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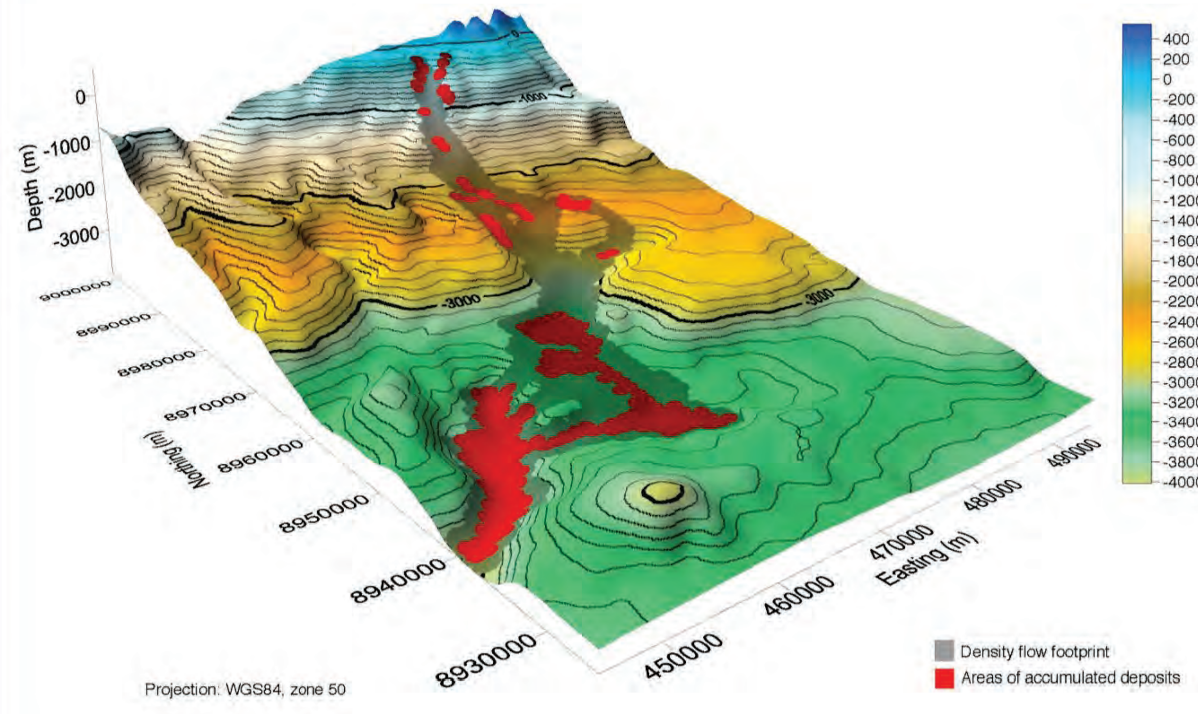
REPORTS AND STUDIES

GESAMP

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

PROCEEDINGS OF THE GESAMP INTERNATIONAL WORKSHOP ON THE IMPACTS OF MINE TAILINGS IN THE MARINE ENVIRONMENT



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GESAMP
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

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Cover photo: Red shows mine tailings deposits resulting from deep sea tailings disposal (DSTP) at Batu Hijau in Indonesia.

Credit: Stuart Simpson, CSIRO, Australia.

Notes:

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Contents

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DISCLAIMER

THIS REPORT CONTAINS A SUMMARY OF THE PRESENTATIONS AND DISCUSSIONS AT THE GESAMP MINE TAILINGS WORKSHOP, HELD FROM 10 TO 12 JUNE 2015 IN LIMA, PERU, AND IS NOT A STUDY OR REVIEW PERFORMED BY GESAMP ITSELF.

THE VIEWS EXPRESSED MAY NOT NECESSARILY CORRESPOND WITH THOSE OF GESAMP, NOR ITS SPONSORING AGENCIES. EVERY EFFORT HAS BEEN MADE TO PROVIDE AN ACCURATE, COMPREHENSIVE AND BALANCED ACCOUNT OF THE PRESENTATIONS AND DISCUSSIONS AT THE GESAMP MINE TAILINGS WORKSHOP; ANY OMISSIONS, INACCURACIES OR OTHER SHORTCOMINGS REMAIN THE RESPONSIBILITY OF THE AUTHORS OF THIS REPORT.

EXECUTIVE SUMMARY

The GESAMP International Workshop on the Impacts of Mine Tailings in the Marine Environment was held at the Meliá Hotel, Lima, Peru, from 10 to 12 June 2015 and attended by more than 90 participants. The workshop was hosted by the Maritime Authority of Peru (DICAPI) and organized as a joint IMO-GESAMP activity. The workshop was supported by the Office for the London Convention/Protocol and Ocean Affairs, the International Maritime Organization, the International Network for Scientific Investigations of Deep-Sea Ecosystems (INDEEP), the Deep Ocean Stewardship Initiative (DOSI), and the Research Council of Norway (Norges Forskningsråd, NFR) through the MITE-DEEP project. In addition, excellent support was received from the Sociedad Nacional de Minería, Petróleo y Energía (National Society for Mining, Petroleum and Energy) of Peru and Iniciativas Sustentables para la Minería (Chilean Mining Industry Initiatives in Sustainability), and the Peruvian Coast Guard. Funds were also allocated from the GESAMP Trust Fund.

The invited participants represented the scientific community, the mining industry, policy makers, coastal and marine managers, and environmental NGOs. The aim was to create a forum where key stakeholders could discuss the broader issues and inform GESAMP on the topic.

A snapshot of the workshop participants

The primary findings and conclusions along with recommendations from the workshop are set out in the following paragraphs.

Findings and conclusions

Overall, the workshop concluded that there are major gaps that need to be addressed in the scientific understanding of the behaviour of mine tailings in the sea at depths greater than 20 to 80 m and consequently the short and long term impacts on the marine environment and other potential users of marine resources. Furthermore, scientific gaps in measurement and monitoring techniques in assessing impacts of existing and proposed new deep-sea discharges of mine tailings need to be addressed. Although much is known about impact assessment methods in the upper ocean, further work is needed regarding how to conduct impact assessments in the upper stratified ocean waters. However, much more needs to be done to extend and modify physical, chemical, and biological assessment techniques developed for surface waters in order to apply them to the deep sea.

Areas requiring more information

1. Understanding behaviour of sediment plumes; physical and chemical behaviour of pollutants through the marine ecosystem.
2. Modelling of plumes (horizontal shearing and upwelling) and the resulting tailings footprint.
3. Enhanced toxicity testing to assess impacts to deep-sea ecosystems.
4. Understanding the ecological significance of smothering all benthic organisms in the disposal site footprint and physically altering the bottom habitat.
5. Identification of the reduction in species composition/abundance and biodiversity of marine communities.
6. Determining and understanding the significance of bioaccumulation of metals through food webs and ultimately into human fish-consuming communities; and potential increases in risk to human health.
7. Assessing recolonization potential of deep-sea benthos and limiting factors by deep-sea benthos; timescale for recovery of impacted areas.
8. Specialized sampling equipment for the deep-sea.[1]

The workshop also concluded that the focus of future work should initially be on the scientific gaps and the impact of mine tailings on the marine environment. These efforts should inform the policy discussion on the need to develop international guidelines, including best management practices.

Gaps in scientific information and measurement techniques

Gaps in the current science and information/understanding of deep-sea ecosystems as well as the behaviour of mine tailings in the marine environment were emphasized. These abiotic and biotic processes and techniques include physical oceanography (e.g. plume behaviour and modelling), chemistry, and impacts to ecological systems in the deep sea, such as impacts to the composition and functioning of the pelagic and benthic communities.

- Marine organisms normally used for toxicity testing are from the upper stratified layers of marine water, not the deep sea. There is a need to develop standard sediment and aquatic toxicity tests that use species from deeper water. While the preference would be to conduct in situ testing with marine species in the deep sea, that is recognized as both complicated and costly. Toxicity test issues that should be addressed include:
  - The use of suitable test temperatures;
  - Incorporating pressure into laboratory experiments where possible to simulate the deep-sea environment;[2]
  - The measurement of bioavailability and bioaccumulation in the deep sea;
  - Chronic studies with variable exposure regimes/scenarios;
  - The use of a wide taxonomic range of marine species; and
  - Expanding available toxicity tests to represent tropical marine environments.
- There is a need to better understand the physical and chemical behaviour of mine tailing slurries and sediment plumes in the deep sea, including empirical work and modelling. Available current studies are generally from surface currents, not the deep sea. Issues include:
  - Spatial and temporal variability of horizontal and vertical gradients of currents, and physical and chemical properties of the water-column; and
  - Shearing off and fate of plumes and suspended sediments after discharge into the water column, in view of such factors as currents, flocculation, characteristics of the tailings, and deep-sea pressures. The dynamics of deep-sea canyons and sporadic events such as benthic storms or dense shelf water cascading also need to be addressed.
- The toxicological effects (and their significance) of mine tailings in the water column, at the disposal site, and in the far field need to be better understood. Key elements:
  - Deep-sea exposure pathways need to be understood;
  - The significance of physical smothering of benthos, and the impact of bioavailable fractions of heavy metals upon biota;
  - Understanding of the effects on abundance and biodiversity, and the relationship (i.e. impacts) to biota in the upper stratified waters;
  - Sensitivity of fauna to suspended loading, and recovery dynamics; and
  - Cumulative effects over long periods of time (e.g. 50 years), possibly from multiple sources.

[1] The equipment for research is available (ROVs, AUVs, mapping systems, imaging systems, trawling, coring, water-column studies), however this is very expensive and only available in some countries.

[2] Several institutions can maintain deep-sea animals under pressure (e.g. NOCS in United Kingdom; IFREMER in France).

- The knowledge base that currently exists regarding recolonization is from intertidal and shallow water experiments. More research is needed on the rates and factors that influence recovery and recolonization in the deep-sea, as well as on the specific tailing variables that may limit such recolonization (e.g. grain angularity, heavy metal and/or process chemical concentrations, and organic matter content).
- More efforts are needed to define the specific elements that constitute a comprehensive oceanographic and ecological baseline survey of a proposed disposal site and surrounding areas. The workshop recognized that deep-sea surveys need specialized sampling gear and procedures.

The workshop noted that there were strong correlations between the issues identified for deep-sea tailings placement (DSTP), such as the lack of knowledge on biota, unknown impacts of plumes, ecotoxicology, and ecosystem recovery, and those identified for wastes produced during deep-seabed mining. Further work or studies should address both activities as much as possible to reduce effort and costs.

Gaps in evaluation tools – water and sediment quality criteria

The workshop noted that existing sediment and water quality criteria are limited to specific contaminants and not all contaminants. These criteria were developed using continuous dissolved chronic exposure, and mostly were based on single-species data. The methods and thereby the criteria are not well developed for application in the deep sea. Thus, existing criteria rely on surrogate species, raising uncertainties on the applicability to the deep-sea discharge of mine tailings. It was noted that sediment quality guidelines have greater uncertainty than water quality guidelines. Concerns were expressed about the unknown influence of deep-water environmental conditions on bioavailability, the effects of plumes of fine particulates on filter feeders, and the uncertainties in fluctuating exposure. Further efforts into developing guidelines based upon ecological change (DNA-based techniques) should be considered.

Total contaminant concentrations are often poor predictors of the risk posed by contaminants in sediments. While total metal concentrations in sediments impacted by mine tailings can often appear alarmingly high, a large portion of the metals within tailings exist in highly mineralized forms that are less bioavailable to organisms when compared to metals introduced to the environment from other common anthropogenic sources. While no standardized whole-sediment toxicity tests exist that utilize deep-sea organisms, tests that use surrogate organisms are generally considered appropriate for assessing contaminant bioavailability and risks or toxicity. Tests on sediments containing mine tailings indicate that site-specific sediment quality guidelines that better reflect the low bioavailability of mine-derived metals may be appropriate for management purposes.

Science to inform regulatory decision-making

The development of new and enhanced measurement tools and models and baseline surveys at disposal sites should be conducted with the end uses in view.

- The information and data generated through environmental impact assessment of deep-sea discharges of mine tailings should be useful to regulatory authorities to provide sufficient information from which they can make decisions. Comprehensive baseline conditions at the disposal site are critical to understand potential impacts and actual impacts during and post-disposal.
- Information generated through scientific assessments in understanding the risks at disposal sites from mine tailings discharges should be useful in informing the development of national or international best practices or guidelines in relation to the management of mine wastes.

Gaps in best practices in waste management

The workshop concluded that development of guidance on best practices in relation to the management of mine wastes should go beyond strictly engineering aspects of marine discharge, generally thought of as addressing such items as piping materials, depth of discharge, and angle of discharge. Best practices should include appraisal of all practical waste management options and evaluation of opportunities for waste reduction and also address the comprehensive list of what data and information needs to be generated to prepare environmental risk assessments for use by decision-makers.

The workshop also discussed what constitutes best practice beyond the engineering aspects, e.g. collection of information for assessment of environmental impacts. The importance of monitoring was also highlighted. Best practices should include such information as the following:

- Baseline surveys of physical, chemical, and biological characteristics of the disposal site and surrounding areas;
- Information on suitable discharge locations, e.g. depth and current regimes, and ecological resources;
- Full knowledge of the physical, chemical, and toxicological characteristics of the mine tailings proposed for discharge;
- Identification of in-plant process controls or mine tailings treatment prior to discharge, e.g. treatment of process wastewater, modify reagents and tailings size, and consider reuse or recycling;
- Options for recycling or reuse of mine wastes;
- Identification of key elements of environmental impact assessments, including impact hypotheses and ecosystem risk evaluations;

- Identification of the detailed elements of monitoring programmes to assess the extent of impacts of ongoing discharges; and
- Transparency and acknowledging what we do and do not know.

Moving forward with limited scientific data

The workshop concluded that development of supporting scientific assessment tools, conducting the environmental assessments, evaluating the resulting data and information, along with regulatory frameworks, guidelines, or best practices in relation to the management of mine wastes all contribute to decision-making. The workshop identified the following fundamental questions to be addressed:

- How to apply the precautionary principle and what level of precaution is needed?
- What is important in ecological impact assessment and how to prioritize necessary research to support risk assessments? What are the practical impacts?
- How to assess the impacts to the deep-sea ecosystem and determine the relationship to the productive upper coastal waters? For example:
    - Is there a physical or biological indicator or suite of indicators to determine significant effects?
- The workshop also asked the crucial questions that will face decision-makers.
    - What is the cost to ecosystem services versus the benefits of deep-sea disposal?
    - How to competently compare risks of land versus sea disposal, which requires integration of all of the disciplines to make judgements? The issue cannot be considered solely on tailings placement in the oceans. The costs and benefits analysis needs to include the alternative of land disposal. In order to do this, an appropriate institutional framework is needed.

Recommendations of the GESAMP workshop

Finally, the workshop discussed the necessary steps to move the issue forward. These included:

- Generate basic knowledge to close the scientific gaps, including development of scientific measurement tools and assessment of impacts. While some knowledge is available and provides useful lessons, specific case studies of the behaviour and impacts of mine tailings are needed;
- Operational practices for mining processes and discharges must be adapted to the specific conditions of deep sea disposal in order to minimize impacts, such as treatment of mine tailings before discharge or modifying use of chemical reagents in processing;
- Monitoring of the marine environment will be essential to confirm any risk assessments made. This includes long-term monitoring after closure. Some examples were given during the workshop where this kind of knowledge is now being gathered, but monitoring of deep-sea environments is expensive and consequently examples are rare;
- Informed by the efforts to close the scientific gaps and additional knowledge on the impacts of mine tailings disposal to marine waters, appropriate regulatory or guidance frameworks, including best management practices in relation to the management of mine wastes, should be developed and implemented;
- There is a need to "socialize" the process, beyond only engineering issues, involving the full range of stakeholders early in the information gathering process, and during the evaluation and decision-making processes; and
- There is a need to assess cumulative impacts, both from the same industry and with other industries (fisheries, mining) and stressors related to climate change and ocean acidification.

Consequently, the workshop recommended that a global assessment of the impacts of mine tailings in the marine environment as a whole should be initiated under the leadership of GESAMP and with the cooperation of the UN Agencies, Regional and National Administrations, IGOs, NGOs and the DOSI-DSTP Working Group,[3] in order to further advise policy-makers on the many aspects of mine tailings disposal, which are currently poorly understood.

It is recognized that any such assessment (STD and DSTP) would be necessary to compile data from primary sources including the scientific literature, and the available regional assessments, some of which may provide quantitative data overviews on this topic. Without waiting for all the unknowns to be filled in, such an assessment will need to develop agreed methodologies for estimating the fate and potential impacts of mine tailings in the marine environment.

Finally, in recognition that no international agency has set global standards for mine tailings discharges to marine waters, the workshop concluded that the London Convention and Protocol should address the issue working with regional bodies and other interested international entities. The workshop recognized that London Convention and Protocol members have expertise and experience in addressing dumping of wastes into the marine environment, and application of these assets to marine discharges of mine tailings is a logical next step, while addressing their general obligation to protect and preserve the marine environment from all sources of pollution. The workshop also noted ongoing discussions between the London Convention and Protocol and the International Seabed Authority concerning regulation of deep-sea waste disposal.

[3] The DOSI-DSTP Working Group is preparing a global GIS map of Submarine Tailings Disposal (STD) and Deep-sea Tailings Placements (DSTP).

It is hoped that this workshop report will provide a balanced and reliable perspective as well as a good starting point for such a global assessment. GESAMP thanks all the participants who gave generously of their time and ideas both during the workshop and in the writing of this report.

Marine discharge versus submarine tailings disposal (STD) versus deep-sea tailings placement (DSTP)

In the context of this report, these terms mean the same thing – disposal of mine tailings into deep marine waters. Discharges in marine waters are intended to be placed below the mixing zone, such that impacts to the biologically productive zone are avoided.

The notion of deep water is different in Norway from other marine discharges in Turkey, Indonesia, and Papua New Guinea (PNG). Norway's fjords can be 30 to 300 metres in depth whereas placement in Turkey, Indonesia and PNG is intended for the mine tailings to reach the bottom at 1,000 to 4,000 metres' depth.

The term deep-sea tailings placement has been in use since the 1990s as a more descriptive phrase.

1 INTRODUCTION

1.1 Rationale for conducting the workshop

This report is the record of a workshop organized by GESAMP as part of its “New and Emerging Issues” Programme and the MITE-DEEP project funded by the Norwegian Research Council. It was held at the Meliá Hotel, Lima, Peru, from 10 to 12 June 2015 and hosted by the Maritime Administration of Peru. The workshop was generously sponsored by the Office for the London Convention/Protocol and Ocean Affairs, the International Maritime Organization, the International Network for Scientific Investigations of Deep-Sea Ecosystems (INDEEP), the Deep Ocean Stewardship Initiative (DOSI), and the Research Council of Norway (Norges Forskningsråd, NFR). In addition, excellent support was received and appreciated by the Sociedad Nacional de Minería, Petróleo y Energía (National Society for Mining, Petroleum and Energy) of Peru and Iniciativas Sustentables para la Minería (Chilean Mining Industry Initiatives in Sustainability), and the Peruvian Coast Guard. Funds were also allocated from the GESAMP Trust Fund.

The invited participants represented the scientific community, the mining industry, policy makers and environmental NGOs in developing as well as developed countries. The aim was to create a forum where key stakeholders could discuss the broader issues and inform GESAMP on the topic. The workshop agenda is reproduced in Annex I and the list of participants in Annex II.

GESAMP has a remit to advise its sponsoring UN Agencies (IMO, FAO, UNESCO-IOC, UNIDO, WMO, IAEA, UN, UNEP, and UNDP) on “New and Emerging Issues” in relation to the state of the marine environment. Members of the Joint Group of Experts and its Working Groups may propose new topics for GESAMP to consider in the form of a short proposal. Once approved, GESAMP may appoint a correspondence group to prepare a scoping paper. Upon discussion of the scoping paper, GESAMP, with the support of its Sponsoring Organizations, may recommend an international workshop to bring stakeholders together in order to formulate advice on the weight and merits of the issue in question. As a final step, GESAMP may recommend that a Working Group be set up to provide a global Assessment of the topic in order to advise policy makers.

GESAMP has, since 1975, conducted several assessments that are relevant to the current issue of disposal of wastes at sea, namely:

- Scientific criteria for the selection of sites for dumping of wastes into the sea (GESAMP, 1975);
- Scientific aspects of pollution arising from the exploration and exploitation of the seabed (GESAMP, 1977);
- Scientific criteria for the selection of waste disposal sites at sea (GESAMP, 1982);
- An oceanographic model for the dispersion of wastes disposed of in the deep sea (GESAMP, 1983);
- Land-sea boundary flux of contaminants: contributions from rivers (GESAMP, 1987);
- Long-term consequences of low-level marine contamination: An analytical approach (GESAMP, 1989);
- Guidelines for Marine Environmental Assessments (GESAMP, 1994);
- Protecting the oceans from land-based activities: land-based sources and activities affecting the quality and uses of the marine, coastal and associated freshwater environment (GESAMP, 2001); and
- Pollution in the open oceans: a review of assessments and related studies (GESAMP, 2009).

The issue of mine tailings in the marine environment was recently discussed at a side-event organized by GESAMP and UNIDO entitled “Discharge of mine tailings and coastal runoff in the marine environment” at GESAMP’’s 40th session in Vienna, 2013. The event addressed three related topics:

- industrial submarine tailings disposal (STD), also known as deep-sea tailings placement (DSTP);
- industrial riverine tailings disposal; and
- artisanal tailings disposal, which is riverine.

Presentations and panel discussions during GESAMP’s Vienna meeting in 2013 highlighted gaps in international governance, as it is not clear which international agency should take the lead on these issues. GESAMP also acknowledged the importance of adequately describing the receiving environment, as well as a number of knowledge gaps including the behaviour of slurries underwater, physical smothering, ecotoxicological effects and recovery times. GESAMP agreed to develop a scoping paper for possible activities to fill knowledge gaps and to inform further action by the Sponsoring Organizations.

GESAMP also noted that the issues raised at the side event are of great interest to a number of the Sponsoring Organizations including IMO, UNIDO, UNEP-GPA and IAEA-EL. GESAMP further noted that it would be useful to organize an international workshop either at one of the Sponsoring Organizations or in a country where mining operations using riverine or submarine tailings disposal are underway or being planned. GESAMP agreed to the formation of a correspondence group to produce a scoping paper and make recommendations. The draft scoping paper, entitled: Impacts of Mine Tailings in the marine environment was discussed at GESAMP’s forty-first session, held in Malmo, Sweden, in September 2014 where it was concluded that the most appropriate next step was to organize the workshop and encourage participation from a wide variety of sectors (science, industry, regional and global policy and non-governmental organizations (NGOs). The workshop was therefore designed as a collaborative exercise to include different views from stakeholders. A key objective was also to hear from developing country representatives and from regional bodies directly involved with the problem of mine tailings.

The Parties to the London Convention and Protocol (LC/LP) have also been interested in riverine and submarine disposal of tailings and associated wastes since 2001, and in 2012 noted the cooperation of the LC/LP Secretariat at IMO with UNEP-GPA in gathering information on the issue. The LC/LP Secretariat also commissioned a report on the issue, which was submitted to the LC/LP Scientific Groups and finalized during the meetings of the governing bodies of the LC/LP in November 2013. The report, entitled International Assessment of Marine and Riverine Disposal of Mine Tailings (Vogt 2013), is available on the IMO, London Convention and Protocol website at: http://www.imo.org/en/OurWork/ Environment/LCLP/minetailings/Documents/Mine%20Tailings%20Marine%20and%20Riverine%20Disposal%20Final%20for%20Web.pdf.

The Parties to the LC/LP noted the absence of international guidance and/or codes of conduct and, like GESAMP, noted there is a governance gap and it is not clear which international body should take the lead. During the November 2013 meetings the governing bodies also established a correspondence group to, inter alia:

- Develop an inventory and understanding of the scope of the LC/LP and other international bodies; and
- Gather information on best practices, existing guidance and other issues of marine and riverine disposal of mine tailings around the world.

In May 2014 and again in April 2015, the LC/LP Scientific Groups reviewed progress reports of the correspondence group. They were also informed that Chile had established, in 2013, a National Deep-sea Tailings Placement Initiative. This is a research programme established by mining companies to conduct research to close knowledge gaps relating to STD and evaluate it as an alternative to land disposal. The Scientific Groups were also provided with a summary of the International Workshop on Deep-sea Tailings Placement held in Chile in January 2014. At the May 2014 meetings, the delegation of Peru offered to host a workshop on STD, and the delegation of Chile offered to provide support. Thus, there is considerable interest in STD by a wide range of stakeholders, as well as support for GESAMP's involvement in addressing information gaps, with the aim of supporting the development of international guidance and/or codes of conduct for assessing and implementing STD.

In parallel, the Deep-ocean Stewardship Initiative (DOSI) acknowledged in 2014 the need to address knowledge gaps and for fluent communication pathways between science, industry, policymakers and environmental organizations interested in DSTP activities. Thus, a DOSI-DSTP Working Group was established (http://dosi-project.org/working-groups/tailings-placement). The first activity of this working group was to secure funds from the Norwegian Research Council and the INDEEP network (MITE-DEEP project) to organize an international workshop on DSTP issues. As this was coinciding in scope and time with the planned GESAMP workshop, it was decided to merge the available resources, both human and financial, and hold a single, large international workshop in Lima, Peru, in June 2015.

1.2 Workshop objectives

As the title suggests, the focus of this workshop was on the impacts of mine tailings in the marine environment resulting largely from disposal at sea via pipelines. The overall objectives of the workshop were:

- To provide a synthesis of the current understanding of the impacts of marine disposal of mine tailings and to identify gaps in scientific knowledge in this field; and
- To develop partnerships to address issues through further work.

The workshop was attended by more than 90 participants, including relevant researchers, policy makers, coastal and marine managers and industry. The final programme, the list of participants, and presentations are available at: http://www.gesamp.org.

This report is a record of these discussions and is intended to lay the groundwork for a possible global assessment in the future and to highlight information gaps.

1.3 Organization of the workshop

The workshop was organized into six plenary sessions following the official welcome by the Maritime Authority of Peru, a keynote presentation providing an overview of the nature and scale of the issues associated with marine discharges of mine tailings and possible environmental impacts, and a panel discussion providing perspectives from key stakeholders. The six plenary sessions included:

- Mining practices, waste generation and disposal (tailings) (session 1);
- Mine tails disposal research and current questions (session 2 and session 3);
- What we know and what we do not know about the effects of mine tailings in the marine environment (session 4);
- Existing regulatory (best) practices (session 5); and
- Panel discussion: the gaps in regulatory frameworks and science – path forward (session 6).

1.4 Background: mining and marine disposal of mine tailings[4]

Mining is the process of extracting minerals from the earth's crust. Mining is a huge industry with over 2,500 industrial-sized mines around the world, and thousands more smaller mining operations.

[4] Mike Huber, GESAMP, and Craig Vogt, Craig Vogt Inc.

Approximately 100,000 exploration licenses are awarded per year worldwide. At any one time there are about 8,000 drilling projects underway, 1,500 reserve-definition studies, 800 feasibility studies and 400 mines under construction (Vogt 2013).

The biggest environmental challenge of mining operations is the safe and environmentally sound disposal of mine tailings. Mine tailings are what is left after the target metal (e.g. copper) is removed from the ore because the separation process does not recover all of the minerals. Mine tailings contain heavy metals, mill processing chemicals and reagents, and commonly include sulphide-bearing materials.

In the vast majority of operating mines around the world, on-land disposal of mine tailings is conducted using impoundments or dams to store mine tailings under water to avoid generation of sulphuric acid and control the potential impacts of exposure to heavy metals. In 2015, 16 major mining operations were discharging their mine tailings into marine waters (Table 1), plus four others that are using riverine disposal.[5] In 2015 during the workshop, it was reported that there are several additional mines discharging mine tailings from phosphoric mines in Togo, Morocco, Tunisia, and Algeria in Africa. Phosphoric acid and fertilizers are produced resulting in a waste of phosphogypsum, rich in uranium, cadmium, lead, polonium and radium. About 10 to 15 million tons of phosphogypsum are dumped yearly into the sea in these countries (Gnandi, ppt 2015).

Deep-sea tailings disposal has become increasingly the disposal method of choice for certain areas of the world since the early 1990s. It is estimated that marine disposal of mine tailings is being considered by upwards of 15 to 20 existing and new mines worldwide. For example, five applications in Norway; Papua New Guinea (PNG) approved Woodlark and is considering Simberi, and an Initiative in Chile is evaluating DSTP.

Marine disposal of mine tailings (also termed submarine tailings disposal STP or deep-sea tailings placement (DSTP)) means disposal of mine tailings into marine waters via a pipeline.[6]

Table 1 Mines around the world using marine disposal of mine tailings

Country	Mine
Chile	Huasco
England	Cleveland Potash
France	Gardanne
Greece	Agios Nikolaos
Indonesia	Batu Hijau
Norway	Sibelco Nordic, Stjernøya
Norway	Bokfjorden
Norway	Skaland
Norway	Rana Gruber
Norway	Hustadmarmor
Norway	Quartz Corp
Norway	Norcem
Papua New Guinea	Lihir
Papua New Guinea	Ramu Nickel
Papua New Guinea	Simberi
Turkey	Cayeli Bakir

Marine disposal is no longer practiced along shorelines in shallow water, except for mine discharges in western and northern Africa. Currently, marine disposal discharges are in deep water at final deposition depths of 30 metres to 300 metres and often at depths over 1,000 metres. The intent is to discharge the mine tailings in deep stratified waters below the pycnocline, such that the mine tailings flow as a dense coherent slurry to a deposition site on the bottom of the seabed, essentially trapped below the biologically productive, oxygenated zone (i.e. not mixing with the surface layer).

After release into marine waters from the pipeline, plumes of finer material including tailings process water and suspended sediment can form at various depths. The intention is for these plumes to remain in the deep waters below the stratified layer. Knowledge of the distribution and fate of mine tailings is only beginning to emerge.

The rationale for use of deep-sea disposal of mine tailings varies from site to site, but commonly cited are economics, land-use conflicts, avoidance of acid mine drainage, and engineering constraints (e.g. geotechnical, topography, rainfall, and seismic activity), avoiding the need for long term maintenance, and avoiding environmental and human health risks of storage dams. Potential environmental impacts of marine disposal of mine tailings include:

- Smothering all benthic organisms in the disposal site footprint and physically altering the bottom habitat;
- Reduction in species composition/abundance and biodiversity of marine communities; and
- Bioaccumulation of metals through food webs and ultimately into human fish-consuming communities; increases in risk to human health.

[5] Riverine disposal is simply piping the mine tailings to the river and discharging them. This technique has been practiced throughout mining history. However, because of the catastrophic environmental consequences experienced by the discharge of mine tailings to rivers, riverine disposal is no longer practiced except at four mines in Indonesia and Papua New Guinea (Vogt 2013). Another mine, the closed Panguna gold/copper mine on Bougainville Island, PNG, is taking steps toward re-opening and may be considering riverine disposal. This is not clear, however, and UNEP has agreed to assist with remediation of environmental damage caused by the mine's former riverine discharge, which would appear to make resuming the practice unlikely. The focus of the GESAMP workshop was therefore on marine discharges.

[6] Note: This report uses STP and DSTP interchangeably, and is usually directly related to the participant in the workshop that provided the information contained in the text at the point in the report.

In addition to the fundamental question of whether the size of the footprint and associated direct impacts are acceptable, critical to the understanding of potential impacts to ecosystem services is whether the impacts reach beyond the intended footprint. Are there currents that move plumes of the material to adjacent marine habitats? Does periodic upwelling bring the contaminants to the shallow water fisheries and habitats? Figure 1 attempts to display the many complexities of assessing impacts of marine discharge of mine tailings.

Management of mine tailings discharges to the deep sea should focus initially on design and operation, including de-aeration, discharge below the euphotic zone and mixed layer (including upwelling and overturn), a low energy environment, and a final receiving environment that is soft-bottom and depositional. In addition to the above best practices, new proposals to use marine disposal, as well as renewal of existing permits, should include sufficient information from studies, site-specific research, and monitoring programmes to support comprehensive environmental risk assessment and evaluation of alternatives prior to government permit decisions.

