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THERMAL REGIMES IN THE DETACHMENT FAULT ENVIRONMENT AS DEDUCED FROM FLUID INCLUSIONS; Richard E. Beane, AMAX Exploration, Inc., Tucson, Arizona, Joe Wilkins, Jr., St. Joe American, Tucson, Arizona, Tom L. Heidrick, Gulf Oil Corp., Bakersfield, California

Extensional tectonism, which dominates middle- and late-Tertiary geology in western Arizona, southeastern California, and southern Nevada, is characterized by normal displacement of Precambrian through Tertiary rocks along regionally extensive, low-angle detachment faults. The decollement movement of upper plate rocks relative to lower plate assemblages created extensive zones of dilatency, including synthetic and antithetic listric normal faults, tear faults, tectonic crush breccias, shatter breccias, and gash veins in lithologic units above and below the detachment. The tectonically enhanced permeability above and below the detachment fault permitted mass migration of large volumes of hydrothermal solutions along the fault zone during and following upper plate movement. Major quantities of MgO, CaO, K_2O, FeO/Fe_2O_3, SiO_2 and CO_2 were added to rocks in and near the detachment and related structures. Also introduced were varying amounts of trace elements including Mn, Cu, S, Mo, Ba, Au, Pb, Zn, U and/or Ag. Deposition of sulfide/oxide minerals and gangue containing all or part of this elemental suite occurred in the following loci, which are keyed to Figure 1. Minerals containing fluid inclusions were

1. Along the detachment fault.
2. Replacing reactive units.
3. Listric fault breccias.
4. Gash veins.
5. Fold axes.
6. Chlorite breccia.
7. Tear fault zones (parallel to Figure 1 section).

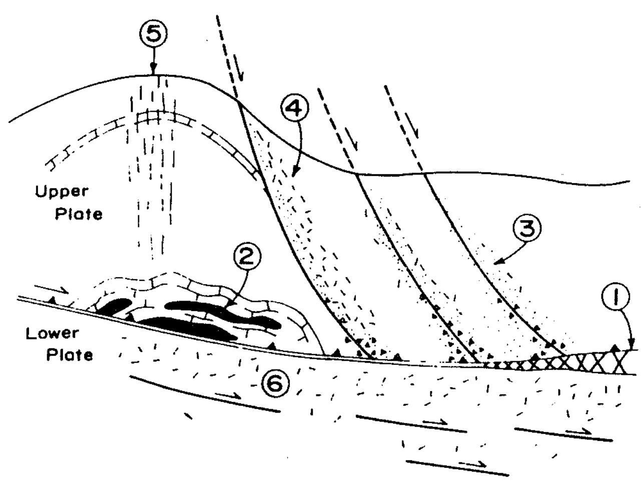

Figure 1. Structural-tectonic model of mineralization loci related to the detachment fault process (after Wilkins and Heidricks, 1980).

collected from all of these loci at locations in detachment faulted terranes in western Arizona and southeastern California.

Fluid inclusions are small cavities in minerals which form by entrapment of fluid in crystal irregularities during or after formation. In hydrothermal systems, these inclusions often provide a record of temperatures and salinities of the aqueous fluids from which minerals were precipitated. Fluid inclusions from minerals in detachment fault environments are consistently filled with a liquid accompanied by a relatively small vapor bubble (less than 30 volume percent), occasionally small daughter-product minerals are present. Freezing temperatures of liquids yield equivalent NaCl salinities of the included solutions. Temperature of homogenization of the liquid and gas phases when heated to a single high-density fluid phase provide minimum formation temperatures. By analogy, the temperature of formation of synkinematic mineralization provides a measure of the heat present during the detachment fault process.

