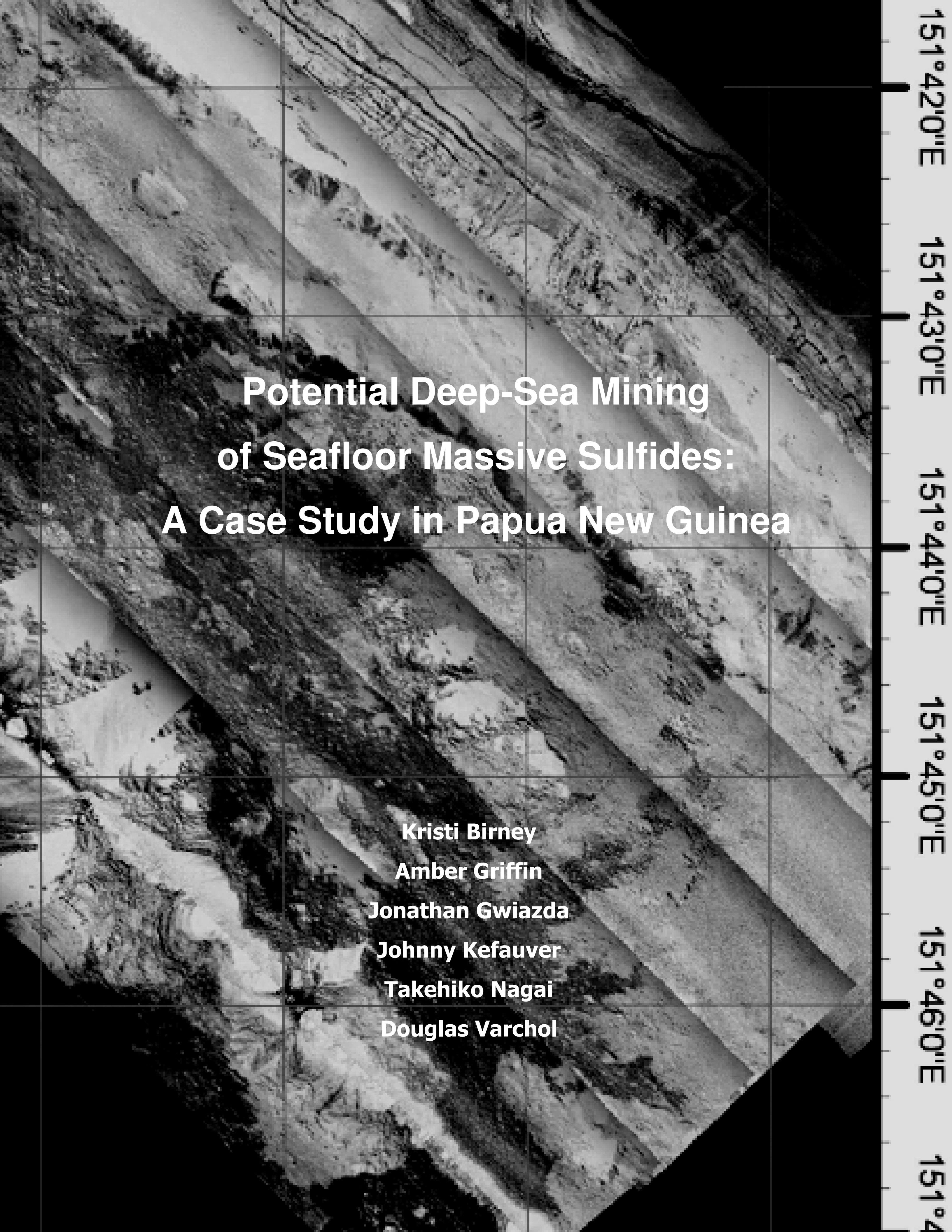

Potential Deep-Sea Mining of Seafloor Massive Sulfides: A Case Study in Papua New Guinea

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ABSTRACT

Seafloor massive sulfides have the potential to become a significant mineral resource. The initial stages of exploration are underway and extraction could start within the next decade. However, the range and extent of potential impacts of Deep-Sea Mining (DSM) on the environment and stakeholders are uncertain. This study considers the environmental, technological, and policy aspects of DSM using the Papua New Guinea project as a case study. The goals of the study are 1) to provide an overview of the current status and the associated issues of DSM and 2) to influence the development of DSM, a nascent industry, with environmental analysis and recommendations. General recommendations include overarching policy structures such as the Precautionary Principle, scientific collaboration, and transparency to address the inherent uncertainty of developing a new industry in a new environment. Specific recommendations include a monitoring methodology the Before After Control Impact Paired Series (BACIPS), as well as policy applications like adopting the Code of Environmental Management of Marine Mining. A short documentary film is available as a companion piece to this study.

FINAL REPORT SIGNATURE PAGE

Potential Deep-Sea Mining of Seafloor Massive Sulfides: A Case Study in Papua New Guinea

As authors of this Group Project report, we are proud to archive it on the Bren School's web site such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Donald Bren School of Environmental Science & Management.

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

ADVISOR____________________

DEAN____________________

DATE____________________

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EXECUTIVE SUMMARY

Mineral resources are becoming increasing difficult to extract on land, and recent research in the deep-sea has identified rich ore deposits that may be economically extractable through the development of a deep-sea mining industry within the next decade (Fujita, 2001). Deep-sea mining (DSM) exploration has already begun. During January and February 2006, Nautilus Minerals and Placer Dome carried out their first drilling cruise of seafloor massive sulfide (SMS) deposits in the Bismarck Sea, Papua New Guinea. DSM represents a new trend in ocean exploration which has significant unanswered questions about the potential environmental impacts and the sustainable use of ocean resources.

The purpose of this study was to recognize and research the primary issues surrounding DSM and to guide a nascent industry before exploration begins. Our main objective was to influence this industry so that it develops useful and sensible environmental practices. To achieve our objective this study 1) provided an overview of the current status and associated issues of DSM and 2) has influenced the development of DSM with environmental analysis and recommendations. General recommendations include, among others, overarching policy structures such as the precautionary principle, scientific collaboration, and transparency to address the uncertainty of developing a nascent industry in a new environment.

Background

The implementation of commercial DSM of SMS associated with hydrothermal vents is probably 5 to 10 years in the future. The primary reasons for the mining industry's current interest of the deep-sea are three-fold: 1) SMS deposits are located at relatively shallow depths and accessible by current technology, 2) DSM may be cheaper than terrestrial mining (Heydon, 2005), and 3) the global demand for minerals is increasing, specifically the future economies of India and China may require large amounts of copper, making DSM even more economically viable (Yamazaki, 2005a). Nautilus Minerals Inc, an Australian mining company, and Placer Dome, a Canadian gold mining company, are currently engaged in a deep-sea drilling and ROV exploration program in

the Eastern Manus Basin off the coast of Papua New Guinea to determine if ocean-floor mineral tenements they lease host sufficient grade and size SMS deposits to "justify a future potential mining operation" (Baulch, 2005a). If mining operations do proceed, then Papua New Guinea (PNG) may be the first country that will have a significant test and development of DSM processes.

A literature review was carried out focusing on five areas of significance to deep-sea mining which include: active and in-active hydrothermal vent environments, DSM extraction technology, potential impacts from the use of this technology, legal and policy issues of mining in territorial waters, and identifying stakeholders and their concerns. Since DSM represents a new trend in ocean mineral extraction, with many uncertainties about potential environmental impacts, this document offers recommendations from the literature review, Nautilus/Placer Dome exploration case study, and personal communication with experts in the field.

The following sections briefly describe areas of significance for the DSM industry to address.

Environment

The deep-sea environment in the Manus Basin presents several particular challenges to DSM exploration. Mining tenements are located ~2,000 meters deep with operations taking place in an environment with extreme conditions such as total darkness and temperatures that reach up to 400°C. The topography along the back-arc basin, specifically the SuSu Knolls, is rugged terrain, potentially making extraction of SMS deposits difficult.

Potential mining operations will be located at inactive SMS deposit sites. Communities at inactive areas are modestly understood as studies have not examined the organisms or communities found in these locations. In addition, inactive vent sites are adjacent to active vent sites. As active vent sites host an abundance of organisms, the mining community will have to determine if their activities will impact these communities. Operating in this new environment, mining companies will face many challenges determining specific sites to mine and the potential impacts it may have on communities in the surrounding area.

Technology

The design and application of DSM technology will largely determine the impacts on the environment. The technology that will be used for DSM is adapted from the offshore gas and petroleum industries. The proposed technology roll-out will consist of the following stages: exploration including sampling and drilling; extraction; transportation, processing, and siting. The process of extractive technology uses a drum cutter for breaking up the SMS. The SMS ore with its associated sediment will be transported through a riser pipe up to the ship where it is dewatered. The ore is then transported to shore and waste water slurry is returned to a currently undetermined location. Adaptation of the technology presents a possible opportunity for industry to directly mitigate negative environmental impacts.

Potential Impacts

Many uncertainties surround deep-sea mining and one of the most significant is the potential impacts to the surrounding environment. To better understand and identify the potential impacts, a brief review of nodule DSM experiments was completed. Information gathered from these studies and other research studies focused on SMS mining led to the identification of potential impacts from exploration and extraction of SMS deposits. These impacts were categorized as follows: direct physical disturbances, sediment plumes, acoustic impacts, waste water disposal, and machinery leaks or malfunctions.

In order for the industry to determine the extent of impacts environmental assessments will need to be conducted. It is suggested that a Before After Control Impact Paired Series field assessment be conducted. This will allow for a comprehensive and targeted environmental monitoring program in the dynamic deep sea environment. Placer Dome may be the first company to conduct a full scale deep-sea mining operation; it is essential that they use a sampling method that will identify impacts and quantify the magnitude of these impacts. The assessment method they choose will need to be rigorous so that it stands up to outside review and critique by scientists and stakeholders.

Law and Policy

The importance of law and policies addressing deep-sea mining cannot be understated because establishing such regulations allows all deep-sea mining stakeholders a better command of their interests. This includes how effective the management of marine mineral extraction will be and how well the ocean environment is protected. Therefore, a careful assessment of current and past laws and regulations of deep-sea mining are addressed such as; international legislation, national legislation and environmental regulations in PNG, local and state government legislation in PNG, and the Madang Guidelines and code for environmental management of marine mining.

Conclusion

The methodology used in this case study identified, contacted, and opened a dialogue between the group project members and key players from industry, non-government organizations (NGO), the Papua New Guinea government, and scientists currently studying hydrothermal vent systems. An extensive literature review complemented by personal communications with experts provided the foundation for a set of recommendations for each chapter topic. It is our hope that the mining industry can use these recommendations to identify and mitigate environmental impacts before they occur. In addition to generating this report, a documentary film on DSM issues was made for a general audience. This was produced through interviews with scientists, industry members, legal and policy experts, and group project members. Overall, outreach with experts has opened up new doors of understanding and collaboration for this project. Throughout this project we have found the deep-sea mining industry and other stakeholders to be interested and open to a discussion to identify, minimize, and mitigate environmental impacts. It is hoped that this research will consolidate available and relevant information for stakeholders to review, and can serve as an initial forum for debate, exchange, and alliance building.

Introduction

Historical Background of Deep Sea Mining

Mineral resources are becoming increasing difficult to extract on land, and recent research in the deep-sea has identified rich ore deposits that may be economically feasible for mining in the next decade (Fujita, 2001). Deep-sea manganese nodules were first discovered during the voyage of the H.M.S. Challenger in 1873 (GBCO, 1965), and then collected by many scientific cruises throughout the first half of the 20th century. In the early 1960s, a significant increase in the commercial use of copper, nickel and cobalt drove metals prices upward, focusing attention on mining the deep-sea for manganese nodules. As nodules are mostly found in international waters, four multinational mining companies were started, and the governments of the Soviet Union, China and India sponsored deep-sea mining enterprises (Yamazaki, 2005a). Close to 0.5 billion dollars went into developing the technology and processes necessary for the retrieval of deep-sea manganese nodules (Yamazaki, 2005a). The United Nations Law of Sea Convention at that time began to consider who exactly owned the mineral deposits on the ocean floor in international waters, ultimately establishing the International Seabed Authority to collect fees and royalties in the name of the "heritage of mankind" for commercial entities wishing to exploit these deep-sea deposits (Division of Ocean Affairs and the Law of the Sea, 2006). However, before deep-sea mining became a viable business enterprise, major land deposits of nickel and copper were discovered in the 1970s driving metal prices downward, making mining for manganese nodules economically unfeasible (Ifremer, 2005).

Economic Drivers of Deep Sea Mining

As we enter the 21st century, and assuming mining companies are finding deposits of sufficient size and grade, there are three possible economic drivers required for DSM to become a viable industry: 1) deep-sea mining may actually be cheaper than land mining, as suggested by Nautilus Minerals' Worley Parson Engineering study (Heydon, 2005) which indicates that DSM for copper could cost about half the price of developing a land-based mine, 2) though unproven, the concept of "surgical mining" of relatively small areas of SMS deposits may have less impact on the environment than terrestrial mining (Heydon, 2005), and 3) India and China will both need large amounts of copper to build power-grid infrastructure, driving the metals market to deep-sea mining (Yamazaki, 2005b).

Deep Sea Mining in Papua New Guinea

Nautilus Minerals Inc, an Australian mining company, and Placer Dome, a Canadian gold mining company, are currently engaged in a deep-sea drilling and remotely operated vehicle (ROV) exploration program in the Eastern Manus Basin off the coast of Papua New Guinea. The goal of this exploration program is to determine if ocean-floor mineral tenements they own host sufficient grade and size seafloor massive sulphide deposits to justify a future potential mining operation (Baulch, 2005a). If mining operations do proceed, then Papua New Guinea (PNG) may be the first country that will have a significant test and development of deep-sea mining processes. DSM represents a new trend in mineral extraction, with many uncertainties about potential environmental impacts.

Project Objectives and Approach

This project uses the Nautilus/ Placer Dome operation as a case study to preemptively address the potential impacts of this new industry.

The specific project objectives are three fold:

1. Create a public document that will identify the most pressing issues for consideration by deep-sea mining companies and stakeholder groups before deep-sea mining occurs.

2. Develop a set of recommendations based upon the findings of the research that may influence the nascent industry.

3. Create a 7-10 minute documentary film for general distribution by conducting interviews with scientists, industry members, legal and policy experts, and group project members that explore deep-sea mining issues.

To achieve these goals a literature review was carried out, focusing on five topic areas: 1) identifying stakeholders and their concerns, 2) the active and in-active hydrothermal vent environment, 3) DSM extraction technology, 4) potential impacts from the use of this technology, and 5) legal and policy issues of mining in territorial waters. Because mining operations are in the initial start-up phase, limited public research has been done and additional outreach was needed in order to have the most up to date information. To achieve this goal the project established a working relation with the mining companies involved and contacted specific researchers in the field.

It is hoped that this research will consolidate available and relevant information for stakeholders to review, and can serve as an initial forum for debate, exchange, and alliance building.

Chapter 1: Identifying Stakeholders and their Concerns

Case Study Stakeholders

The Setting

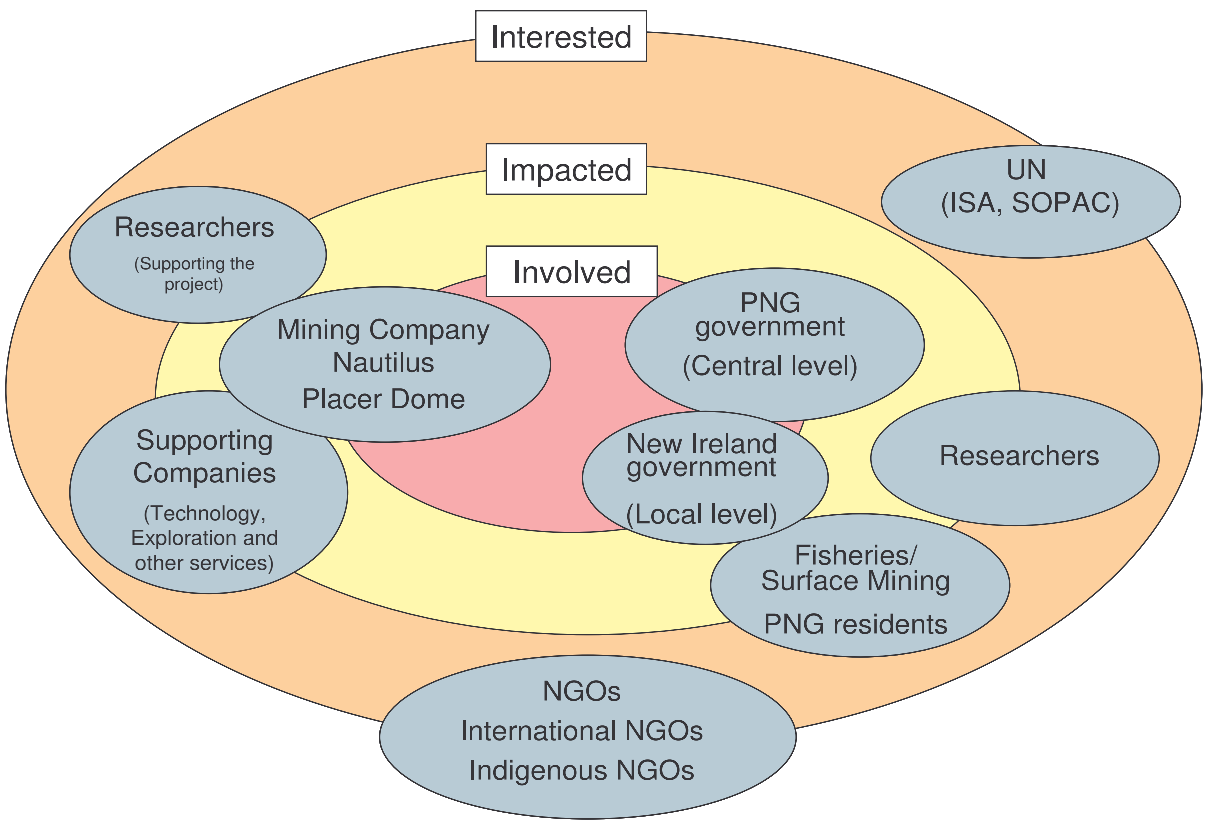
Papua New Guinea (PNG) is a group of islands located north of Australia and includes about half of the island of New Guinea. PNG was originally a Dutch, and then British colony, but after World War II its administration fell to Australia, until receiving independence in 1978. The PNG federal government is a unicameral parliament wherein each province is represented (See Chapter 6 – "Law and Policy" for more on the PNG local and federal government structure). The island of New Ireland is a province of PNG and three of Nautilus Minerals offshore leases are located in the territory of the province, including the Suzette Fields explored and drilled by Placer Dome in the winter of 2006.

The Stakeholders

Large-scale projects by their nature tend to affect a wide array of people, industries, and government bodies. Deep-sea mining is no exception. There are several methods by which these "stakeholders" can be identified and grouped into common concerns. One method classifies stakeholders into primary, secondary and opposition groups (WWF, 2000). Primary stakeholders have authority and responsibilities, and are critical participants in the project. Secondary stakeholders have an indirect interest in the project, while opposition stakeholders are against the project. The second method classifies them by power/interested matrix (Recklies, 2001). High interest and high power stakeholders are key players, while low power stakeholders have a minimal effect. The third method classifies stakeholders by their influence level as a set of inner and outer circles, ranging from involved, impacted or interested concerns. The inner circles stand for the most important stakeholders who have the highest influence (Recklies, 2001). The involved, impacted and interested classification breaks the stakeholders into those entities directly involved or representing a party directly involved, or into those impacted or who may be impacted, but who have no direct involvement, or into those entities who have no direct involvement, and will not be impacted, but have an implicit interest.

To identify the deep-sea mining stakeholders and stakeholder concerns in the case study area, the "involved, impacted and interested" classification fits best, with Figure 1-1 and Table 1-1 illustrating the three stakeholder levels and concerns.

Figure 1-1 The DSM Stakeholders



Involved

At the directly involved level the two main entities are Placer Dome/Nautilus Minerals and the Papua New Guinea federal government, with the New Ireland provincial government involved in the sense that the lease holdings are located in their provincial waters, but the extent to which they will have any say in potential deep-sea mining efforts is uncertain at this time. The mining companies are potentially going into business with the PNG government, and the PNG government in turn is responsible for encouraging this relationship. For a full analysis of how PNG federal and local laws and policies will or will not affect any deep-sea mining effort in PNG territorial waters or EEZs, see Chapter 6 – Law and Policy.

