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ABSTRACT

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PRESENT STATUS OF THE ANALYSIS OF HEAVY METALS IN FLUID INCLUSIONS

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Most ore deposits have formed as result of the flow of aqueous-rich fluids that have transported and then precipitated the metals in concentrated form. An understanding of the physics and chemistry of these processes of transport and deposition should help in constructing the ore deposition models so essential to modern mineral exploration programs. Study of fluid inclusions in ore deposits has provided a wealth of data on the temperature, pressure, density, and the major chemical constituents of ore fluids, but only recently have quantitative analytical data become available on perhaps the most important of the compositional variables, the metal contents of these fluids. As in many other aspects of earth science, the history of such analysis has progressed with time from speculation to qualitative, to semiquantitative, and finally to quantitative procedures.

Speculation-qualitative. Obviously the presence of the metals in an ore deposit requires that they were present in the fluid, but contrary to some statements, the ratios of the various metals in the fluid and in the resulting ore deposit could have been (and probably were) vastly different. The concentration of any given metal in the ore fluid could also have ranged widely. Many have speculated that high concentrations (percents or even tens of percents) were needed, to avoid having to pass "excessive volumes" of fluid through the deposit. However, simple mass-balance considerations show that even for large deposits of gold, only a few ppb of gold need to precipitate from the fluid passing through, using geologically reasonable assumptions as to flow rates and time. Similarly, even large deposits of copper could form by the precipitation of only 100 ppm of Cu. This "amount precipitated" is some fraction of the total, possibly much larger, amount of the metal in the ore fluid. Thus in some porphyries the copper visible as daughter mineral chalcopyrite may amount to hundreds or even several thousands of ppm Cu, and the iron present as daughter minerals may total tens of percent. (These values are only minima, as the same element may also be present in solution in the fluid phase). A basic ambiguity exists in the interpretation of such inclusion data: do these ore-metal daughter minerals represent the amount of metal which would normally have precipitated in the deposit from that volume of fluid (if it had not been trapped in the inclusion), or do they represent the amount of metal which did not precipitate in the ore body, and would have been carried onward, even to the surface? In this latter case, the trapped inclusion fluid might be termed a "spent residue". Only detailed field and petrographic data can distinguish between these two cases.

Semiquantitative-quantitative. These two types are lumped here

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because the line between them is difficult to draw, there is ambiguity in all, and none are truly quantitative at this time. Some of the analytical methods for metals from samples containing multiple inclusions (e.g., 0.1-1.0g of host mineral), after extraction by various procedures, may yield high sensitivities, and good element ratios for many metals. The methods included here are crush/leach, decrepitate/leach, decrepitate/SEM, decrepitate/ICP, laser ablation/emission spectrography, etc. However, many samples cannot provide material that is appropriate for such methods (i.e., only one generation of inclusion), and generally the concentrations of metal in the fluid can only be estimated from indirect or inexact measures of the total volume of all inclusions opened.

Use of the above procedures in the analysis of single selected inclusions, rather than multiple inclusions, removes or minimizes several sources of ambiguity based on sample characteristics, but increases analytical difficulty by decreasing sample size. None of the various methods currently under development provides a panacea, as all have limitations. Determinations of individual inclusion volume, and hence of metal concentrations, are inexact at best, though perhaps better than those obtained by the multiple inclusion methods above.

Two procedures for analysis of heavy metals in unopened single inclusions have shown considerable promise for the future: the proton probe (PIXE), and synchrotron X-ray fluorescence (XRF). Both provide sensitivities into the ppm range for many metals on 10-micrometer inclusions, or even smaller, but both have stringent sample requirements, particularly on maximum inclusion depth below the sample surface. As above, metal concentrations in the fluid are subject to the same large uncertainties in determination of sample volume. Both provide qualitative and semiquantitative data with relative ease, but highly variable sample parameters and a variety of instrumental and calibration problems make the step from semiquantitative to quantitative a large one.