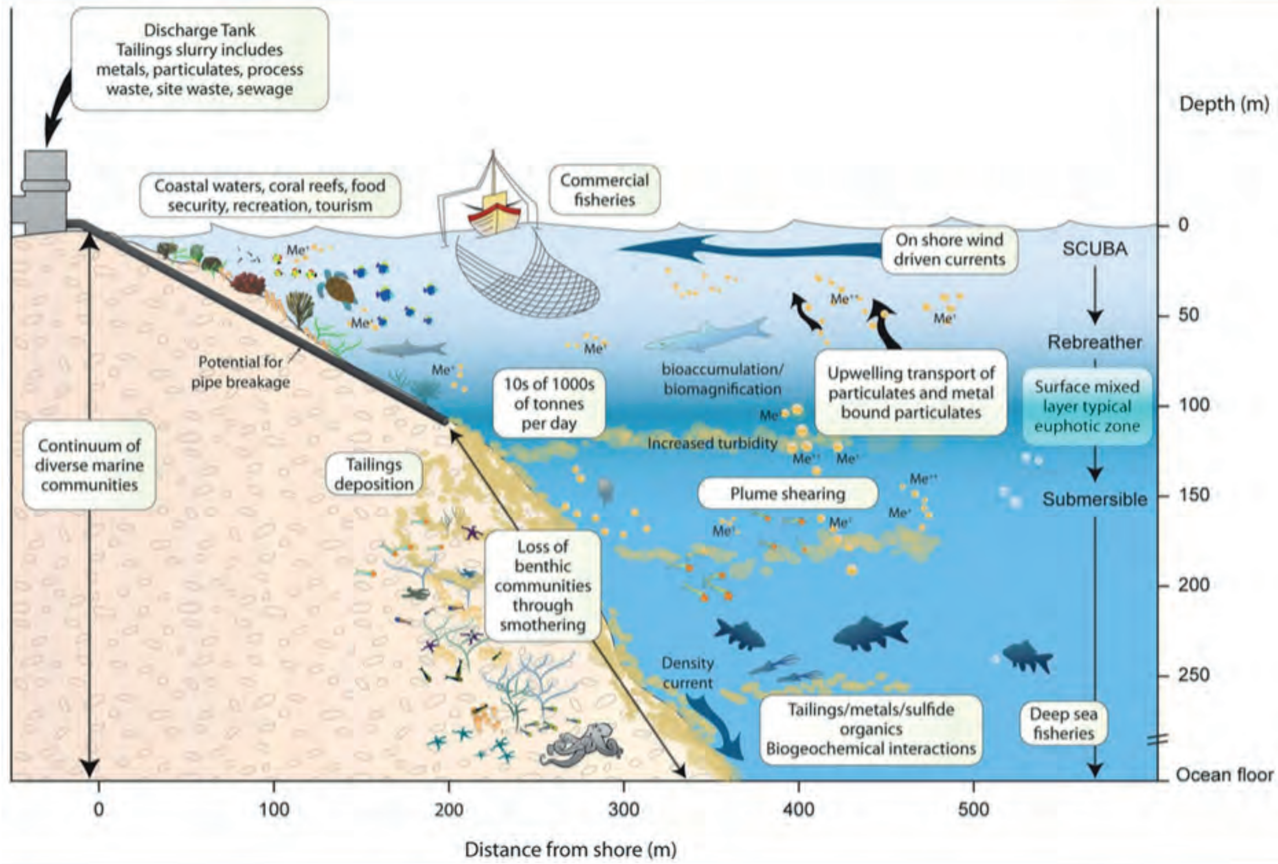

Figure 1 *Generalized conceptual model of exposure pathways of deep-sea mine tailings placement. Credit: Amanda Reichelt-Brushett (2012), Southern Cross University, Australia*

2 MINING PRACTICES, WASTE GENERATION AND DISPOSAL

This section provides information on mining and mine tailings experiences in Chile, Peru and Mexico.

2.1 Mining: production, waste generation and tailings disposal in Chile[7]

Metallic mining practices in Chile are summarized here, as well as one of its most relevant environmental effects, specifically tailings management and disposal, being undoubtedly the most challenging aspect of mining development.

Mining in Chile is an extraordinarily important activity. In fact it is the main economic industry that supports much of the economic and social development of the country and represents around 11% of the gross domestic product. Just copper (2013), represented 51% of the total country's exports: US $39,800 million.

This presentation focuses primarily on the metallic sector, and particularly copper (without forgetting the other ores and minerals). Chile is home to the largest copper mines in the world, and produces about 34% of global copper production. It also has more than 320 million tons of fine copper reserves and therefore will eventually, if those reserves are mined, and processed through flotation/concentration processes, generate large amounts of mine tailings.

Copper mines consist primarily of open pit, hard-rock mining of sulphide minerals, and are characterized by being of low ore content. Most of the current mines operate with minerals that are less than 1% copper, meaning that for each ton of copper produced, 990 kilograms of tailings are to be managed.

2.1.1 *Mining in Chile*

A basic premise of this presentation is that mining in Chile is a legal and regulated activity. This regulation is especially severe with regard to environmental effects and it is strictly enforced. We are also aware that the way it is performed continuously evolves and we do not see an end to it in the coming decades, even though current mines are reaching maturity and therefore their ore content diminishes (consequently producing more tailings per unit of copper produced).

The most important metal mines in Chile are:

- *Chuquicamata,* which saw its first industrial operations start around 1882, produces 630,000 tons of copper, and is the world's largest open pit. The dimensions of its main pit are 5 km long, 3 km wide and 800 m depth. It is now starting its underground phase;
- *Escondida,* which started operating in 1988, produces 1,193.7 tons of fine copper (the world's largest single producer of copper);
- *El Teniente,* being the world's largest underground copper mine, started operating in 1905 and produces 450,390 tons of fine copper;
- *Los Pelambres,* which started operating in 1992 and produces 419,200 tons of fine copper;
- *Collahuasi,* which started operating in 1999 and produces 444,500 tons of fine copper;
- *Andina,* which started operating in 1970 and produces 236,000 tons of fine copper; Andina is in the middle of a big expansion oriented to double its production;
- *Los Bronces,* which started operating in 1927 and produces 416,300 tons of fine copper; and
- *CMP Iron Mines* that produce 9,088 kilotons of iron ore concentrate and has mines located in Chile's III and IV Regions.

In 2013, Chilean mines produced 5,900 thousand tons of copper, 51 thousand tons of gold, 38 thousand tons of molybdenum, 1,200 thousand tons of silver, 9.1 thousand tons of iron, and 30 thousand tons of zinc. Major production of other non-metals includes nitrates, lithium, iodine, boron, and potassium (National Geological Service (Sernageomin)).

In terms of undeveloped resources, the situation is as shown in Figure 2 below.

Mine tailings are the solid fraction of unrecoverable and uneconomic metals, minerals, chemicals, organics and process water discharged normally as slurry to a final storage area. It is a solid residue generated by crushing and flotation processes.

Its composition is directly dependent on the ore and mineral extraction processes (oxides and sulphides) and can be treated as needed or as mandated by regulations. Dominant chemical compounds will depend on the ore and process. Chemical reagents used in the flotation/extraction process in copper mines tend to be xanthates, sodium sulphide (NaSH), dithiophosphate, dithiocarbamate, methyl isobutyl carbinol (MIBC), sodium hydroxide, polyacrylamides and refined oils.

In the case of iron mines (mostly magnetic concentrations processes are used), they tend to be composed mainly of calcium and magnesium aluminium silicates. As most copper ores are sulphide minerals (pyrite), their tailings can oxidize and generate acid drainage in contact with oxygen.

[7] Ricardo Katz, Environmental Consultant, Managing Director GAC (Gestion Ambiental Consultores SA, Chile).

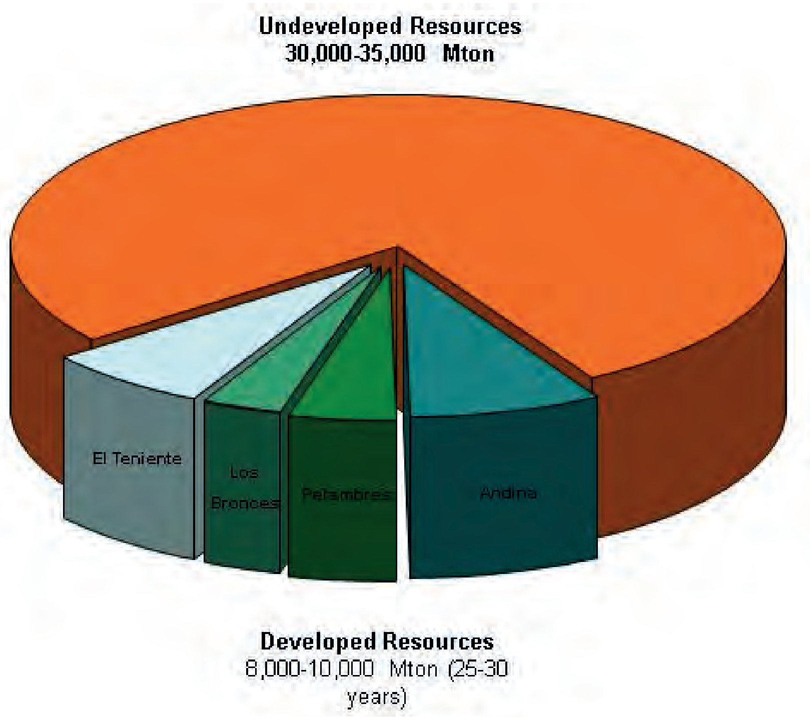

Figure 2 *Chile's undeveloped and developed resources*

2.1.2 *Mine tailings disposal and future constraints*

Chile has experience with several disposal methods for mine tailings, including riverine (Figure 3), shallow submarine (Figure 4), submarine (but not deep), and surface impoundments (Figure 5). Riverine and shallow disposition are no longer allowed as surface impoundments are by far the most common storage method used today, mainly located on river basins or ravines.

Figure 3 *Riverine and shallow submarine disposal created new beach sediments*

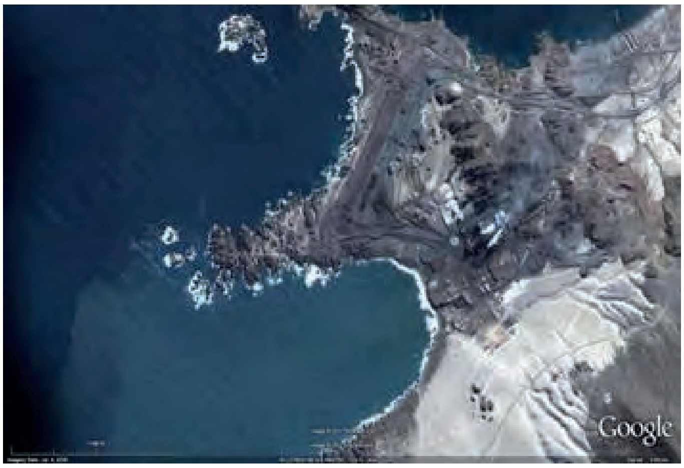

Figure 4 *Current location of marine disposal of mine tailings from iron producer*

Figure 5 *Mine tailings storage facility on land in Chile*

Copper reserves in the Central Region of Chile are located near highly populated areas that generate a competition for land use as there are limited options for building new mine tailing storage impoundments. Storage facilities using dams are considered of high environmental and health impact and risk, with a very negative perception by local populations. This situation collides with the generation of large amounts of tailings, which need to be disposed of. Interestingly, given its economic relevance for Chile, the majority of the population do not consider mining activities valuable. Most reserves are located in Central Chile where more than 50% of Chileans live.

Tailings placement, on land or in marine waters, carries a great deal of social and environmental risk as shown in the boxes below, which compare the different effects of land versus sea-based disposal. The mining and environmental (NGO) communities would like to minimize the associated impacts and internalize environmental costs into production to reflect the real costs/impacts of mining.

In terms of knowledge related to the development and operations of different forms of tailings management, a qualitative comparison is provided below. It is obvious that the mining community has developed a far larger amount of evidence for land-based situations compared to deep-sea based placement. If deep-sea placement is to become an option, the gap must decrease.

Tailings placement: environmental impacts and risks	
Land-based disposal	**Deep-sea disposal**
• Potential chemical reactions • Infiltration to groundwater, streams and rivers • Dispersion of dust to surrounding areas • Requires a considerable area • Permanent (in terms of human life span) destruction of environment • Ecosystem's damage relatively easy to assess • Unpredictable climate and natural events: floods, earthquakes, hydrological events, landslides • Operational failure • High level of experience, known capex and opex costs • Experience of contingency requirements • Known closure environmental requirements and monitoring	• Few studies on chemical reactions with seawater: requires comprehensive study of tailings' characteristics • Resuspension of tailings by upwelling events • Larger footprint area (two orders of magnitude larger) • Temporary destruction (in terms of human life span) of the environment • Difficult to quantify damage to ecosystem • Unpredictable natural events: tsunamis, earthquakes • Operational failure • Low level of experience, undetermined capex and opex monitoring • Little experience of contingency requirements • Little experience of closing environmental requirements and monitoring

Tailings placement: communities' impacts and risks	
Land-based disposal	**Deep-sea disposal**

• Might require relocation of surrounding populations
• Space availability and competition for agricultural/ urban development use
• Negative perceptions
    • Pollution of water, land, wildlife, and vegetation
    • Health impact
    • Continuous engagement of local community
    • Mining benefits not valued by population
• Well-developed regulatory framework
• Existence of mitigation, compensation, and reparation measures
	• Probable relocation of small coves (land operations)
	• Site specific option
	• Negative perceptions
	    • Pollution of water
	    • Economic losses for fishing communities
	    • Health impact by bio-accumulation through food webs
	    • Continuous engagement of local communities
	    • Mining benefits not valued by population
	• Lack of proper regulatory framework
	• Little experience of proper mitigation, compensation and reparation measures

Disposal options		
	Knowledge level	**Current developments/knowledge**
Land disposal alternatives	●	• Conventional impoundments • Paste tailings • Filtered • Burrowed fill • Backfilling
and/or		
Reduce, recycle (other uses)	○	• Arsenic: extraction from smelter's gases; preliminary results for extraction from copper concentrates (still require dumping space) • Bricks/roads: amounts generated exceed the potential use • No commercially viable developments on the long term
and/or		
Deep-sea Disposal (DSTP)	◔	• Existing "niche" option. No definite conclusions so far • Operational history of around 30 years

2.1.3 *What needs to be done and policy options*

The development of a mine and/or of a tailings deposit is a long-term endeavour. It takes on average 10 years, taking into account location definition, permitting (considering the need for an EIA process), and construction before it can operate. This process means that when a tailing disposal option is rejected, it is likely that the whole mine development breaks down. In view of this situation, tailings disposal is probably the core aspect of the permitting and development process for mining; therefore, especially but not exclusively in the case of Chile, it is necessary to have a portfolio of options that allows society as a whole to come forward with the social and environmental cost solution.

On the other hand, mining projects last a long time and whatever solution is selected it normally will be subject to regulatory and social changes. What is permitted today could be deemed unacceptable tomorrow. Mining timescales are often lengthy in the sense that they normally transcend human timescales. The concept of irreversibility is also an issue. This means, at the most, we cannot reinstate changes or impacts that have occurred, in our lifespan or that of our children, and therefore these aspects must be included in the evaluation of impacts. When we economically evaluate a project, costs or benefits beyond 25 years are not captured in the present value. The same criteria must be taken into account for environmental impacts. It is not enough to develop and implement plans for closure and monitoring. They must be "observed and perceived" by the people who are impacted by the project.

Therefore the following list of actions are proposed:

- "Think outside the box." Be open to scientific and technical information. Business as usual is bad advice when innovation is needed. This piece of advice includes mine developers, who are set in their ways. Probable new options for upstream measures will be needed, especially in terms of changing processes and eventually minimizing and treating tailings before disposal. *Consider residues management issues as a challenge not a difficulty;*
- DSTP could be a viable option, but it requires scientific research and regulatory adaptation prior to evaluation and decision-making. It is necessary to understand that scientific knowledge that is not validated socially does not exist and therefore the interaction with government, NGOs and civil society is a priority;
- Any option selected must prioritize risk minimization not only from a "catastrophic" point of view but from the perspective of assessing sustainable solutions, ensuring their viability from the human health and environmental perspectives based on the best information available;
- Assessment of all potential disposal options (without exception) is recommended well in advance (10 to 15 years) of a project's development; and
- This assessment should state the environmental (including social) costs of all options. The proper evaluation of environmental effects should stress the avoidance of irreversible impacts, and therefore prioritize recovery.

A conclusion could be: *"If mining as we know it is to be performed, tailings will be produced. This undesirable outcome of the process has to be managed to cause least environmental and social cost and therefore all options have to be considered. Those management options tend to be site specific and have to be supported by scientific and technical information validated by society, and they have to consider the human time frame and be flexible enough to adapt to natural and social evolution".*

2.2 Mining practices in Peru: the impact of mineral exports[8]

Peru has had an interesting GDP evolution. The authorities managed to reduce Peru's inflation drastically in line with global inflation. GDP growth and the reduction in inflation generated a solid macro-economic framework that increased investment in the country. Finally, this reduced poverty, both in overall terms as well as for extreme poverty.

This improvement allowed Peru to bring about a major change in the structure of the country. Not only did this lead to Peru becoming a more developed country, but the mining sector has become more dynamic and important. The mining industry's contribution to GDP increased from 4% to 14%.

So why is the mining sector important to Peru?

Peru is a mining country; it has developed out of the diversity of its geography, its people and its weather. Its culture is rich and diverse. Peru is potentially one of the countries with the greatest ecological and economic variation in the world.

If Los Andes created a dividing line between a sandy coast and a tropical forest, it also resulted in a history of more than 5,000 years of mining activity. Mining has been present in the country since before the Incas or the Spaniards and they have learned to live with it, harvest it and use it.

According to a World Bank study, 75% of world mining production is concentrated in China, Russia, the United States, Canada, Chile, Zambia, Australia, Peru, Zaire, South Africa, Mexico and Brazil. Minerals are sold as concentrates – more bulk mineral content of the main metal: zinc, lead, copper, gold, silver and iron.

The minerals produced in Peru are in high demand in today's global market, where development is based on production and industry. The United States, China, Switzerland, Japan, Canada and the European Union are the main buyers.

Despite this importance in world production, mining in Peru is not an intensive activity in its territory. Only 1.3% of Peruvian territory is used for exploration or exploitation of minerals.

Today, Peru is the first Latin American producer of gold, zinc, lead, and tin, and the second in copper and silver in the world. Peru is the third producer of copper, silver, zinc and tin, fourth in lead and seventh in gold.

Peruvian exports have been growing in recent years. The mining sector currently accounts for 58% of total exports. Due to the large share of foreign sales, the mining sector contributes significantly in taxes. Mining accounts for 29% of income tax paid by companies operating in Peru and is the main contributor (Figure 6).

The share of the mining sector in exports in the last 10 years has been, on average, 58%. However the value of mining exports has been falling.

The taxes paid by the mining sector enable the State to provide money to the communities where this activity is developed, and, with the help of the "Canon Minero", communities finance their own social projects.

In addition, the mining sector is inextricably linked to the country in the demand for goods and services, contract labour and consumer inputs, linked to public spending through taxes, and linked to production and exports, affecting the internal exchange rate. All these factors make the mining sector an activity that drives the country's economic performance.

For Peruvians, mining invigorates the domestic market, causing a virtuous circle of investment, increasing operations and uniting it with the country.

[8] David Vela. Mining Society of Peru.

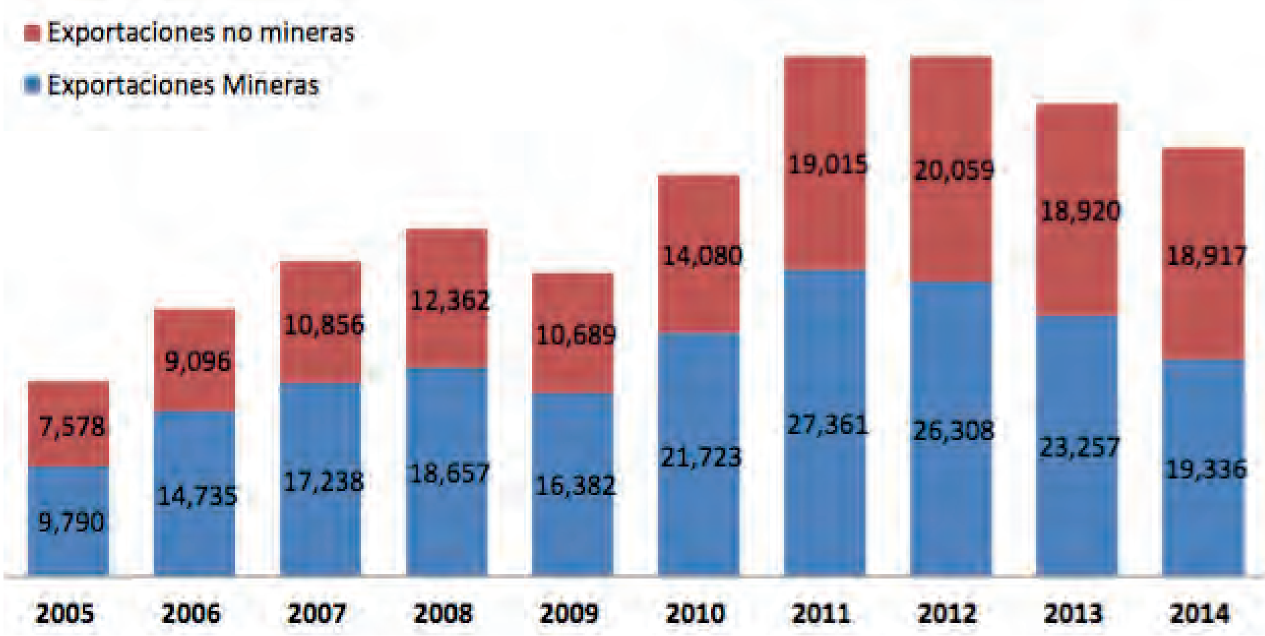

Figure 6 *Mining exports are important for the country. In millions of US $, red shows non-mining exports and blue shows mining exports*

Metals are very important to people's daily lives. They can be used for construction, housing, transportation, heavy industry and light vehicles, telecommunications, new technology (mobile computing appliances), in jewellery, health, nutrition and especially in research and development.

Today, it is almost impossible to do anything without a cell phone and a cell phone is one hundred per cent a product of mining and technology.

They may have a huge mining projects portfolio, but mining companies continue to struggle with difficult market conditions, including price volatility, geopolitical tensions, rising costs, and a general lack of finance.

Peru also has a logistical advantage in the arrangement of its various ports embarking minerals, where other economic activities also take place. This is why our country has been a member of IMO since 1968.

Working with this international institution, Peru follows all IMO agreements, guides and instructions, including the Directorate General of Harbours and Coastguards (DICAPI), rules for maritime issues such as ports, ships, etc.

However, other public institutions, such as Environmental Affairs, Defence, Communication, and Transportation Ministries, are also important, some of whom guide the private sector in improving their performance. One such piece of advice was the underwater tailings disposal that changed the way that they were released. Since the mid-90s no mining company has released or discharged tailings into the sea. They are treated, disposed of and controlled within specially prepared areas.

Peru is a good example of a country which implements rules and laws, including international treaties.

2.3 Assessment of land-based mining pollution: a case study in Sinaloa, Mexico[9]

Worldwide, it is estimated that two to five major accidents associated with tailing dam failures occur per year; and about 25% of these accidents are related to extreme meteorological events. However, many failures go unpublished due to sensitivity and legal implications.

Mining has been practiced on a large scale in Mexico, for five centuries. Currently 29% of the surface area of Sinaloa, Mexico, is under concessions for mining exploration and extraction and, according to the Federal Attorney's Office for Environmental Protection, among the 1,252 mines legally established in Sinaloa, one in every 20 carries a potential risk of an accident. Mine tailing failures might cause the accumulation of pollutants in soils and sediments, which are prone to erosion by water and wind, and to diagenesis alteration, which might release the pollutants back to the water column. Thus, the pollutants are recycled and might disperse further than if they had been released and for longer periods.

Between 2013 and 2014, at least three tailing dam failures have been reported to affect rivers that cross Sinaloa State and are connected either to water reservoirs or to coastal lagoons where fish production is an important economic activity.

The dam failure from the Minas de Bacis Company provoked an avalanche of waste that killed a family of tourists, and contaminated with trace elements the sediments of Remedios River, as well as the drinking water reservoir of Comedero, that hosted a successful tilapia farming project.

[9] Ana-Carolina Ruiz-Fernández, F. Páez-Osuna, J. A., Sanchez-Cabeza; Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México.

The contamination assessment of Comedero reservoir showed high concentrations of trace elements in water and biota, which greatly enriched the sediments to levels that might be harmful for the biota and humans through fish consumption. The tilapia fish production has been strongly affected by the spill and more than 300 fishermen's families have lost their income. According to local newspapers, the authorities of the National Water Commission recognized that 130 km of Remedios River "was contaminated by bacteria that killed the fish the length of the river" and Minas de Bacis Mines Company paid an imposed fine equivalent to 5,000 times the minimum daily wage in Mexico (about US $24,000).

This is an example of a recurrent scenario associated with mining activities in Mexico: mine-tailing spills that result in contamination of the surrounding aquatic environment, which are covered up by the mining companies, and poorly handled by the environmental authorities (Figure 7). There is an evident lack of regulation concerning trace metal pollution in sediments, including the absence of reference values to demonstrate the metal enrichment, and the proper guidelines to identify the impact on the biota.

The frequent tailing spills recently observed in Sinaloa have shown the need to improve management practices in the mining industry, as well as the environmental regulations, taking into account the role of the sediment compartment either to retain or to redistribute the metals released by the mine tailings to the aquatic environment.

Figure 7 *El Universal. Mine tailing dam overflow in Durango; one person died. 21 January, 2013*

3 UNDERSTANDING THE MARINE ENVIRONMENT

3.1 Unique attributes of marine ecosystems[10, 11]

Planet ocean

The deep sea, the largest biome on Earth, has a series of characteristics that make this environment both distinct from other marine and land ecosystems and unique in the entire planet. Seventy-one per cent of the planet's surface is ocean and 50% lies below a depth of 3,000 m, with a mean depth of 3,800 m. Of this, only an area equivalent to a few football fields has been sampled and studied in detail (Ramirez-Llodra et al., 2010). Deepsea fauna was sampled as early as 1818 by Sir John Ross, while dredging at 1,600 m during his exploration of the Northwest Passage (Menzies et al., 1973). However, systematic investigations of the deep-sea and its fauna did not begin until the late 19th century. In 1844, Forbes published his Azoic Theory of deep ecosystems, based on the decreasing number of species as he sampled deeper in the Eastern Mediterranean (Forbes, 1844). The theory stimulated debate and investigation, with the Challenger expedition marking the birth of modern oceanography (Murray and Hjort, 1912) and the Galathea expedition which sampled marine life from the greatest ocean depths in the Philippines Trench, at 10,190 m depth (Gage and Tyler, 1991).

Since Forbes's Azoic Theory, 22 new habitats and associated fauna have been discovered, often with new species and new physiological adaptations (Ramirez-Llodra et al., 2010). In the 1960s and 1970s, the development of new sampling equipment allowed for the collection of quantitative samples, providing evidence of very high levels of biodiversity in deep-sea sediments (Grassle and Sanders, 1973). Furthermore, in recent decades, the development of modern research submersibles and other underwater technologies led to one of the most important discoveries of recent oceanographic research: the discovery of hydrothermal vents and their associated fauna, in 1977 in the East Pacific (Lonsdale, 1977).

[10] Eva Ramirez-Llodra Norwegian Institute for Water Research (NIVA), Oslo, Norway; and Maria Baker, University of Southampton, National Oceanography Centre, Southampton, United Kingdom.

[11] Based on the papers: Ramirez-Llodra, E., Brandt, A., Danovaro, R., De Mol, B., Escobar, E., German,, C.R., Levin, L.A., Martinez Arbizu, P., Menot, L., Buhl-Mortensen, P., Narayanaswamy, B.E., Smith, C.R., Tittensor, D.P., Tyler, P.A., Vanreusel, A. & Vecchione, M. (2010). Deep, Diverse and Definitely Different: Unique Attributes of the World's Largest Ecosystem. Biogeosciences, 7: 2851–2899.Ramirez-Llodra, E., Tyler, P.A., Baker, M.C., Bergstad, O.A., Clark, M.R., Escobar, E., Levin, L.A., Menot, L., Rowden, A.A., Smith, C.R., & Van Dover, C.L. (2011) Man and the Last Great Wilderness: Human Impact on the Deep Sea. PLoS ONE, 6, e22588.

3.2 Unique characteristics of deep-sea ecosystems

Because of its unique abiotic attributes, the deep sea hosts a specialized fauna (Figure 10). Although there are no phyla unique to deep waters, at lower taxonomic levels the composition of the fauna is distinct from that found in the upper ocean (Ramirez-Llodra et al., 2010). Deep-sea biodiversity is among the highest on the planet, mainly composed of macro and meiofauna, on continental margins and abyssal plains (Snelgrove and Smith, 2002), and new species are regularly described. Although not universal, large-scale biodiversity patterns often follow a unimodal relationship with depth, with a peak at intermediate depths (Rex et al., 1993).

Most deep-sea ecosystems are heterotrophic, thus depending ultimately on the flux of organic matter produced in the overlying surface ocean through photosynthesis. Surface productivity varies regionally and seasonally, resulting in spatio-temporal differences of organic matter input to the seafloor (Billett et al., 1983). Only about 0.5 to 2% of the net primary production in the euphotic zone reaches the deep seafloor below 2,000 m, resulting in abyssal benthic communities being amongst the most food-limited on the globe (Smith et al., 2008). In these food-limited regions, faunal biomass and productivity are low, but biodiversity is high (Rex and Etter, 2010). On the other hand, chemosynthetically-based ecosystems such as hydrothermal vents and cold seeps (amongst others) are supported by in situ primary productivity from chemoautotrophic microorganisms that use the reduced compounds from the fluids as a source of energy. This high-energy availability supports oases of life in the deep sea, characterized by high abundance and densities of fauna but low biodiversity of highly specialized species (Tunnicliffe et al., 2003). Other ecosystems, such as seamounts, canyons or cold-water corals have an increased productivity through specific physical processes, including topographic modification of currents and enhanced transport of particles and detrital matter. (Refer to Figure 8, below, for illustrations of such unique fauna).

Large-scale patterns of abundance show that these parameters decrease with depth for macro- and megafauna, probably because these groups are more vulnerable to low energy availability, while the trend of abundance for bacteria and meiofauna is more stable with depth (Rex et al., 2006). The same is found for biomass, with a decreasing trend for macro- and megafauna even more pronounced. These large-scale patterns cause a shift in fauna composition from the upper bathyal zone, where macro- and megafauna dominate, to the lower bathyal and abyssal zones, where meiofauna and microorganisms dominate. Large-scale biodiversity patterns of deep-sea fauna often show a unimodal pattern of diversity with depth. However, this trend is not universal and the drivers that shape this pattern are not fully understood (Rex and Etter, 2010). There are complex interacting factors at different spatio-temporal scales, including biological processes, food availability and habitat heterogeneity, that shape bathymetric patterns of biodiversity for different groups and in different geographic regions.

