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IDENTIFICATION OF GEOPRESSURED OCCURRENCES OUTSIDE OF THE GULF COAST *

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ABSTRACT

Methane dissolved in saline formation waters under abnormally high pressure (geopressure) is one of several unconventional gas sources that is under intensive investigation by the Department of Energy. The most well-known and studied region of geopressures in the U.S. is the Gulf Coast geosyncline. Recent studies, however, indicate that this phenomenon is displayed in many other sedimentary basins encompassing lithologies and sedimentary environments unlike those of the Gulf Coast. These include various Rocky Mountain and Mid-Continent basins, onshore and offshore Californian, Alaskan and Pacific Coast basins, and other isolated occurrences. Of this group, two prime target areas, based on the indicated methane content of geopressured formation waters, would include the Cambrian sands of the Rome trough in West Virginia and selected Miocene sediments along the west side of the San Joaquin Valley in California.

TERMINOLOGY

The terminology used in describing the state of pressure in rock formations at depths is as follows:

Formation pressure refers to the pressure acting upon the fluids (water and hydrocarbons) in the pore space of a rock unit. A normal formation pressure is one in which the pressure is equal to the hydrostatic head of water from the surface to the subsurface formation and any departure from the normal trend is considered abnormal resulting in either:

a) underpressured formation pressure or
b) overpressured or geopressured or abnormally high formation pressure.

Hydrostatic pressure, another term for normal pressure, as indicated, refers to a unit weight and vertical height of a fluid column, the size and shape of which have no effect. However, the hydrostatic pressure gradient expressed in pounds per square inch per foot (or psi/ft) is affected by the concentration of dissolved solids (or salts) in the fluid column as well as by the temperature gradient.

The following are the typical average hydrostatic gradients generally found in the United States:

Region	Salinity of Water	Hydrostatic Gradient
Mid-Continent and Rocky Mountains	Fresh Water and Brackish	0.433 psi/ft
Gulf Coast	Salt Water	0.465 psi/ft

Within this framework, overpressured or geopressured gradients will therefore commonly occur between .433-.465 and 1.0 psi/ft, although both the lower range of values and the upper value may be somewhat higher than the above.

The above pressure terms are generally applied to waters of varying salinities; however, in a number of basins, geopressured occurrences have been noted where formation waters are nearly absent as in the overpressured oil zones of the Williston basin and certain gas-condensate zones in the Anadarko basin.

GENERAL CHARACTERISTICS AND CAUSES

Abnormally high subsurface formation pressures have been observed in all types of geologic environments:

- at shallow depths below the surface, measured in hundreds of feet, to depth in excess of 25,000 feet
- in clastic sediments as well as massive evaporites and carbonate sections
- as rather isolated occurrences or on a basinal or regional basis
- in rocks of all ages - from indurated Cambrian formations to unconsolidated Recent sediments
- in oil reservoirs with little or no formation water, in high or low volume gas reservoirs with little or no condensate, and in high salinity and low salinity waters
- in one formation but not in the overlying or underlying formations
- accompanied by anomalously high temperature gradients as well as by normal temperature gradients

There are numerous causes of geopressuring and one or more of the following may be operative in a given area or basin:

- Rapid sedimentation and compaction of sands and shales in a subsiding basin often characterized by "undercompacted" overpressured shales and growth faults (e.g. Gulf Coast)
- Generation of hydrocarbons from source rocks such as shale, oil shale, coal, or other organic rich rocks (e.g. Williston basin, Green River basin, Uinta basin and other Rocky Mountain basins)
- Tectonic activities including faulting, folding, diapiric salt or shale intrusions, etc. (e.g. California basins, Alaskan basins)
- Chemical action of pore waters trapped in a sealed formation involving such reactions as salt recrystallization, secondary precipitation of cementation minerals, rehydration of anhydrite, etc. (e.g. Interior Salt basin)
- Thermal expansion or contractions of fluids reacting to temperature changes
- Diagenesis of clay minerals
- Electrochemical effects including osmosis.

