Newsletter

of the

International Association of GeoChemistry

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Mel Gascoyne, Newsletter Editor

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ASSOCIATION NEWS

IAGC Council "sub-meeting", Sunday, August 10, 2008, Oslo, Norway (during 33rd IGC)

Provisional Minutes (T. Bullen, IAGC Secretary version)

In attendance: Russell Harmon, Clemens Riemann, Thomas Bullen, Yousif Kharaka, Alakendra Roychoudhury, Norbert Clauer, Andrew Parker, ???

The meeting started with introductions around the room. Following are topics discussed:

1. **Status of "Geochemical Training in Developing Countries" working group**. The working group currently consists of one person, and council has decided not to approve rechartering. Roychoudhury will look into identification of other possible chairpersons for the working group and ways to expand the sphere of influence, aimed toward successful rechartering in the future.

2. **Discussion of Applied Geochemistry journal status**: the journal is healthy, although the Impact Factor decreases slightly each year. However, other indicators are good. The journal nets IAGC $40K per year in royalties from Elsevier, which in addition to association dues adds to the coffers each year. This past year, $8-9K was spent out of the IAGC capital fund for the Applied Geochemistry special edition (due out soon) devoted to the Koln Goldschmidt conference.

3. **Committee business**:
Budget audit group: was supposed to review "the books", but this did not work in the recent cycle. A new group is going to be chosen and given a new mandate by council. It was suggested that IAGC statutes be revised to say that council can either appoint this group, or choose to use outside auditors if working within is not successful.

Publications: John Gray is no longer head of committee, Norbert Clauer is the new committee chair. Hitcheon award was made this year.

Nominations: Jan Kramers has been in charge of that committee, task has been taken over by Shaun Frape.

Awards: Clemens Reimann (committee chair) reported that the Vernadsky Medal was awarded to Bolviken. The Abelman Award (for young investigators) will not be given this year, as there were no new nominations for the award this year. It was pointed out that the working group chairs need to proactively submit nominations for the various awards. Likewise council members need to be proactive in this regard (are REQUIRED (!) to be proactive in this regard). The Vernadsky Medal will be awarded in 2010; it was noted that there has been disagreement about the basis for the award, whether it should focus on contrbutions to IAGC or to science in general. (***RUSS: I'm a bit confused about the Frederickton, New Brunswick meeting, what the name is, will an award be given, etc. Can you fill this in?***)

Student Research Grants: Russell Harmon is chair. There were 13 proposals this past year, resulting in one $3K award and 3 $1K awards to be used to support geochemical analysis. In addition, if the person is not already a member of IAGC, they are given a gratis membership. Discussion ensued about how to get more nominations, who to target, etc., and it was noted that there is difficulty promoting the grants (and other awards) by email, as the emails are not always read by recipients. We need to find additional ways to advertise the existence of these awards.

Plans and Program Committee: Nancy Hinman will chair.

4. **New officers and council members**: Attila Demeny has resigned as Secretary, Tom Bullen has accepted the position. Russell Harmon is the President, Clemens Riemann is the Vice-president, John Ludden is Past-president. The term of all these positions is four years. New council members are Rona Donahoe, Zhonghe Pang, Nancy Hinman and Harue Masuda. These new members were chosen from across the fields of geochemistry, and not across working groups. It was noted that the new members were mainly associated with the Water-Rock Interaction WG.

5. **Applied Isotope Geochemistry 8 (AIG8)**, to be held in September 2009 in Quebec and chaired by Martine Savard, has been given $7.5K from Council and $3K from AIG7 organizer Jodie Miller for startup funding.

6. **Issues related to the publication Elements** were discussed. It was noted that we pay a fee per member to Elements, currently set at $14 per year. This led to a discussion of dues, and the need to raise IAGC dues in part to cover increasing costs each year for Elements (an increase viewed as realistic, as the publication seems to be operating on the edge). Initially, it was proposed that dues be increased to $35 for members from high income countries, retain the $20 charge for members from low income countries, and charge students $15. In the end, the group thought that the increase to $35 was too much, and finally agreed to raise the fee for all members (including students) to $25.

7. **Budget matters**: current statutes say that only 85% of income can be spent each year. The group thought that a request to increase the limit to 95% might be appropriate, until the financial situation of the Association is further strengthened. Also, it was noted that there is now a two-tier charge for IAGC sponsored meetings, with non-members being charged extra to cover a new membership fee. Meeting organizers are provided with a list of current members, and should use that list to make sure that non-members pay the extra fee during registration.

The Ingerson Lecture will happen in 2009, at either the Fredericton, New Brunswick meeting or AIG8 in Quebec. The lecturer receives a certificate, a $500 stipend and travel expenses. We should aim to have a candidate from

the northeast US or Canada, to minimize travel costs!

In 2011, both AIG(9) and GES(?) will meet. As it now stands, IAGC probably can't provide $7.5K support to both organizing groups and will probably limit the contribution to $5K each. The chairs of those organizing groups should be notified of this. It was then suggested that AIG and GES might try to co-locate, even co-mingle in order to potentially maximize resources. But this led to discussion of "is bigger better", or do we risk losing the coziness of those meetings.

8. Business office: Mel Gascoyne is up to his ears with tasks as business office manager, and a new model for this function seems appropriate. He gets $15K for the business office operation, $1.5K for the GSA booth, and $4K for two newsletters. The discussion turned to how to get additional operational support. It was suggested that a line could be put on the registration form asking for a "contribution". This worked for last year's Water-Rock Interaction meeting.

9. Additional items: how to get meetings going from other working groups. Here there are issues of activation energy, fear of the unknown, etc., but it is a topic worth pursuing. Also, the web site and its maintenance were discussed. It was felt that if we could somehow get the website into the hands of a student-rich organization, that might be a great thing. Someone mentioned Atilla Demeny as a possible host source, but Atilla was not present to gracefully decline.

GSA: A New Division?

This message concerns the Geological Society of America Meeting, 18-21 October in Portland, Oregon.

