

International Seminar:

SEAFLOOR MINERAL DEPOSITS FOR THE GLOBAL SUSTAINABLE DEVELOPMENT

Madrid

7 May 2019

ETSI Minas y Energía



This Project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 731166

Organizer:



Participants:



Collaborators:



INTRODUCTION

Covering more than 70% of the planet, oceans represent a potentially promising new frontier for the exploration of mineral resources. Security of mineral supply has been identified by the European Commission as a priority challenge facing the raw materials sector. The 2017 list of Critical Raw Materials (CRM) now reflects societies growing demand for an ever-increasing number and quantity of elements and minerals that supply the green energy and technology sectors. The global demand for cobalt, tellurium, nickel, lithium, rare earth elements, copper, and other rare and critical metals, concurrent with the rapidly diminishing quality and quantity of land-based mined deposits, has situated the seafloor as a promising new frontier for the exploration of mineral resources. Spanning a large diversity of environments and resource style, including high and low temperature hydrothermal deposits (SMS, SEDEX), phosphorites, cobalt-rich ferromanganese crusts, and manganese nodules, deep-sea deposits are particularly attractive for their polymetallic nature with high contents of transition, rare and critical metals. Moreover, shallow-water resources, like marine placer deposits, represent another source for many critical metals and gems. The EC's Blue Growth strategy estimated that "By 2030, 10% of the world's minerals, including cobalt, copper and zinc could come from the ocean floors. Global annual turnover of marine mineral mining can be expected to grow from virtually nothing to €10 billion by 2030". The International Seabed Authority (ISA) is finishing the normative regulations that will permit the states, organizations or companies to extract minerals in areas beyond their national jurisdictions. Twenty-nine contractors have entered into 15-year contracts with ISA for exploration for manganese nodules, polymetallic sulphides, and cobalt-rich ferromanganese crusts in and on the seabed of the deep Atlantic, Pacific, and Indian oceans.

The EU research programmes are funding projects to increase knowledge about seabed minerals, marine minerals exploration, extraction technologies, and environmental issues. The project GeoERA-MINDeSEA aims to map and to establish the metallogenic context for different seabed mineral deposits with economic potential in the pan-European setting. It is a joint contribution of 12 national Geological Survey Organisations and Marine Institutes from 8 European countries, USA, and Russia. The project is part of GeoERA, an ERA-NET action under Horizon 2020 "Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA)".

This International Seminar on "Seafloor Mineral Deposits for the Global Sustainable Development" is a contribution to GeoERA-MINDeSEA, to disseminate and discuss the "state of the art" with stakeholders including policy makers, industry and academia. The Seminar will introduce how the global community gains valuable knowledge into seafloor mineral deposits in a challenging world, and develop legal, technical, and scientific understanding of submarine mineral systems. The European, National and the International programs related to the research, exploration, and exploitation of marine minerals, and environmental impact studies of marine mining activities, will play a pivotal role in the emerging Blue Economy and sustainable industrial growth.

PROGRAMME

- 09h45-10h00 **Opening** by the Director of IGME and the Director of the ETSIME
- 10h00-10h30 **Georgy Cherkashov** - *Overview of Recent International Seabed Authority Activity in Exploration and Exploitation of Mineral Resources in the Area*
- 10h30-11h00 **James Hein** - *A Comparative Evaluation of Deep-Ocean and Land-Based Mineral Resources: A Look Ahead to the Future of Seabed Mining*
- 11h00-11h30 Coffee break
- 11h30-12h00 **Fernando Tornos** - *Present Day vs Fossil Volcanosedimentary Massive Sulphides. Insights from the Major VMS Districts*
- 12h00-12h30 **Georgy Cherkashov** - *Massive Sulfides: Active and Inactive Sites - Resource Potential and Exploration Methods*
- 12h30-13h00 **Thomas Kuhn** - *Methods for Resource Assessment of Ferromanganese Nodules and Crusts- Lessons Learned from the German ISA Contract Area in the Pacific Ocean*
- 13h00-13h30 **Luis Somoza** - *Types of Seabed Mineral Deposits and Morphotectonics in NE Atlantic: from the Margins to the Mid-Ocean Ridge*
- 13h30 Seminar closure and wine reception



