IGCP project short title: Global Comparison of Volcanic-Hosted Massive Sulphide (VMS) Districts

Duration: 2004 - 2008

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Project Secretary: Rodney Allen (see address above)

Date of submission of report: December 19, 2007

Signature of project leader(s):
1. **Website address(es) related to the project**

IGCP-502 uses Lulea University of Technology (LTU), Sweden, as host institution. Access is via the home pages of the Institution of Applied Chemistry and Earth Sciences, and the Division of Ore Geology and Applied Geophysics [http://www.ltu.se/tkg/]. The first page of the IGCP-502 site is at: [http://www.ltu.se/tkg/avd/kgo/forsk/IGCP](). This website is linked to the International Geoscience Programmes home page (via Geoscience, Earth Resources).

2. **Summary of major past achievements of the project**

- The project has built up an active scientific network that includes the majority of the world’s leading scientists in the field of volcanic-associated massive sulphide (VMS) ore deposits, plus 32 scientists from 16 developing countries and postgraduate students. This network now comprises 193 scientists from 41 countries.

- Increased level of cooperation amongst several government institutions and private mineral resource companies in Turkey, Russia, Namibia, Mexico, Morocco, Canada, Sweden, Spain, Australia and Saudi Arabia. This increased cooperation has been of tangible benefit to all involved, and especially to scientists in the developing countries.

- Discovery of fossil hydrothermal chimneys in a VMS deposit of Cretaceous age in Turkey during an IGCP-502 field workshop in 2004. This is the first discovery of hydrothermal chimneys in Turkey and one of few such discoveries in ancient rocks.

- Joint field meeting with IGCP-450 in Namibia and South Africa in 2005 concluded that classification schemes for VMS deposits don’t allow for transitional deposit types between the end-members VMS, SEDEX, BIF, epithermal and skarn deposits. This has a negative effect on exploration strategies worldwide. Accordingly, our project is studying transitions between VMS and SEDEX deposits in the Rosh Pinah area, Namibia, and between VMS, BIF and skarn magnetite deposits in Bergslagen, Sweden, and seeks to revise the classification and genetic models of VMS deposits.

- Increased awareness of the effects of metamorphism, deformation and weathering on massive sulphide deposits, and how these processes affect the economics of mining. Papers on these topics are included in the IGCP-502 special volume (see below).

3. **Achievements of the project this year only**

### 3.1. List of countries involved in the project (*countries active this year*)

IGCP-502 has 193 participants (see list at section 8) from the following 41 countries. During 2007 we attracted 19 new members and increased our coverage to 8 new countries.

<table>
<thead>
<tr>
<th>Argentina</th>
<th>Great Britain*</th>
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<tr>
<td>Australia*</td>
<td>Greenland</td>
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<td>Bulgaria</td>
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<tr>
<td>Georgia*</td>
<td>Namibia*</td>
<td>Venezuela</td>
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</table>
3.2. General scientific achievements and social benefits (Meetings listed under heading 3.3.)

- The IGCP-502 group produced a large number of high quality publications during 2007 (see list attached in section 8). Several of these are collaborations between scientists from different institutions and countries, which have resulted from scientific exchange and “networking” at IGCP-502 meetings and field workshops.

- Several new projects related to IGCP-502 were started during 2007 (see also section 7.2 additional funding), including (1) study of the relationship between VMS and Iron oxide deposits in Bergslagen, Sweden, (2) two projects that compare ancient VMS deposits in China with modern VMS.

- The IGCP-502 Special Volume of Mineralium Deposita Journal titled: "Key Issues And Controversies In The Geological Setting And Genesis Of Volcanic-Hosted Massive Sulphide (VMS) Deposits" has continued to progress during 2007. There are 23 proposed papers in the volume and authors have started to write their contributions (see details attached in section 8).