As you may recall, IAGC is an 'Affiliated Society' of the Geological Society of America. This relationship allows IAGC to have a booth at the GSA Annual Meeting and the awards of every 'Affiliated Society' are advertised at each GSA Annual Meeting. As an 'Affiliated Society', IAGC has contributed to the GSA Annual Meeting for the last dozen or so years by organizing and conducting a special theme session on 'Sources, Transport, and Fate of Trace and Toxic Elements in the Environment' under the leadership of members Dave Long, Berry Lyons, and LeeAnn Munk,

Now, GSA is exploring the possibility of creating a new 'Mineralogy, Petrology, Volcanology, & Geochemistry' (MPVG) Division based upon a general expression of interest that has been received from the membership. GSA members that were interested in the new division or wanted more information about it, were invited to an organizational meeting held during the GSA meeting in Portland on Monday, October 19, 2009 in the Oregon Convention Center after the conclusion of the technical sessions. Aside from discussion about the proposal to establish a MPVG Division within GSA, the purpose of this initial organizational meeting was to select provisional officers until the normal sequence of elections can be held. According to GSA, the roster of initial officers can be designated by the organizing committee from among the individuals of the proponent group actively involved in establishing the new Division and may be ratified by attendees at the initial organizational meeting.

The outcome of the GSA meeting was that (i) GSA did decide to create a new Division of 'Mineralogy, Petrology, Volcanology, & Geochemistry'and (ii) two Faure Awards were selected from the IAGC-sponsored session (see Awards on page 8)

Russell Harmon, President

FEG 2011

Here follows an announcement of the conference 2011 'Frontiers in Environmental Geoscience' to be held in Aberystwyth, Wales, between the 21st and 23rd June 2011. This meeting will be the main Annual Meeting of the Mineralogical Society of Great Britain and Northern Ireland, and aims to cover a number of 'hot topics' that will be of interest to those working in mineralogy, environmental mineralogy, waste management and contamination clean-up. We are expecting in the region of 120 to 150 delegates (although would welcome more) at the conference, and currently we have suggested the following sessions:

1. Mine drainage: geochemistry and mineralogy.
2. Tracking contaminant transport from geological media through the food chain to humans.
3. Urban geochemistry and mineralogy: impacts on water, air and health.
4. Toxicity and environmental behaviour of man-made materials.
5. Applied mineralogy in the critical zone: metal reactions at mineral surfaces
6. Integration of computational and experimental environmental mineralogy
7. Environmental clay mineralogy and technology
8. Geochemistry of platinum-group minerals

Although IAGC cannot support the meeting financially (because we already are facing the problem of having two of our WG meetings scheduled for 2011 (GES & AIG). However, we would like to encourage IAGC members to get involved in the organization of these and other sessions and invite members to get involved in co-convening a session or in proposing/organizing special theme sessions.

Those interested should contact the Convenor, Dr. Nick Pearce, and for more information about the conference, please do not hesitate to contact him directly on <mailto:njp@aber.ac.uk>njp@aber.ac.uk (telephone: +44 (0) 1970 622599).

Information, circulars and registration details as they emerge will appear on the Mineralogical Society's web pages:(<http://www.minersoc.org/pages/meetings/frontiers-2011/frontiers-2011.html>http://www.minersoc.org/pages/meetings/frontiers-2011/frontiers-2011.html)

Recent Titles in Geochemistry

One of the benefits of attending a large national/ international geosciences meeting is visiting the display stands of the major textbook and research text publishers. IAGC members Bill Evans and Phil Verplank volunteered to spend a few hours during the recent Geological Society of America Meeting, held in Portland OR from 18-21 October, perusing the new book offering of the publishing companies that participated in the GSA exhibition. Listed below are a selection of the geochemistry books on display at the meeting. Many thanks Bill and Phil!

Publisher: Geological Society of America

1) Title: Hydrothermal Processes Above the Yellowstone Magma Chamber : Large Hydrothermal Systems and Large Hydrothermal Explosions, Editors: L.A. Morgan, W.C. Shanks, & K. L. Pierce, Geological Society of America Special Paper 459, Year 2009, in press, Available from the GSA Bookstore.
Overview description: This work presents information on the timing, distribution, and possible causes of these events in Yellowstone, which will aid in the planning and monitoring strategies of large hydrothermal systems.

2) Title: Frontiers in Geochemistry: Global Inorganic Geochemistry, Konrad Krauskopf Volume 1, Edfitor: G. W. Ernst, International Book Series, volume 5, Year 2002, 323 pages, Available from the GSA Bookstore.
Overview description: The technical papers resulting from a symposium entitled "Frontiers in Geochemistry," held at Stanford University in honor of Professor Konrad B. Krauskopf, were published in separate installments in International Geology Review and are collected here in an attempt to recognize Krauskopf's lifetime of extraordinary achievement in both geology and geochemistry.

3) Title: Frontiers in Geochemistry: Organic, Solution, and Ore Deposit Geochemistry, Konrad Krauskopf Volume 2, Editor: G. W. Ernst, International Book Series, volume 6, Year 2002, 235 pages, Available from the GSA Bookstore.
Overview description: The technical papers resulting from a symposium entitled "Frontiers in Geochemistry," held at Stanford University in honor of Professor Konrad B. Krauskopf, were published in separate installments in International Geology Review and are collected here in an attempt to recognize Krauskopf's lifetime of extraordinary achievement in both geology and geochemistry.

Publisher: Mineralogical Society of America

1) Title: Thermodynamics and Kinetics of Water-Rock Interaction (Reviews in Mineralogy and Geochemistry, volume 70), Editors: E. H. Oelkers and J. Schott, Year: 2009, 569 pages, Cost: $40 PB
Overview description: Full in-depth review of the topic with 12 chapters contributed by attendees of the Davos Goldschmidt Conference.

Publisher: Cambridge University Press

1) Title: Geochemistry, Author: F. Albarede, Year: 2009, 356 pages, Cost: $60 PB; $130 HB
Overview description: Second edition. Introduction to the field covering e.g. natural waters, magmas, solid earth in 14 chapters.

2) Title: Isotope Geology, Author: C. J. Allegre, Year: 2008, 512 pages, Cost: $80 HB
Overview description: Textbook level coverage of the topic in 8 chapters containing problems and solutions.