FSBI "VNIIOkeangeologia"

Leading Research Institute in the field of marine geology

Overview of recent International Seabed Authority activity in exploration and exploitation of mineral resources in the Area

Georgy Cherkashov, Institute for Geology and Mineral Resources of the Ocean (VNIIOkeangeologia), Angliyskiy av. 1, 190121, St. Petersburg, Russia

E-Mail: cherkashov@vniio.ru

The International Seabed Authority (ISA) is an autonomous international organization established under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Agreement relating to the Implementation of Part XI of the UNCLOS. The ISA is the organization through which States Parties to the Convention shall organize and control activities in the Area, particularly with a view to administering the resources of the Area. The primary means by which the Authority is required to organize, carry out and control activities in the Area is to adopt and uniformly apply rules, regulations and procedures. Starting from 2001 ISA issued regulations for exploration for three main deep-sea minerals: ferromanganese nodules (2000), polymetallic sulfides (2010) and cobalt-rich ferromanganese crusts (2012). Currently 29 contractors have entered into 15-year exploration contracts with ISA. As regulations governing exploration have been adopted, the challenge now is to make the transition to exploitation. Regulations for exploitation must reflect best international standards and practices, as well as agreed principles of sustainable development. The draft of Regulations on Exploitation of Mineral Resources in the Area was published on 25 March 2019 and will be reviewed by the ISA Council at its 25th Session from 15 to 19 July 2019. According to the Roadmap the delivery of exploitation regulations should be ready for adoption by ISA in 2021. During the rest period of time a lot of issues should be discussed and approved. One of the key question is the financial and payment mechanism which should be apply for the mining development. The open-ended working group was established to discuss the financial model and in particular to review the comparative study of alternative models prepared by the Massachusetts Institute of Technology.

Concurrent with the preparation of exploitation/mining code many other issues are developing by ISA Council and Legal and Technical Commission now. The following items *inter alia* could be mentioned in this regards:

- Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area
- Review and development of regional environmental management plans
- Issues relating to operation of the Enterprise
- Implementation of the data management strategy of the Authority

The nearest ISA workshop will be devoted to the development of standards and guidelines for the Mining Code (13 - 17 May, Pretoria, South Africa).

Regarding the review of current Contractors activity the particular ISA interest is paying to the study of environmental impact assessments for the testing of collector components in the Clarion-Clipperton exploration area by the Germany Federal Institute for Geosciences and Natural Resources and Global Sea Mineral Resources (Belgium).

Massive sulfides: active and inactive sites – resource potential and exploration methods

Georgy Cherkashov, Institute for Geology and Mineral Resources of the Ocean (VNIIOkeangeologia), Angliyskiy av. 1, 190121, St. Petersburg, Russia
E-Mail: cherkashov@vniio.ru

Black smokers and associated seafloor massive sulfides (SMS) have been discovered 40 years ago and considered as a main target during all period of oceanic hydrothermal system scientific research. However, exploration of SMS deposits which was started after signing the first ISA contract for prospecting of this type of marine minerals in 2011 provoked discussion regarding the environmental issues of future mining operations. As a result of this discussion general idea of prioritization of inactive sites for potential exploitation activity became popular between stakeholders. While this statement is not included in any of ISA regulations issued for contractors yet it seems we should be ready to get this recommendation/regulation in the nearest future. In this regard we should determine the strict definitions for active/inactive sites, estimate their resources and check the methods which could be used for their exploration.

Statistics for the distribution of active/inactive sites is rather limited but demonstrates approximately equal amount of them within best studied exploration areas in Atlantic and Indian oceans. The critical point is the distance between active and inactive sites. Current available data and environmental models based on field experiments have to be used to delineation of Environmental Protect Areas and management of SMS exploitation projects as a whole. Methods of exploration of inactive sites are based on SMS deposits specific characteristics and detection of anomalies in hosted rocks and sediments. The most efficient are electromagnetic methods (EM and SP) particularly installed on AUV. However, classical geochemical and mineralogical methods carrying out during current exploration works are effective as well.

