Seabed Mineral Resources: A Review of Current Mineral Resources and Future Developments

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A B S T R A C T

The lack of new discoveries and ever decreasing average grades of on-land resources have pushed exploration of the seabed for valuable minerals to the forefront of the global minerals sector. With the seabed exploration industry rapidly gaining momentum, it is anticipated that many more seabed resources will be discovered, developed and reported in the near future.

It is crucial for seabed resources to be defined and reported following the same principles and to the same standards as those established for traditional land-based resources. That is, to have the resources reported in accordance with a code recognised by the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) and based on documentation prepared by a Competent Person as defined by such a code. Misperceptions within the seabed industry that these codes are not relevant and that they exist only to protect investors lead to poor or inefficient resource management, bad financial decisions and ultimately to missed opportunities. While these codes originate from the requirement to provide transparent reporting to the market, their use also carries the inherent benefit of ensuring international standards of good practice. Higher quality mineral resources, completed by Competent Persons, reported publicly under a code have a greater potential to be successfully explored and brought into production.

Since the first seabed mineral resource was reported publicly under a code in 2008, a total of five mineral resources have been reported publicly in accordance with CRIRSCO-compliant classification and reporting standards, specifically the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) National Instrument 43-101 Standards of Disclosure for Mineral Projects (NI 43-101) and the Australasian Joint Ore Reserves Committee's Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC 2012 Code). These include three inferred mineral resources and two indicated mineral resources.

This discussion paper presents an overview of known seabed resources and summarises the current state of seabed mineral resource reporting. It highlights issues that should be addressed by those seeking to formally define seabed resources in the future.

Keywords:
seabed resources
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CRIRSCO
Competent Person
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INTRODUCTION

Exploration and exploitation of solid deep-sea mineral resources (excluding oil and gas) was first proposed by Mero (1965)[1] who highlighted the potential economic value of manganese nodules on the seabed within the Clarion-Clipperton Zone (CCZ) in the central eastern Pacific[2]. This work helped stimulate an exploration boom that lasted throughout the 1970s[3,4] but which declined during the early 1980s as commodity prices crashed and in many cases offshore mineral exploitation became financially unviable[2]. At that time, a lack of a rigid regulatory framework that could guarantee title and exclusive rights to mine the seabed further, prevented explorers from progressing to commercial-scale project development[5,6]. In recent years interest in marine solid-mineral resources has been renewed and has rapidly gained momentum as internationally accepted regulations for seabed exploration and exploitation have been established[7-9] and global demand for commodities increases[10-12] concurrent with dwindling discoveries of new onshore deposits and decreasing grades of land-based resources[13,14].

There are numerous potential benefits offered by seabed mining. Seabed resources tend to be rich in widely utilised elements that are under increasing demand and that have no substitute in their technological and industrial applications (such as Ni and Mn)[12]. Seabed mining offers an alternative and often high grade, polymetallic source of such commodities without the need for permanent infrastructure at a mine site as the equipment could be remobilised and reused to exploit other deposits in different locations[15-17]. The numerous offshore solid mineral resources currently under development typically have little or no overburden[15,16] and will not dislocate communities for mining operations to be carried out[15]. Global mineral resources are not evenly distributed. (For instance, in 2012[18] Chile produced 32% of the world's copper, Congo produced 50% of the world's cobalt and China produced 43% of the world's phosphate rock, 37% of the world's zinc and 90% of the world's rare earth elements (REEs)[19]. Seabed resources offer the chance for nations with limited land-based deposits to develop their own metal supplies. Maritime nations have opportunities to develop resources within their Exclusive Economic Zones (EEZs)[20] and extended continental shelves, and both maritime and land-locked nations can apply for exploration licences for seabed resources within international waters. These fall under the jurisdiction of the International Seabed Authority (ISA) whose duty it is to enforce stringent environmental and safety regulations, as well as to ensure developing nations benefit from mining developments in international waters[12]. Consequently, seabed resources have the potential to provide some balance in terms of global supply and financial benefit from exploitation of numerous commodities.

This vast range of potential benefits means seabed solid mineral exploration and development is progressing steadily despite a recent downturn in the minerals industry as a whole, which has seen a lack of investor confidence and funding for land-based exploration and resource projects in general[21]. The bulk of seabed mineral exploration is currently being conducted by private companies and government-funded consortia. However, publicly listed Nautilus Minerals was the first explorer to publicly report a deep-sea mineral resource, releasing an NI 43-101 code-compliant resource report in 2008[22]. Nautilus' Solwara 1 project is a polymetallic seafloor massive sulphide (SMS) deposit, located in the Bismarck Sea, within the EEZ of Papua New Guinea. An updated resource statement was published for the deposit in 2012[23] and, in collaboration with the Government of Papua New Guinea, Nautilus plans to develop Solwara 1 into the world's first deep-sea mining operation[24].