3) Title: Geochemical and Biogeochemical Reaction Modeling, Author: C. M. Bethke, Year: 2008
564 pages, Cost: $81 HB
Overview description: Comprehensive overview of reaction processes in 33 chapters closely linked to the Geochemist's Workbench software.

4) Title: Chemical Oceanography and the Marine Carbon Cycle, Authors: S. Emerson and J. Hedges, Year: 2009 (revision of 2008 release), 468 pages, Cost: S81 HB.
Overview description: Textbook level coverage of the topic in 12 chapters.

5) Title: Metal Contamination in Aquatic Environments, Authors: S. N. Luoma and P. S. Rainbow Year 2008, 588 pages, Cost: $108.
Overview description: Discussion of the science and the relation between science and policy in 18 chapters.

Recent Titles in Geochemistry (continued)

Publisher: Springer

1) Title: Contaminant Geochemistry, Authors: B. Berkowitz, I. Dror, and B. Yaron, Year: 2008, 412 pages, Cost: $189 HB.
Overview description: Coverage of the field with 16 chapters discussing such topics as transport, partitioning, and biotic and abiotic transformations.

2) Title: Stable Isotope Geochemistry, Author: J. Hoefs, Year: 2009, 288 pages, Cost: $99 HB.
Overview description: Sixth Edition of well-known reference and textbook.

3) Title: Hydrothermal Processes and Mineral Systems, Author: F. Pirajno, Year: 2009, 1252 pages, Cost: $239 HB.
Overview description: Very extensive coverage of the field in 13 chapters with discussion of numerous field cases.

4) Title: Modeling Groundwater Flow and Contaminant Transport, Authors: J. Bear and A. H.-D. Cheng, Year: 2010 (release in Nov 2009), 855 pages, Cost: $99 HB.
Overview description: Full coverage of the field in 11 chapters.

5) Title: Uranium, Mining and Hydrogeology, Editors: B.J. Merkel and A. Hasche-Berger, Year: 2008, 958 pages, Cost: $339 HB.
Overview description: Subject of the book is uranium and its migration in aquatic environments.

6) Title: Radiogenic Isotopes in Geologic Processes, Authors: S. V. Rasskazov, S. B. Brandt, and I. S. Brandt, Year 2009, 285 pages, Cost: $129 HB.
Overview description: This volume presents a modern approach to applying radiogenic isotope methods to solve theoretical and practical problem in geology.

Publisher: Elsevier

1) Title: Marine Chemistry and Geochemistry, Author: J. Steele, Year: (release in Nov 2009), 608 pages, Cost: $99.95.
Overview description: A derivative of the 6-volume Encyclopedia of Ocean Sciences.

2) Title: Handbook of Stable Isotope Analytical Techniques, Editor: P. A. De Groot, Year: 2009, 1398 pages, Cost: $220 HB.
Overview description: Volume 2 of the encyclopedic series on analytical techniques (complimenting Volume 1 released in 2004).

3) Title: Adsorption of Metals by Geomedia II, Editors: M. O. Barnett, D. B. Kent, Year: 2008, 430 pages, Cost: $140 HB.
Overview description: Discussion of tools and techniques and the latest technological advances in the field.

4) Title: Environmental Geochemistry, Editors: B. De Vivo, H. E. Belkin, and A. Lima, Year: 2008, 350 pages, Cost: $116 HB.
Overview description: Discussion of the field with case histories in 17 chapters.

Publisher: J. Wiley & Sons

1) Title: Groundwater Monitoring, Editors: P.P. Quevauviller, A.M. Fouillac, J. Grath, and R. Ward, Year: release in Nov 2009, 450 pages, Cost: $175 HB.
Overview description: Seven chapter textbook on groundwater quality assessment monitoring.

2) Title: Arsenic: Environmental Chemistry, Health Threats and Waste Treatment, Author: K. Henke, Year: April, 2009, 588 pages, Cost: $190 HB.
Overview description: An overview of the chemistry, geology, toxicology and environmental impacts of arsenic.

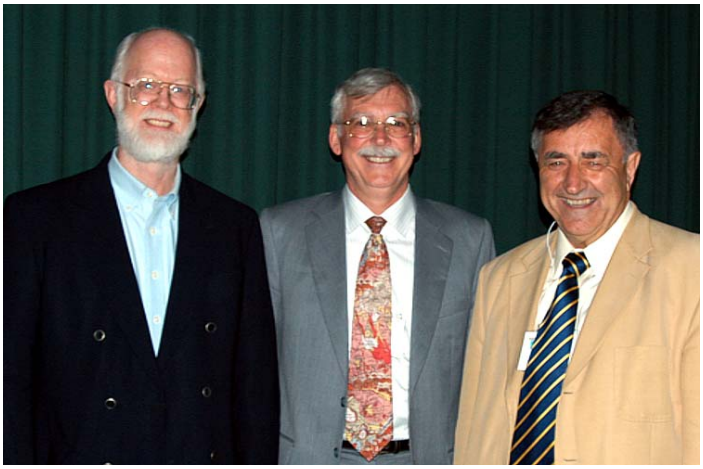
3) Title: Natural Groundwater Quality, Editors: M. Edmunds and P. Shand, Year: 2008, 488 pages, Cost: $157.99 HB.
Overview description: This text presents a series of thematic chapters together with chapters on representative groundwater systems in Europe which illustrate the main processes and evolution of water quality

4) Title: Pollution of Lakes and Rivers: A Paleoenvironmental Perspective, Author: J.P. Smol, Year: 2008 (2nd ed), 396 pages, Cost: $64.99 HB.
Overview description: Provides insights into present -day water quality problems from an international perspective.

Meetings ...meetings .. meetings

The 24th International Applied Geochemistry Symposium (IAGS 2009) was held at the University of New Brunswick in Fredericton, New Brunswick, Canada from 1-4 June under the primary sponsorship of the Association of Applied Geochemists, in partnership with the International Association of GeoChemistry (IAGC) and the *International Association of GeoAnalysts*. The meeting was preceded by 5 professional development and pre- and post-meeting field trips throughout Maritime Canada.
IAGC participated directly in the conference by organizing/co-organizing three topical theme sessions. Two of the IAGC awards for 2009 were presented at the conference (Figure 1). Yousif Kharaka received the first IAGC Distinguished Service Award and Kirk Nordstrom was honored as the IAGC Ingerson International Lecturer for 2009.

