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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Current Geothermal Environment of Oil and Gas in Indus River Basin of Pakistan

Subsurface temperature measurements within wells along the Indus River basin in the search for oil and gas form the data bank for this study. The objective of the work was to evaluate the geothermal environment associated with the location of oil and gas fields taking into consideration all available subsurface temperature information. The location of the study area along the thrust fault plane between continents presents an interesting opportunity to observe the current geothermal environment along such a major tectonically active feature. The paper presents the results of the survey in the form of a regional geothermal gradient map identifying areas with greater than fourfold changes in relative geothermal intensity.

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Calculation of Thermal Conductivity from Lithology and Laboratory Measurements on Oil Well Cores

The harmonic mean thermal conductivity of the whole rock column traversed by a well is calculated from the thicknesses of the different kinds of rock in the section and their respective thermal conductivities. Lithologic logs provide the thicknesses; laboratory measurements on cores, the conductivities. Heat flow can be then calculated by multiplying the mean conductivity by the temperature gradient obtained from corrected bottom-hole temperatures. In the sedimentary basins of Sumatra and Brazil the conductivities range from 4.1 to 6.5 mCal/cm°C sec but the average for all the basins is close to 5. The mean conductivity of a well depends on the sand-shale ratio and can probably be calculated without loss of precision without recourse to more measurements on samples. Conductivity determinations and heat flow in three Tertiary basins in Sumatra and in two Cretaceous basins in Brazil involving over 2,000 wells are reviewed. It is suggested that calculations of mean conductivity and heat flow be added to the existing AAPG compilation of temperature gradients in North America.

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The drilling of deep wells on the continental margins provides a means to augment the relatively sparse heat-flow data in this geologic province. For this purpose we have analyzed data from the COST B-2 well in the Baltimore Canyon basin off New Jersey. Although the temperature gradient to nearly 5 km depth is relatively well determined from successive bottom hole temperature measurements at several depths in this hole, very few cores suitable for the determination of thermal conductivity (K) were taken. We have determined K for various lithologies from transient needle-probe measurements on selected samples of drill cuttings. The appropriately average in-situ conductivity (K), over the depth intervals between temperature measurements, is estimated by using lithology and porosity determinations over the drilled section.

The correlation of K with grain size of clastic sediments is probably related to quartz content. A relatively large uncertainty in the estimated value for limestone produced only a small uncertainty in heat flow. Shale K values show a significant decrease below 3,350 m depth.

Comparison of K with laboratory results shows the large effect of in-situ porosity and temperature. The uppermost estimate of Q (1.30 HFU at 1,220 to 3,068 m) may be low owing to unrealistically low estimate of K; the reason for an even lower estimate of Q (0.78 HFU) deeper than 4 km is uncertain. The most consistent and reliable values (1.26 to 1.30 HFU) are for the depth interval between 1,220 and 4,104 m. The implications of these measurements for the maturation of hydrocarbons on passive margins will be mentioned.

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Thermal Anomaly Detected by Shallow Measurement Across San Sebastian Oil and Gas Field, Eastern Tierra del Fuego

Low thermal diffusivity of peat and soils overlying parts of the oil and gas province of the eastern Magellan basin has resulted in several unusually shallow (< 2 m deep) relative heat-flow determinations. The values are in agreement with the single published heat-flow value for Tierra del Fuego of 2.3 HFU and with deep bottom-hole temperature measurements located in coincidence with the shallow determinations. They are furthermore consistent with local surface air temperature measurements obtained for a period of one year prior to the field work. Compared with that for similar tectonic provinces (post-Precambrian, non-orogenic) the heat flow in eastern Tierra del Fuego appears to be about 0.5 HFU greater than might be expected. Maturation level estimates based on burial history of sediments in the area suggest considerable lateral migration (> 100 km) of hydrocarbons from deeper in the Magellan basin. A model is explored whereby the same mechanism for transport of the hydrocarbons, namely, deep ground-water movement can also explain the heat-flow results. The dramatic 10 HFU decrease in relative surface heat flow observed across the southwestern edge of the San Sebastian oil and gas field is of similar magnitude as other thermal anomalies reported to be in close association with hydrocarbon accumulations.