International Reporting Codes

Code-compliant reporting of mineral resources and reserves[1] is a concept that is well defined, widely accepted and fully implemented within the commercial land-based exploration and mining sector. Standardisation of reporting started in the early 1990s, as a means of developing a set of international standard definitions for the reporting of mineral resources and mineral reserves (e.g. the CRIRSCO Standard Definitions[25]). Incidents such as the 1970's Poseidon boom and bust[26] and the 1997 Bre-X scandal[27] quickly transformed the reporting landscape and led to the creation of reporting codes, such as the JORC Code and the NI 43-101 standard which have the primary purpose to protect investors and provide them with standardised, unambiguous and reliable information. They provide the same benefits to all other stakeholders in the minerals sector, including developers, consumers and assessors[28]. The national codes and standards currently in accord with the CRIRSCO International Reporting Template together account for >80% of the listed capital within the global mining industry[29].

Of these, the JORC Code (2012) and the NI 43-101 standard are generally considered the most prescriptive and are used as the templates for the majority of resource, reserves and project feasibility reporting across the English-speaking world. These codes are also starting to find wider acceptance in the non-English speaking world (e.g. a Chinese translation of the JORC Code was released in 2014[30]).

Each code requires reports to be transparent, unambiguous and contain all relevant information, but the critical component of all codes is that they require reports to be based on documentation compiled by one or more Competent Persons (or, depending on the code, a "Competent Person" (e.g. JORC) or a "qualified person" (e.g. NI 43-101)). A Competent Person is strictly defined as someone who is *qualified*, with at least five years' experience *relevant* to the commodity and/or sections of the report for which they are responsible (exploration results, resource estimation, reserve estimation, project feasibility, etc.), and who is also a member of a professional organisation with a code of ethics to which that person can be held accountable[31,32]. This ensures that reporting is undertaken by people of sufficient knowledge, skill and integrity to present complex information critical to the objective evaluation of projects in an appropriate and unbiased manner.

Having met all of these criteria, information that is material to the understanding of the estimate of mineral resources then needs to be made publicly available in a transparent manner along with all the necessary compliance statements (Competent Person's declaration, etc.) to be considered code-compliant. Thus, in this paper the term "code-compliant" means "reported in accordance with an internationally accepted reporting code, based on documentation prepared by a Competent Person as defined by such a code, and with information that is material to the understanding of the estimate of mineral resources transparently reported in the public domain (e.g. JORC 2012 Table 1)".

An increasingly frequently seen statement in the seabed resource industry is that resource estimates themselves (and not the reporting) are "code-compliant" (i.e. use of the term "code-compliant resource"). A code regulates the public reporting of data, not the manner in which a Competent Person estimates mineral resources or ore reserves. The term "code-

[1] Terms such as 'Resources', 'Reserves', 'Competent Persons', 'Code' and 'Reports' are capitalised where they are used in specific context and in compliance with JORC or other CRIRSCO codes that capitalise key terms (see further explanation in text). Lower case 'resources', 'reserves' and 'reports' are used in all other situations, including references to resource reports compiled by qualified persons in compliance with NI 43-101, which does not capitalise key terms.

compliant" therefore refers to the manner of reporting and not to the estimates. Use of the words "code-compliant" to describe resources or estimates is potentially misleading.

Several seabed explorers have already successfully utilised current frameworks to issue code-compliant public reports for seabed mineral resources[2,23,33-35]. These are summarised in this paper, along with several other mineral resources that have been presented in the public domain but which lack the accompanying statements and/or documentation that would enable them to be deemed code-compliant public reports. Individual deposits, projects and reports mentioned in this report have not been assessed by the authors for specific points of *technical* compliancy. For example, a company listed on the TSX, having made public a report, stated to be compliant with NI 43-101, along with supporting information and with a resource statement that is compiled by a qualified person is discussed herein as "code-compliant". Errors or omissions of specific technical matters discussed in such a report that would jeopardise its strict compliancy terms are disregarded for the sake of the discussion in this paper. Regulation of specific points of technical compliancy is a highly debated and complicated matter and outside the scope of this paper. It is the responsibility of the relevant security exchanges and member organisations to govern such detailed technical compliance. The reader is directed to the various guidelines for more information on this subject [25,32,36-43].

Only publicly listed companies are subject to reporting regulations in their respective jurisdictions and therefore private companies, which form the majority of the seabed exploration community, are not necessarily affected, unless they operate in waters under national jurisdiction and are required to report to specific standards by the government of that nation. This paper argues that private explorers, too, will benefit from following the same international guidelines. This will standardise the industry, "lift the bar" and provide a clear framework to report confidence in mineral resource estimations. Simply put: better defined measuring sticks will provide better quality outputs for all involved.