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The genesis of geopressures through time is dependent on a number of factors including the environment of deposition, the form and lithology of the sediments, nature of faulting, basinal structure, burial and compaction, and subsequent tectonic activity. In view of the interaction of all of these processes, it is difficult, if not impossible to ascribe geopressuring in one area or one basin to a particular cause or origin. However, a dominent mechanism can be ascribed in certain basins, e.g. in California, tectonism in the Sacramento Valley and burial and "undercompaction" of shales in the San Joaquin Valley.

Geopressuring is a transient phenomenon that was probably characteristic of most, if not all, sedimentary basins at one time in their development, but over geologic time these high fluid pressures have stabilized and the reservoirs are now essentially either normally pressured or underpressured. In many cases, as in several of the Rocky Mountain basins, there may be anomalously low and high pressures - the former at shallow depths while relict high pressures may be found at depths usually below 10,000 feet. In other basins, such as the Anadarko and Delaware, geopressured zones may occur in the 10,000 through 15,000 foot intervals while the formations below are normally pressured. One primary requirement for the existence and preservation of geopressures is a seal, otherwise the pressure would equalize to hydrostatic. This seal essentially requires impermeable rocks separating more permeable rocks and the seal may be horizontal involving shales and evaporites or vertical consisting of fault displacements, fault gouges, or lateral facies changes.

OCCURRENCES

Geopressured occurrences outside the Gulf Coast have been encountered during drilling operations in numerous onshore and several offshore sedimentary basins. In undrilled offshore areas, seismic surveys have detected shale diapirs (presumably due to methane generation) in various deep-water basins off Alaska, Pacific coast from northern California northward, and isolated areas of the Atlantic OCS. These geopressured reservoirs in many cases differ from that found in the Gulf Coast in terms of lithology, geologic age, temperature gradient, genesis, salinity of water, and other parameters. In at least two basins, formation water is nearly absent in certain geopressured zones. In addition, certain basins, such as those in the Rocky Mountains, are characterized by anomalous overpressured and underpressured areas; elsewhere, there may be alternating geopressured formations interspersed between normally pressured strata.

The basins, areas, and isolated occurrences of geopressuring outside of the Gulf Coast are indicated in Figure 1. The principal features in each of the major basins are summarized below.

Appalachian Basin

- Slightly overpressured zones in selected moderately shallow Devonian and Ordovician sediments
- Abnormally high pressures prevalent in deep Cambrian rocks of the Rome trough in West Virginia apparently characterized by very low salinity waters with contained gas.

Interior Salt Basin

- Various Jurassic carbonates at great depths (below 20,000') are highly overpressured in places approaching the lithostatic pressure gradient
- Commonly accompanied by highly saline waters and large quantities of sour gas

Anadarko Basin

- Abnormally high pressures are generally concentrated in the western Oklahoma-eastern Texas Panhandle region of the basin in various Paleozoic sediments
- Geopressured formations are usually gas-bearing and in selected fields, formation waters are apparently lacking in gas-condensate zones
- Temperature gradient is normal

Delaware Basin

- Geopressured zones are found at moderate to great depths in various Paleozoic formations throughout this basin and the geologically similar Val Verde basin
- Temperature gradients are normal

Rocky Mountain Basins

- Characterized by anomalously normal, underpressured, and overpressured formations, the latter are generally encountered at moderate to great depths
- Geopressured zones are commonly found accompanied by gas, but there are various exceptions such as the oil fields of the Altamont-Bluebell trend of the Uinta basin, oil fields of the Wamsutter Arch area of the Green River basin, etc.
- Abnormally high temperature gradients (over $2^{\circ}F/100'$) have been generally encountered but there are numerous exceptions
- Specific data on salinity of formation waters are unavailable but based on SP curves of selected wells, it appears to be relatively low

