At Durkee oil field, a cool anomaly of about 1°C was found to be caused by a reverse drag fold at a depth of about 6,000 ft (1,829 m). Two warm anomalies of about 1°C were found to be the result of two distributary channel sands at 7,000 ft (2,134 m) depth. Another warm anomaly of about 1°C and perpendicular to the channel sands was found to be the result of a fault intersecting the surface.

Where Woodgate fault possessed a scarp, a temperature maximum was found directly on the scarp. Where no scarp was visible, temperature measurements made at 2 m depth were successfully used to trace the fault and some of its associated fractures. The shape of temperature anomalies on and near the fault were found to be related to the pattern of ground-water flow in the area.

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Exploration Applications of Temperatures Recorded on Log Headings: Theory, Data Analysis, and Examples

Using the least accurate of temperature data types, temperature anomalies, "hot spots" believed to be hydrocarbon anomalies have been defined by application of a new analytical technique. To date, the technique has been successful to a significant degree when applied to known fields using only dry hole data and, in some places, only dry hole data for wells drilled prior to field discovery as initial steps toward before-the-fact analysis. Technique testing by the drill remains undone.

The theory accepted herein is that heat flows from the earth's hot interior toward its colder surface in nature's attempt to establish temperature equilibrium. Three facts are accepted: (1) hydrocarbon fluids have very low thermal conductivities (oil about one-fifth that of water and gas about one-fourteenth that of water); (2) equal heat input elevates the temperature of a largely hydrocarbon fluid volume relative to a laterally equivalent volume of largely water-filled porosity; and (3) there are fewer grams of hydrocarbon fluids to warm than water filling an essentially equal porosity volume.

Hydrocarbon fluids insulate more (fact 1) and their temperatures are elevated more easily (facts 2 and 3) than contiguous waters. Hydrocarbon reservoirs whose heat flow effects are not obscured by the anisotropic effects of adjacent water reservoirs, should be potentially definable temperature anomalies.

The technique formulated involves the following steps: (1) calculation of geothermal gradient values; (2) creation of a geothermal gradient field areally; (3) vector analysis or contouring of created data; and (4) anomaly definition. Technique application to ten fields representative of a range of complexities shows promise for this up-the-odds exploration tool. Results for three examples (Black Lake field, Louisiana; Haverhill field, Kansas; and Salt Creek field, Texas) may demonstrate principal use as a grading method for prospects based initially on classical study.

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Stability of Natural Gas at High Temperatures in Deep Subsurface

The components of natural gas are reactive in the deep subsurface and may not survive under all conditions. The stability of natural gas in reservoirs of various lithologies is studied using a combined theoretical and experimental approach.

A computer program uses real gas data to calculate equilibrium in multicomponent (up to 50), multiphase (up to 30) systems simulating subsurface conditions to 12 km. This program predicts the stability of hydrocarbons in sandstone reservoirs by first considering clean sands and then sequentially adding feldspars and clays, carbonate cements, and iron oxides. All equilibrium compositions have been computed for low, average, and high geothermal gradients; hydrostatic and lithostatic pressures; and with and without graphite. Graphite is present when deep gases are generated by the cracking of oil but is absent in reservoirs originally filled with dry gas. Similar calculations have also been made for limestone and dolomite reservoirs with various combinations of clays, iron minerals, anhydrite, and sulfur, again with and without graphite. Natural gas shows considerable stability in sandstone reservoirs under most conditions, but its concentration in deep carbonates is more variable and tends to a hydrogen sulfide-carbon dioxide mixture except when an appreciable concentration of iron is present. Hydrogen is present at the 1 to 2 percent level for most lithologies.

A multicolumn gas chromatograph is used to analyze inorganic and organic gases released by crushing rock samples in a Teflon ball-mill. Samples from deep wells in the Anadarko basin and southern Louisiana have been analyzed and the gas compositions compared with those predicted from the computer program.

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Subsurface Temperatures, Sacramento Valley, California: Guide to F-Zone (Forbes) Gas Accumulations

A complicated hydrodynamic system exists in the Sacramento Valley. Abnormally high fluid potentials are present regionally owing to regional tectonic forces as shown by previous studies. Certain parts of the Colusa basin in the Sacramento Valley have significant near-vertical fractures which permit the rapid ascent of deep waters under channel-flow conditions, and thus with a minimum loss of fluid potentials. The traps for the erratic F-zone (Forbes) gas accumulations are critically dependent, both laterally and vertically, upon the existence of these high fluid potentials as barriers to gas migration.

Advective water transport occurs along these near-vertical fractures under nearly isothermal conditions. The magnitude of the thermal anomalies caused by this transport is so large that the fracture-high potential features can be detected with conventional maximum temperature readings from well logs despite the considerable error in such values. Well log temperature data are much more readily available than accurate subsurface pressure data. Thus, practical exploration for these elusive gas accumulations is facilitated greatly through mapping the subsurface temperature regimes.

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Geotemperatures of North Sea Basins: Implications to Exploration

The petroliferous North Sea basin is classified as an intracontinental failed-rift basin and should as such exhibit "normal to high geothermal gradients," if relating to the world average of 25°C/km.

