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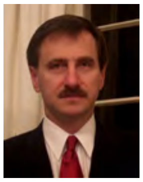
Newsletter for the Association of Applied Geochemists
THE ASSOCIATION OF APPLIED GEOCHEMISTS

President's Message


David Cohen

It is now just 12 months until the 24th International Applied Geochemistry Symposium in Fredericton, New Brunswick (Canada). We are looking forward to a good turnout of members and students. Some sessions at the symposium are being arranged by the International Association of GeoChemistry, which will hopefully boost attendance at the IAGS and provide some opportunity for the pure and applied sides of the geochemical coin to broaden each other's horizons. We hope that the move will also assist AAG in fulfilling the Association's aim of expanding its formal interests into areas of environmental chemistry linked to mining activities and beyond. This initiative may lead to further opportunities for the various scientific societies within our somewhat fragmented geochemical world (as indicated by the substantial list of organisations that sponsor *Elements*) to cooperate.

It also raises the question "what is the optimum size and scope for a scientific society?" There is, of course, no single correct model and the answer depends on the purpose and the intended geographical boundaries of a society. Some of the smaller societies draw on membership from a small area, others may be international in membership but focus on a very small discipline area. Some of the larger societies act as an umbrella under which smaller disciplinary groups exist. Increasing the size of a society by various methods, including more effective outreach and inducements to join or strategic mergers, can provide a number of advantages including the financial strength to better support central office facilities, transfer of some operational functions from volunteer members to paid staff, and a better flow of good quality manuscripts to journals. Disadvantages may include loss of focus for the society and reduced connection between members. Such issues will, no doubt, be the subject of debate over a few libations at Fredericton.

Revisions to the structure and registration of the Distinguished Applied Geochemists Fund, to ensure it will have charitable status for the purpose of tax deductibility of donations, is in the hands of Revenue Canada. Once we clear this hurdle, AAG will be renewing efforts to obtain further contributions from various sources to assist with initiatives to promote applied geochemistry, and especially to encourage and support more students to take up the discipline. The fund is chaired by Gerry Govett.

The deadline for submission of nominations for the next SGS Minerals Services 2008 AAG Student Paper Competition is the end of 2008. Readers of GEEA, members of AAG and especially supervisors, are invited to submit nominations. There are no forms to complete – just send me a note outlining the reasons why you thought the paper was of high quality/impact. The only proviso is that the paper must have been published (or been accepted for publication) in the last three years by GEEA.

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Exploration for Volcanogenic Massive Sulfide Mineralization along the Kermadec Arc—Havre Trough, New Zealand

INTRODUCTION

The discovery of hydrothermal venting on the Galapagos Spreading Center in 1977 resulted in considerable interest in mid-ocean ridge hydrothermal systems as analogues to ancient volcanogenic massive sulfide (VMS) deposits (Hannington *et al.* 1995; Herzig & Hannington 1995; Herzig 1999). Considerably less attention has been given to submarine arcs (de Ronde *et al.* 2001), despite evidence for significant mineralization related to geothermal systems on subaerial arc volcanoes, e.g. White Island, New Zealand (Hedenquist *et al.* 1993; Giggenbach *et al.* 2003) and Lihir, Papua New Guinea (Petersen *et al.* 2002; Kamenov *et al.* 2005). However, over the last decade, submarine arcs have started to receive greater attention, with the result that many have been found to be hydrothermally active (de Ronde *et al.* 2003; de Ronde *et al.* 2005; Stoffers *et al.* 2006; de Ronde *et al.* 2007).

Although useful as analogs of ancient VMS ore forming processes, mid-ocean ridge settings are difficult targets in terms of exploitation owing to their depth (typically ≥ 2,500 m). Furthermore, ridge settings are dominated by basaltic lava flows, whereas many large ancient VMS deposits are associated with intermediate to felsic pyroclastic rocks. Arc-associated systems are typically at shallower water depths compared to mid-ocean ridges, and the association with arc-volcanoes means that they may be longer-lived and more focused in terms of magma supply and heat production, potentially producing much larger deposits than are typical along mid-ocean ridges. Compared to mid-ocean ridge hydrothermal deposits, those on arcs also tend to have higher f_{O2}, lower Fe and higher Au concentrations (Wright *et al.* 1998; de Ronde *et al.* 2005). Elevated Au contents makes such deposits more attractive for exploration and potential exploitation (Herzig 1999).

The Kermadec intra-oceanic arc is a 1,220 km long system formed by the subduction of the Pacific Plate beneath the Australian Plate (Fig. 1). The Kermadec arc is the most systematically explored submarine arc in the world for hydrothermal activity. Exploration over the last nine years has shown that the majority of the volcanoes and calderas along the arc are hydrothermally active, ranging from diffuse low-temperature venting

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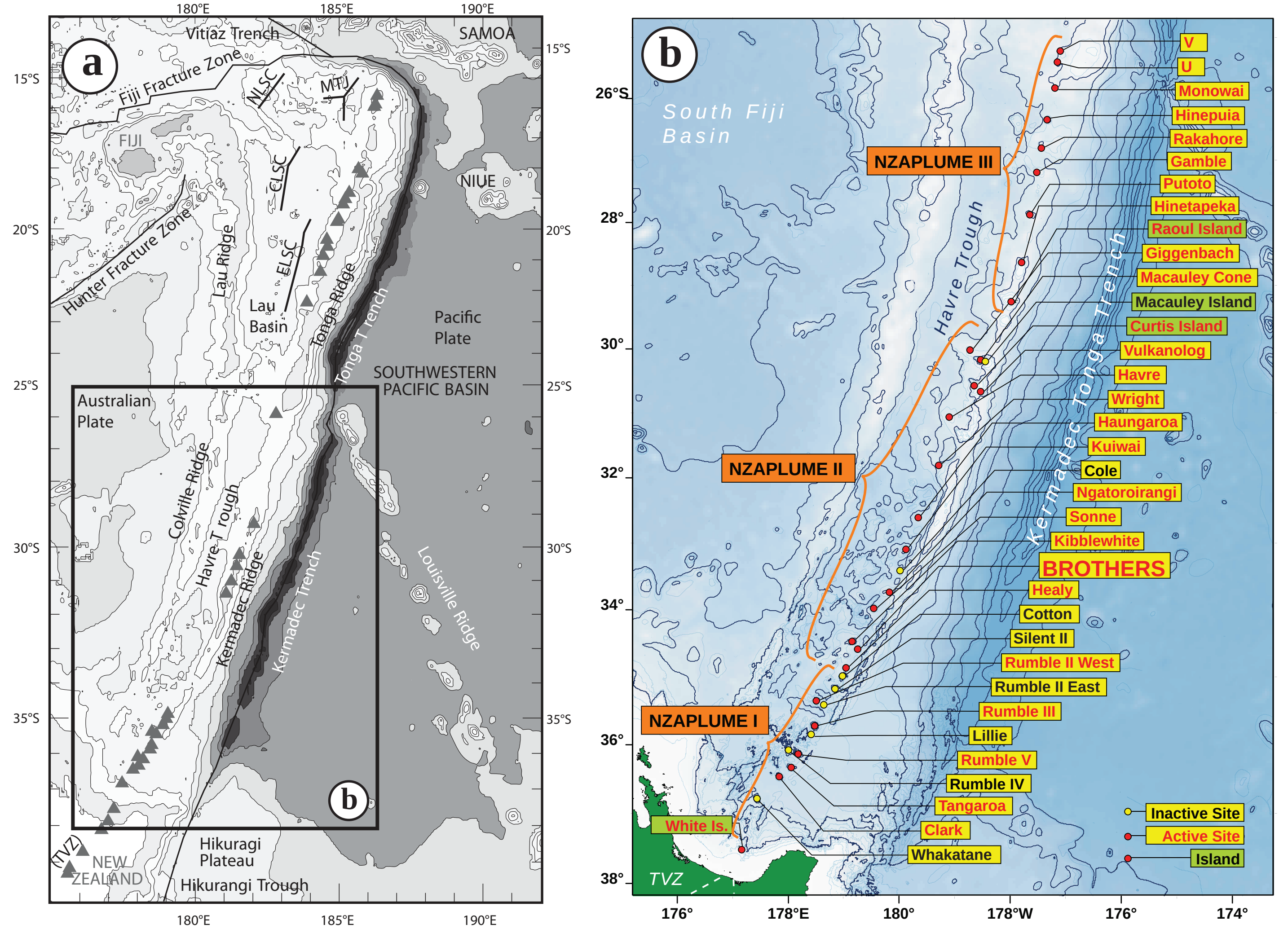

Figure 1. The Tonga-Kermadec subduction system; the Pacific Plate is being subducted westward underneath the Australian Plate. A) The active arc is denoted by triangles. B) Expanded view of the southern portion of the Kermadec arc, showing the location of important hydrothermally active submarine volcanoes and calderas. After Massoth and de Ronde (2006).

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to robust black-smoker style venting with associated VMS mineralization. The primary exploration tool has been mapping of hydrothermal plumes in the water column above submarine volcanoes, utilizing a number of sensors to detect both physical (e.g., light-scattering) and chemical (e.g., ^{3}He) anomalies. Subsequent tracing of these plumes back to their sources has revealed significant mineralization on several of the volcanoes along the Kermadec arc. Significantly, these systems are Cu- and Au-rich, with concentrations considerably elevated compared to ridge settings. For example, the Solwara 1 deposit in the Bismarck Sea, near Papua New Guinea, has indicated reserves of 870 kt @ 6.8% Cu, 4.8 g/t Au, 23 g/t Ag and 0.4% Zn (at a 4% Cu cut off; www.nautilusminerals.com). In contrast, mineralized samples from Brothers volcano are much more Zn- and Pb-rich, with up to 1850 ppm Au, 38% Zn, 8% Pb and 2.7% Cu (de Ronde *et al.* 2005).