3.3. List of meetings with approximate attendance and number of countries

3.3.1 Society for Geology Applied to Ore Deposits (SGA) Dublin, Ireland, 20-23 August 2007
IGCP-502 organised two scientific sessions (16a, 16b) entitled: “seafloor hydrothermal systems”. 18 excellent papers were presented in the IGCP-502 sessions including papers from Cuba, China and southern Africa, and more than 80 persons from numerous countries attended the sessions at any one time. IGCP-502 also ran two field trips: One trip to VMS deposits in Wales and Ireland (field trip 7), and the other to VMS deposits in the Iberian Pyrite Belt (field trip 5). Both trips had about 20 participants (see meeting report below).

3.3.2 VMS deposits and the Evolution of Volcanic Arcs, Japan, 27 Oct - 4 Nov 2007
IGCP-502 ran a 1-day symposium at Tokyo University followed by a 7 day field workshop in Northern Honshu. The purpose of the meeting was to discuss the relationships in time and space between the formation of VMS ore deposits and the evolution of marine volcanic arcs. The NE Honshu arc was used as a field laboratory for this meeting. The meeting was extremely successful and was attended by 37 scientists from 15 countries, including the developing countries Myanmar, Papua New Guinea, Ghana, Morocco, Mexico, Russia and Malaysia. Six women scientists attended the meeting. A meeting report is attached below.

3.4. Educational, training or capacity building activities

3.4.1. Field workshops
IGCP-502 ran a field workshop in Japan this year, and also sponsored 2 scientific meetings and two field trips (see above). The IGCP-502 field workshops have been particularly popular and have proved to be an excellent way of disseminating experience and skills between scientists from the developed and less developed countries. This year, the field workshop in Japan provided an opportunity for 8 scientists from developing countries and 12 PhD students to interact with VMS specialists from the IGCP-502 group.

3.4.2. Short courses
IGCP-502 members ran two major short courses during 2007. Steve Piercey and Richard Herrington ran a course on VMS deposits for the Irish Association of Economic Geologists in Dublin, and Rodney Allen ran a course on VMS deposits at the International Exploration Meeting (FEM) in Rovaniemi, Finland. Both courses had attendances of about 50 registrants from mining companies, universities and government geological surveys.
3.4.3. Lectures to students
Members of IGCP-502 are active in presenting lectures to students throughout the world. IGCP-502 was formerly asked by the Mining College of Akita University, Japan, to give 2 lectures to PhD and MSc students at Akita University during the 2007 workshop in Japan.

3.4.4. Post-graduate students
Fourteen PhD students have been sponsored by, or involved with, IGCP-502 activities during 2007: Kofi Adomako-Ansah (Ghana), Htay Thara Kyow (Myanmar), Adong Bin Laming (Malaysia), Paul Moiya Kia (Papua New Guinea), Fardin Mousivand (Iran), Alireza Monazami (Iran), Yasusi Mori (Japan), Denis Schlatter (Sweden), Jorge Carriedo (Spain), Carmen Conde (Spain), Hannah Grant (Canada), Susan Belford (Australia), Sarah Gordee (USA), Martin Jutzeler (Germany).

3.4.5. Collaboration and capacity building activities
IGCP-502 continues to assist scientists and projects in Namibia, Peru, Russia, Turkey and Morocco (see also 2006 report). These projects are aimed at introducing new technology, methods and experience to the local organizations. For example, in Turkey the Mineral Research and Exploration Authority (MTA) have two geological mapping projects in collaboration with IGCP-502: (1) Cerattepe mine and surroundings, 700 km², (2) Trabzon-Sürmene region, 20 km².

The Czech team continued collaboration with the Spanish team on the distribution of PGE in VMS deposits of the Iberian Pyrite Belt (Pasava et al. 2007a), and with IFM-GEOMAR (Germany) on the study of PGE fractionation in seafloor hydrothermal systems (Pasava et al. 2007b).

The Canadian, French and Moroccan teams continued collaboration on the study of VMS deposits in Morocco (Belkabir et al., in press; Marcoux et al., in press).

