

# Granite-Related Mineral Deposits: Geology, Petrogenesis and Tectonic Setting

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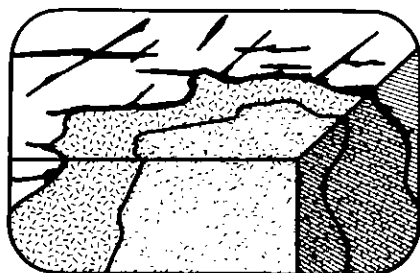
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# Conference Reports



## Granite-Related Mineral Deposits: Geology, Petrogenesis and Tectonic Setting

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In the first half of this century, few geologists questioned the idea that hydrothermal ore deposits form from solutions which emanate from granites. It was considered one of the better established "truths" of mineral deposits geology. But in the decades of the 60's and 70's, the pendulum of geological fashion swung wildly to alternative concepts, and only a few anachronistic Cornishmen, and perhaps a scattering of East Europeans and Northern Australians, most of them concerned with deposits of strange metals like tin, tungsten, bismuth, etc., resisted the new gospels of exhalative hydrothermalism, lateral secretion and metamorphogenesis. Now, the tables are turning, and the rear guard now find themselves, much to their delight, I'm sure, at the front of the pack. The situation has changed so quickly (or perhaps it is just that memories are so short) that we even have the odd situation of geologists claiming scientific priority for "discovering", for example, the magmatic hydrothermal origin of gold deposits!

However, despite the lapse in popularity, the magmatic hydrothermal hypothesis has always been based on a sound background of field and laboratory data. This conference made that point, loud and clear, in three

crowded days of technical presentations (15-17 September 1985), following a pre-meeting field trip in New Brunswick, and followed by a post-meeting trip in Nova Scotia. The meeting was organized through the Canadian Institute of Mining and Metallurgy (CIM), and major credit for "making it happen" goes to the convenor Richard Taylor, now of Carleton University, Ottawa.

Although the meeting was convened in large part as a response to new developments in the Maritime provinces mineral industry, particularly the exploration and development of granite-related deposits at East Kemptville (Sn), Mount Pleasant (W, Mo, Sn), and Lake George (Sb, W-Mo), the technical program was by no means confined to the geology of this area, or to Canadian researchers. In fact, only 20% of the papers were concerned with the geology of the Maritime provinces and only one-third with Canadian geology. Other areas covered were the western USA and Mexican Cordillera (25% of papers), England, Australia, South America and the Malaysian peninsula. Several speakers presented reviews of experimental work and general petrology. The geographic and topical scope of the meeting was so broad, in fact, that only the briefest review of the highlights can be squeezed into these columns. However, a 289-page book of extended abstracts (for the most part, short papers!) has been published by the CIM and was made available to meeting participants (extra copies are available from Dr. Richard Taylor, Department of Geology, Carleton University, Ottawa, Ontario, K1S 5B6; cost is \$C25.00). Full papers were required of all speakers on their arrival at the meeting, and will be published in a CIM special volume. Again, the convenor, Richard Taylor, and his committee, as well as the Geology Division of the CIM is to be congratulated for their success in getting this material out, as are the authors for conforming to the timetable, and for the quality of their contributions.

Most of the papers given at the meeting were concerned with the granites, and extrusive equivalent rhyolites, associated with mineralization, particularly their chemical, mineralogical and isotopic properties. Areas and topics covered were granites associated with rare earth element pegmatites in the

Precambrian (Cerny and Meintzer, U. Manitoba); granitoids associated with Cu-Au, Mo-W, Sn-W, U, W-Cu, etc. mineralization in the northern Canadian Cordillera (R.G. Anderson, GSC); granites associated with cordilleran tungsten deposits (Newberry and Swanson, U. Alaska); the Ackley granite of Newfoundland (Tuach, Strong, Kerrich and Willmore, Memorial U. and U. Western Ontario); the rapakivi granite-bearing igneous complexes of Finland (Haapia, U. Helsinki); the topaz rhyolites and subvolcanic granites associated with Sn deposits of western USA (Christiansen and others, U. Iowa) and Mexico (Burt and Sheridan, Arizona State and Ruiz, U. Arizona); altered granites associated with Sn deposits of Queensland (Taylor and Pollard, James Cook U.), the South Mountain batholith and associated mineralization of Nova Scotia (Clarke, Dalhousie; Chatterjee, N.S. Dept. Mines; Strong, Memorial U.); alkali granites associated with Nb-Zr-REE-U-Th mineralization in Saudi Arabia (Jackson, Drysdall, Stoesser; USGS); peraluminous granites associated with Sn-W in Saudi Arabia (du Bray and Elliot, USGS); pyrrhotite- and anhydrite-bearing rhyolites associated with Ag-Cu-Bi-Pb-Au-Bi-W mineralization in Peru (Drexler and Muñoz, U. Colorado); the granites of the Colorado Mineral Belt, and in particular, the granite complex associated with the Henderson mine Mo mineralization (Carten, Walker and Geraghty, Amax; Stein, USGS); the early extrusive products from the Pine Grove Mo-bearing igneous system (Keith, U. Georgia and Shanks, USGS); the petrology of comb quartz layers and associated complex textures in granites associated with porphyry deposits (Kirkham and Sinclair, GSC); and the high-K rhyolites of SW New Mexico (Bornhorst, Michigan Tech. U.).