The authors suggest that this could be implemented and regulated by a committee appointed and managed by the International Seabed Authority (ISA) and the Secretariat of Pacific Communities (SPC) (see below). This will greatly assist overseers in activities such as regulating licence expenditure requirements, progress monitoring on each issued licence and stimulating best practice, which in turn will promote proper exploration techniques, quicker turn-over of licences that are not optimally explored and ultimately improved chances of establishing a mine.

The authors present data in this paper that is within the public domain. While efforts have been made to ensure the information presented and discussed is as up to date and as accurate as possible, the dynamic and often confidential state of resource estimation and development means that in some instances (i.e. for private companies) this may not be the case.

International Seabed Authority

Approximately 64% of the world's oceans (by surface area, 95% by volume) is classified as international waters[44]. Consequently the majority of global seabed and its mineral resources fall under the jurisdiction of the ISA. The ISA was established by the 1982 United Nations Convention on the Law of the Sea (UNCLOS)[45]. It became a functioning body following the signing of an Agreement Relating to the Implementation of Part XI of UNCLOS[46] in 1994, and became an autonomous organisation in 1996[47].

In accordance with UNCLOS, national jurisdiction of a nation over its seabed is limited to the EEZ which extends up to 200 nautical miles offshore, except where this zone overlaps between neighbouring nations and alternative boundaries are negotiated. National jurisdiction can extend beyond 200 nautical miles in some cases where the continental shelf extends beyond the limit of the EEZ and is contiguous with a nation's landmass. Nations have exclusive rights to seabed mineral resources within these zones[45] and seabed explorers must follow the laws and requirements of the nation's waters in which they operate. Seabed beyond the limits of national jurisdiction constitutes international waters and is referred to collectively as the "Area". UNCLOS Part XI defines the Area and its resources as "the common heritage of mankind" and the ISA (referred to in UNCLOS as "the Authority") has the responsibility to oversee and regulate activities in the Area, particularly with regard to administration of its resources[45,47].

The ISA is headquartered in Kingston, Jamaica, is administered by a Secretariat and governed by an Assembly currently composed of 166 member states (notably not including the United States of America which does however have Observer status). A 36-member Council establishes policies and coordinates mineral exploration and exploitation activities within the Area through the execution and oversight of exploration contracts with state-sponsored entities (ISA "contractors"). A Finance Committee oversees the financial management of the Authority and a 25-member expert Legal and Technical Commission (LTC) supervises exploration and mining activities within the Area and advises the Assembly and the Council on all matters relating to non-living marine resources[47].

The ISA has established deposit-specific regulations for prospecting and exploration as part of a Mining Code, including specific regulations for polymetallic nodules (adopted in 2000 and amended in 2013), for polymetallic sulphides (i.e. SMS) (adopted in 2010) and for cobalt-rich ferromanganese crusts (adopted in 2012)[47]. Prospecting within the Area can be undertaken in accordance with UNCLOS and the regulations, following notification to the ISA of a prospector's intentions. It is not necessarily clear from this Mining Code what the rules are if there are no regulations for a specific deposit. While reasonable quantities of minerals can be recovered for testing purposes, prospectors do not have exclusive rights to the areas in which they are conducting their activities, nor do they have any rights to exploit minerals for commercial use without first applying for an exploration licence and signing a contract with the ISA[7-9]. Applications are deposit-specific, do not need to comprise a single area but have maximum and minimum size allowances depending on deposit type. The total area applied for must be of sufficient size to conceivably allow two mining operations to be developed, and have two designated areas of equal commercial value (based on available data). A joint venture (JV) with the ISA must be negotiated or one of these two areas relinquished to the ISA (in stages over several years) for incorporation into Reserved Areas. These are set aside by the ISA for its own activities or to be issued upon applications for exploration licences by developing nations. This system of site-banking serves to safeguard equal opportunities for all states to seabed resources within international waters[47].

The ISA issued its first exploration contracts in 2001. All six of these were for polymetallic nodules and each comprised 75,000 km^2 of seabed within the CCZ. Currently 19 contracts have been issued (13 for polymetallic nodules, four for polymetallic sulphides and two for ferromanganese crusts), and three further applications for polymetallic nodules exploration have been approved and are awaiting execution of contracts. A summary of these is given in Table 1. Contracts are issued for a period of 15 years and the first contracts are due to expire in March 2016. The ISA

Table 1: ISA Contractors (updated from[48] with information from[49-55])

