InterRidge

Working Group on Seafloor Mineralization

Meeting Report

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Present: **Working Group:** Fernando Barriga, Georgy Cherkashov, Yves Fouquet, Mark Hannington, Jonguk Kim, Lisa Levin, Rachel Mills, Kamesh Raju, Xuefa Shi, Maurice Tivey (Working Group Chair), Ingunn Thorseth, Cindy Van Dover; **InterRidge Office:** Stace Beaulieu, Jian Lin (InterRidge Chair); **ChEss Office:** Chris German (also InterRidge Co-Chair), Eva Ramirez-Llodra; **Guest** (Graduate Student): John Jamieson.

Absent: **Working Group:** Yasuhiro Kato.

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1.0 Summary

Hydrothermal vent systems host seafloor massive sulfide (SMS) deposits that are typically rich in copper, zinc, gold, and silver. In recent years, these systems have attracted considerable interest from commercial mining companies, and in 2007 the International Seabed Authority (ISA) released the first "Draft regulations on prospecting and exploration for polymetallic sulphides in the Area." In 2008 InterRidge formed an international and interdisciplinary Working Group for Seafloor Mineralization (http://www.interridge.org/WG/Mineral). The primary scientific objectives of this Working Group are to examine SMS deposit distribution, maturation and evolution and to investigate the processes (biological, chemical, geological) that are responsible for their formation and preservation. A sound scientific base of knowledge would both advance science but also inform the commercial and political world of the importance of these multi-faceted resources and encourage responsible development.

The InterRidge Working Group on Seafloor Mineralization (SMWG) held its first meeting on 3 April 2009, following a two-day science and policy workshop on deep-sea mining of seafloor massive sulfides with approximately 100 participants from 20 countries. The workshop was sponsored by ChEss, InterRidge, U.S. Ridge 2000, and WHOI's Deep Ocean Exploration Institute and concluded with a public colloquium sponsored by WHOI's Morss Colloquium program. The SMWG met to discuss the main themes/topics and issues that arose in the previous two days and to identify gaps in scientific knowledge of seafloor massive sulfide (SMS) deposits. A central charge of the SMWG was to assess the current knowledge of seafloor hydrothermal/SMS deposits and to relate what we know and don't know about active vent systems to the relatively poorly studied inactive systems. Science has focused on the active systems for obvious reasons: they are the locus of active processes, they host unique fauna, they are easier to locate, and along with inactive deposits they provide analogs to ancient deposits. There has been markedly less focus on the inactive or extinct deposits. Part of the reason for this has been because inactive deposits are hard to locate except in the vicinity of active systems, they do not host the spectacular and abundant fauna found at active vents, and the processes that are occurring at these inactive sites are likely occurring within the deposits or mounds and possibly occur over long timescales.

The Working Group developed three groups of questions and recommendations to advance the scientific knowledge of SMS deposits:

- What are the spatial controls on hydrothermal activity and SMS deposition?
- What are the timescales for the evolution of SMS deposits?
- What are the changes in biological communities that occur during the evolution of an SMS deposit?

Recommendations range from developing a list of criteria to quantify the extent of activity at a hydrothermal vent site, to using cutting-edge technology to locate and characterize inactive deposits, to encouraging biological studies of inactive and extinct SMS deposits. The definition of what constitutes an inactive vent site was discussed at length by the SMWG and should be defined within the context of the evolution of SMS deposits. It was recognized that these inactive systems are just one aspect of a continuum of seafloor hydrothermal activity that ranges from active systems to completely dead or extinct deposits. Commercial seafloor mining/exploration of SMS mineral resources will likely focus on extinct and inactive deposits to minimize impacts due to extreme environmental conditions; however,

active systems have also been targeted, and it will be important to assess impacts on the complete range of unique ecosystems found at active and inactive systems. Specific questions and recommendations for research, conservation, and international collaboration are outlined below. Advancing the science of SMS will require multi-national, collaborative, and interdisciplinary efforts that may be fostered by the InterRidge program.

List of Specific Questions and Recommendations for Research

For the full text of the SMWG's specific questions and recommendations along with accompanying narrative, please consult the full body of this document.

2.1 What are the spatial controls on hydrothermal activity and SMS deposition?

2.1.1 What is the distribution, size, and grade of SMS deposits in the full range of seafloor settings?

2.1.2 What are the controls on the size and occurrence of SMS deposits?

2.1.3 Are there volcanic and tectonic settings for hydrothermal activity that we have not explored? (e.g., mid-ocean ridge flanks, continental margins, sedimented spreading centers, etc)

2.1.4 Can we classify SMS deposits/vent sites according to their fluid and solid compositions as is done for terrestrial deposits?