Short CV Georgy Cherkashov

Georgy Cherkashov is Deputy director of the Institute for Geology and Mineral Resources of the Ocean (VNIIOkeangeologia, St. Petersburg, Russia). He holds a Dr. Sci. for research of seafloor massive sulfide (SMS) deposits of the Mid-Atlantic Ridge (2004). Chief scientist of 13 ocean-going expeditions for prospecting of SMS deposits (1983-2007) including diving missions on MIR and other submersibles. President of International Marine Minerals Society (2011-2012). Member of the Legal and Technical Commission of the International Seabed Authority (since 2012). Professor of St. Petersburg State University (Marine Geology, since 2005). Published more than 120 articles and chapters in monographs related to marine geology and deep-sea mineral resources. Few ones published during last 5 years are listed below:



- Cherkashev, G., Ivanov, V., Bel'tenev, V., Lazareva, L., Rozhdestvenskaya, I., Samovarov. M. 2013. Massive sulfide ores of the northern equatorial Mid-Atlantic Ridge, **Oceanology**. 53 607–619.
- Cherkashov, G. 2013. Mining for Marine Minerals. In “The regulation of continental shelf development: rethinking international standards”. Eds. M. Nordquist, J. Moore, A. Chircop and R. Long. Center for oceans law and policy. **Martinus Nijhoff Publishers**. V. 17 pp. 71-79.

- Firstova, A., Stepanova, T., Cherkashov, G., Goncharov, A., Babaeva, S. 2016. Composition and Formation of Gabbro-Peridotite Hosted Seafloor Massive Sulfide Deposits from the Ashadze-1 Hydrothermal Field, Mid-Atlantic Ridge. **Minerals**, 6, 19.
- Madureira, P., Brekke, H., Cherkashov, G., Rovere, M. 2016. Exploration of polymetallic nodules in the Area: Reporting practices, data management and transparency. **Marine Policy** 70. 101–107.
- Cherkashov, G., Kuznetsov, V., Kuksa, K., Tabuns, E., Maksimov, F., Bel'tenev, V. 2017. Sulfide geochronology along the Northern Equatorial Mid Atlantic Ridge. **Ore Geology Reviews**. P. 147-154.
- Cherkashov, G. 2017. Seafloor Massive Sulfide deposits: distribution and prospecting. In: Deep-Sea Mining. Resource Potential, Technical and Environmental Considerations. R. Sharma (ed.) **Springer International Publishing AG**. P. 143-165.
- Lobkovsky, L., Cherkashov, G. (eds). 2018. The World Ocean. Mineral resources and gas hydrates. Moscow. **Scientific World**. 708 pp. (in Russian)



A comparative evaluation of deep-ocean and land-based mineral resources: A look ahead to the future of seabed mining

James R. Hein, United States Geological Survey (USGS), Pacific Coastal and Marine Science Center, Santa Cruz, California, USA

E-Mail: jhein@usgs.gov

Deep-ocean mining has not yet occurred in the Exclusive Economic Zone (EEZ) of any coastal nation, nor in Areas Beyond National Jurisdictions (ABNJ). The transition from a global hydrocarbon economy to a green-energy economy and the rapidly growing middle class in developing countries are driving the need for considerable new sources of critical materials, and deep-ocean minerals can help fulfill that need. The infrastructure required for marine and land-based operations are very different and provide unique and potentially favorable characteristics to deep-ocean mineral extraction.

Manganese nodules are essentially two-dimensional deposits sitting on abyssal plain sediments at about 4000-6000 m water depths. Metals of economic interest include Ni, Cu, Mn, Mo, Co, and Li. Ferromanganese crusts are also two-dimensional deposits forming pavements on rock outcrops on seamounts and ridges at water depths of about 800-7000 m, with greatest economic interest in crusts from 1500-2500 m. Metals of economic interest include Co, Mn, Ni, Mo, Te, Pt, V, Nb, and REY. Hydrothermal seafloor massive sulfides (SMS) occur along 89,000 km of ocean ridges, arcs, and back-arcs forming small-tonnage deposits exposed at the seabed and up to several tens of meters thick creating three-dimensional deposits. They will be mined for Cu, Zn, Au, and Ag at depths of ~1000-3000 m. The concept of terrestrial-dominant and deep-ocean-dominant critical metals will be discussed.