3.5. Participation of scientists from developing countries, and in particular young and women scientists
The project’s 193 members include 32 scientists from 16 developing countries: Morocco, Namibia, Mexico, Bulgaria, Georgia, Cuba, China, Hungary, Iran, India, Kosovo, Russia, Turkey, Argentina, Peru and Venezuela (see list of members below in section 8). Furthermore, this number is not a true picture of the participation from developing countries, because in many cases the project has just one or two email contacts with chosen IGCP-502 co-ordinators in these countries. These co-ordinators disseminate information from our project to other scientists in their country.

About half of the participants from developing countries are young scientists and 4 are women. It is difficult to reach women scientists in many developing countries, because these countries generally nominate men as their representatives, but we are trying.

Scientists from Morocco, Turkey, Russia, Iran, Mexico, Namibia and Peru have been particularly active in the project. We have tried to support these scientists as much as possible via scientific collaboration and financial support to our field workshops.

The project supervises a PhD student in Iran (supervisor Jan Peter) and a PhD student from Peru (supervisor Rodney Allen). (1) Fardin Mousivand, Tarbiat Modares University, Tehran; title of PhD thesis: Geology, geochemistry and genesis of the Chahgaz Zn-Pb-Cu deposit and comparison with the Bavanat Cu-Zn-Ag VMS deposit, south Sananda-Sirjan zone. (2) Marcello Imana, Lulea University of Technology; title of PhD thesis: Geology, ore genesis and alteration of the Storliden Cu-Zn deposit, Sweden.

3.6. Publications in 2007 (including maps; no abstracts).
The projects incorporated within IGCP-502 produced 60 major peer-review papers, 17 books and other peer-review publications, and 1 completed PhD thesis during 2007. This list of publications is attached below in section 8.

3.7. Activities involving other IGCP projects, UNESCO, IUGS or others

Collaboration and capacity building activities continue in Namibia and stem from the joint field workshop held by IGCP-450 and IGCP-502 in Namibia and South Africa in 2005. The Finnish team has collaborated with IGCP-486 in joint research on Bi-Pb-Te sulphide minerals (Cook et al., 2007, section 8.2)

4. Activities planned

4.1. General and specific goals
The general goal of IGCP-502 is to make a major step forward in the understanding of where, when and how VMS deposits form during the evolution of extensional plate margin terranes. We believe that in order to make this step forward it is essential to compare and contrast the geology of the world’s major VMS mineral belts so that the critical common features can be distinguished from the myriad of other less important features. The IGCP-502 field workshops are an important step toward realizing this goal. These workshops enable comparisons of the various VMS belts by the ICP-502 group, and also enable transfer of ideas, results and new technology between scientists and research groups in the best possible environment – on site in the field and in the laboratory. To date IGCP-502 has run field workshops in 8 VMS belts in 11 different countries.

A major specific goal is the IGCP-502 Special Issue of Mineralium Deposita Journal entitled: "Key Issues And Controversies In The Geological Setting And Genesis Of Volcanic-Hosted Massive Sulphide (VMS) Deposits". The contents of the volume have now been determined and authors are writing their contributions. The preliminary publication date is late 2008. Details of this special volume are attached in section 8.

4.2. Tentative list of specific meetings and field trips (list the participating countries)

4.2.1. 33rd International Geological Congress, Oslo, Norway, 2008
The major meeting of IGCP-502 in 2008 will be in conjunction with the IGC in Oslo. IGCP-502 is organising the scientific session on VMS deposits at the IGC and is also organising a field workshop (post-congress excursion 12) to the Bergslagen mining district in Sweden. Participation is expected from over half of the project’s 41 member countries.

4.2.2. Other project meetings
Two other meetings and field workshops are proposed for 2008; one to the Variscan belt in Morocco and the other to the Flin Flon belt in Canada. The leadership will decide in early 2008 whether to proceed with one or both of these proposals.

5. Project funding requested

IGCP-502 requests full funding from IGCP. US$ 150,000 has also been requested from CAMIRO/AMIRA Canada/Australia. Section 7.2 provides a list of funding that was granted to IGCP-502 from other sources for 2007.

