Published literature documents varying degrees of correlation between geologic structures and geothermal highs (halos) of several petroleum fields. In conjunction with these fields, additional structures and associated productive trends have been evaluated to develop certain predictive criteria. The studies attempted in this regard include structural and stratigraphic traps, rollover anticlines, and salt domes with productive beds of different ages in Louisiana.

As part of the characterization of the subsurface temperature regime of the regions studied, the following broad generalizations seem to be in order: (a) geothermal halos observed near faults appear astride the fault, or clearly confined to one fault block or the other; (b) a single geothermal halo in a deep section may be overlain by multiple halos, generally of lower relief, in shallow sections; (c) geothermal halos associated with deep-seated salt domes are located in the sedimetnary section on or near the top of the dome, near the perimeter or on the flanks. Such halos are not discernible on shallow domes; (d) in the interior basin, a salt dome with productive horizons appears to have a geothermal halo of higher relief than those in the vicinity with no petroleum accumulations; and (e) even some petroleum traps, created by sedimentary facies changes with no distinct structural closures, are marked with geothermal haols.

The observed characteristics of the subsurface thermal regimes are generally explained in terms of thermal properties of rocks and pore fluids, and fluid migration induced by changes in the density, viscosity, and pressure potential of the subsurface fluids.

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Present Thermal State of Western Canada Sedimentary Basin

The regional geothermal pattern of Western Canada sedimentary basin was studied using available temperature data from shut-in wells. Average heat conductivity was estimated with net-rock data from Canadian Stratigraphic Services. These data allowed heat flow estimations.

The geothermal gradient and heat-flow values for the basin are exceptionally high in comparison with the other Precambrian platform areas, especially in the northwestern part of the Prairies basin in Alberta and British Columbia and most of southern Saskatchewan. Low-gradient areas are found close to the eastern limit of the Disturbed belt of Alberta and British Columbia. Neither the analysis of regional conductivity nor heat generation of the basement rocks based on U, Th, and K data after Burwash explains the heat-flow patterns. Certain hydrogeologic phenomena do suggest the significant influence of fluid flow on geothermal features. Low geothermal gradient areas coincide with water recharge and high hydraulic head regions.

The phenomenon of upward water movement in the deep strata and downward fluid flow through much of the Cenozoic and Mesozoic strata seems to be the main influence on heat distribution in the basin. Analyses of coal metamorphism in the upper and middle Mesozoic formations of the Foothills belt and in the central Prairies basin suggest that pre-Laramide heat-flow distribution was different from the present. It is very probable that the Foothills belt had a higher geothermal gradient than the central part of the Prairies basin, opposite to the present relation.

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Limits of Subsurface Temperature and Fluid Pressure Field of Commercial Oil and Gas Reservoirs

The free energies of formation and fugacities of the fluid components of an accumulating sedimentary pile are acquired largely during geothermal heating of initially cool constituents of highly porous sediment. Thermal maturation of organic matter, with accompanying release of potentially migrant products (CO_2, H_2O, CH_4, and various hydrocarbons), consists of a complex of specific burial diagenetic and low temperature ($<$ 250°C) metamorphic reactions activated and promoted by heat moving upward through the pile. Likewise, the progressive dewatering of a sedimentary pile, manifested in the net reduction of intergranular porosity with increased burial depth (temperature), reflects another, only partly interrelated, complex of thermochemical reactions. Fluid migration is thus a dynamic response to induced gradients of temperature, fluid pressure, and concentration as determined by routing of heat through lithologically controlled nonisotropic arrangements of thermal conductivities. Rapid fluid movements along permeable pathways may locally influence shallow subsurface temperature distributions in dynamic and possibly transient ways through convective heat transfer.

For establishing practical limits to investigations of such burial changes, paired values of virgin reservoir temperature and fluid pressure (T and P_f) were compiled from the international literature $>$ 700 commercial oil and gas reservoirs. Higher-than-average geothermal gradients were deliberately sought. The limits of the T-P_f field defined by these points are well constrained, and only eight reservoirs were recorded that produced commercially at temperatures 175°C. Deep-ocean petroleum prospects appear to offer advantageous characteristics in terms of the T-P_f field because of the low T and high P_f at the deep sea floor.

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Temperature Anomalies Associated with Rocky Mountain Oil and Gas Fields

Over the years, several observers have reported on temperature observations which show a particular oil or gas field to be "hotter" at the pay depth than the surrounding rock at the same depth. Our study of 22 oil and gas fields from six states in the Rocky Mountain region demonstrates that at least 15 of these fields have positive temperature gradient anomalies at the pay level. Nine of these "hot" fields are contained in structural traps and six are primarily stratigraphic accumulations. Three of them are gas and 12 are oil fields.

All of our temperature measurements were recorded during drill-stem tests except for a few values from temperature logs. Drill-stem test temperatures usually are recorded a longer time after mud circulation has ceased in the well bore than are wireline log temperatures. Therefore, the former generally are a truer measure of the formation equilibrium temperature than are the latter.