Impacted

Those stakeholders impacted by the project includes the people of PNG through economic and environmental concerns, the PNG fishery industry, the supporting technical service companies, and the various scientific researchers who are involved in the exploration and potential exploitation effort.

Interested

The outer level is the interested stakeholders, including the United Nations (UN) via the International Seabed Authority (ISA), the South Pacific Applied Geoscience Commission (SOPAC), large international NGOs like Conservation International, and local PNGs NGOs such as Individual and Community Rights Advocacy Forum (ICRAF).

Interacting Stakeholder Concerns

The identification of stakeholders and their concerns is an important component of the success of any project, especially deep-sea mining with its large number of unknowns concerning the environment. Having stakeholder input from all concerned tiers is essential when envisioning an industry that acts as a good corporate citizen, alongside an enlightened government that promulgates clear and effective rules and regulations.

As shown in Table 1-1, each stakeholder has different concerns, and sometimes these concerns interact with each other. For example, DSM companies are interested in making a profit, while at the same time they understand that as a cutting edge industry with many uncertainties, with many eyes watching them, they have a responsibility for protecting the environment (Heydon, 2005). Nautilus Minerals and Placer Dome are working with marine science researchers, and the government of PNG to ensure environmental protection at each stage of their operation. Simultaneously, marine researchers are expecting to find new scientific data about the deep oceans as they work with the mining company, showing further overlap of concerns and interest among stakeholders.

The PNG government and local communities have positive and negative concerns about DSM. The positive factor is that DSM could be a local economic driver. The mining sector in PNG accounts for 29 percent of GDP and 77 percent of total exports in 2000 (PNG forum, 2005). DSM could add to the GDP. Additionally, local communities would expect job opportunities with the offshore mining companies. The negative factor is that PNG suffers from terrestrial mining pollution, and DSM could have environmental impacts. PNG fishers care about the impact of DSM on the catch of fish. The PNG government must make the appropriate decisions based on these concerns, encouraging development, yet requiring the mining companies to act as good corporate citizens.

NGOs are also part of the stakeholder mix, and represent the weak or “no voice bodies” such as flora and fauna, and indigenous people. In the case of the potential mining of the Suzette Fields, it is expected that NGOs will play an important role in keeping a balance between development and environmental protection by working with industry and the government.

Advisory committee consisting of key stakeholders

In order to establish confidence between stakeholders, it is important that details of the project be disclosed to all interested parties, as well as a forum for exchange of opinions be conducted. Some terrestrial mines have set up advisory committees to handle this exchanged of information and opinions, usually consisting of local residents, NGOs, the government, and the company. The Porgera Gold Mine, which is one of the largest gold mines in PNG, is an example.

The Porgera Environmental Advisory Komiti's (PEAK) was established in 1996 to raise awareness of and address concerns about the social and environmental impact of the mine (PEAK, 2005). PEAK represents the interests of key stakeholders in the mine, including the PNG government, environmental and aid groups, independent technical experts and the company. The group has periodic meetings, reviews the annual environmental monitoring reports, and advises the companies on the necessity of relevant studies for the mine closure plan. These types of actions should also be applied to the DSM.

Table 1-1 The DSM Stakeholders list

Tier	Name	Status	Concerns
Involved			
Industries			**Promoting PNG project**
	Nautilus Minerals	Core company	Promoting PNG project Managing all concerns towards PNG project
	Placer Dome	Supporting company	Supporting Nautilus financially and technically
	Nautilus Allience Group	Supporting company	Supporting Nautilus technically
Government			**Supervising Mining Industry**
	PNG Federal Government	Federal Government	Supervising safety and environmental conservation issues Governing offshore mining Taking DSM as resource of economic growth
	New Ireland Provincial Government	Provincial Governemnt	Supervising environmental conservation issues by checking the Environmental Plan
Impacted			
Fisheries			**Caring about the impact on fisheries**
	Forum Fisheries Agency	A consortium of 17 Pacific Island countries	Defending member country fisheries
	National Fisheries Authority	PNG's fisheries regulatory authority	Defending PNG's fisheries
Supporitng Industories			**Potential job opportunities**
	PNG Coastal Shipowners Association	PNG's shipowners	Potential job opportunities
	PNG Maritime Workers Industial Union	PNG's maritime workers	Potential job opportunities
	PNG Maritime College	PNG's maritime school	Potential job opportunities
Marine Science reserchers			**Scientific interst**
	The Commonealth Scientific and Industrial Research Organization (CSIRO)	Australian national science agency	Scientific interst Supports Nautilus and others
	College of William & Mary	Univeristy	Dr. Cindy Van-Dover, investigating the site with Nautilus
	InterRidge	Association of oceanic ridge researchers	Scientific Interest
	The Underwater Mining Institute (UMI)	Association of deep-sea mining expertises	Scientific and technical interest
Interested			
International Authorities			**Support PNG policy making**
	Int'l Seabed Authorities (ISA)	UN based oversight body	Supports PNG policy making Considers PNG project as a leading casestudy
	South Pacific Applied Geoscience Commission (SOPAC)	Regional oversight body	Environmental and social issues related to offshore mineral resources PNG is a member of SOPAC
NGOs			**Cares impact on the enviornment**
	Conservation International	US based international NGO	Environmental interest with branch in PNG
	Terra Nature	New Zealand based NGO	Environmental and legal interest It protested DSM activity by Neptune in NZ
	Indivisual and Community Rights Advocacy Forum (ICRAF)	PNG based NGO	Environmental interest and land rights

Chapter 2: The Science of Hydrothermal Vents

Geography, Geology and the Tectonics of the Manus Basin

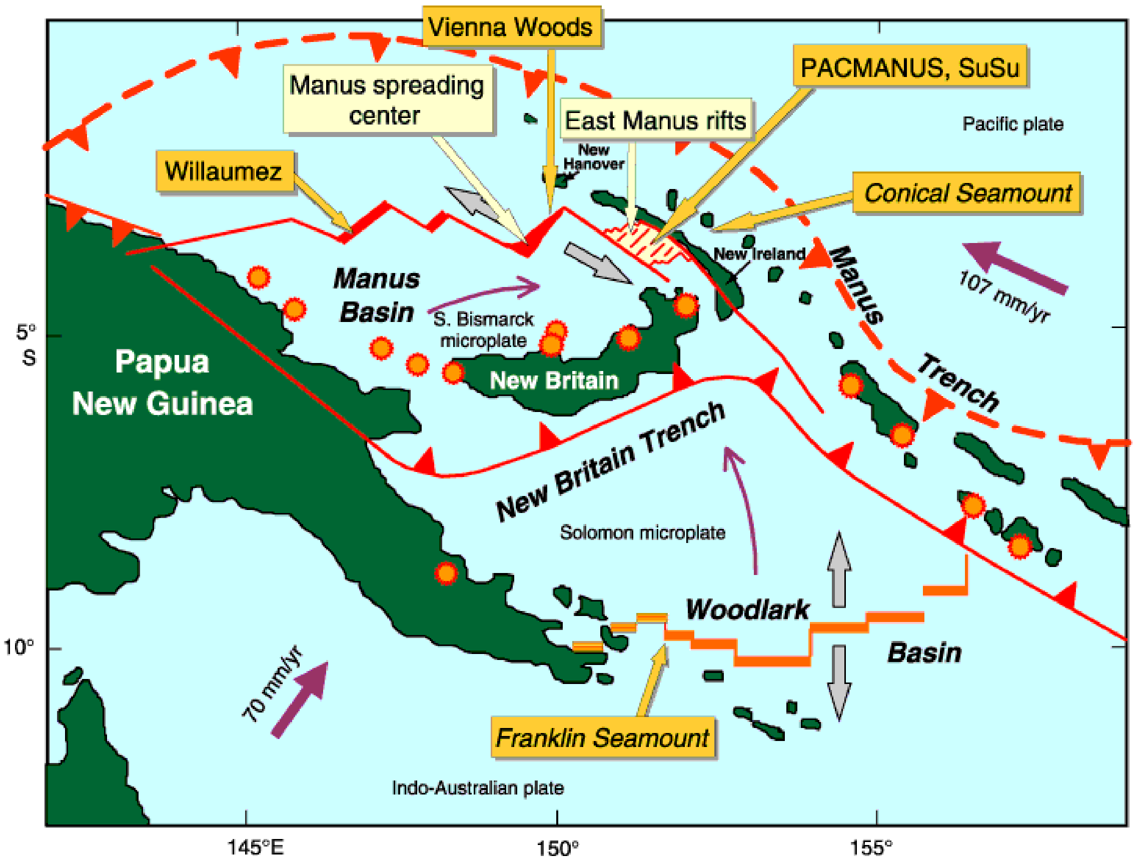
Placer Dome's interest of deep-sea mining of seafloor massive sulfides is focused on the eastern part of the Bismarck Sea, specifically in the eastern Manus Basin, which is tectonically classified as a back-arc basin (Figure 2-1). These basins are usually formed behind island arcs, which in turn are formed along active plate margins. In these areas, oceanic slabs of thick crust are subducted beneath a plate moving in the opposite direction. At the Manus Basin, the Solomon Sea plate subducts at the New Britain trench along a northeast or northwest direction (Binns, 1995). As the slab sinks it pulls on the overlying plate, creating a portion of Earth that splits open and forms a zone of extension. Magma upwells into this extension accumulating material to the crustal plate and essentially forms the back-arc basin (Van Dover, 2000). Because water from the sinking oceanic slab may be injected into the hot mantle below, the magma upwelling into the extension zones has a geochemistry known to be rich in ores that terrestrial mining companies seek (Van Dover, 2000). The back-arc basins are known to be rich in seafloor massive sulfide deposits due to the tectonic activity and mineralization on or near hydrothermal vent sites (Herzig, 2004).

The Manus Basin, in particular, is an 80-100 km wide rift zone with three major transform faults running through it, and reaching depths of up to 2500 meters (Binns, 1995). The bottom of the central Manus Basin may be predominantly basaltic crust formed in an earlier phase of back-arc spreading about 5 million years ago. Seismic profiles of the eastern Manus Basin show ~300 meter wedges of presumed late Pleistocene sediment lapping against older growth faults (Binns, 1995). The crustal thinning is caused by present day tectonic activity, therefore creating rugged topography. The eastern Manus rift zone is a "pull-apart" structure between two of the major transform faults.

The basin includes three hydrothermal zones named PACMANUS (Papua New Guinea-Australia-Canada-Manus), DESMOS, and SuSu Knolls, which includes the Suzette Vent field. It is an area of rough geomorphology where hydrothermal zones have the characteristic black-smoker chimney structure, indicating active hydrothermal vents, whereas a lack of a black-smoker is known to be an inactive vent (see page 20). Previous expeditions completed by CSIRO, Australia's national science agency, detected large plumes in this vicinity leading to the discovery of the 5 km long active hydrothermal sulfide mounds in 1994 at the Suzette field (McDonald, 1998).

The Suzette Vent field is one of three domes or cones in the SuSu Knolls area, each 1 km apart. It is the lowest dome, reaching 1550 meters and contains 200 to 300 meters of closely packed chimneys where sulfide sediments are both fine and coarse along the field (Binns and Dekker, 1998). Once the intense plume was isolated at the field, scientists further discovered the particular chimney structure at Suzette contained large amounts of chalcopyrite-rich massive sulfide and included minerals such as copper, zinc, gold, and silver (Binns, 1997; WWF/IUCN, 2001). Therefore, this discovery led to the interest of further exploring the Suzette field for seafloor massive sulfides in the back-arc basin, which in turn led to Placer Dome's exploration phases.

Figure 2-1: Vienna Woods (Australian Government, Geoscience Australia)



Hydrothermal Vent Formation & the Formation of Seafloor Massive Sulfides

Hydrothermal vents exist in various sites around the eastern Manus Basin and these vents form seafloor massive sulfides. The disruption of the sea floor allows cracks to form creating a system where cold seawater flows in, and hot, mineral rich seawater flows out creating a hard chimney structure and plume known as a "black smoker." Some of these cracks may extend thousands of meters into the lower crust. These cracks evolve into a series of passageways known as stockworks (Hannington, 1995). A circulation system develops where seawater enters the cracks in the crust at one location, is transported downwards where it makes contact with hot rocks or even magma, and boils to the surface. The seawater and oceanic crust interact becoming superheated from the intense pressure, often reaching temperatures up to 400 degrees Celsius. This superheated water mixes with the cold 2 degree Celsius bottom water and allows iron sulfides and other metals to precipitate. From the opening on the sea floor to a few meters away from the vent, a temperature gradient is formed (Van Dover, 2000).

Once the seawater interacts with the basalt, the chimney begins to form. The following steps detail the growth of a black-smoker chimney.

1) Anhydrite (calcium sulfate, CaSO4) precipitates
2) The anhydrite forms a sheath around the exiting fluids that are released from the crust
3) Development of anhydrite deposits grow up to 30 cm/day (Van Dover, 2000)forming the chimney wall and insulating the hydrothermal fluids
4) Deposition of chalcopyrite (copper), or other metals
5) Pore spaces of the chimney become filled with anhydrite and other sulfide minerals
6) Anhydrite dissolves into the seawater from the outer wall of the chimney
7) Other chimney-like structures may form such as a "bee hive" and flanges can grow which are horizontal from the sulfide mounds
8) The structure can continue to grow up to heights of 10-20 meters
9) When hot fluids cease to flow, the metal sulfides begin to oxidize
10) The oxidation causes the chimney to become unstable and chimneys lacking siliceous, barite, or calcites are also fragile and therefore tectonic activity will cause the chimney to fall.
11) Ultimately, hot fluids cease to flow through chimney structures either from the chimney falling and sealing off the orifice or from the lack of fluid flowing from the Earth's crust.

The formation of a black-smoker chimney is a process that involves multiple gases and chemicals, which can eventually create the massive sulfides on the sea floor. The vent fluids have a range in pH of 3-5 and are enriched in sulfides, hydrogen, methane, manganese, iron, zinc, copper, lead, cobalt, and aluminum. The vents fluids lack oxygen and magnesium. The ocean currents disperse the hot mineral rich water, where the minerals interact with cold ocean water and particulates settle out to form metal-enriched sediments or "metalliferous" sediments (Mills, 1995). Once the sediments of the plume have settled on the ocean floor a mound is formed resulting in the formation of polymetallic sulfide deposits containing the previously described metals.

Seafloor massive sulfides are areas of ore that contain more than 50% sulfide minerals (Binns, 2005). They are highly concentrated and in some cases may be comparable or larger than some deposited on land (Scott, 2004). The following table describes the average gold content of sulfide mounds in various locations of the deep sea surrounding Papua New Guinea (Herzig, 2004). The deposits with the highest ore grade found to date is located at Conical Seamount in the EEZ of Papua New Guinea. Sample ores contain up to 26 percent zinc, 15 percent copper, and a record average of 15g of gold and 200g of silver per tonne (Borgese, 2000).

Table 2-1

Location	Average Gold Content (PPM)	Maximum Gold Content (PPM)	Number of Samples (N)
Vienna Woods	30	50	10
PACMANUS	15	54.9	2676
Woodlark Basin	-	21	-
Conical Seamount	26	230	40

The metals that precipitate out of the chimney form the particle-rich plume. The plume is a zone of great importance for the hydrothermal vent as it maintains chemical reactions between vent fluids and the seawater. It is a habitat for microorganisms and zooplankton. For the mining industry, it will be the first means of detection of an active hydrothermal site (Van Dover, 2000). The plume itself is a column of hydrothermal fluids and precipitates where cold water is drawn in forming turbulent eddies. There are three types of fluids that arise out of the chimneys.

1) Seawater that has been heated from hot rock, losing magnesium and sulfates and gaining other elements.

2) Vapor that is rich in volatile compounds

3) Brine that is rich in metals and depleted gases.

Active versus Inactive Hydrothermal Vent Sites

Placer Dome's exploration phase will be completed in what the mining company has described as an inactive site of the Suzette field. There is uncertainty between what is considered active and inactive, and one might call it a continuum. Active hydrothermal vent sites have large plumes with thriving, abundant communities of organisms. Within the ecosystem, competition for space is not unusual and animals rely on symbiotic relationships with microbes. Mussel beds are abundant with clams, shrimp and crab commuting around the vent periphery (see page 22 for further explanation of biodiversity). These communities are ever changing and short lived, ranging from 10 to 100s of years and long lived, ranging from 100 to 1000s of years (Van Dover, 2004).

Inactive vents have minimal plume eruption but still transport larvae and support microbial life. Macrofaunal invertebrates such as crabs and shrimp have been found at inactive sites (Van Dover, 2004). The International Seabed Authority has listed hydrothermal vent sites as either active or inactive, (table 2-2). This table lists various sites of the Manus Basin and offers locations and site descriptions. The third row depicts the site where exploration mining trials have begun, SuSu Knolls, and describes that it is active.

Table 2-2: Hydrothermal Vent Sites of the Manus Basin, International Seabed Authority

Location Name, Area, & Depth (m)	Tectonic Setting	Deposit Type	Site Description
CENTRAL MANUS BASIN MANUS BASIN, BISMARCK SEA Depth 2500m	BACK-ARC SPREADING CENTER	POLYMETALLIC MASSIVE SULFIDES **(INACTIVE)**	INACTIVE, MASSIVE SULFIDE DEPOSITS, FE OXIDE GOSSANS, LOW-TEMPERATURE FE OXIDE AND SILICA CHIMNEYS, AND FE-MN CRUSTS ON THE MANUS BACK-ARC SPREADING CENTER (UP TO 150 M EXPLORED DIMENSIONS)
CENTRAL MANUS BASIN, VIENNA WOODS MANUS BASIN, BISMARCK SEA Depth 2500m	BACK-ARC SPREADING CENTER	POLYMETALLIC MASSIVE SULFIDES (**ACTIVE**)	ACTIVE BLACK SMOKERS (285-300oC), MASSIVE SULFIDE DEPOSITS, FE OXIDE GOSSANS, LOW-TEMPERATURE FE OXIDE AND SILICA CHIMNEYS, AND FE-MN CRUSTS ON THE MANUS BACK-ARC SPREADING CENTER (UP TO 150 M EXPLORED DIMENSIONS)
EASTERN MANUS BASIN, PACMANUS & SUSU KNOLLS MANUS BASIN, BISMARCK SEA Depth 1650m	BACK-ARC SPREADING CENTER	POLYMETALLIC MASSIVE SULFIDES **(ACTIVE)**	ACTIVE SULFIDE DEPOSITS, FE OXIDE GOSSANS, LOW-TEMPERATURE FE OXIDE AND SILICA CHIMNEYS, AND FE-MN CRUSTS ON THE MANUS BACK-ARC SPREADING CENTER (UP TO 150 M EXPLORED DIMENSIONS), DIFFUSE LOW-TEMPERATURE VENTS (<30oC), HIGH-TEMPERATURE VENTS (245-268oC)
DESMOS CAULDRON EASTERN MANUS BASIN, BISMARCK SEA Depth 2100m	BACK-ARC SPREADING CENTER	DISSEMINATED SULFIDES AND NATIVE SULFUR DEPOSITS **(ACTIVE)**	DEPOSITS OF DISSEMINATED PYRITE AND NATIVE SULFUR CEMENTING VOLCANICLASTIC SEDIMENTS IN SUBMARINE CALDERA ON SPREADING CENTER, EVENT PLUME

Hydrothermal Vent Ecosystems

1) Words such as exotic, bizarre and strange have been used to describe the hydrothermal vent ecosystems because of the distinct life forms that are found to be living there. The first discovery of a hydrothermal vent ecosystem was in 1977 on the Galapagos rift off of the coast of Ecuador. This area, known as the Rose Garden, was studied extensively and shown to host animals that had to adapt to large changes in temperature as well as a harsh chemical environment without any sunlight. Now, these once "bizarre" sites of deep-sea communities are known to thrive in many locations at the bottom of the sea floor along plate margins and hot spots. The largest vent site to date is known as TAG –Trans Atlantic Geotraverse

– and is approximately a hectare in size with black smoker chimneys measuring up to 160 meters.

