Melt inclusions and vesicles as indicators of metal-rich ore fluid generation in modern and ancient hydrothermal systems

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Introduction. Magmatic-hydrothermal models have been developed from investigation of modern subaerial volcanic hydrothermal systems where direct measurements of fluxes are possible (e.g., Simmons and Brown, 2007). The model is well defined for high temperature fluids that produce porphyry and epithermal ore deposits but is less well understood for volcanic-hosted massive sulfides containing base and precious metals (de Ronde, 1995; Yang and Scott, 2006).

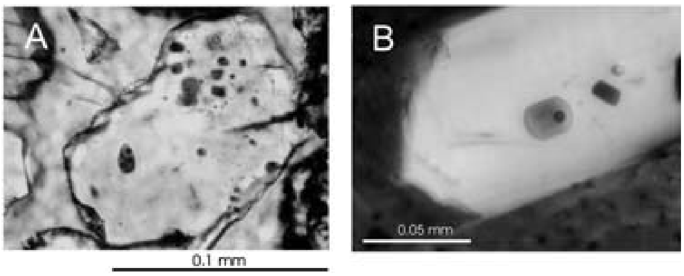

Fig. 1. (a) Melt inclusions with multiple vapour cavities in plagioclase from Kick'em Jenny; (b) Melt inclusion (brown glass) with a single vapor bubble in plagioclase in rhyodacite from Manus Basin.

The conventional model, for both present-day seafloor massive sulfide (SMS) and ancient volcanic-hosted massive sulfide (VMS) deposits, has metals being leached from rocks in the subsurface by heated seawater and subsequently precipitated, primarily as sulfides, when the discharging hydrothermal fluid mixes with the cold, metal-depleted ambient seawater. This leach-and-deposit action can easily explain small accumulations of sulfides, which are typical of seafloor sites and many ancient ores, but is less successful explaining "giant" (>10^8 t) VMS ores in the ancient geologic record. This has led to a consideration of an enriched source of metals that could be mixed with the ubiquitous hydrothermal circulatory system.

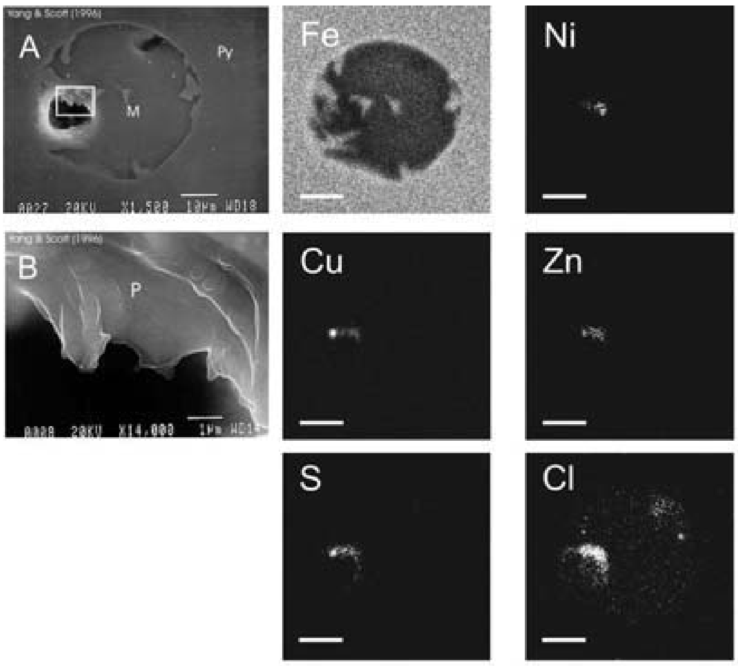

Fig 2. SEM images of (a) melt inclusion (M) containing two vapour cavities in a pyroxene phenocryst (Py) of a basaltic-andesite from Manus and with precipitates in the larger cavity (box); (b) enlargement of the precipitates (P) in a. To the right are element maps of the precipitates in B. From Yang and Scott (1996).

This paper examines the hypothesis that magmatic fluids can provide significant quantities of ore metals for the hydrothermal systems that are producing SMS deposits and their ancient VMS analogs, particularly the very large VMS deposits. Evidence for a magmatic hydrothermal fluid in these systems is found in melt inclusions (fig. 1), tiny amounts of magma that are trapped in growing phenocrysts, and in the contents of thick walled vesicles. Examples are taken from the SMS in the eastern Manus basin offshore eastern Papua New Guinea (1600-2000m water depth), the weak hydrothermal system on Kick'em Jenny volcano (200-300m water depth) in the lesser Antilles arc of the eastern Caribbean, and the large Brunswick 12 Ordovician VMS deposit (330 mt, >1000m estimated water depth at time of formation) of New Brunswick, Canada.