GEOLOGICAL SETTING

The Kermadec arc represents the southern half of the ~2,500 km long Kermadec-Tonga arc (Fig. 1),

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formed by the subduction of the Pacific Plate westwards underneath the Australia Plate. Although there are about 57 submarine volcanic centers along the entire arc, most (33) occur along the 1,220 km-long Kermadec arc (de Ronde *et al.* 2005). The Kermadec arc represents the northeastward extension of the Taupo Volcanic Zone of the North Island of New Zealand, and varies from continental crust just offshore to oceanic crust in the north. The southern portion of the Kermadec arc front (south of ~ 32°S) is represented by submarine stratovolcanoes that occur west of the high-standing Kermadec Ridge (Fig. 1) (Wright *et al.* 1996). The southward transition from oceanic to continental crust, combined with subduction of continentally-derived sediments and overthickened oceanic crust of the Hikurangi Plateau, results in a variety of magma source compositions that are reflected in the elemental and isotopic composition of erupted products along the arc, and likely the variability in the hydrothermal fluids and mineralization (de Ronde *et al.* 2001; Massoth *et al.* 2003; de Ronde *et al.* 2005; de Ronde *et al.* 2007).

The backarc to the Kermadec-Tonga comprises the Lau-Havre-Taupo backarc complex (Fig. 1), which is southward propagating and undergoing active extension. This backarc complex evolves from north to south from oceanic spreading in the central and northern Lau Basin, through rifting of arc crust along the southernmost Lau Basin and the Havre Trough to continental rifting within New Zealand (Wright *et al.* 1996). West of the Lau Basin and Havre Trough is the Colville Ridge, a remnant arc, which became isolated from active arc volcanism at ~ 5.5 Ma. The Lau Basin is undergoing more rapid extension compared to the Havre Trough, with rates as high as 159 mm yr^{-1} in the northern Lau Basin, whereas extension is 15-20 mm yr^{-1} in the Havre Trough. The transition from more rapid extension and oceanic spreading in the Lau Basin to rifting-dominated extension in the Havre Trough occurs where the trench-oblique Louisville Seamount Chain is subducted; subduction of this chain has progressively migrated southwards over the last 4 Ma (Wright *et al.* 1996).

METHODOLOGY

Prior to 1996, active hydrothermal activity along the submarine portion of the Kermadec was unknown (Wright *et al.* 1998). A series of research cruises using New Zealand, German, Japanese and American research vessels were undertaken to systematically explore the arc for hydrothermal activity and subsequently to undertake more detailed studies on volcanic centers shown to be hydrothermally active (Wright *et al.* 1998; de Ronde *et al.* 2001; Massoth *et al.* 2003; de Ronde *et al.* 2005; de Ronde *et al.* 2007). A variety of sophisticated technologies is utilized in order to carry out these studies. These methods involve the following: 1) conductivity-temperature-depth-optical (CTDO) sensor surveys, 2) remotely operated vehicles (ROVs), 3) manned submersibles, 4) autonomous underwater vehicles (AUVs), and 5) ship-based and shore-based geochemistry (elemental and isotopic).

The principle method of detecting and locating sites of hydrothermal venting is by mapping plumes that are formed in the water column above actively venting hydrothermal systems (Figs. 2A, 3); these provide a broad and widely dispersed exploration target. Hydrothermal plumes occur in both dissolved and particulate forms. Thus, exploration for plumes has relied on a number of chemical and physical parameters to determine the different styles of venting. Hydrothermal plumes along the Kermadec arc have been most successfully mapped in real-time using light-scattering detection (measured in ΔNTU), based on the presence of venting-associated particulates (primarily Fe- and Mn-oxyhydroxides), Eh, and CH_4 (de Ronde *et al.* 2001).

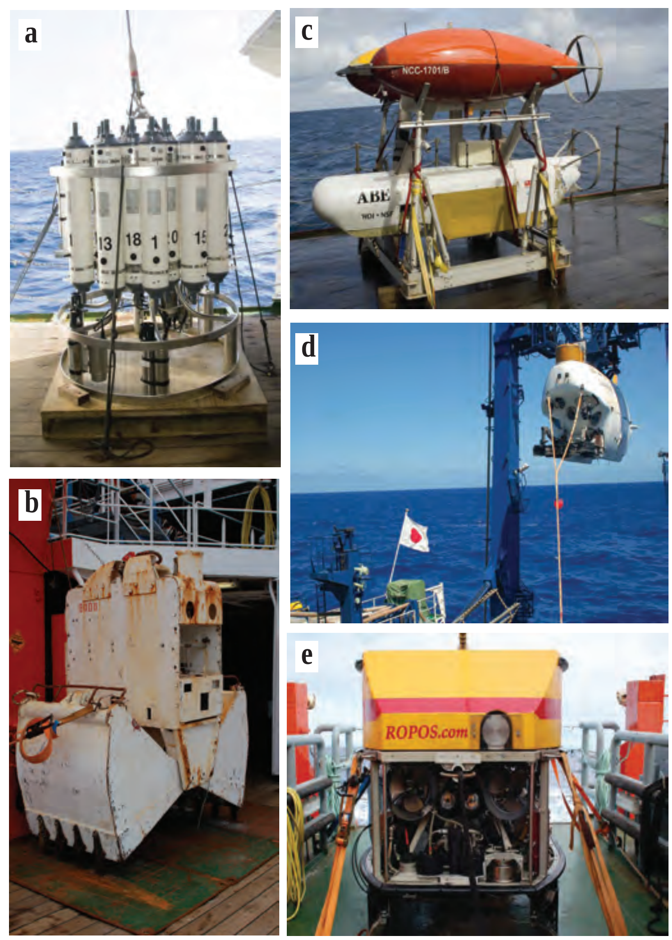

Figure 2. Since 2001, GNS Science has mounted six research expeditions to the Kermadec arc (NZAPLUME I, II, and III, ROVARK, and two legs of NZASRoF), as well as participating in nine cruises led by groups from Japan, Canada and Germany. These cruises have involved the use of plume mapping (CTDO), manned (Shinkai, Pisces) and unmanned (ROPOS, QUEST) submersibles and autonomous underwater vehicles (AUVs e.g., ABE): a) CTDO rosette, R/V Sonne, July 2007, b) TV-grab, R/V Sonne, April 2007, c) ABE after a mapping mission on Brothers Caldera, R/V Sonne, July 2007, d) JAMSTEC submersible Shinkai 6500, being deployed in the Havre Trough, October 2006, e) ROV ROPOS on the R/V Sonne, April 2007.

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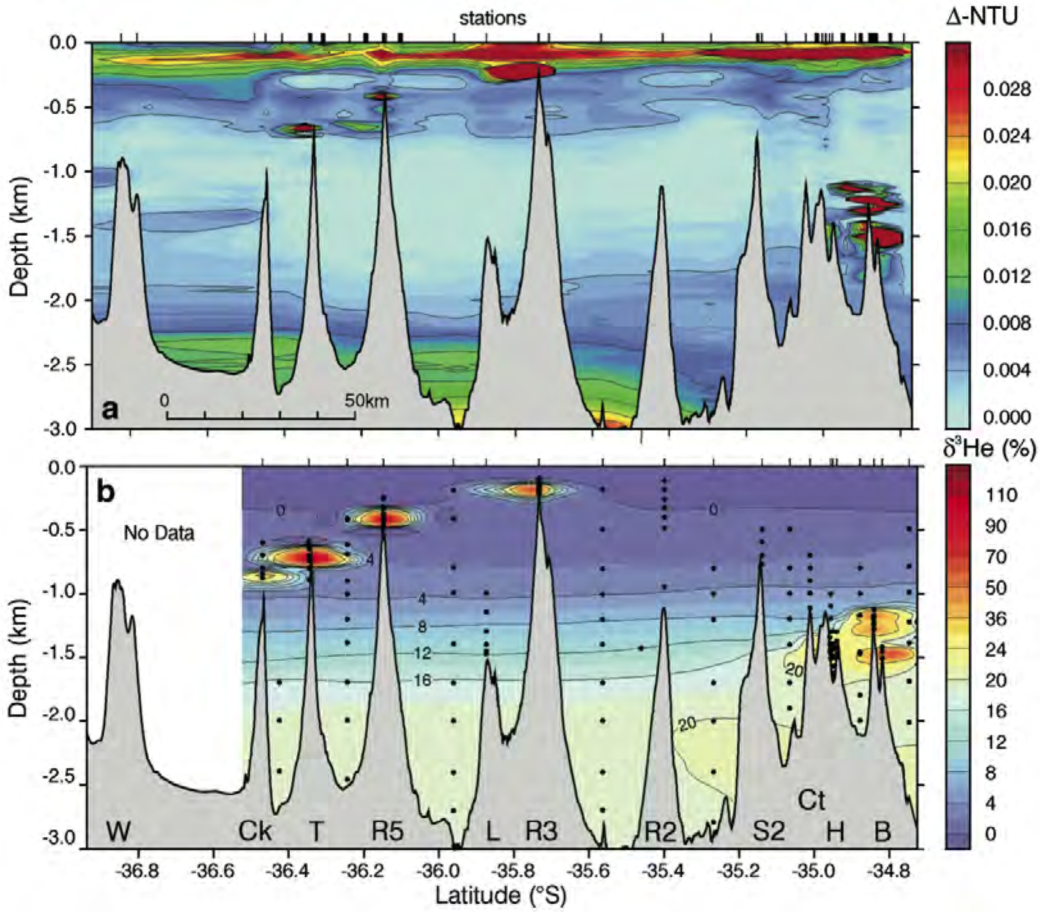

Figure 3. Longitudinal profile of the southern-most part of the Kermadec arc, showing contoured results for light scattering (a) and helium isotopes (b). Light scattering is represented as ΔNTU, where NTU is nephelometric turbidity units, a nondimensional optical standard. Volcano names are: W = Whakatane, Ck = Clark, T = Tangaroa, L = Lillie, R5 = Rumble V, R3 = Rumble III, R2 = Rumble II East, S2 = Silent II, Ct = Cotton, H = Healy, B = Brothers. After de Ronde et al. (2001).

