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Mercury as a Lithogeochemical Exploration Vectoring Technique: a Review of Methodologies and Applications, with Selected VMS Case Histories

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Introduction

Mercury has long been recognized as a potentially valuable tracer in the search for various types of mineralization mainly because of its high vapour pressure in the native, chloride, oxide, and sulphide forms. Saukov (1946) was the main proponent early on, recognizing that this behavior could produce anomalies around certain types of mineral deposits. His study was followed by an explosion in instrumentation development, coupled with experimental and empirical analytical research on numerous mineralized systems, particularly in the former Soviet Union. The studies flourished with Fursov (1958) and Friedrich and Hawkes (1966a, b) being some of the first to characterize the distribution of Hg around various mineral deposits. Since the 1960's, Hg has become a valuable tool in water, vegetation, soil, bog, stream sediment, overburden, and rock geochemical exploration (Warren et al., 1966; Dickson, 1968; Köksoy and Bradshaw, 1969; McCarthy et al., 1969; Fleisher, 1970; Dall'Aglio, 1971; Ozerova, 1971; Trost and Bisque, 1971; McNerney and Buseck, 1973; Garrett, 1974; Ozerova et al., 1975, to name a few). Methodologies for surficial trace-metal vectors have received considerable attention in the literature as well (Hall, 1998), including those for Hg (see Hall et al., 2005; Hall and Pelchat, 2005 and references therein). The later interest in Hg is no doubt in part driven by the known toxicity Hg has to most animal species and the potential health threat it possesses to humans (Jonasson and Boyle, 1972; Rasmussen et al., 1998; Parsons and Percival, 2005); the acute awareness about Hg has been enhanced by the various anthropogenic inputs to the environment beyond those related to natural surficial processes, including those associated with reaction with near-surface mineral deposits containing elevated levels of Hg (see Rytuba, 2003). However, lithogeochemical techniques have mainly focused on total Hg analysis, not always using the most robust methods for effective threshold determination or differential thermal analytical techniques. In the author's experience, precision and accuracy of total Hg determinations, as well as cost and turnaround, has been a deterrent to the routine application of Hg in lithogeochemical exploration. However with the latest instrumentation available (see below) at reduced cost, Hg determinations may become more generally utilized as an effective technique for locating otherwise blind mineral resources of various types.

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Analytical Considerations

Cold vapour absorption techniques for Hg analysis have become quite standardized (Barringer, 1966; Azzaria, 1967; Vaughn, 1967; Azzaria and Webber, 1969; Köksoy et al., 1969; Jonasson et al., 1973; Wilmshurst and Ryall, 1980; Fletcher, 1981; van Loon and Barefoot, 1989; Hall, 2005) using flameless atomic absorption (cold vapour AAS), as well as the Hg vapour analysis technique (low temperature adsorption and direct soil gas) (Carr et al. 1986; Fengchi and Guolian, 1989; Fedikow and Amor, 1990; Fursov, 1990). Since then, these techniques have been used by the mineral

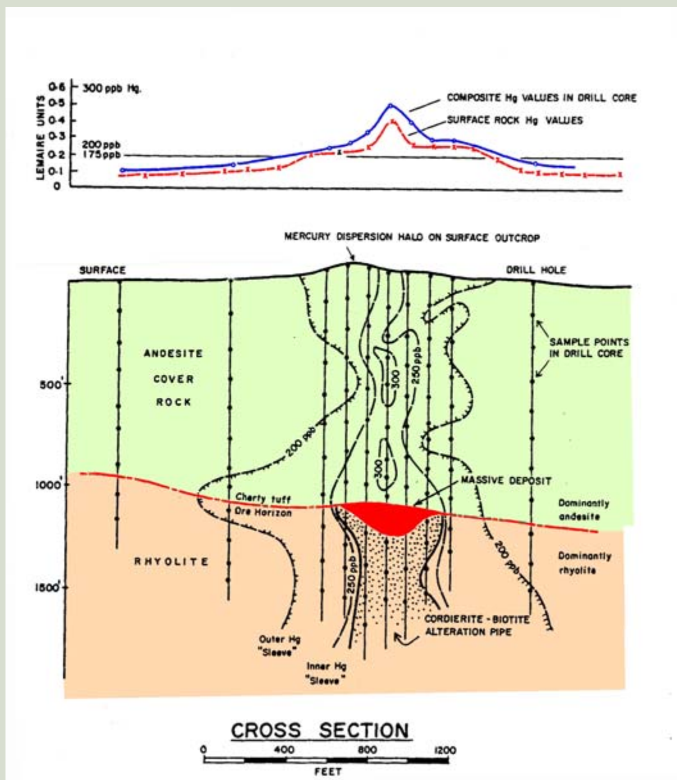

Fig. 1. Contoured mercury compositions in a vertical cross-section through the hanging wall and footwall of a blind massive sulphide deposit, Noranda District (modified after Boldy, 1979).

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MDD Goals and Objectives

The Gangue is published quarterly by the Mineral Deposits Division of GAC and is distributed to its members. The Mineral Deposits Division of the Geological Association of Canada is Canada's foremost society for promoting the study of mineral deposits by supporting local and national meetings, symposia, short courses and field trips. We sponsor the publication of research relating to ore deposits and metallogeny, and recognize the contributions of outstanding Canadian economic geologists by annually awarding the Duncan Derry and William Harvey Gross medals and the Julian Boldy Certificate.

Publication Schedule:

SUBMISSION	DATE
December 15	January
March 15	April
June 15	July
September 15	October

Information for contributors:

The objective of this newsletter is primarily to provide a forum for members and other professionals to voice new ideas, describe interesting mineral occurrences or expound on deposit models. Articles on ore deposits, deposit models, news events, field trips, book reviews, conferences, reprints of presentations to companies, mining groups or conferences, or other material which may be of interest to the economic geology community are welcome. Manuscripts should be submitted by email in WP or WORD format. A printed version should be mailed or FAXed. Illustrations should be camera-ready (ideally as CDR digital files); photos should be of good quality. Short items dealing with news events or meetings can be submitted by FAX, postal mail or email. Contributions may be edited for clarity or brevity.

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Message from the Chair

May 25, 2005

Dear Members,

My time as the Chairperson of Mineral Deposits Division has drawn to an end and I now become the past-Chairperson. It has been a busy year and I did want to fill you in on the activities of the MDD. I believe that next year promises to be even better with new initiatives and activities.

This year's executive was instrumental in all the MDD activities. Jan Peter (GSC-Ottawa) stepped right in to his role as vice chair of the MDD and will be well prepared to assume the role of chair for the coming year. 'Lyn Anglin (GSC – Vancouver) will be continuing to keep the organization running, reminding us of the tasks that need still to be accomplished. Jason Dunning (Yukon Zinc) has done a great job keeping our finances straight, even in the midst of a very busy corporate schedule. Dan Marshall (SFU-Vancouver) will continue as awards coordinator, coaxing the nominations and maintaining the MDD website. Dirk Tempelman-Kluit (Vancouver) continues in his role as publications coordinator, keeping our expectations in line with our means. Kay Thorne (Govt. of NB) has done an excellent job as editor of the Gangue and I look forward to reading new editions. This is not an easy job, as it sometimes requires considerable harassment of people to get their contributions! Steve Piercey (Laurentian) will be stepping down as the short course coordinator due to family and work commitments but he will continue to offer his guidance and advice.

The ranks of our ever-helpful directors are also changing and I welcome Rob Carpenter (Committee Bay Resources) and Moira Smith (Teck-Cominco) (MDD Chair 2003-4). I look forward to their contributions, as directors are expected to participate by: helping judge the Boldy Awards at annual meetings; submitting candidates for consideration for the Derry and Gross awards; submitting one paper for publication in the Gangue during their 3 year tenure, and attending the AGM and informal meetings at the Round-Up. Finally, I would like to thank the outgoing directors, Cliff Stanley for his ideas and thoughts on many issues and Suzanne Paradis who will be stepping down as director to assume the role of the new vice chair.

Some of this year's highlights included:

- **The Ore Minerals Atlas**, by Dan Marshall, 'Lyn Anglin and Hamid Mumin, is now available. In addition to their roles on the executive, both Dan and 'Lyn have worked extremely hard on the Ore Minerals Atlas resulting in an excellent and high quality publication. Initial sales at the PDAC were great and we have high hopes for continued sales this fall. I recommend that all members have a look at this book. Thanks also to the steering committee for their valuable input and to all for keeping the price as low as possible.

- **Robinson Lectureship:** Responsibility for the Robinson Lectureship alternates between the Precambrian Section and the MDD; this year it was their turn. For next year, we have selected the speaker: Dr. Bruce A. Kjarsgaard will be traveling coast to coast to deliver his

(Continued on page 4)

lecture entitled "The Diamond Fields of Canada" to universities and institutions. Given the ongoing excitement over this commodity and the quality of the speaker, this lecture should be very well received.

- **Gross and Derry Medal winners:** Dr. Yuanming Pan (U. of Sask.) was awarded the Gross Medal and Jeff Hedenquist (Col. Sch. of Mines) was awarded the Derry Medal for 2005 for their significant contributions to the study of mineral deposits. Congratulations to them both!

- **Boldy Award winners:** At the St. Catharine's Meeting 2004, three papers were identified as worthy of recognition: Kesler, S.E. *Gold In Sulfide Minerals And Ore Deposits*; Wood, S.A. *The Hydrothermal Geochemistry Of The Rare Earth Elements*; and Hollings, P. et al. *The Characteristics, Distribution And Controls Of Giant Porphyry Copper Deposits*. Congratulations for these excellent presentations. I would also like to congratulate Craig Hart on his 2005 GAC Service Award. This is certainly well deserved for all the time and effort that he put into the editorship of Geolog.