A conservative estimate is that 21.1 billion dry metric tons of manganese nodules exist in the Clarion-Clipperton manganese nodule field (CCZ), the largest of the nodule fields in the global ocean. Based on that tonnage, contained metal contents show more Mn, Ni, Mo, Co, As, Y, Te, and Tl than the global land-based reserves, and land-based reserve-base* for all those metals except As and Mo. About 7.5 billion dry tons of ferromanganese crusts are estimated to occur on seamounts in the Pacific Prime Crust Zone (PCZ), the area with the highest tonnage, critical-metal-rich deposits. Based on that tonnage, contained metal contents show more Mn, Co, As, Bi, Y, Te, and Tl than the global land-based reserves, and land-based reserve-base* for those metals except Mn. Approximately 20% of the CCZ nodule and PCZ crust deposits would be economic for first-generation mine sites. The tonnages of few SMS deposits have been determined, most from active hydrothermal systems that are enriched in Cu, Zn, Au, and Ag, but those deposits are generally small. Inactive SMS have not been widely studied and may differ in grade and tonnage but are of greatest economic interest. If deep-ocean mining follows the evolution of offshore production of petroleum, we can expect that about 30-40% of the demand for critical metals will come from deep-ocean mines by about 2065.

*Reserve-base includes those resources currently economic (reserves), marginally economic, and sub-economic (USGS).

Short CV James R. Hein

James R. Hein, Ph.D., is a senior scientist with the U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, California, USA. He received his Ph.D. from the University of California at Santa Cruz in 1973. His main research interests are in deep-ocean mineral deposits (ferromanganese crusts, manganese nodules, seafloor massive sulfides, phosphorite, barite, and others) and paleoceanography based on proxies archived in ferromanganese crusts. Hein has authored or co-authored over 590 papers and abstracts, including editing six books and Special Issues of the journals. He is a Fellow of the Society of Economic Geologists and the Geological Society of America and is Past-President of the International Marine Minerals Society. Dr. Hein's has had 50+ papers published over the past 5 years, so only a few relevant ones are included in this short Vita:



- Hein, J.R., de Ronde, C.E.J., et al. 2014. Layered hydrothermal barite-sulfide mound field, East Diamante caldera, Mariana volcanic arc. **Economic Geology**, 109, 2179-2206.
- Hein, J.R., Spinardi, F., Okamoto, N., Mizell, K., Thorburn, D. and Tawake, A. 2015. Critical metals in manganese nodules from the Cook Islands EEZ, abundances and distributions. **Ore Geology Reviews**, 68, 97-116.
- Hein, J.R., Koschinsky, A., Mikesell, M., Mizell, K., Glenn, C., and Wood, R. 2016. Marine phosphorite deposits as a potential resource for heavy rare earth elements and yttrium. **Minerals** 2016, 6(3), 88, 1-22.
- Koschinsky, A. and Hein, J.R. 2017. Marine ferromanganese encrustations: Archives of changing oceans. **Elements**, 13 (3), 177-182.
- Hein, J.R. and Cherkashov, G. (eds.), 2017. Marine mineral deposits: New resources for base, precious, and rare metals. **Ore Geology Reviews**, 87 (July), 1-192.
- Hein, J.R., Konstantinova, N., et al. 2017. Arctic deep water ferromanganese-oxide deposits reflect the unique characteristics of the Arctic Ocean. **Geochemistry, Geophysics, Geosystems**, 18 (11), November 2017.
- Gartman, A. and Hein, J.R. 2019. Mineralization at oceanic transform faults and fracture zones. In: Duarte, J.C. (ed.), Transform plate boundaries and fracture zones, **Elsevier**, Chapter 5, pp. 105-118.

