Economic Geology — An Invited Commentary on Journal Papers

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The Hemlo Gold Deposit, Ontario: An Example of Melting and Mobilization of a Precious Metal-Sulfosalt Assemblage during Amphibolite Facies Metamorphism and Deformation

by Andrew G. Tomkins, David R.M. Pattison, and Eva Zaleski

For the past few years several researchers have been re-examining the old idea that ores may melt during high-grade metamorphism. Experiments have shown that it is certainly possible for sulfide or "polymetallic" ores to melt under granulite facies conditions (Mavrogenes et al., 2001), but field evidence has been harder to come by. The Challenger Au mine in South Australia provided an excellent natural example of a melted Au deposit (Tomkins and Mavrogenes, 2002), but the most conclusive evidence of sulfide melting is provided by sulfide melt inclusions. Hofmann (1994) showed unambiguous polymetallic melt inclusions associated with the ores of Lengenbach, Switzerland, and Sparks and Mavrogenes (2003) identified abundant sulfide melt inclusions in garnetite associated with the ores at Broken Hill, Australia.

Now that we know that ores melt, it is not unreasonable to ask the question: So what? The importance of the melting process falls somewhere between an interesting oddity and a major revolution in ore deposit studies. The jury is still out on this question, and it is difficult to predict the impact that the recognition of this process will have. However, the recent paper in *Economic Geology* by Tomkins, Pattison, and Zaleski (2004), entitled, "The Hemlo gold deposit, Ontario: An example of melting and mobilization of a precious metal-sulfosalt assemblage during amphibolite facies metamorphism and deformation," foreshadows the importance of melting on determining the current disposition of an orebody. Without understanding that the ore at Hemlo melted, one could never have explained the field observations. Even worse, all previous models for the formation of this huge gold deposit were, in retrospect, misguided. This does not reflect on the competence of previous researchers, but rather on the difficulty of explaining the ore assemblages and textures present at Hemlo exclusively through hydrothermal processes.

One of the strange results of the evolution of our science is that economic geologists tend to be specialists in hydrothermal OR magmatic processes, but not both. This has resulted in two main areas of research: studies of magmatic Ni and PGE deposits, and those examining hydrothermal Pb-Zn or Au deposits. Research on porphyry systems fits a bit in between, but these are generally concerned with hydrothermal processes. In general, each group finds that they can quite adequately explain things without invoking processes from the other camp. The difficulty of the sulfide partial melting phenomenon is that it requires application of purely magmatic skills to deposits that clearly fall under the jurisdiction of the hydrothermalists. On the other hand, the beauty of this process is that it is truly multidisciplinary.

Much as pre-plate tectonic mountain building processes seem implausible today, all conclusions regarding the timing of mineralization at Hemlo seem equally absurd once one realizes that the deposit melted. I am not presumptuous enough to suggest that this change in thinking is on a par with the plate tectonic revolution, but I suggest that once one realizes that a particular deposit melted, one's view of that deposit is changed irreversibly.

It is not the case that Tomkins et al. (2004) conclusively prove that the Hemlo ores melted. Rather, they reexamined the deposit assuming that the ore was present before peak temperatures (>600°C) were attained. In this light, the current disposition of the ore is explained simply and elegantly from the macro- to the microscale. In this paper, the authors clearly document that high strain zones host high-melting-point sulfide assemblages (e.g., sphalerite), whereas low-melting-point sulfide and sulfosalt assemblages are concentrated in low strain zones. They conclude that the low-temperature melting assemblages migrated from areas of high strain into lower strain domains as polymetallic melts, where they cooled and crystallized.

Included in this paper is a host of relevant phase diagrams pointing out that the galena-stibnite system has a eutectic at 523°C, Au-Sb at 360°C, Au-Te at 416°C, etc. This amazing collection of diagrams reinforces the real message here, which is that ore assemblages that include Au, Ag, Hg, Sb, Tl, and or Bi melt at the drop of the hat. Hoffman's inclusions from Lengenbach, which are similar in composition to the low melting-temperature assemblage at Hemlo, homogenized below 400°C, confirming that these compositions really do melt at low temperatures. Accordingly, anyone studying a polymetallic deposit that has seen post-formation temperatures above about 400° should seriously consider the possibility that the ore melted, even though it may have started life hydrothermally.

