Geopressure zones as proximal sources of hydrothermal fluids in sedimentary basins and the origin of Mississippi Valley-type deposits in shale-rich sequences

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Synopsis

An unresolved aspect of the genesis of carbonate-hosted Pb–Zn (Mississippi Valley-type) deposits is the relatively high temperatures of mineralization in the absence of igneous intrusions. A phenomenological model is presented that relates Pb–Zn mineralization to proximal geopressure zones. Typically, geopressure zones (GPZ) consist of masses of undercompacted sediment encapsulated within impermeable shales and are characterized by high formation fluid pressures. Heat flow is perturbed in some GPZ on account of their insulating properties. Geothermal gradients as high as 150°C/km have been observed over short distances in sediments of the U.S. coast of the Gulf of Mexico. Some modern geopressure zones are known to reach temperatures of 120–150°C at depths of 2.5–3.5 km. It is demonstrated that GPZ may act as proximal sources of hydrothermal fluids, thus explaining the high temperatures of mineralization observed in the deposits, which are hosted in basins characterized by thick, rapidly deposited, shale-rich clastic sequences.

The genesis of sediment-hosted epigenetic ore deposits that have formed in the absence of igneous intrusions has long been an active field of research. This class of deposits includes the Mississippi Valley-type (MVT). MVT deposits have a broad range of characteristics and settings; nevertheless, some generalizations can be made. They are interpreted as having formed at quite shallow depths (approximately 1 km) and are found along the present-day margins of sedimentary basins.[1] The ore is generally composed of void-filling, banded galena and sphalerite associated with a gangue of pyrite, calcite, quartz, barite and fluorite. Bitumen may also be present. Porosity appears to be an important control on emplacement as deposits are often associated with breccia and karst-related caverns. Fluid-inclusion studies indicate that the ores of most of these deposits were precipitated from brines with low Na/K ratios relative to oilfield brines.[2] Estimates of the temperature of formation vary, but for the most part are in the 100–200°C range. The related problems of determining heat sources, the timing of mineralization and fluid pathways are perhaps the least constrained aspects of MVT genesis.[3]

Jackson and Beales[4] studied the mineralization of the Pine Point deposit, Northwest Territories, Canada, and related it to the late stages of diagenesis. They concluded that metal-charged brines from permeable clastic sediments formed the ore deposits on entry into porous, H_2S-bearing carbonate rocks, but offered no explanation for the observed high temperatures of mineralization. Many authors have postulated that the ore fluids migrated from depth under the influence of compaction-driven processes in basins with higher than average heat flow.[5,6] These models require fluid migration from depth, along shallow-dipping, permeable aquifers over large horizontal distances, to the basin margin (Fig. 1): Cathles and Smith[7] and Bethke[8] have shown that for most migration paths and at average compaction rates the rate of fluid flow is low. Thus, the fluids equilibrate with the host rocks and cool to ambient temperature during ascent. To explain the temperatures of mineralization fast-flow, episodic dewatering models and gravity-flow models have recently been proposed. Garven[9] and Garven and Freeze[10] modelled cross-formational gravity flow as an important energy source for fluid transport. This large-scale process requires that the distal portion of a basin be uplifted to create a potential gradient for fluid flow. During uplift fluids are modelled as flowing down across the section to a lower, permeable aquifer. Flow is then confined to this aquifer over hundreds of kilometres to the stable area of low potential (Fig. 1). The process has been used to model the genesis of the Pine Point deposit.[9] Similarly, it has been demonstrated that although a compaction-driven flow mechanism cannot account for the temperatures of MVT mineralization in the Illinois Basin, U.S.A., gravity flow induced by a 700-m uplift across the 700-km basin is feasible. The calculations indicate that permeability is the critical factor determining transport velocity in gravity flow, whereas the rate of compaction is critical for compaction-driven flow.[11]

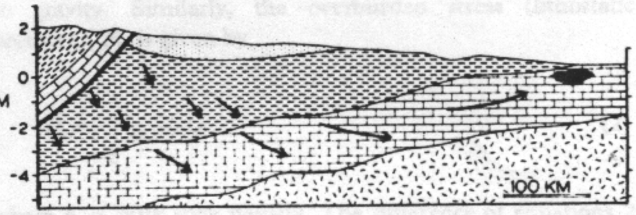

Fig. 1 Schematic diagram of cross-formational, gravity-driven, long-distance migration model (modified from Garven[9]): distal portion of basin has been uplifted, causing potential gradient; fluid flow is focused into permeable formation overlying basement. Compaction-driven models rely on expulsion of fluids deep in basin due to loading. Both models require fast fluid transport, hence very permeable aquifers, so that heat from deep within basin (~4–5 km) is conserved in fluid over long migration distances (hundreds of kilometres)

Cathles and Smith[7] and Sharp[12] have modelled a variant of compaction-driven flow that allows for rapid fluid loss from mid-basin and fast transport over hundreds of kilometres along homogeneous and permeable aquifers, thus accounting for the conservation of heat. Duane and de Wit[13] have provided evidence that the mobilization of fluids may be related to large-scale tectonic forces. It has been demonstrated elsewhere[14] that the large permeabilities required for rapid transport by long-distance migration models to conserve heat make them inappropriate for basins that contain large amounts of shale. In illustration of this point Table 1 lists the permeabilities used in several models, together with

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