Melt inclusions in VMS systems. Melt inclusions are trapped in phenocrysts at the high temperature and pressure of the magma chamber and record the behaviours of metals and volatiles in pre-erupted magma. A fluid phase is typically observed in cavities within melt inclusions, as well as in small vesicles, indicating that the magma was saturated with volatiles prior to its eruption. In some cases, a separate CO_2-H_2O gas phase was trapped along with the melt. Tiny crystals and amorphous precipitates (recrystallized at Brunswick 12) of Fe, Ni, Zn, Cu and Mn chlorides, sulfides and oxides coat the walls of the vapor cavities (fig. 2 and 3). Ag and Au were detected by ultra-high resolution ToF-SIMS. At Manus, the compositions of the precipitates on the bubble walls of melt inclusions are similar to those found in the vesicles in the matrix glass of the same sample (fig. 4). The ore metals in the volatile phases changed systematically as the magma evolved from basalt to rhyolite (fig. 5). The Kick'em Jenny site has only very minor sulfides being deposited and its ubiquitous melt inclusions (fig. 2a) do not contain metallic precipitates. Glass of the melt inclusions compared to that of the matrix of the rocks from Manus has significantly higher concentrations of H_2O (av. 1.64 vs 0.7 wt%), Cl (av. 2500 vs1300 ppm) and S (av. 900 vs 100 ppm) demonstrating that these volatiles were extensively exsolved from the magma after the melt inclusions formed. The focused discharge of a magmatic fluid as a result of pre-eruptive degassing could be responsible for the metals in the sulfide deposits on the seafloor.

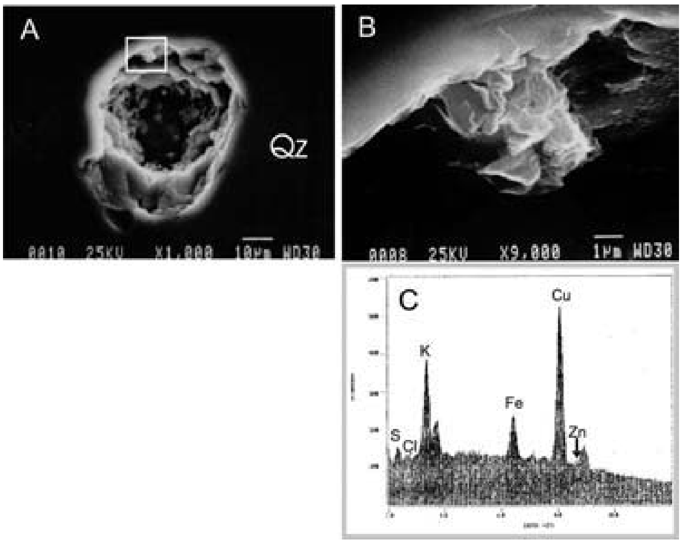

Figure 3. SEM images of (a) vapor cavity in a quartz phenocryst in quartz porphyritic rhyolite immediately beneath the Ordovician-age Brunswick 12 deposit, Bathurst, New Brunswick, Canada; (b) recrystallized precipitates rich in copper, zinc and sulfur on the cavity wall located in (a). C is an EDS spectrum.

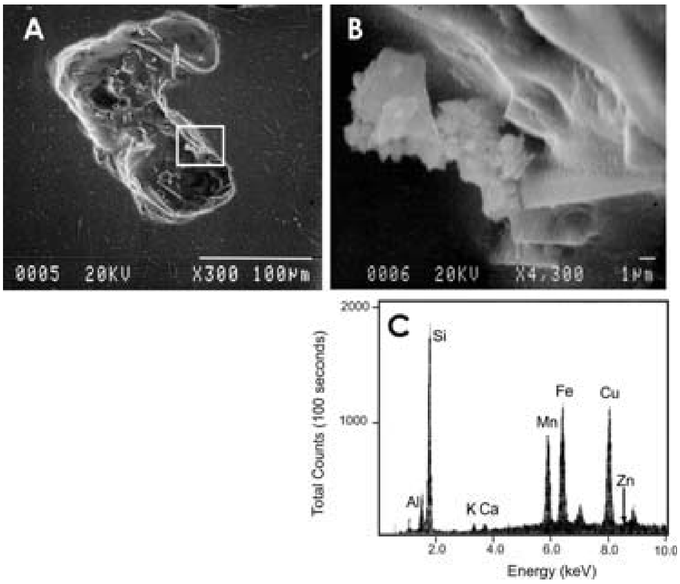

Fig. 4. SEM image of (a) a vesicle with metallic precipitates on its wall (box) in the matrix glass of dacite from PACMANUS; (b) magnified portion of A showing the precipitates. (c) EDS spectrum of the precipitates. This spectrum has no S or Cl peaks, indicating that these precipitates are probably oxides or carbonates. Other spectra do have S and Cl peaks.