During plume mapping exercises using the CTDO (Fig. 2A), discrete water samples are also collected, permitting more detailed ship- and shore-based geochemical and isotopic characterization, including total dissolvable Fe and Mn, CH_4, H_2S, and He isotopes (Fig. 4). Results from the Kermadec arc show that hydrothermal plumes originate from focused high temperature and diffuse low temperature venting at discrete volcanic cones in addition to more complex caldera systems (de Ronde *et al.* 2001). For example, venting occurs from both the cone site and the NW caldera wall at Brothers caldera (Figs. 5, 6). Given that submarine arc volcanoes have

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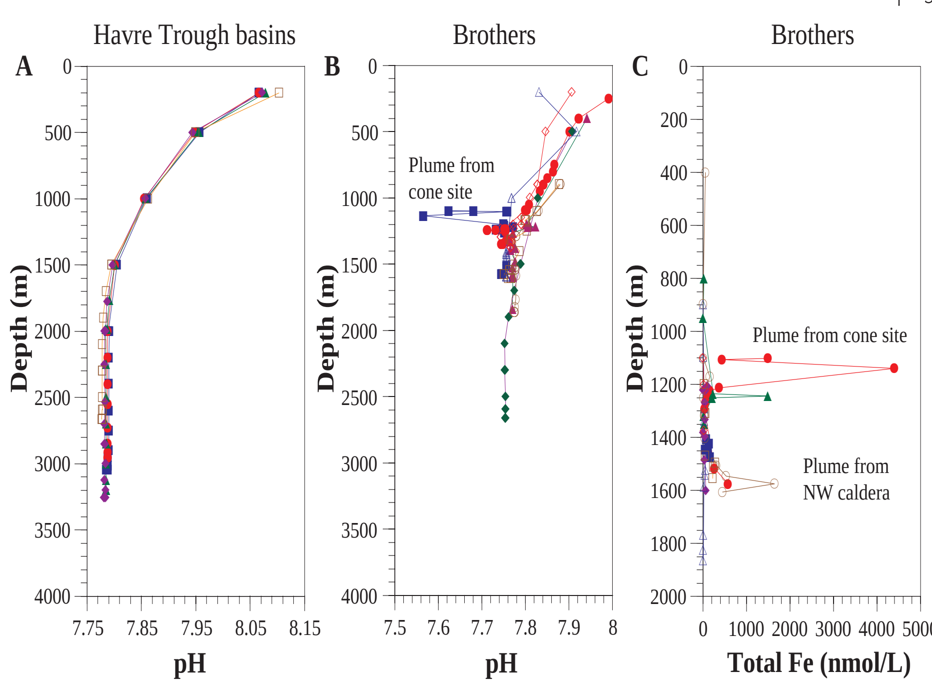

Figure 4. Depth profiles of pH for several basins in the Havre Trough (A) showing a typical background profile for pH. In contrast, over Brothers volcano, pH anomalies are evident, (B) in particular for the plume generated by venting at the cone site. Venting at the cone site and from the NW caldera site produces plumes that display clear anomalies in Fe concentration (C). Data collected during the 2007 ROVARK cruise (Leybourne et al., unpublished data).

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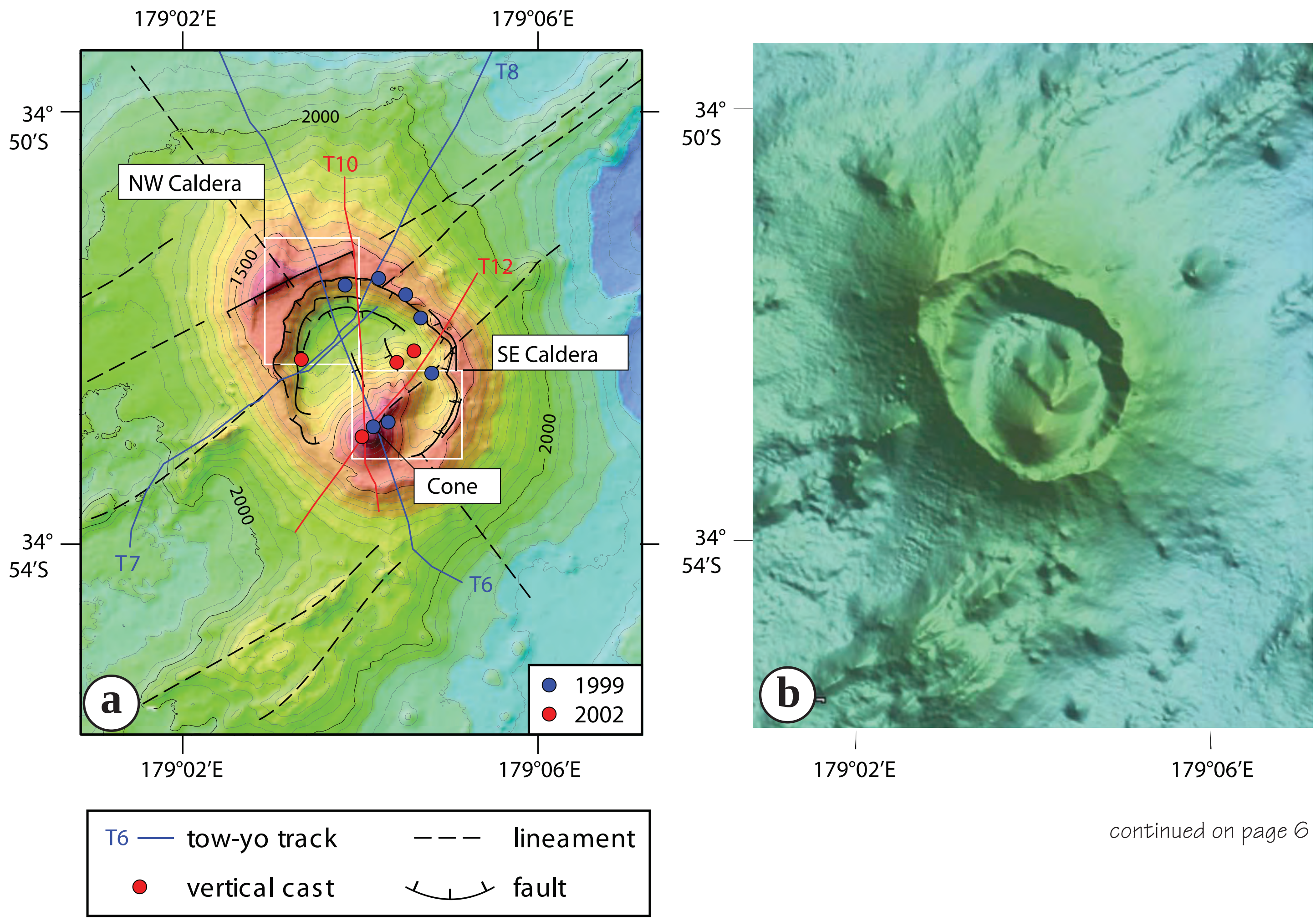

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Figure 5. Brothers volcano is 1,850 m deep caldera, ~11-13 km long by 7-8 km across, with a basal diameter of 3-3.5 km, surrounded by 290-530 m high walls. A volcanic cone rises 350 m from the caldera floor. A) Color bathymetry of Brothers volcano. Also shown are fractures, faults and volcanic structures that are generally aligned to the to the inferred regional basement fabric. The dots represent vertical casts using the CTDO for 1999 and 2002 studies, although additional vertical casts and tow-yo surveys were undertaken in 2007. Lines labeled "T" are tow-yo tracks (see text for details). Boxes outlined in white encompass the northwest caldera, southeast caldera, and cone sites, as indicated. B) Digital elevation model of Brothers caldera volcano based on gridded EM300 multibeam echosounding data at a cell size of 25 m (sunlight from the north). Figure from de Ronde et al. (2005).

depths to their summits ranging between > 1800 m and ~ 100 m, plumes occur predominantly in shallow and mid-water depths (Figs. 3, 5). The chemical composition of hydrothermal plumes along the Kermadec arc are different to those at mid-ocean ridges and commonly have elevated concentrations of Fe, H_2S and CO_2; Fe/Mn values range from 0.2 to 18, at the high end significantly greater than those typically found at mid-ocean ridges (Massoth & de Ronde 2006). In addition, because the depth of venting on arc volcanoes is typically shallower than occurs on the ridge crests, maximum venting temperatures are generally lower along arcs, constrained by the pressure-dependent boiling point of hydrothermal fluids. Although the frontal Kermadec arc has been systematically surveyed (critically, CTDO casts are performed between volcanic centers to properly define background values), only recently has exploration been extended into the Havre Trough with the 2007 ROVARK (NZASRoF`07) cruise.

Manned and unmanned submersibles have been deployed during a number of cruises to the Kermadec arc-Havre Trough over the last four years, including dives using *Shinkai 6500* in 2004 and 2006, 23 *Pisces V* dives in 2005, and *ROPOS* in 2007. More recently, the AUV ABE (Autonomous Benthic Explorer) has been deployed at

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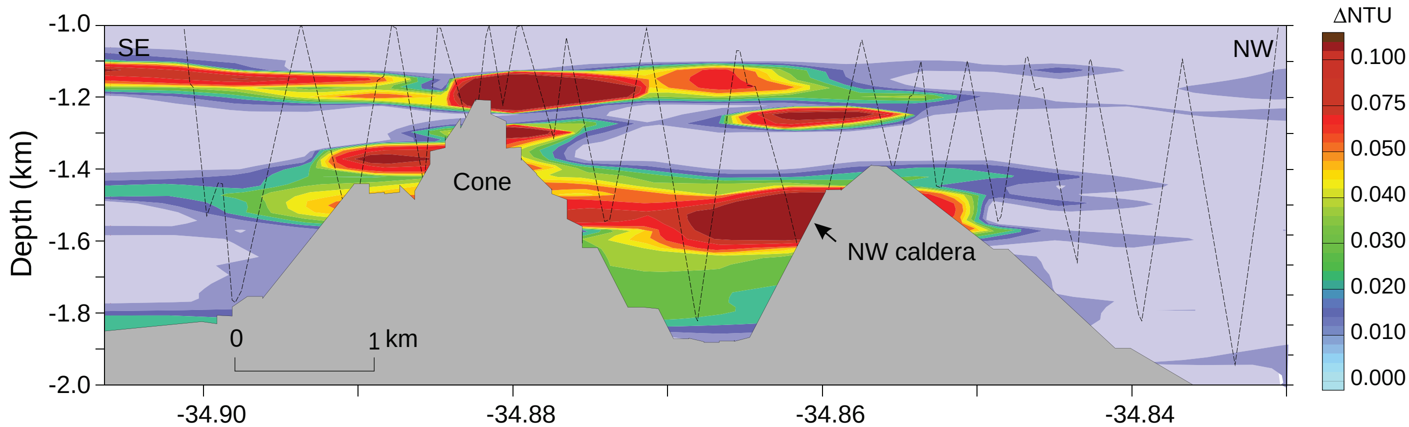

Figure 6. Light scattering measurements (ΔNTU) based on CTDO profiling of Brothers volcano in 1999. Note the presence of plumes that originate from distinct sites on Brothers Cone and the NW caldera wall. The thin sawtooth line indicates the tow-yo path of the CTDO array as it was towed across the volcano.