Active versus Inactive Hydrothermal Vent Sites

Active hydrothermal vents support productive concentrations of animals and microbes that have adapted to life under extreme conditions. These conditions include deep ocean depths with high pressures, particular chemical conditions, extreme temperatures and total darkness. Organisms found at venting sites are dependent on hydrothermal fluid; thus, they are adapted to living in an unstable environment. Thermal upwelling of mineral rich fluid plays an important role in vent communities. Once the fluid from the hydrothermal vent stops, the food source is no longer available. These animals must be adapted to recolonize new areas through immigration or larvae transport when venting ceases. Geothermal activity creates new habitat for organisms to colonize. In contrast, venting can stop or become blocked thus eliminating habitat. Due to this variable environment the ecological characteristics of the organisms found at vent sites has been described as weedy and ephemeral (Childress, 2005).

Food Web

The vent ecosystems are rich in carbon dioxide, hydrogen sulfide, organic carbon compounds, methane, hydrogen, and ammonium. Mineral rich venting fluid forms the basis for the food web. The bacteria found in the vent systems are chemoautotrophic and use hydrogen sulfide or methane as their energy source. The majority of bacteria obtain their energy source from sulfide. Bacteria are specialized for extreme conditions. Hyperthermophiles can be found in extreme temperatures over 80°C, barophiles survive at high pressure, and acidophiles survive in acidic conditions.

Bacteria can be found living in the subsurface of the vents, on surfaces surrounding vent openings, on the surfaces of vent animals, and suspended within the effluent itself (Hessler, 1995). Bacteria and hydrothermal vent organisms form symbiotic relationships with various animals. The importance of the symbiotic relationships between these organisms is illustrated by the Giant Tubeworm, *Riftia pachyptila,* where the relationship with bacteria is obligatory (essential for both host and symbiont). This tubeworm is a large animal reaching 1-2 meters in length. The host, *Riftia*, provides the symbiont, bacteria, with a stable supply of nutrients from the external environment, and the symbiont supplies the host with a stable supply of organic carbon (Van Dover, 2000). *Riftia pachyptila* lacks a digestive system, and relies exclusively on the chemosynthetic bacteria for energy. The bacteria live inside the trophosome of the tubeworm, which is a specialized organ to house the sulfide-oxidizing bacteria. It is imperative that the higher organisms are able to incorporate the energy produced by the microorganisms so that they can survive at hydrothermal vents. Other symbiotic dependent organisms include the Giant White Clams and the mussel *Bathymodiolus*. In both cases bacteria live in the gill filaments. Snails and clams are also known to host symbiotic bacteria.

In addition to maintaining symbiotic relationships, the bacteria also form the basis of the food web as primary producers. Organisms such as the blind Atlantic vent shrimp, *Rimacaris,* feed on the sulfur bacteria directly. Similarly, other worms and polychaetes have been observed with bacteria in their gut, suggesting they feed directly on the mats of sulfur bacteria. Larger organisms, such as crabs and fishes are opportunistic feeders and feed on other vent organisms. Thus, a food web is established, consisting of primary producers (chemoautotrophic sulfur bacteria), the secondary producers (tubeworms, mussels, clams, shrimp), and predators (fishes) or detritivores (crabs).

Sample Zoning of Hydrothermal Vents

Hydrothermal vents have their own zonation pattern around the vent. This pattern can be broken down into three distinct zones: vent opening, near field, and vent periphery (Hessler, 1995).

1. The Vent Opening

The rich hydrothermal fluid is the source of energy for most of the biomass in these ecosystems; consequently, many organisms can be found in this zone. Animals in this area are highly dependent on endosymbiotic bacteria. This zone supports animals such as vestimentiferan tubeworms, vesicomyid clams, and mussels.

With regard to community ecology, competition for space and predation are major forces shaping species abundance and community composition at the vent opening. The high concentration of food around the vent opening creates competition for space. Predation also plays a key role in shaping community structure at the vent opening. Micheli et. al., (2002), found that hydrothermal vent communities are dependent on large mobile predators because they may remove the dominate grazers. Predators directly reduce the abundance of gastropod species and this indirectly reduces grazing; thus, creating more food for other organisms. Predation may play a larger role when one species dominates the space at a vent opening (Micheli, 2002).

2. Near-Field

Vent fluid is less concentrated in the near-field than at the vent opening, and organisms rely on filter feeding to supplement their diet. Benthic fauna found in this zone are dominated by sessile suspension feeders such as feather duster worms, barnacles, anemones, and bivalve mollusks. Mobile predators such as fish, polychaetes, and crabs are among the animals that surround the permanently attached animals. Space is not as limited in the near field or the vent periphery; therefore, space completion does not play as large of a role in shaping community structure. In both the near-field and the vent periphery, completion for food, rather than space, can play a role in community structure.

3. Vent Periphery

The animals found in these zones do not live in the extreme chemical and thermal environments but they rely on the productivity at vent openings and in the near-field for food. Often these organisms feed directly on vent openings and near-field organisms. These communities consist of spaghetti worms, sea cucumbers, spider crabs, and the large protozoan, Xenophyophoia. Little is understood about community composition and structure in this zone.

Organisms Found in PNG

The recent cruise in Papua New Guinea have found that this region is dominated by several organisms which are distinctive from other regions including the large gastropod, *Fremeria nautilei*, sessile barnacles, and tubeworms (Van Dover, 2000). Discoveries from cruises conducted in 1996 and 1998 at the PACMANUS and DESMOS sites indicate that the large communities of the gastropod, *Fremeria nautilei,* is the predominate organism found at these sites. Other organisms that can be found in PNG region include: limpets, barnacles, alvinocarid shrimp, bythograeid crabs, squat lobsters, and zoarcid fish, (Table 2-3) (Hashimoto, 1999).

Table 2-3: Typical Animals Found at Hydrothermal Vent Sites in the Manus Basin

Microorgansims	**Macrofaunal and Magafaunal Organisms**	
	Families	*Example Species*
Bacterioplankton	Polychaeates	Scale Worms and Vestimentiferans
Bacterial Mats (*Beggiatoa*)	Gastropods	Phenocolepadid and Limpets
Endosymbiotic Bacteria	Bivalves	Vesicomyid Clams
Chimney Microbes (*Halobacteriales*)	Crustaceans	Eolepadid Barnacles, Squat Lobster, and Bresilidae Shrimp
Sub-Surface Microbes (*Geobacillus*)	Echinoderms	Sea Cucumbers and Sea Urchins

Placer Dome and Nautilus conducted their first drilling cruise in January 2006. Video footage was collected for active and inactive sites in the Suzette Vent field. ROV footage showed that megafauna are present at both active hydrothermal areas and inactive hydrothermal areas. Active areas hosted moderate to high densities of gastropods, shrimp, and crabs. Although tubeworms have been observed in the Manus Basin, no tubeworms were found in the area surveyed by Placer Dome and Nautilus. ROV footage indicated that inactive areas (potential mining sites) hosted far less megafauna than active areas. In many instances only one solitary fish was observed at inactive areas. Megafuana at inactive sites consisted of crabs and the zoarcid fish. Data on macrofauna, meiofuana, and microfauna were also collected during the cruise at both active and inactive areas; however, data have not yet been analyzed.

Active and Inactive Endemism

There is currently debate about the endemism of organisms at active and inactive sites. Active venting areas around the world have been studied for 30 years but areas in the Manus Basin have only been studied for 10 years. While there is some information on the community structure and composition at active vents areas, very little is known about inactive areas. To date, there is no published research on community composition or structure at inactive SMS deposits in the Manus Basin. Due to the limited research it is difficult to assess the endemism of communities at both active and inactive sites in PNG. Hessler and Kaharl (1995) suggest that the fauna at vent ecosystems around the world are endemic at the higher taxonomic levels including: one class, one order, five super families, eight families, and numerous genera. It has yet to be determined if animals found in both active and inactive sites in the Suzette Vent field are endemic to the PNG area.

Chapter 3: Seafloor Massive Sulfide Mining Technology

The fundamental difference between terrestrial and seafloor massive sulfide deposits from an engineering perspective is land-based deposits are covered by overburden, which must be removed before extraction can begin; seafloor massive sulfide deposits are covered by a few kilometers water, which does not need to be removed for extraction. For terrestrial exploration it is not uncommon to drill through a kilometer or more of rock just to sample the ore grade of a deposit. Next, an exploratory shaft is dug. The shaft is expanded into a trial mining operation and then finally, a much larger mature mining operation starts. Terrestrial mining has developed large extraction equipment to counter falling ore grades, using an economies-of-scale approach to remain profitable.

DSM technology may not need to be large, but it will be required to operate in an extreme environment. Temperature at hydrothermal vents can be up to 400°C and as low as 2°C short distances away. The acidity around vents field is a pH of 3-5. The topography around mining site is very rugged. Beyond basic functionality, technology will be required to operate safely and efficiently while minimizing environmental impacts.

In order to develop DSM technology, Nautilus put together an Alliance of eight key players from the offshore equipment, services and engineering industries. These players are still developing deep-sea mining technology. Current designs have drawn upon existing technology from both the offshore petroleum and transoceanic communications cable industries. The basic methods and designs for exploration and extraction are in the public domain. Specific designs and methods developed by industry first movers are considered patentable or trade secrets. As such, for the purposes of this section, we will only review currently proposed DSM technology and operations designs within the public domain and then offer some potential solutions to identified problems.

Proposed Mining Procedures

Deep-sea mining technology and its application in the environment represent the most direct impacts of the industry. Hence, technology and the practices developed for its application represent the best opportunity for the industry to directly mitigate the negative impacts as well as enhance any potentially beneficial impacts.

Exploration

1. Locating

Exploratory technology for deep-sea mining is currently in use and is similar to petroleum exploratory technology. Active vents can be located from the plume, which can be detected up to 10 km away, and tracked it to its source. Continental margin fault lines can be followed using side scan sonar. Vent fields generally occur along continental margins where geologic instability is common. Inactive vents and active vents can generally be found in close proximity (Baulch, 2005b).

Active vent plumes can be located by detecting compounds or elements such as methane and manganese, which occur in the water around the source vent. (Herzig and Petersen, 2000). Locating inactive vents is more difficult; exploration teams use side-scan sonar, seismic surveyors, and deep-tow video systems to find the telltale features of an SMS mound (Herzig and Petersen, 2000).

2. Sampling

Once a SMS deposit is identified, it must be sampled for ore grade and deposit tonnage. Ore sample retrieval can be achieved by a submarine, remotely operated vehicle, drilling, or dredging. (Herzig and Petersen, 2000). Submarines and ROVs are typically equipped with multi-function manipulator arms. ROVs can also be equipped with a drill pack capable of retrieving a 75mm diameter core 15m in length. (Nautilus, 2005).

Submarines require pilots and are more expensive to operate than ROVs. Submarine depth ratings range between 400-6500m. (Herzig and Petersen, 2000). ROVs used are depth rated to 3500m and can dive for a week or more (Herzig and Petersen, 2000) (Nautilus, 2005). ROVs also allow more than one scientist to be involved in the dive, though submersibles may provide scientists with a much better appreciation for seafloor that video cannot duplicate (Herzig and Petersen, 2000).

3. Drilling

If the initial samples indicate a high-grade ore, and the video and sonar surveys show a SMS deposit of commercially exploitable size, then coring is required. Grid drilling is used to determine the average ore grade throughout the body of the deposit and to determine its volume.

Drilling can be achieved by drill ship or by a remotely operated coring machine. A scientific research drilling vessel like the JOIDES Resolution can cost $180,000/day (Herzig and Petersen, 2000). The need for a cheaper solution has led to remotely operated coring machines which can be lowered to the drill site thus avoiding the need for long drill strings. Two designs; PROD (Portable Remotely Operated Drill) and BMS (Benthic Multicoring System), are currently proposed.

Table 3-1: Available Drilling and Coring Devices

System	Depth	Coring Depth	Core Diameter
PROD[1]	2,000 m	100 m	40 mm
1. Portable Remotely Operated Drill, Australia/USA			
BMS[2]	6,000 m	20 m	44 mm
2. Benthic Multicoring System, Japan/USA			

When these prototype systems were initially deployed, core sample retrieval was as little as 26%. It has been previously suggested that "portable" drilling and coring capabilities must improve to a drilling depth of 50-100m and core recovery of >50% to be used from ships-of-opportunity (Herzig, 1999). In September of 2005 Williamson & Associates, Inc. tested the second generation BMS system and successfully recovered a cored 7.4m of a core sample in 3377m of water. The BMS2 is rated to depths of 6000m and 30m coring (Williamson, 2005).

Extraction

After the size and ore grade of the deposit have been assessed, trial mining may begin. Specific designs for SMS extraction are still in development and have not been disclosed, but concepts have been publicly discussed. These are a mixture of previous designs for crust and nodule mining, including modified technology from terrestrial coal and ocean diamond mining methods. SMS deposits present several challenges for extraction technology. First, the ore body is comprised of a combination of loose material such as fallen chimneys, and solid fused minerals such as re-crystallized sulfides and deposition layers (Herzig, 1999). Second, the seafloor terrain may be rugged due to tectonic activity. Extracting the ore body, while minimizing environmental impacts, will require a combination of technologies working in stages. An SMS extraction device can be divided by three components: 1) drive body, 2) ore crusher and 3) ore lifter.

1. Remotely Operated Vehicles: "Drive body"

Nautilus has investigated the use of proven subsea technology for mining the SMS deposits. This 900HP ROV oil/gas pipelay trenching machine is as powerful as a D11 bulldozer.

Figure 3-2: Remotely Operated Vehicle

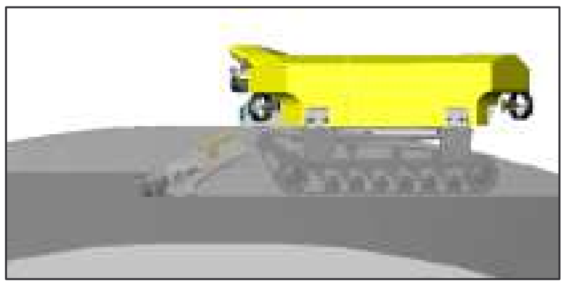


Figure 3-3: ROV with drum cutter

The prime workhorse for DSM operations is the ROV. Used originally in transoceanic communications cable laying applications, it has found a new application in DSM. According to Dave Heydon of Nautilus Minerals, by digging a trench in the ocean floor these ROVs "are already 'mining' just not recovering the material." The flexible nature of the ROV's use of attachments, make it ideal for working in an uncertain environment.

Nautilus has proposed the use of two 1,000 hp ROVs fitted with drum cutters originally used in terrestrial coal extraction. The ROV crawls over the seafloor on tracks "after one track length (the 'miner') has made a flat 'road' to operate on" (Hayden, 2004). However, if the seafloor is rugged it may be difficult to set down and apply the proposed big ROVs to cut the first layer. Therefore, a special ROV which bulldozes the rugged surface and prepares for setting up the proposed big ROV may be needed (Yamazaki, 2005b).

A different solution may be the use of 7 m diameter rotating cutter heads originally designed for ocean diamond mining operations (De Beers Marine, Namibia). The cutter heads are mounted on a flexible drill string and could be used to clear loose material to create a flat surface. For the solid sulfide bearing rocks underneath the loose material, the cutter heads would require the application of weight (tens of tonnes) to crush the sulfide bearing rocks to a suitable grain size for lifting to the surface (Herzig and Petersen, 2000). The ROV may be able to use its own weight (3700 kg) along with the weight of the drill heads to produce some of the necessary force. Added weight will likely be required to use the cutter heads for extraction of the solid portion of the ore body.

These ROVs will be powered electrically from an anchored platform, each mining 200 tons per hour (Heydon, 2004). ROVs operate on an electric-to-hydraulic conversion system. Typically electric-hydraulic conversion is not very efficient, but modern ROVs compensate for this by "the ability to locate very powerful but compact hydraulic motors right where the power is needed. Comparatively the power to weight ratio of hydraulic motors is more than twice that of electric" (Miller, 2004).

2. Cutters: "Ore crusher"

Figure 3-4: Coal mining drum cutter

Currently, there are two designs for breaking up the sulfides: 1) A cutter drum used for coal mining applications, and 2) three-head rotational cutters used for ocean diamond mining. Cutting teeth on the drum cutter are designed to minimize the production of ultra fine particle and optimized to produce particles averaging 50 mm in size and as large as 70 mm. Natural particle sizes of the minerals in the ore depend on the formation processes and can range from 10 to 600 microns, though larger sizes can form when "early-formed minerals are continuously re-crystallized by hydrothermal reworking" (Herzig and Petersen, 2000).

Plumes can be caused through the production of ultra-fine particles (<10 microns) where the cutter teeth meet the rock. Rock cutters are designed such that the separation distance of the teeth fractures the rock. Cutter teeth distance and pattern is dictated by the fracturing characteristics of the target rock. Fine material is created by the crushing force of the tooth as it enters the rock and forms a "pressure bulb" between the tooth and rock, which then creates the fractures that form the desired rock chips (ATS, 2006).

The drum cutter design may be less expensive and easier to modify, but its open design may still create pluming problems. The cutter head design may reduce pluming because the rotation of the 3 cutter heads draws the crushed ore to the middle of the three heads where the lift hose opening is located.

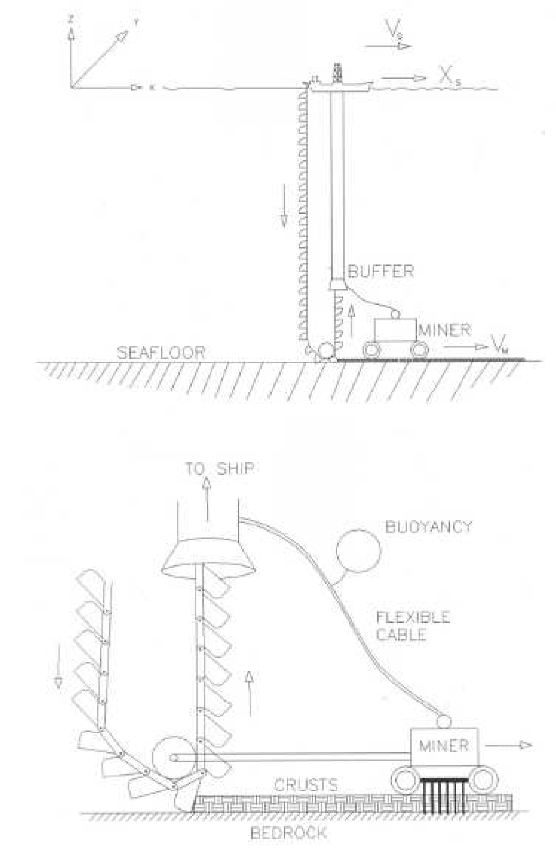


Fig. 5 A crust Mining System—hybrid mining systems: (a) continuous line bucket (CLB) system through pipe; (b) combined CLB and hydraulic system (Chung, 1994)

Figure 3-5: Line bucket lift system

3. Risers: "Ore lifter"

The SMS ore will then be lifted to the platform and prepared for transportation to a processing plant. Currently, two methods are proposed. One is a riser pipe using cold deep-sea water as a transport fluid. The ore is then "dewatered" and the fines recovered by cyclones. Lift water is then returned to a (currently undetermined) location in the water column. A depth of 500 m was suggested by Nautilus' CEO Dave Hayden. He also suggested that the nutrient rich water might have a beneficial use/impact such as the deep water used in aquaculture from Hawaii's OTEC (Ocean Thermal-Electric Conversion) project. This method is appropriate for extraction scales in excess of a few million tons per year (Yamazaki, 2005b). Extraction cycle periods for a 2 million ton deposit are estimated at a year. A different method, originally designed for crustal mining, is a "wire-line-bucket method", which uses big buckets connected in series by a wire. This more conventional method is appropriate when the scale is less than a few millions ton per year (Yamazaki, 2005b) (Chung, 2005).

Transportation

Preliminary studies conducted by Nautilus Minerals determined that offshore processing and/or storage of the SMS ore would be financially infeasible. (Hayden, 2004) The ore body will be transported to shore by ships, which means platform-to-shore transport. Cargo ships generally run off of diesel engines that operate in multi-megawatt range, consuming hundreds of gallons of diesel fuel per hour (Walke; Wartsila).

Processing

Ore processing technology has typically had the most widespread, concentrated, and lasting environmental impacts in the mining industry. The use of cyanide leaching techniques in gold processing and the resultant cyanide settling ponds have been the source of some of the worst environmental mining catastrophes (i.e., Summitville Mine in Colorado, Marcopper Mine in the Philippines, or Omai Gold Mine in Guyana).