- **New Contributions:** Many thanks are also due to Placer Dome for their on going support of the Boldy Award. While Bob Cathro was treasurer, he pointed out that with the decline in interest rates, the endowment for the Boldy award was steadily declining. Through Bob's efforts and with this continued generous contribution we can have a new certificate printed and the annual prize expanded. On an unfortunate note Mrs. Shirley Gross passed away this year but the family has made a major endowment to the William Harvey Gross Award. This will allow us to continue recognizing a geoscientist less than 40 years of age (as of December 31 of the nomination year) who has made a significant contribution to the field of economic geology in a Canadian context. Our thanks and condolences to the Gross Family.

- **New Student Presentation Award:** Unfortunately our attempts to start a new student award based on the Boldy Award have stalled. We are now in the process of canvassing for new donors to make this award a reality in time for the Montreal Meeting. If you or your corporation would like to be the sponsor for this award please contact Jan Peter.

- **Field Trips: Myra Falls and Eskay Creek**. This year the MDD has started organizing field trips again. The first one to Myra Falls on Vancouver Island was run in conjunction with the Exploration Round Up. As a participant I can attest to the success of this field trip. The next one to Eskay Creek promises to be highly memorable. In addition to an underground tour at the exceptional Eskay Creek Mine, visits to Galore Creek – Copper Canyon – McLymont Creek have also been arranged starting Sept 12 to Sept 16 from Smithers B.C. If you would like more information contact Garth Kirkham gdkirkham@shaw.ca

- **Student Night:** At the Round Up this winter, the MDD was a co-sponsor of a very successful student night. This event was organized by 'Lyn Anglin in conjunction with the SEG, GAC Cordilleran Section and the BCY Chamber of Mines. This event allowed for students to listen to leading geologists and then talk with them on a one on one basis to learn about the advantages of becoming a geologist. Many more students than anticipated took advantage of this opportunity and both students and potential employers found it to be a very useful evening. We will be looking at repeating this event next year and the possibility of holding a similar night in conjunction with the PDAC in Toronto.

Looking forward, the 2006 GAC meeting in Montreal is fast approaching. We will help sponsor symposia on: the Evolution and Mineral Deposits of the Canadian and Brazilian Shields, the Diversification of Mineral Exploration as well as a special session on Isotope Geochemistry and Ore Mineralization, in addition to various other sessions, and the annual luncheon. 'Lyn Anglin, Danny Wright, Elizabeth Ambrose and I are working hard on editing the Yellowknife EXTECH volume for publication by MDD, to be available this fall. It is to be followed by a publication on the Athabasca EXTECH volume edited by Charlie Jefferson. A number of ideas for new publications and short courses were discussed at the recent meeting of executive and directors at the Halifax AGM. A new volume on Canadian Mineral Deposits is being considered as a future MDD publication.

It has certainly been an interesting year with an ever-changing set of issues and challenges to deal with. In the words of my predecessor, Moira Smith, "Although we didn't accomplish everything we set out to do this year, I think the MDD is in a good position to finish some of these tasks in the near future and to go forward with new initiatives." In closing, I would like to extend my thanks to the executive, directors, and all the other people who make the MDD a success. It has been a great year and I'm very honored to have had the opportunity to take part in it.

Hendrik Falck

Chair, MDD, 2004-2005

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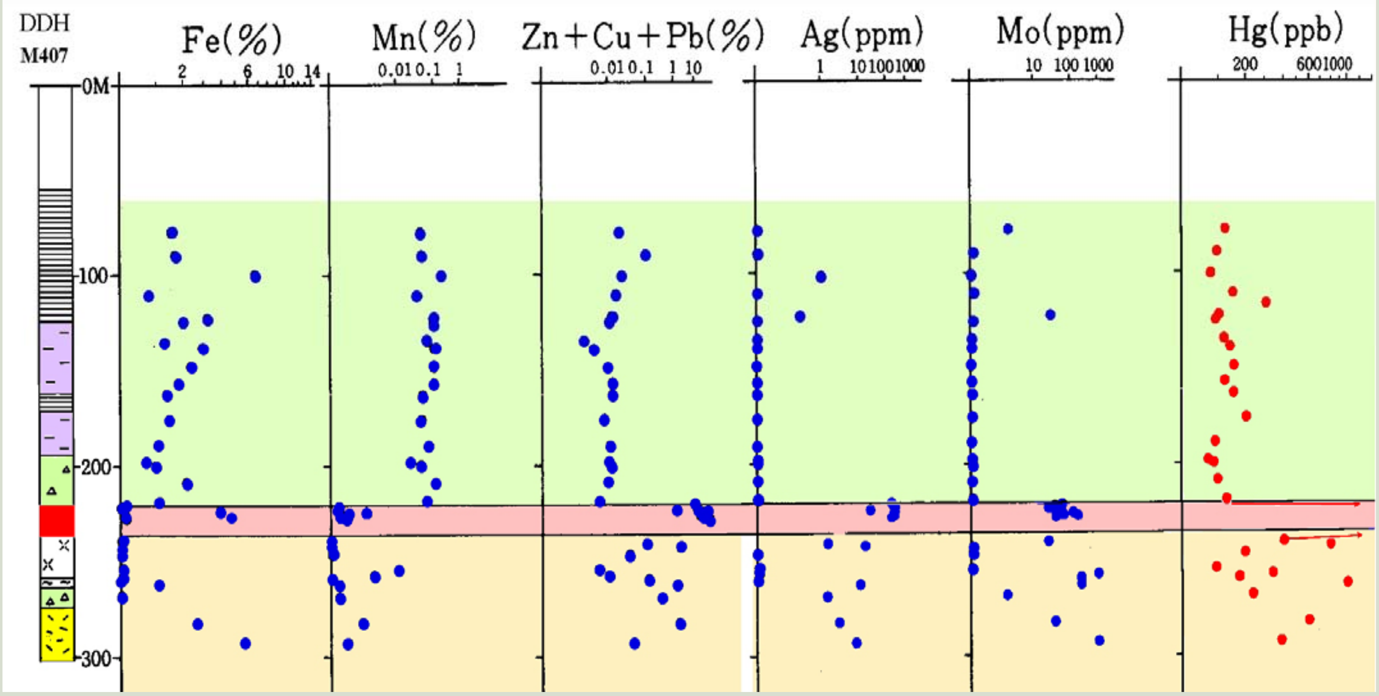

Fig. 2. Geochemical profiles for Fe, Mn, base-metals, Ag, Mo, and Hg in drill hole M407 through the hanging wall and into the footwall of the Uwamuki First deposit, Japan (modified after Tono, 1974).

exploration industry with varying degrees of success both from an anomaly discrimination standpoint and a cost analysis perspective. Recently, Hall and Pelchat (1997) and Hall (2005) have described a CV-AAS system that combusts a sample directly and has the approval of the US Environmental Protection Agency (Method 7473); several robust models (see Hall, 2005) are currently available that are relatively portable to the field area. This technological development enables direct analysis of small aliquots (e.g., 100 to 300 mg) of inorganic or organic solids and liquids using a high temperature thermal combustion and collection (amalgamation) technique, with an increase in the resulting signal to noise ratio. The technique features rapid analyses (< 5 minutes), few chemicals (there are the catalysts), no pretreatment, and no waste disposal, with instrument detection limits superior to standard CV-AAS (0.01 ng/g, 0.01 ppb), and a working range of 0.05 ng to 600 ng/g. Memory effects during the intermediate amalgamation step can be problematic, if samples with vastly different abundance levels are introduced into the automated sampling system, although these can be rectified during the analysis stage. For the analysis of natural waters with very low Hg abundances, CV-AFS (atomic fluorescence spectrometry) is the preferred technique, with several reliable suppliers available (see Hall, 2005). Lastly, Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) is used to analyze total Hg (DL in solution is 5 ppb), as well as numerous other elemental abundances, although careful sample preparation is required, therefore the Direct Combustion CV-AAS technique is preferred for routine lithogeochemical evaluation.

Previous Hg distribution studies

Mercury and its associated elements (Cd, In, Sb, Tl) have been used to lithogeochemically explore for more than just Hg-related deposits. These include detecting geothermal energy (Shiikawa, 1983; Bingqiu et al., 1986), gold deposits (Erickson et al., 1964; Polikarpochkin et al., 1965; Lovering et al., 1966; Akright et al., 1969; Wells et al., 1969; Sears, 1971; Ewers and Keays, 1977; Boyle, 1979; Aftabi and Azzaria, 1983; Berger and Silberman, 1985; Silberman and Berger, 1985; Fedikow and Amor, 1990; Nelson, 1990), antimony to tin deposits (Koksoy and Bradshaw, 1969; Ozerova, 1971), uranium deposits (Carr et al., 1986; You and Li, 1990), porphyry-skarn Cu-Mo deposits (Azzaria and Andrè Carrier, 1976; Theodore and Nash, 1973; Olade and Fletcher, 1976), W-Mo deposits (Garrett, 1974), as well as base-metal deposits (Fursov, 1958; Hawkes and Williston, 1962; Friedrich and Hawkes, 1966a,b; Ozerova, 1971; Boldy, 1979; Lahti and Govett, 1981; Fedikow and Amor, 1990) that will be highlighted later. It is also well known that in surficial materials, the distribution of organic matter affects the retention of mobilized Hg due to reduction processes, although the distribution is not always, relatively speaking, that anomalous compared to the inorganic material (Azzaria and Webber, 1969). Detailed studies on Hg-rich epithermal systems do provide valuable insight into the processes involved in Hg mobility and deposition, although the complexity of these processes are rarely related to other deposit systems that are noted above; this is a field that could use considerable new research.