2.1.5 Recommendations:

Establish a "Census of SMS Deposits" Initiative to quantify and characterize the distribution, classification, and other essential parameters of SMS deposits.

Define the "district" scale distribution to test the magma/thermal budget hypothesis.

2.2- What are the timescales for the evolution of SMS deposits?

2.2.1 What is the episodicity and subsurface evolution of SMS deposits? (including metal redistribution)

2.2.2 What are the geological controls on the longevity of hydrothermal vent systems?

2.2.3 How do we define an inactive vent deposit?

2.2.4 What are the parameters needed to define the range in activity for a given vent site? i.e., what are the criteria needed to define a site as inactive?

2.2.5 What are the processes, rates, and products of weathering/oxidation of SMS deposits?

2.2.6 What are the processes responsible for preserving SMS deposits: capping, burial, tectonic preservation, alteration?

2.2.7 Should we expect to find significant deposits on the flanks of ridges or have these been so disintegrated by chemical weathering that they are no longer economic?

2.2.8 Recommendations:

Develop a list of criteria for quantifying the extent of activity at a vent site.

Encourage alteration studies focused on inactive vent deposits.

Utilize advanced isotopic methods for dating of SMS deposits.

2.3 What are the changes in biological communities that occur during the evolution of an SMS deposit? (*Do biological phases reflect changing geology*?)

2.3.1 How do the natural changes in the geology and chemistry of an SMS deposit as it ages influence the microbiology and faunal communities?

2.3.2 What are the timescales for the recovery of deposits and their ecosystems after disturbance?

2.3.3 Recommendations:

Encourage biological studies of inactive and extinct SMS deposits.

Develop a list of indicator species for different biogeographic regions, substrates and SMS ages.

Link existing biological databases to the "Census of SMS Deposits" Initiative.

Assess spatial scales for colonization and genetic linkages for species associated with active and inactive SMS deposits.

Establish biological linkages of SMS communities to other ecosystems and habitats.

2.0 Specific Questions and Recommendations for Research, Conservation, and International Collaboration

2.1 What are the spatial controls on hydrothermal activity and SMS deposition?

2.1.1 What is the distribution, size, and grade of SMS deposits in the full range of seafloor settings?

2.1.2 What are the controls on the size and occurrence of SMS deposits?

2.1.3 Are there volcanic and tectonic settings for hydrothermal activity that we have not explored? (e.g. mid-ocean ridge flanks, continental margins, sedimented spreading centers, etc)

2.1.4 Can we classify SMS deposits/vent sites according to their fluid and solid compositions as is done for terrestrial deposits?

In the spatial context, we wish to quantify and characterize the distribution of SMS deposits and hydrothermal vents within a single ridge segment to determine controls on this variation. Can we compare the ridge segment length-scale to that of an "ore district" as defined in terrestrial deposits? For example, the TAG hydrothermal field might represent a district encompassing both the active mound and the other mounds known to exist. Likewise Main Endeavour Field is a single field within a "district" or ridge segment that includes other known vent systems including Mothra, High Rise, Salty Dawg, etc).

Presentations at the workshop both from thermal flux calculations and the mass flux perspective as well as the statistics of Mid-Atlantic Ridge (MAR) SMS distributions showed that the average spacing of vent systems was on the order of 100 km along the mid-ocean ridge system. Can we test this magma budget/heat flux hypothesis (Baker and German, 2004) by investigating the distribution of SMS deposits along a given ridge segment? Assuming an active vent draws heat from 20 km of crust then how do we reconcile, for a 100 km segment, the possibility of old deposits within the remaining 80 km of a segment? Can we estimate the frequency of inactive systems? These are all questions that will need a comprehensive characterization of the mid-ocean ridge to find both the active and inactive/extinct vent systems. It should also be noted that hydrothermal systems are also found associated with submarine arc volcanoes, often in relatively shallow water (<1000 m) and often located within national Economic Exclusive Zones (EEZ). These systems typically have strong magmatic volatile signatures in the fluids that may enhance mineral deposition at depth. This combination of factors suggests that submarine arc volcanoes may become some of the first sites to be exploited for their mineralization.