6. Request for extension, on-extended-term-status, or intention to propose successor project

A decision whether to apply to extend the current project or to propose a successor project will be made during 2008, the final year of the current project.
7. Financial statement ($ USD only)

7.1. Use of IGCP funds

IGCP-502 was allocated US$ 8,000 for 2007 by the IGCP committee. This funding was used completely to support project members, especially those from developing nations, to attend the project meeting in Japan, and to pay for transport and accommodation at that meeting. The financial statement is attached below in section 8.

7.2. Additional funding obtained from other sources (funding for 2007 only is shown)

US$ 608,155 was obtained from other sources in 2007. Details are attached in section 8.7.
8. ADDITIONAL INFORMATION NOT INCLUDED IN THE FIVE MAIN TEXT PAGES OF THIS REPORT

8.1. List of participants in IGCP-502 and their email addresses (193 members)

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Francisco Velasco <nppverof@lg.ehu.es>
8.2. List of publications in 2007 (including maps) (no abstracts).

8.2.1. Most important peer review literature (those dated 2006 were actually published in 2007)


Monecke, T., Giorgetti, G., Scholtysek, O., Kleeberg, R., Goetze, J., Hannington, M. D., and Petersen, S., 2007, Textural and mineralogical changes associated with the incipient


8.2.2. Books, Special Volumes and Other peer reviewed publications


Buschmann, B., and Maslennikov, V.V., 2006, The late Ordovician or earliest Silurian hydrothermal vent fauna from the Yaman Kasy VMS deposit (South Uralides, Russia). - Paläontologie, Stratigraphie, Fazies (14), Freiberger Forschungshefte C., v. 511, p. 139-172.


8.2.3. Completed PhD theses


8.3. Preliminary contents of the IGCP-502 Special Issue of Mineralium Deposita

Title: "Key issues and Controversies in the Geological Setting and Genesis of Volcanic-hosted Massive Sulphide (VMS) deposits"
Publication: Special volume of Mineralium Deposita
Editors: Allen, Peter, Tornos

Contents
1) Introduction to the Special Volume and synthesis of results. Rodney Allen, Jan Peter, Fernando Tornos
2) Tectonic Settings of VMS Deposits. Richard Herrington + co-authors
3) Regional Settings of VMS deposits. Mike Solomon and Ross Large
4) The timing and location of VMS deposits in the evolution of the NE Honshu volcanic arc, Japan. Or: The roles of felsic and mafic arc magmatism in the formation of VMS deposits: evidence from the NE Honshu Arc, Japan. Ryoichi Yamada, Takeyoshi Yoshida
5) Volcanic facies and eruption styles related to kuroko-type massive sulphide deposits: a re-assessment based on the Hokuroku district, NE Japan. Rodney Allen, Takeshi Ohguchi (Ray Cas, Ryoichi Yamada)
6) What are the large-scale volcanic-tectonic structures that host clusters of VMS deposits: rift basins, calderas, cauldrons? Harold Gibson, Rodney Allen
7) The relevance of recent studies of the modern ocean floor to understanding the tectonic and volcanic setting of ancient VMS deposits. Cornel de Ronde + co-authors
9) The Evidence For A Continuum Between VMS, Sedex and Epithermal Deposits. Ross Large, Bruce Gemmell, David Cook, Mike Solomon (Duncan Large, Fernando Tornos, John Thompson, Jeff Hedenquist, Thomas Monecke)
10) Are Modern Seafloor Sulphide Deposits True Analogues to the Ancient Examples? Steve Scott, Mark Hannington, Thomas Monecke, Sven Petersen
11) The Roles of Felsic and Mafic Magmatism in the Formation of VMS Deposits. Steve Piercey + co-authors
12) The Role of Magmatic Fluids and Volatiles in the Formation of VMS Deposits. David Huston + co-authors
13) Basinal fluids and the origin of massive sulfides: A numerical fluid flow study from the Iberian Pyrite Belt. Carmen Conde, Matthai, Fernando Tornos
15) A Critical Appraisal of the Role of Oceanic Anoxia in the formation of VMS Deposits. Wayne Goodfellow, Ian Peter, Steve Piercey

16) Black shales and massive sulphides: causal or casual relationships. Moreno, C., Sáez, R., Almodóvar, G.R. and González, F.