Another large group of papers was concerned mainly with the mineralization: the Coal Creek deposit, Alaska (Grant and Thurow, Billiton); the Thor Lake deposit, N.W.T. (Trueman and Pedersen, Highwood Resources and de St. Jorre and Smith, U. Alberta); the Strange Lake deposit, Labrador-Quebec (Miller, Nfld. Dept. Mines); the Tanco pegmatite, Manitoba (Thomas and Spooner, U. Toronto); the Lake George Sb-W-Mo deposit, N.B. (Seal and Clark, Queen's U.); the Oliver

Creek Sn breccias, Yukon (Emond, D.I.N.A.); the St. Austell tourmaline breccias, Cornwall (Smith *et al.*, U. Windsor); the St. Lawrence fluor spar deposit, Newfoundland (Collins and Strong, Memorial U.); and the Henderson Mo porphyry deposit, Colorado (Seedorf, Stanford U.).

Only a few papers dealt primarily with "metallogenesis" — the time-space relationships of granite-related deposits in the geological evolution of large areas: Eastern Canada and western Europe (Strong, Memorial U.); New Brunswick (Ruitenbergh and Fyffe, N.B. Dept. Nat. Res.); Sn and W in Peru (Kontak and Clark, Queen's U.); the granites and Sn-W deposits of Cornwall, England compared with those of SE Asia (Manning, U. Newcastle); and Mo-bearing intrusions in the western Cordillera of America (Kirkham, GSC).

Three papers reviewed experimental and thermodynamic data. The experimental evidence for the influence of various different volatiles on magma properties and on partitioning of metals between magma and co-existing hydrothermal fluids was considered in a paper by Manning (U. Newcastle) and Pichavant (CNRS-CRPG, Nancy), and another by Dingwell (Geophysical Lab, Washington). Eadington (CSIRO, Australia) reviewed the solution chemistry of tin in relation to common mineralogical patterns observed in tin deposits. Finally, Taylor (GSC) presented a review of his work on hydrogen isotope evidence for magma degassing.

The major issues of the meeting can be grouped into two broad categories: what are the granites like, and how can this variability be explained in terms of nature of source materials, processes of magma generation, and processes of magma solidification; and what are the ore deposits like, what is their relationship to associated granites, and how can this relationship be explained in terms of late magmatic and magmatic-hydrothermal processes?

With regard to what the granites are like, the real work clearly is just beginning, now that there is general recognition that a simple pigeon-holing into an I or S or A category is inadequate. An impressive group of variables can be defined by looking at granites; temperature and pressure of crystallization, fH<sub>2</sub>O, fHF, fB, fO<sub>2</sub>, metal contents, mineral crystallization sequences, REE abundances (both relative and absolute),  $\delta^{18}\text{O}$ ;  $\delta\text{D}$ ;  $^{87}\text{Sr}/^{86}\text{Sr}$ ; Pb isotopes, peraluminosity, peralkalinity and alkali-calcic indices; chemical, physical and temporal relationship between spatially associated igneous bodies, etc. Clearly, there is little chance that these variables will be so inter-related that the complexity of this population of rocks can be reduced to, say, three or four independent parameters. However, there does appear to be some natural groups with wide geographic distribution, such as the topaz rhyolites (commonly associated with small, generally uneconomic tin deposits) and the

high-silica granites (associated with Climax-type Mo deposits).