Present day vs fossil volcanosedimentary massive sulphides. Insights from the major VMS districts

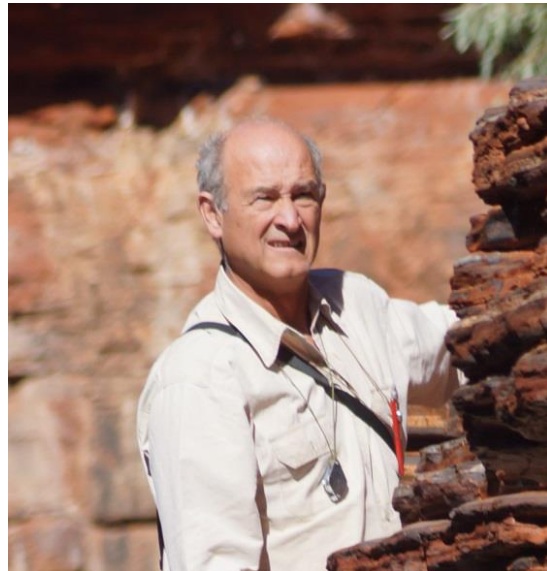
Fernando Tornos, Instituto de Geociencias (IGEO-CSIC-UCM), Severo Ochoa 7, 28040 Madrid, Spain

E-Mail: tornos@csic.es

Due to their widespread occurrence in present day and fossil submarine hydrothermal environments, volcanogenic massive sulphides (VMS) are some of the best known ore forming systems. However, direct comparison between actual systems being formed on the seafloor and ancient ones preserved in the geological record show puzzling differences, suggesting that a direct comparison is not always possible. Some key contrasting issues include the formation of present day systems in oxic environments, the origin and evolution of fluids, the environment of formation and the mechanisms of preservation, the size of the deposits and the role of microbial activity. As a whole, the evidences suggest that nowadays the rate of formation and preservation of VMS deposits is not as vigorous as in the past but that major deposit, if any, should be found in sub-seafloor hydrothermal systems.

Short CV Fernando Tornos

Fernando Tornos is currently researcher at the Instituto de Geociencias (CSIC-UCM) and adjunct professor at the Memorial University of Newfoundland and Lulea University of Technology. He has worked for more than 25 years in the Instituto Geológico y Minero de España on the geology and geochemistry of ore deposits, including volcanogenic massive sulphide deposits. His current main research interests are the environments of formation and preservation of VMS deposits, the role of microbes in the formation of ore deposits and IOCG systems. Few relevant papers included in this short CV:



Tornos, F., Oggerin, M., Ríos, A. d. I., et al. 2019. Do microbes control the formation of giant copper deposits?: **Geology**, v. 47, no. 2, p. 143–146.

- Tornos, F., Peter, J. M., Allen, R., and Conde, C. 2015. Controls on the siting and style of volcanogenic massive sulphide deposits: **Ore Geology Reviews**, v. 68, no. 0, p. 142-163.
- Tornos, F., Velasco, F., Menor-Salvan, C., et al. 2014. Formation of recent Pb-Ag-Au mineralization by potential sub-surface microbial activity: **Nature Communications**, v. 5, p. 4600.
- Velasco-Acebes, J., Tornos, F., Wiedenbeck, M., et al. 2019. Isotope geochemistry tracks the maturation of submarine massive sulfide mounds (Iberian Pyrite Belt): **Mineralium Deposita**.
- Tornos, F. 2006. Environment of formation and styles of volcanogenic massive sulfides: The Iberian Pyrite Belt: **Ore Geology Reviews**, v. 28, p. 259-307.



Bundesanstalt für
Geowissenschaften
und Rohstoffe

GEOZENTRUM HANNOVER

Methods for resource assessment of ferromanganese nodules and crusts - lessons learned from the German ISA contract area in the Pacific Ocean

*Thomas Kuhn, Federal Institute for Geosciences and Natural Resources (BGR),
Stilleweg 2, 30655 Hannover, Germany*

E-Mail: thomas.kuhn@bgr.de

Polymetallic manganese nodules occur as potato-shaped concretions on the seafloor of abyssal plains in about 4000 m to 6000 m water depth in all major oceans. They form two-dimensional deposits on top or within the first 10 cm of the deep-sea sediments. Despite the fact that they occur in all major oceans, the Clarion-Clipperton-Zone (CCZ) of the northeast equatorial Pacific Ocean hosts the largest contiguous occurrence of Mn nodule fields, covering an area of about four million square kilometers. The International Seabed Authority (ISA) has granted so far 16 licenses for the exploration of manganese nodules in the CCZ. Each license covers about 75.000 km² and lasts 15 years.