Remote-sensing techniques will be needed for the detection of inactive to extinct SMS systems and will need to survey large areas and provide sufficient resolution to image the 100-m scale features typical of hydrothermal activity. This will probably require autonomous underwater vehicles or towed systems to be economical. Remote-sensing techniques would include using geophysical methods, geochemical sniffing, and possibly biological cues. There is also a great need for subsurface sensing in order to estimate deposit volumes, depth extent, etc.

2.1.5 Recommendations

The WG recommends that a "**Census of SMS Deposits**" Initiative be established to quantify and characterize the distribution, classification, and other essential parameters of SMS deposits. A key metric for any discussion of SMS deposits is their global distribution, including their size, tectonic setting, level of activity, fluid composition, and geochemistry of the deposits. We also need to begin to classify these marine deposits in terms of land-based ore deposits. The existing Global Database of hydrothermal vent deposits published by Hannington et al., (2005), and provided to the International Seabed Authority (ISA), is in need of updating and this could be a good starting point for the working group. Substantially more information is now available, both on listed hydrothermal deposits and on new sites discovered over the past 5-10 years. This revised Global Database of hydrothermal deposits plus the linked geochemical database of analyses should be updated (a lot more data is now available) and also linked to the relevant biological databases including, but not limited to: ChEssBase, COMARGIS and BIOCEAN, which are all available through the OBIS network. This would also be useful to the InterRidge community as a whole.

The WG proposes that Mark Hannington should lead this effort and that the ISA be approached to fund this initiative. The InterRidge Vents database will be fully revised in 2009 and will update the listings for active vents, serving as a subset of the Hannington compilation. Any update to the vents database should include the ability to link to this updated "Census of SMS" effort and also provide closer links to existing biological databases.

The WG recommends that comprehensive mapping and cataloguing of representative ridge segments locating all occurrences of hydrothermal mineral deposits defining the "district" scale distribution needs to be done to thoroughly test the ideas advanced in the magma/thermal budget hypothesis of Baker and German (2004).

2.2 What are the timescales for the evolution of SMS deposits?

2.2.1 What is the episodicity and subsurface evolution of SMS deposits? (including metal redistribution)

2.2.2 What are the geological controls on the longevity of hydrothermal vent systems?

2.2.3 How do we define an inactive vent deposit?

2.2.4 What are the parameters needed to define the range in activity for a given vent site? i.e., what are the criteria needed to define a site as inactive?

2.2.5 What are the processes, rates, and products of weathering/oxidation of SMS deposits?

2.2.6 What are the processes responsible for preserving SMS deposits: capping, burial, tectonic preservation, alteration?

2.2.7 Should we expect to find significant deposits on the flanks of ridges or have these been so disintegrated by chemical weathering that they are no longer economic?

SMS deposits form a continuum of activity from actively venting to inactive to extinct vent deposits that may become preserved in the geological record. While an active vent site can probably be defined by the emission of hydrothermal fluid and the exiting temperatures of those fluids, the definition of inactive vent sites is more difficult to assess at the present time for a variety of reasons discussed earlier. If we assume that SMS deposits evolve through many different stages, it may be better to define a list of criteria that describes the various properties/characteristics of a deposit so that a system can be given a ranking that classifies the extent to which it is inactive. One can provide the analogy of volcanoes: we have active volcanoes where gas and lava is regularly expelled. There are dormant or inactive volcanoes where activity has been quiescent for some time period (typically over the historical record) and yet the deep seated underlying heat source may be reactivated by some trigger. Extinct volcanoes are those that have lost their source of heat and/or magma and there is no possibility of reactivation. Similarly with vent systems: an active vent is one that demonstrates ongoing fluid expulsion, an inactive vent site refers to a system that no longer vents fluid, but could be reactivated if disturbed or triggered by some external event. An extinct deposit is one that has no possibility of reactivation in terms of fluid flow from depth.

There have been few attempts at quantifying the age of deposits and the episodicity inherent in these types of features. An effort to improve the dating of hydrothermal vent deposits would be helpful to understanding the controls on these systems in many ways.