Brothers volcano during the 2007 ROVARK cruise where it was used to map the caldera floor at a resolution (< 2 m) not previously undertaken for a submarine volcano (initial results of this work are available at: http://www.oceanexplorer.noaa.gov/explorations/07fire/welcome.html). ABE was also equipped with a magnetometer and Miniature Autonomous Plume Recorders (MAPRs) to map in high resolution the magnetic signature associated with hydrothermal activity and the precise location of vent fields.

DETAILED STUDIES OF MINERALIZATION

Following initial dredging of sulfide samples from Brothers and Rumble II West calderas in 1996 (Wright *et al.* 1998), samples of vent fluids and sulfide chimneys have been recovered from a number of vents sites along the Kermadec arc. The most extensive exploration to date has been carried out at Brothers caldera volcano (de Ronde *et al.* 2005). Brothers is host to two distinct styles of active venting: 1) gas-rich, low-temperature (typically < 70°C) emanations from the young cone in the southern

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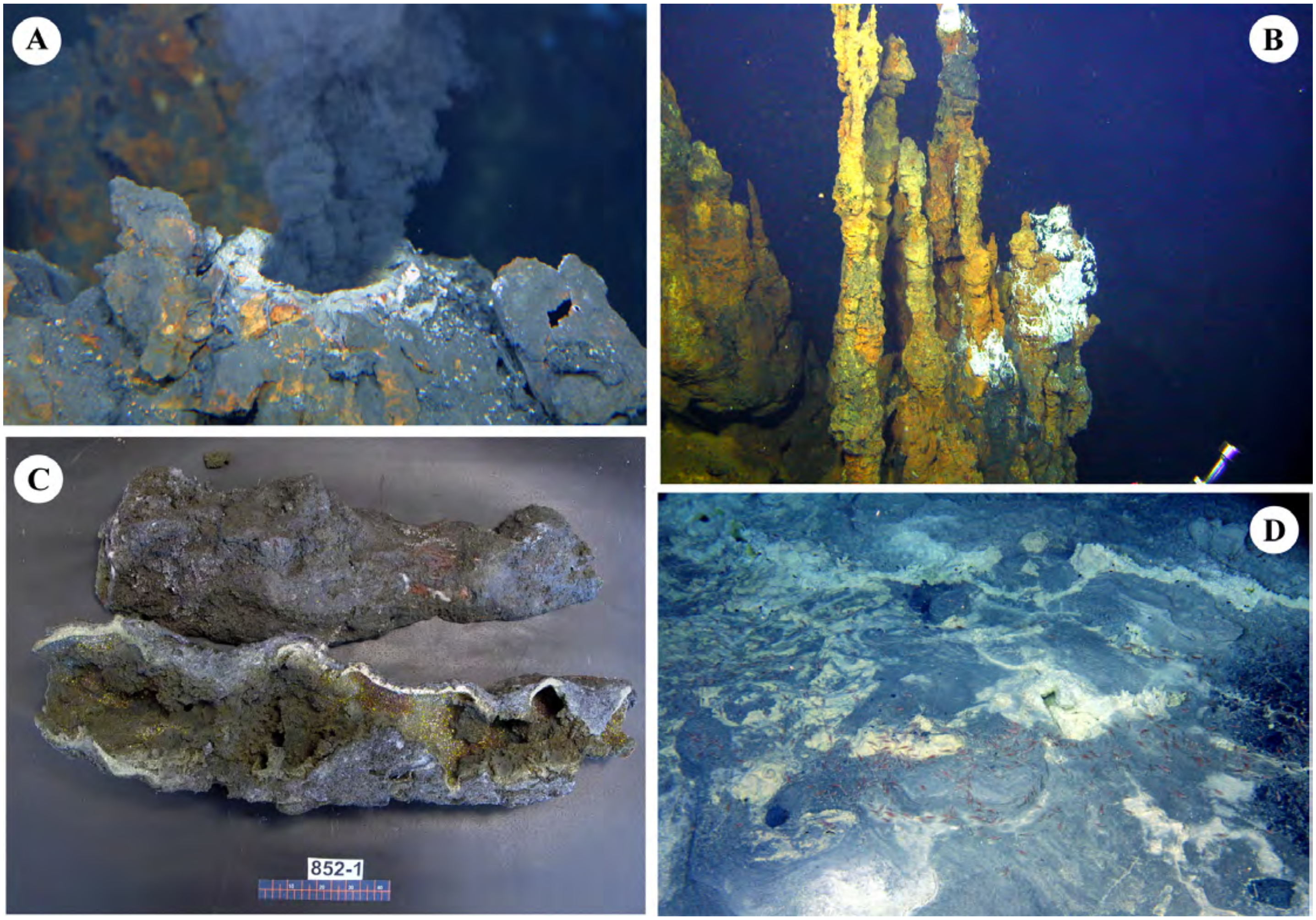

Figure 7. A) Black smoker at the NW caldera site, Brothers, venting at 274°C. Horizontal field of view ~ 0.5 m. B) Inactive chimneys at Brothers. Vertical field of view ~ 3 m (chimneys are ~ 5 m tall). C) Interior of massive sulfide chimney from Brothers, dominated by pyrite, chalcopyrite, sphalerite and barite. D) Diffuse venting (68°C) at the cone site, Brothers. The pale yellow/white material is dominantly elemental sulfur forming a crust over sediment. Horizontal field of view ~ 5 m.

part of the caldera, and 2) high-temperature (max 302°C) metal-rich emanations from the NW caldera site (Fig. 7). At the NW caldera site, sulfides crop out over an area ~200 x 600 m, with numerous 1-5 m tall sulfide chimneys (Fig. 7) (de Ronde *et al.* 2005). Numerous active chimneys occur around a depth centered at ~1,650 m. The walls of the NW caldera site are steep, with the active chimneys commonly perched on intervening benches and typically aligned orthogonal to the slope of the walls.

Microscopy and X-ray diffraction studies of sulfide samples recovered from Brothers indicate that mineralization is dominated by pyrite, marcasite, chalcopyrite, and sphalerite, hematite, goethite, and barite (de Ronde *et al.* 2005). Less abundant minerals include epidote, titanite, albite, quartz, cristobalite, anhydrite, natroalunite, pyrrhotite, arsenopyrite, enargite, bornite, intermediate solid solution, chalcocite, covellite, galena, rutile, birnessite, and native sulfur (Reyes *et al.* 2004; de Ronde *et al.* 2005).

Mineralization at Brothers is characterized by two dominant types: Cu-Fe-rich and Zn-Ba ± Pb-rich. In addition, mineralization at Brothers is relatively enriched in Au (especially with the Cu-rich mineralization), Ag, Tl, Ga, As, Sb, and Cd (de Ronde *et al.* 2005). Recent analytical developments have produced new techniques for age dating seafloor massive sulfide samples, based on $^{210}Pb/^{226}Ra$ and $^{226}Ra/Ba$ (Ditchburn *et al.* 2004; de Ronde *et al.* 2005). Results from Brothers and Rumble II volcanoes indicate sulfide chimney ages on the order of months to 1,200 years (Ditchburn *et al.* 2004; de Ronde *et al.* 2005).

CHALLENGES AND FUTURE DIRECTIONS

More recently, other submarine volcanic arcs have been investigated for hydrothermal activity, in particular the Mariana arc (e.g., Embley *et al.* 2006), but none have been explored as systematically as the Kermadec arc has. GNS Science, along with scientists from NOAA and the Italian Istituto Ambiente Marino Costiero (IAMC-CNR), in late 2007 explored using CTDO and swath mapping for the first time the entire Aeolian arc in the Mediterranean Sea.

There are currently three exploration companies

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dedicated to exploring for seafloor massive sulfides: 1) Nautilus Minerals, which has greater than 370,000 km^2 of tenements off-shore of Papua New Guinea, Fiji, Tonga, the Solomon Islands and, as of 2008, in the Havre Trough in New Zealand waters; 2) Neptune Minerals, which has exploration licenses of greater than 278,000 km^2 along the Kermadec arc in New Zealand waters as well as in the waters of Papua New Guinea, the Federated States of Micronesia and Vanuatu; and 3) Blue Water Minerals, Inc. Challenges include difficulties of mining in an active submarine arc setting, in particular the environmental impact on vent-associated communities. Nautilus Minerals is in the mine planning stages to exploit Cu-Au mineralization (Solwara 1) in 1500 m water depth in the Bismarck Sea, near Papua New Guinea. Solwara 1 is a relatively small deposit by the standards of Cu-Au deposits mined on land, with indicated reserves of 870 kt @ 6.8% Cu, 4.8 g/t Au, 23 g/t Ag and 0.4% Zn and inferred resources of 1,300 kt @ 7.5% Cu, 7.2 g/t Au, 37 g/t Ag and 0.8% Zn (at a 4% Cu cut off; www.nautilusminerals.com). Future exploration will likely involve development of geochemical and geophysical techniques to explore in older, inactive portions of arc systems (e.g., Colville Ridge; Fig. 1).

Acknowledgments

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The AAG Needs You as a Councilor

Each year the Association of Applied Geochemists needs motivated and energetic AAG Fellows to stand for election to the position of "Ordinary Councilor". Fortunately, each year some of our most outstanding Fellows are ready, willing, and able to meet this challenge. This is the annual article in EXPLORE summarizing the job and describing how one goes about getting on the ballot. It is our sincere hope that this might entice more Fellows to step forward for election to this most important position.