The type of degassing process controls the efficiency of transfer of magmatic metals to the hydrothermal system. If a fluid exsolves entirely by syn- and post-eruptive degassing processes, the fluid is largely released into seawater as the magma erupts onto the sea floor and, to a less degree, is contained in the vesicles of the erupted lavas. On the other hand, a pre-eruptive degassing process within the magma chamber would result in the concentration of the fluid exsolved from the magma and the possibility of it being added to the normal hydrothermal seawater circulation system.

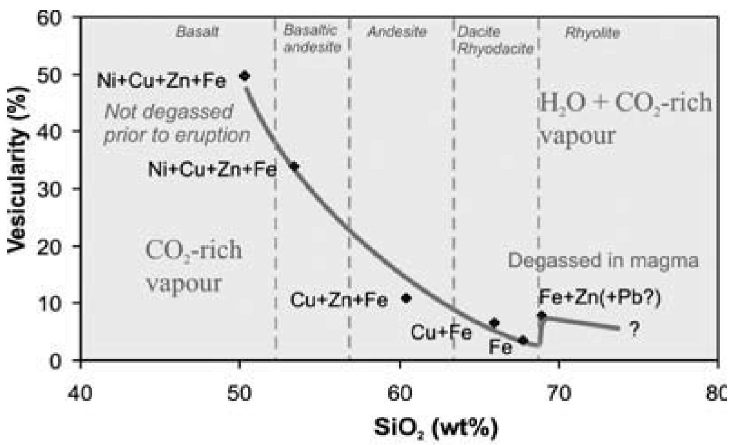

Fig. 5. Systematic variation in the composition of precipitates and the gas phase within vapour cavities of melt inclusions from Manus basin (Yang and Scott, 2002). The vesicularity is an indication of whether or not the magma had degassed prior to eruption.

Conclusion. Magmatic fluids may have played an important role in the formation of large ancient VMS deposits by providing a major source of ore metals beyond that which can be derived by leaching. Only 1% of a metal-rich magmatic fluid mixed with 99% of heated seawater, that has leached its metals from rocks, would contribute over 85% of the total metals to form an ore body and could be responsible for the formation of giant ore deposits such as Brunswick #12. Such magmatic fluids are most likely to be formed from volatile-rich felsic magmas that are prevalent in island arcs. In this model, the subvolcanic intrusion that typically occurs beneath VMS deposits is not just a passive "heat engine" that causes the hydrothermal circulation but plays a critical role in providing metals. Miarolitic cavities in an intrusion associated with volcanic rocks of low vesicularity may indicate degassing of the magma prior to eruption.

References:

de Ronde, C. E. J. Fluid chemistry and isotopic characteristics of seafloor hydrothermal systems and associated VMS deposits: potential for magmatic contributions // *Magmas, Fluids, and Ore Deposits*, edited by J. F. H. Thompson, p. 479-510, Mineralogical Association of Canada, 1995

Simmons, S. F. and Brown, K. L. The flux of gold and related metals through a volcanic arc, Taupo Volcanic Zone, New Zealand // Geology 2007, v.35, p.1099-1102

Stanton, R. L., Ore Elements in Arc Lavas // Oxford Science Publications, 1994

Yang, K. and Scott, S. D. Magmatic degassing of volatiles and ore metals into a hydrothermal system on the modern sea floor of the eastern Manus back-arc basin, western Pacific // Economic Geology 2002, v.97, p.1079-1100

Yang, K. and Scott, S. D. Magmatic fluids as a source of metals in arc/back-arc hydrothermal systems: evidence from melt inclusions and vesicles: in, D.M. Christie, C.R. Fisher and S-M Lee, editors, Back Arc Spreading Systems: Geological, Biological, Chemical and Physical Interactions // American Geophysical Union, Geophysical Monograph 166, p. 163-184, 2006