There is a strong need to address questions concerning the range in styles, rates, and products of alteration and weathering of SMS deposits. It is important to know if these weathering/alteration processes proceed at rates that will render the possibility of finding deposits on the ridge flanks an unlikely occurrence. The sedimentary geochemical work at TAG is probably the most comprehensive work to date on this topic, but much remains to be done. There are many mechanisms that could contribute to the alteration and evolution of an SMS deposit including oxidation, physical breakdown, tectonic dissection, mineral recrystallization, zone refining, and other types of alteration including microbial activity. Similarly, the processes involved in SMS deposit preservation also remain relatively vague. For example, the roles of sediments in capping deposits or lava eruption burying deposits are not well studied. A comparison of the present inventory of SMS deposits in the oceans with ancient deposits now on land find that we have only found the smaller-sized deposits in the oceans compared to the generally larger deposits found on land. Have geologic conditions for SMS formation changed over geologic time or are we missing a significant fraction of these deposits? The burial and preservation of deposits under sediment cover, volcanics or by other tectonic processes have been difficult to characterize in the modern ocean environment. The detection of these buried "blind deposits" is challenging; there are geophysical techniques such as electromagnetic profiling and sounding and magnetic and gravity measurements but access to technology and cost effective spatial coverage remain limited at present. Finally, microbial activity undoubtedly plays an important role in Fe oxidation and probably other types of alteration as well.

2.2.8 Recommendations

The WG recommends that a list of criteria for quantifying the extent of activity at a vent site be developed to address the definition of inactive vent sites. A definition of SMS deposits could be based on observed physical properties including but not limited to fluid exit temperatures (for active sites), heat flow, pore-water chemistry, geochemical and mineralogical profiles in sediments, the geochemistry of the solids, fluids and gases, and various biological indicator species. A background level would also need to be defined. One could imagine a hydrothermal mound that may not be venting fluid but could have high heat flow and indications of fluid circulation within the mound from geochemical indications in the pore fluids and sediments.

The WG recommends that alteration studies focused on inactive vent deposits should be undertaken. Inactive vent sites have essentially gone through a complete lifecycle of evolution and so may preserve this longer timeframe of activity and insight on episodicity.

The WG recommends that efforts should be made to improve the dating of SMS deposits utilizing advanced isotopic methods.

2.3 What are the changes in biological communities that occur during the evolution of an SMS deposit? (*Do biological phases reflect changing geology*?)

2.3.1 How do the natural changes in the geology and chemistry of an SMS deposit as it ages influence the microbiology and faunal communities?

2.3.2 What are the timescales for the recovery of deposits and their ecosystems after disturbance?

The development of the hydrothermal vent ecosystem over the complete lifetime of a vent system is not entirely known; biological communities in the senescing and inactive vent stages are relatively unstudied. We do not know if there are endemic species at inactive sites. We hypothesize that "background" deep-sea fauna (non-endemic to vent systems) that inhabit the hard substrata and sediments at inactive sites may benefit from a chemosynthetic food web driven by microbes that fix carbon through low-temperature mineral weathering. Such sites are likely to host a more "cosmopolitan" population compared to active vent sites. While these could be more resilient against disturbance from seafloor mining, they may also have longer life spans and grow more slowly than animals at active vents. Thus recovery of this fauna could be slow. A thorough inventory is needed of species found at the complete spectrum of hydrothermal sites from active to inactive and on different substrates, including hydrothermal sediments. Microbial communities might be similar across the full range of activity, but variation in geochemistry suggests they will differ. There is great need for coupled geochemistry/microbiology/animal studies on inactive SMS deposits, aimed at identifying the rock/mineral assemblages more favorable to specific microbial and faunal populations.

The effect of disturbance of vent systems and their recovery from natural variability, such as an eruption (e.g. 2006 EPR 9°50'N) has been studied in only a few regions. The effects of human-induced activities, such as by seafloor mining, and their similarity to natural disturbance remain unstudied. The few studies of natural disturbance to date show recovery at vent sites depends on recruitment from wide areas. The lack of adequate species and population distribution data limits our knowledge of this issue, although analogs may exist from the polymetallic nodule project studies for the inactive vent sites.

2.3.3 Recommendations

The WG recommends carrying out micro- and macro-biological studies of inactive and extinct SMS deposits coupled with detailed mineralogical/geochemical studies. This should be undertaken in a global context because community composition varies broadly across ocean basins.

The WG recommends that a list of indicator species for different biogeographic regions, substrates and SMS ages be developed. This list should evaluate the functional, reproductive/dispersal and trophic attributes of these species.

The WG recommends linking the existing biological databases to the geological databases on the Global vent distribution and geochemistry.

The WG recommends an assessment of the spatial scales over which recolonization occurs and to quantify the genetic linkages as a function of distance for species associated with active and inactive SMS deposits.