Co-chaired by David Smith (USGS-Denver) and Andy Rencz (GSC-Ottawa), the *North American Soil Geochemical Landscapes Project* session focused on the North American Soil Geochemical Landscapes Project. This is collaborative project involving the Geological Survey of Canada, the Mexican Geological Survey, and the U.S. Geological Survey is to establishing (i) a soil geochemical data base for North America and interpretive products based on the data base and (ii) an archive of samples for future investigators. This effort represents North America's contribution to the IUGS/IAGC Working Group on Global Geochemical Baselines.
A second theme session on *Sources, Transport, and Fate of Trace and Toxic Elements in the Environment* was organized and co-chaired by LeeAnn Munk of University of Alaska-Anchorage) and Sarah Fortner of Ohio State University. The environmental chemistry of trace and toxic elements is an important and growing field of research in applied geochemistry. This session examined the sources, transport, and fate of trace and toxic elements in different environments, both natural settings and those areas impacted by anthropogenic activities and understanding the processes that affect the release, transport, and uptake of these elements and making connections between the presence of trace elements and in environment and their toxicology. The 2009 IAGC Ingerson International Lecture**,** "Hydrogeochemical Processes Governing the Origin, Transport, and Fate of Major and Trace Elements from Mine Wastes and Mineralized Rock**",** was presented as the keynote lecture of this session.
IAGC also sponsored and organized the conference session on *Current Capabilities and Future Prospects of Real-Time, In-Field Geochemical Analysis*. A long-term goal in analytical geochemistry has been a capability for real-time analysis in the field. Co-chaired by Russell S. Harmon, North Carolina State University, and Nancy McMillan, New Mexico State University,
this session reviewed technology developments in instrumentation that have occurred over the past decade and highlighted current and emerging analytical technologies for real-time field-portable geochemical analysis.



Kirk Nordstrom, IAGC President Russell Harmon, and Yousif Kharaka at IAGS2009

Conference Report

The 8th Applied Isotope Geochemistry Symposium

AIG-8

August 30 to September 04, 2009

The Geological Survey of Canada hosted the 8th Symposium on Applied Isotope Geochemistry under the um-

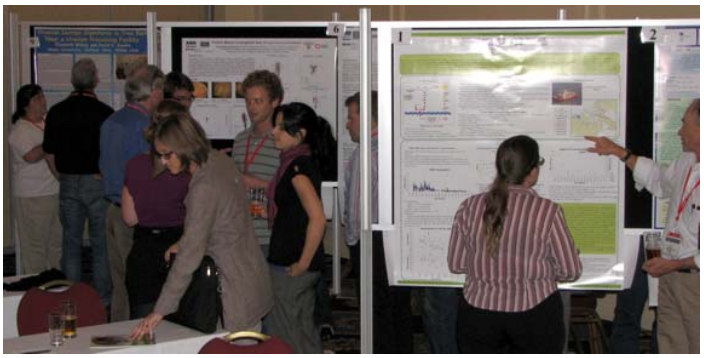
The conference venue nested in the Laurentians and overseeing the St. Lawrence estuary.

brella of the International Association of GeoChemistry (IAGC) during the first week of September. The organizing committee (Jason Ahad, Geneviève Bordeleau, Tom Bullen, Pascale Côté, Marie-Noëlle Croteau, Roger Koopmann, Martine Savard and Marie-Josée Tremblay) invited the isotopists of the world to convene at the Manoir Richelieu, in La Malbaie (Quebec), an inspiring venue nested in the Laurentians and overseeing the St. Lawrence River. This selection was well appreciated by all participants as the Charlevoix region is known for its joie-de-vivre and for offering unique regional delicacies. In this edition of the AIG Symposium, 74 scientists from 12 countries interacted in a plenary session during four days. The scientific program was neat and tight even if the number of participants was slightly lower than expected due the global economy, and to a minor extent, to the recent change of regulations for obtaining Canadian

Dr. Bernhard Mayer from University of Calgary giving his presentation in front of a very attentive crowd.

visas.

The discussion concentrated on seven distinct scientific themes: climate & climate reconstruction, contaminant tracing and remediation, isotope geochemistry for exploration, atmosphere-hydrodrosphere-biosphere-lithosphere interactions, multi-tracer approaches, anthropogenic environmental perturbations, non-traditional isotopes and novel analytical approaches that were proposed by the scientific committee (Drs. Marie-Noëlle Croteau, USGS, Kurt Kyser, Queen's U., Bernhard Mayer, U,



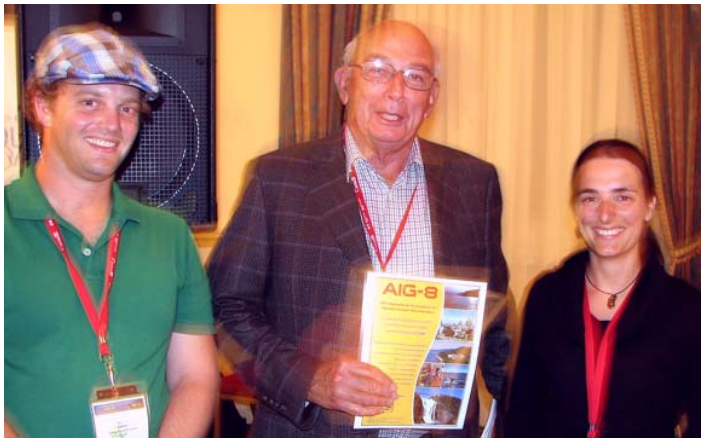
A well attended poster session. Beers always help!

of Calgary, Alain Prinzhofer, IFP, and Martine Savard, GSC). The breadth of the presentations indicates that isotope geochemistry serves an increasing number of themes in environmental research, while being still judiciously applied to solve pertinent questions relative to resource exploration and lithosphere process studies. Four solicited keynote speakers presented theme lectures on: Biospheric coupling of terrestrial water and carbon fluxes: implications for the climate system (Prof. Jan Veizer, Ottawa University, Ottawa); Mass Independent Fractionation effects on isotope geochemistry in mineral exploration (Prof. Kurt Kyser, Queen's University, Kingston); Use of geochemical and isotope tracers to evaluate the fate of cyanide in mine tailings (Prof. Ramon Aravena; University of Waterloo, Waterloo); Recent developments in strontium isotope fractionation studies: techniques and applications (Dr. Jan Fietske, Leibniz Institute of Marine Sciences, Kiel).