Job Description

The AAG By Laws state that "the affairs of the Association shall be managed by its board of directors, to be known as its Council". The affairs managed by Council vary from reviewing and ranking proposals to host our biennial Symposium to approving application for new membership to developing marketing strategies for sustaining and growing our membership. These affairs are discussed and decisions made at Council teleconferences usually held 3-4 times per year. Each teleconference lasts about 90 minutes. In addition, there is often a running email discussion about a selected issue or two between each teleconference. So for a commitment of about 8 hours of your time per year, you can help influence the future of your Association. If you want to spend more than the minimum time required, there is plenty of opportunity to do so through committee assignments and voluntary efforts that greatly benefit the Association.

Qualifications and length of term

The only qualification for serving as Councilor is to be a Fellow in good standing with the Association. Please note the difference between being a Member of AAG and being a Fellow. A Fellow is required to have more training and professional experience than a Member. Consult the AAG web site, Membership section, for further details. If you are not currently a Fellow and have an interest in serving on Council, please go through the relatively painless process of converting to Fellowship status in AAG.

Each Councilor serves a term of two years and can then stand for election to a second two-year term. The By Laws forbid serving more than two consecutive terms, although someone who has served two consecutive terms can stand for election again after sitting out for at least one year. Elections are usually held in the fall of the year for a term covering the following two years. Our next election will be in the fall of 2008 for the term of 2009-2010.

How to get on the ballot

If you are interested in placing your name into consideration for election to AAG Council, simply express your interest to the AAG Secretary (Dave Smith, dsmith@usgs.gov) by August 31, 2008 and include a short (no more than 250 words) summary of your career experience. All that is asked is that you bring energy and ideas to Council and are willing to share in making decisions that will carry the Association forward into a successful future. We look forward to hearing from you.

David B. Smith
Secretary,
Association of Applied Geochemists

President's Message...

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On the education front, the AAG has sponsored a number of very successful workshops on various aspects of exploration geochemistry at conferences over the last year. AAG members are also involved in delivery of short courses and workshops within industry. With few universities able to offer applied geochemical courses that provide students a broad introduction to the application of geochemistry to mineral exploration, AAG will have a growing mandate and opportunity to fill the void and expand its offerings to industry and possibly universities. I should, however, relate the very encouraging trend in geology (and geochemistry) enrolments at my own institution over the last year – 26 are taking the third year geochemistry course (a 25-year record).

David Cohen
President, Association of Applied Geochemists

3D Geochemical and Mineralogical Model of the Sleeper Low Sulphidation Gold System, Nevada, U.S.A.

INTRODUCTION

Hydrothermal mineral systems, including low sulphidation gold systems in Nevada, are often zoned geochemically and mineralogically. This zonation creates the opportunity to use relationships in surface and drill-hole data to vector from the periphery of a mineralized system to the location of undiscovered ore within the system. Two analytical developments have made it possible to acquire the type of data needed to define these zonation relationships: 1) the inductively coupled plasma mass spectrometer spectrometer (ICP-MS), which provides inexpensive, multi-element data with low detection limits, and 2) the analytical spectral device (ASD), capable of identifying and estimating relative abundance of clay and other alteration minerals. The interpretation of these types of data, in excess of 60 variables, is facilitated by interpolating element or mineral distributions among drill holes using 3D gridding techniques to create 3D block models. In this form, data relationships and spatial patterns can be fully explored using 3D visualization exploration tools. Gocad 3D pattern recognition software provides a way to identify and illustrate zonation characteristics and to develop targeting vector criteria. The display of these features in relation to modeled and integrated 3D geology (lithologies, faults), 3D bodies generated from inversion of geophysical data, and surface data can further aid in identifying new exploration targets. An example of the wealth of information that can be derived from data modeling and 3D visualization is presented using data from the Sleeper deposit located in Nevada, U.S.A.

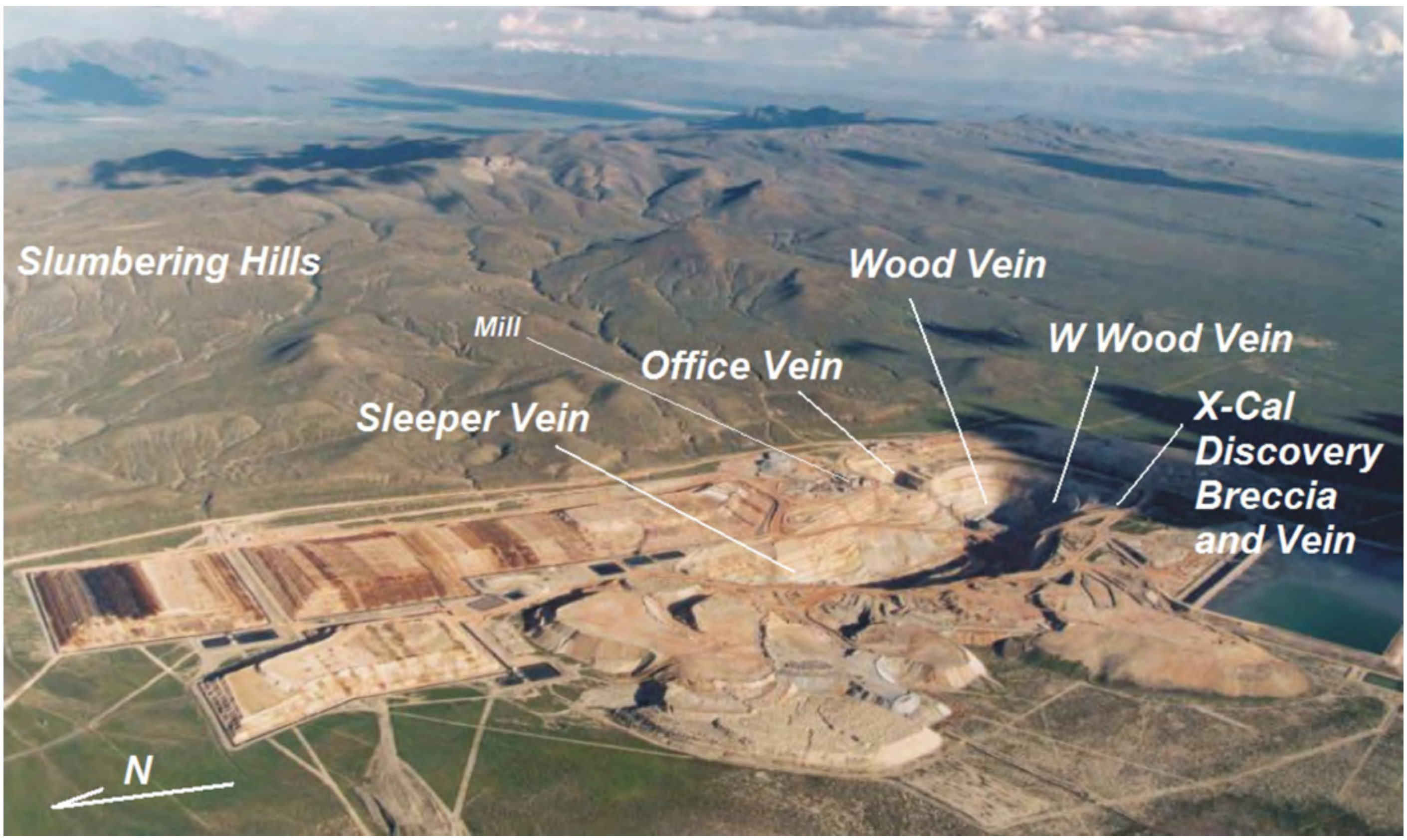

Figure 1. Areal view of the Sleeper open pit looking SE along the Cortez Gold trend of Nevada, U.S.A.

The Sleeper deposit is a low sulfidation, bonanza gold vein ore body enveloped by bulk tonnage, low grade disseminated gold ore (Wood & Hamilton 1991; Nash & Trudel 1994; Nash et al. 1995). It was a shallow, Nevada range-front, pediment discovery drilled by Amax in 1984 (Wood & Hamilton 1991). Open pit mining took place from 1986 to 1996, originally centered on the Sleeper Vein itself. Successful exploration lead to the discoveries of the Wood, Office, and West Wood Veins and the open pit was expanded to mine those ore bodies (Thomason et al. 2006, Wood & Hamilton 1991) (Fig. 1). Recorded mine production was 1.682 M oz Au, 2.8 M oz Ag (Thomason et al. 2006).

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3D Geochemical and Mineralogical Model... *continued from page 12*

In 1996 X-Cal Resources Ltd. (X-Cal) optioned the property from Amax, combined it with their contiguous land holdings, and began exploration for additional mineralization related to the Sleeper gold system (Thomason et al. 2006). X-Cal drilled the X-Cal Discovery Breccia just outside the SW end of the pit (Fig. 1). A 2004 to early 2006 exploration joint venture of the property produced a large volume of exploration data that has recently been integrated and synthesized with the past mine data in 3D, utilizing Gocad pattern recognition software.

Datasets include: Au and Ag data from historic mine and recent exploration drill-holes; new multi-element, low detection ICP-MS data and spectral reflectance (ASD) mineralogical data on select holes; geophysical surveys (detailed air magnetics, pre-mine IP, CSAMT, gravity), and surface geochemistry (rocks, soils, soil gas). The 3D modeling provides new insight into the Sleeper deposit, mineralization controls, alteration patterns and exploration potential. This paper presents a refined geologic framework for the Sleeper system and newly recognized multi element and alteration mineral zoning patterns related to gold mineralization.

ACKNOWLDEDGEMENTS

Shawn Kennedy, President of X-Cal, is the force behind the Sleeper District exploration with his vision to fully realize the gold potential of the Sleeper district with the development of multiple open pits within the range-front pediment. He has assembled a team of experienced consultants whose observations, interpretations, and ideas have significantly contributed to the current understanding of the system. These include geologists, Dr. Ken Snyder, Robert Thomason, Winthrop Rowe, Larry Martin, Larry Kornze, Keith Blair, and geophysicist, Jim Wright. Dr. Richard Sillitoe and Dr. Jeffrey Hedenquist provided key insights and interpretations with respect to the geology and mineral potential based on site visits to the property.