Williston Basin

- Geopressures are localized in the Bakken shale, the major presumed oil source rock in the basin, especially where in contact with a permeable bed
- Waters in the basin are generally highly saline but in the overpressured Bakken formation, formation waters are almost completely absent

California Basins

- Abnormally high pressures are found at moderate depths in Cretaceous formations in the gas fields of the Sacramento Valley and at shallow depths in the Franciscan complex of the Coast Ranges
- Geopressures have been encountered in numerous fields and wells in Tertiary formations of the San Joaquin Valley, Los Angeles basin, Ventura basin, and offshore Santa Barbara Channel
- Temperature gradients in the geopressured zones are generally relatively high, over $2.0^{\circ}F/100'$ to as much as $3.5^{\circ}F/100'$ though there are some exceptions
- Salinity of geopressured waters are commonly considerably lower than those of the Gulf Coast

APPALACHIA AND CALIFORNIA

Further studies of geopressured occurrences in Appalachia and the Great Valley of California indicate two potential target areas where reasonably high methane contents may be found. One of these includes the Cambrian sediments of the Rome trough in West Virginia (Figure 2) where at depths below 10,000', abnormally high pressures, approaching the lithostatic gradient, and moderately saline waters have been encountered. It is estimated that the formation waters have a methane content in the range of 30 to 35 SCF/barrel.

The second target area would include two Miocene formations along the west side of the San Joaquin Valley (Figure 3) which are characterized by high geopressures, very low salinity waters, and geothermal gradients that are as much as twice the normal gradient. It is estimated that the methane content of these formation waters will vary between 30 to 40 SCF/barrel.