Geochemical standards and background determination

Particularly key to all geochemical methods is the appropriate use of geochemical standards in both surficial medium (Table 1)

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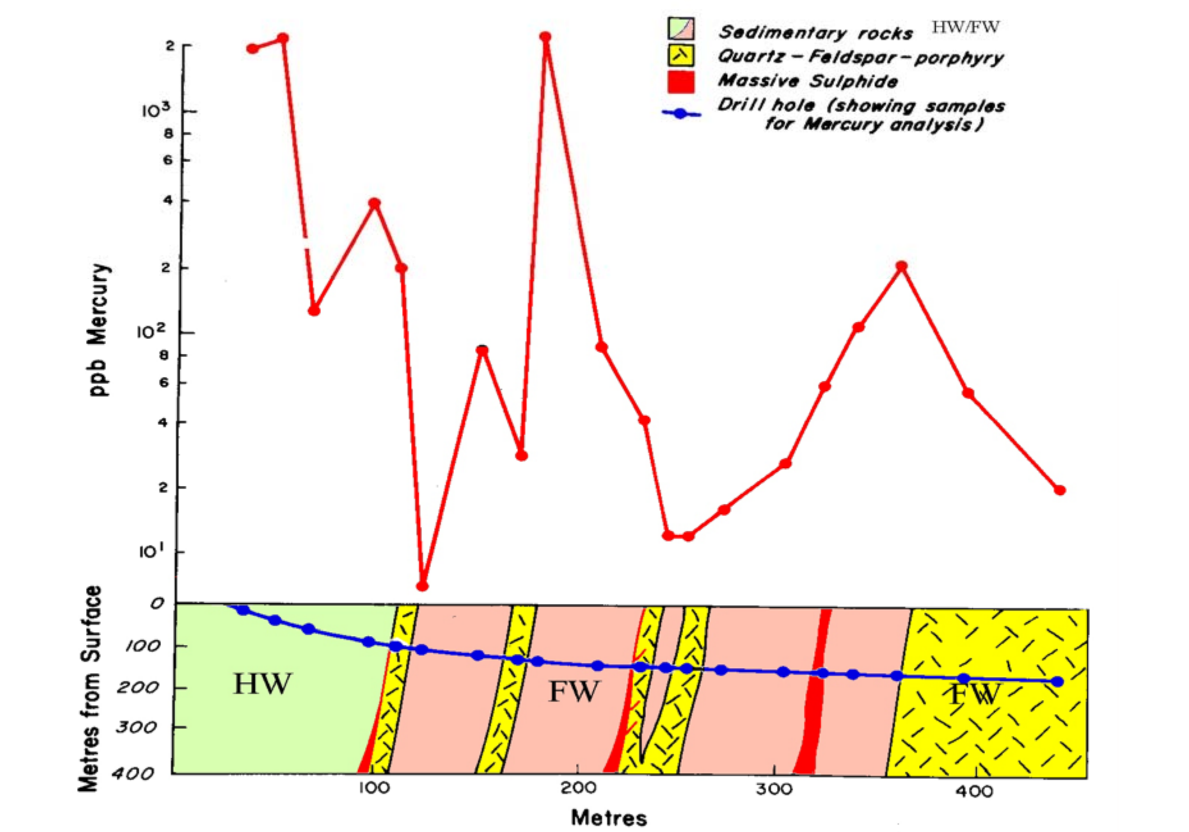

Fig. 3. Mercury distribution in a selected drill hole intersecting the hanging wall and extending into the folded footwall of the Brunswick No. 12 Zn-Pb-Cu-Ag massive sulphide deposit (modified after Goodfellow, 1975).

through to lithogeochemical standards and the ores themselves (Table 2). These are readily available from CANMET, and other analytical research facilities (see Hall, 2005). Govinaraju (1994) has a complete listing of most official geostandards. Any analytical method selected for routine geochemical exploration must consider the background variations in the various medium being analysed in order to enhance anomaly discrimination. Tables 3a and 3b are a compilation of Hg data in the Geochemical Earth Reference Materials (GERM) database that is available on the internet. The low Hg contents of natural waters (Table 3a) limits the use of certain analytical techniques in regions of low Hg content, unless preconcentration (i.e., evaporation) techniques are used. As presented by Rose et al. (1979) and Barnes and Seward (1997), there is a considerable variation in Hg contents in various inorganic materials, as well as organic materials, due to the adsorption/reduction processes associated with clays and carbon compounds. As such, there is a much higher background Hg content in various sedimentary rocks and their partially metamorphosed equivalents compared to other rock types (Tables 3a, b), which must be ascertained for all key elements (see Table 4), if they are to be effectively applied to lithogeochemical vectoring. Like those for other metals, Hg thresholds need to be determined in a particular region for a specific ore-forming system, so that anomalies can be recognized. The calculation of enrichment factors (EF) (or anomaly ratio, sample/background average; Govett, 1983) is a

Table 1. CANMET partial extraction compositional standards for lake sediments (LKSD), soils (SO), stream sediments (STSD), and till (TILL).

LKSD1 110 ppb	**LKSD2** 160 ppb	**LKSD3** 290 ppb	**LKSD4** 190 ppb
SO-2 82 +/- 9 ppb	SO-3 17 +/- 7 ppb	SO-4 30 +/- 6 ppb	
STSD-1 110 ppb	STSD-2 46 ppb	STSD-3 90 ppb	STSD-4 930 ppb
TILL-1 92 ppb	TILL-2 74 ppb	STSD-3 90 ppb	TILL-4 39 ppb

Table 2. CANMET Ore compositional standards.

CH-4 (Gold Ore) 30 +/- 7 ppb	**CZN (Zinc Concentrate)** 5 +/- 1 ppm
FER-1 (Iron Formation) 20 ppb	**CCU-1c (Copper Concentrate)** 32 +/- 8 ppm

Table 3a. GERM Global Geochemical database estimates for various reservoirs.

Continental Crust 40 ppb Wedepohl (1995)	Upper Continental Crust 56 ppb Wedepohl (1995)	Lower Continental Crust 21 ppb Wedepohl (1995)	Precambrian Crust 96 ppb Shaw et al. (1986)
Seawater 0.005 ppb Li (1982)	Rivers 0.07 ppb Li (1982)	Marine Clay 100 ppb Li (1982)	

Table 3b. GERM Global Geochemical database estimates for various rock types.

Sandstones 25 ppb Alltschuller (1998)	**Marine Shale** 400 ppb Alltschuller (1998)	**Pelite** 29 ppb Gao et al. (1998)	**Carbonates** 25 ppb Gao et al. (1998)
Mafic Volcanics 16 ppb Gao et al. (1998)	**Mafic Intrusions** 9.3 ppb Gao et al. (1998)	**TTG's** 8.2 ppb Gao et al. (1998)	**Granites** 7.2 ppb Gao et al. (1998)
Amphibolites 4.9 ppb Gao et al. (1998)	**Felsic metavolcanic** 7.3 ppb Gao et al. (1998)	**Granulites** 5-7 ppb Gao et al. (1998)	**Diorites** 12 ppb Gao et al. (1998)

useful technique that for some elements like Hg are required, since there can be a pronounced variation in the background abundance levels.

Lithogeochemical Hg studies in massive sulphide systems

Mercury halos have been identified in association with massive sulphide deposits by various researchers with different degrees of success (Ozerova, 1959; Friedrich and Hawkes, 1966a,b; Takeuchi et al., 1970; Watling et al., 1973; Tono, 1974, Turek et al., 1976; Sinclair, 1977; Ryall, 1979a,b, 1981; Ryall et al., 1981; Boldy, 1979, 1981) including several deposits in the Bathurst Mining Camp, e.g., Brunswick No. 12 (Goodfellow, 1975; Lentz and Goodfellow, 1993a,b), Caribou (Gandhi, 1978) (see also Govett, 1983; Goodfellow, 2003), and Heath Steele (Lentz et al., 1997). If previous studies are any indication of the behavior of Hg in this environment (Ozerova, 1971, Ozerova et al., 1975; Sinclair, 1977; Ryall, 1981) then the degree of secondary dispersion should be affected by diagenetic, metamorphic, and structural evolution of these deposits enhanced by the porosity and permeability of the host lithotypes.

Lithogeochemical techniques are valuable tools in exploration for many massive sulphide deposits, particularly for deeply buried systems. The standard lithogeochemical techniques identify primary alteration zones directly associated with the formation of deposits, although lithogeochemical exploration techniques do not generally discriminate whether a dispersion halo anomaly is primary, secondary (diagenetic and metamorphic), and tertiary (post uplift). However, like surfical methods, various extraction methods or differential thermal analysis can potentially discriminate primary halos from a secondary and tertiary dispersion halo. Regardless of the anomaly, the dispersion halos are useful for deep exploration because they can extend well beyond any noticeable primary alteration system. However, the detailed Hg systematics and thresholds are different in many deposits from various host rocks, but need to be known so that Hg exploration vectors and gradients can be used practically. The controls imposed by various lithotypes on background Hg contents, fixation of secondary Hg mobilized after deposition of massive sulphide deposits, and the timing of the secondary dispersion and later processes, are not well understood. In addition to the total analysis technique for Hg and numerous other elements (to ascertain the host phases for Hg and controls on Hg abundance in the rock), various partial extraction and step heating volatilization techniques could be used in order to determine the nature of the loosely bound Hg and other elements in some of the host lithotypes (cf. Goodfellow, 1975; Goodfellow and Wahl, 1976; Gandhi, 1978).