LOCATION

The Sleeper deposit is located 51 miles by road, NNW of the town of Winnemucca in Humboldt County, central Nevada, U.S.A. (Lat. 41.336, Long. –118.051) on a NW extension of the Eureka, Cortez, Battle Mountain gold trend (Fig. 2).

GEOLOGY

Principle host rocks of the Sleeper veins are Sleeper rhyolite interbedded with volcaniclastic rocks deposited in a fault controlled basin along the range-front (Wood & Hamilton 1991; Nash & Trudel 1994; Nash et al. 1995). These rocks are part of a Miocene bimodal volcanic sequence dated at 16.5 Ma with mineralization and alteration in the range 14-16.5 Ma (Conrad et al. 1993). The Sleeper rhyolite has been interpreted as a flow dome complex (Conrad et al. 1993; Nash et al. 1995). A more recent interpretation based on logging of new holes and re-logging of past holes is that the Sleeper rhyolite is either

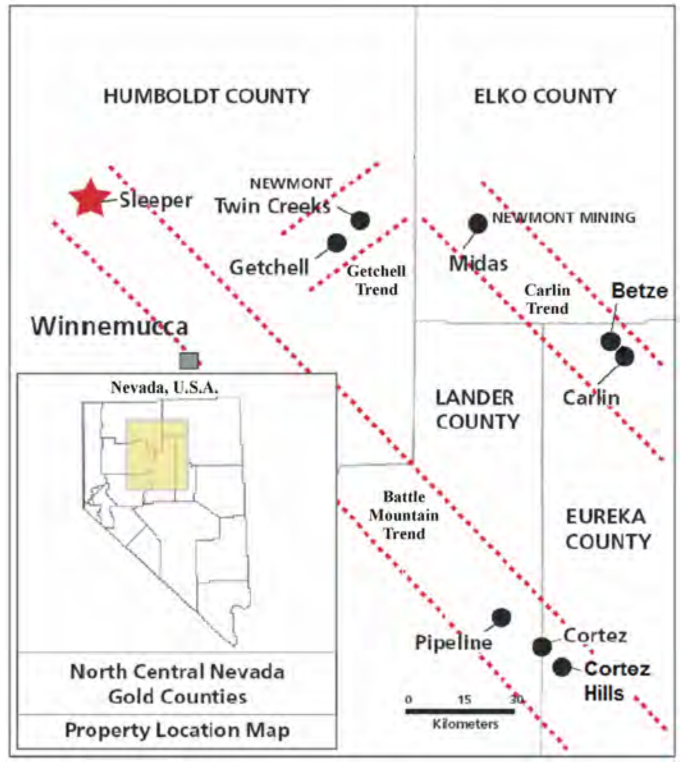

Figure 2. Location of the Sleeper Deposit in Nevada, U.S.A.

a sill or an intrusive cryptodome complex (laccolith-like) within tuffaceous rhyolites (Sillitoe 2006). Metamorphic basement rocks of the Upper Triassic and Jurassic Auld Land Syne Group (Wilden,1964) are present beneath the volcanic sequence and are locally mineralized.

A distinctive mafic marker unit (pillow basalt) in the Miocene sequence is present beneath the Sleeper Rhyolite. Offsets on this contact provide evidence of the basin faults and recurrent faulting which controlled gold mineralization. Previous recognition of abundant and systematic relief on the hanging wall (HW) contact surface of the mafic marker unit (early cross sections of Oviedo 1998; Nash & Trudel 1994; Nash et al. 1995; Blair 2005) is clearly evident using 3D modeling (Fig. 3). The geometry (relief) of the HW contact surface is interpreted to reflect composite horst and graben structures controlled by intersecting NS, NE, EW and NW trending normal faults. Sleeper rhyolite and other subsequent Miocene

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3D Geochemical and Mineralogical Model... continued from page 13

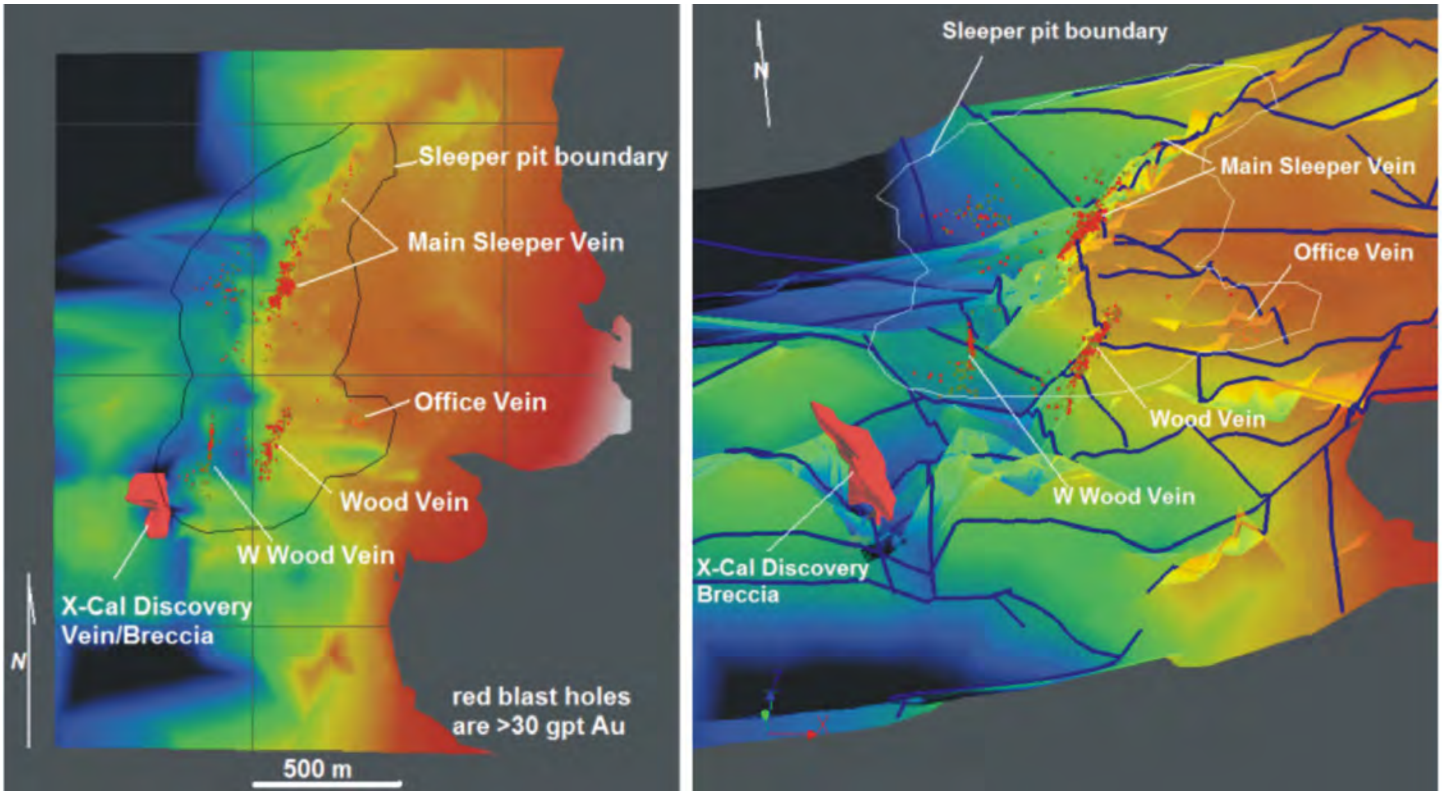

Figure 3. Left a: Structure contour map (colored by Z elevation) of modeled HW contact surface of basalt unit within host sequence beneath Sleeper rhyolite. High grade open pit blast holes defining veins and modeled surface of X-Cal Discovery Breccia are shown in red. Right b: Oblique view looking NNE illustrates the correlation of gold with interpreted graben bounding faults. The ore bodies are within Sleeper Rhyolite which overlays the modeled HW contact of the basalt unit of the mine host sequence.

basin fill units were deposited into the horst, graben, range front basin and its associated sub-basins. Gold vein, breccia and disseminated mineralization is present along reactivated, basin controlling normal faults. Known bonanza gold veins mimic the geometry of reactivated basin growth faults along composite graben boundaries (Fig. 3).

ANALYTICAL METHODS AND DATA PROCESSING

Drill-hole samples were analyzed using a near total 4-acid digestion and ICP-ES/ICP-MS determination. Partial digest aqua regia data for some drill-holes were incorporated into the database for elements that could be satisfactorily leveled with the total digest. All analyses were completed by ALS-Chemex Ltd. The geochemical data were converted to log (base 10) units to facilitate display and spatial analysis. The occurrence and relative abundance of alteration minerals were determined for selected samples using ASD (spectral reflectance) analysis. Relative abundances were converted from presence or absence to numeric values of 1 and 0. Notations of trace, weak and strong were assigned values of 2, 3, and 4 respectively. The down-hole data were gridded with GOCAD 2.07 software to produce individual element block models (xyz cell dimensions of 50x50x5 m) using: 1) an inverse distance squared algorithm, 2) an unconstrained search radius of 150 m in all directions, and 3) a restriction of gridding to the region from the surface topography to a vertical depth of 30 m below the end of drill

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3D Geochemical and Mineralogical Model... *continued from page 14*

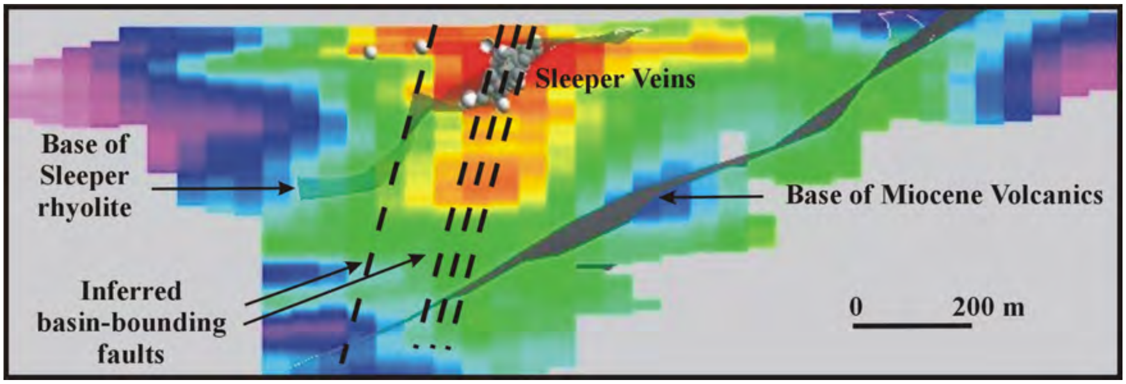

Figure 4. Gridded image of the Au distribution in an E-W section through the Sleeper Vein (yellow > 0.003 oz/ton). White spheres are Au assays >3 oz/ton.

holes. The alteration minerals identified by ASD were gridded using a nearest neighbor categorical interpolation.