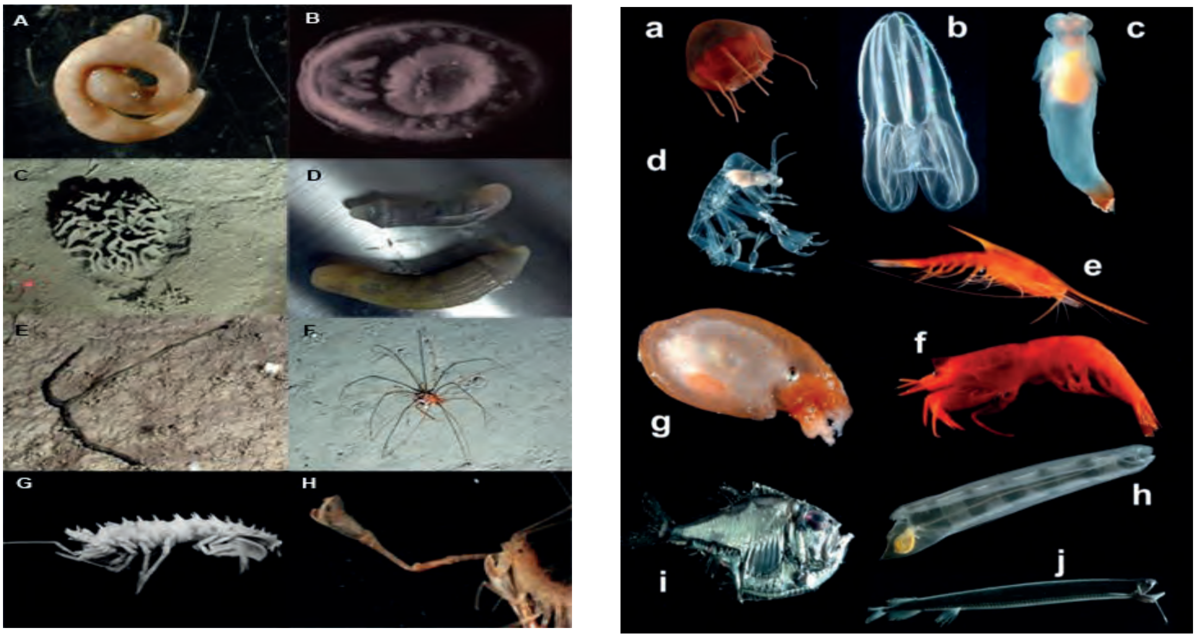

Figure 8 *Fauna that make the deep sea unique.*
Benthic: A, aplacophoran. B, monoplacophoran. C, xenophyophore. D, sipunculid. E, echiuran. F, pycnogonid. G, H, isopods **Pelagic**: A, cnidarian. B, ctenophore. C, gastropod. D, amphipod. E, crustacean. F, decapod crustacean; G, octopod. H, urochordate or salp, I, hatchetfish. J, scaly dragonfish. From Ramirez-Llodra et al., 2010. Biogeosciences

3.3 Ecosystem services and anthropogenic impact

The high biodiversity of deep-sea ecosystems support important ecosystem functions, including among others, the biological pump, nutrient regeneration, microbial processes and the trophic web. These functions are often poorly investigated in deep-sea ecosystems and operate at small spatial scales. However, because of the vast expanse of the deep seafloor, their cumulative processes are crucial for the global functioning of the ocean, and thus of the planet (Thurber et al., 2014). These functions, in turn, provide important ecosystem services, including provisioning (biological, hydrocarbon and mineral resources), supporting and regulating (e.g. nutrient cycling, water circulation, CO_2 exchange, waste disposal) and cultural (e.g. scientific knowledge, education, literature, tourism) (Armstrong et al., 2012; Thurber et al., 2014).

Recently a positive relationship between biodiversity and ecosystem function has been proposed (Danovaro et al., 2008). Thus, a reduction in biodiversity, often of small and uncharismatic organisms, may lead to significant reductions in functions and services. This is particularly important in an era where the depletion of biological and mineral resources on land and in shallow waters, coupled with technological developments, are promoting an increased exploitation of deep-sea resources. The deep ocean is increasingly affected by a number of human activities (e.g. commercial fishing, oil and gas exploitation, exploration for deep-sea minerals, marine litter and waste, such as mine tailings), (Figure 9), as well as effects from climate change and ocean acidification (Ramirez-Llodra et al., 2011).

Although single anthropogenic pressures can have direct effects on deep-sea communities, there may also be cumulative impacts where two or more impacts interact and result in synergies with a magnified effect on the ecosystem.

There is, thus, an increasing urgency to conduct research (Figure 10) to better understand the processes that drive and maintain deep-sea ecosystems to better assess their resilience and recovery potential, providing sound scientific knowledge from which to develop robust ecosystem-based management options (Mengerink et al., 2014). To address this issue, the Deep-ocean Stewardship Initiative (DOSI, http://dosi-project.org/) was created in 2013, with the mission to integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction. DOSI has recognized the importance of deep-sea tailing placement (DSTP) and, in 2014, the DSTP working group was created (Ramirez-Llodra et al., 2015).

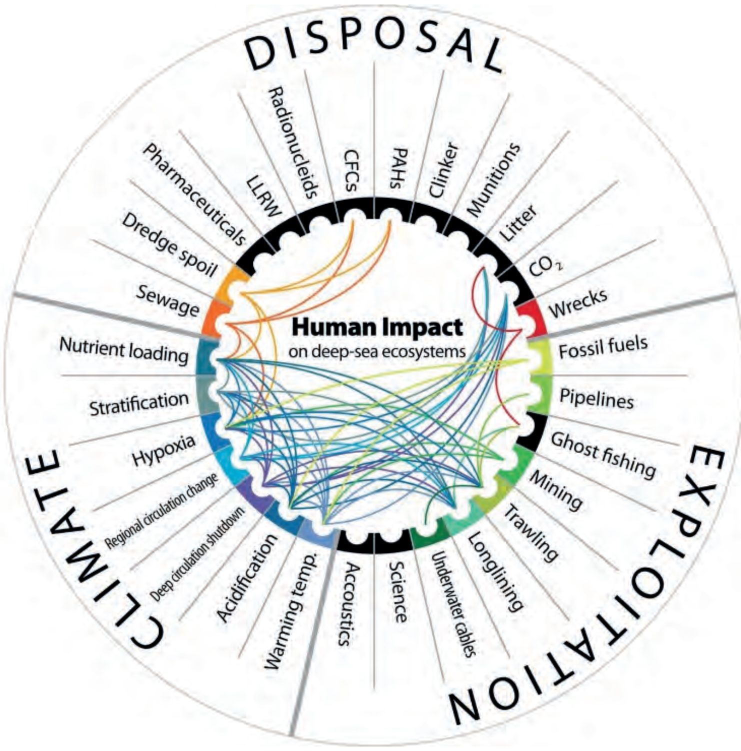

Figure 9 *Potential human impact on deep-sea ecosystems. (Ramirez-Llodra E, Tyler PA, Baker MC, Bergstad OA, Clark MR, et al. (2011); Man and the Last Great Wilderness: Human Impact on the Deep Sea. PLoS ONE 6(8): e22588. doi:10.1371/journal.pone.0022588)*

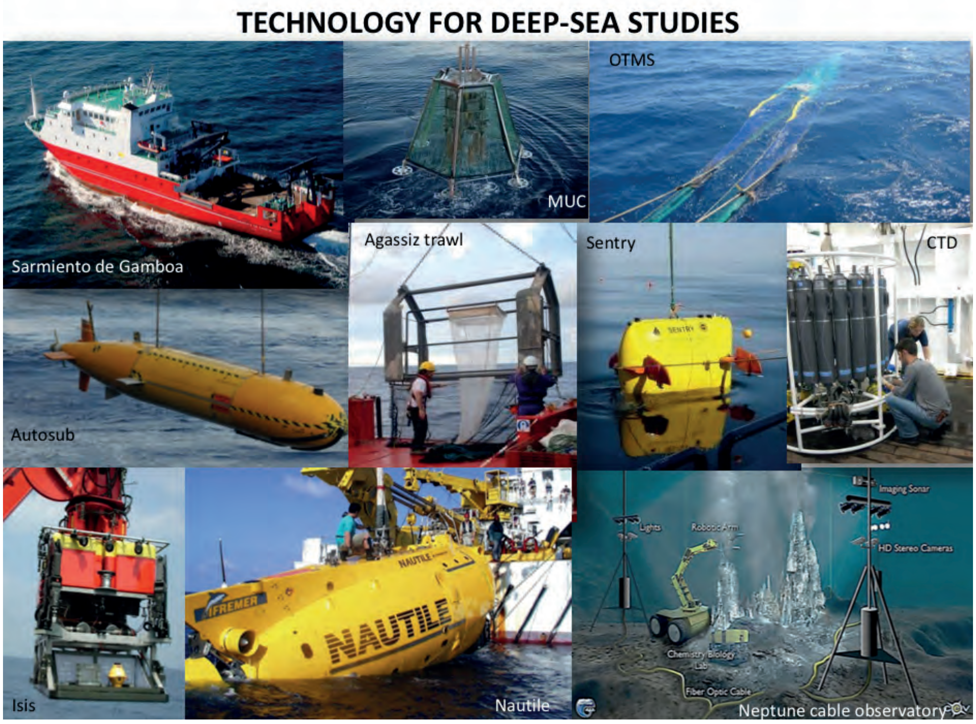

Figure 10 *Deep sea research technology*

The overall goal of this working group is to promote international collaboration and sharing of information at all levels (i.e. institutional, scientific, industrial, economic and societal) to enhance the effective use of information and data and, thus, facilitate the development of robust best available practices and management measures. One of the main activities of the DOSI-DSTP WG was to secure funding from the Norwegian Research Council (MITE-DEEP project, ref. 243664/E40) and INDEEP (http://www.indeep-project.org/) to co-organize the International Workshop on the Impacts of Mine Tailings in the Marine Environment (Lima, June 2015) with GESAMP-IMO. This was followed by an additional one-day DOSI-DSTP meeting, where a number of follow up activities were agreed, which are now progressing, including the analysis of an online survey on DSTP issues, a scoping paper, the creation of a centralized data repository for STD and DSTP activities, a GIS map and initial discussions for a potential capacity-building workshop on DSTP in Papua New Guinea.

3.4 Physical oceanography and Deep-sea Tailings Placement (DSTP) in the Peru-Chile Current System[12]

The Peru-Chile Current System (PCCS) is recognized as one of the most biologically productive regions of the global ocean. Several important factors support this high marine production. These include a persistent coastal poleward undercurrent which carries nutrient-rich but oxygen-poor Equatorial Subsurface Water, a persistent wind-driven upwelling which lifts the nutrient-rich water towards the surface and recurrent mesoscale eddies which transport Equatorial Subsurface Water westward extending the upwelling region to the deep ocean. Here, long time series (about a decade) of current observations, sea level and sea surface temperature along the coasts of Peru and Chile, together with satellite data of wind stress, sea level anomalies and chlorophyll are used to understand the spatial and temporal variability (from regional to mesoscale and from intra-seasonal to interannual, respectively) along the west coast of South America.

Coastal current and sea level at mid-latitude along the coasts of Peru and Chile are strongly modulated by the El Niño/La Niña cycle in the intra-seasonal (30-90 days) and semi-annual bands. This modulation is linked to coastal trapped waves and Rossby waves[13] forced by winds blowing on the equator, and equatorial Kelvin waves and their interaction with the South American coast (Figure 11). This well-known equatorial-mid-latitude connection within PCCS has been confirmed by good agreement between conceptual model simulations forced by satellite winds from the equator and the South American coast with local observation of currents and sea level fluctuation off central Chile. However, some oceanic variability observed over PCCS in coastal current and sea level is forced by local winds. For instance, in the intra-seasonal band, local wind variability appears linked to the tropical Pacific by equatorial-mid-latitude teleconnections in the atmosphere. Intra-seasonal variability is a prominent feature in coastal currents, sea level, and sea surface temperature. Intra-seasonal equatorial Kelvin waves[14] force strong coastal-trapped waves during austral summer. The former waves are particularly strong during the initial phase of El Niño, and rather weak during La Niña periods.

[12] Samuel Hormazabal, Pontificia Universidad Católica de Valparaíso, PBox. 10120, Valparaíso, Chile and Instituto Milenio de Ocenografía (IMO), Universidad de Concepción, Concepción, Chile.

[13] Rossby waves, also known as planetary waves, are a natural phenomenon in the atmosphere and oceans of planets that largely owe their properties to rotation.

[14] A Kelvin wave is a wave in the ocean or atmosphere that balances the Earth's Coriolis force against a topographic boundary such as a coastline, or a waveguide such as the equator.

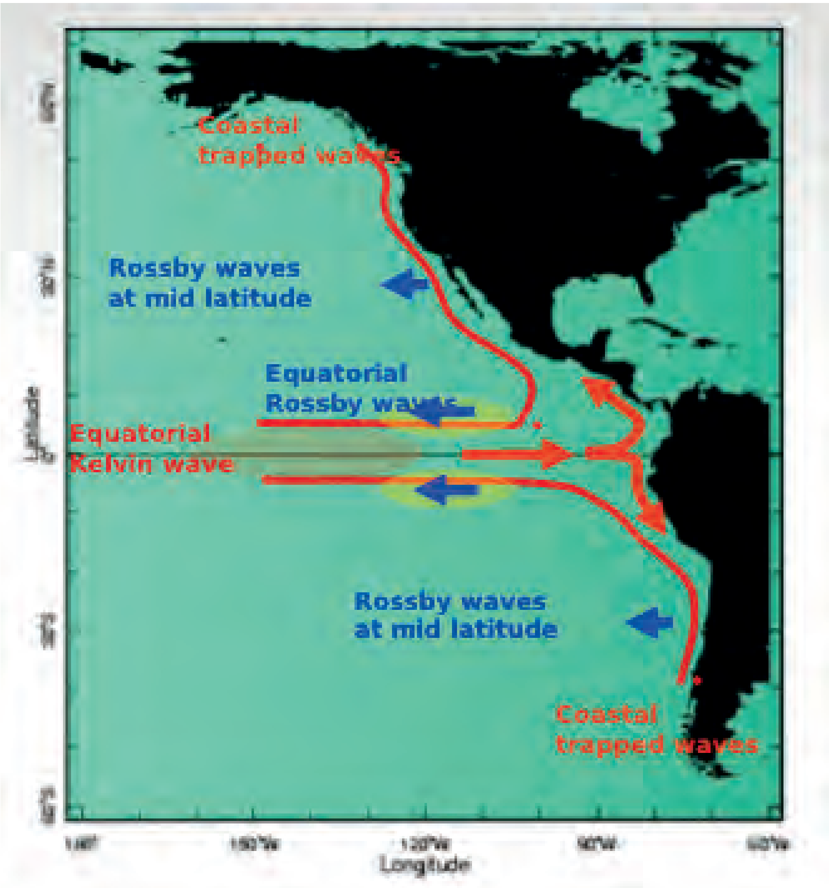

Figure 11 *Sources of variability: Rossby and Kelvin Waves*

A significant interannual variability related to El Niño-Southern Oscillation (ENSO) is found in coastal sea level and sea surface temperature in the PCCS. This variability is stronger near the equator and decreases southward along the coast. A significant fraction of interannual mid-latitude disturbances have been associated with westward propagation of free baroclinic Rossby waves forced by equatorial winds. A time-frequency analysis performed on a 10-year period of current observations in a mooring station located at the slope off Coquimbo (30°S) revealed that during the warm ENSO phase (El Niño) semi-annual fluctuations dominate seasonal scale variability of coastal currents and during the cold ENSO phase (La Niña) the annual band is dominant. Both frequencies appear to be associated with seaward propagation of baroclinic Rossby waves. Semi-annual Rossby waves seems to be forced by equatorial winds through equatorial Kelvin waves. In addition, annual fluctuations are also important for the seasonal-scale variability of coastal currents and appear to be more related to winds along the South American coast than to winds along the equator.

Rossby waves emanating from the eastern boundary, alongshore wind stress, and baroclinic instability of coastal currents play important roles in current variability and in the surface and subsurface eddy formation, including their propagation in the Coastal Transition Zone off Chile. Observations and high resolution model results have revealed that along the coast off Chile several anticyclone subsurface eddies denominated "Intra-thermocline eddies" (ITEs) are detached annually from the Peru-Chile Undercurrent. Within the PCCS region observed ITEs are around 400 m thick, ~ 100 kilometres in diameter (horizontal scale), exhibit a westward mean speed of ~ 2.5 km/d, and live from several months to years. The ITEs transport into the deep ocean a large volume of cold, high-salinity, low-oxygen and nutrient-rich coastal water, extending the nutrient-rich waters beyond the zone which is directly affected by coastal upwelling. This aspect exerts an important influence on the different trophic levels in oceanic waters. Model results show that the variability of the ITEs (number and transport) is significantly correlated with the El Niño-Southern Oscillation equatorial signal. During strong El Niño events (e.g. 1982; 1998), while the Peru-Chile Undercurrent transport increases, the volume of coastal waters transported by ITEs decreases.

Strong mesoscale eddies and meanders, that characterize the Coastal Transition Zone, are closely associated with enhancement of primary production and fish distribution. The offshore propagation of mesoscale eddies contributes significantly to expanding the area of high chlorophyll concentration beyond the coastal upwelling centre. The estimation of that transport indicated that eddies make up $> 50\%$ of the winter chlorophyll peak in the coastal transition zone. From the physical oceanography viewpoint, to understand the possible impact of DSTP in the Peru-Chile Current System, it is pivotal to understand the physical dynamics of smaller areas (e.g. submarine canyons) and also in which extension smaller regions are affected by processes acting on a larger scale.

Some questions associated with the knowledge gaps on a smaller scale are related to:

- The spatial and temporal variability of the dominant physical process;
- The temporal variability of horizontal and vertical gradients of currents and physical and chemical properties of the water column (e.g. gradients of temperature, salinity, density, oxygen);
- The characteristics of the intra-seasonal, seasonal and interannual fluctuations of currents and physical and chemical properties in the smaller area;
- The effect of local forcings (e.g. coastal wind) and remote forcings (e.g. coastal trapped waves, Rossby waves) on currents and physical and chemical properties of the water column;
- The dynamics of internal waves and their role in the mixing processes in the study region; and
- The impact of internal waves on currents and physical and chemical properties of the water column.

From the above, to use the DSTP technique we claim that is mandatory to develop research activities necessary to obtain in situ and modelling data. Those data are requested to fill the knowledge gaps in the study area, especially the gaps associated with the dynamics of submarine canyons (one of the less explored areas in the Peru-Chile Current System) and the offshore transport associated with mesoscale eddies. Some of the research activities that would be included are research cruises to cover seasonal and interannual variability, monitoring with autonomous submarine vehicles (Glider and Micro Rider), long term moorings (e.g. acoustic Doppler current profiles, sediment traps, oxygen sensors), coastal stations (weather stations, monitoring by high frequency radars, sea level) and numerical modelling (regional and local resolution).

3.5 The application of water and sediment guidelines to DSTP management[15]

The process of quantifying the risks posed by deep-sea tailings placement (DSTP) operations is complex, but can be assisted by the application of robust water and sediment quality guidelines and well-structured risk-based assessment frameworks. General best practice for DSTPs includes consideration of the suitability of the location (bathymetry and physical oceanography), discharge depth and conditions (no upwelling, subsurface tailings plumes and resuspension of deposited tailings), and location of DSTPs in low productivity environments (i.e. not impacting a precious ecosystem). In the early stages of feasibility planning, environmental impact assessment (EIA) studies are conducted to inform communities, government, and the industry

[15] Stuart Simpson, Senior Principal Research Scientist Group Leader, Aquatic Contaminants, CSIRO Land and Water Centre for Environmental Contaminants Research (CECR), Australia.

proponents of the risk to the ecosystem. The ecological risk assessment (ERA) will include evaluating the risk of adverse effects to aquatic organisms both within the water column (pelagic organisms) and sediment environment (benthic organisms).

The intent of DSTPs is to minimize impacts to the most biologically productive surface waters (e.g. the surface mixed layer and photic zone), for no tailings to deposit in near-shore coastal environments, and for impacts from the deep-sea deposition (e.g. below 500 m depth) to be predictable. The tools and frameworks for assessing potential impacts to pelagic species within surface waters or organisms within near-shore environments are reasonably well developed. For deep-sea environments, many of the desirable assessment tools do not yet exist and the residual uncertainty for assessments is greater. Prime examples include the lack of species and the difficulty in replicating the conditions of deep-sea environments when conducting aquatic toxicity testing (e.g. extreme pressure), and the inadequate knowledge of deep-sea ecosystem structures, functions, and connectivity to enable informed ecological assessments.

The most recognized impacts of DSTPs on benthic organisms involve direct smothering, changes in the benthic habitat, increases in suspended sediment, and exposure to contaminants. The first two of these are predictable impacts that remain for the entire DSTP operation. The occurrence (location or intensity) of suspended sediments is less predictable, and significant challenges remain regarding the assessment of the fate and impacts of sub-surface tailings plumes at all water depths. Chemical impacts, i.e. those being caused through toxicity of metals or metalloids associated with the tailings liquid or solid, or that may be released from tailings in the short or long term, are potentially avoidable through tailings management from the mine to the sea. However, challenges exist relating to chemicals for which guidelines either do not exist or are of low reliability (e.g. many residual milling chemicals), as well as the ability to predict the bioavailability of major metals and metalloids.

It is well recognized that total contaminant concentrations are often poor predictors of the risk posed by contaminants in sediments (Simpson et al., 2011). While total metal concentrations in sediments impacted by mine tailings can often appear alarmingly high, a large portion of the metals within tailings exist in highly mineralized forms that are less bioavailable to organisms when compared to metals introduced to the environment from other common anthropogenic sources. While no standardized whole-sediment toxicity tests exist that utilize deep-sea organisms, tests that use surrogate organisms are generally considered appropriate for assessing contaminant bioavailability and risks of toxicity. Tests on sediments containing mine tailings indicate that site-specific sediment quality guidelines that better reflect the low bioavailability of mine-derived metals may be appropriate for management purposes (Figure 12).

However, significant uncertainty remains with respect to the potential longer-term transformation of mine tailings from largely inert into more bioavailable forms. For many DSTP operations, a common justification is to minimize the problem of acid rock drainage associated with the oxidation of residual sulphide minerals within tailings. While risks posed by metal-sulphide phases are predicted to be low in deep-sea environments due to lower dissolved oxygen concentrations, burial of tailings and the buffering capacity provided by seawater, the presence or formation of oxidized and more bioavailable metal forms remain an uncertainty for both deposited and resuspended tailings. The issues of bioavailability and transformations represents an example of scientific uncertainty, and a knowledge gap, when assessing risks posed by DSTPs.

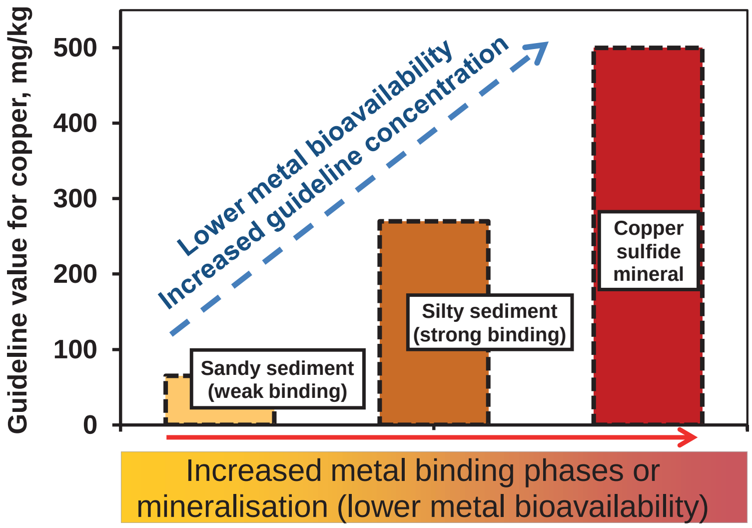

Figure 12 *Schematic representation of the influence of sediment properties (increase metal-binding strength) on the predicted sediment quality guideline value for copper*

For all assessments, there is a need to consider multiple lines of evidence (LOE) (Figure 13) in order to inform communities, governments and industries of risks posed to the environment (Simpson and Batley, 2016). For many deep-sea assessments, there will be a need to develop new and specialized tools to provide new LOE for assessments (e.g. eco-genomics-based tools to provide new LOEs for ecology – community structure, function and connectivity). There will also remain a need to utilize existing tools that are well developed for near-shore coastal environments, as these can also provide useful information on environmental risks. Proposed and existing DSTP operations continue to require a high level of environmental scrutiny and monitoring during operation and post-closure. The assessments, approvals, and monitoring will continue to improve as new science-based tools are developed to cover all aspects of chemistry, ecotoxicology, ecology, and oceanography. This is necessary to enable the most informed and robust management decisions associated with DSTP.

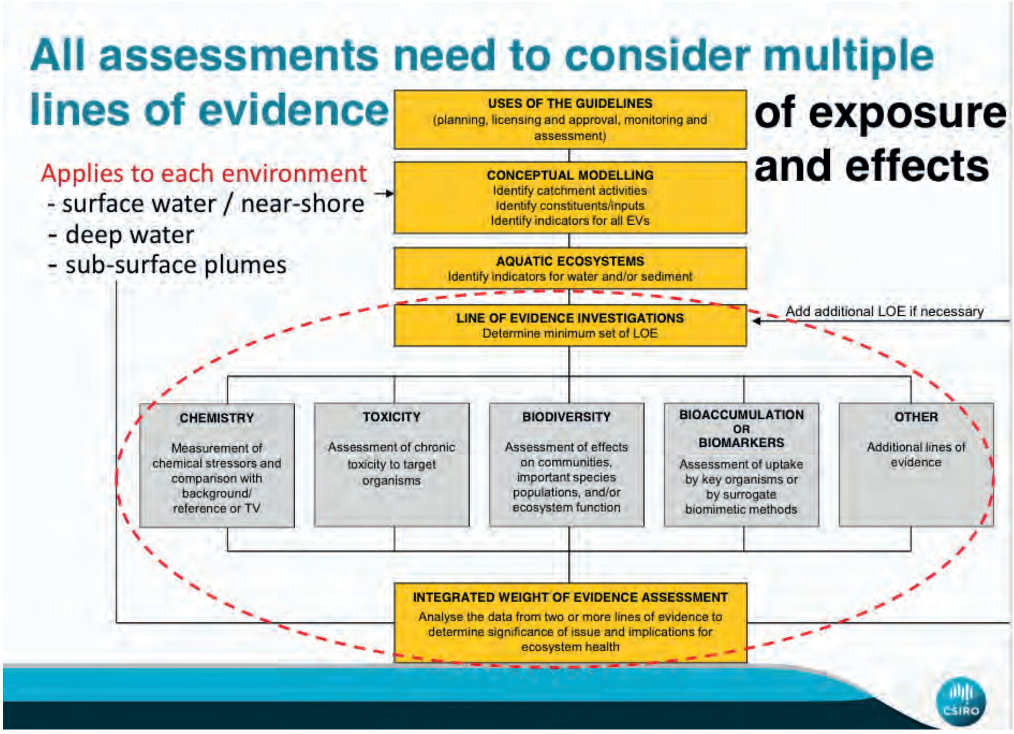

Figure 13 *Decision-making needs to involve multiple lines of evidence. Credit: Stuart Simpson*

3.6 Proposed seabed mining off New Zealand: What had to be learnt about the marine environment before mining could begin?[16]

New Zealand's marine environment is rich in mineral resources with economic potential. Exploratory and prospecting permits have been issued for most of these minerals (except cobalt-rich crusts and manganese nodules). Mining permits have been issued for phosphorite nodules and ironsands to Chatham Rock Phosphate (CRP) and Trans-Tasman Resources (TTR), respectively. However, before commercial-scale mining can begin, a marine consent is required.

Marine consents are decided upon, under the legal requirements of New Zealand's Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act, by the Environmental Protection Authority (EPA). Marine Consent applicants must provide the EPA with information on how their proposed activities relate to a set of criteria, including ones concerning potential environmental effects. Applicants for a consent must include in their Environmental Assessment (EA) a description of the current state of the area; identify any environmental effects of the activity; and specify measures intended to avoid, remedy or mitigate adverse effects of mining.

[16] Ashley A. Rowden and Alison MacDiarmid, National institute of Water & Atmospheric Research, Private Bag 14-901, Wellington, New Zealand.

Both CRP and TTR gathered a wide range of data including those which related to oceanographic conditions; seabird, marine mammal, fish, plankton and benthic fauna and habitats; current flow and particle dispersal; sensitivity of benthic fauna to suspended and deposited sediment; and ecosystem trophic structure.

The lessons learnt about the collection and analysis of environmental data during the environmental assessment process include the following:

- Some important information was not collected:
    - Whole faunal components were ignored, e.g. meiofauna sampled in the South Taranaki Bight (STB) but not on Chatham Rise (hyperbenthos); and
    - Limited characterisation of ecosystem function, e.g. no examination of the relationship with biodiversity; the importance of habitat-providing species was examined in STB but not Chatham Rise;
- Some information only inferred:
    - No in situ or laboratory studies were examined:
        - Toxicity of re-deposited sediment to local fauna;
        - Sensitivity of fauna to suspended sediment loading;

- Impact of sedimentation on benthic fauna (even short-term); and
- Recovery dynamics of benthic fauna (even short-term);
- Some concepts in the Act are difficult to address:
  - Rarity – most species in deep sea are rare; potentially a sampling and taxonomic impediment issue;
  - Threatened – the list of threatened invertebrate species was inadequate, and data from surveys was not always at species level; and
  - Vulnerable ecosystems – the concept was not defined, and inconsistent with the term 'sensitive environments' in associated regulations.

4 WHAT WE KNOW AND WHAT WE DO NOT KNOW ABOUT THE EFFECTS OF MINE TAILINGS IN THE MARINE ENVIRONMENT

4.1 Impacts of large-scale disposal of mining waste in the deep sea (Papua New Guinea)[17]

The need for economic growth to maintain the living standards of a rising human population is driving demand for the Earth's non-renewable resources, particularly hydrocarbons and metals. Oil and gas extraction is being extended into ever more challenging oceanic environments and the deep-seabed is increasingly being explored as a source of valuable minerals. In January 2011, the Papua New Guinea (PNG) Government granted a mining licence for the commercial extraction of metal-rich sulphide deposits in the Bismarck Sea, and if this proves a success it is likely to be followed by other mining operations in deep-seabed environments.

[17] Tracy Shimmield, Managing Director, SAMS Research Services Ltd (SAMS: Scottish Association for Marine Science).

Traditional land-based mining produces large volumes of waste, which includes overburden, waste rock and tailings. There are a number of different methods in which tailings have been managed throughout the world; one of these is the placement of tailings in the deep sea (DSTP) (Figure 14).

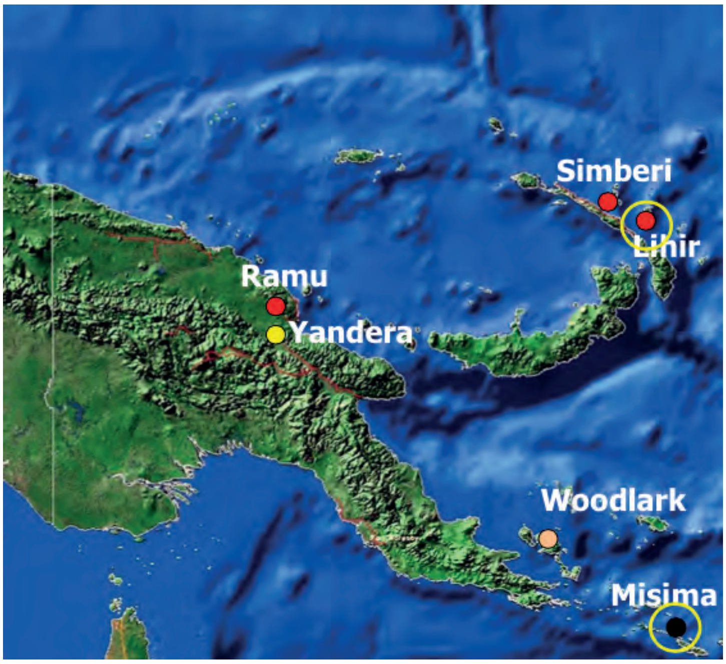

Figure 14 *Mines in PNG currently using DSTP are Lihir, Simberi, and Ramu. Proposing to use DSTP are Woodlark and Yandera*

For all categories of industrial use of the ocean, it is essential to identify and measure potential impacts so that these can be minimized and mitigated as far as possible. It is essential for human communities, the environment and the mining sector that the best mining practices and technologies are developed and adopted to permit the highest standard of environmental impact assessment and monitoring to be achieved.

PNG is a mineral-dependent economy. In 2009, PNG mines produced 63 tonnes of gold, 154,000 tonnes of copper and 75 tonnes of silver to contribute K7.5 billion which represented 62% of PNG's total export receipts in that year (Figures 15 and 16).

Papua New Guinea's aim is to promote a healthy and sustainable mineral industry and provide a regulatory environment which maximizes mining opportunities and minimizes impact on the environment to ensure optimum benefits for the people of PNG.

Environmental issues associated with extraction of minerals are receiving greater attention throughout the world. In addition to developing seabed mining, the ocean also continues to be used as a repository for waste produced by land-based mines. For all categories of industrial use of the ocean it is essential to identify and measure potential impacts so that these can be minimized and mitigated as far as possible. It is essential for human communities, the environment and the mining sector that the best mining practices and technologies are developed and adopted to permit the highest standard of environmental impact assessment and monitoring to be achieved.