Processing methods of massive sulfide deposits typically recover only 40% of the gold (INEEL, 2005). Much of the losses are because the gold particles in the sulfide ore are too fine (<10 microns) whereas the average particle size used in ore processing slurries is 70 microns (Newmont). This leaves much of the gold on the inside of the ore particle, unavailable to the cyanide molecules during leaching. The gold left in the particle ends up in the tailings, considered too uneconomical to recover. The polymetallic nature of the SMS deposits may further complicate processing, though "dore" bullion (gold bullion with other metallic impurities such as Zn, Cu, or Ag) can be separated further during smelting.

A potential solution to cyanide tainted sulfide tailings disposal may be the ocean. The basic design involves a pipe from the processing plant out to a slope on the seafloor that falls to a kilometer depth. The technique relies upon anoxic conditions at the bottom to be sufficient to inhibit the formation of sulfuric acid and heavy metal dissolution and transport associated with terrestrial acid mine drainage problems. There are 26 such tailings disposal operations in the world and the majority are found in the Asia-Pacific region (Pearce, 2000).

Siting

It is unclear at this time whether new, coastal processing facilities will be built, or whether the ore will be further transported to inland processing facilities associated with existing terrestrial mines. As offshore mining ramps up, the need for coastal processing facilities will increase correspondingly. The closest gold processing plant to the Suzette field is located in the Lihir Islands (Niolam Island) and consists of a crusher, SAG (Semi Autogenous Grinding) and ball mill circuit, flotation circuit, pressure oxidation, and carbon-in-leach processing facilities as well as a smelter and electrowinning facility (Infomine, 2006). This processing plant uses ocean tailing disposal. The choice of new coastal processing facilities vs. the use of existing inland facilities will determine the extent and characteristics of impacts. Inland facility impacts include increase in ore volume, transportation, and energy requirements. In siting of coastal processing facilities, technology risks (such as tailings ponds), and run-off are significant points of impact.

Chapter 4: The Potential Environmental Impacts of DSM

This chapter defines the potential environmental impacts and examines some of the uncertainties surrounding the mining of seafloor massive sulfides (SMS). It begins with a brief review of experiments conducted to examine deep-sea mining impacts from nodule mining experiments that took place over the last twenty five years. Then it evaluates five broad categories of impacts that deep-sea mining of SMS may have if developed. Each category is followed with a brief discussion of mitigation approaches that have been recommended or are being pursued by the companies involved.

Previous Deep-sea Mining Research Experiments

The impacts from DSM have mainly been studied when looking at the potential mining of nodule deposits. Therefore many of the experiments that have been carried out over the last twenty five years operated in a different deep-sea environment than the vents. However, they can shed light on the current situation and in some cases the same issues may apply. The literature on these studies is extensive and has been reviewed previously (Sharma, 2005; Thiel, 1991; WWF/IUCN, 2001). For our purposes, highlighting the timeline of previous research, agencies involved, the locations, and some of the important differences from SMS mining will be sufficient to inform the subsequent discussion of impacts.

One of the primary differences between SMS and nodules is that the substratum does not have the same fine sediment layer that surrounds nodules. Nodules occur much deeper in the ocean, 4,000 to 5,000, meters and are often buried in a layer of mud and fine sediments. The SMS deposits have thinner sediment layers which reduce the extent of potential sediment plumes, but it does not eliminate the issue.

The topography and depth of different deep-sea deposits vary greatly, but the PNG deposits are significantly shallower than those of nodules studied in the past. This makes the exploration and extraction more feasible. In addition, nodule mining was proposed on the sea floor, which is relatively flat and expansive compared to the SMS deposits, which are on ridges and peaks created by tectonic activity. The result is that there will be potentially greater dispersal of plumes from the relatively higher elevations of the mining site to the lower surrounding areas.

These factors create a considerable gap between the knowledge and research done to date and the proposed mining of SMS deposits. However, building on the previous research of impact studies will be particularly useful in predicting potential impacts from sediment plumes and understanding the ecological processes that occur in the deep sea.

Table 4-1 outlines some of the more salient impact experiments that looked specifically at deep-sea mining issues. It identifies the countries and agencies involved as well as the location, depth, and duration of the study. Table 4-2 defines the acronyms used for the following discussion. A major focus of these studies was on the plume impacts on benthic organisms and the slow recovery rates expected in this extreme environment. The experiments also examined and designed methodologies for impact assessments at these extreme depths. This will be addressed more explicitly at the end of this chapter through a comparison to the BACIPS sampling design.

Table 4-1 – Nodule Mining Experiments

Experiment Name	Organization/Country	Location	Time Span*	Depth (m)
MESEDA	Germany	Red Sea	1979	-
DOMES	OMI, OMA, NOAA, USA	Eastern Pacific Ocean	1972-1981	5100, 4300
DISCOL / ATESEPP	TUSCH Research Group, BMBF, German	Deep South Pacific (Peru Basin)	1988-89	4135
NOAA-BIE	NOAA, USA	CCFZ	1991-1993	4800
JET	MMAJ, Japan	CCFZ	1994-1997	5300
IOM-BIE	Inter-Ocean Metal Consortium	CCFZ	1995	4400
INDEX	National Institute of Oceanography, India	Central Indian Ocean Basin	1995 -2002	5120 - 5400
DIETS	MMAJ, Japan	Near Minami-Tori-Shima Island	1998-2002	2,200

Adapted from Sharma (2005), Additional References: (ISOPE, 2002; Thiel et al., 2001; WWF/IUCN, 2001; Yamazaki and Sharma, 2001)

* Includes Baseline Studies

Acronym	Experiment Name
MESEDA	Deep Metaliferous Seidment Development Programme
DOMES	Deep Ocean Mining Enviornmental Study
DISCOL	DIsturbance and reCOLionisation experiment
ATESEPP	Impacts of potential technical interventions on the deeps sea (German translation)
NOAA-BIE	NOAA - Benthic Impact Experiments
JET	Japan deep-sea impact ExperimenT
IOM-BIE	Inter-Ocean Metal Consortium - BIE
INDEX	Indian Deep-sea Enviornment Experiment
DIETS	Direct Impact ExperimenT on Seamount
Acronym	**Full Name**
BIE	Benthic Impact Experiments
CCFZ	Clarion Clipperton Fracture Zone
MMAJ	Metal Mining Agency of Japan
NOAA	National Oceanic and Atmospheric Administration
OMI	Ocean Mining Inc.
OMA	Ocean Mining Associates
TUSCH	German: Tiefseeumweltschutz, deep sea environmental protection

A review of the deep-sea impact experiments by Sharma (2005) concluded that experiments will be more effective if they are done at a scale similar to that of actual mining operations. This would include: using equipment that resembled the mining machinery, creating appropriate sediment discharge, a similar distribution of materials, and real time monitoring of the activity. It was also recommended that a long timeline for studying the impacts be used to better understand the recovery process (Sharma, 2005).
A conclusion that may be drawn from this review of nodule mining experiments is that in order to understand impacts an assessment will need to be a well-documented trial mining endeavor. Scaling up from smaller studies or trying to simulate impacts will be less effective than using the actual technologies and doing a real time assessment of the impacts. Additionally, baseline data collection, before and after impacts, will need to have a long time horizon due to the slow processes occurring in the deep sea.

Identification of Potential Impacts from SMS mining

A review of the scientific literature was conducted and impacts were classified according to a set of attributes that allowed them to be compiled into a matrix. This matrix could then be searched by the impact mechanism, the category of impact, the area of impact, the type of impact, as well as other attributes. The data were compiled from the nodule mining experiments as well as studies concerning more specific potential impacts from mining SMS deposits. The matrix allowed for comparisons of studies that have looked at similar impacts and to identify different categories that are useful for discussion.

Discussions of potential impacts have been organized along oceanic zones in the past. (ISOPE, 2002; Markussen, 1994). This focuses the discussion on how the habitat maybe affected and the specific considerations for that oceanic zone. However, we have chosen to organize the structure of the discussion by categories of impacts. This allows us to focus on the sources of impacts in each category and see what mitigation options may be available. Impacts that fall under the same category may have similar mitigation strategies. From a management or industry perspective this may be more useful in developing mining plans and avoiding environmental impacts.

The potential impacts have been divided into five overall categories that describe the nature of the impact broadly. These categories are as follows: direct physical disturbance, sediment plumes, acoustic impacts, waste water disposal, and machinery leaks or malfunction (See Table 4-3). The sources of these impacts are then discussed as well as potential mitigation techniques that have been proposed in the literature and/or by the mining companies involved. The concerns raised in each section are then applied to the specific case study in PNG when appropriate.

Table 4-3 – Categorical Impacts and Identified Sources

	Direct Physical Disturbances	Sediment Plumes	Acoustics	Waste Water Disposal	Machinery Leaks/Malfunction
Exploration	Sampling	Minimal from drilling	Sonar mapping	Standard ship impacts	ROV oil leaks
	Drilling	Minimal from ROV sampling	Seismic surveys		Collisions
	Disruption of vent flows		Drilling		
			ROVs		
Extraction	Habitat destruction	Significant from ROVs	Cutting	Nutrient rich water	Riser pipe
	Mortality of individuals		Riser pipe	Presence of toxins	ROV oil leaks
	Disruption of vent flow				
	Destruction of fossils				

The types and extent of potential impacts will ultimately depend on the technology used, and for the purposes of this overview a system similar to that described in the technology section will be assumed. Therefore, it is in reference to a mining system that will have the basic structure of ROVs mining the ore and sending it to the surface as a slurry through a riser pipe (See Chapter 3 Technology for details).

Direct Physical Disturbances

This category is defined by the impacts caused in the closest proximate environment of the mining operation. These impacts are those that are mostly unavoidable in the mining process and will be a result of extracting the ore body.

Exploration - Direct Physical Disturbances

During the exploration phase physical disturbance will primarily come from drilling for ore samples and ROV sampling. The disturbance from sampling may include biological samples as well as surface grab samples of minerals. The impact of these activities should be small if conducted on a small scale, and the baseline data before impacts will help inform later stages of the project.

The drilling operation will have direct impacts on the species at the drilling site and may create small sediment plumes, which will be addressed as a separate category.

Additionally, it has been suggested that drilling could impact the flow of vent fluid diverting hydrothermal fluids away from the vent communities (Interridge, 2000). This could result in a wide range of impacts on the vent ecosystem, including the possibility of activating a new area at the drilling location. This may be diverting vent fluid away from previously active locations resulting in significant short term effects on the ecosystem. However, the vent ecosystem is well adapted to a changing environment because of natural tectonic activity as discussed in the environment section so long term impacts may be less severe over the entire vent field.

Mitigation of these exploration impacts can be done through monitoring of the drilling equipment and limiting sampling to a level that does not create a disturbance at the community scale. Due to the nature of the physical disturbance careful site selection and sampling protocols will be the most effective mitigation tool. The potential for affecting vent fluid flows may be more difficult to address and may need further research to fully understand and prevent.

Currently, baseline studies are being conducted by Placer Dome for future EIS reports that will use data collected in the initial exploration phases. Video recordings and detailed mapping of the area with ROVs will help minimize impacts through careful site selection for drilling and physical sampling of the biota in the area (Creed, 2006)

Extraction - Direct Physical Disturbances

During extraction the impacts from the ROVs that will be doing the cutting of the ore will result in the destruction of habitat in the mining region and direct mortality for sessile and slow moving organisms living in the impacted area. However, the important factor to examine is not the loss of individuals but the ability of the representative community to recover. An additional concern that has been raised is the destruction of fossil records that may exist at older vent sites. Depending on the age of the inactive vents, fossils may or may not be present, but scientific research is limited to date by the number of samples and could benefit from more research (Van Dover, 2004).

Based on nodule mining experiments, Jankowski and Zielke (1996) recommend a buffer zone of non-impact areas to facilitate re-colonization after the mining operation surround the mining tracts. The concept is to leave areas undisturbed in sufficiently close proximity to facilitate the re-colonization of large tracks of mined sediments. Derrick Ellis also elaborated on how leaving areas as recruitment zones can be applied when the mining area is small for cases like the currently proposed SMS mining in PNG. He recommends that in the case of a small mining site that areas be mined in sections so that recolonization could be carried out by the surrounding intact communities. This would mean in a mining site that had several blocks to be mined that they would not mine one entirely and then move to the next but to mine a portion and then move to the next block (Ellis, 2005)

Following a method similar to the one described by Ellis allows for habitat to be preserved and re-colonization to occur at mined areas before the entire habitat is disturbed in a particular block. However, the remaining issue is that the habitat will have been severely altered from the mining operations and the inactive vent habitat of fallen chimneys, debris, and a harder substrate may be eliminated at the end of a mining cycle. The remaining habitat may consist of finer sediments that do not support the same organisms as the inactive vent site did before and organisms that live in similar sediments and muds will be the ones to colonize (Ellis, 2005).

The question then becomes that if the inactive vent habitat is important to particular organisms then it may need to be preserved to some degree within the overall mining site area. As discussed earlier there is uncertainty as to the endemism at particular vent sites due to the limited amount of research done to date. This uncertainty is even greater at the less studied inactive vent habitat. Considering this lack of data, it could be more feasible from a mining perspective as well as from a conservation standpoint to reserve certain areas for conservation and further research. This would serve the dual goal of having a non-impacted area for comparison to the mining site as well as protecting unknown organisms.

The complete mining of an area's inactive vents could be considered an improbable scenario because of the ore grade and volume needed for mining to feasibly occur. In addition, the organisms living in this habitat may be able to live in nearby similar habitats as well. Further studies on the organisms living in these inactive vent sites should seek to clarify the issue of habitat type and the uniqueness of the species living at those sites. However, without sufficient data it would be desirable to protect specific blocks within the mining area from disturbances to prevent a loss of habitat beyond which the organisms can recover.

In addressing these concerns Placer Dome is currently supporting biological studies of inactive vent species to determine the level of biological activity at these sites. The course of action needed if the project continues to the extraction phase will be informed by baseline studies of these inactive vent communities (Creed, 2006). Defining the habitat and the biodiversity that exists will not only inform the scientific community through new research but also create a clear picture of the community before mining activities commence.

In addressing the issue of the fossil records, mitigation efforts could be directed towards ROV samples being taken in initial stages through a scientific cooperative effort. However, if analysis was not done promptly the remaining samples and potentially fossil records could be destroyed by the mining efforts at that location. Ideally this could be incorporated into the exploration phase of projects so that additional research could be done if warranted. There are specific time periods that would be of particular relevance to the research in this field (Little and Vrijenhoek, 2003) and aging the deposits could be an estimate of the relative importance of samples for research.

Table 4-4: Summary of Direct Physical Impacts and Mitigation Options

	Direct Physical Disturbances	Mitigation Options
Exploration	Sampling	Site selection distribution
	Drilling	Site selection to reduce incidental mortality
	Disruption of vent flows	Further research
Extraction	Habitat destruction	Habitat conservation
	Mortality of individuals	N/A
	Disruption of vent flow	Further research
	Destruction of fossils	Collection of specimens and aging of samples

Sediment Plumes

Sediment plumes are created during the mining operation by releasing particles into the water column. Impacts may include the smothering of individual organisms, clogging filter feeders, and possibly the disruption of trophic pathways. The impact from sediment plumes on benthic and sessile organisms has been the most extensively studied due to the previous research on nodule mining. However, many of the impact studies have dealt with the issue in a different environment. The dose-response relationship of sediment plumes has not been studied in the current ecosystem. Extrapolating from these nodule studies, we can evaluate the potential impacts and include the proximity to hydrothermal vent species as a critical additional factor.

Exploration – Sediment Plumes

In the exploration phase of the project the source of plumes will be primarily from drilling core samples. These may be minimal, but monitoring is currently planned to ensure accurate site selection and to observe the extent of the plumes created (Baulch, 2005a). In order to minimize potential impacts, site selection for core sampling will be the most critical factor. Plumes will most likely impact nearby areas. In the Suzzete vent field, hydrothermal vents are located in close proximity to proposed mining sites; therefore, it is likely that vent communities may be impacted to some extent. It will be important to monitor for potential impacts before proceeding to the extraction phase.

Extraction - Sediment Plumes

During extraction significant sediment plumes may be created by the mining operation. The extent of the plumes will depend on the technology used for extraction, the size of the particles, the strength of the currents at the mining site, and the topography of the area. The primary concern is the effects on organisms from the resettling of the particles. This may result in smothering of individual organisms and clogging of filter feeders as well as increases in toxicity and alterations in the food web (Ahnert and Borowski, 2000; Jankowski and Zielke, 1996; Thiel et al., 2001). However, this may primarily apply to benthic and sessile organisms. The ATESEPP study (See Table 4-5) on nodule mining has shown that benthopelagic fauna may be able to escape the disturbance to some degree (Thiel et al., 2001). Additionally the issue has been raised that sediments may clog hydrothermal vents effectively cutting off the food supply for vent communities (Interridge, 2000)

The size and duration of the mining plume will ultimately determine the impacts and some previous impact studies and modeling show the wide range of potential plume impacts. The DIETS experiment observed plumes traveling up to 290 meters away from the disturbance site and ranging between 0 and 1.8mm thick (Ohkubo and Yamazaki, 2003). Likewise, Jankowski and Zielke (1996) modeled plumes that traveled 600 meters and resulted in approximately 0.1mm of sediment collection. Later research done by the ATESEPP study, extrapolated from these initial models, indicated that the plumes may have impacts of 0.5 mm thick between one and two kilometers away from the site (Thiel et al., 2001). Clearly the range of impacts will be based on the types of sediments modeled, but the proximity of active and inactive vents means that plumes will most likely impact hydrothermal vent communities to some extent.

The most effective way to mitigate these impacts is by considering the impacts in the development of the technology to be used for extraction. This is the intention of the companies currently involved: to design cutter drums that work in a way that minimizes the plume created thus reducing the loss of material and the impact of plumes (See Technology Chapter). Additionally, the monitoring and modeling of deep-sea currents will assist in the understanding of the potential extent of the plumes.

Monitoring is currently being carried out by Placer Dome by using 75kh ADCP (Acoustic Doppler Current Profiler) for application in the drilling phase and opportunistically throughout the exploration process. It will be done more extensively if the operation continues beyond the exploration stage because it will be required for baseline studies. The currents on the bottom 1-2 meters of the sea floor are particularly important to capture for modeling of sediment plumes (Creed, 2006).

The setting of the PNG mining tracts shows that the topography may be a critical factor in the dispersal of plumes. Considerations for the settlement of plume particles in this region will need to include the topography as well as the currents to predict where sediments will ultimately fall out of the water column. The topography also creates an issue for plumes generated from waste water disposal (see specific section for background). If the water is deposited from the same depth that it is removed a plume will be created that will be suspended well above the seafloor. This means that the settling time will be extensively longer and that an area of disposal will need to be carefully chosen.

Table 4-4 Summary of Sediment Plumes and Mitigation Options

Sediment Plumes	Mitigation Options
Minimal from drilling	Concurrent monitoring
Minimal from ROV sampling	Concurrent monitoring
Significant from ROVs	Adaptive technologies, current monitoring and modeling, identification of impact zones

Acoustic Impacts

The acoustic impacts may be generated from a variety of sources in the mining process. As opposed to the impacts from sediment plumes, the research on acoustic impacts has been very limited when concerned with DSM. However, other marine research may be applied because much of the same technology is used in the exploration phase. Additionally studies are continuing that will broaden the research of acoustic impacts beyond marine mammals.

Exploration – Acoustic Impacts

During exploration geophysical surveys are necessary for mapping the sea bed in order to identify potential areas for exploration and to map known areas. Research to date has been primarily done on the potential impacts from sonar on marine mammals. Impacts are classified as TTS (Temporary Threshold Shifts) and PTS (Permanent Threshold Shifts) and may be associated with altered behavior by marine mammals (Llewellyn et al., 2004). Research has recently begun to look at the impacts on other marine life by the National Marine Fisheries, and may be able to identify potential impacts on a much wider range of species for establishing future guidelines by NOAA (Batelle, 2005).

Additionally in the exploration phase there may be acoustic impacts from ROV and drilling machinery that has not yet been quantified. The decibel level of acoustic impact from machine operation may be less than that for seismic surveys but it will be a more sustained endeavor and should be considered, especially when it is a persistent impact.