In particular, the detailed study of Boldy (1981) in the Noranda Camp (Fig. 1) highlights the potential of Hg in lithogeochemical vectoring in certain massive sulphide districts. In the Kuroko District as well, there are significant Hg anomalies evident in both the hanging wall (extensive) and footwall (limited) sequences, although admittedly these studies lack the statistical rigor of most geochemical studies. From the few studies in the Bathurst Mining Camp, the background values for Hg range from 20 to 50 ppb within the footwall, which are anomalous at those levels in volcanic rocks, and hanging wall anomalies typically on the order of 200 to 2000 ppb. Although the geometry is complexly folded in the footwall in particular at Brunswick No. 12, the magnitude of the Hg variations in the footwall and hanging wall (Goodfellow, 1975; Fig. 3) are impressive, but even more so in that alteration in the hanging wall since the alteration is cryptic relative to the footwall (see also Lentz and Goodfellow, 1993b). However, there are no major Hg anomalies in the Caribou hanging wall (Goodfellow 2003).

Previous studies have indicated that metamorphic grade influences the distribution and magnitude of Hg anomalies around mineral deposits, although to variable degrees (Ozerova, 1971; Ozerova et al., 1975; Ryall, 1981). In general, increasing metamorphic grade tends to reduce the magnitude of Hg anomalies near the deposit at least and distribute it in the various host lithologies, probably related to metamorphic devolatilization-

Table 4. Averages for selected ore-forming elements in average Continental Crust (red/upper) & Shale (blue/lower) (Mason, 1982; Wedepohl, 1995).

Ag (0.070 ppm) Ag (0.070 ppm)	Bi (0.085 ppm) Bi (0.4 ppm)	Sb (0.3 ppm) Sb (1.5 ppm)
As (1.7 ppm) As (13 ppm)	Cd (0.10 ppm) Cd (0.30 ppm)	Se (0.12 ppm) Se (0.6 ppm)
Au (2.5 ppb) Au (3 ppb)	Hg (40 ppb) Hg (400 ppb)	Te (5 ppb) Te (<10 ppb)
B (11 ppm) B (100 ppm)	Mo (1.1 ppm) Mo (2.6 ppm)	W (1.0 ppm) W (1.8 ppm)

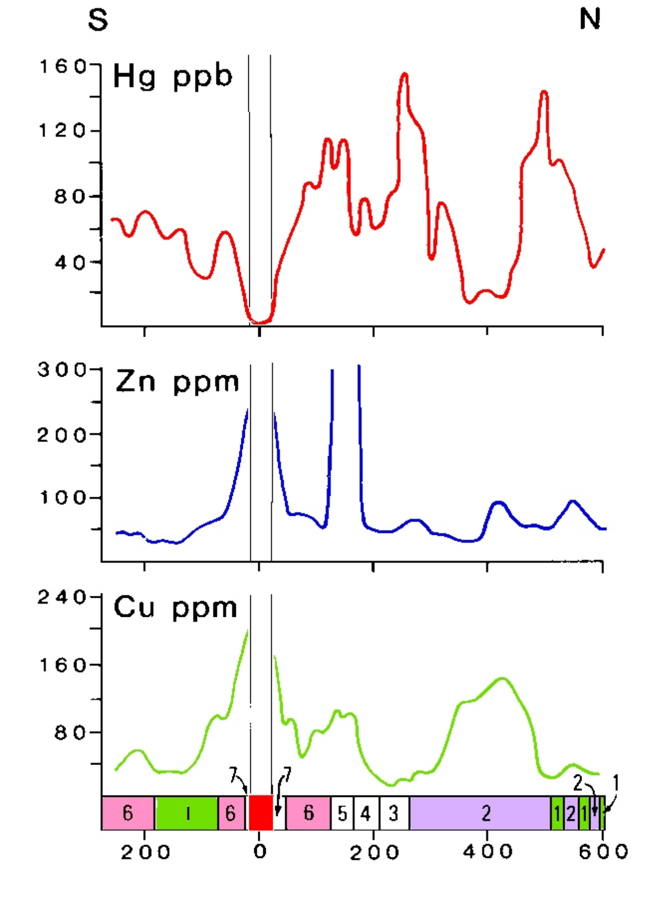

Fig. 4. Distribution of Hg, with Zn and Cu, in a section through the Fox Zn-Cu massive sulphide deposit, northern Manitoba (modified after Turek et al., 1976). The numbers refer to units identified in the section. 1 – mafic intrusion (quartz hornblende gneiss), 2 – andesite (amphibolite), 3 – and 4 – coarse metasedimentary rocks (paragneiss), 5 – argillite (paragneiss), 6 – quartz-bearing ferromagnesian gneiss, 7 – alteration zone (quartz mica (amphibole) gneiss.

dehydration reactions (see Shaw et al., 1986). This may explain why deposits in high-grade metamorphic terranes, like the Paleoproterozoic Fox massive sulphide deposit in northern Manitoba (Turek et al., 1976; Fig. 4), do not show significant or predictable Hg anomalies around the deposit that can be used for exploration; in fact just the opposite trend is observed. This is, in part, a function of the minerals that Hg is associated with in both the primary and secondary dispersion halo and the degree to which the sulphides retain their primary Hg contents during deformation and metamorphism. For example, the variation in sphalerite composition in the presence of compositionally changing pyrrhotite is an obvious critical factor. The multiple valence states of mercury (native, mercurous - Hg^{1+}, and mercuric - Hg^{2+}) indicate that redox behaviour is also an important factor in various reactions. Not surprisingly, the redox states of fluids and rocks affect Hg mobility and therefore, lithologies with different redox characteristics can affect Hg solubility. There are numerous types of primary substitutions that control the distribution of Hg between coexisting sulphide minerals, which can explain the overall primary dispersion halo but, the secondary dispersion halo, which may be formed during or after the diagenesis of the deposit system, will be composed of Hg within sulphide phases, as well as numerous other less stable phases or gases fixed in the host rock (cf. Tunell, 1969). Koksoy and Bradshaw (1969), Watling et al. (1973), Ryall (1981), and Aftabi and Azzaria (1983) have used differential heating and chemical extraction methods to identify various types of Hg compounds that are associated with mineral deposits. For the most part, similar techniques should be used to identify the types and styles of Hg dispersion [Hg, $HgCl_2$, HgS, $Fe(Hg)S_2$, Zn(Hg)S, etc.], so that the optimal sample preparation and extraction techniques are used in exploration and ultimately the data is interpreted correctly.

The Bathurst Mining Camp deposits, for example, have been characterized by Jambor (1979) as proximal autochthonous deposits that are structurally upright (structural and stratigraphic hanging wall are the same), which is obviously an important consideration in exploration. Considering the intensity and complexity of deformation in the Bathurst Mining Camp, gaseous Hg fixed in the primary and secondary dispersion halo should be volatilized from the host rocks. Mercury hosted in discrete sulphide phases in the alteration envelope will survive some of the redistribution, although metamorphically recrystallized and remobilized sulphides may have liberated Hg in various forms that can be fixed as sulphides around the deposit. Remobilization (post Acadian uplift) of Hg can also occur in response to ground water movement that may be enhanced by the electrical potential field that could be generated around a large conducting sulphide body (cf. Govett et al., 1976). These late surface-related (tertiary) processes would be the only mechanism for forming gaseous or native Hg compounds around the deposits considering the relative stability fields of these species. Determination of the proportions of these compounds compared to Hg fixed in sulphides of primary and secondary origin should be done by cold and weak acid extractable methods (Goodfellow and Wahl, 1976), as well as step heating extraction techniques with comparisons to conventional whole-rock complete digestion analysis techniques.

The Hg content of the ore deposits themselves is a key factor in the secondary and tertiary dispersion of Hg from a deposit and also reflects the overall abundance of Hg in the original ore-forming system. Although it is not absolutely critical that a deposit have high Hg contents to be effective as an exploration tool, it definitely helps. Knowing the general magnitude of those possible **E**nrichment **F**actors, it means that it is important to know the abundances in possible ores being sought. Until the work of Goodfellow and McCutcheon (2003), there was very limited data in the published literature on the Hg content of ores in the Bathurst Mining Camp as an example, with average data on mill feeds from Brunswick No. 12 (9 ppm; Petruk and Schnarr, 1981) and Heath Steele (< 4 ppm; Chen and Petruk, 1980), as well as its distribution in various concentrates. Goodfellow and McCutcheon (2003) note that the Hg contents of the deposits along the Brunswick horizon (5.3 ± 6.4 ppm) and Caribou Horizon (8.7 ± 15.2) correlate strongly with Cd, Zn, Pb, and Sb; it is important to note that the deposits on the Caribou Horizon are generally at a lower metamorphic grade (lower greenschist) versus the Brunswick Horizon deposits (upper greenschist), which is reflected in the sulphide textures preserved in the Caribou deposits. Petruk and Schnarr (1981) determined that 35% of the Hg is tied up in sphalerite with an average of 18 ppm Hg, similar to analyses determined by Jonasson and Sangster (1974). However, the Hg content of ores in the Bathurst Mining Camp seems to be quite variable, if Hg contents of sphalerites from other Bathurst Mining Camp deposits (Jonasson and Sangster, 1974) is any reflection of the bulk Hg contents. The bedded pyritic zones have very low Hg (7 ± 8 ppb) relative to the Cu-rich vent complex ores (1.1 ± 1.9 ppm), and the Zn-Pb-Ag-rich bedded ores (9.7 ± 16.4 ppm). It is known from the lithogeochemical case studies of the Caribou and Brunswick deposits that Hg distribution is irregular, but definitely anomalous in the stratigraphic hanging wall to these deposits, as well as weakly anomalous in the footwall of the Brunswick No. 12 deposit. In the past, the irregularity of Hg geochemical anomalies in this setting has been viewed with skepticism and thus not commonly used in routine lithogeochemical analysis. However at Heath Steele, Lentz et al. (1997) noted that Hg and Sb were enriched in the hanging wall and footwall as well. It has been noted that some of the trace-metal anomalies in the Bathurst Mining Camp have been affected by diagenesis and metamorphism (Whitehead and Govett, 1974; Lentz, 1996, 1999).