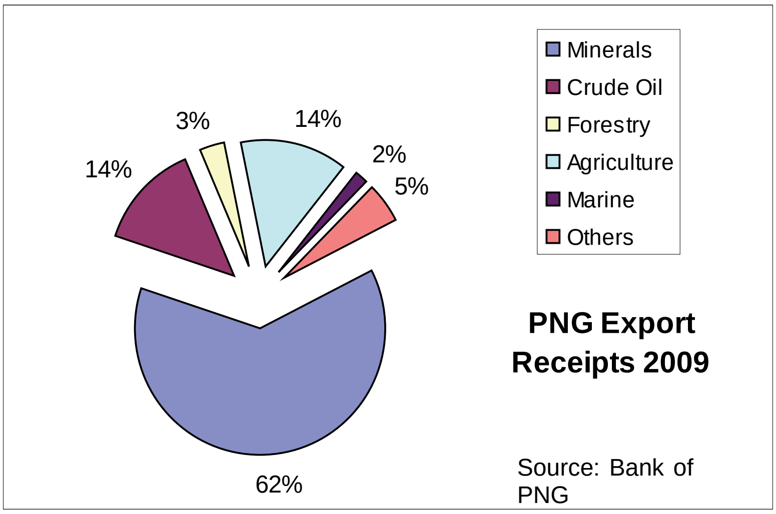

Figure 15 *PNG Export Receipts for 2009*

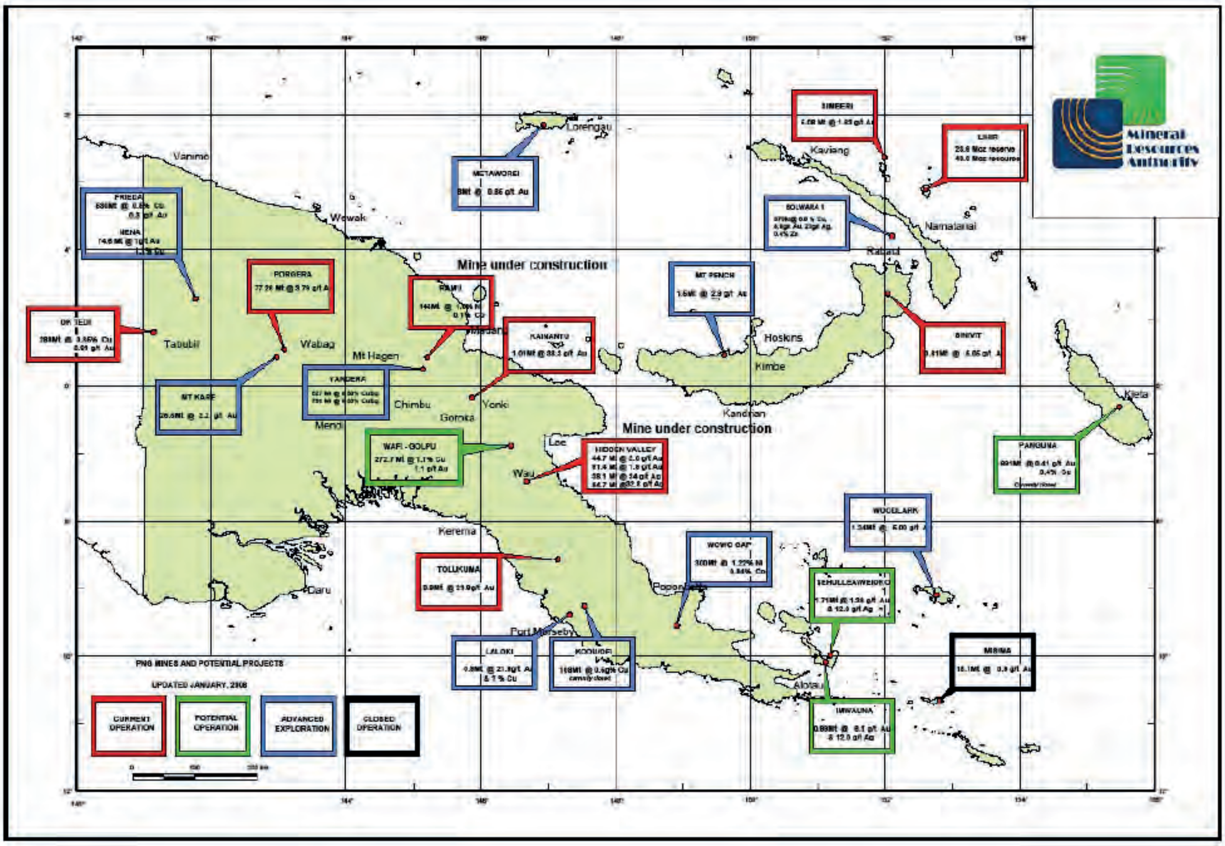

Figure 16 *Current and Potential Mines in PNG*

DSTP has been used as a waste option in a number of countries worldwide and lately there has been a drive to gather more relevant scientific information of the impact of DSTP on the marine environment of PNG. This information has led to the development of new regulations incorporating draft guidelines in Papua New Guinea for the use of DSTP. The increase in understanding of the effects of anthropogenic disturbance on the Deep Ocean and developing regulation which have been obtained from the study of DSTP and the advancement of smart observation technology is also applicable to seabed mining.

Since the first offshore exploration licence was granted in 1997, there are currently 70 offshore exploration licences granted with an additional 54 under application (Figure 17).

The mining lease granted to Nautilus Minerals is for Solwara-1, an area in the Bismarck Sea, within the territorial waters of PNG (Figure 18). The project aims to extract gold and copper deposits associated with deep sea hydrothermal vents and will be the first large scale mining of minerals in the deep ocean in the world.

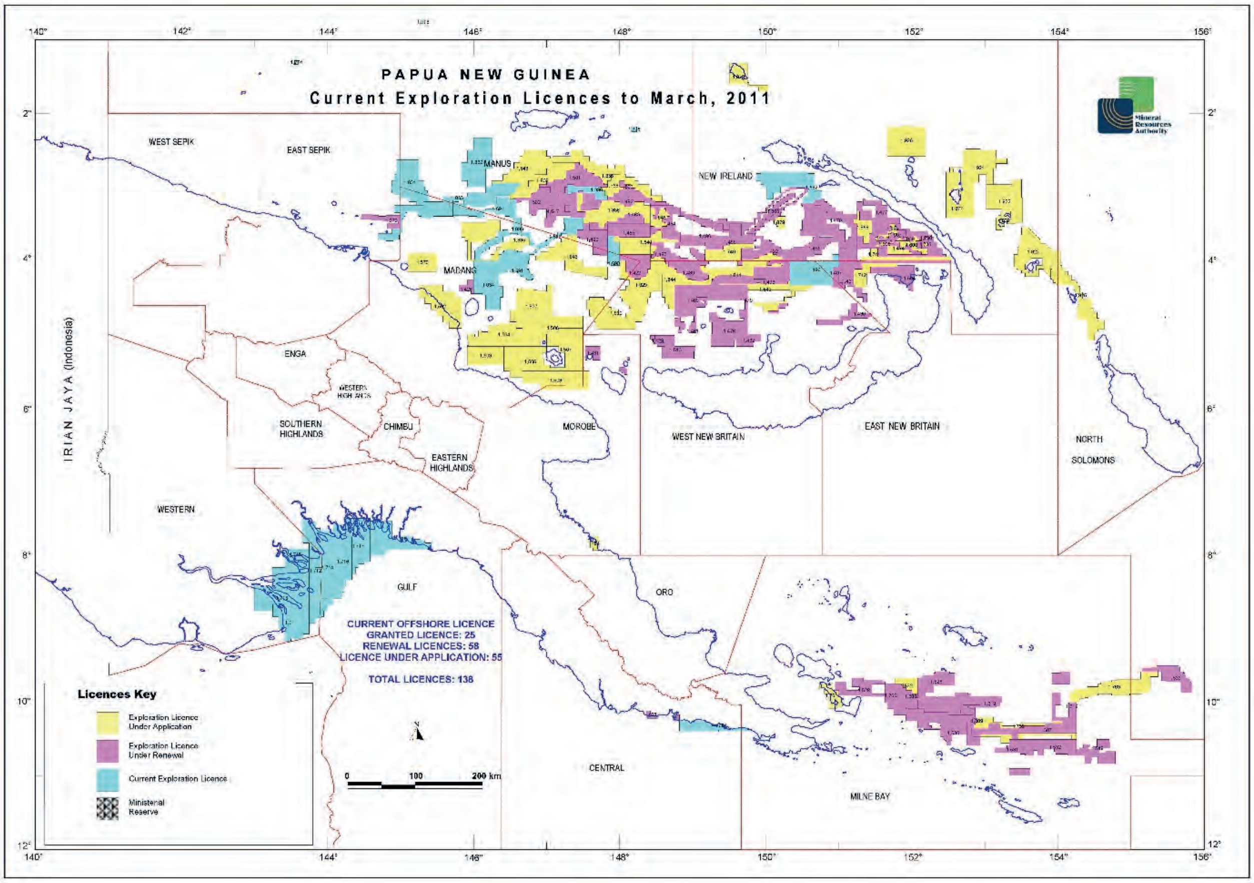

Figure 17 *Current Offshore Exploration Licences, PNG*

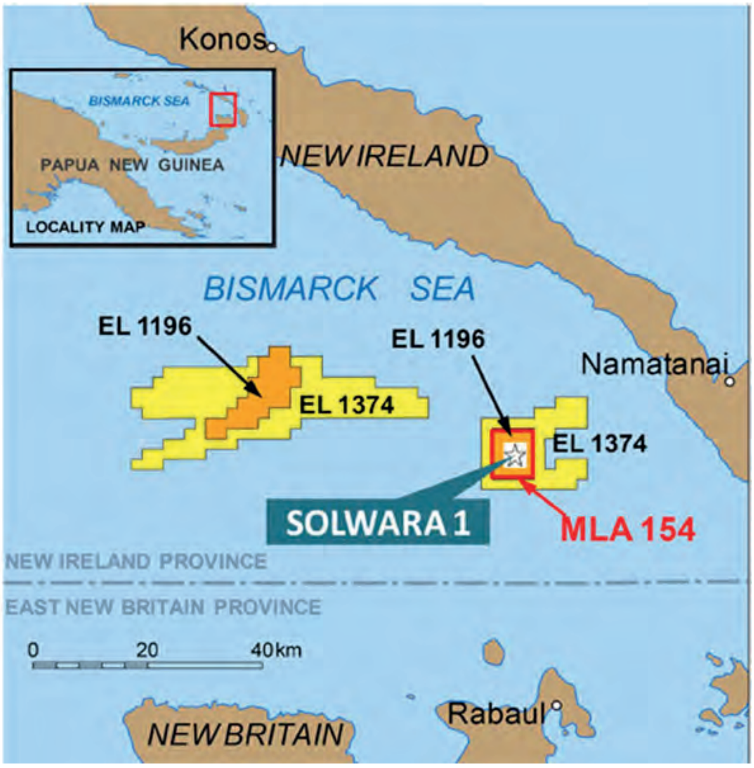

Figure 18 *Location of SOLWARA 1 mining lease. EL: exploration lease. MLA: mining lease applied. Source: Nautilus Minerals Inc*

The government is currently developing an offshore mining legislation that will determine the regulation and policy to administer the deep-sea mining prospects.

As this will be the first large scale deep-sea mining project, there is no precedent for EIS or operational environmental monitoring. However, the draft PNG guidelines and legislation pertaining to DSTP will be pertinent to deep-seabed mining and the operation and environmental monitoring plans must be developed to ensure that there is sufficient and timely monitoring of the near and far field areas affected by this operation.

The impact of the mine tailings discharge to the deep ocean of two mines has been investigated. The first, Lihir, where DSTP has been in operation since 1996 with the outfall at 115 m depth. Mine tailings settled over a wide area, to $>$ 2000 m depth.

The second mine was Misima. This mine had ceased discharging tailings three years before the sediments surrounding the mine were sampled (Figure 19). DSTP was in operation for 15 years until 2004, with outfall at 112 m depth. Tailings have accumulated in a semi-enclosed basin.

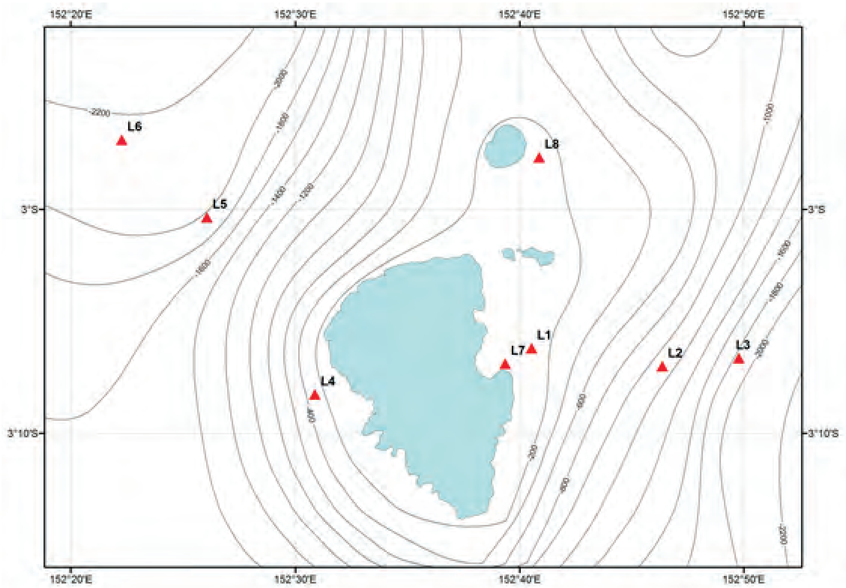

Figure 19 *Location of sediment sampling stations, Lihir*

4.2 Major and minor element concentrations in sediment from Lihir

The sediments and pore-waters from Lihir were analysed for major, minor and trace elements and the combined data were used to evaluate sediment composition and provenance, identify biogeochemical controls and assess any post-depositional mobility of elements within the marine environment surrounding Lihir Island, (Figure 19).

The concentrations of aluminium (Al), potassium (K), iron (Fe) and barium (Ba) are all higher within the top 5-10 cm of the impacted stations (L1-L3) when compared to the control stations (L4-L6). In contrast, calcium (Ca) concentrations are much lower in the impacted stations compared to those of the control stations, (Figure 20).

Concentrations of the elements are all similar at depth indicating that the mine tailings slurry has at least twice the concentration of Al, four times the concentration of K, twice the concentration of Fe, three to five times the concentration of Ba and twelve to fifteen times lower concentration of Ca than the natural sediments of the area.

The concentrations of the minor and trace elements also vary between the impacted and control stations. Figure 21 illustrates the differences between a number of elemental concentrations in sediments from the impacted station L2, 1,750 m depth and L5, control station, 1,715 m water depth. There are significant differences in concentrations of beryllium (Be), vanadium (V), copper (Cu), molybdenum (Mo) and Lead (Pb) between stations L2 and L5, with concentrations of all elements being higher at the impacted station, L2. However, the concentrations of cobalt (Co) and nickel (Ni) are similar at both the impacted and control stations.

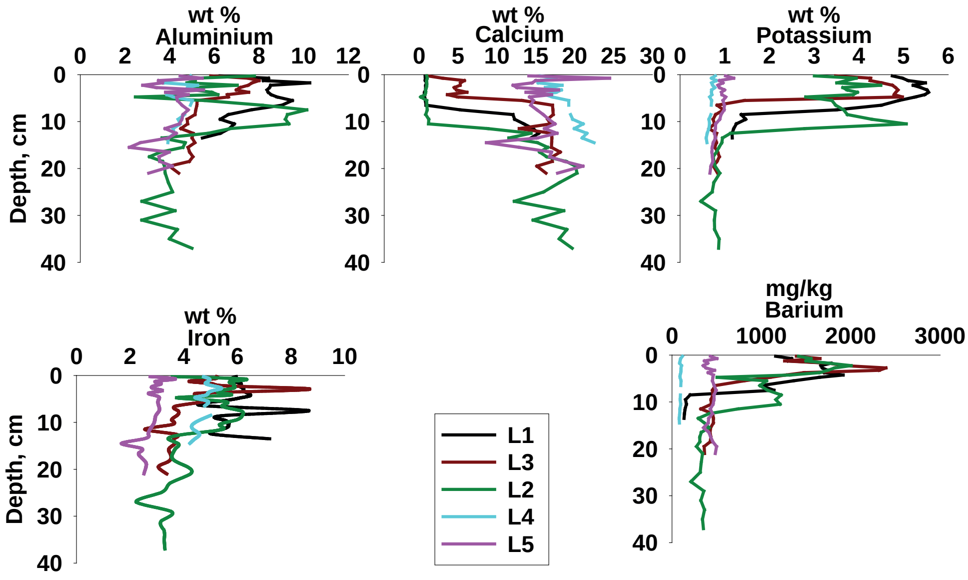

Figure 20 *Major and Minor elemental concentrations, Lihir*

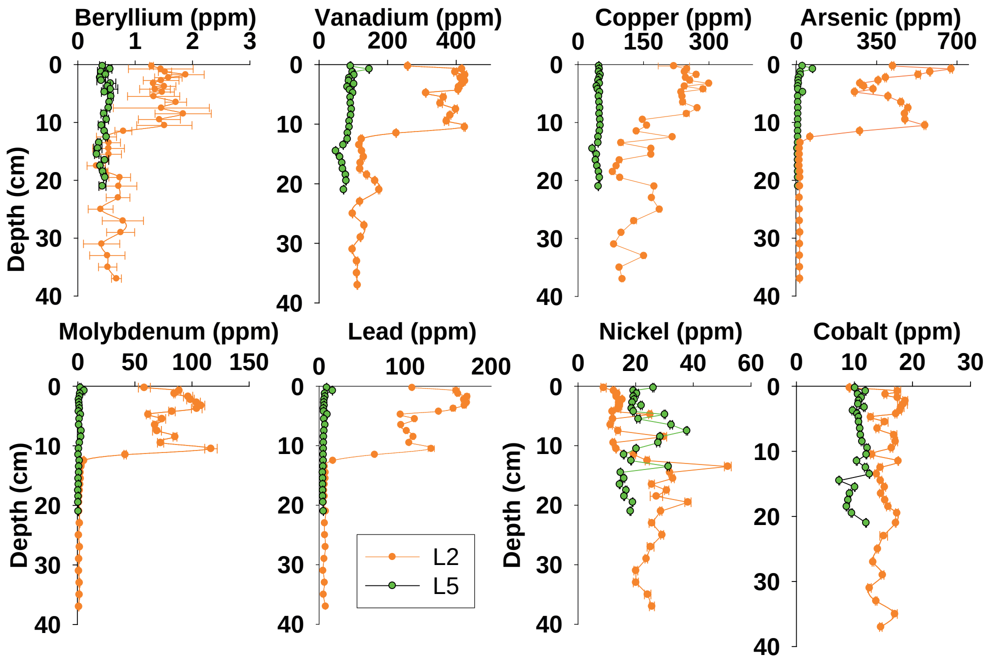

Figure 21 *Minor and trace elemental concentrations within sediment, L2 (impacted, 1,750 m) and L5 (control, 1,715 m), Lihir*

The geochemical results for the sediment samples around Lihir indicate that the discharge of mine tailings is impacting on the sediment regime of the marine environment east of Lihir. The stations L1-L3 have all been impacted by the discharge of the tailings.

The chemical analyses of the sediment cores show elemental depth profiles which penetrated below the mine tailings at the impacted stations. These profiles indicate that the mine tailings composition is significantly different from the naturally occurring sediments and can be identified by their geochemical signature. The mine tailings are contributing to the metal content of the sediments at the impacted stations yielding significantly higher inventories of K, Rb, Ba, Cu, Zn, V, As, Pb, Tl, and U.

Summary of findings for operational mine: Lihir

- First replicated study of the benthic and seabed geochemical impacts of an operational DSTP system;
- Very large and profound differences in the biological assemblages present in impacted vs reference stations;
- There are still measurable numbers of meiofauna in the surface layers of the impacted sediment; and
- The sediments contain much higher concentrations of metals in both solid and aqueous phases, including ecotoxic elements such as Cu, Cd and As.

4.3 Major and minor element concentrations in sediment from Misima

The major element composition is shown in Figure 22. Stations M1-M3 are the stations on a transect moving eastward away from the mine; station M4 is located south westward of M2. Station M5 is located south eastward from the transect with M6 located south westward from Misima Island. M5 and M6 are assumed to be control stations.

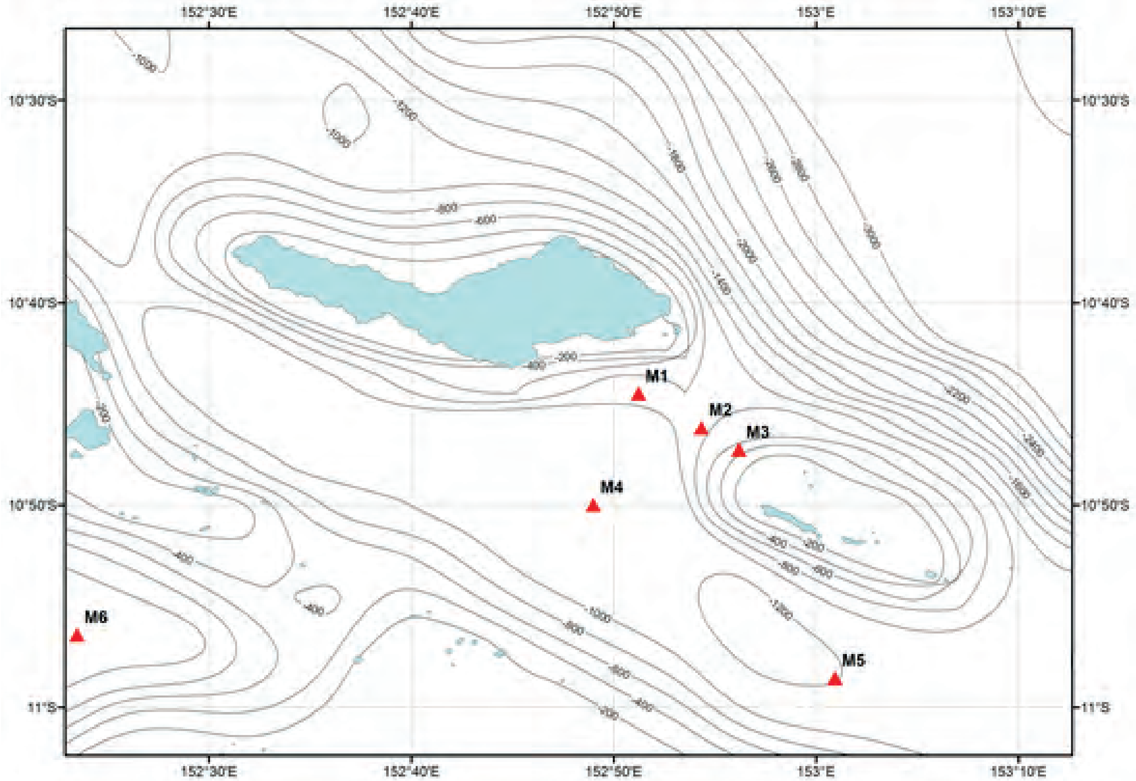

Figure 22 *Location sampling station positions at Misima*

The concentrations of Al, K, Fe and Ba are all higher within the complete length of the core for the impacted stations (M1-M3) when compared to the control stations (M5-M6) indicating that only sediment impacted by mine tailings was sampled at these stations. M4 has high concentrations in the top 5 cm of the core after which the concentrations decrease to similar values observed in the control stations M5 and M6. In contrast, Ca concentrations are much lower in the impacted stations compared to that of the control stations. Ca concentrations are three to five times lower at M1-M3 than the sediments of the control stations (M5 and M6) with maximum concentrations of 5%. The Ca concentrations of M4 are similar to those of M5 and M6 having a maximum concentration of Ca of 28% compared to 34 and 35% for M5 and M6 respectively. The range of concentrations within the sediment of the six stations suggests that the impacted stations (M1-M3) have a different chemical signature to the control stations (M5 and M6) and that M4 has a signature that varies between that of the impacted and control stations, (Figure 23).

The concentrations of the minor and trace elements also vary between the impacted and control stations. Figure 24 illustrates the differences between a number of elemental concentrations in sediments from the impacted station M1, 1,380 m depth and M6, control station, 1,250 m water depth. There are significant differences in concentrations of Be, V, Cu, As, Ni and Co between stations M1 and M6, with concentrations of all elements being higher at the impacted station, M1.

The geochemical results for the sediment samples around Misima indicate that the past discharge of mine tailings has impacted on the sediment regime of the marine environment surrounding Misima. The geochemical signature and elemental inventories of stations M1-M3 indicate that these stations have been impacted by tailings and continue to have high concentrations of metals within the sediments. The two control stations M5 and M6 have lower concentrations of metals and in addition M6 differs in composition from M5, possibly being influenced by a high Ca supply from surrounding coral reef areas. Station M4 has a similar chemical signature in the top 2.5 cm of the core to sediments at stations M1-M3.

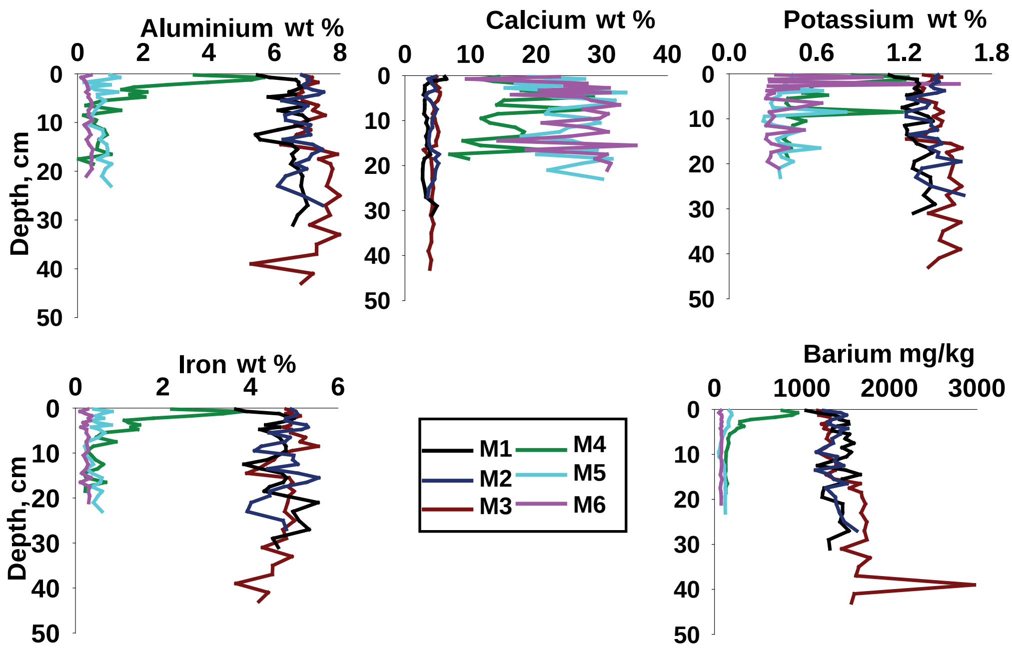

Figure 23 *Major and Minor elemental concentrations Misima*

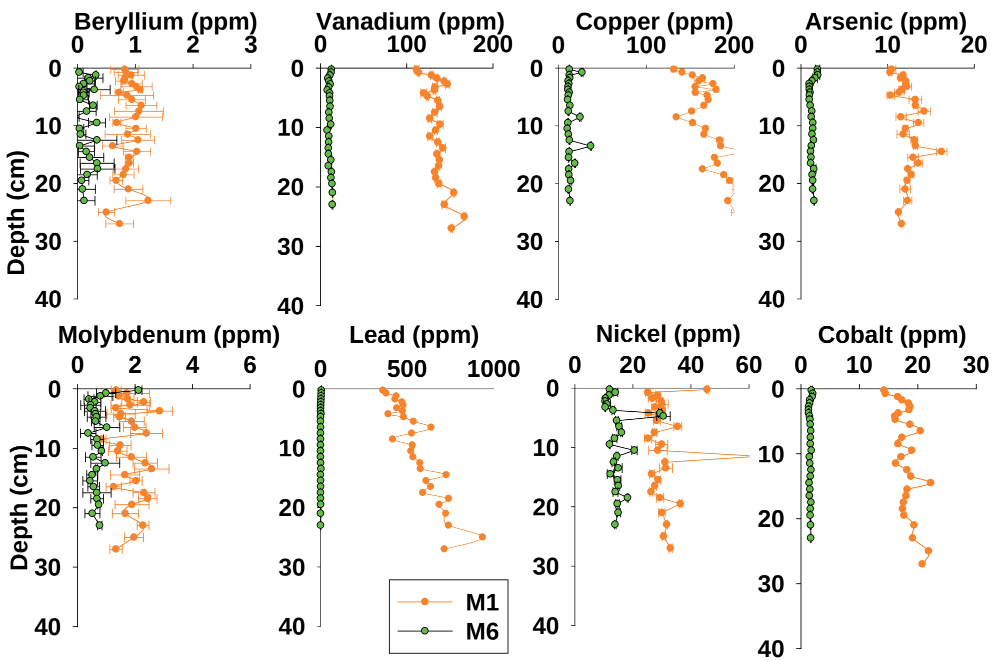

Figure 24 *Minor and trace elemental concentrations within sediment, M1 (impacted) and M6 (control), Misima*

Summary of findings for post-operational mine: Misima

- First ever multidisciplinary study of marine environment after the closure of the DSTP system;
- Stations adjacent to the DSTP are very clearly impacted by mine tailings;
- Stations further away from the mine have been impacted either directly through mine tailings deposition or indirectly through post-depositional resuspension and re-deposition; and
- In addition to geochemical analyses, it was observed that the impacted stations showed some degree of post impact recolonization, and that results indicate very clear differences between the benthic community of impacted and non-impacted stations.

The geochemical analysis of the sediment has allowed us to construct a picture of the impact of the mine tailings deposited in the marine environment of Lihir and Misima. The tailings are contributing a substantial amount of material to the immediate marine environment of the mine sites and further afield. The material being discharged contains a significant amount of heavy metals with the finer particulate material having higher specific concentrations of metals. The mine tailings have a very different geochemical signature to that of natural sediment resulting in an elemental “fingerprint” which allows tailings to be traced within the marine environment and therefore enable the identification of sites of deposition of tailings.

Conclusions: Impacts of large-scale disposal of mining waste in the deep sea

The increase in understanding of the effects of anthropogenic disturbance on the deep ocean and the advancement of smart observation technology is important in managing and minimizing the impacts of DSTP. An objective of any programme monitoring DSTP will be to determine the passage of any plumes of suspended material in the water column and to provide a rapid (real time) alert to any failure in the operational management of the discharge of unconsolidated sediment and waste rock to deeper water.

The data presented here are a small part of a much larger multidisciplinary investigation (Shimmield et al., 2010). The data obtained from the study have been used to develop a set of General Guidelines for the use of DSTP in PNG and Site Specific Guidelines for operating mines using DSTP. These are presently being incorporated into the Mineral Policy of PNG by the Department of Mineral Policy and Geohazards.

PNG is the first country to develop guidelines for the use of Deep Sea Tailings Placement as a waste management method for mine tailings. Areas requiring more information:

- Understanding behaviour of sediment plumes, physical and chemical;
- Transport of pollutants through the marine ecosystem, e.g. pelagic species;
- Modelling of the tailings footprint;
- Timescale of recovery of impacted area, recolonization by deep sea benthos; and
- Sampling and analysis techniques, correct sampling equipment and quality assurance of analysis. Use of technology in assessment and monitoring, remote technology with novel sensors.

4.4 Numerical modelling of particle spreading from mine tailing deposits in Norwegian fjords[18]

Recently, marine mine tailing placement has become a topic of much public debate in Norway, as new mining operations are being proposed. These operations result in deposition of mine tailings onto the seabed in certain Norwegian fjords (see Ramirez-Llodra et al. (2015) for a recent review (1)). Concerns have been raised over spreading of particulate fines and their potential impact on vulnerable fjord ecosystems and nearby fish farms. Numerical models can be useful in this context by exploring outcomes of different scenarios, which in turn can be used to inform debates and support decision-making. For instance, placement of discharge pipes can be optimized by considering the predicted spreading patterns of different scenarios, choosing a location that produces the smallest impact, as shown in Figure 25.

In the context of marine mine tailing placements, numerical models can be used to study spreading of particulates, the concentration levels one may expect in the water column, and the area and amount of sedimentation. These can then be related to environmental impacts, and are thus useful for environmental risk assessment. It is crucial for accurate model predictions that the relevant processes are sufficiently accounted for; in the context of marine mine tailings; these include current-driven transport, flocculation, sedimentation, and resuspension from the sea bed. Flocculation is a particularly relevant process as the suspended sediment concentrations typically associated with a mine tailing discharge have the potential to significantly alter the fate of the discharge. While much is known about the flocculation process, this knowledge is largely derived from studies of natural sediment dynamics in estuaries. For marine mine tailing discharges, the situation is somewhat different, and there may be other processes operating, which could present novel phenomena that should be investigated through observational studies.