The Faure Award committee (Tom Bullen, Barry Batts, Shaun Frape) unanimously decided to give an ex aequo prize to David Snider (University of Waterloo, Waterloo, Canada) and Mirjam Kiczka (ETH Zurich, Zurich, Switzerland), both Ph.D. students who scored equally in the competition due to their excellent oral presentations: 18O/16O ratios of N2O and NO3- produced in agricultural and temperate forest soils - Isotope labelling experiments

Dr. Castonguay explaining the development of the Logan's Line and Appalachian Front, the St. Lawrence River and Isle-aux-Coudres in background.

and implications for source partitioning; and Fe isotope fractionation by plants - mass balances and controlling factors, respectively.



David Snider *of U. of Waterloo (left) and* ***Mirjam Kiczka*** *of ETH Zurich (right) received the* ***Faure Award*** *for best student presentations from Dr. Barry Batts (center).*

The mid-conference field trip brought the 85 participants (scientists and accompanying members) to discover the landscape and rock texture due to the meteorite collision that impacted Charlevoix likely during late Ordovician (exact age unknown). The field trip guides, Drs. Leopold Nadeau and Sébastien Castonguay from GSC-Québec, also explained the geological evolution of the Laurentians and Appalachians born of continental collisions, and discussed spectacular outcrops and stunning landscapes under a great blue sky. The field trip ended on a boat, which gave another point of view on the St. Lawrence rift system and Saguenay Fjord, and allowed for whale observation!

The AIG-8 group posing on the shore of the St. Lawrence River.

The meeting was sponsored by Natural Resources Canada, IAGC, Spectromat inc, FPinnovations, the Mineralogical Association of Canada, and the Institut national de la recherche scientifique. This financial support allowed to cover the costs of the mid-symposium excursion, to directly help four students to cover their accommodation costs, and to diminish the registration fees of all students. In addition, the Geological Survey of Canada offered a great logistical support to this event and made sure to optimize the efficiency of its organization.

Section through a shatter cone visible in an Ordovician limestone bed surface.

Dr. Nadeau at the Discovery Outcrop composed of charnockitic gneiss, explaining the finding of the meteorite impact by Dr. J. Rondot in 1966.

Overall, as in most former editions, the 8th symposium of AIG has allowed world's leading isotope biogeoscientists and students to have extended discussions and build new collaborations in a friendly and relaxed atmosphere.

We will likely all meet again in 2011 near Barcelona, Spain, for AIG-9!

Au revoir! Hasta la vista!

Martine M. Savard
Chair of AIG-8, Chair of the AIG working group of IAGC
Geological Survey of Canada (GSC-Québec)

The AIG-8 group posing on the shore of the St. Lawrence River.

IAGC Technical Report: Abandoned mining sites: lessons learned from hydrogeochemical studies in Sardinia

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Abandoned mining sites pose physical safety and environmental hazards. Because environmental regulation of mining activities has been introduced relatively recently, the magnitude of the impacts from past mining in countries with a long mining history is considerable, though the extent of mining sites often remain undocumented. Mining activities have a relevant influence on the quantity and quality of water resources in the surrounding environment. Therefore, the chemical contamination of water systems at abandoned mining sites demands investigation strategies capable of describing sources and pathways of contaminants and containment strategies devoted to limit the diffusion of toxic components.

This paper reports some results of hydrogeochemical surveys carried out in Sardinia (Italy), a Mediterranean region with mining activities dating back to pre-Roman times. Industrial mining in Sardinia started in the 1850-1870; main exploited minerals were comprised of galena, sphalerite, chalcopyrite, antimonite, barite and fluorite. Peaks in Pb-Zn-Cu-Sb production were reached in the 1950-1960 decades. The decline of mining industry, due to the fall in value of base-metals and the increase of labor costs, led to the cessation of mining activities in the 1980-1990 period.

Responsibility for rehabilitation was non-identifiable at many mines, this has led to non-action when mining operations in Sardinia ceased. The potential adverse effects of mine closure, especially the risk to human health due to the proximity of mining sites to water resources, were not given proper consideration by the Regional and National Authorities. In particular, the contaminated residues derived from exploitation and processing of ores have been left exposed to erosion and weathering, and the underground workings have been left to be flooded after shutdown of pumping systems used to keep dry the pits. This resulted in legacies estimated at 169 abandoned mines and $71*10^6$ m^3 of mining wastes that occupy a 19 km^2 surface (RAS, 2003).