Conclusions

The purpose of this review was to reacquaint explorationists to the detailed Hg geochemical research in the past. Too often older techniques in mineral exploration are overlooked as new techniques are developed and tested or when new analytical technologies are developed that increase the robustness and cost effectiveness of the earlier methods. The development and refining of the Direct Combustion CV-AAS analysis system for Hg determinations as described above and in the quoted publications is potentially one of these techniques that should be re-examined as a practical exploration tools in a range of mineral exploration applications including lithogeochemical ones. The **E**nrichment **F**actors for Hg associated with various deposit systems is quite variable, but overall it is anomalous in many ore deposit types. As in the detailed studies associated with surfical media, further research is evidently needed to understand the processes of forming primary and secondary distribution halos around these ore deposits in order to use the Hg lithogeochemical techniques most effectively. Baseline studies also need to be undertaken to ascertain the background distributions of metals like Hg in the host rocks, as well as the potential ores, in regions where no studies have been done for the same reason. In the case studies of massive sulphide systems reviewed, it is obvious that complications associated with the structural-metamorphic history will modify the interpretation of any halos identified, although these processes may have added an element, to pardon the pun, of complexity to the host rock environment that may actually aid exploration for these deposits.

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REFERENCES

Aftabi, A. & Azzaria, L.M., 1983. Distribution of mercury compounds in ore and host rocks at Sigma gold mine Val d'Or, Quebec, Canada. Journal of Geochemical Exploration, v. 19, p. 447-464.

Akright, R.L., Radke, A.S., & Grimes, D.J., 1969. Minor elements as guides to gold in the Roberts Mountain Formation, Carlin Gold Mine, Eureka County, Nevada. Colorado School of Mines Quarterly, v. 64, p. 49-66.

Alltschuller, Z.S., 1980. The geochemistry of trace elements in marine phosphorites. GERM database (on-line).

Azzaria, L.M., 1967. A method for determining trace mercury in geologic materials. Geological Survey of Canada Paper 66-54, p. 13-26.

Azzaria, L.M. & André Carrier, J., 1976. Mercury in rocks as a possible ore guide, Gaspé copper mines property, Murdochville, Quebec, Canada. Journal of Geochemical Exploration, v. 6, p. 331-344.

Azzaria, L.M. & Webber, G.R., 1969. Mercury analysis in geochemical exploration. Canadian Institute of Mining and Metallurgy Bulletin, v. 62, No. 685, p. 521-530.

Barnes, H.L. & Seward, T.M., 1997. Geothermal systems and mercury deposits, *in* Barnes, H.L., ed., Geochemistry of Hydrothermal Ore Deposits, Third Edition. John Wiley and Sons, Inc., p. 699-736.

Barringer, A.R., 1966. Interference-free spectrometer for high-sensitivity mercury analysis of soils, rocks and air. Transactions of the Institute of Mining and Metallurgy, Section B, v. 75, p. 120-124.

Berger, B.R. & Silberman, M.L., 1985. Relationships of trace-element patterns to geology in hot-spring-type precious-metal deposits, *in* Berger, B.R. and Bethke, P.M. eds., Geology and Geochemistry of Epithermal Systems, Reviews in Economic Geology, v. 2, p. 233-247.

Bingqiu, Z., Jinmao, Z., Lixin, Zhu, & Yaxin, Z., 1986. Mercury, arsenic, antimony, bismuth and boron as geochemical indicators for geothermal areas. Journal of Geochemical Exploration, v. 25, p.379-388.

Boldy, J., 1979. Exploration discoveries, Noranda district, Quebec. (Case History of a Mining Camp), *in* Hood, P.J., ed., Geophysics and Geochemistry in the Search for Metallic Ores, Geological Survey of Canada Economic Geology Report 31, p. 593-603.

Boldy, J., 1981. Prospecting for deep volcanogenic ore. Canadian Institute of Mining and Metallurgy Bulletin, v. 74, No. 834, p. 55-65.

Boyle, R.W., 1979. The Geochemistry of Gold and its Deposits. Geological Survey of Canada Bulletin 280, 584 p.

Carr, G.R., Wilmshurst, J.R., & Ryall, W.R., 1986. Mercury as a pathfinder in exploration geochemistry – case history studies. Journal of Geochemical Exploration, v. 22, p. 353-354.

Chen, T.T. & Petruk, W., 1980. Mineralogy and characteristics that affect recoveries of metals and trace elements from the ore at Heath Steele Mines, New Brunswick. Canadian Institute of Mining and Metallurgy Bulletin, v. 73, p. 167-178.

Dall'Aglio, M., 1971. Comparison between hydrogeochemical and stream sediment methods in prospecting for mercury, *in* Geochemical Exploration, CIM Special Volume 11, p. 126-131.

Dickson, F.W., 1968. The origin of mercury haloes. International Geological Congress, 23rd, Prague, v. 7, p. 357-365.

Erickson, R.L., Marranzino, A.P., Oda, U., & James, W.W., 1964. Geochemical exploration near the Getchell Mine, Humboldt County, Nevada. U.S. Geological Survey Bulletin 1198A, 26 p.

Ewers, G.R. & Keays, R.R., 1977. Volatile and precious metal zoning in the Broadlands geothermal field, New Zealand. Economic Geology, v. 72, p. 1337-1354.

Fedikow, M.A.F. & Amor, S.D., 1990. Evaluation of a mercury-vapour detection system in base- and precious-metal exploration, northern Manitoba. Journal of Geochemical Exploration, v. 38, p. 351-374.

Fengchi, C. & Guolian, H., 1989. A case history of finding ore deposits by mercury gas survey. Journal of Geochemical Exploration, v. 33, p. 145-153.