The DREAM model (2-4), developed for the oil and gas industry (Figure 26), has been used to study particle spreading and sediment build-up for a planned marine tailing deposit in Norway (5). The predictions for these endpoints were then used for environmental risk assessment, by comparing with threshold values. Additionally, different release arrangement scenarios were compared, which showed some clearly preferable alternatives, illustrating how to make practical use of models to minimize environmental impact. Presently, DREAM is under active development to better describe mine tailing transport, through the NYKOS project.

[18] Raymond Nepstad, Emlyn Davies, and Henrik Rye, SINTEF, Norway.

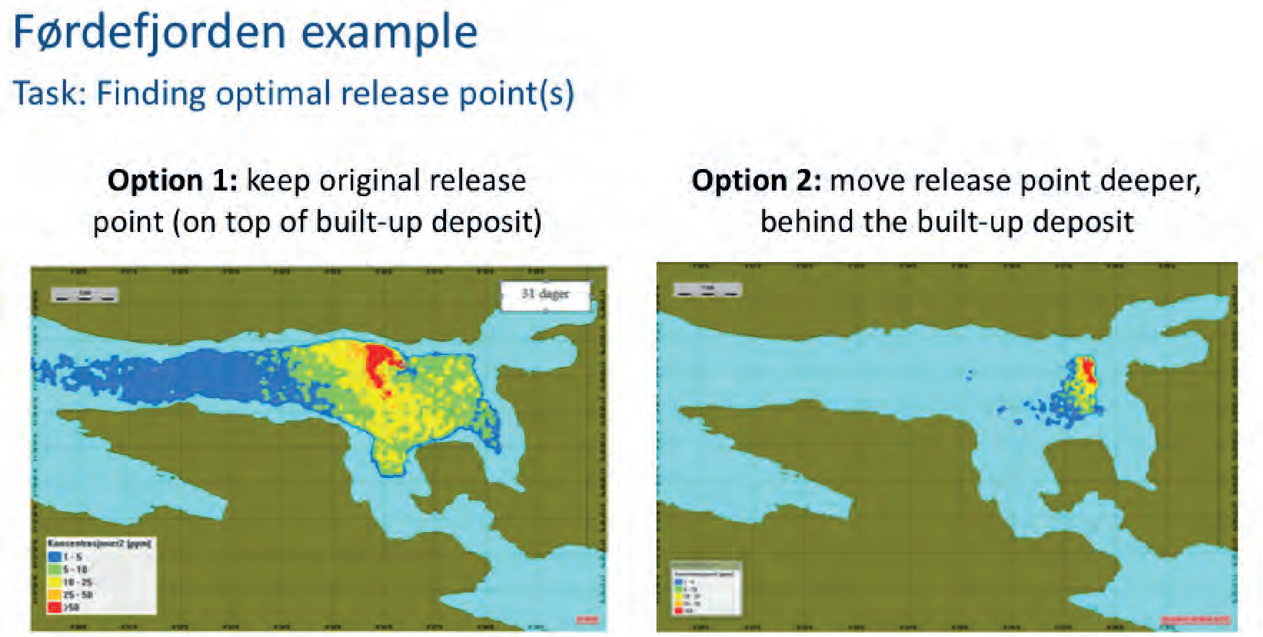

Figure 25 *Modelling of the discharge identified the location of discharge that would limit the spreading of particulates*

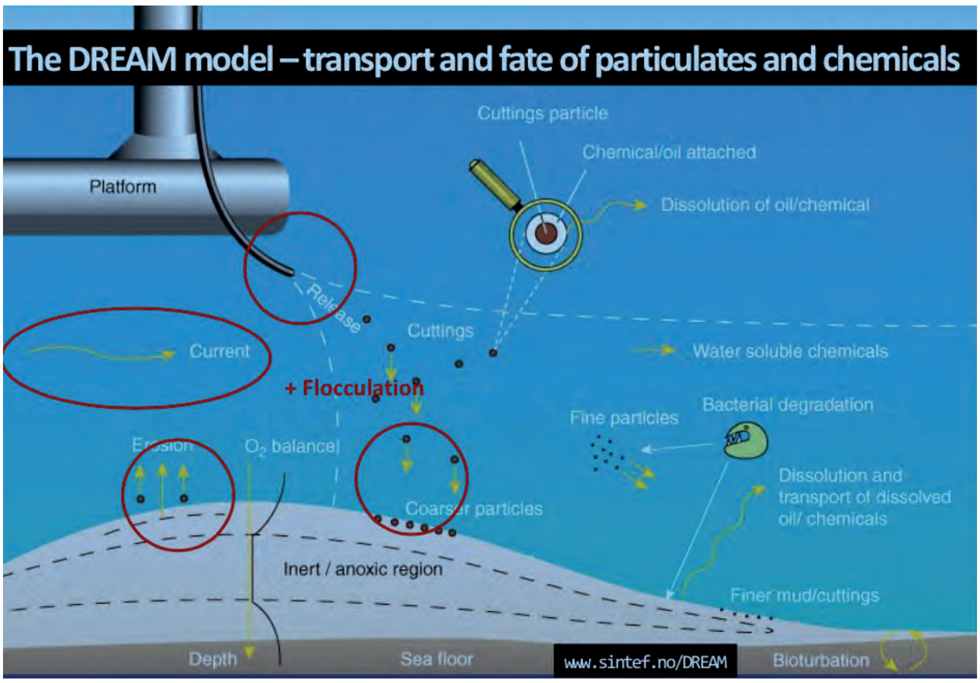

Figure 26 *The Dream Model for predicting distribution discharges of particles*

A tighter integration of model use and development with new and improved in situ measurement technology for suspended mine tailings is important to achieve improved predictions and more robust models in general. In advance of a recent field campaign, initial model predictions of particle transport were used to highlight target areas, where model uncertainty was highest. Regular discharges of flocculating material were released into the fjord, requiring particle observations to span several orders of magnitude in size and concentration. The approach to tackling these monitoring challenges exploits the capabilities of both commercially available instruments and research prototypes by combining data from a LISST-100, LISST-HOLO, and a bespoke Silhouette-based particle imaging system. Together, these instruments produced size distributions ranging from 2.5-10000 microns. In situ imaging proved essential in providing a realistic picture of the nature of the flocculated material, with many long, string-like flocs of several centimetres in length being observed several hundred metres from the discharge location.

Recent development in real-time data transfer technology for submarine environments opens up the possibility for improved monitoring of an active tailing placement site, allowing suspended sediment concentrations, particle types, and sedimentation rates to be continuously monitored. By integrating this with real-time models, a more complete picture of the discharge can be obtained, and short-term predictions used to optimize discharge times or positions, when this option is available. A prototype of a real-time modelling and monitoring system for offshore drilling operations was recently demonstrated (4). If such systems could be adapted for the mining industry, it could be a significant step towards reducing environmental impacts of marine tailings deposit sites.

4.5 How fast do mine tailings deposits colonize, can we boost colonization, and does colonization imply recovery of ecosystem functioning? Faunal Colonization of Submarine Mine Tailings: An Intertidal Experiment to Investigate the Influence of Sediment Organic Carbon Content[19]

Mineral resources are used in all walks of life. EU industries currently consume around 20% of the world production of metals, yet at the same time only produce 3% of the world´s supply. Countries in Europe are therefore partially dependent on imports of mineral resources from non-European countries. Tailings, fine-grained waste-rock produced during mineral processing, ar-e the main waste product from the extraction of valuable minerals and metals from mineral ores. The proximity of mineral resources to vulnerable water bodies creates a real environmental challenge. One of the main tools used to overcome the sheer volume of tailings produced during mining is to dispose of them at the seafloor as submarine mine tailings placements (STPs). By submerging reactive tailings permanently under water, acid mine drainage (AMD) or the production of sulphuric acid and metal leaching (e.g. Cu, Ni, Zn, Pb, Hg) from sulphide minerals can be reduced or, at least restricted, to the top centimetre of an often 50 m thick deposit. STPs are also very cheap compared to land-based impoundments. STPs' advantages mean they are practiced in many areas around the world, including Norway (Kvassnes et al., 2009, 2012, Kvassnes & Iversen, 2013). Currently 33 fjord- or near-coastal STP sites exist in Norway and six of these are still in operation (Kvassnes and Iversen, 2013). Norwegian STPs' discharge permits range from $4x10^4$ tons yr_{-1} (Skaland Graphite AS, Troms) to $4x10^6$ tons yr_{-1}-(Sydvaranger Gruver A/S in Finnmark) – refer to Figure 27.

[19] Andrew K. Sweetman, International Research Institute of Stavanger, Norway; Barbro T. Haugland, Institute for Marine Research, Norway; Stefan G. Bolam, Centre for Environment, Fisheries and Aquaculture Science, United Kingdom.

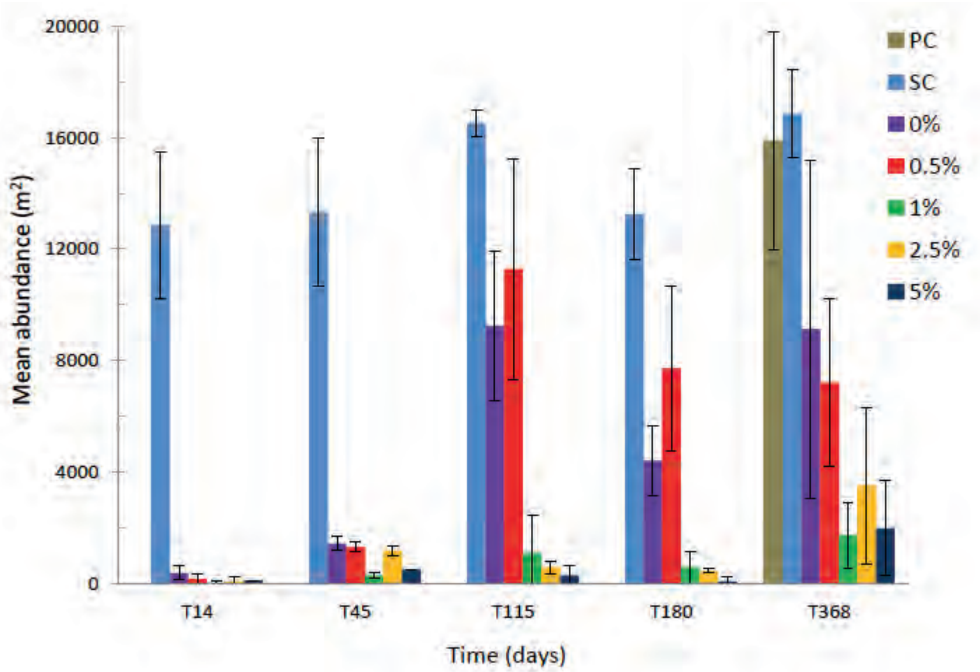

Figure 27 *Changes in mean macrofaunal abundance (± 95% confidence intervals) over time in the different tailings treatments and the sampling controls. Procedural control data (PC) is included for T=368d. Source: Haugland MSc thesis (2014)*

STPs cover and decimate the seafloor environment close to the outflow pipe and leave the benthos organically sterile, and will therefore significantly modify marine ecosystems where STPs exist. One of the most important prerequisites for STPs is that fauna can rapidly colonize the deposit after cessation of mining. See also Figure 27. However, very little is currently known about the factors controlling colonization of STP deposits – in particular the role of organic carbon (C_{org}) content. Bolam (2004) showed that faunal recolonization in organically enriched sediments hindered faunal recovery following dredge spoil placements in an intertidal habitat compared to unamended controls. However, the "organically enriched" sediment treatments used were over 3% C_{org}, which is known to negatively impact faunal community structure (Hylland et al., 2005) due to the build-up of toxic metabolic byproducts from organic matter decomposition.

In this study, the effect of adding organic C to tailings was quantified as a means to speed-up faunal recolonization and facilitate rapid rehabilitation of STPs. To do this, an inter-tidal experiment was conducted in the Crouch Estuary, Essex (United Kingdom) from April 2012 to April 2013. Tailings from Rana Gruber A/S were used as starting material for the experiments, using a randomized complete-block experimental design at a semi-protected field site which ensured access to a large larval pool, and protection from high hydrodynamic activity. Thirty large (0.25 m^2 x 10 cm deep) freezer trays of inert mine tailings were set up. Seven trays were unamended (ensuring a C_{org} content of 0%). The rest were mixed with ground up fish farm feed, which increased the organic C content of the tailings incrementally from 0% to 0.1% C_{org}, 1% C_{org}, 2.5% C_{org}, and 5% C_{org}. Plots were divided into six blocks running parallel to the shoreline ensuring that all plots were at the same depth, subjected to the same amount of hydrodynamic activity, and of a sufficient distance apart so that experimental treatments are independent of one another. The trays were laid out on the sediment so they were flush with surrounding sediments, which reduced turbulent flow around each treatment plot, which could modify larval colonization processes.

The plots were sampled 45d, 115d, 180d and 368d after placement for sediment chemistry, sediment grain size, and faunal abundance and diversity. Faunal biomass was measured in all samples and used to calculate secondary productivity (i.e. an ecosystem function). The data revealed that a concentration of 0.5% organic carbon was the optimum concentration to enhance macrofaunal colonization, and after one year, the majority of the univariate indices indicated recovery in the mine tailings with a low concentration of organic carbon (Figure 28). However, the macrofaunal communities functioned differently and had a far less total production than the ambient sediments. This indicates that factors other than organic carbon are also important (e.g. sediment angularity, Figure 28) when it comes to colonization of mine tailings.

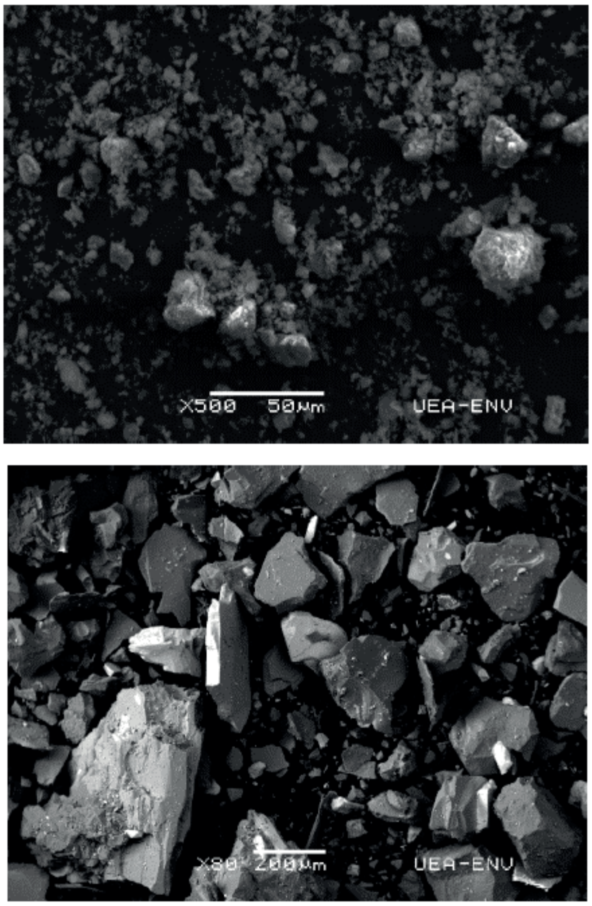

Figure 28 *Scanning Electron Microscope (SEM) images of background sediment (top panel) and tailings (bottom panel) from the experiment*

4.6 Impacts of discharge into the sea of mine tailings from phosphorite mines in Africa. The environmental impact of the dumping of mine tailings in the West African sea: the case of the disposal of phosphorite tailings in Togo[20]

The marine sedimentary phosphorite deposits of Hahotoé-Kpogamé (southern Togo), like those elsewhere in the world, are highly enriched with numerous trace metals such as Cd, Cr, Cu, Ni, V, Zn, Pb, U, Th, Mo, Ag, F, Y, and Rare Earths (Altschuler, 1980). The main phosphorite mineral in Togo's phosphorite is a carbonate fluorapatite also called francolite (Kunkel, 1990; Johnson, 1987). The chemical composition of francolite is very variable because its crystal structure allows numerous ionic substitutions (McConnell and Lehr, 1969; McArthur, 1990; McClellan,1980; McClellan and Van Kauwenbergh, 1990). Phosphorites have been exploited since 1959 in the areas of Hahotoé and Kpogamé (southern Togo). The processing of the phosphorite ore to commercial grade is done mechanically by wet sieving, using sieves and hydrocyclones. Seawater is pumped to a factory at Kpémé close to the beach situated 25 km from the mining sites. Two types of mine wastes are principally produced during this processing: a fine-grained clayey muddy tailing and a coarse-grained waste. About 40% of the raw ore is rejected as tailings during the processing. The muddy tailings are dumped directly into the coastal waters of Togo without any pre-treatment (Figures 29-31). About 2.5 million tons of phosphorite tailings are thus dumped annually into the coastal waters of Togo (since 1959). The aim of this work is to study the environmental impacts of the coastal disposal of mine tailings on sediments, water, and biota in the area. Phosphorite mining and the dumping into the sea of phosphogypsum tailings also occurs in Morocco (Figure 32).

Material and methods: To reach the objectives, phosphorite samples, coastal sediments, coastal waters and biota (fish, shrimps) have been sampled, dried, ground and digested using acids (HNO_3 and HCl). Heavy metals (Cd, Pb, Cu, Ni, Zn, Sr, Ba, U, Rare Earth, and major elements P, Ca, Mg, Na, K, Fe, Mn, Ti, Si, have been analysed by ICP-AES. The bioavailability of heavy metals has been assessed using weak acid and saline water extraction.

Results and discussion

Chemical composition of phosphorites: The results of chemical analysis indicate that the phosphorites of Togo contain high amounts of Cd, Cr, Cu, Ni, Zn, V, Zn, Sr, Ba, U and Rare Earths. Compared to shale values the enrichment factors are, 237 for nickel, 236 for cadmium, 25 for uranium, 9 for zirconium, 6 for chromium, 4 for strontium, 2 for vanadium, 1.5 for zinc and copper. Compared to similar phosphorite deposits in the world (Altschuler, 1980), studies for phosphorite show an enrichment factor of 4 for cadmium and chromium, 3 for copper, 2 for vanadium and zinc, 1.5 for nickel. Zirconium, uranium and lead are depleted in Togo phosphorites with factors of 0.9, 0.8 and 0.2 respectively. A grain size dependence study of heavy metal distribution in phosphorite shows that contents of Cd, Zr, V, REE, U decrease by decreasing grain size whereas the contents of Cr, Cu, Ni, Ba, Zn increase by decreasing grain size. Cd, Zr, V, REE, U show significant positive correlation with P2O5 whereas contents of Cr, Cu, Ni, Ba, Zn show significant correlations to Al and Fe. This grain size dependence has a significant influence on trace metal distribution in the sea environment by currents.

Trace element bioavailability: Extraction with weak acid shows that, compared to their total contents in analysed phosphorite samples, average extracted values reach up to 72% for Pb, 66% for Sr, 42% for Mn, 38% for Cd, 34% for Cr, 32% for Cu and Zn, 31% for V, 27% for Ni, 18% for Fe, 15% for Al and 1% for Ti. The results for some selected trace metals for extraction with saline water indicate that when salinity increases (from 10 to 17 and to 33 g/l), the solubility of phosphorus and trace metals increases also. The high trace metal bioavailability in phosphorites and the high salinity of seawater are factors that enhance the metal contamination of the marine environment

Seawater pollution: Once dumped into the sea, the muddy tailings are transported by littoral currents (littoral drift stronger eastwards and seawards rip currents) and contribute to a transboundary optical and chemical contamination (from Togo to Bénin and Nigeria). Closer to outfall, the pH of seawater becomes acid, turbidity and the electrical conductivity increases. The seawater content of heavy metals Cd, Pb, Al, Fe and Zn decreases when moving far away from tailing outfall.

Sea sediment pollution: Trace element concentrations in bottom sediment ranged from 2-44 ppm for Cd, 22-184 ppm for Cu, 1 15-753 mg/kg for Cr, 19-281 ppm for Ni, 22-176 ppm for Pb, 179- 643 ppm for Sr, 38-329 ppm for V, 60-632 ppm for Zn and 18-8928 ppm for Zr. Spatial distribution of trace elements in the marine environment indicates that from the outfall the concentrations of Cr, Cu, Ni, Pb, V, Sr and Zn increase seawards and along the coastal line outwards of the tailing outfall, whereas Cd and Zr showed reversed spatial patterns. Generally trace metal associated to apatite structure such as Cd, REE, U shows decreasing concentrations when moving far away from the pollution source (since apatite is denser and settles down earlier during transport by currents), whereas trace metals associated to the clay fraction (Cr, Cu, Ni, Zn, V, Sr) show the opposite (clay minerals are lighter). Thus, transport and sorting of phosphorite particles by coastal currents are the main factors controlling heavy metal distribution in coastal marine environment.

Bioaccumulation in biota: Generally there was a high level of trace metals in the tissues of the studied species, especially for Cr, Ni, Pb, Fe and Se. Compared to WHO norms, the average relative health factors (RHF), i.e. the ratios of the measured to the WHO threshold concentrations for metals, in fish are 97 for Ag, 250 for As, 10 for Cd, 7 for Cr, 53 for Fe, 63 for Mn, 78 for Ni, 36 for Pb, and 470 for Se, while Al, Cu and Zn are less bioconcentrated. In mussels, the relative health factors are 70 for Ag, 295 for As, 14 for Cd, 4 for Cu, 9108 for Fe, 186 for Mn, 71 for Ni, 276 for Pb, 273 for Se. Generally the bioconcentration is higher in mus-

[20] Kissao Gnandi, University of Lome, Department of Geology, Togo.

sels, which is the reason why mussels are often used as bioindicators of marine pollution. The filter-feeding behaviour of mussels results in the accumulation of both trace metals adsorbed onto the sediments and dissolved in water.

Conclusion and recommendation

The phosphorite deposits of Hahotoé-Kpogamé, southern Togo, (see Figure 29) are naturally more highly concentrated with toxic trace metals such as Cd, Cr, Cu, Ni, V, U, Zn, and Rare Earth Elements (Figures 33-35). Their processing using wet sieving techniques with seawater and the dumping of mine tailings into the sea represent a major source of trace metals pollution of coastal waters, sediments, and biota in Togo. Even though the marine pollution is anthropogenic in source, natural factors such as heavy metal bioavailability, seawater salinity, and coastal currents are playing an important role in metal distribution and bioaccumulation.

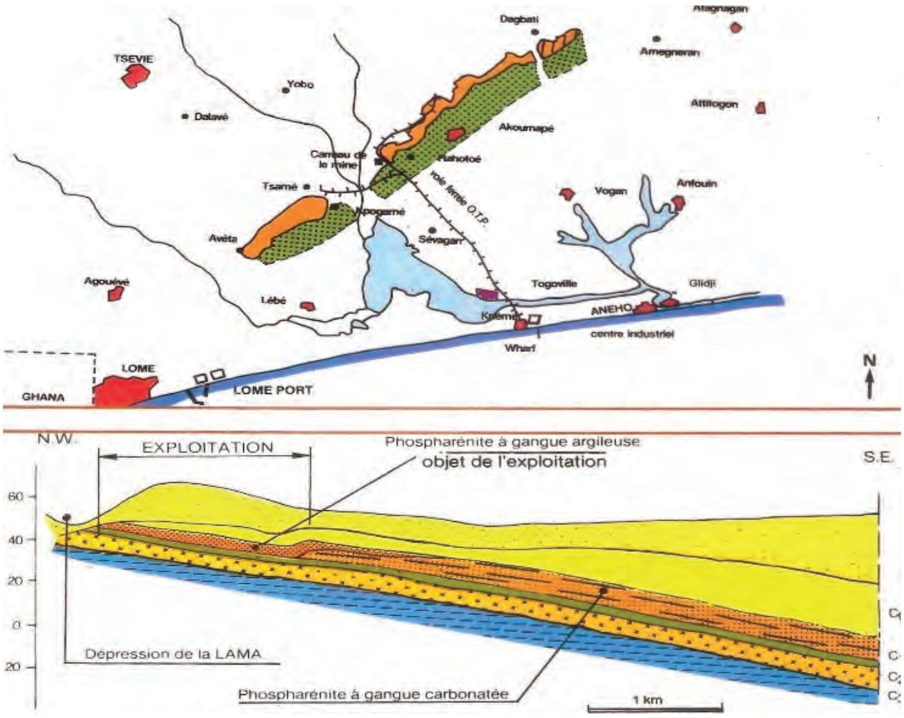

Figure 29 *The phosphorite deposits of Southern Togo and the dumping of heavy metal spread mine tailings into the coastal waters of Togo*

Specifically, the high bioaccumulation rate in fish and mussels represents a serious threat to the marine ecosystem and human health through the food chain. We recommend the governmental and mining authorities to stop dumping mine tailings into the sea, to build sedimentation basins to treat mine tailings by decantation and flocculation, and to conduct research for the reuse of phosphorite tailing, e.g. in agriculture, since those tailings contain up to 18% P_2O_5 compared to raw phosphorites which have an average P_2O_5 content of 32%.

Figures 30 and 31 *Mine Tailings discharge into West African Sea.*
Credit: K. Ghandi, University of Lome, Togo

Figure 32 *Phosphorite mining and the dumping of phosphogypsum tailings in Morocco. This is known to be piped to the seashore. Phosphogypsum is a by-product in the manufacture of phosphoric acid in the fertilizer industry*

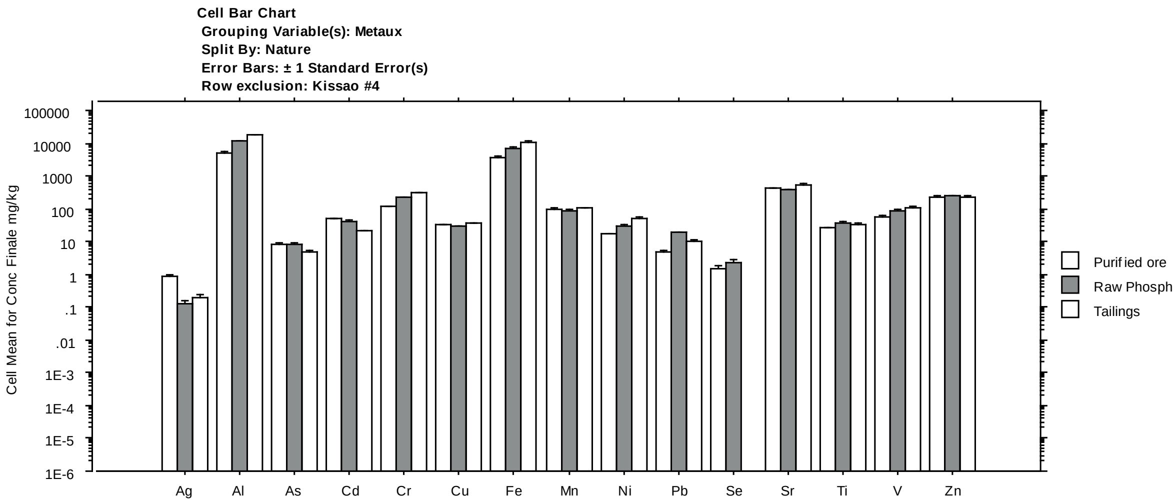

Figure 33 *Distribution patterns of some selected major and trace elements in bottom sediments of the coastal area of Togo*

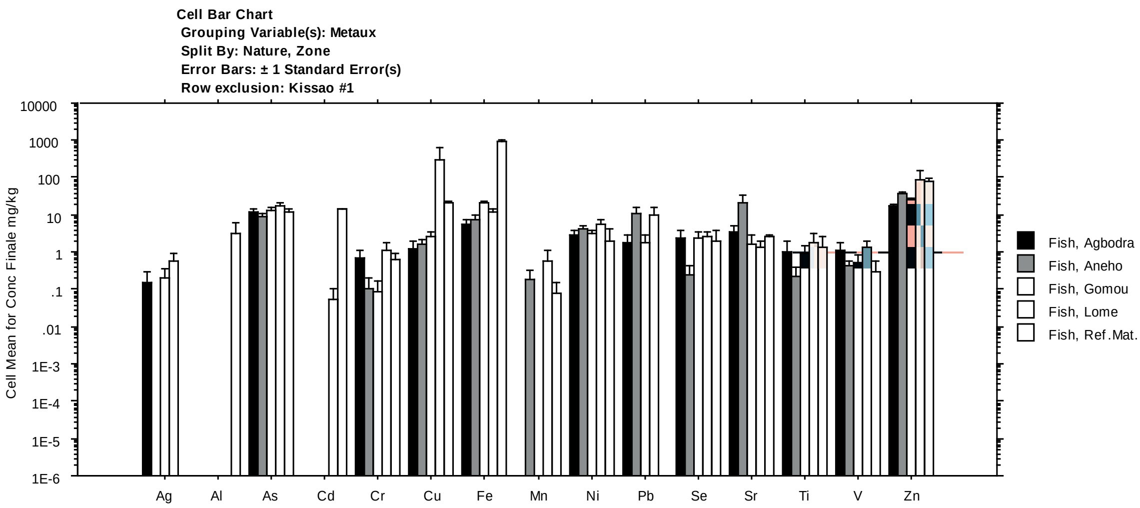

Figure 34 *Metal content of fish in contaminated coastal area*

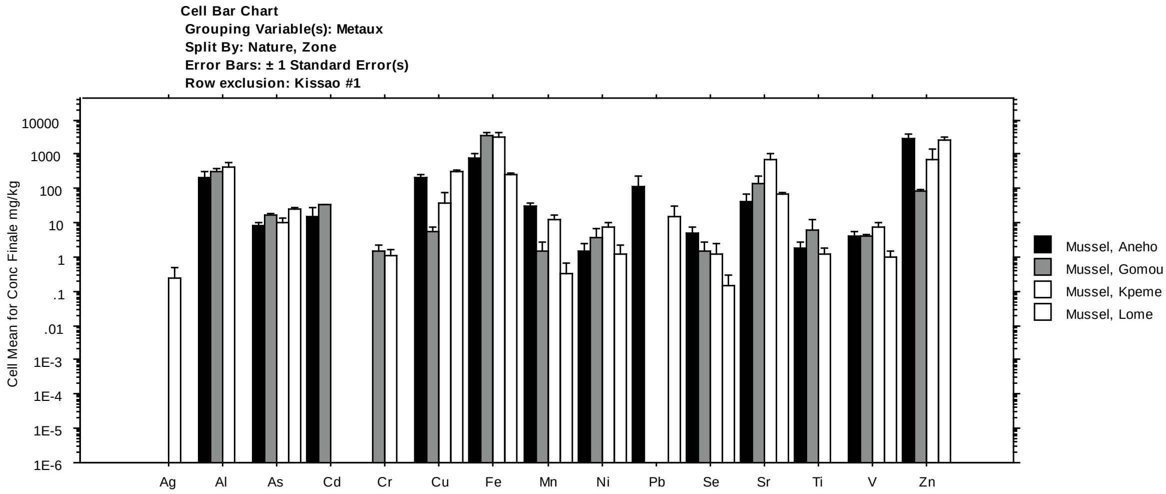

Figure 35 *Metal content (mg/kg) of mussels of the contaminated coastal area*

4.7 Studies of metal release during deep-sea mining activities[21]

To understand the impacts of metal release from mine tailings, multidisciplinary research is needed, addressing geochemistry, marine biology and sedimentology studies. There is real synergy between different aspects of studying the problem of introducing sediments into the oceans that are chemically reactive. The relationships between the different processes are important to assess, i.e. what is the chemical and biological response, the sedimentology, and the effect of physical oceanography in all processes? These relationships and potential impacts are being addressed by the MIDAS project.

The National Oceanography Centre, Southampton is part of the European Union funded MIDAS project. This project seeks to address some of the fundamental environmental issues relating to the exploitation of deep-sea mineral and energy resources, specifically polymetallic sulphides, manganese nodules, cobalt-rich ferromanganese crusts, methane hydrates and the potential mining of Rare Earth Elements. Many aspects of these issues are also directly relevant to the processes that may occur during seafloor tailings disposal. The in situ mining of seafloor massive sulphides and in particular the pulverization of massive sulphides on the ocean floor will produce highly reactive sulphide mineral surface areas, with the potential for seafloor acid generation and the release of potentially harmful major and trace metals into the local environment, (Figure 36).