GEOCHEMICAL MODEL

The Sleeper low sulphidation Au-Ag system is related to vertical plumes in Au, Ag, and As concentration emanating from depth that trace out fluid pathways along high angle structures (Fig. 4). Within the large system plume, there is a general zonation east to west from more Ag dominated to more Au dominated. The basalts and, in some cases, the ryholite, are altered in the area of the system plume as expressed in depletion of Na and other elements east of the deposit; Ca-Mg depletion is centered on the deposit and along a NW trending corridor, and enrichment in K and Rb occurs on the outer margin of ore to the west. The high grade Au veins are located along the western fringe of the system plume at the boundary between K-Rb and Na-Ca-Mg alteration signatures. The distributions of anomalous Ag, As, Ge, S, Se, Te, and Tl concentrations are similar to that of the Ca-Mg depletion alteration. The distributions of Sb, Mo, Re, and W are more closely associated with the K-Rb enrichment alteration.

High grade mineralization appears to have a strong elevation control that also has an expression in other elements. The base of high grade mineralization coincides with the bottom of a flat-lying, saucer-shaped zone of Zn depletion at 120-150 m depth. Above this boundary, Ba, and Mo concentrations are enriched while below it, As, S, and Zn concentrations are enriched. This feature is interpreted to be the reflection of hypogene oxidation related to a boiling horizon. The highest grade Au and Ag intercepts are generally restricted to the oxidized portion of the profile. The base of oxidation, visually, is generally at a similar depth to the lower limit of Zn depletion but can be as much as 50-60 m higher in the profile. The observed zonation sequence relative to the redox boundary is believed to be hypogene in origin as it differs significantly from that related to supergene oxidation (Jackson 2007). Supergene Au has been noted in the upper 30 m of bedrock (Saunders 1993) where a flat-lying Au layer is observed (Fig. 4).

MINERALOGIC ALTERATION MODEL

A zoned sequence of clay minerals is present from east to west in the order of illite → kaolinite-buddingtonite-illite(NH4) → montmorillonite → nontronite (Jackson 2007). The boundaries between the various zones are more or less vertical or steeply dipping to the west and are observed to cross-cut stratigraphy. The high grade veins are positioned within the buddingtonite-illite(NH4) halo within the larger kaolinite zone. The distribution of buddingtonite resembles that of two vertical plumes that flatten out at higher elevations to encompass the high grade veins (Fig. 5). The location of at least one of these is spatially associated with a NW-trending structural corridor. The distribution of silica (quartz, opal, chalcedony) forms an outer boundary to the Au system and, in some areas,

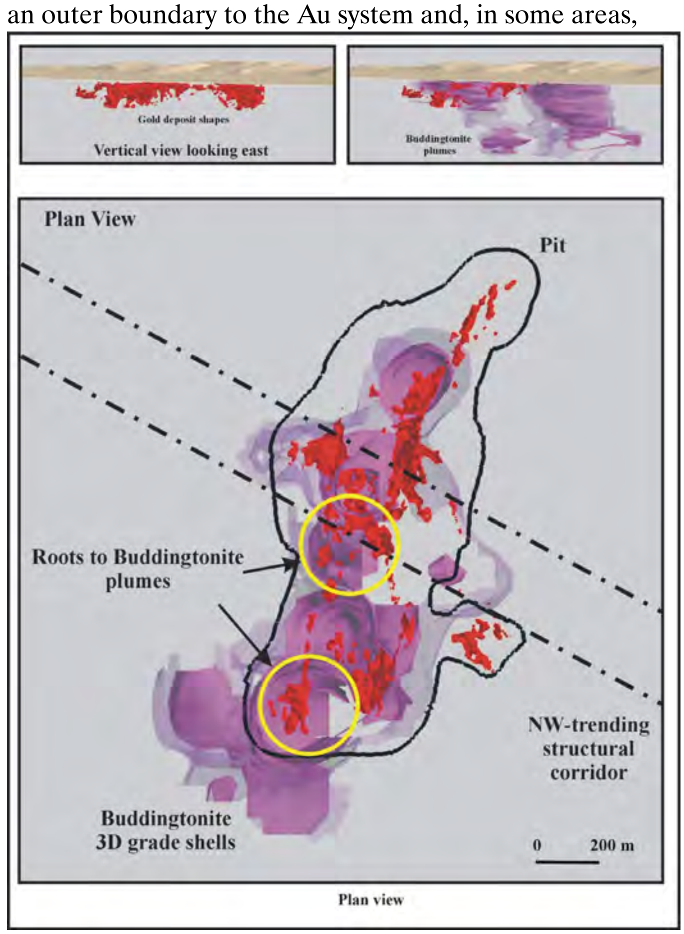

Figure 5. Buddingtonite alteration plumes associated with the Sleeper Vein gold deposits. Distribution of gold mineralization shown in red as determined from blast hole data. Part of the Au shape is obscured in the upper right inset due to the buddingtonite 3D shape.

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3D Geochemical and Mineralogical Model... *continued from page 15*

underlies it. The eastern margin of the silica zone is located at approximately the same location as the eastern margin of the montmorillonite halo. Chalcedony is present within a NW structural corridor that cross-cuts the range-bounding structures whereas opal is distributed to the north and south of the chalcedony zone within the quartz halo. Another zoned sequence is that of jarosite → gypsum → CO_3-bearing minerals. The distribution of jarosite is centered on the high grade veins to a depth of about 100 m below them, locally deeper. Gypsum is present in a halo marginal to the jarosite zone both laterally and beneath it. Samples with CO_3 spectra occur within the gypsum halo but exclusive to samples with gypsum. A long string of CO_3-bearing samples is located at depth between the two buddingtonite plumes. The distribution of hematite is generally restricted to above the redox boundary. However, within the oxide zone, the distribution of abundant hematite is centered on the high grade veins with possible extensions along the NW structural corridor that intersects the range-bounding structures. This relationship is likely due to the higher concentration of sulphide minerals surrounding the deposit that were subjected to oxidation. Associated with sulphide oxidation is the presence of alunite above the redox boundary in close proximity to the high grade veins.

3D SPATIAL DATA INTEGRATION AND PATTERNS

The distribution of high grade Au and Ag appears to reflect the concurrence of 3 main features: 1) a major lithologic contact, 2) high angle structures, and 3) a redox gradient. The coincidence of the oxidized zone (boiling horizon) with open high angle structures developed at the rhyolite/basalt contact created conditions favourable for the formation of high grade Au veins. Many of the alteration zones have a geochemical expression. The distribution of illite is most similar to that of Na depletion alteration. The relative abundance of illite is closely correlated with the intensity of Na depletion. The distribution of jarosite with its peripheral zone of gypsum is similar to that of depletion in Ca and Mg and anomalous concentrations of Ag, As, Ge, S, Se, Te, and Tl. The kaolinite-buddingtonite zone is generally coincident with anomalous K, Rb, Sb, Mo, Re, and W. The opal-chalcedony zone is the host for anomalous Bi concentrations. The hematite zone is located within the shallow saucer-shaped feature defined by Zn depletion. The Sleeper system lies within the boundary of a large magnetic low. In 3D, the limits of the Ca-Mg depletion anomaly correspond closely to the boundaries of the magnetic low. This pattern suggests that the alteration process resulted in both mafic mineral and magnetite destruction.

A NW trend to Au and As anomalies observed in the 3D model is traceable further to the south-east by weak Au and As anomalies in shallow soils covering the bedrock of the adjacent range. This feature is expressed as a disruption in the strong gravity response located along the margin of the range, possibly as a result of alteration.

CONCLUSIONS

The full integration of all geologic, geochemical, and geophysical data in 3D space has contributed to a better understanding of the Sleeper mineral system including mineralization controls, alteration patterns, and exploration potential. An important component of this integration was 3D modeled down-hole geochemical data and mineralogic ASD data.

Some key observations include: 1) mineralization is focused along basin-bounding normal faults; 2) Au, Ag and

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alteration patterns are larger scale than the discreet veins and graben bounding fault controls 3) the Au core within the Sleeper graben grades eastward to a Ag rich zone beyond the pit boundary; 4) trace element signatures and alteration mineralogy are zoned in relation to the deposit in a very systematic and predictive fashion; 5) high grade Au mineralization is floored by a saucer-like zone of Zn depletion and other redox related signatures reflecting hypogene oxidation due to boiling; and 6) mineral trends and alteration signatures relate well to features in other data sets such as airborne magnetics, gravity, IP, and soils.