A major new point made here is the link between deformation and melting. At Hemlo, Tomkins et al. (2004) clearly document that low-melting-point chalcophile elements (LMCEs; Frost et al., 2002) are squeezed out of the high-strain zones, taking refuge in areas of low pressure. This opens up the possibility that melting is aided by deformation in two ways: (1) more grains are physically put in contact, thereby facilitating melting of LMCE assemblages; and (2) that once formed, melts are driven down pressure gradients to accumulate in low-pressure zones. This same process has been suggested for silicate systems in which deformation plays a role in the accumulation and escape of anatectic melts. Strain partitioning processes may act on many scales, including regional. If, as shown at Hemlo, gold is concentrated into low-temperature melts, then entire gold camps could be the end result of a major melting event of one or more preexisting hydrothermal deposits.

Sulfide partial melting obscures primary textures to the point that their origin becomes unclear. This is bad news for those of us that spend our time trying to figure out how ore deposits form. But even more frightening is that melt movement into late structures gives the appearance of late introduction, even in a syngenetic deposit. This is something we all need to be careful of because we cannot be re-interpreting deposits as "late" every time somebody finds a low-melting-point veinlet in a late structure. This vein may have formed recently, but the initial hydrothermal orebody did not.

Most people think of sulfide melting as a VERY high temperature phenomenon. But, based on this work, we now should be aware that any ore deposit that has been over ~400°C may have melted, because if it happened at Hemlo it could happen anywhere that such conditions occurred.

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Industry Commentary

The Challenge of Discovering Mineral Deposits Under Cover: What Can We Learn from the Past?

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Successful mineral exploration in the future will depend on our ability, as exploration scientists, to discover ore deposits under deep cover at a cost that will not prohibit an economic return.

Great strides have been made in advancing efficient mineral exploration under shallow cover. We now understand much more about the regolith and the weathering processes involved, and as a result, there have been major improvements in geochemical exploration. There have also been new and improved methods of acquiring geophysical data, and dramatic improvements in computing power to process data. But the challenge of economic mineral exploration under deep cover, at 50 m or more, remains.

If the depth of cover increases from 5 to 250 m, the cost of sampling increases a hundredfold. The deeper the cover, the more difficult and expensive the search becomes, the greater the risk, and thus, the greater the reward for success must be. Many will say such a search will be impossible, or impossibly expensive. When you hear this, you might want to recall the following anecdote involving Tommy Thompson.

On Sunday, 13 September 1857, the SS *Central America* sank in the deeps of the Atlantic Ocean, and with the ship went 21 tonnes of Californian gold. The experts on deep ocean floor exploration and recovery said the possibility of finding the ship and recovering the gold was impossible (Kinder, 1999). The U.S. government had already spent hundreds of millions of dollars trying to work effectively on the deep ocean floor and had failed.

Tommy Thompson, along with two colleagues, set out to find the SS *Central America* and recover the gold. To them, working on the bottom of the deep ocean wasn't impossible, it was only considered impossible, or, as G. Kinder (1999) maintained, "People label things impossible, not because they couldn't be done, but because no one was doing them."

By 1988, after having spent only $12 million, this small exploration team had not only found the ship but had begun recovering the gold. You see, finding the SS *Central America* and recovering the gold was only considered impossible by people who resisted shedding old ways of thinking. In mineral exploration, we also must be prepared to go on an adventure in new ways of thinking: a renascence of thought! And we need to be conscious of the debilitating disease of intellectual blindness.

I first observed intellectual blindness in 1964 and 1965 when, as a young graduate from the University of Western Australia, I took some of the best and most knowledgeable geologists of Newmont, Anglo American, and North Broken Hill to see small outcrops of ironstone at an abandoned gold camp called Red Hill, in Western Australia.

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