For example, the MIDAS project will assess the nature and scale of the potential impacts including 1) physical destruction of the seabed by mining, the creation of mine tailings and the potential for catastrophic slope failures, 2) the potential effects of particle-laden plumes in the water column, and 3) the possible toxic chemicals that might be released by the mining process.

[21] Martin Palmer, National Oceanography Centre Southampton, United Kingdom.

4.8 Copper pollution effects on benthic faunal communities: lessons from shallow water studies for submarine and deep-sea tailings disposal[22]

Copper (Cu) pollution has become a global environmental problem due to increasing demand for Cu for multiple uses. Cu enters the marine environment from anthropogenic activities, such as mining and smelting, fish farm activities, disposal of waste and sewage sludge, and leaching of antifouling paints and wood preservatives. While trace amounts of Cu are fundamental for the growth and metabolism of all living organisms due to its central role in a range of enzymes, Cu is toxic to marine organisms at slightly higher levels.

There is increasing pressure for use of the deep sea as a reservoir for Cu mine tailings disposal. Increasing input of Cu through mine tailings disposal to coastal and deep waters, in concert with ocean warming, deoxygenation and acidification may increase the bioavailability and hence toxicity of Cu, with unpredictable consequences not only for the benthic ecosystem but also for pelagic-benthic coupling. Thus, among the most probable effects of massive Cu tailings disposal are: (a) habitat destruction – smothering benthos, (b) acidic slurry increases bioavailability and toxicity, (c) reduction of metal complexation capacity, (d) shift in benthic faunal composition, (e) reduction of biomass and biodiversity, (f) disruption of faunal colonization, and (g) disruption of pelagic-benthic coupling.

Knowledge of Cu effects on marine ecosystems is limited, and information about Cu effects on community dynamics in particular is very hard to obtain in deep water. The same basic taxa are present and the same principles govern sediment assemblages in shallow and deep waters. Thus, it is instructive to draw information about deep-water impacts from studies in shallow marinas where Cu contamination can be severe.

[22] Carlos Neira, Scripps, United States; Collaborators: L.A. Levin, G. Mendoza, M. Porrachia, D. Deheyn, C. Stransky, F. Delgadillo-Hinojosa, A. Zirino.

Figure 36 *Sea mining will pulverize sulphides on the ocean floor*

Through experimental studies, the extent and magnitude of Cu pollution were examined in San Diego Bay (SDB) shallow waters marinas together with the impact of Cu on benthic faunal community structure and biodiversity as well as its effect on initial stages of recolonization. Cu is the most common contaminant due to its extensive use in antifouling paints, especially for recreational boats. Boat paint passively leaches Cu into the water and it ultimately accumulates in sediment through binding and adsorption processes (Zirino et al., 2013). Cu contamination, when evaluated at high spatial resolution, exhibits clear gradients and concentration hotspots linked to boat moorings (Neira et al., 2009), revealing major effects on benthic faunal communities (Neira et al., 2011). Sites with elevated sediment Cu concentrations not only have less diverse macrofauna in sediments (Neira et al., 2014), but also their total macrofaunal biomass and body size were reduced compared to sites with lower Cu (Neira et al., 2011).

Further manipulative experiments using defaunated, Cu-spiked, translocated sediments showed that Cu can influence early stages of recolonization, with reduced biodiversity and lower structural complexity that may last several months (Neira et al., 2015). Cu concentration in animal tissues varies between and within macrofaunal species (from one location) reflecting their distinct sensitivities and tolerances to Cu contamination (Neira et al., 2011; 2014). Results suggest that sediment Cu is the main driver influencing marina benthic faunal communities and also affects metal body burden. However, the picture is complex, as the benthic communities in different adjacent marinas experience varying levels of Cu stress. Defence mechanisms (Zirino et al., 2013) conferred by a stronger complexation capacity, with higher dissolved organic carbon as well as favourable hydrodynamic regime seem to yield a more diverse benthic community.

The ecosystems targeted both for deep-sea mining and deep-sea tailing disposal (placement) largely remain poorly studied in terms of their impact on and recovery of biological communities. There is much to be gained from combining information and expertise from mechanistic studies in shallow and deep water, as fundamental ecological patterns in faunal communities such as lifestyles or feeding modes or benthic faunal colonization processes are similar for shallow and deep waters. Cu effects on infaunal abundance, distributions, biodiversity, species tolerances, and body burden information are potentially relevant for the deep sea where mine tailing can affect larger areas and a wider range of habitats and ecosystems.

4.9 Deep-sea tailings placement: unknowns, secrets, and differing perceptions: a non-industry perspective[23]

Much of the mining industry and scientific community agree that we lack adequate technical information to understand the long-term impacts and risks to marine and terrestrial ecosystems that will result from disposal of metal-mine tailings in deep marine waters. Nevertheless, such tailings disposal is already occurring in several countries, i.e. Papua New Guinea, Indonesia, and Norway. Most of the relevant experience has been gained in only the last 15 years. Decades of experience from tailings disposal in both terrestrial and shallow marine environments show that these wastes are not inert.

[23] Robert E. Moran, Ph.D., Michael-Moran Assoc., LLC; Hydrogeology/Geochemistry, Golden, Colorado, U.S.A.

Gaps in long-term knowledge for deep marine settings are daunting, but the governance weaknesses are more significant. Many governments in developing countries lack adequate technical staff, budgets and political support to effectively oversee land-based tailings disposal operations; oversight of DSTP operations will be much more complex and costly. These countries may have reasonable, relevant regulations, but often lack the political will to enforce them. Mine corporations control the collection and dissemination of most data, and filter what information is made public to society at large, their consultants and regulators. Much is secret and not released to the public, i.e. detailed tailings chemical compositions; other data are inadequately detailed, such as water (especially unfiltered samples) and sediment quality, true baseline data, and water balances. Thus, society often mistrusts the operators, their consultants, regulators, and their reports, as is evidenced by demonstrations and opposition to numerous projects in such locations as Peru, Mexico, Guatemala, and Mongolia.

Industry arguments for investigating and promoting DSTP include: increasing populations and limited available land have increased competition with other users (e.g. cities, agriculture) for disposal sites, and tailings stability concerns due to storms and seismic events. Additional drivers for industry interest in DSTP are likely to include: significant contamination of ground and surface waters; increased competition for scarce fresh water; financial liabilities from perpetual operation of water treatment facilities, collapsed dams, and remediation and maintenance of tailings facilities.

Public trust for DSTP proposals will not develop if relevant studies and reports are not conducted and prepared by experts who are financially and politically independent of the mining industry, and who are allowed to disclose all major, long-term impacts and public costs, many of which are presently hidden.

4.10 The ecosystem diagnostic analyses of the various impacts on the Humboldt Current Large Marine Ecosystem[24]

The Humboldt Current Large Marine Ecosystem (HCLME) covers an area on the southeastern Pacific seaboard from the Ecuador-Peru border in the north to the Chile-Argentina frontier in the south, stretching out to the full extent of the Exclusive Economic Zone (370 km) for both countries – an area of approximately 2.5 million km^2 (Figure 37). The Humboldt Current System (HCS), the area influenced by the Humboldt Current, is usually referred to as being the area related to the seasonal or permanent upwelling areas from approximately 4 to 40° south which bring nutrients to the surface generating high levels of primary productivity 142.8 mg C m^{-2} d^{-1} and approximately 11% of the world's capture fisheries including the single largest fishery, that of the anchovy at an average of 7.2 million mt/year for the last 11 years but currently very much in decline. Due to its rich anchovy stocks, Peru is the world's largest fishmeal producer and exporter which, along with fish oil, provide essential inputs to much of the global finfish aquaculture industry. A study completed by the GEF-UNDP Humboldt project in 2015 has valued the annual delivery of goods and services from the HCLME area at US $19.5 billion and that of the HCS to be US $15.0 billion. However the system's resilience is at risk from a range of anthropogenic factors.

[24] Michael J. Akester, Regional Project Coordinator, GEF-UNDP Humboldt Project.

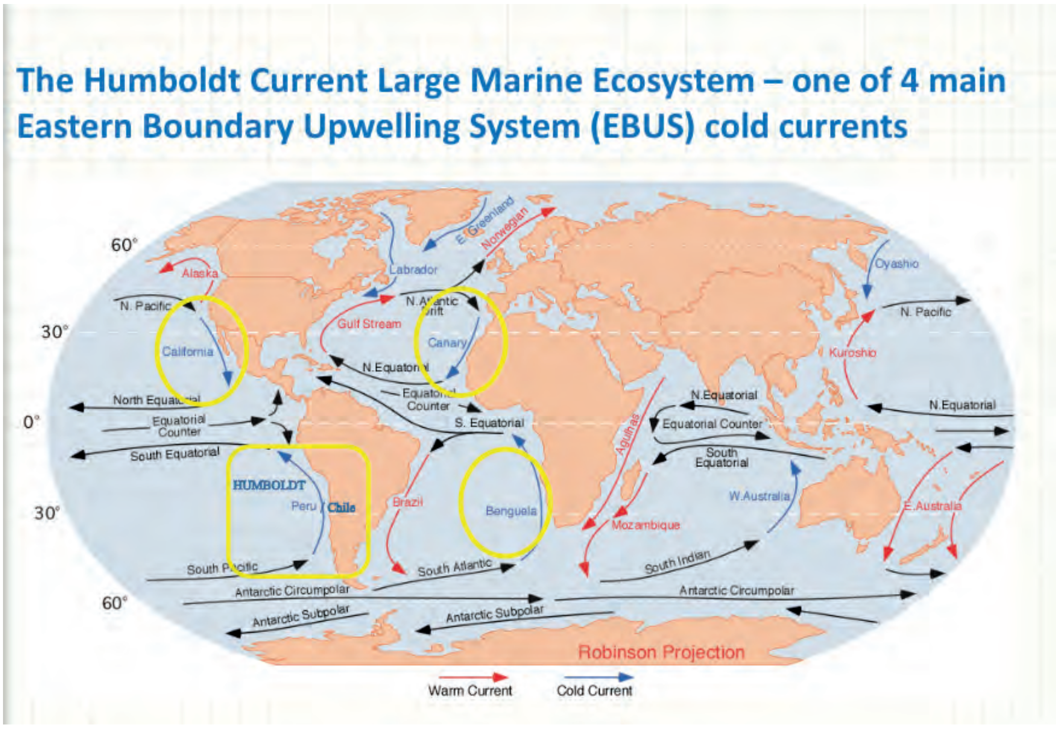

Figure 37 *Humboldt Current Large Marine Ecosystem*

The GEF-UNDP Humboldt Project (2011-2016) carried out a series of modular assessments as shown in Figure 38 (Productivity; Fish & Fisheries; Pollution & Ecosystem Health; Socioeconomic Aspects; and Governance) in both Chile and Peru as the starting point for country level Diagnostic Ecosystem Analyses: see www.humboldt.iwlearn.org. The latter were then combined into a Transboundary Diagnostic Ecosystem Analysis (TDEA), a description of all the negative impacts on the HCS incorporating causal chain analyses to identify the immediate, underlying, and root causes of the main problems.

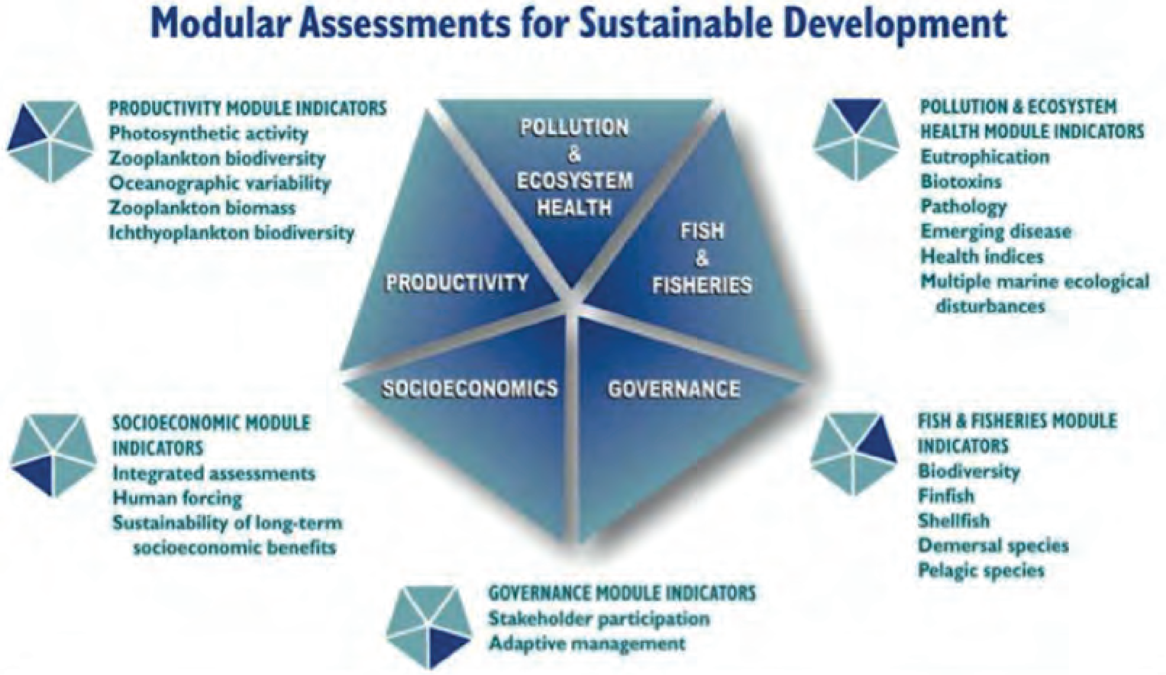

Figure 38 *Assessments for sustainable development*

The Diagnostic Ecosystem Analyses in both Chile and Peru acknowledged anthropogenic alterations of the marine habitat as a significant problem to be addressed at the transboundary level, the main cause being pollution from several sources both domestic and agro-industrial including the mining industry. Both Chile and Peru are mineral rich countries, hence the HCS natural background levels of metals in sediment and solution is often high. Coupled with the fact that the countries are in the world top ten as producers of important heavy metals, there is an increased pollution risk from watersheds discharging to the Pacific. This pollution, combined with pesticides from intensive agriculture and domestic sewage discharges from coastal population concentrations ($>$ 60% of the population live in the coastal zone), has a significant impact on habitat destruction and associated biodiversity loss with potential reductions in the delivery of goods and services from the Large Marine Ecosystem.

Actions to mitigate the root causes of these negative impacts have been assembled in a binational Strategic Action Programme. The Strategic Action Programme vision is: “A healthy, productive and resilient HCLME by means of ecosystem-based management that ensures the conservation and sustainable use of its goods and services for the benefit of the people”.

The Strategic Action Programme has five main objectives as follows:

1. Recover and maintain optimal population levels of the main fishery resources considering the environmental variability while maintaining the health and productivity of the ecosystem;

2. Improve the environmental quality of the coastal marine ecosystem through an integrated management approach while considering the various sources of pollutant;

3. Restore and maintain the habitat and biodiversity of marine and coastal systems to sustainable levels;

4. Diversification of fisheries activities and the creation of new productive opportunities for fisherfolk organized in integrated civil society organizations; and

5. Contribute to the general population’s food security and food safety.

Clearly, pollution from mine tailings has a negative impact on the marine environment and fisheries, biodiversity, employment, food safety and food security within the HCLME. This impact also extends globally as Peru, at the northern end of the HCLME, is the world’s main fishmeal and fish oil producer for the aquaculture industry.

It is equally evident that the prevention of mine tailing contamination in the marine environment is a more cost-effective way of solving the problem than a massive clean-up exercise. The HCLME’s goods and services total economic value is in excess of US $20 billion per annum and this is currently under threat due, in part, to pollution from mine tailings and associated coastal human settlement.

The fulfilment of the Strategic Action Programme’s second objective, to improve the environmental quality of the coastal marine ecosystem, will contribute to the delivery of other objectives in terms of habitat and fisheries' recovery, along with improved food safety, by reducing heavy metals in seawater and marine sediments. To do this, the following will be carried out under the implementation of the Strategic Action Programme:

1. The establishment of a binational coastal–marine pollution monitoring programme, focusing on the main Humboldt Current System pollution sources;

2. The development of pollution control National Action Plans to ensure the maintenance of targeted environmental quality aspects;

3. Improvements in the treatment and disposal of liquid and solid wastes in the coastal zone; and

4. Strengthening of the environmental inspection agencies at local and central levels to allow improved environmental quality objectives to be adhered to.

4.11 Open questions on the flow and mixing of hyperconcentrated, cohesive gravity currents[25]

Hyperpycnal flows are defined as subaqueous sediment-transporting density flows where the solid-liquid ensemble is heavier than the ambient where the discharge takes place (Mulder & Alexander, 2001). They were first reported in the late 19th century, and are commonly found in lakes and the ocean (Mulder et al., 2003). A special class, and comparatively less studied related flow, are lofting gravity flows (also referred to herein as lofting flows). They are particle-laden gravity currents, where a density inversion by interstitial fluid lower in density than the ambient occurs, enabling the possibility of a flow separation via plume detachment. They were first identified in the literature as effects of volcanic eruptions, and their distinctive mechanism is the decrease of the bulk density of the discharged particle-laden mixture, until the equivalent mixture becomes buoyant. Then, a buoyancy-induced plume, either of saline concentration or thermal nature, emerges with the capacity to transport sediment and heat through the water column (Turner, 1973).

This plume detachment has already been identified in the literature as a source of contamination in submarine tailing discharges (e.g. Lottermoser, 2010). Unlike the aforementioned natural processes, these man-made discharges feature comminution products, fine mineral and chemical species which are not naturally liberated in natural sediments. In ore sulphide processing especially, they include chemical additives from the flotation and the thickening stages, which give particular characteristics to the lofting mechanism. From a purely hydrodynamic standpoint, to assess the potential for mixing – and thus contamination – of these discharges, the complex dynamics of tailing settling, plume detachment and subsequent settling needs to be understood in light of the interplay between the tailings physicochemistry and rheological characteristics and the ambient water conditions, including their chemistry and flow (Figure 39).

[25] Christian Ihle, Universidad De Chile, Mining Engineering Department & Civil Engineering Department; Yarko Niño, Universidad De Chile, Civil Engineering Department & Advanced Mining Technology Center.

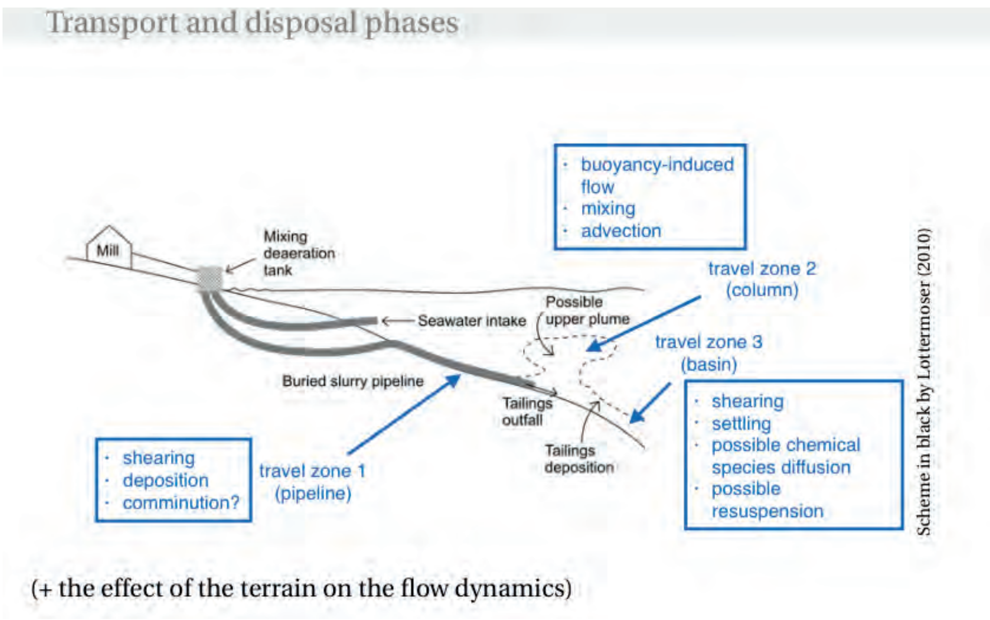

Figure 39 *Flow dynamics of transport and disposal phases*

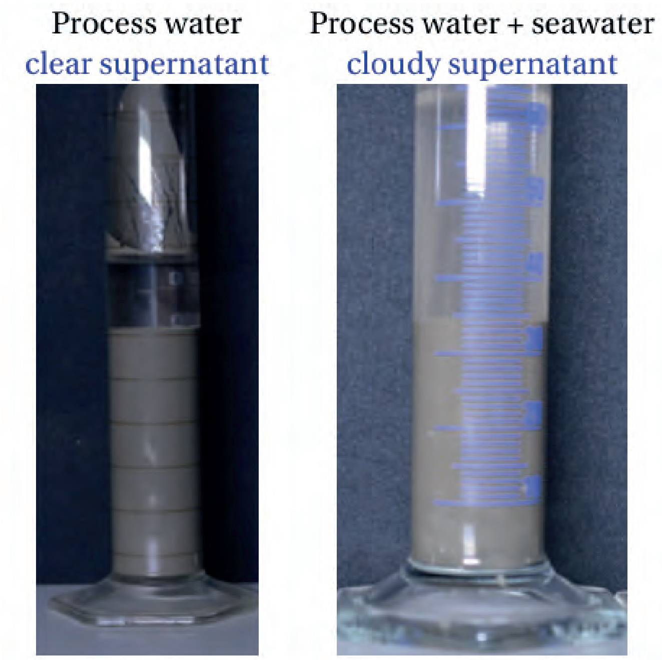

Figure 40 *The impact of seawater on settling of magnetite tailings*

The effect of the presence of additives such as frothers and flocculants may have a number of adverse effects, ranging from toxicological issues to their potential to hinder the settling process. They may also interact with seawater and their effect on discharged solids may be significantly affected, besides shear and local concentration, by the ambient pressure at discharge points, which might be significantly high. The interplay between chemistry and hydrodynamics on the effect of discharges on the spatiotemporal distribution of contaminants extends not only to settling but also to resuspension. Ambient currents and seismicity, which are strongly local, may induce resuspension processes, whose characteristics depend on the consolidation of tailings which, again, depends on the short- and long-term chemical stability of the settled flocs (Figure 40).

In particular, there is a significant knowledge gap pertaining to flocculant ageing at moderate to high pressures and their impact on the flow stability.

Submarine tailings discharges, and especially those at the deep sea, inherit a several-hour trajectory in pipelines, exerting particular conditions on the turbulence and, in particular, the shearing of these slurries. Industry-standard hydraulic transport systems are designed to optimize the hydraulic transport of solids (e.g. to minimize the risk of plug formation). To the knowledge of the author, there is no established knowledge to identify transport conditions suited to minimize the impact of discharges. For a given solids throughput, such transport conditions include solids concentration, additive dosing and pH control according to the mineralogical characteristics of the tailings. As there is a known relation between surface chemistry, concentration and the rheology of clays present in the tailings (e.g. Zhou et al., 2001), the consequences of suitable transport conditions on the final disposal and plume detachment at the sea bottom are yet unknown. The process conditions of massive tailings discharge facilities in some countries may relate to maximal particle settling and minimal plume detachment with prohibitive amounts of fresh water. To the knowledge of the author, this is also an unexplored topic.

These elements may be summarized in the following questions:

- How are tailings rheology, floc formation and subsequent settling affected by seawater?
- Is it possible to anticipate the features of aggregate distribution after (potentially long) pipeline transport?
- What are the short-term and long-term mechanical and physico-chemical responses of deposited tailings (consolidation, floc integrity, etc.)?
- What is the effect of pressure on the aforementioned elements?
- Is it possible to eliminate plume formation considering other constraints? How?
- (If not) what is the relation between aggregate formation and plume features?
- What would be the fate of plumes and suspended sediment in light of background currents? What are the local spatiotemporal effects (basin/upper ocean temporal forcing, seismicity)?

Added to these elements is the technological gap, including the ability to monitor operations reliably at such salinity and depth conditions and respond to contingencies including plugs and leaks at significant depths.

5 EXISTING REGULATORY (BEST) PRACTICES

5.1 International framework: disposal of wastes at sea[26]

The Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter, 1972 (London Convention) and its updated version, the *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter, 1972* (London Protocol) are the primary international instruments to protect the world's oceans from pollution. See Figures 41 and 42, below.

Dumping at sea is "any deliberate disposal into the sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures." It includes storage of wastes in the seabed, abandonment or toppling at a site of platforms, industrial waste, and incineration at sea. Wastes from exploitation/processing of seabed resources are excluded, and that includes deep-sea mining.

Figures 41 *Publication available at www.imo.org on the specific provisions of the London Convention and Protocol*

Dumping does not include operational discharges from vessels or offshore installations, pipeline discharges from coasts or cities, wastes discharged into rivers and out to sea, or placement of matter for a purpose other than disposal. Discharges of mine tailings into marine waters are not "dumping" and therefore not under the direct jurisdiction of the London Convention or Protocol, except for the overall objective of protecting the marine environment from all sources of pollution.

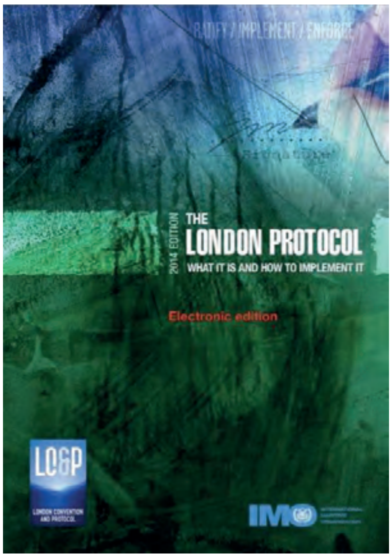

Figure 42 *Publication available at www.imo.org on The London Protocol, What it is and How to Implement it*

Parties to the London Convention and Protocol are to take effective measures, according to their scientific, technical, and economic capabilities, to prevent, reduce and where practicable eliminate marine pollution caused by dumping of wastes into the sea. Applications to dump wastes into marine waters are to demonstrate appropriate consideration of a hierarchy of waste management options:

- Reuse;
- Off-site recycling;
- Destruction of hazardous constituents;
- Treatment to reduce or remove hazardous constituents;
- Disposal on land, into air and into water;
- Can the waste or other matter be made acceptable for disposal at sea? and
- The practical availability of other means of disposal (land, air) should be considered in the light of a comparative risk assessment involving both dumping and the alternatives.

Concern has been expressed by Parties to the London Convention and Protocol and by UNEP-GPA regarding the adverse impacts upon marine waters from marine and riverine discharge of mine tailings. The objective of the two conventions is control of wastes and other matter that is dumped from vessels into marine waters; the overall objective of the London Convention and the London Protocol is to protect and preserve the marine environment from all sources of pollution. The objective of UNEP Global Programme of Action is the protection of the marine environment from land-based activities.

[26] Edward Kleverlaan, Head, Office for the London Convention/Protocol and Ocean Affairs (OLCP&OA), IMO.

Parties to the London Convention and Protocol (Figure 43) are in agreement that there is a need for a comprehensive, global understanding of the issue, and that international guidance and/or codes of conduct could be developed on environmental management of marine disposal of mine wastes in order to protect the marine environment. Other interested entities include UNEP, IAEA, UNDP, UNIDO, and UNESCO-IOC. GESAMP concluded that it warrants attention, and this workshop is the first step by GESAMP to undertake a global assessment to produce a UN-wide view of marine disposal of mine-tailings. The initial effort would be assessment of the impacts of mine tailings discharges into marine waters and an identification of the gaps in scientific understanding. That effort would inform the policy discussion regarding the development of international guidance or best management practices.

Figure 43 *Parties to the London Convention and Protocol in plenary session at IMO Headquarters in London, England*

5.2 Current approaches, limitations and future needs in DSTP risk assessment: experiences from the Ramu Nickel challenge in Papua New Guinea[27]

Introduction

Mining makes an important contribution to the economy of many developing tropical regions. Many mines in these regions have island geographies and tend to look at the marine environment as a depository for mine waste. The risk of pollution from Deep-sea Tailings Placement (DSTP) in the Coral Triangle region (a global hotspot of biodiversity) is unprecedented. Experience shows that this method of tailings disposal can have unexpected consequences for the environment and for local communities near discharge sites. Furthermore, in the case of Ramu Nickel in Papua New Guinea (PNG), the DSTP discharge site is far removed from the mine site where positive benefits to the economies of communities are most prevalent. Local coastal communities have the potential to be burdened with much of the risk but few benefits of such mining and waste disposal operations. Figure 44 shows the Ramu Nickel processing facility.

The Ramu Nickel Story

Since 1999, the proposal for DSTP had been controversial with reports highlighting concerns particularly with El Niño/La Niña induced upwelling that occurs on decadal cycles and potential risks from upwelling hard to determine through current risk assessment practices. Indeed, the original Department of Conservation approval in 2000 was contingent upon:

> *"…the results of further oceanographic studies to determine, with great accuracy, the base of oceanic upwelling in the vicinity of the DSTP outfall at Basamuk and a recommendation on whether the proposed depth of the DSTP outfall should be varied."*

Later in 2000, the Evangelical Lutheran Church of PNG commissioned the Minerals Policy Institute to undertake an independent review of aspects of the Ramu Nickel Environmental Plan 1999. The fundamental finding was:

> *"there can be no doubt that disturbance on the scale of a Submarine Tailings Disposal operation will have significant biological impact."*

[27] Amanda Reichelt-Brushett, Marine Ecology Research Centre, Southern Cross University, Lismore NSW, Australia 2480.

Figure 44 *Ramu Nickel in Papua New Guinea. Credit: www.ramunico.com*

Despite further oceanographic studies never being completed, and the mine operation being sold to a Chinese consortium in 2007, the Director of the Environment issued an Environmental Permit which allowed the construction of infrastructure and disposal of waste to the ocean. This resulted in a massive community outcry and in 2008 the Papua New Guinea Government commissioned a review of DSTP in PNG from the Scottish Association of Marine Science with financial support from the 8th European Development Funding Initiative. Furthermore, the ecotoxicological test methods used to assess the risk of contamination and toxicity associated with DSTP were limited and lacked relevance to the ecosystems at risk. Ecotoxicity testing is a tool used in the multiple lines of evidence approach to assessing risk. Over the approval cycle for the Ramu Nickel DSTP, several sets of toxicity test were completed (1998, 2007, 2008). None were on deep-sea species because these test methods had not yet been developed and few were on species found in the tropics. Furthermore, test temperatures were not relevant to tropical deep water or tropical shallow waters. The extent of the limitation is summarized below.

- All tests either 0.45µm or 0.22µm filtered slurries.
- All tests $<$ 72-hour exposure time.
- All test temperatures 14-21˚C.
- All static (no static renewal or flow through).
- Sample integrity compromised in some studies (transport of filtrates) resulted in loss of dissolved contaminated load probably through adsorption to the wall of storage containers.
- No sediment or pore water toxicity tests were ever completed even though these were recommended in sub-consultant reports.
- No tests were completed on elutriates or fines associated with plumes and plume sheering.

In 2010, legal action was taken by 1,085 landowners (Figure 45) to grant a permanent injunction to prevent a deep-sea tailing programme in the Bismark Sea.

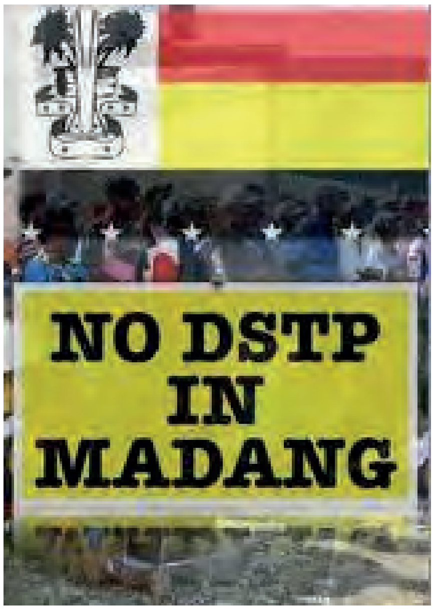

Figure 45 *Protests over the proposed DSTP in Madang*

The case was lost in 2011 although it was noted by the presiding judge, His Honour Mr. Justice David Cannings, that:

> *"likely serious environmental harm to the Astrolabe Bay and the plaintiffs are coastal people who depend on the sea for maintenance of their livelihood and way of life.*
>
> *I therefore feel obliged to state that my considered opinion as a Judge, having heard extensive evidence on the likely environmental effect of the DSTP and made findings of fact on that subject, is that the approval of the DSTP and its operation has been and will be contrary to National Goal No 4.*

It amounts to an abuse and depletion of Papua New Guinea's natural resources and environment – not their conservation – for the collective benefit of the People of Papua New Guinea and for the benefit of future generations, to discharge into a near-pristine sea (a widely recognized hotspot of biodiversity), mine tailings at a rate of 5 million tonnes of solids and 58.9 million cubic metres of tailings liquor per year.