17) Hydrothermal sedimentary rocks associated with VMS deposits. Ian Peter and co-authors

18) Textural and Chemical Evolution of Clastic Sulphide Textures in VMS deposits. Maslennikov and co-author(s) Bruce Gemmell, Ron Berry

19) Anatomy and interpretation of hydrothermal alteration systems associated with VMS deposits. Bruce Gemmell, Daizo Ishiyama

20) Post-depositional tectonic modification of VMS deposits and its economic significance. Ricardo Castroviejo and Cecilio Quesada

21) Applicability of Heat and Fluid Flow Modelling in the Study of VMS Deposit Formation. Larry Cathles

22) Supergene alteration of VMS deposits. Paco Velasco + co-authors


8.4. Meeting report: Japan, 27 October - 4 November 2007

Title: Relationship between VMS (Kuroko) deposits and the Evolution of Volcanic Arcs
Date: 27 October – 4 November 2007
Place: University of Tokyo and NE Honshu, Japan
Itinerary: Symposium at Tokyo University on 27 October, followed by field workshop in NE Honshu 28 October-4 November

Scope of Meeting
This meeting comprised a 1-day symposium in Tokyo followed by a 7 day field traverse across the NE Honshu volcanic arc. The purpose of the meeting was to discuss the relationships in time and space between the formation of VMS ore deposits and the evolution of marine volcanic arcs. We used the NE Honshu arc as an example and field laboratory. The symposium was held at the Earthquake Research Institute at Tokyo University and was attended by 37 scientists from 15 countries, including the developing countries Myanmar, Papua New Guinea, Ghana, Morocco, Mexico, Russia and Malaysia. The field workshop was attended by 26 scientists from 14 countries, including the developing countries listed above. Six women scientists attended the meeting.

Achievements of Meeting
• The meeting was attended by field geologists, modern seafloor specialists, igneous petrologists, ore deposit geologists and geochemists, with the result that there was excellent scientific exchange and multi-disciplinary debate.
• The 16 formal presentations at the meeting were of very high quality.
• The meeting was attended by a good number of scientists from developing countries (see above) and PhD students.
• The meeting was supported by Tokyo University, Akita University, Tohoku University, Akita Prefecture Government, Society of Resource Geology of Japan.

Outcome of Meeting
• Participants gained an appreciation of the geology of the Japanese Kuroko VMS deposits, which are the foremost type example of VMS deposits in the world.
• There is increasing evidence that the Kuroko deposits in Japan are intimately related to the evolution of back-arc rifting and consequent magmatic processes.
• It was demonstrated that back-arc rifting progressed from the back-arc toward the arc front, which resulted in diachronous basin formation, magmatism and stratigraphy.
There is increasing evidence that magmatic hydrothermal processes play an important role in formation of VMS mineralization on the modern sea floor and in ancient deposits.

Features observed in active sea floor hydrothermal systems (hydrothermal fluid phase separation, anhydrite "caps") can provide new explanations for some features in ancient deposits (mineral zonation, stratabound anydrite/gypsum).

Participants realised how difficult it is to identify VMS "ore horizons" in the host basin, and what needs to be done to identify them (volcanic facies mapping, careful stratigraphic correlation, petrography and geochemistry, alteration studies, dating).

A participant from Morocco proposed a future meeting and field workshop in Morocco.

8.5. Meeting report: SGA Dublin meeting, 20-23 August 2007

Title: Biennial meeting of the Society of Geology Applied to Ore Deposits
Date: 20th-23rd August 2007
Place: Dublin, Ireland
Itinerary: SGA meeting and 2 field trips (Ireland-Wales and Spain-Portugal)

Scope of Meeting
Biennial meeting of the Society of Geology Applied to Ore Deposits