The exploration of such vast areas normally starts with seabed mapping using swath echosounding systems such as the Kongsberg Simrad EM 122. This system works with 12 kHz frequency in the deep sea and provides up to 864 soundings per cycle and depending on the system settings the resolution can be between 40 and 60 m in about 4000 m water depth. Apart from information about the bathymetry the system also provides backscatter data. These multibeam acoustic imagery data are collected simultaneously during seafloor bathymetric mapping and provide information on the geological conditions of the seafloor. Since the difference in relative backscatter strength between a flat, sediment-covered seafloor with and without nodules is between +11 dB and +13 dB for frequencies between 9 kHz and 160 kHz, it is possible to distinguish nodule fields on the seafloor from areas devoid of nodules. Based on such information it is then possible to select areas of interest to take samples and carry out video stations. Sampling is principally done with a box corer since this tool not only provides nodule samples but it also allows for the calculation of the nodule abundance (in kg/m²) – which is one of the important parameters for resource estimation. Video transects are normally run with deep-towed video sleds. This way samples and information can be gathered from areas of different nodule facies as well as from areas devoid of nodules. All these data are fundamental for an analysis of the prediction of the nodule abundance in the entire license area. Such an approach can be realized by multivariate, multi-scaled statistical methods such as Artificial Neural Networks (ANN) or Random Forest (RF) which provide estimations of the total nodule resources and their distribution in the entire license area. However, such estimations do not meet the requirements of international standards for the assessment of mineral resources and reserves such as the JORC code or NI 43101. They only provide a general idea of the amount of resources and the distribution of the parameter of interest such as the nodule abundance. However, the information from ANN or RF can be used to select areas of interest, which eventually will be explored in detail based on a grid of box corer stations, video mapping, high-resolution mapping with AUVs and side-scan sonars and so on. Finally, these efforts flow into a final resource assessment based on classical geostatistics.

The talk will provide a workflow on the above outlined approach and discuss the pros and cons of the single steps.

Short CV Thomas Kuhn

Thomas Kuhn studied at the Universities of Freiberg and Clausthal and received a PhD from the Free University of Berlin in 1999. He spent 10 years as a Research Fellow at the University of Freiberg and the Institute of Marine Sciences Kiel (IFM-GEOMAR) before moving to the Federal Institute for Geosciences and Natural Resources in 2010. He currently works in the Marine Resource Exploration Group and is responsible for research work in the German Mn nodules license area in the Pacific nodule belt. He has specialized on solid-phase associations and structural control of trace elements in ferromanganese precipitates, rocks, and sediments as well as the geostatistical resource estimation of the nodule fields. Furthermore he has 15 years experience in marine technology with respect to ROVs and autonomous drilling devices. He has also worked on hydrothermal systems north off Iceland, in the central Atlantic (Logatchev area), and the Indian Ocean (southern Central Indian Ridge) as well as on ferromanganese crusts (Louisville Ridge, Central Indian Ridge, Fiji Basin). He has participated in more than 30 research cruises to all major oceans. Few relevant papers included in this short CV:



- Heller, C., T. Kuhn, G.J.M. Versteegh, A.V. Wegorzewski, S. Kasten, 2018. The geochemical behavior of metals during early diagenetic alteration of buried manganese nodules. **Deep Sea Res. Part I**, 142: 16-33, <https://doi.org/10.1016/j.dsr.2018.09.008>.
- Knobloch, A., Kuhn, T., Rühlemann, C., Hertweg, T., Zeissler, K.-O., Noack, S., 2017. Predictive mapping of the nodule abundance and mineral resource estimation in the Clarion-Clipperton Zone using artificial neural networks and classical geostatistical methods. In: R. Sharma (Ed.): Deep-Sea Mining: Resource Potential, Technical and Environmental Considerations. **Springer International**, Cham, pp. 189 – 212.
- Kuhn, T., Rathke, M., 2016. Visual data acquisition in the field and interpretation for seafloor manganese nodules. **EU Project Blue Mining** (GA No. 604500) Delivery D1.31. <http://www.bluemining.eu/downloads>, 34 pp.
- Kuhn, T., Wegorzewski, A., Rühlemann, C., Vink, A., 2017. Composition, Formation, and Occurrence of Polymetallic Nodules. In: R. Sharma (Ed.): Deep-Sea Mining: Resource Potential, Technical and Environmental Considerations. **Springer International**, Cham, pp. 23 – 64.
- Kuhn, T., Uhlenkott, K., Martinez, P., Vink, A., Rühlemann, C., 2019. Manganese Nodule Fields from the NE Pacific as Benthic Habitats. In: P. Harris, E. Baker (Eds.): Seafloor Geomorphology as Benthic Habitat, 2nd edition. **Elsevier**, Chapter 38, in press.
- Volkman, S., Kuhn, T., Lehnen, F., 2018. A comprehensive approach for a techno-economic assessment of nodule mining in the deep-sea. **Mineral Economics**. <https://doi.org/10.1007/s13563-018-0143-1>.
- Wegorzewski, A.V., T. Kuhn, 2014. The influence of suboxic diagenesis on the formation of manganese nodules in the Clarion Clipperton nodule belt of the Pacific Ocean. **Marine Geology**, 357, 123-138.
- Wegorzewski, A.V., T. Kuhn, R. Dohrmann, R. Wirth, S. Grangeon, 2015. Mineralogical characterization of individual growth structures of Mn-nodules with different Ni+Cu content from the central Pacific Ocean. **American Mineralogist**, 100, 2497–2508.



Types of seabed mineral deposits and morphotectonics in NE Atlantic: from the margins to the mid-ocean ridge

Luis Somoza, Geological Survey of Spain (IGME), Ríos Rosas 23, 28003 Madrid, Spain

E-Mail: l.somoza@igme.es

The exploration of seabed minerals requires the use of cutting-edge technology including a wide range of deep-water submarine exploration as high-resolution multibeam bathymetry, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), magnetometers or others. Using this suite of exploration techniques on several oceanographic expeditions, a great variety of mineral deposits have been identified related to different seafloor morphologies in the NE Atlantic such as continental banks and margins, hydrocarbon-related fluid venting areas (e.g. mud volcanoes), oceanic seamounts, hotspot-related hydrothermal deep-water mounds, and mid-ocean ridges. In first place, large amounts of phosphorite hardgrounds and a suite of Fe-Mn oxyhydroxide deposits (nodules and crusts) were discovered in the Galicia Bank region (NW Iberian margin). Surprisingly, this bank at 500-1000 m water depths yielded a complete suite of mineral deposit types: phosphorite slabs and nodules, Fe-Mn crusts, Co-rich Mn nodules and Fe-rich nodules. In the Gulf of Cadiz, several fields of ferromanganese nodules and hardgrounds were discovered in relation to hydrocarbon seeps. Siderite-rhodochrosite nodules exposed to the oxidizing sea bottom waters is then replaced by Fe-Mn oxyhydroxides. In this way, bio-mineralization by anaerobic oxidation of methane (AOM) processes, as chimneys and slabs, and periodical oxidation by effects of strong Mediterranean Outflow Water undercurrents control the formation of this type of Fe-Mn nodules. Otherwise, in the Canary Island Seamount Province (CISP) large amounts of Fe-Mn crusts and nodules has been collected at 1700-3000 m water depths formed two distinct types of genetic processes; i.e. Mixed diagenetic/hydrogenetic and purely hydrogenetic. The age of initiation of Fe-Mn crusts dated at 76 Ma point is related to formation of one of the oldest seamount provinces of the world oceans. Significant increase in Fe contents are related to periods of ventilation of the oxygen minimum zone (OMZ) in the eastern Central Atlantic by intrusion of deep upwelling currents from Polar Regions. Contouritic bottom-currents or upwelling undercurrents also control the type of mineral deposits in these environments. Opening of gateways between oceans as the Iceland-Faroe in the Arctic, Drake Passage in the Antarctica or Tethys may also trigger the formation of important submarine mineral deposits in the Atlantic seamounts, banks or margins. Exploration of new mineralizations related to supercritical hydrothermal fluids triggered by sills emplaced in hotspot-related deepwater oceanic basins, between margins and mid-ocean ridges, is one challenge in the near-future.