It constitutes unwise use of our natural resources and environment, particularly in and on the seabed and in the sea.

It amounts to a breach of our duty of trust for future generations for this to happen. It is a course of action that shows deafness to the call of the People through Directive Principle 4(2) to conserve and replenish our sacred and scenic marine environment in Astrolabe Bay.

It puts other coastal waters of Madang Province at risk. Inadequate protection has been given to our valued fish and other marine organisms."

Clearly legal challenges or frameworks, such as the UNEP or the London Convention and Protocol, are limited in their ability to manage or applicability to DSTP.

Current Status Ramu NiCo

In 2011, tailing disposal into the ocean commenced. The 135 km slurry pipeline crosses many unstable slopes travelling from the mine site to the shore of Astrolabe Bay (Wang and Shou, n.d.). The DSTP waste pipe extends 450 m from shore to the 150 m isobath where the slopes are fairly gentle: about 12° or less (Figure 46). The tailings current is expected to continuously flow to the bottom of the Basumuk Canyon at 1500 m depth (Wang and Shou, n.d.). Basamuk Canyon is located 40 km due SE of Madang, PNG, at the eastern side of Astrolabe Bay. Environmental assessment is conducted annually. Recent studies by Dr. Mana at the University of Papua New Guinea as part of the MADEEP 2014 deep-sea cruise in Basamuk Bay showed that red tailings were found in four canyons far exceeding the predicted deposition area. The highest density of red tailings in the water column was found at 560 m and in suspension.

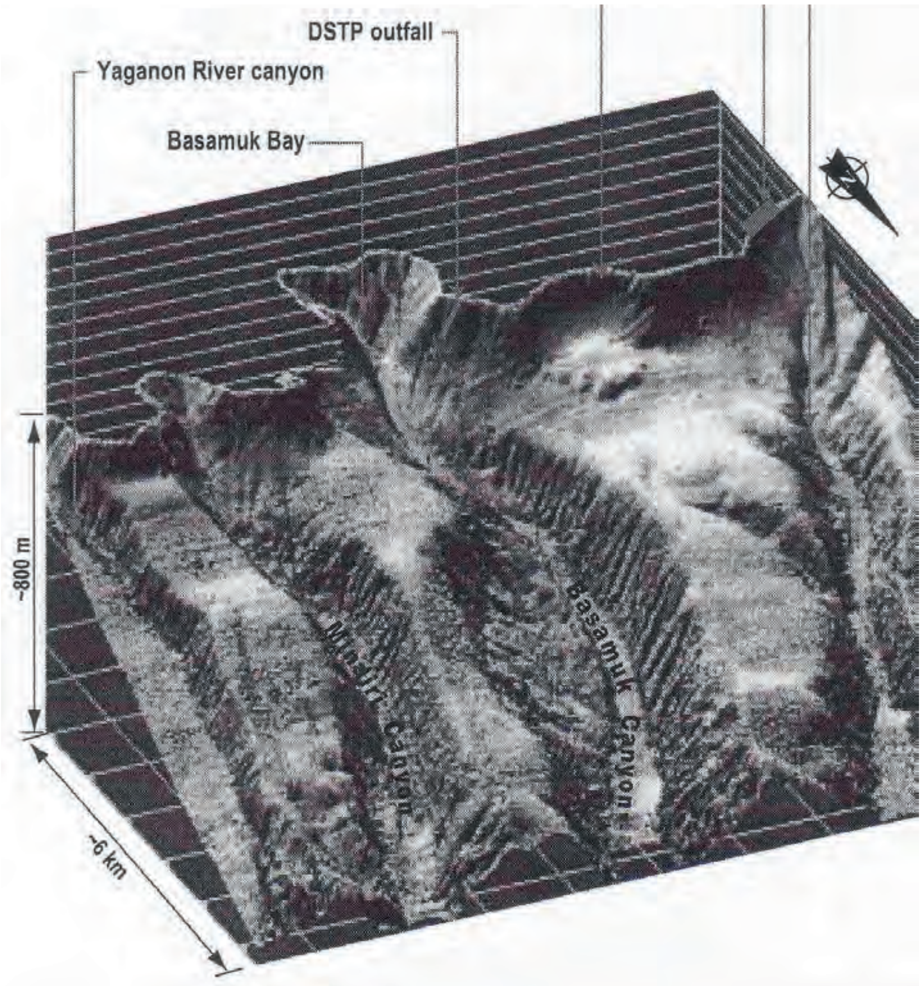

Figure 46 *Ramu Nickel DSTP and impacted submarine canyons*

The joint venture (Ramu NiCo) in 2014, reported its first operating cash surplus of US $44 million, after capital expenditure of US $23 million. In 2015, throughput is expected to increase to 83%, and reach full capacity in 2016.

Risk assessment limitations for DSTP

Much of the following text refers to Reichelt-Brushett (2012) and further context can be gained from reading this publication.

Below ordinary SCUBA diver depths (~40 m), understanding of the impacts of pollution and sedimentation is minimal (e.g. Madin et al, 2004). Understanding of even shallow water systems is limited by logistics, accessibility and funding. While some efforts are being made to develop standard ecotoxicological test species for tropical marine environments (e.g. Lee et al., 2007; Codi King et al., 2008; Stauber et al., 2008; Howe et al., 2012, 2014a, 2014b, 2014c) few studies have considered deep-sea organisms as test species for ecotoxicology (e.g. Black et al., 2015) noting however that questions of effects of temperature and pressure have been explored to some degree (e.g. Cottin et al., 2012; Morris et al., 2015).

The ecosystems at risk during DSTP can be misrepresented as much focus is placed on the expected final resting place of the tailing rather than the continuum of impact down the continental slope and potential impact of tailings transport from upwelling into naturally very clear waters. There is a lack of recognition of the biodiversity and uniqueness of the continental slope; notably there are abundant invertebrates, for every hour of sampling effort, seven new species of fish are found, and new behaviours and new ecology have been discovered in the Rebreather Zone (50-250 m) (Pyle, 2000-2001).

The suggestion that active earthquake areas around PNG create a high risk of dam failure for tailings storage on land is often used as a reason to support DSTP but this argument is also relevant to the risk of underwater earthquakes and tailings redistribution throughout the marine environment. This highlights the importance of understanding the interactions between deeper waters and shallow water environments. Enhanced turbidity is of particular concern in coral reef environments where even small changes in turbidity can reduce coral health and the complexity of coral communities.

When the toxicity of contaminants on organisms is investigated, consideration should not only be made of the concentrations that have lethal consequences but also concentrations of pollutants that can cause the dysfunction of important developmental stages of organisms including fertilization, larval development, metamorphosis, settlement, reproduction, symbiosis, growth and behaviour. If these developmental stages are interrupted in a particular species, then the species itself will have a limited future.

Very little is known about trace metal concentrations in deep-sea organisms and their responses to changes in environmental conditions (Koschinsky et al., 2003). Bioaccumulation studies on deep-sea organisms are hampered by the limited taxonomic information, limited understanding of the relevance of various uptake pathways, costs, logistics and resources. Bioaccumulation in marine biota is of serious concern and has been found to occur with terrestrially derived organic compounds in deep-sea cephalopods (Unger et al., 2008) and deep-sea fish species (Mormede and Davies, 2003; and Storelli et al., 2007).

Conclusions and Recommendations

Risk assessment of DSTP proposals is limited by current methodologies that do not always translate to a realistic assessment of risk specific to deep-sea environments. Nor do they account for the lack of ability to manage the risk of failure. The physicality of large volumes of solid materials being uncontrollably redistributed in the marine environment is of concern, and evidence from the Ramu Nickel experience suggests that the extent of dispersal is hard to predict.

Assessment practices are often limited by budgets and timeframes, and the development of relevant risk assessment methods can be limited. Alternative approaches to tailings disposal, such as paste production, should be seriously considered but are often presented as uneconomical, yet reported mine profits suggest otherwise. As part of the current framework for risk assessment, there is no allowance for considering impacts from multiple mines or impacts from multiple stressors from a single mine. Such a challenge can be noted for all manner of waste disposal activities and has resulted in major environmental damage (e.g. degradation of river systems through inputs from catchment activities).

Future ecotoxological considerations require (see also Reichelt-Brushett, 2012):

- Development of standard sediment and aquatic toxicity tests using species from deeper water;
- Use of the established methods to compare with new and relevant ones;
- Use of suitable test temperatures;
- Tests on different exposure pathways need to be understood;
- Development of tests on how to assess the impacts of fines (particularly in clear oligotrophic waters);
- Challenges of dealing with pressure in toxicity tests to be resolved;
- Expansion of taxonomic range of test species; and
- Inclusion of chronic studies with variable exposure regimes/scenarios.

On a final note, managing the lifecycle of resources is now a relatively common practice for extractive industries, and in this scheme reuse can become part of the economic viability of an industry (e.g. Schiels and Ellis, 2008). The lifecycle management of wastes, including tailings, should also be considered a priority. In the past, tailings have been reworked when new extractive technologies become available. If DSTP is used, then there is very limited capacity to re-mine the tailings.

5.3 Environmental impact assessment, permitting and monitoring process for DSTP in Indonesia: the Batu Hijau Project[28]

The Batu Hijau copper/gold mine, operated by PT Newmont Nusa Tenggara, is located in the south-western part of Sumbawa Island, Indonesia. The mine operates at ~450 m above sea level, and ~10 km from the South Coast. The ores mined contain an average of 0.53% copper and 0.4 per ton (g/t) gold. The mine processes approximately 130,000 tons of ore per day and became fully operational by the year 2000. Tailings management at the mine includes a deep-sea tailings placement (DSTP) system that discharges tailings through a pipeline via an outfall located at a depth of 125 m at the head of the submarine Senunu Canyon (Figure 47).

[28] Stuart Simpson (CSIRO) and Jorina Waworuntu (PT Newmont Nusa Tenggara).

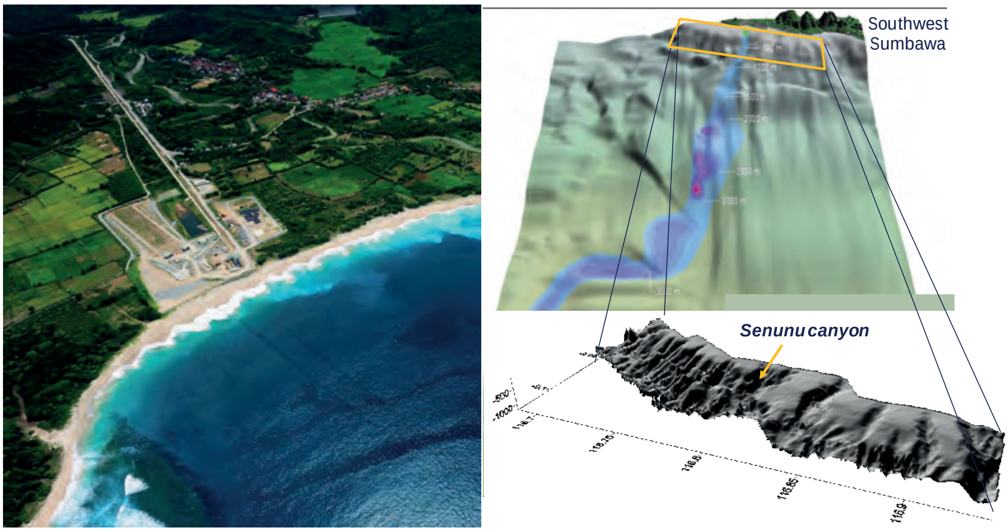

Figure 47 *Batu Hijau Project, Sumbawa, Indonesia: Deep Sea Tailings Placement (DSTP) at the head of Senunu Canyon at 125 m depth, which leads into the Lombok Basin at 3,000-4,000 m depth*

The environmental impact assessment undertaken prior to approval of DSTP evaluated both on-land tailing storage facility (TSF) and DSTP options for tailings management. On-land impacts were predicted to 2,300 ha of forest and agricultural land, and potentially require relocation of > 2,000 people from their communities. A high average annual rainfall (> 2,500 mm) and likelihood of earthquakes would make water management for TSFs challenging, creating a long-term risk of failure. Management of acid-rock drainage would be important, both ongoing and post-closure. Together with the negative attributes associated with TSF options, the final choice of DSTP was influenced by the close proximity of the deep submarine canyon near the mine. The Batu Hijau mine is one of the larger examples of DSTP in the world and deposits tailings at the greatest depth. The depth of the main canyon increases by approximately 1,000 m within 10 km of the coast, to > 2,000 m within 20 km of the coast, and to > 3,000 m approximately 50 km of the coast.

The DTSP at Batu Hijau must comply with an Environment Management Plan and Environment Monitoring Plan of Permit Stipulation that approved its commencement in 2000, and was updated in 2010 and 2015. The environmental management objectives were to avoid impacts to highly productive components of the ecosystem, such as coral reefs, mangroves, surface waters and fisheries, and confinement of impacts to areas of low biological productivity. In the vicinity of the DSTP outfall and within the Senunu Canyon, the management plan predicted significant adverse impacts from the DSTP on the marine ecosystem in the form of: (i) reduction in seawater quality due to elevated turbidity and dissolved copper concentrations, (ii) burial of benthic organisms, and (iii) a reduced habitat for demersal fish. Recovery of the pelagic and benthic ecosystem to pre-operating conditions was predicted in the plan to occur during the first two years after operations cease.

Since before DSTP and over the past 15 years of operation, a range of monitoring programmes has been in effect, with the intention of verifying that the DTSP does not affect inter-tidal ecology and sub-tidal coral reefs of the coastal areas and the productive shallow waters. The monitoring has included tailings volume and physical and chemical characteristics of the solid and liquid fractions (all daily), and other aspects that may affect tailings quality (weekly and monthly).

Monitoring of the coastal environment in the area of tailings placement and the affected areas includes CTD profiles of the seawater column (monthly), seawater and sediment quality (three-monthly), and various components of the marine ecosystem (plankton community and benthos, inter-tidal ecosystems, coral reef fish community, sub-tidal corals, and fish, including metal accumulation in some of these organisms) (six- or 12-monthly). Figure 48 shows leachate testing on tailings and liquid toxicity testing on tailings. Numerous technical supporting and validation studies have been conducted to assess and continuously improve the performance of the system, including deep-sea studies (tracking the tailings footprint and refining models, water column suspended solids), Due diligence studies (to independently verify compliance with permits and evaluate new monitoring objectives), and various highly specialized studies (e.g. tailings recolonization and managing variability associated with tailings properties that influence dissolved copper release).

Figure 48 *Toxicity testing on mine tailings at Batu Hijau*

Monitoring and supporting studies confirm that the environmental management objectives are being met, and the majority of the tailings deposition is observed to occur at depths greater than 3,000 m and at 50 to 100 km from the coast. The tailings sedimentation area is larger than that predicted at the time of commencement, with the main tailings footprint being observed further to the east than predicted, but not above 1,000 m depth. Tailings plumes are regularly observed, particularly near the bottom of Senunu Canyon, and remain below 120 m depth and disperse within the deeper waters (Figure 49). There are no indications of significant impacts on the pelagic ecosystems, with light transmission within the surface water layers remaining high, chlorophyll concentrations in the range consistent with typical phytoplankton populations, and metal concentrations in tissues of demersal fish and filter-feeding organisms with the coastal zone being similar to reference sites. To some extent, the tailings deposition has impacts on the macrobenthic and meiobenthic populations, and this was predicted in the management plan.

Overall, the monitoring and supporting studies are providing excellent information on the DSTP operation and risks posed, and continued improvements are being made to the scope of the monitoring programme and methods for assessing the broader DSTP footprint within the environment.

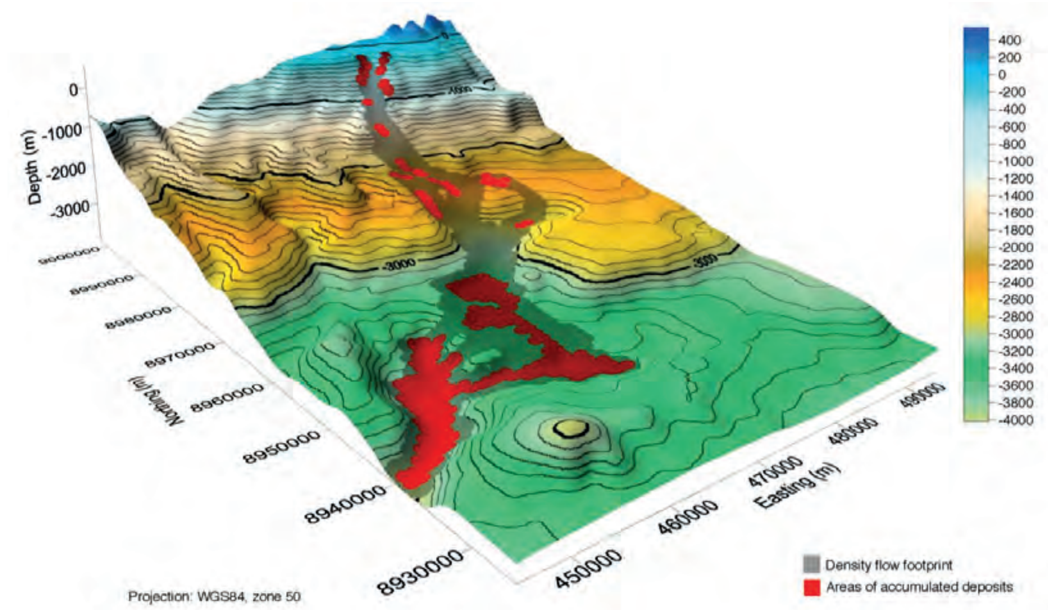

Figure 49 *The density flow current of mine tailings is in dark grey, and the areas of accumulated deposits are shown in red*

The Batu Hijau DSTP continues to be evaluated against objectives that are intended: (i) to ensure that the tailings flow down the canyon and away from the coast and that the tailings are confined below both the surface mixed layer and photic zone; (ii) to ensure there will be no impact to the biologically active near-surface zone and no impact to coral reefs, beaches or other coastal attributes; (iii) to avoid impacts on commercial and subsistence fisheries; and (iv) to confine the impacts to areas of very low biological activity. With active mining due to be completed within 15 to 20 years, environmental studies are increasingly being directed towards optimizing the closure criteria and final site management plans. This includes processing and/or remediation of stockpiles of lower-grade ores, closure of the DSTP, management of the mine pit and site waters, and various forms of in situ rehabilitation. Government and stakeholders (community and scientific experts) participate in inspections and review routine monitoring data and supporting studies.

5.4 Deep sea tailings placement in Papua New Guinea, environmental impact assessment, monitoring and regulation[29]

Papua New Guinea (PNG) is a mineral dependent economy. In 2009, PNG mines produced 63 tonnes of gold, 154,000 tonnes of copper and 75 tonnes of silver to contribute K7.5 billion to the PNG economy which represented 62% of PNG's total export receipts in that year.

PNG's aim is to promote a healthy and sustainable mineral industry and provide a regulatory environment that maximizes mining opportunities and minimizes impact on the environment to ensure optimum benefits for the people of PNG.

Deep Sea Tailings Placement (DTSP) has been used as a waste option in a number of countries worldwide and lately there has been a drive to gather more relevant scientific information of the impact of DSTP on the marine environment of PNG. This information has led to the development of new guidelines in PNG (Figure 50) for the use of DSTP. The increase in understanding of the effects of anthropogenic disturbance on the deep ocean and developing regulations which have been obtained from the study of DSTP and the advancement of smart observation technology is also applicable to sea-bed mining.

[29] Tracy Shimmield, Managing Director, SAMS Research Services Ltd (SAMS—Scottish Association for Marine Science).

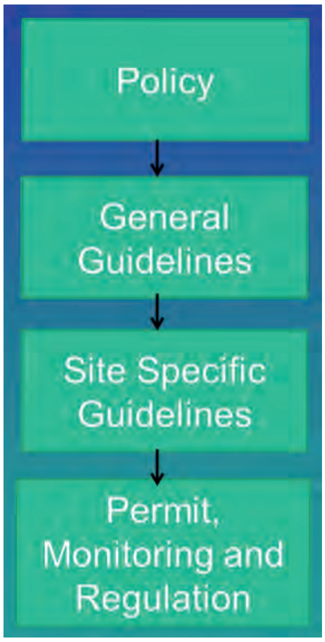

Figure 50 *Following country policies, the general guidelines should be used to determine whether DSTP is a feasible option. If so, then site specific guidelines should be used as the basis of development, and once the EIA is completed, then permit conditions can be established*

In the context of international best practice, the general guidelines for the use of DSTP should consider an examination of:

1. Initial mine planning/development;
2. Mining operations, including monitoring;
3. Future mine closure plans; and
4. Post-mining monitoring.

The main aim of the guidelines should be to minimize the impact on the marine environment while achieving sustainable resource development.

Specific guidelines for each mine site should consider:

- The ore being mined;
- The processes and chemicals used;
- The physical and chemical constituents of the tailings;
- The amount of tailings being discharged;
- The physical oceanography of the marine environment into which the tailings will be discharged;
- The bathymetry of the marine environment into which the tailings will be discharged;
- The biodiversity of the marine environment into which the tailings will be discharged;
- The land to ocean transfer that takes place, i.e. is there a large fresh water and sediment input to the area;
- The fishing activity that takes place in the sea surrounding the mine;
- The social, economic and cultural activities that may be affected by the discharge; and
- The integrity of the discharge pipe and mixing tank including the consideration of the engineering required together with emergency contingency plans.

In addition the guidelines and legislation pertaining to DSTP will be pertinent to deep-sea bed mining and the operation and environmental monitoring plans must be developed to ensure that there is sufficient and timely monitoring of the near and far field areas affected by such operations.

5.5 Granting the permit for a rutile mine with tailings placed in a fjord[30]

A permit pursuant to the Pollution Control Act for a new rutile mine (TiO2) on the west coast of Norway was issued by the Ministry of Climate and Environment on 5 June 2015. The permitting process started in 2008.

Before the permit could be granted, the company Nordic Mining needed approval from the municipalities involved for a zoning plan, including both the land-based activities and the placement of tailings in the Førdefjord. An environmental impact assessment (EIA) pursuant to the Planning and Building Act was prepared and the company applied for a permit pursuant to the Pollution Control Act.

Before activities can start, the company also needs an approval from The Directorate of Mining based on the Minerals Act, and a permit from the Norwegian Water Resources and Energy Directorate for the use of fresh water.

The project plan and EIA/applications process

The company has estimated an annual production of 100,000 tons of rutile concentrate and 100,000 tons of garnet for a period of approximately 50 years. The production will lead to a total of 35 million tons of waste rock and 250 million tons of tailings. They will place the waste rock in a land deposit and the tailings in a fjord at a depth of approximately 300 metres. The fjord deposit will cover an area of 3 km^2 and reach an elevation of a maximum 150 metres from the seabed.

The EIA was finalized in 2009. In 2010, the Directorate of Fisheries raised a formal objection to the zoning plan, based on possible effects on the ecosystem from the planned tailings disposal in the fjord.

Key elements in the application process

In addition to the effects from planned land-based activities, effects on the fjord system were crucial. To be able to assess these effects, properties of the tailings and the process chemicals were examined. Due to the objection from the Directorate of Fisheries, the company undertook further surveys on the marine biodiversity.

To be able to predict possible drift of particles from the tailings disposal, the company engaged contractors to conduct extensive studies of currents in the fjord. The contractors also carried out modelling of the currents and expected spreading of particles.

Furthermore, alternatives to the planned marine disposal were considered. These alternatives were respectively a large dam deposit or placement in a freshwater lake. Alternative use of tailings for other purposes and the use of backfilling has also been discussed (Figure 51).

[30] Harald Sørby, Norwegian Environment Agency; Glenn Storbråten, Norwegian Environment Agency.

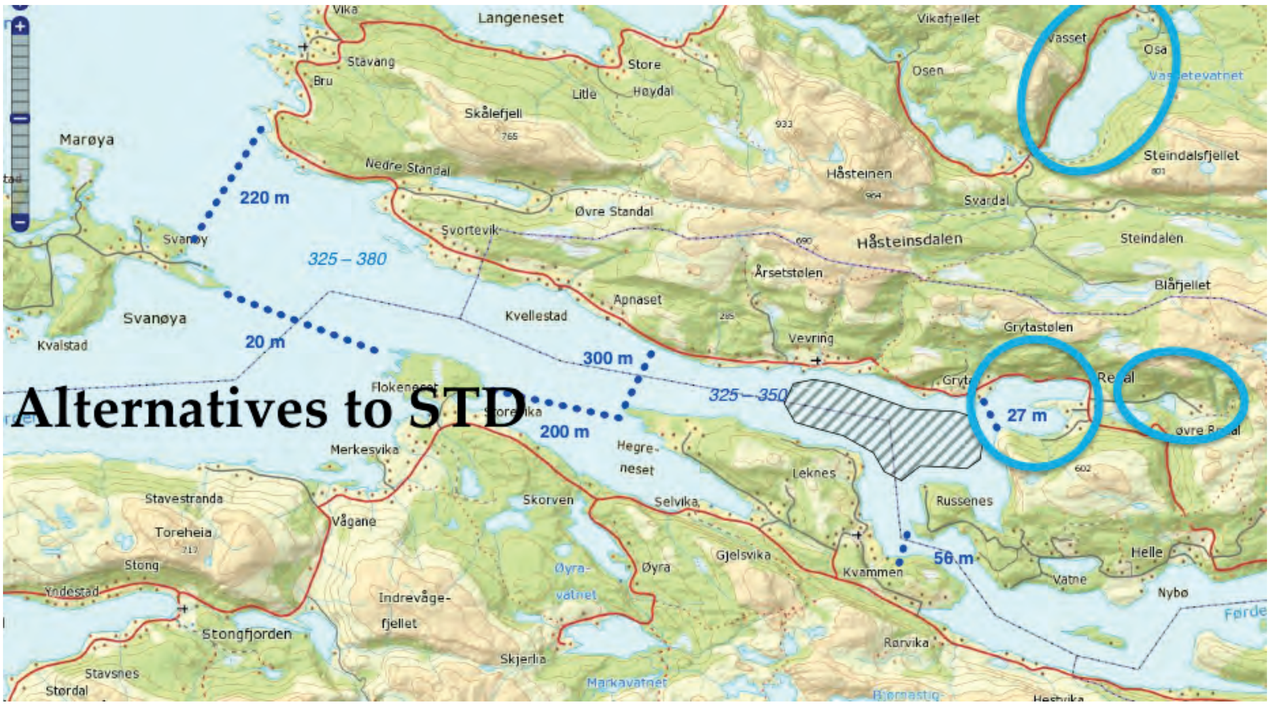

Figure 51 *The hashed area is the selected STP site. The circles show the other alternatives considered for placement*

Marine biodiversity

Tailings will smother 3 km^2 of the seabed and the bottom-dwelling organisms in this area (Figure 52). The bottom habitat will become physically altered. From being a flat bottom with a relatively steep wall as a result of glacial erosion, this part of the fjord will have a slope of 5°. At the highest point, the deposit will elevate the bottom of the fjord by approximately 150 metres.

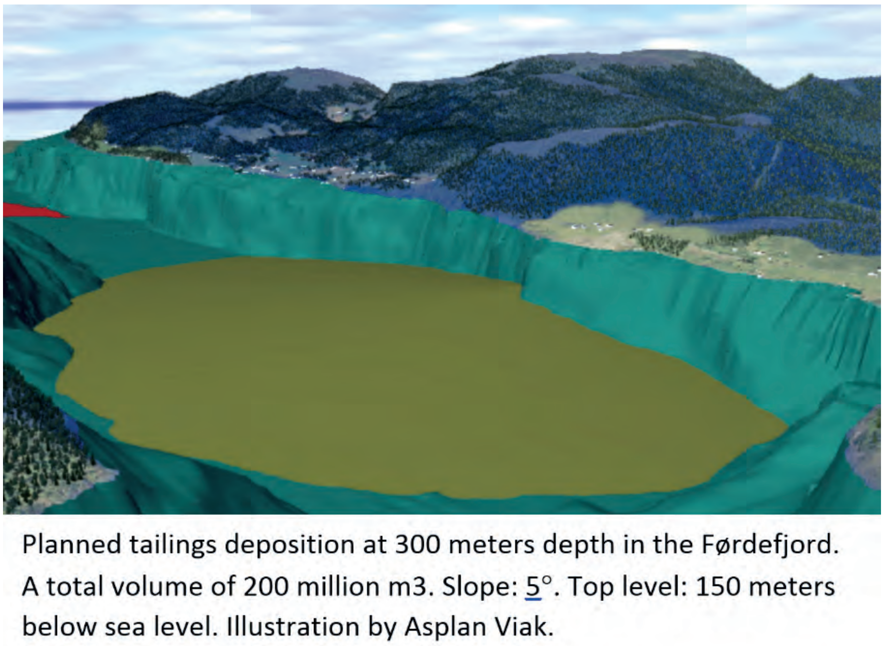

Figure 52 *Placement of tailings in the Førdefjord by rutile mine*

The fact that there is a lack of knowledge about marine biodiversity is challenging. When assessing the impact of sea disposal of the tailings, particular attention was paid to four endangered species found in the area. Blue ling (Molva dypterygia), spurdog (Squalus acanthias), European eel (Anguilla anguilla) and rose fish (Sebastes norvegicus) are all found in the vicinity of the planned deposit. We have considered the effect of the STD for these species in light of the preservation of the species and the risk of extinction. Our conclusions are that the effect on the local population is negative, but the effect on the population in a national and global context will be marginal. In addition to focusing on these species, we have assessed the potential impact on Atlantic salmon (Salmo salar) and the local population of cod (Gadus morhua). In our view, it is not very likely that these species will be directly affected, but unintentional spreading of fine particles in the fjord may cause problems.

Permit conditions

The permit conditions include concentration limits for particles in the fjord. These limits apply at the border of the deposit area and shall ensure that spreading outside the deposit area is minimized so that negative effects of the tailings deposition are kept at a minimum. The concentration of particles shall not exceed 2 mg/l 40 metres above the point of discharge and 3 mg/l at the edge of the planned disposal area. Deposition of particles (sedimentation rate) is limited to 3 mm per year at the edge of the disposal area. To provide information on the effects of deposition, the permit also includes a requirement to monitor before, during, and after tailings deposition.

Conclusion

Issuing a permit pursuant to the Pollution Control Act is based on an integrated approach. Hence, the permit is based on an evaluation of environmental disadvantages held up against the positive effect for society. The knowledge base is fundamental. In this case, we have concluded that with the given permit conditions, the positive effect for society balances the negative environmental impacts.

5.6 Mining and mine tailings in Peru: past and present[31]

Mining in Peru is ancestral, having influenced the livelihood of most pre-Columbian cultures as well as the Inca Empire. Several archaeological sites throughout time and territory have produced metal artefacts, jewellery, and tools that attest to the mining and metallurgical skills developed by these peoples.

Thus, Peru is considered to be a mining country, with reserves in copper, gold, silver, zinc, lead, tin, and iron, to name the most common (see Table 2). Mining has become a pillar of the Peruvian economy and has attracted the presence of several international mining corporations that operate world-class mines (Figure 53).

[31] Carlos Aranda, Sociedad Nacional de Minería, Petróleo y Energía del Perú National.


Figure 53 *Open pit mine and processing facilities in Peru. Credit: Carlos Aranda*

Table 2 Peru metal reserves. Source: USGS (estimated data to 2014)

	World Ranking	% world Reserves	Latin America Ranking
Copper	3	9.7%	2
Gold	7	3.8%	1
Silver	3	18.6%	2
Zinc	3	12.6%	1
Lead	4	8.0%	1
Tin	3	1.6%	1

However, its mining potential has hardly been tapped with about 3.7% of the total available area to develop mining activities being used for extraction or exploration.

In Peru, mining is carried out in underground or open pit operations, the former dedicated to mining veins or deep deposits, and the latter for disseminated or superficial deposits. Most mining operations are located in the Andes Mountains, more than 3,000 metres above sea level. Some operations – and in some cases facilities – date back to the beginning of the 20th century, rendering low efficiency compared to today's technology. Since the 1990s, most old operations have been modernized, striving to improve efficiency in water and energy use, as well as reduction in waste generation.