Achievements of Meeting
The meeting attracted 700 delegates attending from a range of countries worldwide and was the undoubted focus of international ore-deposit geoscientists in 2007. IGCP-502 was represented in two special sessions (16a and 16b of the meeting) under the title of ‘Seafloor Systems’. In addition to the conference, there were 7 field excursions organised before and after the symposium, of which 2 were organised under the auspices of IGCP-502. Trip 1 (pre-conference 3.5 days) comprising 18 participants visited a diversity of sulphide deposits in Snowdonia and Parys Mountain in North Wales, UK followed by the Avoca sulphide deposit of SE Ireland. Many comparisons were able to be made regarding the geology and styles of mineralization with terranes of the Caledonides in North America and Scandinavia. One real highlight was the excellent historical core display at Avoca. Trip 2 (post-conference 4 days) had 20 participants and visited the Iberian Pyrite Belt which is one of the world’s great VMS belts. Mined since the Roman times, mining continues today at Neves Corvo with a number of mines re-opening. Participants on the trip visited the deposits of Neves Corvo, Aljustrel, Aguas Teñidas, La Zarza and the Rio Tinto area. In addition the magmatic Ni-Cu and IOCG deposits respectively of Agua Blanca and Cala were visited.

Outcome of Meeting
18 excellent papers (12 oral and 6 poster) were presented in the IGCP-502 Seafloor Systems special sessions. More than eighty persons attended the sessions at any one time. Special highlights were the continuing discussions concerning the origins of the massive sulphide deposits of the Iberian Pyrite Belt. At the meeting, the nature and chemistry of the felsic volcanic units associated with the deposits was debated and one paper discussed the nature and role of the shale-sequences in generating the IPB deposits. The abstracts from new studies from poorly documented regions such as Cuba, Xinjiang China and southern Africa are very important contributions to the literature. Further presentations concerning the source of metals to the seafloor systems were made both showing evidence of leaching from the footwall and possible direct contributions of magmatic fluids. Two papers added further evidence for the formation of VMS deposits on ultramafic parts of seafloor sequences, extending the range of environments for the deposit types.
8.6. Financial statement for 2007

IUGS funds forwarded by IUGS treasurer USD 8000

EXPENSES FROM IGCP-502 MEETING IN JAPAN, 27 OCT – 4 NOV 2007

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Subtotal Transportation Expenses: 4000 USD

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<tr>
<td></td>
<td>All participants</td>
<td>13 countries</td>
<td>1000</td>
</tr>
</tbody>
</table>

Subtotal Accommodation Expenses: 2000 USD

**Local Transport (ie. bus, minivans)**

Bus hire and petrol

Subtotal Local Transport Expenses: 2000 USD

Organizing Expenses (should be less than 10% of the allocation)

Subtotal Organizational Expenses: 0 USD

Enter GRAND Total of Above: 8000 USD

8.7. Additional funding obtained from other sources (only funding for 2007 is shown)

- Boliden Mineral and Lulea University, Sweden, for IGCP-502 coordination: US$ 19,000
- Society of Resource Geology, for the IGCP-502 meeting, Japan: US$ 1,000
- Akita University, for the IGCP-502 meeting, Japan: US$ 3,125
- Vetenskapsradet Sweden, for the IGCP-502 meeting, Japan: US$ 6,000
- Geological Survey Sweden and Boliden Mineral, for Bergslagen project: US$ 250,730
- IGCP Canada, support for project meeting, Dublin: US$ 900
- Mineral Research Exploration Authority, Turkey (MTA) for IGCP-502: US$ 15,000
- Sabina Silver Corporation, for research of Hackett River, Canada: US$ 15,000
- NSERC Discovery Grant: Metallogeny of Modern and Ancient Oceans: US$ 42,700
- NSERC Discovery Grant: Horizons in proximity to VMS deposits: US$ 20,000
- Xstrata Copper Canada: Near-mine exploration targets, Noranda: US$ 53,600
New Brunswick DNR and Xstrata Zinc, for analytical work  
COMRA, China, for comparison of modern and ancient VMS  
Geological Survey China, for metallogeny of gold in VMS deposits  
Spanish Ministry of Education and Science, for IGCP-502 coordination

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Total additional funding

US$ 608,155

19 December 2007