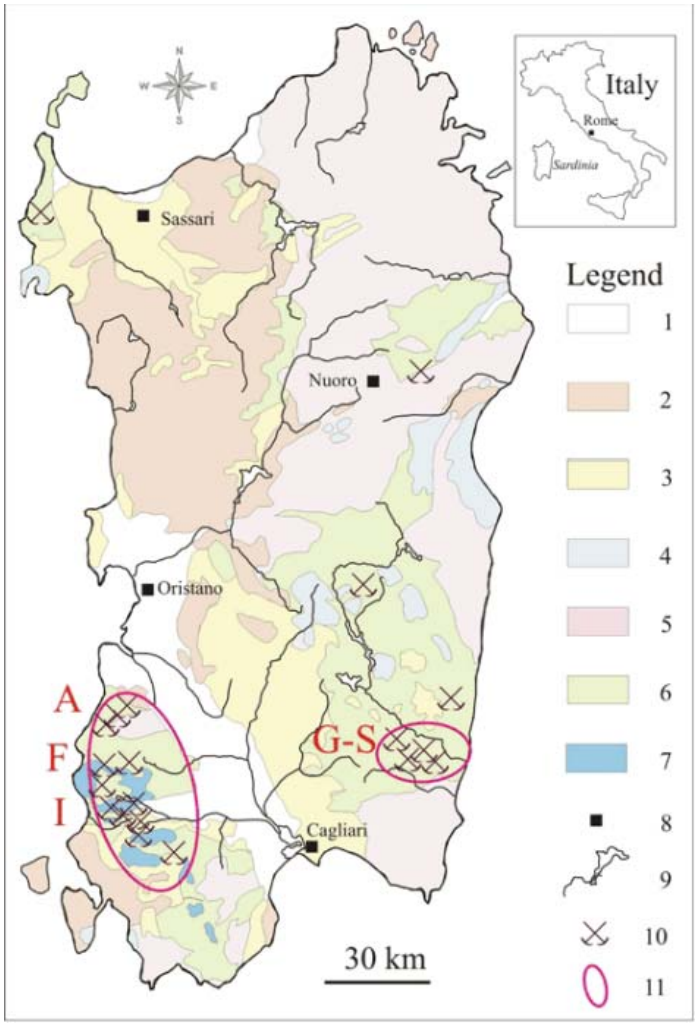

Figure 1: Schematic geologic map of Sardinia showing locations of relevant mining sites. Legend: 1 Recent sediments; 2 Basaltic- (Plio-Pleistocene) and andesite-prevailing volcanic sequences (Oligocene-Miocene); 3 Marly sandstone, siltstone, limestone and conglomerate (Miocene); 4 Limestone and dolostone (Dogger-Malm); 5 Granitic rocks (Carboniferous); 6 Paleozoic basement; 7 Limestone and dolostone (Cambrian); 8 Towns; 9 Main rivers, streams and reservoirs; 10 Large abandoned mines; 11 Relevant mining districts A: Arburese, F: Fluminese, I: Iglesiente, G-S: Gerrei-Sarrabus.

Impact of past mining on water systems

It must be pointed out that in Sardinia river waters collected in reservoirs represent about 70% of the water supply for agricultural, industrial and domestic uses for a population of approximately 2 million people. Large abandoned mines, now flooded, occur in Cambrian carbonate formations, which host important aquifers due to intense fracturing and karst processes. Because the domestic water demand is increasing, and taking into account the difficulty of alternative water supply in some areas, the groundwater hosted in flooded mines is considered a strategic water resource by the Regional Authorities. These considerations highlight the importance of scientific investigations on the environmental status at sites affected by past mining.

Hydrogeochemical surveys in Sardinian mining districts have been carried out since 1993 till present, with selected sites being monitored under different seasonal conditions. At the sampling site, the pH, redox potential (Eh), temperature and alkalinity were measured; waters were filtered through 0.4 µm pore-size filters into pre-cleaned high-density polyethylene bottles. Filtered aliquots were acidified on site with suprapure grade HNO_3 for metal analyses by quadrupole ICP-MS and major cations by ICP-OES. Anions were determined by ion chromatography on a filtered, not acidified aliquot. A few case studies have been selected to show the mining impact on water systems in prominent areas affected by past mining. Dissolved concentrations reported in this paper refer to elements determined in the aqueous fraction <0.4 µm.

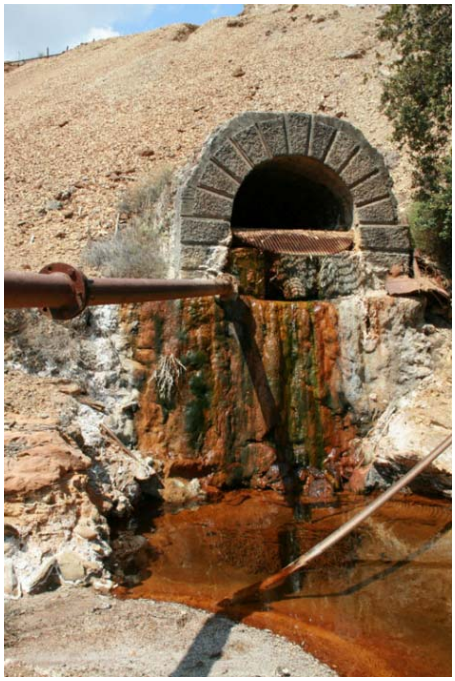

Figure 2. Mine drainage at Montevec-

Arburese district

In the Arburese (SW Sardinia), the exploitation of Pb-Zn vein ores hosted in Paleozoic silicate-dominant rocks extended in a system of overlapping galleries for a depth of 600 m below ground level. Under exploitation, the total flow of water pumped out of the Arburese mines was in the range of 55 to 70 liters per second (L/s); the pumped water was near-neutral with high concentrations of sulfate and metals. After the closure of mines, waters flowing out of galleries and shafts were observed since 1996. At the beginning, dissolved concentrations of sulfate and metals (up to 2000 mg/L Zn, 20 mg/L Cd and 2 mg/L Pb) in mine drainages were much higher than those observed under dewatering conditions. Such extreme concentrations derived from the oxidation of sulfide minerals promoted by flooding. Then, mine wastes and flotation tailings have been used to refill the underground workings; flushing of these materials was facilitated by their small grain size. The acidity produced by the oxidation of sulfide minerals (especially pyrite) has been preserved at sites where carbonates in the ore and host rocks are lacking (e.g. pH: 3.6-4.3 at Montevecchio), while the acidity has been in part buffered at sites where calcite and ankerite occur (e.g. pH: 5.9-6.2 at Casargiu). As compared with values recorded at the first stages of rebound, a significant decrease (about 50%) in sulfate and metal concentrations were observed in 2008, nevertheless, a very high contamination level still persists at these sites after 13 years of flushing.