When it comes to what variations in these parameters mean, in terms of granite genesis, uncertainty prevails. Many speakers appealed to special source rocks to explain the variability. An idea that enjoys wide popularity, being consistent with most of the field and experimental data, is that ore-generating granites form as a result of small degrees of partial melting caused by the high temperature breakdown of refractory F- and Cl-rich biotite and amphibole in deep crustal granulites from which low melting fractions, and much of the incompatible element content, had been extracted by previous partial melting events. The high temperature of generation of such melts, and their relatively high hyperfusible and low water content allows them to rise to high levels in the crust, and to attain a large degree of solidification and thus crystal fractionation) before a hydrothermal phase is exsolved. The low viscosity of such B- and F-rich melts also is critical to the collection of small quantities of dispersed melt into magma bodies large enough to be capable of rising through the crust. Exactly why this magma-generating process results in such different ore metal associations (Mo in some, Sn in others, base metals or various rare earth elements in others, etc.) remains unclear. On this point, most authors fell back to the concept that differences in source rock are responsible. Data bearing on this problem, however, are sparse, and in at least one case where the evidence is relevant, reported by Keith and Shanks, it was not supportive of the special source rock hypothesis. These authors were able to establish that the ash flow sequence they studied, and showed to be "normal" in every respect, was from the top of a chamber of magma which eventually evolved to form the Pine Grove Mo deposit. They appealed instead to special processes, namely, a long period of magma "stewing", perhaps accompanied by "vapour steaming" due to underplating by a mafic magma which gave off gas which bubbled up through the felsic magma.

Another process suggested to explain fertile magmas, was assimilative reaction of the magmas with the intruded rocks. Clarke and Chatterjee, for example, suggested that the chemistry of the South Mountain Batholith was strongly modified by assimilative interaction with the Meguma sediments, known to contain paleoplacer Sn. In general, however, little was said about how the space now occupied by the intrusive bodies was generated, despite the obvious "room problem". Positive evidence for a lack of interaction of magmas with their country rock environment was reported by Stein, who noted that Pb and S isotopes remained very constant for Climax-type intrusions in the Colorado mineral belt, despite a diversity of host rock types.

Obtaining good data on what the deposits are like and the relationship of the deposits

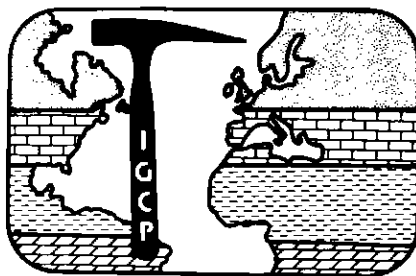
to the granites continues to be a major problem, with the achilles heel of most studies being adequate documentation of geometrical relationships. The importance of good geometrical constraints was made obvious by the outstanding case study of the Henderson deposit reported by Carten and Seedorf. By careful mapping of the distribution of mineralization, alteration, and intrusive rock types, and establishing their relative ages by cross-cutting relationships, they were able to show that a continuum of magmatic through to hydrothermal effects was associated with the emplacement of each one of a series of separate intrusions in the Henderson complex. Then superimposed on the aggregate of early mineralized zones was a series of lower temperature hydrothermal effects, including base metal mineralization, which the lead isotope work of Stein also indicates had a "magmatic" source. The implications of these findings boggle the mind, and one wonders what might come out if a similar effort were put into some of the other granite-associated deposits considered at the meeting. For instance, one implication is that a very unusual melt which appears to have contained several weight percent dissolved molybdenite, as well as major quantities of volatiles, was present in the apical zones of the Henderson intrusions, and the texturally complex rocks (brain rock, plumose feldspar rock, etc.) formed from this magma; as did the Mo-bearing vein dykes. Perhaps this was a two-phase material, a normal magma and a co-existing hydrothermal fluid, but there is really no evidence for this, and if we were not shackled by our thermochemical prejudices, we would say it was a fluid with chemical and physical properties part way between those of a silicate liquid and those of a hydrothermal fluid. If such a fluid is possible, then it must have been immiscible in the normal granite which eventually solidified to form the main mass of the Henderson granites — otherwise, how would they have stayed separate, or even formed in the first place? A fluid of this type has long been a popular concept with geologists who work on pegmatites, which also show part-magmatic and part-hydrothermal features — in fact, as pointed out by Kirkham, the texturally complex rocks of porphyry Mo granite cupolas are directly comparable with those in many mineralized pegmatites. Again, the time and space relationships of the late and lower temperature mineralization at Henderson suggests that a normal hydrothermal fluid separated from the igneous system later in its solidification history. Do we have in this model an insight into the significance of some of the variety of mineralization types we see in granite-related deposits?

Comparing the new with the old Henderson story, one cannot help wondering how much of the mystifying complexity in the relationship of ores to granites is due to erroneous genetic connections assumed between

individual granites and individual ore deposits, in cases where the critical geometrical relationships are unknown? For example, a number of speakers emphasized that lithophile metal deposits typically occur in composite granite terranes, and it was also noted several times that there appears to be a considerable time gap between the emplacement of the granite, and the formation of the deposit. Yet clearly, at places like Henderson, where good documentation is available, ore and granite are very close in time. So perhaps in areas where a time gap seems to exist, the right granite has not been matched with the right ore. Similarly, are we fooling ourselves when we define "differentiation" trends by comparing the chemistry of spatially associated granitoids in a composite intrusive terrane, when the intrusions may be temporally and genetically quite separate? Unfortunately in geology, as in other areas of modern life, our new wings, the machines which make it all so easy to accumulate data, are not very useful when it comes to making some of the fundamental decisions which so influence the final story.