Because of geographical and climate constraints, facilities such as tailings impoundments (Figure 54), have to be well thought out. Impoundment stability is paramount given those constraints, so construction details, as well as dewatering management and risk assessment, follow strict regulations and standards. However, accidents are not unknown and Peru has had its share throughout decades of mining.

Recent technical and environmental regulations for tailings impoundments reflect the concern of both the government and industry to prevent the occurrence of tailings impoundment failures, which may result in damage affecting not only rural populations, agricultural lands, cattle or human fatalities, but generate long-term conflict with rural communities. Thus, the industry has introduced technology to enhance physical and chemical stability of such impoundments and government has highly trained officials performing frequent supervision to ensure proper tailings management.

Historically, there have only been two mining operations (copper and iron) in Peru that disposed of their tailings in coastal waters (Figure 55). In approximately 1996, the Peruvian Government enacted environmental regulations for mining that required tailings to be disposed of on land and with strict criteria. Coastal or underwater disposal (including ocean) of tailings could only be carried out as a last resort and only if clear justification was presented. As a result, during the early 2000s, both mining operations complied and modified their tailings disposal systems to on-land facilities.

Figure 54 *Tailings storage facility in Peru*

Figure 55 *Past practice: discharge of mine tailings on the coastline in Peru*

In addition, mining companies are required to submit a Mining Closure Plan for their operations and facilities and secure an appropriate financial bond. This Plan is updated every five years. It includes closure of tailings facilities, whether on land or underwater. The bond is released only after the company is able to demonstrate human and animal safety, prevent future environmental concerns (physical and chemical stability), and the area is made as compatible as possible to its surroundings. The coastal areas where tailings were disposed of by the two operations mentioned above have been reclaimed and, at least in one case (Ite Bay), it has become a large wetland and bird biodiversity hotspot. As a matter of fact, it is the largest coastal wetland in Pacific South America.

Underwater tailings disposal is still practiced in Peru, but only in continental lentic waterbodies. No permits have been issued for ocean underwater tailings disposal systems.

This progress, notwithstanding, does not include an environmental situation that has become a national curse: illegal mining. The areas affected – to the point of becoming environmental disasters – show a high degree of deforestation, encroachment of barren lands and disappearance of biodiversity, as well as severe, health-risk levels of mercury, hydrocarbons and lime in water and soil. There is no doubt that the negative environmental effect of illegal mining reaches the Pacific and Atlantic coasts through rivers draining into these areas.

Although the Peruvian Government has taken strong and decisive steps to close down these areas and minimize negative environmental effects, the damage to natural areas is extensive and amounts of chemicals dumped into waterways in only the Madre de Dios region results in more than 25% of rivers having high levels of pollution. In some instances, the government of Brazil requested the Peruvian Government to try to prevent mercury from being used in this type of mining (alluvial), as fish in Brazilian waters showed high levels of this element.

As a known mining country and having attracted most of the international mining corporations, Peru is set to continue growing as a world mineral producer. Its mining industry environmental practices are held accountable through strict regulation as well as continuous supervision by increasingly well-trained government officials. Through the modernization of old facilities, it is at the forefront of mining technology applications. This includes tailings disposal systems that use less water and are disposed of on land. Underwater tailings disposal systems are permitted by the government only as a last resort.

As with any technological advancement and regulatory evolution, science needs to be at the centre of discussions, not allowing unharnessed application of precautions that limit the possibility of a solution for environmental mining issues. This view has helped Peru to best manage and dispose of mining tailings.

5.7 Proposed seabed mining off New Zealand: what would it entail, and why did the first applications for mining consents fail?[32]

New Zealand's marine environment is rich in mineral resources with economic potential. Exploratory and prospecting permits have been issued for most of these minerals (except cobalt-rich crusts and manganese nodules). Mining permits have been issued for phosphorite nodules and ironsands to Chatham Rock Phosphate (CRP) and Trans-Tasman Resources (TTR), respectively. However, before commercial-scale mining can begin, a marine consent is required.

Marine consents are decided upon under the legal requirements of New Zealand's Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act, by the Environmental Protection Authority (EPA). Marine Consent applicants must provide the EPA with information on how their proposed activities relate to a set of criteria, including ones concerning potential environmental effects. Applicants for a consent must include in their Environmental Assessment a description of the current state of the area, identify any environmental effects of the activity, and specify measures intended to avoid, remedy or mitigate adverse effects.

CRP and TTR proposed to mine the seabed using different methods and mining strategies, each deemed suitable to the particular environment and resource, and designed to minimize impact to the environment. Both companies also developed adaptive management plans that included measures to mitigate the environmental effects of mining.

The reasons that the EPA did not grant either company a consent to mine are listed below.

- Uncertainty about the receiving environment and the adverse effects of mining on the environment and existing interests (e.g. fishing).
- The Decision-Making Committee (DMC) appointed by the EPA was required to favour caution and environmental protection.
- Mining would cause significant and permanent adverse effects on the existing benthic environment.
- Environmental effects could not be mitigated by any set of conditions or adaptive management regime that might be reasonably imposed.
- A lack of clarity about the extent of economic benefit to New Zealand outside of royalties and taxes and the economic impact of the adverse effects. The economic benefit to New Zealand of the proposal would be modest at best.
- Uncertainties in the scope and significance of the potential adverse environmental effects and those on existing interests (such as fishing and the iwi (Maori) population).
- The conditions proposed by the applicant (including the adaptive management approach) were not sufficiently certain or robust for the application to be approved given the uncertainty and inadequacy of the information presented about the potential adverse effects.
- The application did not meet the sustainable management purpose of EEZ Act, including that the DMC was not satisfied that the life-supporting capacity of the environment would be safeguarded.

[32] Ashley A. Rowden and Alison MacDiarmid, National institute of Water & Atmospheric Research, Private Bag 14-901, Wellington, New Zealand.

6 WORKSHOP FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Findings, conclusions, and recommendations provided in this section were derived from the individual summary papers, the speakers' PowerPoint presentations, and extensive discussions during the workshop. An immense amount of information and data were presented, and readers are referred to the summary of each speaker's presentation in this document and to each speaker's PowerPoint presentation on the GESAMP website at www.gesamp.org, for additional details.

6.1 Evaluation of potential impacts of marine disposal of mine tailings

The most recognized impacts of DSTP on benthic organisms involve direct smothering, changes in the benthic habitat, increases in suspended sediment, and exposure to contaminants. The first two of these are predictable impacts that remain for the entire DSTP operation. The occurrence (location or intensity) of suspended sediments and associated metals and metalloids is less predictable, and significant challenges remain regarding the assessment of the fate and impacts of sub-surface tailings plumes at all water depths.

Evaluation of the potential environmental risks of mine tailings discharges to deep marine waters should include assessment of:

- Toxicity of the tailings;
- Impact on seabed;
- Impact on the pelagic zone during the production period; and
- Impact on biodiversity and ecosystem function in the receiving environment.

The evaluation should also consider the influence upon:

- Marine resources, e.g. fisheries;
- Vulnerable ecosystems;
- Potential redistribution of tailings; and
- Impact of technical failure, e.g. pipeline fractures.

There is a need to characterize ecosystem functions, e.g. what are they and what is their relationship with biodiversity, and the importance of habitat-providing species (e.g. cold-water corals, sponge fields). Key information needed to be developed during in situ or laboratory studies includes:

- Toxicity of deposited tailings to local fauna;
- Sensitivity of fauna to suspended sediment loading;
- Impact of sedimentation on benthic fauna; and
- Recovery dynamics of benthic fauna.

Marine organisms normally used for toxicity testing are from the upper stratified layers of marine water, not the deep sea. While no standardized whole-sediment toxicity tests exist that utilize deep-sea organisms, tests that use surrogate organisms are generally considered appropriate for assessing contaminant bioavailability and risks or toxicity. Specific gaps in toxicity testing were identified:

- Standard sediment and aquatic toxicity tests developed that use species from deeper water would be useful. Use established tests to compare with new ones;
- Suitable test temperatures need to be used, and the challenges for dealing with pressure in toxicity tests should be addressed;
- Different exposure pathways need to be understood, including exposure to metals in the fine particulate material in mine tailings;
- Expand taxonomic range to include marine species relevant to tailing distribution potential, and include chronic studies with variable exposure regimes/scenarios; and
- Total metal concentrations in sediments impacted by mine tailings can often appear alarmingly high; however, a large portion of the metals within tailings exist in highly mineralized forms that are less bioavailable to organisms when compared to metals introduced to the environment from other common anthropogenic sources.

Water column guidelines do not exist for all contaminants, are limited to continuous dissolved chronic exposure, and mostly based on single-species data. Methods are not well developed for the deep sea, as they rely on surrogate species. Other aspects include:

- Unknown influence of deep-water environmental conditions on bioavailability;
- Plumes of fine particulates affecting diet of filter feeders;
- Uncertainty in guidelines application and fluctuating exposure; and
- Development of guidelines based on ecological change (DNA-based techniques).

For all assessments, there is a need to consider multiple lines of evidence (LOE) in order to inform communities, governments, and industries of risks posed to the environment. For many deep-sea assessments, there will be a need to develop new and specialized tools to provide new LOE for assessments (e.g. ecogenomics-based tools to provide new LOEs for ecology - community structure, function and connectivity). There will also remain a need to utilize existing tools that are well developed for near-shore coastal environments, as these can also provide useful information on environmental risks.

The ecosystems targeted both for deep-sea mining[33] and deep-sea tailing disposal (placement) largely remain poorly studied in terms of the impact on and recovery of biological communities. There is much to be gained from combining information and expertise from mechanistic studies in shallow and deep water, as fundamental ecological patterns in faunal communities such as lifestyles or feeding modes or benthic faunal colonization processes are similar for shallow and deep waters. The effects of copper on infaunal abundance, distributions, biodiversity, species tolerances, and body burden information are potentially relevant for the deep sea where mine tailing can affect larger areas and a wider range of habitats and ecosystems.

Risk assessments of DSTP proposals are generally limited by current methodologies that do not always translate to a realistic assessment of risk specific to deep-sea environments. For example:

- Limited knowledge about the abiotic and biological/ecological characteristics of most deep-sea systems where DSTPs are proposed, before baseline surveys are conducted, limits the ability to estimate risks;
- They do not account for the lack of ability to manage the risk of failure;
- The physicality of large volumes of solid materials being uncontrollably redistributed in the marine environment and the extent of dispersal is hard to predict; and
- They need to assess impacts to the deep-sea ecosystem and its relationship to the productive upper coastal waters, i.e. is there a serious impact on the commercial or sports fishery or ecosystem services of those coastal waters?

In addition, as part of the current framework for risk assessment, there is generally no allowance for considering impacts from multiple mines or impacts from multiple stressors from a single mine.

6.2 Physical oceanography and tracking plumes

Plume models are useful for exploring potential outcomes, integrating knowledge of multiple disciplines, providing a crucial method to link with observations, biological mechanisms, and ecosystem understanding (impacts). Each tailing disposal site is unique, but the same fundamental processes operate. The building blocks are in place for an integrated predictive modelling and environmental monitoring system, as practiced in the oil and gas extractive industry.

Observations and model results have revealed that the Peru-Chile Currents System exhibited a strong variability associated to ENSO (El Niño Southern Oscillation), coastal wind, and the interaction between them. This variability is related to coastal trapped waves, Rossby waves, mesoscale eddies, and upwelling.

[33] See also the MIDAS Project under the European Commission's Framework 7 programme which is evaluating environmental impacts of deep sea resource exploitation (http://eu-midas.net).

The impact of these phenomena on a smaller spatial scale (e.g. submarine canyons) or on a shorter time scale (e.g. inertial oscillations, internal waves) remains unknown.

To understand the possible impact of DSTP in the Peru-Chile Current System, from the physical oceanography viewpoint, understanding is needed of the physical dynamics of smaller areas (e.g. submarine canyons) and how smaller regions are affected by processes on a larger scale including:

The spatial and temporal variability of the dominant physical process;

- The temporal variability of horizontal and vertical gradients of currents and physical and chemical properties of the water column (e.g. gradients of temperature, salinity, density, and oxygen);
- The characteristics of the intra-seasonal, seasonal and interannual fluctuations of currents and physical and chemical properties in the smaller area;
- The effect of local forcings (e.g. coastal wind) and remote (e.g. coastal trapped waves, and Rossby waves) on currents and physical and chemical properties of the water column;
- The dynamics of internal waves and their role in the mixing processes in the study region; and
- The impact of internal waves on currents and physical and chemical properties of the water column.

From the point of view of physical oceanography and use of DSTP, research activities are needed to obtain in situ and modelling data to fill the knowledge gaps in the study area, especially the gaps associated with the dynamics of submarine canyons.

Other influences upon plume modelling and predictions of behaviour of mine tailings include the characteristics of the mine tailings as they are discharged into marine waters. Submarine tailings discharges inherit a several-hour trajectory in pipelines, exerting particular conditions on the turbulence and, especially, the shearing of these slurries. Knowledge is needed to identify transport conditions (e.g. pH, solids concentration, additives) suited to minimize the impact of discharges. Gaps include:

- How are tailings rheology, floc formation and subsequent settling affected by seawater?
- What are the features of aggregate distribution after (potentially long) pipeline transport?
- What are the short-term and long-term mechanical and physico-chemical responses of deposited tailings (consolidation, floc integrity)?
- What is the effect of pressure on the above elements?
- Is it possible to eliminate plume formation considering other constraints? How?
- (If not) what is the relation between aggregate formation and plume features?

- What would be the fate of plumes and suspended sediment in light of background currents? What are the local spatiotemporal effects (basin/upper ocean temporal forcing, seismicity)?
    - What are the risks of transboundary (between neighbouring nations) effects of tailing plumes?

6.3 Recovery and recolonization

The deposition process will completely smother the resident benthic community locally and leave the benthos devoid of labile organic material. Therefore, an important requirement is to develop strategies that will facilitate maximal faunal recolonization following mine closure.

There are important knowledge gaps in several aspects relevant to recolonization: 1) regional distribution of species; 2) availability of source populations that would provide the necessary propagules (i.e. eggs, larvae, juveniles and/or dispersing adults) for recolonization; 3) population connectivity processes (e.g. reproductive patterns and fecundity, larval ecology, larval transport); 4) the rate of recovery of benthic community structure and important ecosystem processes (e.g. sediment mixing) and how these are affected by sediment properties (organic matter, grain size and shape). The current data limitations on these issues strongly limit the predictability of how the benthos will recover, and thus, the development of suitable sediment rehabilitation practices.

Another question would be: What is the optimum range of organic material in mine tailings to allow improved invertebrate colonization at the end of the life of an STP? Tailings likely form a different physical environment to natural background conditions, which seem to exert an effect on the colonization process; other influences on recolonization may include different grain sizes and angularities of mine tailings relative to background sediment.

6.4 Lessons learned in case studies

Marine disposal of mine tailings

Deep-sea tailings placement has been used as a waste management option in PNG for over 20 years (as well as in many other parts of the world), with the key aim of the PNG government to mitigate and manage the environmental impacts of mining. Exploitation of mineral resources and disposal of mine tailings in the deep-sea bed will inevitably increase throughout the 21st century.

At the currently operating mine, **Lihir, PNG,** which uses DSTP, environmental impact studies show:

- Very large and profound differences in the biological assemblages present in impacted versus reference stations;
- There are still measurable numbers of meiofauna in the surface layers of the impacted sediment; and
- The sediments contain much higher concentrations of metals in both solid and aqueous phases, including ecotoxic elements such as Cu, Cd, and As.

Environmental impact studies at the site of DSTP for the closed mine at **Misima, PNG** show:

- Results indicate very clear differences between the benthic community of impacted and non-impacted stations;
- Stations adjacent to the DSTP are very clearly impacted by mine tailings;
- Stations further away from the mine have been impacted either directly through mine tailings deposition or indirectly through post-depositional resuspension and re-deposition; and
- Impacted stations show some degree of post-impact recolonization.

At the currently operating mine, **Ramu Nickel, PNG,** SAMS and MPI reviews[34] found that:

- Likely upwelling from the prevailing onshore current at depth will inevitably cause some fraction of STD material to enter the ocean over a range of depths. This will be transported as patches of turbid water well out of the source area; and
- Ecological damage over the wider Astrolabe Bay region will greatly be increased towards the North West up to Madang and as far as Kar Kar Island. This will clearly have significant biological impact, including adverse impact on both shallow and deep water fish.

The MADEEP 2014 deep-sea oceanographic cruise in Basamuk Bay (Dr. Ralf Mana UPNG) confirmed the earlier predictions:

- Red tailings were found in the four canyons; and
- The highest density red tailings were at a depth of 560 m and in suspension.

At the currently operating mine at **Batu Hijau, Indonesia,** the depth of discharge is 125 m at the head of an underwater canyon leading to Lombok Basin at 3,000 to 4,000 m in depth. Comprehensive baselines studies were conducted from 1994-1996 and the mine was fully operational in 2000. Since that time, a series of studies have been conducted:

- Deep sea studies (tracking tailings footprint and refining models, water column TSS);
- Copper in the water column (spikes due to processing oxidized ore, refinement of controlled process sulphidization (CPS) and blending);
- Tailings recolonization (meiofuana more sensitive than macrofauna); and
- Due diligence studies (2004, 2009, 2015 – to independently verify compliance with the permit and evaluate new monitoring objectives).

[34] Scottish Association of Marine Science, and Minerals Policy Institute. Pages 22, 43, 46, and 75 MPI Report and page 131 Final SAMS report.

The general findings of these studies are:

- There are no indications of significant impacts on the pelagic ecosystems, with light transmission within the surface water layers remaining high, chlorophyll concentrations in the range consistent with typical phytoplankton populations, and metal concentrations in tissues of demersal fish and filter-feeding organisms with the coastal zone being similar to reference sites. To some extent, the tailings deposition has impacts on the macrobenthic and meiobenthic populations, and this was predicted in the management plan; and
- The Batu Hijau DSTP continues to be evaluated against objectives that are intended: (i) to ensure that the tailings flow down the canyon and away from the coast and that the tailings are confined below both the surface mixed layer and photic zone; (ii) to ensure there will be no impact on the biologically active near-surface zone and no impact on coral reefs, beaches or other coastal attributes; (iii) to avoid impacts on commercial and subsistence fisheries; and (iv) to confine the impacts to areas of very low biological activity.

In 2015, Norway approved a permit for disposal in **Førdefjord** (marine waters) for a rutile mine. Key elements of the permit application process included:

- Extensive studies of the currents in the fjord – modelling and measurements;
- Alternatives to marine disposal – alternative use of tailings and alternative sites for disposal;
- Survey of the marine biodiversity in the fjord; and
- Characteristics of the tailings (heavy metals) and processing chemicals.

The conclusion by the Norwegian Environment Agency is that issuing a permit pursuant to the Pollution Control Act is based on an integrated approach. Hence, the permit is based on an evaluation of environmental disadvantages held up against the positive effects for society. The knowledge base is fundamental. In this case, the conclusion was that with the given permit conditions, the positive effects for society outweigh the negative environmental impacts.

Lessons from New Zealand's Evaluation of Deep-sea Mining Permit Application were that permits were denied in the face of multiple uncertainties:

- Uncertainty about the receiving environment and the significance of adverse effects on the environment and existing interests (e.g. fishing);
- Significant and permanent adverse effects on the existing benthic environment;
- Whether environmental effects could be mitigated;
- Lack of clarity about the extent of economic benefit to New Zealand;
- Significance of the potential adverse environmental effects; and
- Sustainable management such that the life-supporting capacity of the environment would be safeguarded.

Land disposal of mine tailings

Worldwide, it is estimated that two to five major accidents associated with tailing dam failures occur per year, and that about 25% of these accidents are related to extreme meteorological events. However, many failures go unpublished due to sensitivity and legal implications.

The frequent tailing spills recently observed in Sinaloa, Mexico, have shown the need to improve management practices in the mining industry, as well as the environmental regulations, taking into account the role of sediment management either to retain or to redistribute the metals released by the mine tailings to the aquatic environment. In Sinaloa it was found that:

- The public were concerned about the frequency of mine tailing failures in the region (three cases in one year);
- Poor management practices, inadequate regulation, and no environmental assessments are evident; and
- With climate change and considering that most common mine tailing dam accidents are related to meteorological events, mine tailing storage dam failures incidents might increase.

6.5 Discussion regarding best practices and guidelines

Development of guidance on best practices for mine wastes should go beyond traditionally considered concepts, that is, beyond the strictly engineering aspects of marine discharge, generally thought of as addressing such items as piping materials, depth and angle of discharge, pretreatment (e.g. de-aeration), and density of discharge slurry. Best practices should include appraisal of all practical waste management options and evaluation of opportunities for waste reduction and also address the comprehensive list of what data and information need to be generated to prepare environmental risk assessments for use by decision-makers.

The workshop identified a general outline of best management practices:

Appraisal of all practical waste management options:

- Marine discharge, i.e. in deep waters;
    - On land storage, i.e. tailings storage ponds; and
    - No mine tailings, i.e. no mine;
    - Evaluation of waste reduction, such as treatment before discharge;
- Evaluation of recycling or reusing wastes;
- Comprehensive baseline survey of proposed disposal site and surrounding areas;
- Characterization of mine tailings, physical, chemical, and toxicity;

- Suitable disposal site location (bathymetry, physical oceanography, and ecology);
    - Suitable discharge depth and conditions (no upwelling, subsurface tailings plumes and resuspension of deposited tailings);
    - Low productivity environment (i.e. not impacting a precious ecosystem);
    - Robust ecological risk assessment to demonstrate low risk of adverse effects to aquatic organisms, i.e. water quality and sediment quality; and
    - Advanced monitoring and ongoing improvements to management of waters at surface and at depth, including plumes;
- Engineering elements of the discharge, the discharge pipe (e.g. physical safety of the pipeline from wave action and seismic activity), and location;
- Adaptive management and mitigation procedures; and
- Transparency and acknowledging what we know and what we don't know.

No global[35] regulations or guidelines specifically apply to marine discharge of mine tailings. The only national guidelines developed specifically for DSTP have been prepared in PNG. PNG's aim is to promote a healthy and sustainable mineral industry and provide a regulatory environment that maximizes mining opportunities and minimizes impact on the environment to ensure optimum benefits for the people of PNG. To meet these objectives, PNG has developed guidelines for use of DSTP. The main objectives of the guidelines are to: (1) minimize the impact on the marine environment while achieving sustainable resource development; (2) inform and guide the developer/operator; and (3) assist government agencies to inform policy and regulation.

[35] The European Directive 2006/21/EC of the European Parliament and the Council of 15 March 2006 on the Management of Waste from Extractive Industries and amending Directive 2004/35/EC. Additionally MTWR BREF, is currently under review by the EU: Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities.

The PNG Guidelines require that each mine site consider:

- The ore being mined;
- The processes and chemicals used;
- The physical and chemical constituents of the tailings;
- The amount of tailings being discharged;
- The physical oceanography of the marine environment into which the tailings will be discharged;
- The bathymetry of the marine environment into which the tailings will be discharged;
- The biodiversity of the marine environment into which the tailings will be discharged;
- The land to ocean transfer that takes place, i.e. is there a large fresh water and sediment input to the area;
- The fishing activity that takes place in the sea surrounding the mine;
- The social, economic and cultural activities that may be affected by the discharge; and
- The integrity of the discharge pipe and mixing tank including the consideration of the engineering required together with emergency contingency plans.

6.6 Other observations

Gaps in long-term knowledge about deep marine settings are daunting, but the governance weaknesses are more significant. Many governments in developing countries lack adequate technical staffs, budgets, and political support to effectively oversee land-based tailings disposal operations; oversight of DSTP operations will be much more complex and costly. DSTP is ongoing around the world and, increasingly, new and existing mining companies will look to marine disposal to dispose of their mine tailings.

No global agency has direct jurisdiction over mine tailings discharges to marine waters. The workshop concluded that the London Convention and Protocol should take ownership of the issue working with regional bodies and other international entities to provide guidance and advice. They recognized that the London Convention and Protocol members are obligated to protect and preserve the marine environment, having the expertise and experience in addressing dumping of wastes into the marine environment.

The workshop recognized the reality that "this train has left the station", coupled with the certainty that mining will continue, mine tailings will be generated, and in a number of locations mine tailings will continue to be placed in the sea. Management of these actions to minimize effects upon the marine environment is critical; this means working toward closing the gaps in scientific assessment techniques, and developing advice on best management practices. The other reality is that addressing the scientific gaps will take time, effort and huge resources, and that in the interim, decision-making will necessarily be based upon imperfect sets of information and data requiring a precautionary approach.

The outcome of the mining process is that mine tailings need to be managed to the least environmental and social costs, and therefore all alternatives should be considered. Those management options tend to be site specific including new options for upstream measures, especially in terms of changing processes and eventually minimizing and treating tailings before disposal.

A proper risk analysis needs to consider costs and benefits. This issue cannot be considered solely on tailings placement in the oceans. The costs and benefits analysis needs to include the alternative of land disposal. To conduct comprehensive assessments on how to make sustainable decisions, an appropriate institutional framework is critical. This comprehensive framework that will allow a risk assessment of the cost to land and ocean does not exist today. There is an information gap on how to competently compare risks to land versus sea disposal, integrating all the disciplines to make a judgment. The ecosystem services issue (i.e. the cost to ecosystem services versus the benefits of deep sea disposal or land disposal) is far from being accepted by ministries around the world; despite a significant amount of research, it has not been included in regulatory frameworks, with some exceptions.

Overall, the workshop felt that DSTP could be a viable option, but further scientific research is required before it can be judged sustainable. Thus, it is increasingly urgent to understand the processes that drive and maintain deep-sea ecosystems to better assess their resilience and recovery potential, providing sound scientific knowledge from which to develop robust ecosystem-based management options.

It is necessary to understand that scientific knowledge should be transparent and validated socially and therefore interaction with governments, NGOs, and civil society is a priority.

To accomplish these objectives, international collaboration and sharing of information should be promoted at all levels (i.e. institutional, scientific, industrial, economical, and societal) to enhance the effective use of information and data and thus facilitate the development of robust risk assessment tools, and best available practices and management measures.

ANNEX I – LIST OF REFERENCES

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ANNEX II – WORKSHOP PROGRAMME

GESAMP International Workshop on the Impacts of Mine Tailings in the Marine Environment

10-12 June, 2015

Meliá Hotel, Lima, Peru

Final Programme

DAY 1: Wednesday 10 June		
08.30-09.00	**Arrival and registration of participants**	
Time	**Session**	**Speaker**
09.15-10.30	**Plenary Session – Official opening** • Welcome address by hosts and IMO and GESAMP	Vice Admiral Victor POMAR Calderon (National Maritime Authority, Peru), Edward Kleverlaan (Head, Office for the London Convention/ Protocol and Ocean Affairs, IMO/GESAMP)
	Keynote presentation • Scene setting: nature and scale of the issue and overview of STD and possible environmental impacts	Dr. Mike Huber (GESAMP)
	Panel discussion (30 mins) • Perspectives from key stakeholders	Representatives from government, mining industry, maritime users (fisheries, tourism) and NGOs (Captain Renzo Rebisso (Peru); Dr. Carlos Aranda (SNMPE - Peru); Mr. Harald Sørby (Norway))

10.30-11.00	*Refreshments*	
11.00-13.30	**Thematic Sessions** **1) Mining practices, waste generation and disposal (tailings)** **2) Understanding the marine environment**	**Moderators: Dr. Mike Huber and Capt. Walter Vera Tudela (Peru)** 1 Mr. Ricardo Katz (Gestion Ambiental Consultores SA, Chile) - Title: TBC 2 Dr. Bio. Carlos ARANDA (Peru) - Mining Practices in Peru 3 Dr. Ana-Carolina Ruiz (GESAMP): Assessment of land-based mining pollution: a case study in Sinaloa, Mexico. **Moderator: Dr. Patricio Bernal (Pontificia Universidad Catolica de Chile) and and Capt. Carlos Lema (Peru)** 1 Dr. Eva Ramirez-Llodra (NIVA, Norway): Unique attributes of deep-sea ecosystems 2 Dr. Samuel Hormazabal (Pontificia Universidad Católica de Valparaíso (PUCV), Chile): Physical oceanography and its relation with DSTP
13.30-14.30	*Lunch*	
14.30-16.30	**2) Understanding the marine environment – continued**	3 Dr. Stuart Simpson (CSIRO, Australia): The application of water and sediments guidelines to DSTP management 4 Dr. Ashley Rowden (NIWA, New Zealand): Proposed NZ mining: what had to be learnt before mining could begin
16.30-17.00	*Refreshments*	
17.00-17.30	**2) Understanding the marine environment – continued** **Wrap-up session and conclusions**	**Moderator: Dr. Patricio Bernal** **Rapporteur: Dr. Eva Ramirez-Llodra**
End of day one		

DAY 2: Thursday 12 June		
08.30-10.30	**Thematic Session – What we know and what we do not know about the effects of mine tailings in the marine environment**	**Moderator: Dr. David Johnson (Seascape, United Kingdom)** 1 Dr. Tracy Shimmield (SAMS, United Kingdom): Impacts of large-scale disposal of mining waste in the deep sea 2 Dr. Raymond Nepstad (SINTEF, Norway): Numerical modelling of particle spreading from mine tailing deposits in Norwegian fjords 3 Dr. Andrew Sweetman (IRIS, Norway): How fast do mine tailings deposits colonize, can we boost colonization and does colonization imply recovery of ecosystem functioning? 4 Dr. Kissao Gnandi (Uni. Lomé, Togo): Impacts of submarine mine tailings from phosphorite mines in Africa 5 Dr. Martin Palmer (NOCS, United Kingdom): Studies of metal release from seafloor mining of sulphide deposits

10.30-11.00	*Refreshments*		
10.00-11.30	**Continued session on knowns and unknowns**	6	Dr. Carlos Neira (Scripps, United States): Copper pollution effects on benthic faunal communities: lessons from shallow water studies
		7	Dr. Robert Moran (Michael-Moran Assoc., LLC, United States): Mine tailings: some unknowns, uncertainties and secrets.
		8	Mr. Michael Akester (UNDP-GEF) - Ecosystem Diagnostic Analyses of the various impacts on the Humboldt Current Large Marine Ecosystem
		9	Mr. Christian Ihle (ISUM SpA, Chile): Open questions on the flow and mixing of hyperconcentrated, cohesive gravity currents
11.30-13.30	**Thematic Sessions – Existing regulatory (best) practices**	**Moderator: Mr. Craig Vogt (C Vogt Inc)**	
		1	Mr. Edward Kleverlaan (IMO): International Framework: Disposal of wastes at sea
		2	Dr. Amanda Reichelt-Brushett: Current approaches, limitations and future needs in DSTP risk assessment –experiences from the Ramu Nickel challenge in Papua New Guinea
		3	Dr. Stuart Simpson (CSIRO, Australia): Environmental Impact assessment, permitting and monitoring process for DSTP in Indonesia
		4	Dr. Tracy Shimmield (SAMS, UK): Deep Sea Tailings Placement in Papua New Guinea, Environmental Impact Assessment, Monitoring and Regulation
		5	Mr. Harald Sørby (Norway): Granting the permit for a new rutile mine with placing of tailings in a fjord (Norway)
		6	Eng. David Vela (Peru) - Mining Process and Components/ Methodology for Mine Tailings disposal
		7	Dr. Ashley Rowden (NIWA, NZ): Proposed seabed mining off New Zealand – what would it entail, and why did the first applications for environmental permits fail
13.30-14.30	*Lunch*		
14.30-16.30	**Plenary Session – Discussion - Gaps in regulatory frameworks and science, Path forward and next steps**	**Moderators: Dr. Mike Huber and Mr. Craig Vogt**	
16.30-17.00	*Refreshments*		
17.00-17.30	**Closing session**	**Rapporteurs and hosts**	
	Workshop wrap up	GESAMP/IMO/Peru	
End of Workshop			

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ANNEX IV – GLOSSARY

Organizations

GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
IAEA-EL	International Atomic Energy Agency – Environment Laboratory, Monaco
IMO	International Maritime Organization, London, United Kingdom
IOC-UNESCO	Intergovernmental Oceanographic Commission of the United Nations Educational Scientific and Cultural Organization, Paris, France
UNEP	United Nations Environment Programme, Nairobi, Kenya
UNDP	United Nations Development Programme, New York, United States
UNIDO	United Nations Industrial Development Organization, Vienna, Austria
WMO	World Meteorological Organization, Geneva, Switzerland
UN	United Nations, New York, United States
FAO	Food and Agriculture Organization of the United Nations, Rome, Italy
WHO	World Health Organization, Geneva, Switzerland