a lot of water. You are also talking about changing the pressures by 4,000 or 5,000 psi in a large reservoir—one of the largest ones you can find—not at a small spot.

It may be that there is no earthquake hazard. There certainly is a subsidence hazard. I'm just calling your attention to the potential problem and the fact that it has to be monitored carefully. And we need experiments.