Fletcher, W.K., 1981. Analytical methods in geochemical prospecting, Govett,

G.J.S., ed., Analytical Methods in Geochemical Prospecting, Handbook of Exploration Geochemistry, v. 1, Elsevier, New York, 255 p.
Fleisher, M., 1970. Summary of the literature on the inorganic chemistry of mercury. U.S. Geological Survey Professional Paper 713, p. 6-13.
Friedrich, G.H. & Hawkes, H.E., 1966a. Mercury dispersion halos as ore guides for massive sulphide deposits, West Shasta district, California. Mineralium Deposita, v. 2, p. 77-88.
Friedrich, G.H. & Hawkes, H.E., 1966b. Mercury as an ore guide in the Pachuca-Real del Monte district, Hidalgo, Mexico. Economic Geology, v. 61, p. 744-753.
Fursov, V.Z., 1958. Halos of dispersed mercury as prospecting guides at Achisai lead-zinc deposits. Geokhimica, No. 3, p. 338-344.
Fursov, V.Z., 1990. Mecury vapor surveys: technique and results. Journal of Geochemical Exploration, v. 38, p. 145-155.
Gandhi, S.M., 1978. Exploration Rock Geochemical Studies in and around the Caribou sulphide deposit, New Brunswick, Canada. Unpublished Ph.D. thesis, University of New Brunswick, Fredericton, New Brunswick, 316 p.
Gao, S., Luo, T.-C., Zhang, B.-R., Zhang, H.-F., Han, Y.-W., Zhao, Z.-D., & Hu, Y.-K., 1998. Chemical composition of the continental crust as revealed by studies in East China. Geochimica et Cosmochimica Acta, v. 62, p. 1959-1975.
Garrett, R.G., 1974. Mercury in some granitoid rocks of the Yukon and its relation to gold-tungsten mineralization. Journal of Geochemical Exploration, v. 3, p. 277-290.
Goodfellow, W.D., 1975. Rock geochemical exploration and ore genesis at Brunswick No. 12 massive sulphide deposit, N.B. Unpublished Ph.D. thesis, University of New Brunswick, Fredericton, New Brunswick, 411 p.
Goodfellow, 2003. Geology and genesis of the Caribou Deposit, Bathurst Mining Camp, New Brunswick – A synthesis, *in* Goodfellow, W.D., McCutcheon, S.R., and Peter, J., eds., Massive Sulphide Deposits in the Bathurst Mining Camp, New Brunswick and Northern Maine, Economic Geology Monograph 11, p. 245-302.
Goodfellow, W.D. & McCutcheon, S.R., 2003. Geologic and genetic attributes of volcanic sediment-hosted massive sulfide deposits of the Bathurst Mining Camp, northern New Brunswick – A synthesis, *in* Goodfellow, W.D., McCutcheon, S.R., and Peter, J., eds., Massive Sulphide Deposits in the Bathurst Mining Camp, New Brunswick and Northern Maine, Economic Geology Monograph 11, p. 303-326.
Goodfellow, W.D. & Wahl, J.L., 1976. Water extracts of volcanic rocks - detection of anomalous halos at Brunswick No. 12 and Heath Steele B-zone massive sulphide deposits. Journal of Geochemical Exploration, v. 6, p. 35-59.
Govett, G.J.S., 1983. Rock geochemistry in Mineral Exploration, Govett, G.J.S., ed., Handbook of Exploration Geochemistry, v. 3, Elsevier, New York, 461 p.
Govett, G.J.S., Goodfellow, W.D., & Whitehead, R.E.S., 1976. Experimental aqueous dispersion of elements around sulfides. Economic Geology, v. 71, p. 925-940.
Govinaraju, K., 1994. Compilation of working values and description for 383 geostandards. Geostandards Newsletter, v. 18, 158 p.
Hall, G.E.M., 1998. Analytical perspective on trace element species of interest in exploration. Journal of Geochemical Exploration, v. 61, p. 1-19.
Hall, G.E.M., 2005. Methods for sampling and analysis of geological materials for both total mercury and sequential extraction, *in* Parsons, M. & Percival, J.B., eds., Mercury: Sources, Measurements, Cycles and Effects. Mineralogical Association of Canada Short Course 34, p. 57-78 p.
Hall, G.E.M. & Pelchat, R., 2005. The design and application of sequential extractions for mercury, Part 2. Resorption of mercury onto the sample during leaching. Geochemistry: Exploration, Environment, Analysis, v. 5, p. 115-121.
Hall, G. & Pelchat, P., 1997. Evaluation of a Direct Solid Sampling Atomic Absorption Spectrometer for the Trace Determination of Mercury in Geological Samples. Analyst, v. 122, p. 921-924.
Hall, G.E.M., Pelchat, R., & Percival, J.B., 2005. The design and application of sequential extractions for mercury, Part 1. Optimization of HNO_3 extraction for all non-sulphide forms of Hg. Geochemistry: Exploration, Environment, Analysis, v. 5, p. 107-113.
Hawkes, H.E. & Williston, S.H., 1962. Mercury vapour as a guide to lead-zinc-silver deposits. Mining Congress, v. 48,p. 30-33.
Jambor, J. L., 1979. Mineralogical evaluation of proximal-distal features in New Brunswick massive-sulphide deposits. Canadian Mineralogist, v. 17, p. 649-664.
Jonasson, I.R. & Boyle, R.W., 1972. Geochemistry of Hg and origins of natural contamination of the environment. Canadian Institute of Mining and Metallurgy Bulletin, v. 75, p. 32-39.
Jonasson, I.R., Lynch, J.J.. & Trip, L.J., 1973. Field and laboratory methods used by the Geological Survey of Canada in Geochemical Surveys No. 12; Mercury in Ores, Rocks, Soils, sediments and water. Geological Survey of Canada Paper 73-21, 22 p.
Jonasson, I.R. & Sangster, D.F., 1974. Variations in the mercury content of sphalerite from some Canadian sulphide deposits, *in* Elliot, J.L. and Fletcher, W.K., eds., Geochemical Exploration 1974, Association of Exploration Geochemistry Special Publication No. 2, Elsevier, Amsterdam, p. 313-332.
Köksoy, M. & Bradshaw, P.M.D., 1969. Secondary dispersion of mercury from cinnabar and stibnite deposits, West Turkey. Colorado School of Mines Quarterly, v. 64, p. 333-356.
Köksoy, M., Bradshaw, P.M.D., & Tooms, J.S., 1969. Notes on the determination of mercury in geological samples. Institute of Mining and Metallurgy Transactions, v. 76, p. B121-124.
Lahti, H.R. & Govett, G.J.S., 1981. Primary and secondary halos in weathered and oxidized rocks – an exploration study from Mykonos. Journal of Geochemical Exploration, v. 16, p. 27-40.
Lentz, D.R., 1996. Recent advances in lithogeochemical exploration for massive-sulphide deposits in volcano-sedimentary environments: petrogenetic, chemostratigraphic, and alteration aspects with examples from the Bathurst Camp, New Brunswick, *in* Carroll, B.M.W., Current Research 1995. New Brunswick Department of Natural Resources and Energy Division, Mineral Resource Report 96-1, p. 73-119.
Lentz, D.R. 1999. Deformation-induced mass transfer in felsic volcanic rocks hosting the Brunswick No. 6 massive-sulfide deposit: geochemical effects and petrogenetic implications. Canadian Mineralogist, v. 37, p. 489-512.
Lentz, D. & Goodfellow, W.D., 1993a. Mineralogy and petrology of the stringer sulphide zone in the Discovery Hole at the Brunswick No. 12 massive sulphide deposit, Bathurst, New Brunswick. Geological Survey of Canada Paper 93-1E, p. 249-258.
Lentz, D.R. & Goodfellow, W.D., 1993b. Geochemistry of the stringer sulphide zone from the Discovery Hole at the Brunswick No. 12 massive sulphide deposit, Bathurst, New Brunswick. Geological Survey of Canada, Paper 93-1E, p. 259-269.
Lentz, D.R., Hall, D.C., & Hoy, L.D., 1997. Chemostratigraphy, alteration, and oxygen isotope trends in a drillhole profile through the Heath Steele B Zone deposit stratigraphic sequence, New Brunswick. Canadian Mineralogist, v. 35, p. 841-874.
Li, Y.H., 1982. A brief discussion on the mean oceanic residence time of elements. Geochimica et Cosmochimica Acta, v. 46, p. 2,671-2,675.
Lovering, T.G., Lakin, H.W., & McCarthy, J.H., 1966. Tellurium and mercury in jasperoid samples. U.S. Geological Survey Professional Paper 550-B, p. 138-141.
Mason, B., 1982. Principles of Geochemistry. John Wiley and Sons Limited, New York, 329 p.
McCarthy, J.H. Jr., Vaughn, W.W., Learned, R.E., & Meuschke, J.L., 1969. Mercury in soil gas and air - a potential tool in mineral exploration. U.S. Geological Survey Circular 609, 16 p.
McNerney, J.J. & Buseck, P.R., 1973. Geochemical exploration using mercury vapor. Economic Geology, v. 68, p. 1313-1320.
Nelson, C.E., 1990. Comparative geochemistry of jasperoids from Carlin-type gold deposits of the western United States. Journal of Geochemical Exploration, v. 36, p. 171-195.
Olade, M.A. & Fletcher, W.K., 1976. Trace element geochemistry of the Highland Valley and Guichon Creek Batholith in relation to porphyry copper mineralization. Economic Geology, v. 71, p. 733-748.
Ozerova, N.A., 1959. The use of primary dispersion halos of mercury in the search for lead-zinc deposits. Geokhimica., v. 7, p. 793-802.
Ozerova, N.A., 1971. Primary dispersion haloes of mercury. International Geology Review, v. 13, p. 1-108.
Ozerova, N.A., Rusinov, V.L., & Ozerov, Y.K., 1975. The mercury in sulfide deposits emplaced in volcanic suites. Mineralium Deposita, v. 10, p. 228-233.
Parsons, M. & Percival, J.B., eds., 2005. Mercury: Sources, Measurements, Cycles and Effects. Mineralogical Association of Canada Short Course, v. 34, 320 p.
Petruk, W. & Schnarr, J.R., 1981. An evaluation of the recovery of free and unliberated mineral grains, metals and trace elements in the concentrator of Bruns-