Short CV Luis Somoza

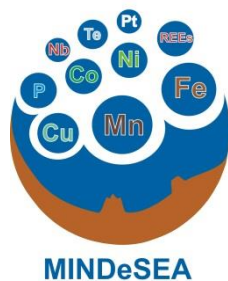
Luis Somoza, Ph.D., is a Research Professor in the Geological Survey of Spain (IGME). His main research interest is focused on active seabed fluid flow systems in deep-water systems including natural hydrocarbon seeps, hydrothermal vents and active submarine volcanism. He has been scientific chief of oceanographic surveys aboard the research vessels Hespérides, Sarmiento de Gamboa and Ifremer's L'Atalante



in Antarctica, offshore Morocco, Gulf of Cadiz, Canary and Madeira Islands, and Galicia, and has participated in international research vessels as the Prof. Logachev (Russia), Urania (Italy) or Sonne (Germany). He is presently the scientific-technical coordinator of the Spanish projects for the Extension of the Continental Shelf according United Nations Convention for the Law of the Sea (UNCLOS). He has advisor for Argentina in the Patagonian continental shelf and for Ecuador regarding the Galápagos Archipelago. He is representative of the Atlantic Seabed Mapping International Working Group (ASMIWG) within the Atlantic Ocean Research Alliance (AORA) between USA, Canada and EU. He has authored or co-authored of more than 110 papers ranked in the Science Citation Index reaching an index h= 44 according Google Scholar. He is presently the coordinator of the EXPLOSEA Project developed in Antarctica and Atlantic areas entitled: "Exploration of active submarine hydrothermal vents, mineralization and associated geobio-systems" which web page is located at <http://www.igme.es/explosea>. Few relevant papers included in this short CV:

- Somoza, L., González, F.J., Barker, S.J., et al., 2017. Evolution of submarine eruptive activity during the 2011-2012 El Hierro event as documented by hydroacoustic images and remotely operated vehicle observations. **Geochemistry, Geophysics, Geosystems** 18 (8): 3109-3137.
- Medialdea, T., Somoza, L., González, F.J., et al., 2017. Evidence of a modern deep-water magmatic hydrothermal system in the Canary Basin (Eastern Central Atlantic Ocean). **Geochemistry, Geophysics, Geosystems** 18 (8): 3138-3164.
- González, F.J., Somoza, L., Hein, J.R., et al., 2016. Phosporites, Co-rich Mn nodules, and Fe-Mn crusts from Galicia Bank, NE Atlantic: Reflections of Cenozoic tectonics and paleoceanography. **Geochemistry, Geophysics, Geosystems** 17, 2, 346-374.
- Somoza L., León, R., Medialdea, T., et al., 2014. Seafloor mounds, craters and depressions linked to seismic chimneys breaching fossilized diagenetic bottom simulating reflectors in the central and southern Scotia Sea, Antarctica. **Global and Planetary Change** 123, Part B, 359-373
- González, F.J., Somoza, L., Lunar, R., et al., 2010. Internal features, mineralogy and geochemistry of ferromanganese nodules from the Gulf of Cadiz: The role of the

- Mediterranean Outflow Water undercurrent. **Journal of Marine Systems** 80, 3-4: 203-218.
- Merinero R., Lunar R., Somoza L., et al., 2009. Nucleation, growth and oxidation of framboidal pyrite associated with hydrocarbon-derived submarine chimneys: lessons learned from the Gulf of Cadiz. **European Journal of Mineralogy**. DOI: 10.1127/0935-1221/2009/0021-1956.
- González, F.J., Somoza, L., Lunar, R., et al., 2007. Fe-Mn nodules associated with hydrocarbon seeps: the new discovery of the Gulf of Cadiz (eastern Central Atlantic). **Episodes** 30, nº 3; 187-196.
- Díaz-del-Río, V; Somoza, L., et al. 2003. Vast fields of hydrocarbon-derived carbonate chimneys related to the accretionary wedge/olistostrome of the Gulf of Cadiz. **Marine Geology** (1-4): 177-200.



<http://geoera.eu/projects/mindesea/>

Twitter: @MINDeSEA