In summary, this was a first class, truly international meeting. Its success is a credit to the organizers, and to the Canadian Institute of Mining and Metallurgy. If you are reading this report, you probably missed the event, and may be regretting it. But you can get the book of extended abstracts, and hopefully, the volume of full papers will be out soon.

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## Penrose Conference "Terranes in the Circum-Atlantic Paleozoic Orogens"

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The Penrose Conference on "Terranes in the Circum-Atlantic Paleozoic Orogens" was held at Liscombe Lodge, Nova Scotia, 27 May to 2 June 1985. A total of 71 people participated in the Penrose Conference from the following countries: USA (29), Canada (9), U.K. (12), France (8), Norway (3), Sweden (3), and one from each of Poland, Czechoslovakia, Austria, Spain, Holland, Eire and Columbia. Financial support from International Geological Correlation Programme, International Union of Geological Sciences, National Science Foundation, Canadian Geological Foundation and the Geological Society of America is gratefully acknowledged and allowed many non-North Americans and five students to attend the Conference.

The Conference began and ended with a session dealing with terrane vernacular as defined in the Cordillera and circum-Pacific region. This was compared with its usage in the circum-Atlantic area. By the end of the Conference it was generally realized that there had been varying degrees of misuse in the circum-Atlantic area. It was also generally agreed that the circum-Pacific terminology was appropriate for the circum-Atlantic also, however workers in the latter region should be more careful in their application of terms. During the opening session, several fundamental questions emerged such as (1) What rock properties distinguish normal, oblique and transcurrent accretion?; (2) What controls the presence/absence and nature of plutonism and metamorphism?; (3) Is it possible to estimate the thickness of continental crust being accreted and, if so, how?; (4) What criteria distinguish pre- and post-accretionary movements?

The next session dealt with the role of various geological specialities in terrane analysis. Dr. B. Bluck (Glasgow, U.K.) demonstrated the application of sedimentology and stratigraphy to terranes with examples from the Himalayas and the Midland Valley of Scotland. Upward-coarsening sediments characterize the Siwalik trough in the Himalayas and record the emplacement of thrust sheets. On the other hand, alluvial fans in Scotland all fine upward and the Midland Valley basins contain fragments a source for which cannot be found in either the Southern Uplands or the Dalradians. An accretionary mechanism involving both strike-slip faulting and thrusting was proposed. Dr. D.L. Bruton (Oslo, Norway) showed that faunal province boundaries record paleotemperature boundaries which do not necessarily coincide with terrane boundaries, and provided a classic example in one continuous stratigraphic section where the fauna alternated between Baltic and North American as the water depth changed from deep to shallow, respectively. Dr. R. Hon (Massachusetts, USA) outlined the difficulties in using correlations of igneous rocks based upon a common tectonic origin and protolith, due to factors such as mixing, alteration and petrogenetic controls. Dr. P.G. Andreasson (Lund, Sweden) illustrated how contrasting P-T ratios, deviating P-T time paths and different tectono-metamorphic histories can be used to distinguish terranes, and pre- from post-accretionary metamorphism. Dr. P. Lapointe (Ottawa, Canada) outlined the principles of paleomagnetism in terrane analysis which allows the construction of pre-accretionary paleogeography and the time of accretion. Paleomagnetic distinctions are presently limited to latitudinal movements greater than 5° or ≈500 km and there are no longitudinal constraints. Thus, it may not always be possible to distinguish paleomagnetically geologically-defined terranes. Complications may arise where the rock and the magnetization ages are not synchronous, e.g. in overprinting remagnetization or where various minerals with different Curie Points contribute to the observed magnetization. Dr. J.P. Lefort (Rennes, France) demonstrated the characteristic magnetic and/or gravity signatures associated with some terranes and terrane boundaries which could be used in tracing terranes beneath cover rocks or beneath the sea. However, caution was advised because several instances were cited where changes in magnetic and/or gravity patterns occur within one terrane due to factors such as metamorphic gradients and plutonic bodies. Also long wavelength anomalies relate to deep structures and may not relate to terrane boundaries at the surface. Dr. K.D. Nelson (New York, USA) illustrated how seismic data allows the three-dimensional shape of terrane boundaries to be traced provided they possess some seismic expression.

This general session was followed by a