wick Mining and Smelting Corp. Ltd. Canadian Institute of Mining and Metallurgy Bulletin, 74, no. 833, p. 132-159.
Polikarpochkin, V.V., Kitaev, V.A., & Sarapulova, V.N., 1965. Structure and vertical zonation of the primary dispersion aureoles at the Baley gold deposits. Geochemistry International, v. 12, p. 741-753.
Rassmussen, P.E., Friske, P.W.B., Azzaria, L.M., & Garrett, R.G., 1998. Mercury in the Canadian Environment: Current Research Challenges. Geoscience Canada, v. 25, p. 1-13.
Rose, A.W., Hawkes, H.E., & Webb, J.S., 1979. Geochemistry in Mineral Exploration. Second edition. Academic Press, Toronto, 657 p.
Ryall, W.R., 1979a. Mercury in the Broken Hill (NSW, Australia) lead-zinc-silver lodes. Journal of Geochemical Exploration, v. 11, p. 175-194.
Ryall, W.R., 1979b. Mercury distribution in the Woodlawn massive sulfide deposit, New South Wales. Economic Geology, v. 74, p. 1471-1484.
Ryall, W.R., 1981. The forms of mercury in some Australian stratiform Pb-Zn-Ag deposits of different regional metamorphic grades. Mineralium Deposita, v. 16, p. 425-435.
Ryall, W.R., Scott, K.M., Taylor, G.F., & Moore, G.P., 1981. Mercury in stratabound copper mineralization in the Mammoth area, northwest Queensland. Journal of Geochemical Exploration, v. 16, p. 1-11.
Rytuba, J.J., 2003. Mercury from mineral deposits and potential environmental impact. Environmental Geology, v. 43, p. 326-338.
Saukov, A.A., 1946. Geochemistry of mercury. Akad. Nauk. USSR. Inst Geol. Nauk., No. 78, Ser. 17, p. 129.
Sears, W.P., 1971. Mercury in base metal and gold ores of the Province of Quebec. Canadian Institute of Mining and Metallurgy, v. 11, p. 384-390.
Shaw, D.M., Cramer, J.J., Higgins, M.D., & Truscott, M.G., 1986. Composition of the Canadian Precambrian shield and the continental crust of the Earth, *in* Dawson, J.D., Carswell, D.A., Hall, J., and Wedepohl, K.H., eds., The nature of the lower continental crust, Geological Society of London, Special Publication 24, p. 275-282.
Shiikawa, M., 1983. The role of mercury, arsenic and boron as pathfinder elements in geochemical exploration for geothermal energy. Journal of Geochemical Exploration, v. 19, p. 337-338.
Silberman, M.L. & Berger, B.R., 1985. Relationship of trace-element patterns to alteration and morphology in epithermal precious-metal deposits, *in* Berger, B.R. and Bethke, P.M., eds., Geology and Geochemistry of Epithermal Systems. Reviews in Economic Geology, v. 2, p. 203-232.
Sinclair, I.G.L., 1977. Primary dispersion patterns associated with the Detour zinc-copper-silver deposit at Lac Brouillan, Province of Quebec, Canada. Journal of Geochemical Exploration, v. 8, p. 139-151.
Takeuchi, T., Momose, H., & Mitsuta, S., 1970. Study of mercury halo method for the prospecting of black ore deposits. Journal of Mining and Metallurgy Institute of Japan, v. 86, p. 409-412.
Theodore, T.G. & Nash, J.T., 1973. Geochemical and fluid zonation at Copper Canyon, Lander County, Nevada. Economic Geology, v. 68, p. 565-570.
Tono, N., 1974. Minor elements distribution around Kuroko deposits in northern Akita, Japan, *in* Ishihara, S., ed., Geology of Kuroko Deposits, Society of Mining Geology of Japan, Mining Geology Special Issue 6, p. 399-420.
Trost, P.B. & Bisque, R.E., 1971. Differentiation of vapourous and ionic mercury in soils, *in* Geochemical Exploration, CIM Special Volume 11, p. 276-278.
Tunell, G., 1969. Mercury Section B to M, *in* Wedepohl, K.H, ed., Handbook of Geochemistry, Springer-Verlag, Berlin, p. 80-B-1 - 80-M-5.
Turek, A., Tetley, N.W., & Jackson, T., 1976. A study of metal dispersion around the Fox orebody in Manitoba. Canadian Institute of Mining and Metallurgy Bulletin, v. 69, No. 770, p. 104-110.
Van Loon, J.C. & Barefoot, R.R., 1989. Analytical Methods for Geochemical Exploration. Academic Press, Incorporated, New York, 344 p.
Vaughn, W.W., 1967. A simple mercury vapour detector for geochemical prospecting. U.S. Geological Survey Circular 540, 8 p.
Warren, H.V., Delavault, R.E., & Barakso, J., 1966. Some observations on the geochemistry of mercury as applied to prospecting. Economic Geology, v. 61, p. 1010-1028.
Watling, R.J., Davis, G.R., & Meyer, W.T., 1973. Trace identification of mercury compounds as a guide to sulphide mineralization at Keel, Eire, *in* Jones, M.J., Geochemical Exploration 1972, Institute of Mining and Metallurgy Bulletin, p. 59-69.
Wedepohl, K.H., 1995. The composition of the continental crust. Geochimica et Cosmochimica Acta, v. 59, p. 1217-1239.
Wells, J.B., Stoiser, L.R., & Elliott, J.E., 1969. Geology and geochemistry of the Cortez gold deposit, Nevada. Economic Geology, v. 64, p. 526-537.
Whitehead, R.E.S. & Govett, G.J.S., 1974. Exploration rock geochemistry – detection of trace metal halos at Heath Steele Mines by discriminant analysis. Journal of Geochemical Exploration, v. 3, p. 371-386.
Wilmshurst, J.R. & Ryall, W.R., 1980. Sirosorb: A collector for use in the determination of mercury in geochemical samples. Journal of Geochemical Exploration, v. 13, p. 1-7.
You, Y. & Li, X., 1990. Research and application of soil-gas mercury surveys for locating deep uranium orebodies. Journal of Geochemical Exploration, v. 38, p. 133-143.

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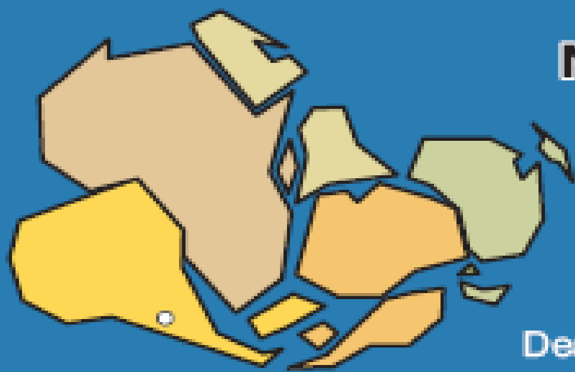

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SYMPOSIA THEMES:

From Rodinia to Gondwana: global reconstructions
Gondwana palaeogeography and palaeoclimate
Western Gondwana -The ties that bind
Neoproterozoic evolution of the biosphere and the Cambrian explosion
Gondwana margins: (a) - Proterozoic and Early Palaeozoic,
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Gondwana basins: sedimentary record, high resolution stratigraphy, correlations and tectonics
Palaeozoic biota: biogeography and diversity patterns
Gondwana break-up: magmatism and geodynamics
Mesozoic marine biota: evolution and palaeobiogeography
Mesozoic continental biota: evolution and palaeobiogeography

Information: gondwana@cig.museo.unlp.edu.ar
http://cig.museo.unlp.edu.ar/gondwana/

Memoriam - Joe Brummer

On January 17, 2005 the world of Applied Geochemistry lost a strong supporter and good friend.

Johannes Jacobus (Joe) Brummer was born in Graaff Reinet, Cape Province, South Africa on September 2, 1921. He was an economic geologist (although he would frequently refer to himself as just a prospector). He obtained degrees in mining engineering (1943) and mining geology (1945) from Witwatersrand University, South Africa and his doctorate from McGill University (1955), Montreal.

Joe was probably one of the most successful mine finders ever. He was responsible for finding Cu mines in Zambia, Ni and Cu-Zn deposits in Manitoba as well as Zn and U deposits in Saskatchewan.

His early work as a geologist in Zambia between 1947 and 1953 on the Zambian Copper belt is well known. He created with W.G. Garlick the unconformity/strata bound model for The Copper Belt contrary to the commonly held notion at that time that there orebodies were hydrothermal.

Subsequently his findings were successfully applied to the discovery of new deposits along the belt. During this same period, less well known but just as significant, was Joe's support of exploration geochemistry research at a time when the western world was just learning about the subject. Most geochemists who graduated from the Royal School of Mines during that time were guided and supported by Joe Brummer in the application of geochemistry to mine finding in the Zambian Copper belt. Subsequently such discoveries as the deeply buried Kalengwa Mine (see World mining, June 1972) would be found using geochemical techniques developed under Joe's tutorship.

With the background in sedimentary ore deposits he arrived at McGill University in 1953 to pursue his PhD and to study and research the Gaspé Copper ore bodies. He mapped and described for the first time the alteration aureole about the deposits and classified the Aiguilles Mountain ores as replacement deposits and the Copper Mountain zones as a later staged porphyry-type ore body. To this day the study is still the bible for exploration geologists searching for these deposits in the Appalachians.

While employed by Kennco Explorations Ltd. (1955-61) he initiated the first reconnaissance geochemical stream sediment surveys in the Cordillera and he carried out the first-geochemical stream sediment survey in the Canadian Shield, (Seal Lake). In reporting on the latter J.J. Brummer (CIM Bull., April 1960) remarked ***"The project, which was primarily aimed at evaluating the copper potential of the area, had, by the use of geochemistry, finished up discovering lead, zinc, thorium and columbium mineralization".*** The Cordillera studies were also successful in indicating the presence of a variety of mineralized areas and occurrences (e.g. Huckleberry, Galore Creek, Sam Goodly). In addition to the above geochemical work Joe found time to study and publish on the copper-uranium mineralization in the Carboniferous sandstones of Nova Scotia.

By his bold, aggressive and at all time unconventional approach to mineral exploration Joe laid the ground work for systematic reconnaissance geochemical surveys in Canada. The subsequent impact of the exploration tool on economic geology is well known.

His record of success continued after he joined Falconbridge Nickel Mines Ltd. (1961-70). He applied geological concepts, geophysical methods (E-M and seismic) and deep drilling techniques to the Manitoba Nickel Belt, which resulted in the discovery of such nickel deposits as Manibridge, Bowden Lake and Bucke Lake. At Stall Lake, Manitoba, he and his team succeeded where others had failed, they found the down plunge extension of the Rod Cu-Zn deposit. Also, in Saskatchewan, Joe successfully applied boulder tracing and a study of the Pleistocene geology to locate the geology to locate the George Lake zinc occurrence.

In 1970 he joined Canadian Occidental Petroleum and headed up their mineral division. In 1976 he was responsible for the first reconnaissance Alphameter survey carried out in the Athabasca uranium province. In 1979 under his leadership a vertical drill hole through the center of an Alphameter-EM anomaly intersected ore grade uranium mineralization beneath 162 meters of Athabasca sandstone – the McClean Lake uranium mine was born.

Joe's superb record of discoveries did not come about by chance. They resulted because he was a knowledgeable economic geologist with extensive experience and interest in many commodities. He was willing to try the untried, to encourage and support applied research in mineral exploration, to be straightforward in his approach, to use every aid at hand, to act quickly and to be very supportive of his geological staff. He was thorough in his research and exploration efforts. He led in the development and applications of new or relatively untried techniques especially in the search for deeply buried deposits and the evaluation of mineral belts.