The current operational strategies for minimizing the impacts from seismic surveys involve monitoring for marine mammals in the vicinity both by human observers and with instrumentation like PAM (Passive Acoustic Monitoring). This reduces the impacts if animals can be located and avoided. Seismic surveys also generally begin with a soft-start or ramping up of the instrument to avoid full exposure to acoustic levels (Llewellyn et al., 2004). Additionally sensitive areas can be avoided through planning operations according to known data about migrations and calving grounds.

ROV and drilling operations may need further research to quantify the level of acoustic disturbance. However, similar strategies could be used to avoid impacts through timing of operations and monitoring for marine mammal presence.

Extraction – Acoustic Impacts

Geophysical surveys will have been completed before the extraction phase, but the extent of acoustic disturbance from machine operations will have increased significantly. The miners will be extracting ore through a cutter drum on an ROV and the material will be transported to the surface through a riser pipe as a slurry of crushed ore and water. The acoustic impacts from these operations will depend on the decibel level and the duration of the operation. If the machinery is operating for extended periods of time it will have a greater chance of impacting marine mammals and other aquatic life.

Similar strategies used for avoidance in the exploration phase could be implemented during extraction. Additionally, measurements of the acoustic intensity could be monitored to examine the decibel range and wave frequencies.

An additional question that has been raised is the possibility of physical impacts resulting from the acoustics of mining activities. The acoustics could affect the soft tissues and growth of the vent community organisms that are in the closest proximity. Possibly even more significant would be impacts on the stability of the sediments and physical structures like the chimneys in the area. The increased pressure and density of water may create conditions that result in a standing wave that has significant force over an extended area. This may even bring into consideration the possibility of land slides in the steep terrain surrounding the mining area that could result in even farther reaching impacts. To determine the risk of this occurring, the power of the acoustic impacts would need to be assessed as well as the integrity of sediments and chimneys in the area. This may be an important research question in the future if the acoustic impacts are found to be significant from the machinery.

Table 4-5 Summary of Acoustic Impacts and Mitigation Opportunities

Acoustics	Mitigation Options
Sonar mapping	Visual and technological monitoring, soft starts
Geophysical surveys	
Drilling	Adaptive technologies, seasonal sensititivity, research
ROVs	
Cutting	Adaptive technologies, seasonal sensititivity, research
Riser pipe	

Waste Water Disposal

The current system proposed, as described in Chapter 3 Technology, involves the use of a riser pipe to lift the ore body as a slurry mixed with nutrient rich deep ocean water. The disposal of this water is of significant importance because of the high nutrient content and the heavy metals that may be present. The depth at which the water is to be disposed of has not been determined. Recommendations have been to dispose of the waste water back at the ocean floor or as close as possible (Thiel et al., 2001) but another option that has been suggested is to use the nutrient rich water for sustaining aquaculture in PNG (Heydon, 2005). The impacts from waste water disposal at this point in time may potentially cover the entire water column and different impacts would be expected at different levels.

In the photic zone high nutrients could lead to increased phytoplankton and primary production for aquaculture (Heydon, 2005). However, the high sediment levels could also limit light penetration and reduce primary productivity. Additionally the sediment particles could adhere to plankton reducing their ability to float through the water (Ahnert and Borowski, 2000). The levels of toxins could also contribute to higher order species effects through bioaccumulation. The magnitude of effect will be determined by the size and duration of the plumes, and one estimate predicts that surface plumes could be narrow but extend 10 to 20 kilometers and mix up to depths of 100 meters (Jankowski and Zielke, 1996).

Below the photic zone, impacts may continue to affect migrations of zooplankton and nekton, up to 1500 meters (Thiel et al., 2001). Additionally marine mammals and other commercial and non-commercial fish stocks could be impacted through food web interactions. This potential is increased by estimates from models that predict 90% of the fine particles will take 3 to 10 years to settle to the sea floor if released between depths of 500 to 3000 meters (Thiel et al., 2001).

The current recommendation to mitigate impacts from the waste water is to dispose of it at the seafloor. However, the scientific community has not studied the issues in depth (Thiel et al., 2001). In order to dispose of material at the surface or at other depths further research would clearly be warranted. Additionally if the material is disposed of on the sea floor, issues of sediment plumes and topography discussed previously would again be of concern.

Machinery Leaks/Malfunction

The issue of oil leaks from equipment and contingency plans is not unique to the deep-sea mining industry. However, it may be a reality that is complicated by operating at greater depths and the unfamiliarity of new technology. Fail-safes and contingency technology are required and described in greater detail in the technology chapter.

Another concern is the possibility of a leak in the riser pipe resulting in water disposal at undesired depths. This would in effect create a plume in the water column that may take extensive time to settle depending on ocean conditions. Preventative measures taken into account in technology development that include monitoring for this type of malfunction will be the best form of mitigation.

Summary of Potential Environmental Impacts

The categories of impacts discussed all involve a level of uncertainty due to the untested technologies, the limited research in the deep sea, and the unknown biodiversity living in the current exploration area in PNG. The companies involved have been proactive in their initial efforts concerning the environmental impacts. However, identifying all potential impacts will require greater scientific collaboration and a rigorous assessment to identify the magnitude and duration of those impacts. To this extent, adaptive technologies will be essential to the long term success of any future operations. Additionally, the precautionary approach towards these uncertainties will help reduce impacts and liabilities. Perhaps, most importantly, it will help ensure that the biodiversity is better understood and protected through further scientific research and the conservation of habitat.

Chapter 5: Impact Assessment: Applying the BACIPS Sampling Design

As seen in the previous section, the full-scale impacts from deep-sea mining are currently unknown. To identify and manage the potential impacts it will be necessary to carry out comprehensive and targeted environmental monitoring programs. Placer Dome may be the first company to conduct a full scale deep-sea mining operation; it is essential that they use a sampling method that will identify impacts and quantify the magnitude of these impacts. The assessment method they choose will need to be rigorous so that it stands up to outside review and critique by scientists and stakeholders.

In general, field assessments in the marine environment have been poorly designed and executed (Schmittt and Osenberge, 1996). They propose the basic premise that: "A field assessment should compare the state of a natural system in the presence of the activity with the sate it would have assumed had that activity never occurred" (Schmittt and Osenberge, 1996). The goals of field assessment are three fold: (1) it should detect local ecological impact from local human perturbations; (2) it should measure the size of the effect (effect size); (3) it should provide a measure of confidence in the findings (Schmittt and Osenberge, 1996). To achieve these three goals it is necessary to implement a Before After Control Impact Paired Series (BACIPS) sampling design field assessment. This sampling method can separate natural spatial and temporal variability from variation imposed by the mining activity. This sampling design will require the establishment of a control and impact zone, and the collection of samples from both the control and impact zone. The control zones should possess the same physical, chemical, and biological features as the impact zones, but should be far enough away that it is not effected by the mining activity (Schmittt and Osenberge, 1996). To control for spatial variability both the control and impact zones should be sampled intensively several times before and after the mining operation. To control for temporal variability, sampling at both sites should be carried out close together in time (Paired Sampling). Steps for completing a BACIPS analysis are provided in the "Analysis" section.

BACIPS Assessment and Monitoring

Monitoring and BACIPS Assessment

Independent Monitoring of Impacts

If the PNG government wants to proactively manage deep-sea mining they will need to have a clear idea of what types of impacts are occurring on the seafloor. The government needs to: (1) know what the impacts are, (2) identify the magnitude of the impacts, (3) and ensure that companies are minimizing or mitigating impacts. To accomplish these three tasks, agencies need to have an independent monitoring system for mining activities. The PNG government cannot rely exclusively on companies to identify and quantify impacts with their own environmental impact assessments. One approach management agencies can take to overcome this challenge is to use real time video to survey the mining area. Several video cameras can be anchored to the seafloor in close proximity to the mining site. Video cameras can be programmed to record mining activity for varying lengths of time over several weeks. Analysis of video footage can be used in conjunction with the environmental plan and impact assessment to make better management decisions. Overall this type of independent site monitoring will benefit both Placer Dome and the PNG government because it will provide a level of transparency to the identification and monitoring of impacts.

Industry Baseline Data Collection for the Impact Assessment

Baseline data for physical and chemical oceanographic conditions needs to be collected previous to conducting a Before-After-Control-Impact-Paired Series (BACIPS) study. This should be done because it will help industries' understanding of environmental conditions at the potential mining site and facilitate creating the appropriate sampling design. Industry should consult with a reputable consultant to design a minimal/affordable sampling design. The consultant should be trained in physical oceanography and specialized in active boundary layer physics and water column physics. Together, industry and the consultant should determine how long they will need to measure different oceanographic conditions including: current direction and speed, erosion processes, temperature, turbidity, near bottom layer particle concentration, and water-column chemistry {Thiel, 2001 #90}. Current measurements will also need to be adapted for the topography and hydrodynamics of the sea surface and seafloor {Authority, 2001 #154}. Knowledge of physical and chemical oceanic conditions will facilitate the establishment of control and impact zones. Placer Dome needs to have a high certainty of what direction mean flow moved along the bottom. In order to get accurate bottom current data a monitoring system should be placed close to the ocean floor and collect data for one year {Thiel, 2001 #90}. It is imperative that Placer Dome use the direction of the current to establish control and impact zones prior to data collection for the "Before" stage of a BACIPS assessment. The identification of control and impact zones will be site and impact specific; thus, independent identification of these zones is required for every BACIPS analysis.

In the winter 2006, exploration of the Suzette hydrothermal fields took place. Although not required by law, Placer Dome carried out an initial environmental monitoring program. This monitoring program included gathering samples from inactive and active vent areas to study the macro, micro and meiofauna; water column ADCP current monitoring, plume generation monitoring using transmissivity meters, water sampling, grab sampling, box core sampling, and ROV-based video site inspections. Tables 5-1 and 5-2 provide details of both the biological and environmental monitoring components.

Table 5-1 – Placer Dome's, Salty Daug, Environmental Monitoring Programs for the exploration cruise were carried out in January and February of 2006. A Monitoring Table was supplied by Placer Dome Ltd.

Monitoring Components	**Objectives**
ROV Video Transects Side Scan Sonar	Preliminary seabed habitat classification Production of a bathymetry map of the target area Assist in high level ecological mapping Assist in planning of future ROV video trans Narrow the scope of environmental sampling sites Accurate drill and cutting site selection minimizing environmental impact direct and plume associated Site selection for deployment of a bottom current sensor
ADCP Current Monitoring	Develop a snap shot of the currents from the surface to the sea floor. Correlate currents with salinity to determine the relationship
Opportunistic ADCP Current Monitoring	Gather opportunist current data for use in future programs
New Seabed Current Monitoring	Gather near seabed current data for use in future programs
Water Monitoring	Gaining a better understanding of water chemistry and potential impacts of mining activities
Drilling and Cutting Plume Monitoring	Gather data that will assist in future plume modeling and to establish the extent of any environmental disturbance from this drilling program.
Sediment Monitoring and Analysis	Different sedimentary composition will be combined with ROV data to distinguish environments independently from the faunal analyses. Allow for habitat classification and mapping using integrated biological and geophysical data.

Table 5-2 – Placer Dome's, Salty Daug, Environmental Monitoring Program for the exploration cruise was carried out in January and February of 2006. The Objective Table was supplied by Placer Dome Ltd.

Biological Monitoring	**Objectives**
Macro Bethic Fauna - James Cook University	The purpose of this research is to undertake a quantitative survey of the macro-benthic fauna in Manus Basin, Bismarck Sea. This will allow comparisons to be made between key environments within the Manus Basin, and between the Bismarck Sea and other deep-sea areas. Comparing fauna at both venting and non-venting hydrothermal fields, as well as an area without hydrothermal history, will allow us to address several interesting questions about deep-sea assemblages. Do these distinct physical environments have distinct faunas? How does hydrothermal activity (current and/or previous) affect the community composition of benthic fauna?
Mega and Macro Fauna - College William and Mary	The purpose of this research is to assess the distribution and activity rates of mega, macro and micro organisms associated with active and inactive massive polymetallic sulfide mounds in the Manus Basin. Data will provide baseline information on microbiology for the purpose of environmental assessment. The focus will be to characterize the invertebrate community that colonizes sulfides of different ages and degrees of weathering, and to determine if there is any isotopic evidence for entry of local microbial primary production (through microbial oxidation of particulate sulfides) into the diets of the invertebrates that colonize the sites.
Geomicrobiology – University of Toronto	The purpose of this research is to assess the distribution and activity rates of microorganisms associated with active and inactive massive polymetallic sulfide mounds in the Manus Basin. Data will provide baseline information on microbiology for the purpose of environmental assessment. It may also provide scientific information on the role, if any, of microorganisms in precipitation-dissolution reactions involving sulfide and other minerals and metals.

Placer Dome's initial environmental baseline data collection is potentially comprehensive. However, this is only the first measure in understanding the environmental impacts related to deep-sea mining. In the next phase of exploration, Placer Dome will need to determine the biological communities which may be impacted from mining activities. A BACIPS assessment will need to be carried out for each impacted community.

The following section reviews the key impacts and communities which will be affected. It also provides a framework Placer Dome can use to carry out a complete BACIPS assessment by:

- Identifying 3 different communities which will require a BACIPS analysis
- Identifying control and impact zones for each of these 3 analyses
- Identifying necessary data collection for both Before and After sampling
- Describing how to complete a BACIPS analysis

As a summary, the final portion of this section proposes a means by which the PNG government could conduct independent monitoring of impacts.

Identification of Impacts

A BACIPS sampling design is the best option for Placer Dome because it detects ecological impacts in the marine environment, addresses uncertainty, and accounts for spatial and temporal variability. The impacts that Placer Dome will need to study include impacts from habitat destruction at the mining site and impacts from dispersal of sediment plumes.

Of these two main impacts, plume impacts are the least understood. Plumes will be generated from two different sources: (1) mining machinery's physical removal of the sea floor, (2) and disposal of the waste water from the riser pipe (See section 3.2). The dispersal of plumes has not been studied for SMS mining. Studies have been carried out for nodule mining, but it is difficult to apply studies of plume dispersal in nodule mining to SMS mining conditions. SMS deposits are associated with less fine sediment. In addition, SMS mining will occur in a much smaller scale and will disturb a smaller portion of the environment {Dave Hayden personal communication, 2005}. Since studies have not examined the extent of SMS plume dispersal, Placer Dome will have to have several impact sites in their BACIPS assessment (see section below for details).

Identification of Impacted Communities

Two distinct areas and their associated communities may be impacted from SMS mining. These locations include the mining site, and areas adjacent to the mining site. Adjacent communities will either consist of deep-sea communities similar to those found at the mining site, or hydrothermal vent communities. One distinctive attribute of potential SMS mining in the Suzette field is that active hydrothermal vents are located within a kilometer of mining sites. It is plausible that plumes from mining activity could impact adjacent vent communities. The high density of organisms found at vent sites makes this potential impact quite significant. Potential impacts may affect the following three communities:

- Extractive removal of SMS deposits will eliminate organisms at the mining site.
- Sediment plumes from mining machinery or riser pipe water disposal will kill or burry deep-sea organisms adjacent to mining locations (these organisms could potentially be similar to the community found at SMS deposits).
- Sediment plumes from mining machinery or slurry water disposal will kill hydrothermal vent organisms adjacent to the mining location.

Taking these issues into consideration we recommend that Placer Dome carry out three distinct studies to asses the impacts on communities of organisms found at: (1) the mining site, (2) the area adjacent to the mining site, (3) the vents adjacent to the mining site. The following section identifies the basic steps necessary for Placer Dome to conduct a rigorous BACIPS analysis for the three identified areas.

Step 1: Identifying Control and Impact Zones at the Mining Site

To determine the potential impact on the community at the mining location, the BACIPS analysis should have a minimum of one impact zone (mining site), and two control zones (up current). Having two control zones serves as an insurance policy. If one control zone experiences large changes then the second control zone can then be used in the BACIPS analysis. If only one control zone is chosen, and this zone experiences significant environmental change it will bias the BACIPS analysis rendering it meaningless. Control zones should be identified up current from mining sites to asses the impacts from mining activity alone, and not impacts from plumes. Control sites should be as similar as possible to one another and to the impacted site in terms of the parameters to be measured in the BACIPS analysis.

Step 2: Identifying Control and Impact Zones at Adjacent Sites (Not Hydrothermal Vents)

To assess the impact plumes will have on adjacent communities (non-vent communities), several impact zones should be placed around the source of the plume at gradient distances away from the source. If the source of the plume is mining machinery, then gradient zones should be placed around the mining site. If the source of the plume is the disposal of the riser pipe waste water, then the gradient zones should be placed around the riser pipe outfall.

For this BACIPS analysis the number of control and impact zones will depend on the current direction. If the bottom current is constant a BACIPS will require 3 impact zones at gradient distance down current from the plume source, and 2 control zones that are not impacted by the plume. If the bottom current is variable a BACIPS will require 6 impact zones, and 4 control zones. Of the 6 impact zones, and 4 control zones half should be up current and the other half should be down current (2 of the control zones can be the same control zones used in step 1 above). Overall, this gradient impact design will help Placer Dome determine how far plume impacts extend away from their source. It may also help determine the dose response levels of these organisms to this type of disturbance.

Step 3: Identifying Control and Impact Zones at Adjacent Sites (Hydrothermal Vent Communities)

To determine the impact plumes might have on vent communities, several impact and control zones will also need to be established at hydrothermal vents adjacent to the sources of pluming. Again the gradient sampling design is optimal for determining how far plume impacts extend away from their source. This analysis will require that several impact zones be placed at gradient distances away from the source of the plume. If the source plume is from mining machinery, then the gradient zones should be placed around the mining location. If the source plume is from disposal of the riser pipe waste water, then the gradient zones should be placed around the riser pipe outfall.

The bottom current data will play a role in determining which hydrothermal vents should be used as impact or control zones. If the bottom current is constant a BACIPS will require that 3 impact hydrothermal vents are identified at gradient distances down current from the plume source, and 2 control hydrothermal vents be identified. If bottom currents are variable a BACIPS will require 6 impact hydrothermal vents be identified, and 4 control hydrothermal vents are identified. Of the 6 impact zones, and 4 control zones half should be up current and the other half should be down current at gradient distances away from the plume source {Hunter Lenihan personal communication, 2006}.

Summary for Identifying Control and Impact Zones

At a minimum, Placer Dome will have to determine the impacts mining activity has on three communities: (1) communities at the mining site (2) communities adjacent to the mining site, (3) and communities at hydrothermal vents adjacent to the mining site. A BACIPS sampling design is an optimum monitoring program to determine environmental impact over time. It is important to note that the previous section only suggested the minimum number of control zones. Placer Dome can increase the power of their environmental impact analysis by having more samples and more control sites.

Collecting "Before" Data

Once impact and control sites have been identified, Placer Dome can begin collecting their "Before" data at all identified impact and control zones. To fulfill the Paired Series sampling methodology of BACIPS, it is imperative that sampling of the control and impact zones be collected as close together in time as possible. Data collection can be carried out with photographic transects and sample grabs. Data gathered from sampling should be used to determine the following: the number of species; trophic groups;

abundance; and biodiversity for mega, macro, and meiofauna. Percent cover should also be determined for macrofaua at hydrothermal vent sites. The sampling design needs to have a temporal component and be scaled realistically for the deep sea. The temporal design should be based on an understanding of temporal scale of change in the different parameters measured in the BACIPS. Otherwise the design becomes a Before After Control Impact (BACI) and this design is not as adequate at a BACIPS. The periodicity of sampling should be based on the best available knowledge (from a risk assessment) of the temporal variability of each parameter. We suggest that Placer Dome work with consultants or scientist trained in deep-sea community and hydrothermal vent community dynamics.

Collecting "After" Data

The same data collection methods should be carried out directly after the mining impact at all control and impact zones. Again data needs to be collected close in time. Sampling techniques and analysis should be the same as used in the "Before" sampling and analysis. If Placer Dome wants to determine how quickly the communities are returning to post-impact levels, post impact study could be carried out one year after the impact. The post impact study should take place during the same time of year as the original impact data was collected so that there is similar seasonal cycle of organic matter being delivered to the seafloor. Subsequent "After" studies could also be preformed at the impact and control sites on years three, six, and nine to address the recovery time of the impacted communities {Thiel, 2001 #90}. A BACIPS analysis can be compared across time for every year data is collected after the impact.