Mine drainages from Montevecchio and Casargiu flow into the local streams. Additional contamination in these streams derives from the weathering of mining-derived solid materials abandoned on the ground (Caboi et al., 1993; 1999). This contamination is enhanced during heavy-rain events that cause high runoff. A decrease in dissolved metals occurs downstream at sites where uncontaminated

Figure 3. Mine drainage at

tributaries flow into the contaminated streams. Further attenuation in the dissolved load of contaminants occurs by precipitation of solid phases, such as iron oxide-hydroxide and sulfate and carbonate minerals. Some of these solid phases may be dissolved in the next precipitation event, so that they act as a temporal removal of dissolved contaminants. In summary, despite concentrations of dissolved contaminants decrease significantly from the mine sites downstream, the dispersion of toxic elements extends about 10 km eastwards to a lagoon, and 4 km westwards to the Mediterranean Sea. The estimated amount of dissolved metals discharged into these recipients is relevant, with potential adverse effects on fishery that represents an important activity for the local community. Just considering the mine drainage from Casargiu, the amount of metals discharged per year into the Mediterranean Sea is estimated at 328, 2, 0.5 and 0.3 tons of Zn, Ni, Cd and Pb, respectively. As compared with the global flux estimation of Gaillardet et al. (2003), the contribution of Zn from the Casargiu mine to the sea corresponds to 1.4% of the global riverine annual flux of Zn.

Fluminese-Iglesiente districts

Ore bodies in the Fluminese-Iglesiente districts (SW Sardinia) consist of massive and lower grade sulfides (sphalerite and galena, with variable pyrite contents) hosted in Cambrian carbonate sequences. In the Fluminese, drainages out of five adits were observed soon after the closure of mines in 1980'. These mine waters were near neutral to slightly alkaline (pH: 6.3-8.2), reflecting their circulation in carbonate rocks, and showed a wide range of metal concentrations depending on the dominant mineral assemblage at each mine. The highest concentrations of dissolved metals were observed for Zn (100 mg/L), Mn (18 mg/L), Fe (15 mg/L), Cd (0.3 mg/L) and Ni (0.3 mg/L). Although the discharge of these mine drainages into the local streams contributes in deteriorating the water quality, the overall contamination level in waters in the Fluminese district is much lower than that observed in the Arburese.

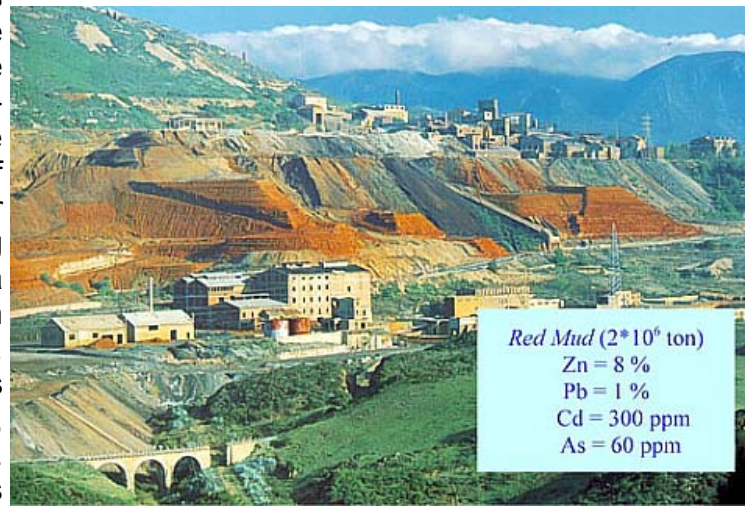

Figure 4. Monteponi mine and Red Mud dump (SW Sardinia)

Rebound of mines in the Iglesiente district did not caused outflows up to present (2009). Since 1910, the most important drainage system in the Iglesiente was located at the Monteponi mine with discharge into the sea through a drain. Pumping stations were successively installed at increasing depths to lower the water table till 160 m below sea level. The water pumped out of Monteponi (1800 L/s in 1996) was near neutral (pH: 7.5) and highly saline (conductivity: 32 mS/cm), with dissolved chloride up to 12 g/L due to contamination by seawater. Concentrations of metals, particularly Pb (100 µg/L), and Hg (50 µg/L), were also relatively high (Cidu et al., 2001; Cidu and Fanfani, 2002). The pumping systems ceased operation in 1997, thereafter the underground workings underwent flooding. During the first year of rebound, the salinity increased significantly in the nearby Campo Pisano mine, due to mixing of the shallow groundwater with saline water from below. Following the progress of flooding, in 1998 a marked increase in dissolved SO_4 (800 mg/L), Zn (57 mg/L), Cd (0.1 mg/L) and Fe (30 mg/L) was observed at Campo Pisano, which was consistent with mining records showing abundant sphalerite and pyrite in the corresponding underground level. As the water table level continued to rise, salinity and metal concentrations gradually decreased, but concentrations of Pb in the range of 10 to 81 µg/L were still observed in groundwater at the mines. The most abundant species of dissolved Pb was $PbCO_3^0$ (80-95%). Lead speciation did not depend on flooding or dewatering conditions, nor on low or high salinity. This might explain the relatively high Pb observed in these mine waters under slightly alkaline conditions.

It is important to recall that the groundwater hosted in flooded mines in the Iglesiente represents a strategic water resource. The quality of groundwater in the aquifers of the Iglesiente mining district has signifi-

cantly improved as compared with the beginning of rebound, especially in the upper aquifer, so that this resource can be properly exploited up to the limit of the annual recharge. Indeed, groundwater from the Campo Pisano mine presently contributes to supply to the town of Iglesias. However, the chemical composition of groundwater at each mine varies from the water table level downwards. Results on hydrochemical surveys carried out in 2004 and 2005 showed that the water quality deteriorates at specific depths due to the increase in salinity and metals (Cidu et al., 2007). Therefore, a greater exploitation of the mine groundwater will require the monitoring of potential contamination sources, and ideally, the deterioration of the groundwater quality should be predicted.

