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Hydrothermal Mineralization at Sea Floor Spreading Centers

The recent recognition that metallic mineral deposits are concentrated by hot aqueous (hydrothermal) solutions at sites along the earth-encircling oceanic ridge-rift system of spreading centers constitutes a scientific breakthrough. The sites where metal-rich hot springs discharge at sea floor spreading centers are natural laboratories to investigate ore-forming processes of economically useful deposits such as massive sulfides in volcanogenic rocks on land. The occurrence of hydrothermal mineral deposits at sea-floor spreading centers enhances the metallic mineral potential of oceanic crust that covers two-thirds of the earth both beneath ocean basins and exposed on land in ophiolite belts.

The occurrence of the series of hydrothermal mineral deposits, including polymetallic sulfides (Cu, Fe, Zn, associated Ag, Au) precipitated from high-temperature primary hydrothermal solutions and metallic oxides (Mn, Fe, associated metals) precipitated from low-temperature dilute solutions, is considered in terms of spatial and temporal frames of reference. Spatial frames of reference comprise structural features along the spreading axis (linear segments that are the loci of sea floor spreading alternating with transform faults) and perpendicular to the axis (axial zone of volcanic extrusion and marginal zones of active extension) common to all sea floor spreading centers. Regional tectonic setting is determined by stage (early, advanced) and rate (slow, fast) of opening of an ocean basin around a sea floor spreading center, and by local tectonic subsetting that incorporates anomalous structural and thermal conditions conducive to mineral concentration (thermal gradient, permeability, system geometry). Temporal frames of reference comprise the relation between mineral concentration and timing of regional plutonic, volcanic, and tectonic cycles, and of episodic local physical and chemical events (transient stress, fluctuating heat transfer, intrusion-extrusion, sealing, hydraulic fracturing, pH and Eh changes, etc).

At this early stage in exploration of the sea floor, most of the hydrothermal mineral deposits so far discovered at sea floor spreading centers may be characterized as mineralized showings rather than as commercial prospects. The most remarkable observation about these mineral occurrences is that they are in situ, in contrast to ancient deposits on land that were displaced from their place of formation some time in the geologic past. A dialog is developing between marine geologists and land geologists, directed to evaluating the information being acquired from the sea floor hydrothermal mineral deposits in terms of analogous deposits presently on land. The dialog is gradually translating the understanding of ore-forming processes gained from the sea floor into exploration guidelines to identify ancient geologic settings on land where former conditions favored the concentration of large and accessible hydrothermal mineral deposits.

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Rocks, Pores, and Enhanced Oil Recovery—A Geological Challenge

The efficiency with which oil can be recovered during the advance of injected fluids is affected by a large number of variables which fall into three main categories: the properties of the rock-pore system, the properties of fluids, and the forces acting on the system. Of these, the rock-pore system is the most poorly known. Although the constituents of rocks have been studied thoroughly, little quantitative information is available on the topology or geometry of pore systems. It is these systems which affect multiphase fluid flow and influence the volume of oil which can be recovered economically.

Important pore properties include aspect ratio (pore to throat size ratio), connectivity (number of throats per pore), surface characteristics of the pore walls, and heterogeneity (degree of order or disorder).

Increasing order affects displacement efficiency adversely and a major difficulty of reservoir description is quantifying the degree and types of order-disorder on scales from a few pore diameters to dimensions approaching those of the reservoir. Degree of order may be related to depositional processes, as in stratification, but more commonly is related to diagenesis.

The relative importance of various pore characteristics can be assessed in relation to fluid properties and properties such as wettability which are the result of fluid-rock interactions. Pore systems are best seen as pore casts following dissolution of the host rock. Selected characteristics of pore systems can be replicated, singly or in combinations, in transparent glass micromodels. Fluid displacements then can be conducted to determine a hierarchy of fluid and pore variables which affect displacement efficiency. Furthermore, displacements can be conducted in reservoir rocks with fluid properties and wettability similar to those of the reservoir but using fluids which can be solidified at residual saturations. Thin sections can be prepared and the form and distribution of multiphase fluids (water, oil, and gas) can be examined in relation to the mineralogical and textural properties of the rock. Conventional fluid displacement tests on core have provided data on the amount of residual oil but not on the size, shape, or arrangement of populations of residual blobs. This information is required to understand processes of oil entrapment and mobilization, and provides a link between the petrographic observations of the geologist and the fluid displacement tests of the engineer.

Fluids injected during enhanced oil recovery may react with solutions or minerals in reservoir systems and fluid compatibility and formation damage problems can be minimized by use of geochemical-mineralogical information. This is another area where geologists can make an important contribution to reservoir production.

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Future of Natural Gas

The future demand for natural gas in the world will depend in part upon the credibility of long-term supply along with an appreciation of its versatility as a source of energy. Natural gas has the potential to make many countries in the world, including the United States and Canada, self-sufficient in energy.

In addition to favorable reserves from conventional sources, there are enormous quantities of recoverable gas in unconventional resources. Such resources include tight gas formations, shales, coal seams, peat, geopressured water, ultra-deep sediments, hydrates, and biomass. New markets for natural gas are expected to expand in several areas; these include transportation, cogeneration, select use in utilities, and fuel cells.

An understanding of how gas can replace other fuels along with an appreciation of the incredible resource base leads to a much brighter outlook for the world energy future than we imagined even a few years ago.

AAPG Membership Directory
New Schedule

The AAPG Membership Supplement/Annual Report will now appear in *January, instead of November.*

Donna Riggs
Membership Manager