Analysis of Before and After Data:

A BACIPS analysis can be carried out to determine the changes in the communities after the mining impact. In order to determine whether the values at the impact zone have changed relative to the control zone from before to after the perturbation, the Impact (I) value is subtracted from the Control (C) value.

The analysis is: mean change (Δ) = Impact – Control

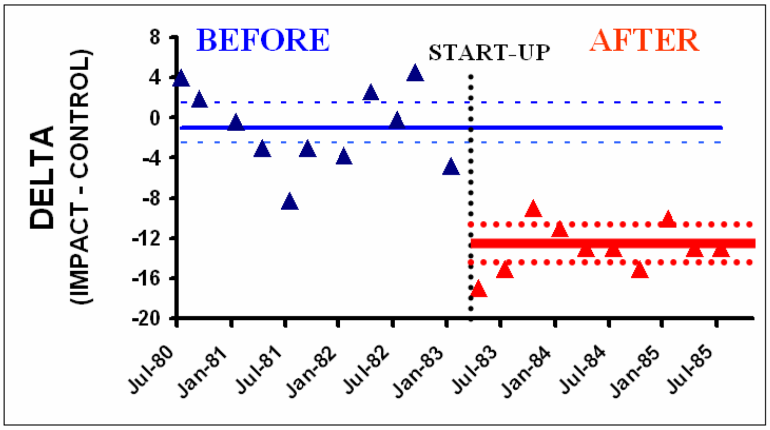


Figure 5-1. Changes in the Δ (Impact –Control) in number pre m^2 of white sea urchins from before to after the start up of San Onofre Nuclear Generating Station, San Diego California. Thick blue and red lines represent grand means. Dashed blue and redlines represent 95% Confidence Intervals around grand means. Data barrowed from Schmitt and Osenberg 1996.

The grand mean can be compared over time and 95% confidence intervals can be calculated around grand means (Figure 5-1). If the confidence intervals do not overlap from before and after the impact, then there is a significant difference between the control and impact zones (Figure 5-1). In contrast, if the confidence intervals do over lap there is not a significant difference between the control and impact zones. Two problems associated with a BACIPS sampling design are additivity and time serial correlation. To correct for both problems data can be log transformed (Figure 5-2) {Schmittt & Oshenberg, 1996 #155}.

The analysis is: Log(mean change (Δ))= log(Impact) - Log (Control)

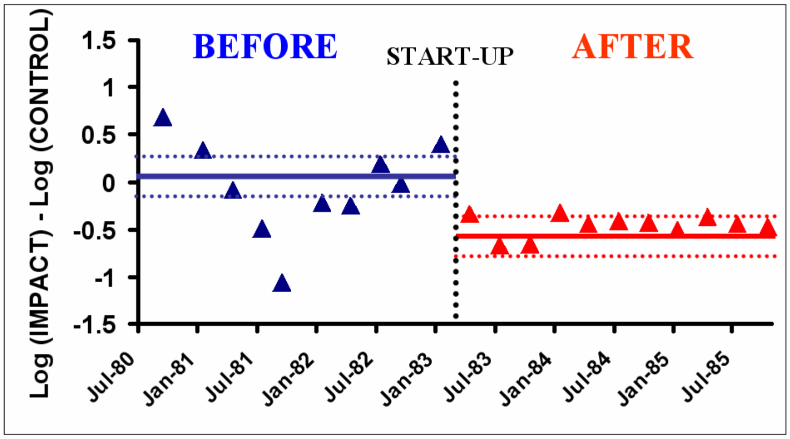


Figure 5-2. Changes in the Δ (Log(Impact) –Log(Control)) in number pre m^2 of white sea urchins from before to after the start up of San Onofre Nuclear Generating Station, San Diego California. Thick blue and red lines represent grand means. Dashed blue and redlines represent 95% Confidence Intervals around grand means. Data barrowed from Schmitt and Osenberg 1996.

Chapter 6: Law and Policy of Deep-sea Mining

As we have seen from the previous sections, the environmental risks and ecological consequences of deep-sea mining are only beginning to be understood. This uncertainty is largely due to poor knowledge of deep-sea ecology, ecological communities, and impacts from mining machinery and processes. In the face of such unknown consequences, the importance of law and policies addressing deep-sea mining cannot be underestimated because establishing such regulations allows all deep-sea mining stakeholders a better command of their interests, including how effective the management of marine mineral extraction will be, and how well the ocean environment is protected. Placer Dome, for instance, cares about law and policy because as a business it makes the investment climate more certain for them. Once they know the rules of the road, they can follow them and be more certain of making a sound financial investment. This will also allow let them know the "right thing to do" when it comes to the environment, and will help them understand financial-environmental responsibilities of their actions ultimately giving them the option of becoming responsible corporate citizens. From the PNG Government's point of view, law and policy considerations force them to bring one more portion of the land they hold in trust for the PNG people under good governance. It allows them to promote growth, and it gives them control over the sustainability of this growth. Additionally, as a nation-state in a world of nation-states, it gives them the opportunity to honor one of the international treaties that it has signed, helping legitimize its status as the government of the land. Further, international conservation NGOs, like Conservation International and others, also are interested in deep-sea mining law and policy because it gives them potential watchdog recourse to step in and demand compliance if laws are broken, as well as these laws and policies with their attendant guidelines allow them to suggest and promote programs to reach the benchmarks proposed in the guidelines. Numerous other DSM stakeholders have an interest in DSM law and policy, and their concerns are addressed in section three. To fully understand where DSM law and policy are today concerning our case study of Placer Dome working in PNG waters, this section will include a short review of the basic resource laws of the sea as provided by the United Nations Convention on the Law of the Sea (UNCLOS), along with an analysis of existing PNG federal and state environmental and mining laws.

International Legislation

On January 14, 1997 PNG ratified the United Nations Convention on the Law of the Sea, thus becoming party to a set of international regulations that included the defining of maritime zones, and the promotion of marine protection and preservation through the conservation and management of living and non-living resources (Division of Ocean Affairs and the Law of the Sea, 2006). Signing UNCLOS was significant for PNG in four ways: 1) it gave PNG the right to extends its legal jurisdiction to 200 nautical miles off its coastal shore, establishing an Exclusive Economic Zone (EEZ) (UNCLOS Part V, Article 57); 2) within this EEZ, PNG was granted access rights over living and non-living marine resources (UNCLOS Part V, Article 56); 3) it made PNG responsible to protect and preserve this new-found marine environment (UNCLOS Part V, Article 61); and, 4) it opened PNG to numerous dispute resolutions, including the International Court of Justice at The Hague, if it did not meet its new-found legal responsibilities (UNCLOS, Part XI. Section 5, Article 186).

Along with extending the jurisdiction of coastal states beyond their traditional territorial waters, UNCLOS also established the International Seabed Authority (ISA) to oversee the regulatory framework of deep-sea mining in waters other than EEZs (UNCLOS, Part XI. Section 4. Article 156). Since its inception more than 30 years ago, ISA has focused primarily on creating marine policy for deep-sea manganese nodule extraction. To date, this regime is well-developed and includes comprehensive environmental standards that provide for high levels of marine area and biodiversity protection. For example, contractors and sponsoring states are required to identify areas that will be set aside and used exclusively for assessing the environmental impacts, such as in a BACIPS impact assessment sampling design discussed earlier. Recently, because the mining industry has targeted seafloor massive sulfide for their high grade ore, the ISA has also started work on creating a regulatory regime for their extraction in areas other than EEZs and territorial waters as well (Odonton, 2005). The SMS regime is similar to the manganese regime, and will also require an Impact Reference Zone and a Preservation Reference Zone.

Importantly, the ratification of UNCLOS by PNG in 1997 laid down a skeletal legal and policy framework that allowed the idea of EEZ deep-sea mining to become a reality in this island-state, establishing the following stakeholder relationships:

- PNG & Nautilus/Placer Dome: The PNG government took clear title to the seabed along with its minerals, thus allowing Nautilus/Placer Dome to go into business with the rightful owner of the resource it potentially wants to extract.
- PNG & International Community: The PNG government took clear responsibility in the eyes of the world and the international court system to make sure the marine environment is not adversely effected by activities under its jurisdiction.
- PNG & International Seabed Authority: The PNG government, like the ISA, is now in the process of developing a comprehensive SMS deep-sea mining regulatory regime.
- PNG Federal Government & PNG mining legislation: The PNG government is now working with its internal departments to extend terrestrial mining laws to cover deep-sea extraction.

National Legislation in PNG

The government of PNG is in a unique position. Currently, no nation on earth has created a comprehensive policy or legislative regime to manage the development of offshore minerals within their territorial waters and EEZs. PNG is well on its way to being one of the first to do so. In many coastal state cases, including PNG, offshore mineral development is governed by onshore mineral management regimes. As the ocean is a complex and interdependent ecosystem, these terrestrial policies do not overlap well to the mining of deep-sea mineral deposits (Wanjik, 2004).

In developing its deep-sea mining legislative strategy, PNG has numerous laws to draw from. These laws regulate terrestrial mining, the environment, conservation, and local government power – rules of the road that could extend governance to the deep-sea floor.

Table 6-1. Lists of key legislation in PNG which will management and regulate deep-sea mining activities.

The Mining Act 1992 – currently regulates offshore mining activities
Green Paper on Offshore Mining Policy (Green Paper) – PNG's proposed offshore mining regulations
The Environmental Planning Act 1978 – establishes environmental rules and regulations for any project taking place in PNG.
Dumping of Waste At Sea Act 1979 – establishes rules for the disposal of waste in coastal and offshore waters.
The Environmental Contaminants Act 1978 – establishes rules and regulations for the discharge of environmental contaminates.
The Fauna (Protection and Control) Act 1976 – establishes rules and regulations for the protection, harvesting, and destruction of fauna.
The Organic Law on Provincial and Local-level Governments - defines power distribution between PNG federal, provincial, local and clan groups
The Lands Groups Incorporation Act 1974- provides a legal structure for local provincials groups by allowing them to manage their own affairs and make binding decisions and agreements with outside organizations.

The Mining Act 1992

The Mining Act 1992 (Mining Act) states that the "federal government has complete control over all minerals in or below the surface of all land in PNG," (Mining Act, Part III. Section 5 & 6) thereby establishing that the basic property rights for minerals on land or in the water belong to the PNG government. By default, and without having an offshore mining policy in place, the Mining Act currently regulates all mining activities taking place onshore and offshore. However, with the advent of PNG signing UNCLOS and establishing its EEZs, as well as the granting of deep-sea mineral exploration rights in its territorial waters and EEZs, the PNG government determined in 1998 that the Mining Act was insufficient to deal with offshore mineral development.

In contrast to land mining, there are many unknown variables to deep-sea mining including the location and extent of minerals, availability of extraction technology, and costs associated with extraction. The PNG government considered the Mining Act deficient in the length of time licenses and permits are granted; the size of the areas the licenses and permits cover, and the upfront financial requirements to the PNG government (Wanjik, 2004). To deal with this inefficiency, and in light of the fact that no other coastal state had at that time developed an offshore mining regime, the PNG government charged a federal inter-agency committee with the task of creating a draft policy framework for offshore mineral development. The policy eventually came to be called the "Green Paper."

Green Paper on Offshore Mining Policy

The Green Paper is a comprehensive "draft" policy document that deals specifically with the extraction of seabed and seafloor minerals depositions, including sand, gravel, diamond, black sands, oil, naturally occurring hydrocarbons, manganese nodules, manganese crust, as well as seafloor massive sulfide deposits. In the Green Paper a framework was laid out for government to promote offshore mineral resource extraction, and assist mining companies in facing the uncertainties of deep-sea mining by:

- Increasing the length of time licenses and permits are granted from two years to three years.
- Increasing the area granted under the licenses and permits from 750 sub-blocks to 1000 sub-blocks. Lowering front end royalties and income tax rates, which will be balanced by reduced profit thresholds and by higher Profit Tax on the back end (Wanjik, 2004).

Additionally, the committee decided to create a pilot-mining licensing category in the Green Paper which allows companies the time to experiment with deep-water technology and determine the worth of a mineral deposit before moving into the next mining stage (SOPAC, 1999).

To address environmental concerns the committee created several additional requirements in the Green Paper, industry must collect baseline parameters such as salinity, pressure, chemistry, currents, benthic flora and fauna, which can then be used in environmental impact assessments and monitoring programs. To deal with uncertainty the state agencies must adopt a precautionary approach for any activities or decisions for deep-sea mining (SOPAC, 1999).

Table 6-2: Draft Offshore Policy Act licensing and leasing terms. Table re-created from a similar table presented in James Wanjik's, Status report for the data and reporting requirements of PNG seafloor massive sulfide deposits page 362 (Wanjik, 2004).

License/Permit	Term	Area	Nature of Right	Rights
Prospector's Right	3 yrs initially	Unrestricted	Non exclusive	Prospecting
Exploration License (EL)	Renewal 3 yrs 5 yrs initially	1000 sub-blocks (3410 sq km)	Exclusive	Exploration
Pilot Mining Test	Renewal 5 yrs Part of EL	20% reduction Part of EL	Exclusive	Test mining technology and systems
Mining Lease	Negotiable	Less than EL	Exclusive	Mining
Lease for Mining Purpose	Need Dependent	Need Dependent	Exclusive	Installation of facilities for purpose of mining
Mining Easement	Dependent	Dependent	Non exclusive	Installation of structures like pipes, and special access ways

Overall, the structure of the Green Paper provides flexible licensing and leasing requirements, as well as stricter environmental regulations for offshore mineral extraction than the Mining Act 1992. At the time of the writing of this report, however, the Green Paper was taken out of legislative process and amendments to the Mining Act 1992 were proposed as a substitute for handling the issues of offshore mining (Solien, 2006) and (Hancock, 2006).

Environmental Regulations PNG

The PNG Environmental Planning Act, the Environmental Contaminants Act, the Dumping of Waste at Sea Act, and the Fauna Act supersede the Mining Act 1992 and the proposed Green Paper in regards to environmental regulation. Companies involved in deep-sea mining in PNG's EEZs and territorial waters will need to meet the environmental rules and regulations set out by these acts. If Placer Dome's winter 2006 drilling explorations warrant a next-phase step into trial mining, then they will have to follow these rules and regulations by obtaining any permitting requirements.

The Environmental Planning Act

This Environmental Planning Act 1978 requires any project taking place in PNG to create a comprehensive Environmental Plan that includes, among other items (Table 6-3), the identification of "environmental changes from the activity," and "actions to mitigate or minimize environmental damage" (Part 1, Section 5 (5)). The plan must receive approval from all affected Provincial governments, applicable agencies (Part III, Section 2(a)), the National Executive Council (Part III, Section 16), and a Board of Inquiry (Part IV, Section 17 (1)). Throughout each step of the review process, the plan, with its associated comments, is published in the national gazette and local newspapers, as well as details of the plan are to be broadcasted over the radio.

If Placer Dome were to engage in trial mining in the Suzette field, then their environmental plan would necessarily include an environmental impact assessment, and a plan to mitigate or minimize any environmental damage, including conserving biodiversity. The environmental data collected on the 2006 drilling cruise puts them well ahead of their schedule in establishing the environmental requirements under the Environmental Plan Act (Table 6-3). It should be noted that the PNG government did not require Placer Dome to submit an environmental plan before commencing its exploration of the Suzette field, however, one was submitted voluntarily. It is the responsibility of society to encourage these actions, whereas it is industry's responsibility to make these actions as transparent and accessible as possible.

Table 6-3. List of the requirements for completing an Environmental Plan under the Environmental Planning Act (section 5).

1) Long term and short term objectives of proposed project
2) Project Proposal and alternative project proposal with alternative sites
3) Alternative methods for carrying out proposal and recommendations for a specific alternative method
4) Environment that is expected to be affected directly or indirectly and in the immediately or in the future
5) Environmental changes from proposed project
6) Mitigation actions that will eliminate or minimize environmental damage
7) Use of natural resources and energy
8) Use and discharge of environmental contaminates
9) Costs and benefits accrued from project
10) Permanent changes in the physical, biological, social, or cultural characteristics of the affected environment and possible use in the future
11) Any additional matter that the Director deems necessary or relevant

Additional PNG Laws Addressing Environmental Impacts

Previous sections have identified some potential environmental impacts. As a synthesis of impacts and policy, the following section identifies key PNG legislation applicable to DSM activities, other than the Environmental Planning Act. Within this section a short summary of each environmental law is preceded by potential impacts and mechanism for regulating the impact are also identified. To address potential impacts key policies include:

- Dumping of Waste at Sea Act (1979)

- Environmental Contaminates Act (1978)
- Fauna (Protection and Control) Act (1976)

The Dumping of Waste at Sea Act will require a permit for any waste dumped (Part II, Division 2, Section 4). This does not including the disposal of a substances or articles derived from normal operation of vessels (Part I, Section 1 (b)). Disposal of substance or article derived form normal operation of vessel, marine structures or other man made structures is excluded from regulations (Part I, Section 1 (b)). As described in the technology section, the current mining system uses a riser pipe to lift the ore body. This results in a slurry water mixture containing nutrient rich deep and sediment. High nutrient content and heavy metals may classify this water as waste. The disposal of this slurry mixture could require a mining company, such as Placer Dome, to obtain permits under the Dumping of Waste at Sea Act.

The disposal of any liquid, solid, gaseous, or radioactive Environmental Contaminates or Hazardous Environmental Contaminates will require a permit under the Environmental Contaminants Act (Part VI, Section 47 (2(a))). If Placer Dome moves ahead with experimental mining in the Suzette Fields the nature of this operation will be "polluting" the water as defined by the act in a number of ways: (1) through the possible creation of deep-sea plumes from mining equipment, (2) through discharging waste water back into the sea at some depth, (3) and the possible leakage of fluids and lubricants from the mining equipment. There is a chance this polluted water may potentially warrant permits under the Environmental Contaminates Act. Additionally, there is the potential that the sediment plumes associated with the sea-bed mining process will also contain metal contaminants, as well as oil and machine lubricants, possibly requiring pollution permits. The need for permits, in turn, triggers monitoring the contaminant under this act (Part V, Section 32).

The Fauna (Protection and Control) Act 1966 establishes the federal governments' control over protection, harvesting, and destruction of fauna. This act might also affect Placer Dome potential experimental mining at the Suzette Fields in three ways: 1) endemic species located at deep-sea mining sites could come under the protection of this act, causing conservation sites and mitigating methods to be developed as describe in the following section of this report, 2) commercial fish populations may be affected by mining activities; thus, impacting fish stocks and engaging the PNG Fisheries Forum Agency (FFA), 3) PNG territorial waters and EEZs have been declared sanctuaries for whales, protecting them from being taken (killed) in these areas. However, if the protection of the sanctuary is extended to the "harming" of whales, as Australia and other Pacific Island nations have done so recently (WWF/IUCN, 2001), then there is a chance that deep-sea mining operations with its ambient noise, and further deep-sea exploration with its various seismic profiling methods, might cause "harm" to the whales. If such proves to be the case, the mining and/or the exploration operation would be in violation of the Fauna (Protection and Control) Act.

Overall the Environmental Planning Act, the Dumping of Waste at Sea Act, the Environmental Contaminates Act, and the Fauna Act complete PNG's environmental legal regime. If Placer Dome moves forward to trial mining stage they will need to comply with all of these environmental laws.

PNG Local and State Government Legislation

When considering deep-sea mining in territorial or EEZ of a coastal state, one would think that this would be handled by the federal government of that state. In PNG, however, this may not necessarily be the case. Unlike many developing nations, most of the resources in PNG are owned by clan groups or indigenous people. Over 97% of the land is held under customary tenure rights, and the federal government owing the remaining less than 3% (Van-Heldeden, 2001). The Lands Groups Incorporation Act 1974 (Lands Act) and the Organic Law on Provincial Governments and Local Level Governments 1995 (Organic Act), have been the cause of this effect, having been enacted more or less to give power back to local communities.

The establishment of the Lands Act in 1974 encouraged the participation of local people in the national economy and promoted more effective land use (Part 1, Section 1 (a-f)). Customary clan property rights are recognized by the act, and allow clan groups to hold and manage their lands under customary clan names. In addition, clan groups can distribute products or profits arising from the management of their land, something that would affect deep-sea mining companies if the clan's land jurisdiction was extended into the deep-sea. The Organic Act (1995) complements the Lands Act by stating that local resource owners, not the federal government, have control over conservation and management of natural resources. Customary land rights under the act extend to terrestrial flora and fauna, freshwater and marine resources, including reefs and fishing grounds (Van-Heldeden, 2001).