Gerrei-Sarrabus districts

In the Gerrei-Sarrabus (SE Sardinia), Sb deposits hosted in Palaeozoic black schists and metalimestones, and base-metal deposits (especially Ag-rich galena) have been exploited and processed until 1960-1980. Among the mining residues left on the ground, flotation tailings and slag derived from Sb-processing are highly contaminated materials. Some drainages from abandoned mining sites flow into tributaries of the southern Flumendosa River, which is a significant water resource used to supply water to a fertile plain. In these districts, surface and ground waters are near-neutral to slightly alkaline and have chemical composition varying from Na-Cl with low total dissolved solids (TDS 0.1-0.5 g/L) to Ca-HCO_3 with TDS in the range of 0.2 to 0.8 g/L. The mine waters generally have a distinguished Ca-SO_4 composition with TDS up to 3 g/L and show much higher dissolved concentrations of toxic or harmful elements. The highest concentrations of Sb and As occurred in the waters that drain the Sb mine of Su Suergiu, and the highest values of dissolved Pb (36 µg/L), Cd (10 µg/L), Zn (400 µg/L) and Mo (37 µg/L) were observed at sites where Pb-Zn(Mo) deposits prevail (Cidu et al., 2008).

The Sb contamination is particularly severe: in the stream draining the Su Suergiu area, about 3 km downstream of the mine site, dissolved Sb concentrations of 800 µg/L and 1200 µg/L were observed under high (about 200 L/s) and low flow (3 L/s) conditions, respectively. The highest concentrations of toxic elements (up to 9600 µg/L Sb and 3500 µg/L As) occurred in waters flowing out of the slag materials derived from processing of the Sb-ore. Contamination from Su Suergiu affects the Flumendosa River: the water sampled upstream of the contaminated tributary showed 4 µg/L Sb and 1.9 µg/L As, i.e. values below the limits established by the World Health Organization guidelines for drinking water (20 µg/L Sb and 10 µg/L As; WHO, 2006), while downstream of the confluence dissolved Sb was 32 µg/L and As 6.7 µg/L. Antimony contamination in the Flumendosa extended some 16 km downstream of the abandoned mines; an attenuation (15 µg/L Sb) was only observed close to the mouth (Cidu et al., 2008).

Actions for reducing the dispersion of contaminants

The hydrogeochemical approach proved to be a valuable tool for the understanding of contamination processes occurring at abandoned mining sites. The examples shown above indicate that drainages from flooded mines and from the mining residues left on the ground are the main mining-related sources of contamination in Sardinia. The major risks to the water systems are associated with the direct discharge of contaminated waters into the aquatic recipients located downstream of the contaminant sources. The dispersion of toxic and harmful elements increases during the rain season, especially under heavy-rain conditions. In fact, high runoff results in elevate concentrations of contaminants (especially Zn, Cd, Pb, Sb and As) in the stream waters, due to

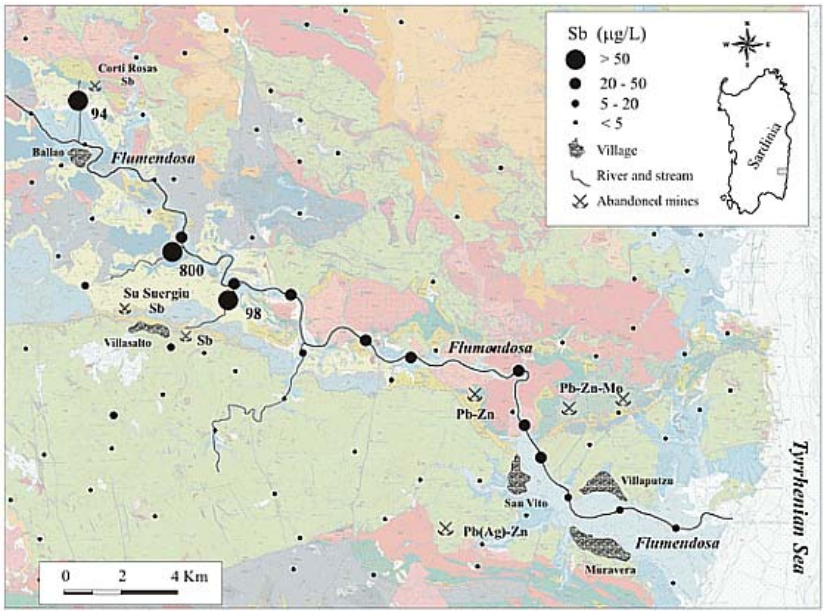

Figure 5. Ranges of dissolved Sb concentrations in waters sampled under high-flow conditions in the lower Flumendosa basin.

the erosion and weathering of the exposed mining-related wastes. Because a high quantity of suspended matter is observed under such conditions, the transport of contaminants via sorption processes onto very fine particles (<0.4 μm) and/or associated to colloids extends downstream far beyond the mine sites.

Taking into account the risk to human health due to the proximity of the Sardinian mining sites to water resources and land that is within reach of animals and humans, different actions aimed to reduce the contamination level are needed at specific sites. Among actions requiring relatively low investments, the physical stabilization of the contaminated solid materials, especially the construction of drain systems to diverting runoff on the waste dumps and impoundments, will reduce rates of erosion and weathering processes. These actions proved to be efficient in reducing significantly the dispersion of contaminants. As an example, the stream receiving the drainages from tailings contained in drained impoundments at Funtana Raminosa (an abandoned copper mine in Central Sardinia) showed relatively low concentrations of metals (170 μg/L Zn, 7 μg/L Cd and 1 μg/L Pb; Cidu, 2007). Also, the collection of the mine drainages in artificial ponds prior to discharge into streams and soils will favor the decrease of dissolved contaminants via settlement of the fine particles and precipitation-sorption processes. Ideally, the extremely contaminated drainages should be 'cleaned' before discharge, and the highly contaminated solid residues should be treated or removed and properly disposed. These actions would require much larger investments, including long-term costs for the management of plants and for the disposal of wastes produced in the treatment processes.

The information derived from our studies should help the Regional and National Authorities to address present environmental regulations, also, might be useful in planning remediation actions at abandoned mining sites elsewhere.

Lessons learnt by past mining in Sardinia indicate that the mining residues pose relevant environmental hazards, therefore, mandatory protocols need to be established for an appropriate disposal and management of these contaminated materials since exploitation and processing start at active mines. This would allow to reduce the environmental risks related to mining activities as well as the cost of rehabilitation after the mine closure.

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