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24th International Applied Geochemistry Symposium, June 1-4, 2009. Hosted by the University of New Brunswick in Fredericton, New Brunswick CANADA. Contact Dave Lentz for more information: dlentz@unb.ca

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THE ASSOCIATION OF APPLIED GEOCHEMISTS

Association of Applied Geochemists web site:

appliedgeochemists.org

CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental and other areas of applied geochemistry. These events also appear on the AAG web page at: www.appliedgeochemists.org

2008

• June 29 - July 4, 2008. **Geochemistry of Mineral Deposits**, Il Ciocco, Lucca (Barga), Italy. http://www.grc.org/programs.aspx?year=2008&program=geochem

• July 5-9, 2008. **SEG-GSSA 2008 Resurgence of Economic Geology and the Minerals Industry in Africa,** Joint Conference of the Geological Society of South Africa and SEG Incorporating GEOFORUM 2008. Johannesburg, South Africa. Website: http://www.seg-gssa2008.org/

• July 15, 2008. **Impact of Analytical Innovation on Geochemical, Environmental, Exploration and Food Science**, London, England.
Website: http://geoanalyst.org/temp/ramsey.html

• July 13 -18, 2008. **Goldschmidt 2008,** Vancouver, BC, Canada. Web site: www.goldschmidt2008.org

• July 20-24, 2008. **Australian Earth Sciences Convention (AESC) 2008,** Perth, Australia. Website: www.iceaustralia.com/aesc2008

• August 1- September 3, 2008. Australasian Institute of Mining and Metallurgy, New Zealand Branch Annual Conference. Wellington, New Zealand. Website: http://www.ausimm.co.nz

• August 5-14, 2008. **33rd International Geological Congress**, Oslo, Norway. Website: http://www.33igc.org.

• August 10-15, 2008. **9th International Kimberlite Conference (9IKC)** Frankfurt, Germany. Website: http://www.9ikc.uni-frankfurt.de/

• August 18-22, 2008. **8th Symposium on the Geochemistry of the Earth's Surface**: Joint Meeting of the IAGC, Minsoc and Natural History Museum, London, UK. Contact: M.E. Hodson, m.e.hodson@reading.ac.uk

• September 1-4, 2008. **XIII World Water Congress - Global Changes and Water Resources—confronting the expanding and diversifying pressures** Montpellier, France. Website: http://wwc2008.msem.univ-montp2.fr

• September 8-10, 2008, **9th International Congress for Applied Mineralogy,** Brisbane, Australia. Website: http://www.icam2008.com

• September 14–18, 2008, **5th International Conference on Uranium Mining and Hydrogeology.** Freiberg, Germany. Website: URL: http://www.geo.tu-freiberg.de/umh

• October 2-3, 2008. **2008 NGWA/U.S. EPA Remediation of Abandoned Mine Lands Conference**. Denver, USA. Website: www.ngwa.org/DEVELOPMENT/conferences/details/0810025019.aspx

• October 5-8, 2008. **Geological Society of America Annual Meeting**, Houston, Texas, USA. Website: www.geoscoiety.org/meetings/index.htm

• November 4–6 2008. **22nd Colloquium of African Geology and 13th Conference of the Geological Society of Africa**. Hammamet, Tunisia. E-mail: afric2008@gmail.com

• December 15-19, 2008. **American Geophysical Union Fall Meeting**. San Francisco, USA. Website: www.agu.org/meetings/fm08/

2009

• May 24 - 27, 2009. **Geological Association of Canada/Mineralogical Association of Canada Annual Meeting** Toronto, Canada.

• June 1 - 4, 2009. **24th International Applied Geochemistry Symposium,** Fredericton, New Brunswick, Canada Website: http://www.unb.ca/conferences/IAGS2009

• June 22 - 26, 2009. **Goldschmidt 2009.** Davos, Switzerland. Website: http://www.goldschmidt2009.org/

• August 17-20, 2009. Society for Geology Applied to Mineral Deposits 10th Biennial Meeting, Townsville, Australia. Email: SGA2009@jcu.edu.au

• September 7-11, 2009. **Geoanalysis 2009**. Drakensberg Region, South Africa. Website: http://geoanalysis2009.org.za

2010

• May, 2010. **Geological Association of Canada/Mineralogical Association of Canada Annual Meeting** Calgary, Canada.

• July 14-18, 2010. **Goldschmidt 2010.** Knoxville, USA. Website: www.geochemsoc.org/news/conferencelinks/

2012

• August 5–15, 2012. **34th International Geological Congress**, Brisbane, Australia. Website: http://www.ga.gov.au/igc2012

Please let this column know of your events by sending details to:

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Book Review

Introduction to Mineral Exploration

(second edition), C.J. Moon, M.K.G. Whateley, A.M. Evans (editors), Blackwell Publishing, Oxford, 2006, 481 pp., £34.99, ISBN 1-4051-1317-0 (paperback).

This book aims to introduce to geologists the principles and some case studies of mineral exploration. It is divided, therefore, into two parts. The first part, of 11 chapters, explains the principles of individual subjects or knowledge fields involved in mineral exploration. The second part, of six chapters, demonstrates case studies of exploration for different types of mineral deposits. As any mineral explorationist is never an expert in all, but in some, of the knowledge fields involved in mineral exploration, this book is appropriately a volume of multi-authored chapters, in each of which an author or a group of authors contributes his or their expertise.

The first three chapters deal, respectively, with economics, mineralogy and geology of mineral deposits. Chapter 1, by Moon and Evans, provides a concise introduction to mineral economics. It begins with definitions of terms, such as ore (of either metallic or non-metallic mineral deposits). It then explains factors of economic mineral recovery, choice of exploration areas and, most importantly, the rationale of mineral exploration. Chapter 2, by Evans, discusses the importance of mineralogical examinations to the extraction of ore minerals. At the beginning, it aptly warns the [aspiring] mineral explorationist about the difference between ore and gangue, as ore minerals in some deposit-types may be gangue in other deposit-types and vice versa. It then explains various methods of mineralogical investigations and the mineral properties that are important to examine. Chapter 3, by Evans and Moon, provides a simple introduction to mineral deposit geology and models. As the chapter deals only with some key features of mineral deposit geology, which is nonetheless a good start for aspiring mineral explorationists, the authors refer the readers to books dealing specifically with the genesis of mineral deposits. In addition, the chapter discusses the importance as well as the pitfalls of using mineral deposit models in mineral exploration.

The next two chapters deal with aspects of the early and later stages of mineral exploration. Chapter 4, by Moon and Whateley, explains reconnaissance exploration and the geo-political aspects that might come into play when acquiring land for exploration in different countries. A short section on application of GIS (geographic information systems) to regional-scale prospectivity mapping would have been a good addition to this chapter, although this topic is treated in a later chapter. Chapter 5, by Moon and Whateley, explains aspects of prospect-scale exploration, in which the key requirement is to explore an area at the lowest cost but without missing significant targets.

The next three chapters deal, respectively, with geological, geophysical and geochemical methods of mineral exploration. Chapter 6, by Whateley, is an introduction to geological remote sensing. It explains briefly the concepts of processing and interpretation of digital space-borne images and analogue air-photos of the Earth's surface in order to identify geological indications of exploration targets. Chapter 7, by Milsom, explains with geophysical methods. It is a good review of the basic principles of individual geophysical methods as well as the advantages and disadvantages of applications of each method to mineral exploration. Chapter 8, by Moon, covers exploration geochemistry. It provides a useful review of do's and don'ts in geochemical exploration surveys, especially about which sampling media to consider in areas of different geomorphology and climatic conditions.

Chapter 9, by Moon and Whateley, explains how mineral exploration data are digitally-captured, stored, analyzed and integrated in order to extract useful pieces of spatial information via the application of GIS. It provides an example of GIS-based district-scale mapping of mineral prospectivity; that is, to delineate areas with high likelihood or probability of mineral deposit occurrence.

The next two chapters deal with evaluation of mineral deposits. Chapter 10, by Whateley and Scott, explains evaluation techniques, which involve sampling and geostatistical analysis in order estimate ore reserves and calculate ore grades. Chapter 11, by Scott and Whateley, explains project evaluation or mine valuation via (pre-) feasibility studies involving the analysis of geo-political and socio-economic conditions where a project is located as well as the analysis of cash flows. These procedures are usually handled by mining engineers, but it is important that mineral explorationists have at least basic knowledge about these subjects.

The next chapters are case studies demonstrating the various principles explained in the preceding chapters to explore for different types of mineral commodities. Chapter 12, by Whateley and Barrett, is about development of an aggregate quarry in England. Chapter 13, by Whateley, is about coal exploration in Turkey. Chapter 14, by Moon and Whateley, is about exploration

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Introduction to Mineral Exploration...

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of paleoplacer-type gold deposits in South Africa. Chapter 15, by Evans and Moon, is about exploration for volcanic-associated (or volcanogenic or volcanic-hosted) massive sulfide (VMS) deposits in eastern Canada. Chapter 15, by Whateley, Bell and Moon, is about exploration for disseminated-type of precious metal deposits in Nevada (U.S.A.). Chapter 17, by Moon, is about diamond exploration in northern Canada.

At the end of every chapter, readers are referred to highly relevant literature aside from those listed in the reference list at the end of the book. The book is well illustrated with grey-scale but high quality figures. Moreover, it is well written.

The treatment of some subjects in the individual chapter may be shallow, but that is to be expected considering the broad spectrum of subjects covered by the book. The book has, however, more than just achieved its purpose because it is more than just an introduction to mineral exploration. It has demonstrated practical applications of the principles of the various knowledge fields in mineral exploration. The book could serve as the main or adjunct textbook for university courses related to mineral exploration. It could also serve as daily reference in the practice of mineral exploration. With its affordable price, students and practitioners of mineral exploration and geological libraries should be able to obtain a copy of this book.

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RECENT PAPERS

This list comprises titles that have appeared in major publications since the compilation in **EXPLORE** Number 138. Journals routinely covered and abbreviations used are as follows: Economic Geology (EG); Geochimica et Cosmochimica Acta (GCA); the USGS Circular (USGS Cir); and Open File Report (USGS OFR); Geological Survey of Canada papers (GSC paper) and Open File Report (GSC OFR); Bulletin of the Canadian Institute of Mining and Metallurgy (CIM Bull.): Transactions of Institute of Mining and Metallurgy, Section B: Applied Earth Sciences (Trans. IMM). Publications less frequently cited are identified in full. Compiled by L. Graham Closs, Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80401-1887, Chairman AEG Bibliography Committee. Please send new references to Dr. Closs, not to **EXPLORE**.

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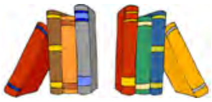

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David Lawie, John Gravel

EXPLORE

Newsletter No. 139 JUNE 2008

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