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Measurement of sediment surface heat flow and its application in deepwater exploration

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A tremendous amount of heat is constantly transported from the earth's center to the surface by thermal convection and conduction. A portion of the heat conducted through the earth's crust is used to drive the chemical reactions that transform organic matter contained in sedimentary rocks into petroleum. Measuring this heat and understanding its transport mechanisms through the crustal rocks are essential to the science of deepwater petroleum exploration.

The thermal history of deepwater sedimentary basins is of great interest to petroleum geologists because the hydrocarbon maturation process is controlled primarily by the temperature the sedimentary source rock has experienced since its deposition. Researchers mathematically constrain the sedimentary thermal history by building a physical model that simulates the processes whereby sediments gradually become heated as they are deposited, buried, and compacted over time. The researcher must have detailed knowledge of the sedimentation history, the thermal properties of the sediments, and the regional geothermal heat flux in reconstructing the thermal history of the basin of interest.

To determine maturity of potential source-rock intervals, either 1-D or 2-D models are constructed and calibrated. To calibrate these models, corrected bottom-hole temperatures or sediment surface heat-flow measurements need to be used. Because most deepwater and ultra-deepwater wells only penetrate the upper 2,000–3,000 m of sediments, there is usually a lack of data regarding thermal conditions at depth. Heat flow through the seafloor is one of the few constraints to such models that can be measured directly. If the main characteristics of the model are correct, the measured heat flow should agree with the model results.

Seabed heat flow measurements can also identify areas of anomalous heat flow that may indicate localized fluid flow within the sediments or the conductive effects of salt diapirism. In addition, for the purpose of field development subsequent to a discovery, the measured temperatures determine how stable gas hydrates are in shallow sediments, which sometimes determines the stability of the ocean floor in deep waters.

On both local and regional scales, fluid flow along faults across formations can modify the conductive thermal regime, as can topographic highs. Fluid flows, when accompanied by gases at pressures above local hydrostatic, can percolate across formation boundaries and yield local geographic anomalies that can point directly to hydrocarbon generation at depth. Other heat flow variations are produced by differing amounts of stretching during basin formation and by varying sedimentation rates. Also, the enhanced thermal conductivity of salt structures refracts heat, and any enhanced radioactive heat generation, especially in black shales, produces additional heat that must be considered when formulating heat flow interpretations.

Case studies for the application to deepwater exploration of sediment surface heat flow measured by this method are presented. Data from basins around the world are presented and compared. Examples from 2D thermal model calibrations, the effects of salt diapirism, and the application gas hydrate boundary zone research are presented.