Even though the Lands Act and the Organic Act give local people control over resources and land use, the Mining Act 1992 bestows the PNG federal government with ownership of all mineral resources in the country. The PNG Constitution further specifies that management of mineral extraction lies within federal jurisdiction (Constitution, Goal 4 (1)). There is currently a debate over how far offshore provincial land claims should extend, centering on whether provinces should be extended by depth into the sea, or by distance out to sea. It has been suggested that the area beyond three nautical miles from the coastline be classified as the "common heritage of the nation," and that taxes derived from mining from this area be shared with all provinces (Wanjik, 2004).

With the decentralization of the PNG federal government the future of resource management is still uncertain. Again, the Lands Act and the Organic Act were clearly established to give power back to the people. By using these acts communities may be able to assert and extend their property rights over marine resources off their coastal shores. While local groups might not manage exploration and exploitation of deep-sea minerals, they could potentially play a critical role in the conservation of organisms found at, or in surrounding areas of deep-sea mining sites. If Placer Dome does move forward with trial mining at the Suzette Field which is in territorial waters off the coast of New Ireland, it might consider engaging in a dialogue with the local provincial authorities when it comes time to develop and submit an environmental plan under the Environmental Planning Act to the federal government.

Madang Guidelines and the Code for Environmental Management of Marine Mining

The Madang Guidelines were the results of an expert group convening under the PNG government and the South Pacific Applied Geosciences Commission (SOPAC) in Madang, Papua New Guinea, in 1999, to address new policy and legislative regime issues that will effectively manage offshore mineral exploration and potential development (SOPAC, 1999). Overall, the guidelines are a useful basis for any nation to formulate effective policy and legislation for offshore mineral development of both seafloor massive sulfide deposits and manganese nodules. For easy reference, Table 6-4 subdivides the nineteen guidelines into seven issue categories. Clearly the Madang Guidelines accommodate the distinctive attributes of the deposits and the pioneering nature of exploration with particular attention to, among others, environmental impacts and impact assessment, stakeholder interests, national legislation and government responsibilities.

Soon after PNG and SOPAC expert group met in Madang and produced its guidelines, industry members of the deep-sea mining community entered the discussion and requested that the International Marine Minerals Society (IMMS) create a set of management guidelines or a code which the industry could use to develop its deep-sea mining plans (Ellis, 2005). Drawing upon preceding marine mining environmental policy statements, including the Madang Guidelines, the PNG Green Paper, and consulting with international marine scientists and mining engineers, the Code for Environmental Management of Marine Mining (The Code) was created in 2001 (Society, 2001).

Table 6-4. Subcategories of issues and recommendations that need to be considered when creating an offshore mining policy. Issues and recommendations were identified in the Madang Guidelines.

Issue	Recommendation
EEZ National Policy for Offshore Mining	To help countries implement measures under UNCLOS, including the establishment of national jurisdiction, navigation, and dispute resolution.
EEZ Exploration and Development Policy	To develop a comprehensive offshore mining act distinct from terrestrial mining act, and create a licensing regime.
Fiscal Regime	To address the creation of a fiscal regime for offshore minerals that keep in mind pioneering effort and incentives for development.
Environmental Consideration	To address environmental assessment and minimization of impacts from exploration and development.
Stakeholders	To identify and address stakeholder concerns.
Fisheries	To address fisheries development and management.
Industry	To address creating a government and human infrastructure for a mining regime.

The Code lays out concise environmental principles and operational guidelines that "provide a framework and benchmarks for implementation by marine mining companies … and for stakeholders in governments, NGOs and communities in appraising actual and intended applications of environmental practices at marine mining sites" (Society, 2001). The Code consist of six environmental principles (Table 6-5) which a company must commit to if adopting the code, and eleven operating guidelines that complement these principles by laying out detailed steps for practicing high environmental standards.

Table 6-5. Environmental Principles from the International Marine Minerals Society Code for Environmental Management of Marine Mining

1. Follow policies of sovereign governments and all sub-divisions, and international agencies.
2. Apply best procedures for environment while considering the future use of that area.
3. Consider environmental implication at all stages of mining operation.
4. Facilitate community partnership for addressing environmental issues.
5. Maintain an environmental quality and review program.
6. Publicly report environmental performance and implementation of the Code.

Overall, the Code establishes industry standards for deep-sea mining and can be used by industry, regulatory agencies, and other stakeholders in creating, implementing, and evaluating a comprehensive environmental management plan for deep-sea mining (Society, 2001). IMMS determined that the use of The Code would insure that environmental concerns were addressed early, and tracked throughout the lifetime of the project. The Madang Guidelines and The Code are certainly important offshore mining policy documents that are available for industry, governments, and other stakeholders world-wide to use when formulating their own responses to deep-sea mining.

Discussion

In conclusion, Table 6-6 summarizes the rules and regulations currently available for governing deep-sea mining issues in Papua New Guinea. UNCLOS establishes EEZs and territorial waters, and grants mineral rights along with environmental responsibilities. The PNG Mining Act establishes clear federal ownership of mineral rights, with limited reference to offshore mining. The proposed Green Paper focuses solely on offshore issues, addressing the risks and uncertainties of deep-sea mining for both policy makers and industry by requiring the state to adopt a precautionary approach to significant decision-making activities, and by allowing mining companies smaller upfront costs and more time to explore and develop potential claims. The PNG Environmental Planning Act requires all projects taking place in Papua New Guinea, including offshore, to develop and submit an environmental plan for federal and state approval, while the

Dumping of Waste Act, the Environmental Contaminates Act, and the Fauna Act, get into the details of specific pollution controls and permits, and fauna protection. Finally, the Organic Law and Lands Groups law give local governments control over local resource conservation and use, which may have an affect on offshore mineral extraction. From the DSM industry point of view, the Madang Guidelines and The Code are important industry "best practices." If adopted by Placer Dome, these practices can decrease environmental impacts and allow industry to become a good corporate citizen by setting high international standard for environmental protection.

Table 6-6. Identification of key laws that are pertinent to deep-sea mining in PNG, each law is identified and followed by a short description of the effect that law has.

LAW	EFFECT
United Nations Convention on the Law of the Sea	Establishes EEZs, and responsibility of the environment
PNG - The Mining Act	Establishes federal ownership of minerals, but offshore applicability is limited
PNG - Green Paper	Creates full offshore mining coverage
PNG - Environmental Planning Act	Requires comprehensive environmental plan
PNG- Dumping of Waste at Seas Act	Requires permit for dumping of waste at sea
PNG-Environmental Contaminates Act	Requires permit and monitoring for all environmental contaminates released
PNG- Fauna (Protection and Control) Act	Allows federal government to manage and protect the harvesting and destruction of fauna
PNG - Organic Law/Lands Groups	Extends local jurisdiction over conservation that may extend into EEZs & territorial waters

Chapter 7: Recommendations & Conclusion

Further research is required before DSM can safely move to commercialization. This case study was developed to serve as an assessment of the current status and potential future impacts of DSM and highlights significant research gaps. The recommendations presented below address overarching issues such as uncertainty and transparency, as well as specific issues and impacts such as monitoring and sediment plumes. It is our hope that the research, analysis, and recommendations presented here will be implemented or can serve as a framework for further environmental discussion.

The future of DSM is impossible to forecast, as was demonstrated by the failure to commercialize nodule mining 30 some years ago. However, the case for present-day SMS mining is advancing rapidly through resource, environmental, and financial assessments. Commercialization of SMS mining is most likely 5-10 years ahead, but the next major steps include improved deposit drilling techniques, passing industry specific policy and regulations, and a scientific trial mining study. Throughout these steps the DSM industry should seek to develop a programmatic policy structure including the Precautionary Principle and the development of industry best practice guidelines.

Industry representatives are aware of the significance of their environmental actions as a nascent industry and have taken a proactive approach in the exploration phase. It remains to be seen if this environmental consciousness will be sustained if commercialization becomes a reality and the industry develops.

The following issues highlight some of the broader questions that have been raised in this study and a series of recommendations are made that will help approach the issues at hand.

Issue: The inherent uncertainty of developing a new industry in an unfamiliar and extreme environment

Precautionary Principle

Companies involved in exploration and extraction of SMS deposits should invoke the Precautionary Principle as an overall approach to deep-sea mining. One example for consideration is the establishment of conservation zones to preserve habitat.

As trial mining moves forward, Placer Dome will be required to identify and mitigate impacts under the PNG Environmental Planning Act. We recommend that Placer Dome establishes impact zones and preservation reference zones to conduct a valid environmental impact assessment that will stand up to scientific critique.

Scientific Research and Cooperation

Scientific research and cooperation will help limit the uncertainty of deep-sea mining. We recommend greater collaboration between scientists, industry, and policymakers. Specific areas of interest identified are the potential acoustic impacts to marine life, dose response reactions to sediment plumes, and the possibility of disruption of hydrothermal vent ecosystems.

Policy Implementation

The draft "Green Paper" Offshore Mining Policy Act has a framework that (1) addresses uncertainty, (2) provides a more flexible licensing and leasing regime, (3) requires marine specific baseline data gathering. We recommend that PNG finalize and implement this policy, as it has been put on hold.

Issue: Mining will occur in areas of "common PNG heritage" and ownership. Other parties, including the public at large, have a right to know how their natural resources are being treated.

Information disclosure

It is important that mining companies with operations that have the potential to impact other stakeholders or the public at large report their actions within a reasonable period prior to implementation to allow for public comment.

Mining companies should proactively disclose information about the project to all stakeholders. Press releases on the website are not enough; local communities may not have access to the Internet. Additionally, the mining companies should open an information center at a local site, assign an information officer to the project, as well as hold public hearings when appropriate.

Establish an advisory committee consisting of key stakeholders

Mining companies need to identify stakeholders and then periodically keep in touch with them. The companies should develop a stakeholder registration system and establish an external advisory committee. Federal, state and local officials should also be asked to join the committee.

Further, as the provincial governments of New Ireland through the Organic Law and Lands Groups law have a potential say in the conservation of natural resources within the province: We recommend that Placer Dome consult with New Ireland authorities as they develop and implement their environmental plan.

Experience Transfer

As PNG will be the first country to potentially experience deep-sea mining, we recommend knowledge and experience transfer between PNG and other states that are developing DSM policy. Experience transfer will benefit other states. They will be able to bypass costly and time consuming mistakes, and implement proven policy applications.

Issue: DSM will impact the environment.

Direct physical disturbance

We recommend the protection of habitat through the establishment of conservation offsets in a similar deep sea environment.

Sediment plumes

We recommend the development of plume reduction/prevention technology, and further research concerning the dose-response of organisms to these plumes.

Waste water disposal

We recommend disposal at or below the depth of the mining site to prevent contamination of the water column or impacts to vent ecosystems

Acoustics

The potential consequences of sound impacts from DSM are significant and warrant further study.

Oil leaks

We recommend the development and implementation of oil leak contingency and prevention technology in DSM engineering designs.

Issue: Information and knowledge about the deep-sea is limited. It is expected that new seafloor marine science may discover new impacts unforeseen during the development of DSM technology.

Impact Assessment

A monitoring program must be in place in order to identify and manage the impacts of DSM on the environment. We recommend the BACIPS sampling design field assessment analysis.

Adaptive Technology Development Strategy

In order to address the inherent uncertainties of developing a nascent industry in an unfamiliar environment we recommend the development of adaptive technology programs and designs to provide engineering flexibility for effective and efficient response to new marine science data.

Issue: Policy frameworks for DSM have already been developed.

Guidelines, Codes & Best Practices

States can use the Madang Guidelines as a framework and the Code for Environmental Management of Marine Mining to create a deep-sea mining industry standard within the offshore policy regime.

To help create transparency we recommend the deep-sea mining industry actively promote the Code of Environmental Management of Marine Mining as a best practices methodology.

Conclusion

The methodology used in this case study identified, contacted, and opened a dialogue between the group project members and key players from industry, non-government organizations (NGO), the Papua New Guinea government, and scientists currently studying hydrothermal vent systems. An extensive literature review complemented by personal communications with experts provided the foundation for a set of recommendations for each chapter topic. It is our hope that the mining industry can use these recommendations to identify and mitigate environmental impacts before they occur.

A documentary film on DSM issues was made for a general audience as an outreach companion piece to the report. Interviews with scientists, industry members, legal and policy experts, and group project members were conducted.

Throughout this project we have found deep-sea mining industry and stakeholders to be interested and open to environmental discussion to identify, minimize, and mitigate impacts. It is our hope that this paper provides some real solutions and will lead the way for the stewardship of our ocean resources.

APPENDIX 1 Stakeholder list for PNG DSM

Involved

Industries

NAME: Nautilus Minerals

SOURCE: http://www.nautilusminerals.com/Home.html
DESCRIPTION:
Nautilus Minerals is an Australian based mining firm specializing in off-shore mining. They have formed an "alliance" of partners such as "Worley Parsons - a leading international provider of professional services to the energy, resource and complex processing industries, Perry Slingsby Systems - the world leader in manufacture of deep ocean remotely operated vehicles for the oil/gas and telecommunications industries, and Canyon Offshore - an international operator of deep ocean remote operated vehicles for the oil/gas and telecommunications industries."
CONTACT:
Dave Hayden, President
NAUTILUS Minerals Group
Sea Floor Massive Sulfide Copper-Zinc Project
Australian Project Office
Level 7, 116 Miller Street
North Sydney NSW 2060, Australia
Email: Office@NautilusMinerals.com

NAME: Placer Dome

SOURCE: http://www.placerdome.com/Home.htm
DESCRIPTION:
"Placer Dome is one of the world's largest and most successful gold mining companies. Based in Vancouver, Canada, the company has interests in 16 mining operations in seven countries and employs more than 13,000 people around the world. The company's shares trade on the New York, Toronto, Swiss and Australian stock exchanges and Euronext-Paris under the symbol PDG."

Placer Dome and Nautilus have partnered in a joint venture to develop off-shore exploration leases in PNG EEZ. The agreement: "Placer Dome has committed a minimum of US$4m to the drilling program, commencing mid January 2006. Placer has already spent US$3m on geophysics and is committed to spend in total at least US$7m by April '06 to earn a 40% interest in Nautilus's gold deposits. Nautilus retains 100% of the high grade copper zinc deposits with < 3 g/t Au, and may engage a base metal partner, (miner or smelter) to exploit these." (1001Nautilus.pdf)

Placer Dome was recently acquired by Barrick Gold Corporation.

CONTACT:

Glenn Creed (Placer Sustainability officer)

Justin Baulch (PNG project Manager)

Perth Office

Level 2, 35 Ventnor Av

West Perth. WA 6005

NAME: Barrick Gold Corporation

SOURCE: http://www.barrick.com/

DESCRIPTION:

Barrick is an international gold mining company with twelve operating mines and numerous development projects in countries such as Australia, Peru, US, Canada, Chile, Argentina, and Tanzania.

CONTACT:

Barrick Gold Corporation

BCE Place

Canada Trust Tower

161 Bay Street, Suite 3700

P.O. Box 212, Toronto, Canada M5J 2S1

Government

NAME: Papua New Guinea Federal government

SOURCE: http://www.pngembassy.org/location.html

DESCRIPTION:

Papua New Guinea is located on the eastern half of the island of New Guinea and is 160 kilometers north of Australia. The western half of the island is Irian Jaya, a province of Indonesia. Papua New Guinea comprises both the mainland and some 600 offshore islands. It has a total land area of 462,800 square kilometers.

Papua New Guinea has a population of over 4.4 million people (using 1997 projections by the National Statistical Office). The majority lives in the highland valleys, many in isolated villages. Apart from the National Capital District (NCD), population density is relatively low.

GDP US$ 4,400 millon (2004) 85% of the population works on farming, fisheries and forestry, and 5% works on mining. The amount of export is US$ 2,518 million and mineral resources except oil are 53%. (The tendency of international mining 2005, Japan, JOGMEC)

Papua New Guinea is a constitutional monarchy with a parliamentary democracy. There are three levels of government - national, provincial, and local.   Reforms in June 1995 changed the provincial government system. Regional (at-large) members of Parliament became provincial governors, while retaining their national seats in Parliament. Papua New Guinea is divided into nineteen provinces and the National Capital District, Papua New Guinea.

Department of Mining (DoM)

DoM is the government organization responsible for the regulating, monitoring, promoting and recording of mineral exploration and mining activity in Papua New Guinea. The Department contains the Geological Survey of Papua New Guinea, and so also has responsibility for collecting, distributing and archiving a wide variety of geoscientific data.

On MSR and Exploration Licenses: “Mr. Wanjik said that under the arrangements with the ODP, the information sought by researchers would have been provided to the

Government of Papua New Guinea. Whether or not Nautilus Minerals or any other potential investor has a license or not, Mr. Wanjik said that any other potential investor in this particular area would be entitled to that information through the government agency concerned. He also said that since the license to Nautilus was issued, JAMSTEC of Japan and IFREMER of France have conducted cruises through the area. He commented that he did not understand why the ODP drilling project should be construed as a problem." (Herzig and Petersen)

NAME: New Ireland Provincial Government

SOURCE: http://en.wikipedia.org/wiki/New_Ireland
http://www.pngbd.com/travel/tourism_guide_tpa/index.php
http://www.new-agri.co.uk/99-1/countryp.html

DESCRIPTION:

Three mining spots belong to New Ireland province. The current population of New Ireland is 118,350 (2000 census), the vast majority of whom live in small rural villages. The main town is Kavieng, the provincial capital, on the northern tip of the main island; Namatanai is another small town halfway along the island. Around twenty languages are spoken in New Ireland, and the number of dialects and subdialects totals perhaps 45.

New Ireland Province includes a number of offshore islands. From the northeast coast are the islands of Tabar, Tanga, Feni and Lihir. Lihir Island is the site of the Lihir gold mine, reputed to have the second largest gold deposit in the world.

In New Ireland, declining German colonial plantations have been turned into productive palm oil and copra plantations. These have their own mills, tanks and wharf where oil is shipped to Malaysia for manufacture of foodstuffs. New Ireland is also famous for its fishing skills and has the only Fisheries College in PNG.

Impacted

Fisheries

NAME: Forum Fisheries Agency (FFA)

SOURCE: http://www.ffa.int/node/33
DESCRIPTION:
A consortium of seventeen "Pacific Island" member countries formed in "1979 to help countries manage their fishery resources that fall within their 200 mile exclusive economic zones." (FFA website) Member governments include Australia, New Zealand, Cook Islands, Marshall Islands, Palau, Nauru, Fiji, Federated States of Micronesia, Kiribati, Tonga, Tuvalu, Vanuatu, Tokelau, Solomon Islands, Samoa, Niue, and Papua New Guinea.
CONTACT:
Official Fisheries Contact
Sylvester Pokajam (Acting Managing Director)
National Fisheries Authority
P O Box 2016, Port Moresby, NCD
Papua New Guinea

NAME: National Fisheries Authority (NFA)

SOURCE: http://www.fisheries.gov.pg/about_role_nfa.htm
DESCRIPTION:
The NFA is a "non-commercial statutory authority established and operating under the Fisheries Management Act 1998 and related regulations." The NFA is PNG's fisheries regulatory authority.
CONTACT:

National Fisheries Authority
P.O. Box 2016 Port Moresby, National Capital District,
Papua New Guinea
E-Mail: nfa@fisheries.gov.pg

NAME: Fisheries of local community

SOURCE: http://www.fao.org/fi/fcp/en/PNG/profile.htm

DESCRIPTION:

PNG's small-scale fisheries reflect the diversity of the country's coastal environments. Along the mainland and high island coasts and in the smaller island communities fishing activities include the harvesting of the reef flats, spear fishing, shallow-water hand-lining from dugout canoes, netting, and trapping in the freshwater reaches of the larger rivers. In the swampy lowland areas net fisheries for barramundi, catfish, and sharks occur, while in the Gulf of Papua and parts of the Northern Islands Region there are also village-based lobster fisheries. Collection of invertebrates, both commercially (beche-de-mer as well as trochus and other shells) and for subsistence purposes is extensive, and may exceed finfish harvesting. Commercial prawn-trawling operations take place in the Papuan Gulf and other parts of southern PNG, and a small-scale tuna longline fishery has been established. A handful of vessels are now successfully catching sashimi-grade tuna and exporting them to overseas markets by air.