The WG recommends that studies investigate the biological linkages of SMS communities to other ecosystems and habitats (e.g., methane seeps, wood falls, background basalt).

3.0 Suggestions on where to go to address some of these main questions?

The questions outlined above and discussed at the workshop will require multi-nation, collaborative efforts for most of the recommendations. The InterRidge office can play an important role in fostering this multi-national cooperation through its leadership and coordination across many disciplines and geographical areas. The most efficient way to go about addressing some of these questions is to build on existing information already being compiled. This could include academic science but also industry data in some cases. A good example might be the Lau Basin back-arc area. This has been the focus of recent U.S. Ridge 2000 Integrated Study Site experiments and surveys. The area is under investigation in a broad effort by many countries including France, Germany, and China to name a few, but also is being targeted by commercial marine mining interests. Parts of the area fall within the EEZ of coastal states Tonga and Fiji and thus could be subject to mining in the near future. The SMWG recommends that comprehensive studies along the Lau spreading center segments detailing the active and inactive sites both in terms of geology but also biology would be of tremendous use to the both the coastal states and the ISA in general.

The SMWG also recommends continued investigation of slow spreading ridges such as the Mid-Atlantic Ridge, Southwest Indian Ridge, and the ultra-slow Gakkel Ridge. Recent discoveries of the prevalence of low angle detachment faulting on these ridges that can provide sustained long-lived hydrothermal activity has changed prevailing views of the distribution of hydrothermal activity along the mid-ocean ridge. The conventional view, that hydrothermal systems are confined to the locus of spreading and volcanic activity, has changed recently and now these vent sites are now known to occur several kilometers off-axis and appear capable of evolving over several tens to hundreds of thousands of years in association with these long-lived fault systems.

A lot of work has been focused on a few key deposits like TAG, Logatchev and Ashadze. InterRidge activities should look at supporting drilling into these deposits and carrying out the dating and time series studies for alteration. There is an IODP drilling proposal for a return to TAG (P. Rona: IODP-584-Full2) that would address many of the issues related to the evolution of SMS deposits over a 100 ka timeframe as well as the subsurface biosphere associated with high temperature hydrothermal systems. The working group strongly endorses the proposed drilling at TAG – which includes a range of inactive SMS deposits in addition to the active mound site.

4.0 Marine Protected Areas (MPA)/Marine Reserve Areas (MRA) and conservation strategies

Many types of information are required to design Marine Protected Areas for hydrothermal vent systems. There are examples of MPAs and MRAs already, and we should build on that experience for hydrothermal systems. The recent announcement of MPA design criteria for the Clipperton/Clarion polymetallic-nodule area (headed up by Craig Smith) provides a template to proceed with this. Smith suggests that the principles applied there are universal and could be used for designing hydrothermal vent MPA/MRAs. There are, however, some important differences between hydrothermal vent communities and those found in the nodule areas, specifically that hydrothermal vents support apparently endemic fauna that are insular and ephemeral. These important characteristics should be highlighted in any future design of MPA/MRAs. The SMWG recommends that a workshop be convened to develop guidelines for the design of MPAs and reserves for hydrothermal settings.

A strong effort should be made to collect biological data prior to mining (where mining will occur), to track changes associated with mining activities, and to monitor the rates and trajectories of recovery following cessation of mining. All human activities should be viewed as part of an experiment from which we can learn about how the geological and biological systems function and interact. Multiple approaches, including conservation by protection, monitoring, remediation, and restoration should be developed as part of a diversified toolkit of practices in which scientists are actively involved.

5.0 International Engagement

InterRidge should consider collaborating with an organization like the United Nations Environment Programme (UNEP) that is leading efforts to train and inform groups, citizens, and stakeholders in under-developed countries on their marine resources. InterRidge has already developed a fellowship program with support from the ISA to foster collaboration and build the knowledge-base in these countries. InterRidge could supply experts to give lectures or courses in these countries.

InterRidge could help to foster more international science collaboration by promoting scientists/students from under-developed countries to participate in hydrothermal research.

6.0 References

Baker, E.T., and German, C.R. 2004. On the global distribution of hydrothermal vent fields. Geophysical monograph 148, American Geophysical Union, pp. 245-266.

Hannington, M.D., de Ronde, C.E.J., and Petersen, S., 2005, Sea-floor tectonics and submarine hydrothermal systems: 100th Anniversary Volume of Economic Geology, pp. 111-142.