Unlike many mineral exploration geologists he managed to publish accounts fo much of his work and has authored or co authored 41 papers dealing with a variety of subjects including: mineral deposits geology, geochemical exploration, diamond exploration; gemology, as well as review papers on exploration geochemistry in Canada and diamonds in Canada.

He was the recipient of the Barlow Gold Medal (CIM) in 1978 and in 1984 the GAC awarded him the Duncan R. Derry medal for his major contributions to economic geology.

Not only was Joe and explorationist par excellence he was also a sincere, honest and forthright person – his equal will not be soon seen.

Joe leaves his ever loving wife and indispensable partner Eve, as well as his sons Douglas and William and grandchildren Katherine and Nicholas.

God bless you Joe.

February 8, 2005.

Chris Gleeson
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GEOFLUIDS V

Fifth international conference on fluid evolution, migration and interaction in sedimentary basins and orogenic belts

May 17th – 21st, 2006

Windsor, Ontario

Canada

www.geofluids5.org

Call for Papers

The term 'geofluids' means different things to different people; from surface and shallow groundwater topics to deep basinal or metamorphic fluids and from fluids in microscopic inclusions to models of fluid flow on a continental scale. As researchers, we use a wide variety of techniques to investigate geofluids: field observations, laboratory experiments, geophysical, chemical and isotopic techniques, and numerical modeling. The Geofluids conferences incorporate all of the above aspects and more – they are aimed at building bridges between scientific disciplines, at encouraging interdisciplinary and multidisciplinary collaborations, and at encouraging interactions between academia, industry, and government researchers. We hope, at Geofluids V, to provide a forum for the presentation of fundamental, applied, and strategic research into the broad range of geofluids topics being investigated by the international scientific communities.

We invite you to submit extended abstracts for oral or poster presentations at the Geofluids V conference. In order to expedite the submission and reviewing process, we are requesting that extended abstracts be submitted by email to g5abstracts@uwindsor.ca . Please follow the instructions outlined in the guidelines for abstract preparation, available in brief form as part of this circular or in more detailed form on the conference website.

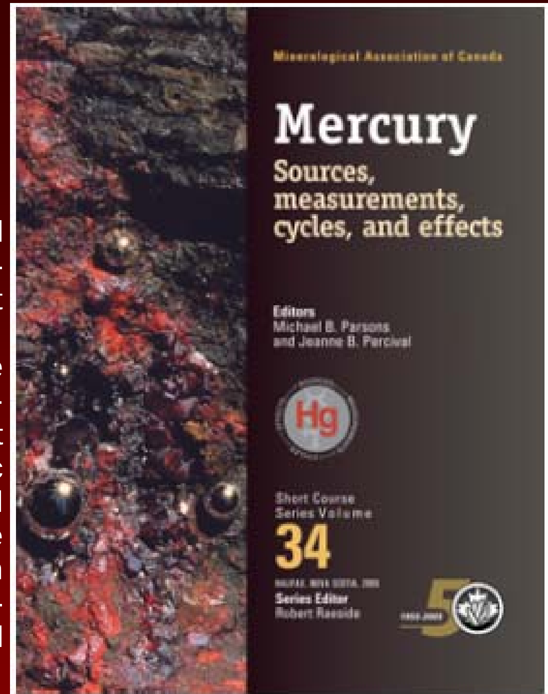
The abstracts and the enclosed abstract form should be submitted before the deadline of August 15th, 2005. Each manuscript will be reviewed by two independent referees. Extended abstracts accepted for oral or poster presentations will be published by Elsevier in the Journal of Geochemical Exploration.

Potential participants are asked to complete the on-line pre-registration form at www.geofluids5.org so that an up-to-date database can be maintained.

NOW AVAILABLE!!

Mercury: Sources, Measurements, Cycles, and Effects

Editors: Michael B. Parsons and Jeanne B. Percival



Mercury (Hg) is of significant human and environmental health concern because of its toxicity and ability to accumulate in fish and wildlife. Levels of mercury in the environment have risen considerably since the onset of industrialization, and even remote locations such as the Canadian Arctic have been adversely affected by the long-range atmospheric transport of mercury. This short course volume discuss the current state-of-knowledge regarding: (1) natural and anthropogenic sources of mercury; (2) sampling protocols and analytical methods; (3) transport and transformation of mercury in the environment; and (4) effects on ecosystems and human health. Most of the material is at a level suitable for senior undergraduate and graduate students and should appeal to all scientists interested in environmental issues.

Price: US$40 (outside Canada), CAN$40 (in Canada)
Mineralogical Association of Canada Member price US$32/CAN$32

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1. A Brief History of Mercury and its Environmental Impact - **Michael B. Parsons and Jeanne B. Percival**
2. Geogenic and Mining Sources of Mercury to the Environment - **Jim Rytuba**
3. Anthropogenic Sources and Global Inventory of Mercury Emissions - **Jozef M. Pacyna and Elisabeth G. Pacyna**
4. Methods for the Sampling and Analysis of Geological Materials for Both Total Mercury and Sequential Extraction - **Gwendy E.M. Hall**
5. Speciation of Inorganic Mercury Associated With Solid Matrices by Thermal Desorption Coupled With ICP-MS - **Julia Y. Lu and D. Conrad Grégoire**
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9. Atmospheric Distribution and Long-Range Transport of Mercury - **Catharine Banic, Pierrette Blanchard, Ashu Dastoor, Hayley Hung, Alexandra Steffen, Rob Tordon, Laurier Poissant & Brian Wiens**
10. Mercury in the Marine Environment - **Gary Gill**
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14. Mercury Management in Canada: Domestic and Global

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For more information, visit www.mineralogicalassociation.ca

MEETINGS, WORKSHOPS, & FIELDTRIPS

- **July 31 - August 5 - Gordon Conference on Inorganic Geochemistry - Metals in Ore-Forming Systems: Sources, Transport, Deposition**, Andover, New Hampshire; http://www.grc..uri.edu/programs/2005/inorgeo.pdf; contact: meyer@erdw.ethz.ch
- **August 8-11 - The Geological Society of America Meeting - Earth System Processes 2**, Calgary, Alberta; http://www.geosociety.org/meetings/esp2/
- **August 20-23 - 8th Biennial SGA Meeting**, Beijing, China; http://www.sga2005.com
- **August 30 - September 13 - Modular Course in Structure, Tectonics, and Mineral Exploration,** Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, Sudbury, Ontario; http://earthsciences.laurentian.ca; contact: blafrance@laurentian.ca
- **September 19-23 - 22nd International Geochemical Exploration Symposium 2005**, Perth Australia; http://www.aeg.org
- **October 16-19 - GSA Annual Meeting and Exposition**, Salt Palace Convention Center, Salt Lake City, Utah; http://www.geosociety.org/meetings/2005/
- **October 28-30 - 55th Annual Atlantic Universities Geological Conference**, St. John's, Newfoundland and Labrador; contact: augc2005@mun.ca
- **November 6-11 - Gondwana 12 - Geological and Biological Heritage of Gondwana**, Mendoza, Argentina; http://cig.museo.unlp.edu.ar/gondwana/; contact: gondwana@cig.museo.unlp.edu.ar
- **November 21-24 - Quebec Exploration 2005**, Chateau Frontenac, Quebec, QC; http://www.QuebecExploration.qc.ca; contact: info@quebecexploration.qc.ca
- **December 8-17 - Modular Course in Exploration Geophysics**, Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, Sudbury, Ontario; http://earthsciences.laurentian.ca; contact: mlesher@laurentian.ca

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- **January 23-23 - 23rd Annual Mineral Exploration Roundup**, Vancouver, British Columbia; http://www.bc-mining-house.com
- **March 5-8 - PDAC 2006 International Convention**, Metro Toronto Convention Centre, Toronto, Ontario; http://www.pdac/conv/index.html
- **April 2-16 - Modular Course in Exploration for Magmatic Ore Deposits**, Mineral Exploration Research Centre, Department of Earth Sciences, Laurentian University, Sudbury, Ontario; http://earthsciences.laurentian.ca; contact: mlesher@laurentian.ca
- **May 14-17 - GAC/MAC Annual Meeting 2006**, Université du Québec, Montreal, Québec; http://www.gacmac2006.ca
- **May 17-21 - Geofluids V**, Department of Earth Sciences, University of Windsor, Windsor, Ontario; http://www.geofluids5.org

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- **May 23-27 - GAC-MAC 2007,** Yellowknife, NWT; http://www.nwtgeoscience.ca/gac_mac/; contact: NTGO@gov.nt.ca

2005 Boldy Award Winners

The Julian Boldy Certificate Award is presented each year to the top three presenters at the MDD session of the GAC-MAC Annual General Meeting. The award is based on the scientific significance and creativity of the individual presentation with respect to mineral deposit research or exploration. This award is supported by an endowment fund provided by Placer Dome in honour of a former exploration manager who was known for his scientific practicality and curiosity. The following presenters were chosen for their outstanding presentations at the GAC-MAC meeting held at Dalhousie University, Halifax, Nova Scotia:

- **Craig Hart-** Classifying, distinguishing and exploring for intrusion-related gold systems
- **Murray Hitzman-** A (r)evolution in mining: implications for exploration
- **Michel Gauthier, S. Trepanier, and S. Gardoll-** Metamorphic isograds: a regional-scale area selection criteria in NE Superior province (Eastern Canadian Shield)

CONGRATULATIONS!!