An updated, regional, present-day geothermal gradient map of the whole North Sea basin shows that the mean gradients rarely exceed 40°C/km and are rarely lower than 20°C/km. In broad outline, the gradient pattern seems to reflect the major structural elements. The positive geothermal anomalies are explained in terms of convective heat transport within an actively subsiding basin. Major fault systems serve as conduits for fluid flow. Salt pillows and salt diapirs are centers of hot areas caused by heat conduction. Isothermal maps of key structural horizons and geoisothermal maps are presented to support these interpretations.

The importance of constructing thermograms is emphasized. In the North Sea basin, variations in interval geothermal gradients are explained by a combination of differences in lithology-related conductivity and subsurface fluid flow. Locally, interval gradients twice as high as the mean gradients are observed.

This investigation does not support the idea that geothermal anomalies are uniquely associated with oil or gas accumulations and hence could be used as an exploration tool. Rather, it seems that detailed mapping of geotemperatures can help explain the pattern of subsurface fluid flow of which water (and not hydrocarbons) constitutes the major part.

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Clay Mineral Evidence for Movement of High Temperature Subsurface Fluids

The study of geopressured formations has provided considerable information on the probable pathways for subsurface fluid movement. The fluids have been traced and associated with structure, pressure distribution, salinity of formation waters, various organic and inorganic diagenetic effects, as well as local changes in the geothermal gradient and the temperature of formations. The temperature changes may be measured directly or inferred from the presence of temperature-controlled reaction products such as the modification of illite/smectites.

Clay mineral changes are detected initially at temperatures as low as 50°C and may extend to temperatures in excess of 300°C. The smectite-illite conversion is most pronounced in the range from 50°C to about 160°C. Significant changes in kaolinite and chlorite occur between 75°C and 250°C.

In shales from the Gulf Coast, the smectite-illite conversion is readily recognized, while kaolinite-chlorite reactions are most apparent in associated sands. In several places the development of kaolinite in sandstones is directly linked to the movement of high temperature fluids and the subsequent blocking of secondary porosity. Kaolinite is most abundant in those zones which experienced maximum flushing.

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Temperature Anomalies and Gulf Coast Structures

Temperature anomalies associated with various structures in the Gulf Coast are interpreted to be the result of fluid migrations from depth. Pressure and salinity data are also part of an exploration model where hot, fresh, hydrocarbon-laden waters are believed to be migrating up faults. Traps in the vicinity of these migrations are of special interest to the explorationist because they are more likely to be charged with hydrocarbons.

The part of southeastern Louisiana studied has twelve areas of possible subsurface fluid migrations. Eight hydrocarbon fields are in the vicinity of these migrations. The areas of migration are most likely to occur at areas of structural expansion, i.e., grabens, crests of diapirs, and most importantly, intersections of faults.

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Relations Between Hydraulics, Temperatures, and Crude Oil and Natural Gas Composition in Some Upper Devonian Reefs of Alberta, Canada

The Upper Devonian Woodbend Group and Beaverhill Lake Formation of Alberta contain numerous crude oil and natural gas occurrences pooled in several carbonate reef chains, which are hydraulically distinct with small but subtle differences in present reservoir temperature. Regionally, these hydrocarbon occurrences exhibit typical trends from immature gases in the shallower pools, sometimes associated with biodegraded crude oils, to deeper mature crude oils. Examination of the composition of the natural gases and the broad general characteristics of the crude oils suggests that there is imposed on these typical maturation trends differences in the fluid compositions and reservoir temperatures which are related to the different hydraulic systems and the position of each system within the low fluid-potential drain which essentially channels flow within the thick sequence of highly permeable Upper Devonian and Carboniferous carbonate rocks in the medium-depth part of the Alberta basin.

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Rocks, particularly those formed from clayey sediments, are capable of retaining pore fluids at pressures greater than hydrostatic. Such pressures are frequently encountered while drilling for oil and gas, and consequently the phenomenon of excess fluid pressure has been studied extensively. Anomalous temperature changes with depth have been observed associated with overpressured zones and these anomalies have themselves been the object of considerable thought. However, few studies have attempted to model simultaneously the generation of overpressuring and the associated temperature patterns. Such a model has been constructed, with an equation describing one-dimensional flow through a porous medium at its heart. Through a computer program, this equation describes the vertical movement of fluids and heat through accumulating sediments and the resultant densities, pressures, and temperatures. This program was applied to an accumulating thickness of "mud" and sand approximating a generalized Gulf Coast section. The resultant plots of pore pressure, porosity, and temperature versus depth are similar to those typifying the drilled areas of the Gulf Coast. These characteristic profiles can be viewed as a consequence of the Gulf Coast overpressured environment.

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Estimation of Heat Flow in Oil Wells Based on Relation Between Heat Conductivity and Sound Velocity

Based on published data, it is assumed that the ratio of sound velocity to thermal conductivity exhibits a linear relation with formation temperature for most sedimentary rocks.