After many years of foreign domination, PNG is promoting more direct participation in the tuna fishery by local companies and individuals. In line with this policy, the Government ceased issuing foreign longlining licences in mid-1995, in an attempt to promote development of a domestic tuna longline industry. Subsequently, after a number of longliners began operating under local charter arrangements, this too was regulated against, so that the fishery was closed to all but bona fide domestic entrants. This is now being reconsidered due to slow growth of the fishery, and consequent loss of government revenue. The fishery may be re-opened to foreign chartered longliners until there are sufficient domestic vessels to take up all available licences.

Shipping

NAME: PNG Maritime Workers Industrial Union

SOURCE: http://www.actu.asn.au/public/news/1022751803_13076.html

DESCRIPTION:

"The Maritime Union of PNG covers all aspects of work on and off the wharf. There is 100% coverage in stevedoring and seagoing labor. Wages for members vary from K100-K150 per week. The MUPNG are attempting to set up a credit union in PNG for union members. They are also in a joint venture with the PEA and community groups owning Workers Mutual Group70%, PEA 20%, MU PNG 10% community based…. The MU PNG is also attempting to start an industry based superannuation scheme."

CONTACT:

John Douglas Gadebo

PNG Maritime Workers Industrial Union

NAME: PNG Maritime College

SOURCE: http://www.pngmc.ac.pg/

DESCRIPTION:

"PNG Maritime College is the only College of its kind in Papua New Guinea offering training in all aspects of Marine Sea-going Personnel. Due to the new ships in Papua New Guinea Coastal and Foreign Going Shipping Trade, there is a great demand for qualified Deck and Engineering Officers from the Shipping Industry.

Students attend the college from East Timor, The Solomon Islands, the Marshall Islands and other members of the SPC.

Member of the South Pacific Uniform Standards Forum means that Papua New Guinea Marine qualifications are required in the South Pacific by all of the members of the forum.

PNG Maritime College courses and systems are audited by AMSA to the same standards as Australian Maritime College and PNG has attained IMO 'white listing' - international recognition of the quality of its courses. The recognition means that PNG certificates are recognized and acceptable world wide."

CONTACT:

PNG Maritime College

P.O. Box 1040, Madang, 0511, Papua New Guinea

EMail: pngmc@global.net.pg

Marine Science Research

NAME: The Commonwealth Scientific and Industrial Research Organization (CSIRO)

SOURCE: http://www.csiro.au

DESCRIPTION:

CSIRO is Australia's national science agency and one of the largest and most diverse scientific research organizations in the world. Its role is to deliver great science and innovative solutions for industry, society and the environment.

Established in 1926, we are the single largest employer of scientists in Australia, with more than 6 500 people conducting and assisting with scientific research at 57 sites in Australia and around the world.

CSIRO's primary roles are to: carry out scientific research assist Australian industry and to further the interests of the Australian community contribute to national and international objectives and responsibilities of the Commonwealth Government encourage or facilitate the application and use of the results of its own or any other scientific research.

NAME: Dr. Cindy Van Dover, Associate Professor of College of William and Mary

SOURCE: cmbc.ucsd.edu/about/CindyLeeVanDover.doc

DESCRIPTION:

Dr. Cindy Lee Van Dover is a deep-sea biologist with a special interest in the ecology of echmosynthetic ecosystems. She began her work in this field in 1982, joining the first biological expedition to hydrothermal vents on the East Pacific Rise. Earning a Master's degree in ecology from UCLA in 1985, she continued her graduate education in the MIT/Woods Hole Oceanographic Institution Joint Program in Biological Oceanography. On receiving her Ph.D. in 1989, Van Dover joined the group that operates the deep-diving submersible ALVIN. She qualified as pilot in 1990 and was pilot-in command of 48 dives. Her work with ALVIN has taken her to nearly all of the known vent fields in the Atlantic and Pacific, as well as to deep-water sea mounts, seeps and other significant seafloor features. Her current research focuses on the study of biodiversity and biogeography of vent faunas. Dr. Van Dover is currently the Marjorie S. Curtis Associate Professor in the Biology Department at the College of William & Mary.

NAME: An Initiative for international cooperation in ridge-crest studies (InterRidge)

SOURCE: http://interridge.org

DESCRIPTION:

The event that sparked the birth of InterRidge occurred when two countries using the same resource- and labor-intensive tools to visit the same place on the ocean floor realized that it made more sense to share resources than have to find ways to independently fund their own. It was 1992. More than a decade later, InterRidge remains anchored by the principle of collaboration: It is an international organization that pools the resources of its member countries to drive oceanic ridge research forward in a way that is cost-effective, cooperative and proven to be successful.

The first ten years of InterRidge produced a coordinated, international ridge community of member countries that had previously been working alone, and left a string of success stories in its wake. Two examples are the first-ever mapping and sampling of one of the slowest spreading and remote centers known to date, the Gakkel Ridge in the Arctic Ocean, and the exploration and study of the South-West Indian Ridge. Embarking on its second decade plan, InterRidge is currently 2700 researchers and 27 countries strong. The doors are wide open for more to join. The plan for the next decade (2004-2013) is three-fold:

· Establish a long-term, real-time presence on the ocean ridges

· Support oceanic ridge science in large-scale international research programs

· Raise public awareness of the oceanic ridge environment through education outreach initiatives

NAME: Ridge 2000 Program

SOURCE: http://www.ridge2000.org/science/info/index.html

DESCRIPTION:

Ridge 2000 is a multidisciplinary science research program focused on integrated geological and biological studies of the Earth-encircling mid-ocean ridge system and funded by the National Science Foundation. The program has two main themes:

Integrated Studies focus and coordinate research activities at a few carefully chosen sites in the Pacific, recognizing that the complex linkages between life and planetary processes at mid-ocean ridges can only be understood through tightly integrated studies that span a broad range of disciplines.

Time Critical Studies are designed to enhance detection of volcanic and other transient events on the mid-ocean ridge and to facilitate rapid-response missions that can observe, record, and sample critical transient phenomena. These studies are largely limited to the Northeast Pacific at this time.

The Ridge 2000 Science Plan gives details of these themes together with program objectives, scientific rationale, and many programmatic details.

NAME: The Underwater Mining Institute (UMI)

SOURCE: http://www.soest.hawaii.edu/HURL/UMI/UMI2005/about.html

DESCRIPTION:

The Underwater Mining Institute (UMI) draws on the expertise of researchers, industry professionals, and environmental, resource, and policy managers worldwide to provide the latest information relevant to seabed minerals. Since the first UMI was held in Milwaukee, Wisconsin in 1970, the Institute's primary goal has remained constant--to encourage prudent and responsible development of marine mineral resources through technical presentations in venues that promote informal and free exchange.

Interested

International Authorities

NAME: International Seabed Authority

SOURCE: http://www.isa.org.jm/en/default.htm
DESCRIPTION:
The International Seabed Authority is an autonomous international organization established under the 1982 United Nations Convention on the Law of the Sea and the 1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea.
The Authority is the organization through which States Parties to the Convention shall, in accordance with the regime for the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction (the Area) established in Part XI and the Agreement, organize and control activities in the Area, particularly with a view to administering the resources of the Area.
Part XI deals with an international seabed area that lies beyond the limits of any nation's jurisdiction and whose resources are designated "the common heritage of mankind."
Three of its main organs have been functioning since its inception in 1994:
Policy-making Assembly: composed of all states that belong to ISA
36-member executive council: set specific policies
Secretariat: composed of staff carrying out the day-to-day activities of information gathering, monitoring and research
Besides the three organs, two permanent subsidiary bodies have been established: a Legal and Technical Committee and a Financial Committee.

The Legal and Technical Committee published several guidelines related to SMS mining as follows:

Establishment of environmental baselines at deep seafloor cobalt-rich crusts and polymetallic sulphide mine sites in the Area : Proceedings of the 16-20 September 2004 workshop held in Kingston, Jamaica.

Standardization of Environmental Data and Information: Development of Guidelines; Proceedings of the International Seabed Authority's Workshop, Kingston, Jamaica, June 25-29, 2001

Polymetallic massive sulphides and cobalt-rich ferromanganese crusts: status and prospects. Technical Study: No.2.

(http://www.isa.org.jm/en/publications/default_ae.asp)

CONTACT:

Nii Odunton, Detuty Secretary General, ISA

E-mail nodunton@isa.org.jm

NAME: South Pacific Applied Geosience Commission (SOPAC)

SOURCE: http://www.sopac.org/tiki/tiki-index.php

DESCRIPTION:

It is an inter-governmental, regional organisation dedicated to providing services to promote sustainable development in the countries it serves. SOPAC’s work is carried out through its Secretariat, based in Suva, Fiji. The work programme is reviewed annually by the Governing Council assisted by: Secretariat representatives, a Technical Advisory Group (TAG), and a Science, Technology and Resources Network (STAR).

SOPAC was established in 1972 under the Economic and Social Division of the UN as a project called the Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC), to promote offshore mineral and petroleum prospecting. The secretariat became autonomous in 1984 with the funding of its member countries, donor countries and international agencies to steer its annual operations. While the initial focus of its work was on marine mapping and geosciences, recent years have seen a broadening of this scope to include hazard assessment and risk management, environmental vulnerability, oceanography, energy, water and sanitation and information and communication technologies.

CONTACT:

SOPAC Secretariat,

Private Mail Bag, GPO

Suva, Fiji Islands

E-mail director@sopac.org , Voice:2010@vip.sopac.org

NGOs

NAME: Conservation International (CI)

SOURCE: www.conservation.org

DESCRIPTION:

A U.S.-based, international organization, Conservation International (CI) is a nonprofit, tax-exempt corporation under Section 501(c)(3) of the Internal Revenue Code.

CI applies innovations in science, economics, policy and community participation to protect the Earth's richest regions of plant and animal diversity in the biodiversity hotspots, high-biodiversity wilderness areas as well as important marine regions around the globe. With headquarters in Washington, D.C., CI works in more than 40 countries on four continents.

NAME: Terra Nature

SOURCE: http://www.terranature.org/about_us.htm

DESCRIPTION:

Terra Nature consists of New Zealand incorporated Charitable Trust and a California Nonprofit Public Benefit Corporation. They are environmental organizations dedicated to protecting native habitat and wildlife, sustaining biological diversity on land and in the sea, conserving terrestrial open space, and establishing marine protected areas.

CONTACT:

Graeme Woodhouse Chair/President
1644 Clay Street   Suite 1
San Francisco   California 94109
E-mail woodhouse@terranature.org

NAME: Individual Community Rights Advocacy Forum (ICRAF)

SOURCE:http://www.roldirectory.org/details.asp?Orgname=INDIVIDUAL%20COMMUNITY%20RIGHTS%20ADVOCACY%20FORUM

DESCRIPTION

ICRAF is a non-profit, non-government organization which was established in 1992 to deal with human rights, environment destruction, and land rights issues in PNG. The ICRAF programs are delivered through the lawyers, community workers and other professionals and two program desks. These are the Women's Desk and the Land and Environment Desk. This NGO is a member of individual advisory group for Porgera Gold mine in PNG.

NAME: MiningWatch Canada (MWC)

SOURCE: http://www.miningwatch.ca/index.php

DESCRIPTION:

MiningWatch Canada (MWC) is a pan-Canadian initiative supported by environmental, social justice, Aboriginal and labour organisations from across the country. It addresses the urgent need for a co-ordinated public interest response to the threats to public health, water and air quality, fish and wildlife habitat and community interests posed by irresponsible mineral policies and practices in Canada and around the world.

The MiningWatch Canada office opened in April 1999. MiningWatch Canada shares infrastructure and services with the Canadian Parks and Wilderness Society (CPAWS) in a central Ottawa location.

CONTACT:

MiningWatch Canada

250 City Centre Ave., Suite 508

Ottawa, Ontario K1R 6K7, Canada

e-mail: info(at)miningwatch.ca

NAME: Earthworks

SOURCE: http://www.mineralpolicy.org/about_us.cfm

DESCRIPTION:

EARTHWORKS brings together activists, organizers, scientists, engineers, and community leaders in a unified effort to protect our communities and the earth's resources.

EARTHWORKS evolved from the work of the Mineral Policy Center (MPC). MPC was founded by Phil Hocker, Mike McCloskey and former Secretary of the Interior Stewart L. Udall to help reform mining laws and practices in the U.S. MPC has worked largely behind the scenes to combat the destructive impacts of mining, drilling and digging. MPC has a track record of success.

MPC has won every community-based campaign in which it has participated, such as protecting Yellowstone National Park from the proposed New World gold mine, protecting 400,000 acres of the scenic Rocky Mountain Front, preventing mineral development near Yosemite National Park and helping to defend Argentina's pristine Patagonia region from another proposed open-pit gold mine. MPC worked to expose mining industry toxic releases, by requiring mining companies to report their toxic releases in the U.S. MPC also worked to impose a moratorium on the $2.50 an acres giveaways of public lands to mining companies by the U.S. government.

We fulfill our mission by working with communities and grassroots groups to reform government policies, improve corporate practices, influence investment decisions and encourage responsible materials sourcing and consumption.

We expose the health, environmental, economic, social and cultural impacts of mining through work informed by sound science.

CONTACT:

Earthworks
1612 K St., NW, Suite 808, Washington, D.C., USA
E-mail info@earthworksaction.org

Advisory Group Consisting of NGOs, Government and Industries

NAME: Porgera Eanvironmental Advisory Komiti (PEAK)

SOURCE: http://www.peak-pjv.com/

DESCRIPTION:

"The Porgera Environmental Advisory Komiti (PEAK) is an independent advisory group which counsels on the environmental performance of the Porgera Gold Mine, one of the largest gold mines in Papua New Guinea.

PEAK represents the interests of key stakeholders in the mine, including the PNG government, environmental and aid groups, independent technical experts and the Porgera Joint Venture (PJV) which owns and manages the mine

PEAK was established to provide a transparent process for advising on Porgera's environmental performance. It was formed following community concern about the long term impacts of the mine's riverine tailings disposal method on the environment and communities living downstream of the mine.

PEAK's primary function is to identify the social and environmental impacts of the Porgera Gold Mine, and to assist in improving its environmental performance and public accountability.

PEAK's major tasks include:

To oversee the implementation of the recommendations made by the independent review;

Review the annual environmental monitoring reports and trends in monitoring data;

Advise the PJV on the necessity of relevant studies to be carried out to assist the PJV in the management of the Mine Closure Plan; and

Review environmental and mine closure issues raised by external stakeholders, including community and environmental groups, for consideration by the Porgera Joint Venture (PJV)."

APPENDIX 2 Acronyms

1. ADCP, Acoustic Doppler Current Profiler
2. AMD, Acid Mine Drainage
3. ATDS, Adaptive Technology Development Strategy
4. ATESEPP, Impacts of Potential Technical Interventions on the Deep Sea
5. BACIPS, Before After Control Impact Paired Series
6. BIE, Benthic Impact Experiments
7. BMS, Benthic Multicoring System
8. CCFZ, Clarion Clipperton Fracture Zone
9. CSIRO, Commonwealth and Scientific Industrial Research Organization
10. DESMOS, DEep Sea MOnitoring Japanese System
11. DIETS, Direct Impact Experiment on Seamount
12. DISCOL, DISturbance and reCOLinisation experiment
13. DOMES, Deep Ocean Mining Environmental Study
14. DSM, Deep-Sea Mining
15. EEZ, Exclusive Economic Zone
16. EL, Exploration License
17. FFA, Fisheries Forum Agency
18. GDP, Gross Domestic Product
19. GPS, Global Positioning System
20. ICRAF, Individual and Community Rights Advocacy Forum
21. IMMS, International Marine Minerals Society
22. INDEX, Indian Deep-Sea Environment Experiment
23. IOM-BIE, Inter-Ocean Metal Consortium – Benthic Impact Experiments
24. ISA, International Seabed Authority
25. JET, Japan Deep-Sea impact Experiments
26. LCA, Life Cycle Assessment
27. MESEDA, Deep Metaliferous Sediment Development Programme
28. MMAJ, Metal Mining Agency of Japan
29. NGO, Non-Governmental Organization
30. NOAA, National Oceanic and Atmospheric Association

31. NOAA-BIE, National Oceanic and Atmospheric Association, Benthic Impact Experiments
32. OMA, Ocean Mining Associates
33. OMI, Ocean Mining Inc.
34. OTEC, Ocean Thermal-Electric Conversion
35. PACMANUS, Papua New Guinea-Australia-Canada-Manus
36. PAM, Passive Acoustic Monitoring
37. PEAK, Porgera Environmental Advisory Komitis
38. PNG, Papua New Guinea
39. PPM, Parts Per Million
40. PROD, Portable Remotely Operated Drill
41. ROV, Remotely Operated Vehicle
42. SAG, Semi Autogenous Grinding
43. SMS, Seafloor Massive Sulfides
44. SOPAC, South Pacific Applied Geoscience Commission
45. TUSCH, German, Tiefseeumweltschutz, deep sea environmental protection
46. UNCLOS, United Nations Convention on the Law of the Sea

APPENDIX 3 Film Dialogue

The following film pitch is for a 7-10 minute documentary on deep-sea mining. The film is meant to serve as an outreach component of the Donald Bren School Masters Thesis Project *Potential Deep-sea Mining of Seafloor Massive Sulfides: A Papua New Guinea Case Study*.

PROBLEM STATEMENT

Scholarly papers are not enough for environmental issues and science.

Most environmental science and policy research papers never reach beyond the small circle of professionals in the field, and rarely do they bridge the gap between the scientific and corporate worlds, much less to the public. And yet the dialogue between corporations, the public, and environmental scientists is more important now than ever and looks to become increasingly important.

This fundamental disconnect between corporations and environmental scientists must be bridged. No matter how brilliant the paper, if corporations and the public are unaware of the issues and solutions, society as a whole will continue to confound the best intentions and recommendations by environmental scientists and professionals.

REASONS FOR THE FILM

Environmental solutions work best through consensual actions

Deep-sea mining environmental stewardship will require environmental expertise and transparency. Although environmental expertise can be hired, transparency requires an alliance with an independent party.

We believe that a successful deep-sea mining Corporate-NGO-Government-Scientist alliance would include Nautilus-Placer Dome, Conservation International, CSIRO, and a deep-sea scientific society such as Ridge 2000.

It is our belief that “putting a face” on the parties involved and “giving a voice” to each perspective through a documentary film will promote communication between these stakeholders.

THE BIG PICTURE

Corporate environmental transparency and scientific exploration have common goals.

The majority of corporate infrastructure supporting our current lifestyle was developed before environmental concerns ever entered into the corporate psyche. This fact is a competitive opportunity for *new* industries that can develop environmentally sustainable infrastructure *as they grow.* Since Corporate Environmental Responsibility is still a relatively new concept first actors stand to gain the most as an industry environmental trend setter. New mining industries in particular stand to benefit a great deal from environmental responsibility due to the industry’s historically poor environmental track record.

IMAX films such as *Volcanoes of the Deep (2003)* and *Aliens of the Deep (2005)* have put the deep sea on center stage by highlighting discoveries including new species and theories about the origin of life on earth and other planets. As a result, no matter what the nascent deep-sea mining industry does, it surely will make news.

Deep-sea mining has the <u>opportunity to set the bar for corporate environmental stewardship on the world stage</u> through its development choices. The documentary film in this proposal is the first step towards the goal of environmental transparency.

Since the deep ocean is inaccessible to all without a submersible, film will play a significant role in any environmental assessment and monitoring program, which in turn can be used for scientific exploration as well. For these reasons our group created a 7-10 minute documentary film on the subject of deep-sea mining.

INTERVIEWS CONDUCTED

Ray Binns, CRIRO Exploration and Mining, Retried Chief Research Scientist

Timothy McConachy, CSIRO Exploration and Mining, Current Chief Research Scientist

Justin Baulch, Placer Dome, Project Manager Solwara

Michael Williamson, Williamson and Associates, President and Geophysicist

Charles Morgan, Underwater Mining Institute Chair

Steven Scott, University of Toronto, Professor of Geology

Yannick Beaudoin, University of Toronto, Geology PhD Candidate

Testuo Yamazaki, Japan National Institute for Resources & Environment, Senior Researcher

Dave Hayden, Nautilus Minerals Inc, CEO

Derek Ellis, Marine Environnemental Scientist

Nii Odunton, ISA, Députe Directory

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Baulch, J., 2005a, personal communication, santa barbara.

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