Fluids flowing through structures temporally and spatially related to detachment phenomona precipitated quartz, specular hematite, chlorite, calcite, and lesser amounts of sulfide minerals. Inclusion fluids in the transparent phases from the above group are hypersaline, having salinities predominantly in the range 12 to 20 weight percent NaCl equivalent. Corresponding homogenization temperatures are in the range 200^{o} to $325^{o}C$. There is no systematic relationship between homogenization temperature and salinity of these fluid inclusions. Younger and/or spatially higher fluids, were localized along listric or tear faults, produced a mineral assesmblage characterized by brown hematite, barite, fluorite, chrysocolla, and precious metals. Inclusions containing these fluids have generally lower homogenization temperatures (125^{o} to $225^{o}C$) and somewhat lower salinities (5 to 20 weight percent NaCl equivalent) than the earlier/higher level fluids. Homogenization temperatures of both of these groups of fluid inclusions must be corrected upward at a rate of 75^{o} to $100^{o}C$ per kilobar of pressure obtaining at the time of fluid entrapment in order to define the actual formation temperatures of the minerals. The temperature-salinity relationship for all fluid inclusion determinations is shown on Figure 2.

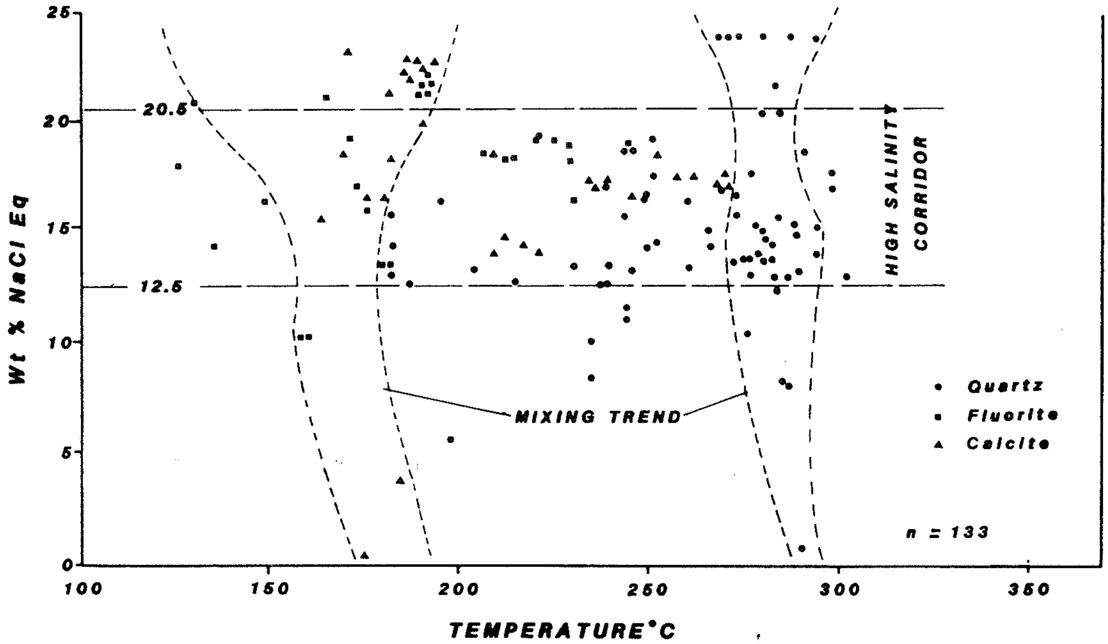

Figure 2. Homogenization temperature and salinity diagram for detachment fault-related mineralization.

The persistently high salinities (the high-salinity corridor on Figure 2) over a considerable range of apparent formation temperatures suggests that significant mixing with more dilute fluids is absent over an appreciable period of time at or near the detachment surface. However, mixing trends are recognized in the generally later and/or structurally higher-level fluids; two such trends are shown on Figure 2. Consistently high salinities of fluids associated with detachment fault mineralization could represent derivation from either 1) an igneous source, 2) basinal brines, or 3) semi-permeable filtration of originally less saline fluids. The presence of petroleum daughter-products or methane (CH_4) gas under pressure in the hypersaline and/or lower-salinity fluid types at several locations suggests that the solutions were derived from Tertiary orogenic basins. The temperatures obtained by the saline fluids flowing near the detachment structure were probably derived initially from deep basin burial in an elevated geothermal gradient and were augmented and maintained by heat supplied in or near the detachment fault.

(1) Wilkins, J. Jr., and Heidrick, T. L., 1982, Base and precious metal mineralization related to low-angle tectonic features in the Whipple Mountains, California and Buckskin Mountains, Arizona, in Frost, E. G., and Martin, D. L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, Calif., Cordilleran Publishers, p. 182-204.