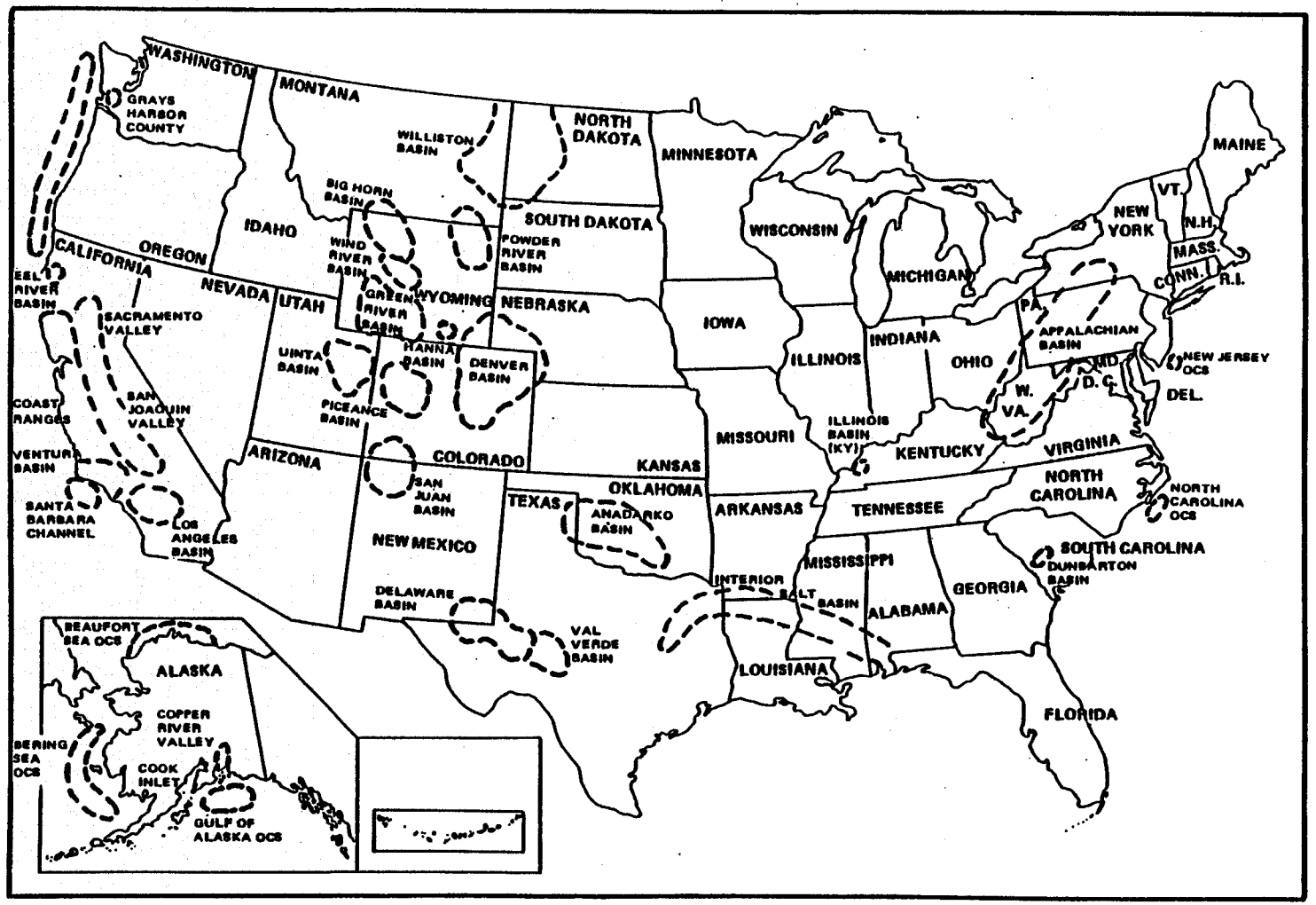

Figure 1. INDEX MAP OF GEOPRESSURE LOCATIONS OUTSIDE OF THE GULF COAST

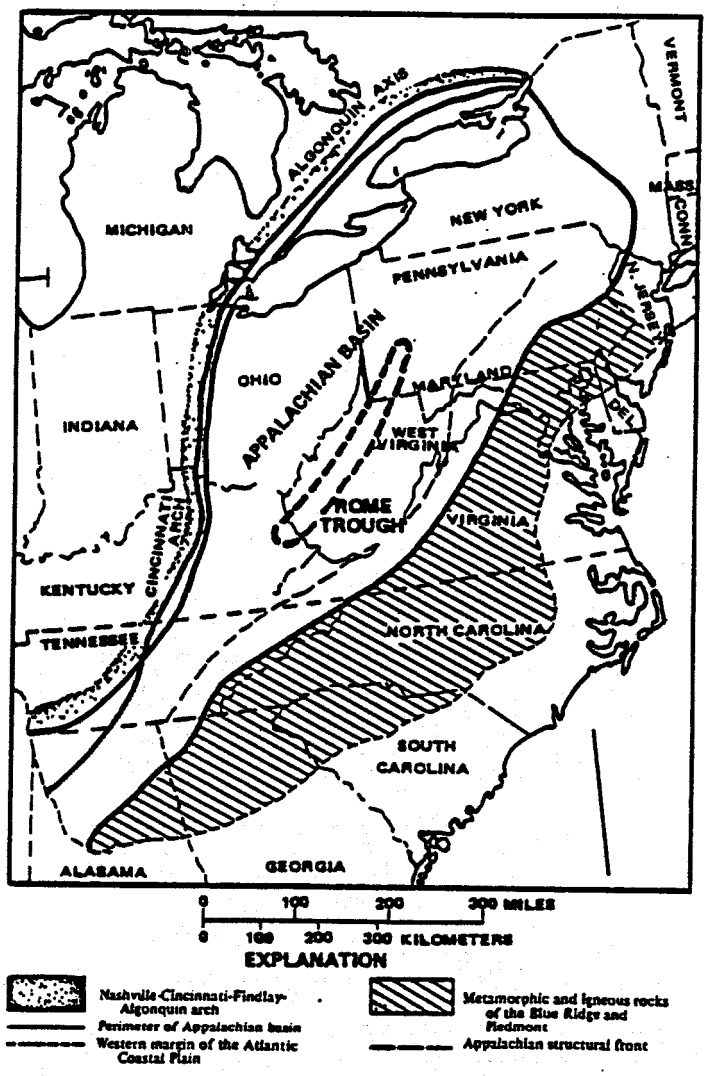

FIGURE 2. MAP OF APPALACHIAN BASIN SHOWING LOCATION OF ROME TROUGH AND OTHER GEOLOGIC FEATURES (EXCLUSIVE OF THE EASTERN OVERTHRUST BELT).