Speculating on the causes of these temperature anomalies over oil and gas fields, we conclude that upward convective fluid movement at depth is the most important factor. The upward moving fluids carry heat along with them and both heat and fluids are trapped whenever suitable trapping conditions are encountered in the reservoir rocks through which the fluids pass. The main evidence for this conclusion is that observed temperature anomalies occur over fields which are contained in stratigraphic traps.

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Geothermics of Landau Field by Corrected Temperature Measurements

One of the most striking geothermal anomalies within the Rhine graben is in the Landau/Pfalz oil field. The temperature at 1,000 m depth is about 100°C in the center of the anomaly. Temperature logs in the oil field are generally disturbed, owing to the former production or injection of fluids. A mathematical model is presented, describing the distribution with depth of the temperature disturbance in a flowing borehole. Based on this, the process of cooling after a period of flowing can be calculated. It is then possible to check whether a borehole is in thermal equilibrium. If favorable conditions prevail (high flow rates and/or small depth of the reservoir) the presented model can be used to estimate the temperature in the reservoir from the surface temperature of the fluid.

The geothermal anomaly is probably associated with deep reaching faults, in which thermal water can rise up from a depth of several thousand meters. The water originates near the crystalline basement and flows into the sedimentary fill, transmitting its heat content to the surrounding rocks.

A numerical model shows that the required water flux to match the observed temperature distribution is very small, and that an anomaly as found in Landau can be created within a time period of about 100,000 years.

The same conditions as in Landau exist in other zones of the Rhine graben, and similar convective systems can account for other temperature anomalies.

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Organic Geochemistry and Petroleum Exploration—Problems?

Results of organic-geochemical studies of deep well bores contradict current concepts on the generation, maturation, and thermal destruction of hydrocarbons. Main-phase hydrocarbon generation (high bitumen coefficients) apparently occurs between 190 and 250°C in Lower Cretaceous to Devonian rocks in five separate well bores. In these same rocks, the kerogen still retains high values of pyrolyzable hydrocarbons normalized to organic carbon. All five well bores have had higher than 250°C paleotemperatures. These results indicate that much higher temperatures than those commonly accepted are required for the complete generation and thermal destruction of hydrocarbons. Other results from these studies contradict the following accepted organic-geochemical trends versus depth: (1) maturation of saturated hydrocarbons; (2) the $S_1/S_1 + S_2$ ratio (S_1 = extractable bitumens and S_2 = pyrolyzable hydrocarbons per thermal analysis); (3) the temperature at the maximum of the S_2 peak; (4) the thermal phaseout of C_{15} + hydrocarbons; and (5) correlation of elemental kerogen composition and vitrinite reflectance with extractable and pyrolyzable hydrocarbons. Laboratory duplication of generation-maturation reactions in closed, pressurized, water-wet systems shows that the controlling parameters of these reactions are not as described in the accepted mathematical formulas modeling these reactions. Concepts concerning the generation and thermal destruction of hydrocarbons apparently have been greatly oversimplified.

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Hydrothermal Approach to Petroleum Exploration

In sedimentary basins the accumulation of raw materials to form oil and gas deposits is in many ways similar to the accumulation of materials to form mineral (ore) deposits. Logic suggests that in either case the job can hardly be done without an active water system, functioning as both solvent and vehicle for the raw materials. Members of the mining community have no problem with this concept. A majority of the petroleum people (especially in the Western Hemisphere), however, seem to have a chronic aversion to water.

The mining and the petroleum people are both working in the same environment of water-wet sedimentary material. It can be shown that some similarities of petroleum and mineral accumulations are not just coincidence. They are essential functions common to both systems.

An important similarity of petroleum and mineral accumulations, and the main topic of this paper, is the hydrothermal regime. In both systems, hydrothermal conditions are supported by field and laboratory evidence. Such evidence has been used effectively in mineral exploration for many years. There is good reason to believe it can be used in petroleum exploration. If moving waters carry raw materials for oil and gas deposits, and temperatures can be used to track those waters, then the temperatures may also point toward possible oil and gas deposits. As with mineral deposits, places of interest could be where depressuring and cooling associated with upward movements of enriched waters are likely to cause hydrocarbon fall-out.

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Present Thermal Conditions in Baltimore Canyon and Georges Bank Basins in Relation to Extensional Models

We examine the thermal evolution of the Baltimore Canyon and Georges Bank basins to derive their present temperature structure. Our models are based on the hypothesis that these basins have formed over continental crust which was thinned by extension during the opening of the Atlantic Ocean. The cooling and subsidence history are simulated using two-dimensional finite difference techniques. The results of this work demonstrate that the extensional model is consistent with seismic, gravity, and heat-flow observations in the two basins. Since the model reliably predicts the observed features of the basins, we believe that its predictions for the temperature structure of the basins are also reliable.

The thermal gradient, heat flow, and temperature at depth in the two basins are expected to vary laterally because of variations in the amount of crustal thinning, sediment distribution, and basement depth. The Baltimore Canyon basin is characterized by one large sediment depocenter, while the Georges Bank basin has several smaller depocenters. This difference is character may be attributed to the oblique, rather than normal, orientation of rifting in the Georges Bank area. The modeling technique used predicts what effects these types of features will have on the present temperatures and temperature history of these parts of the continental margin.

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