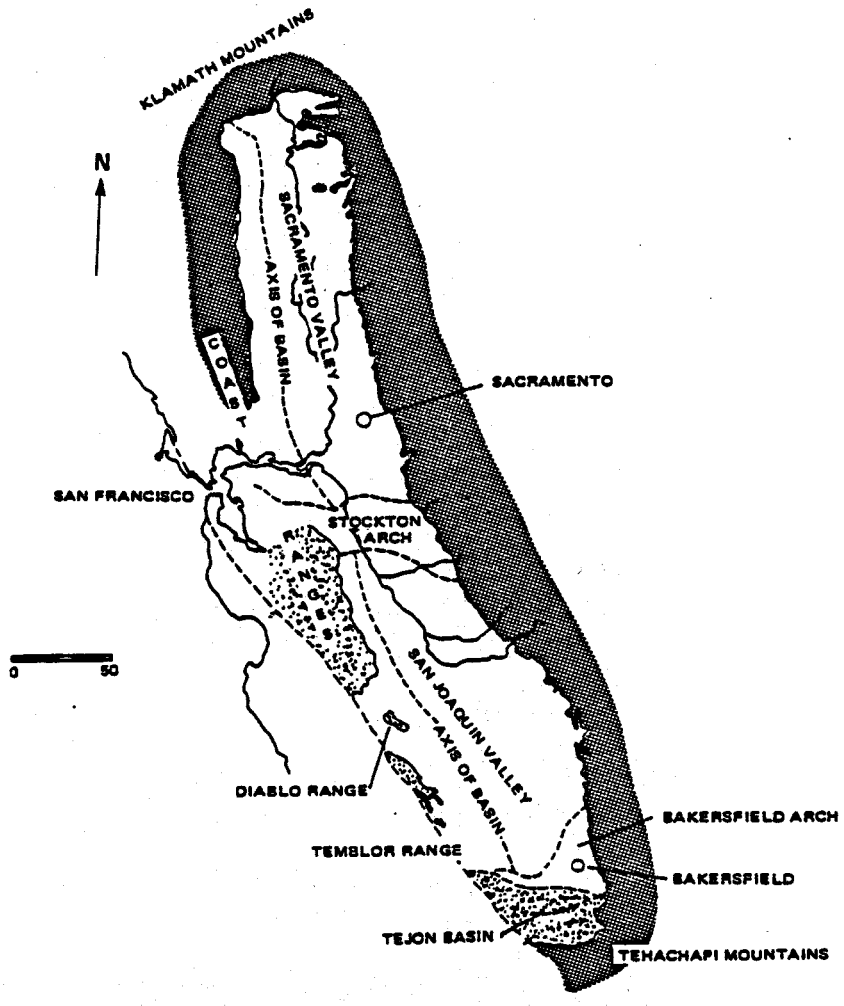

Figure 3. Regional Tectonic Elements of the Great Valley of California

July 9, 1981

U. S. Department of Energy
Technical Information Center
P. O. Box 62
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Re: Contract No. DE-AC08-80NV10133

Gentlemen:

Enclosed please find two copies of a paper that has been submitted and approved by DOE-Nevada Operations Office for presentation at the Inter-Engineering Conference on Energy Conversion to be held in Atlanta in August, 1981.

I have also enclosed a signed copy of FORM IR-426.

Sincerely yours,

Oscar Strongin

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Enclosures

cc: Mary Levick