Contractor	*Deposit Type*	*Location*	*Area (km^2)*	*Sponsoring State*	*Contract Start Date*	*Contract End Date*
Interoceanmetal Joint Organization (IOM)	Polymetallic Nodules	CCZ	75,000	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation & Slovakia	29-Mar-01	28-Mar-16
Yuzhmorgeologia	Polymetallic Nodules	CCZ	75,000	Russian Federation	29-Mar-01	28-Mar-16
Government of the Republic of Korea (KIOST)	Polymetallic Nodules	CCZ	75,000	Republic of Korea	27-Apr-01	26-Apr-16
China Ocean Mineral Resources Research and Development Association (COMRA)	Polymetallic Nodules	CCZ	75,000	China	22-May-01	21-May-16
Deep Ocean Mineral Resources Development Co. Ltd. (DORD)	Polymetallic Nodules	CCZ	75,000	Japan	20-Jun-01	19-Jun-16
Institut Français de Recherche Pour l'Exploitation de la Mer (IFREMER)	Polymetallic Nodules	CCZ	75,000	France	20-Jun-01	19-Jun-16
Ministry of Earth Sciences, Government of India (MOES)	Polymetallic Nodules	Indian Ocean	75,000	India	25-Mar-02	18-Jul-17
Federal Institute for Geosciences and Natural Resources of Germany (BGR)	Polymetallic Nodules	CCZ	75,000	Germany	19-Jul-06	18-Jul-21
Nauru Ocean Resources Inc. (NORI)	Polymetallic Nodules	CCZ	75,000	Nauru	22-Jul-11	21-Jul-26
Tonga Offshore Mining Ltd.(TOML)	Polymetallic Nodules	CCZ	75,000	Tonga	11-Jan-12	10-Jan-27
Marawa Research and Exploration Ltd.	Polymetallic Nodules	CCZ	75,000	Kiribati	19-Jan-15	20-Jan-30
UK Seabed Resources Ltd.	Polymetallic Nodules	CCZ	58,620	United Kingdom of Great Britain and Northern Ireland	8-Feb-13	7-Feb-28
G-TEC Sea Mineral Resources NV (DEME Concessions NV)	Polymetallic Nodules	CCZ	76,728	Belgium	14-Jan-13	13-Jan-28
Cook Islands Investment Corporation (CIIC)	Polymetallic Nodules	CCZ	75,000	Cook Islands	(To Be Signed; Approved 21 July 2014)	
Ocean Mineral Singapore Pte Ltd. (OMS)	Polymetallic Nodules	CCZ	58,280	Singapore	22-Jan-15	21-Jan-30
UK Seabed Resources Ltd.	Polymetallic Nodules	CCZ	149,815	United Kingdom of Great Britain and Northern Ireland	(To Be Signed; Approved 21 July 2014)	
China Ocean Mineral Resources Research and Development Association (COMRA)	Polymetallic Sulphides	Southwest Indian Ridge	10,000	China	18-Nov-11	17-Nov-26
Government of the Russian Federation	Polymetallic Sulphides	Mid-Atlantic Ridge	10,000	Russian Federation	29-Oct-12	28-Oct-27
Government of the Republic of Korea (KORDI)	Polymetallic Sulphides	Central Indian Ocean	10,000	Republic of Korea	24-Jun-14	23-Jun-29
Institut Français de Recherche Pour l'Exploitation de la Mer (IFREMER)	Polymetallic Sulphides	Mid-Atlantic Ridge	300,000	France	18-Nov-14	17-Nov-29
Japan Oil, Gas and Metals National Corporation (JOGMEC)	Cobalt-Rich Ferromanganese Crusts	Western Pacific Ocean	3,000	Japan	27-Jan-14	26-Jan-29
China Ocean Mineral Resources Research and Development Association (COMRA)	Cobalt-Rich Ferromanganese Crusts	Western Pacific Ocean	3,000	China	29-Apr-14	28-Apr-29

requires contractors to submit all of their data as well as resource and reserve estimates at the end of their exploration contracts[56]; however, the format for data reporting as well as the procedure and requirements for applications for extension of contracts and/or applications for mineral exploitation have not yet been determined. These are currently being drafted and will be put before the ISA Council for consideration later this year.

Recognising the urgent need to adopt a standardised code of data and resource reporting, the ISA recently hosted a workshop on Polymetallic Nodules Resource Classification (Goa, India, 13 – 17 October 2014). As well as receiving exploration updates from several contractors, many of the established reporting codes were presented and discussed. An 11-person subcommittee drafted proposed amendments to the CRIRSCO International Reporting Template to make it more applicable to polymetallic nodules resources[57]. Comprising four additional clauses, the proposed amendments were presented to workshop delegates for comment, but it remains to be seen whether they (or other equivalents) will be adopted.

TYPES OF SEABED DEPOSITS

Industrial aggregate and placer heavy mineral deposits have long been exploited in shallow water settings (<200 m water depth) around the world. Current operations include extraction of diamonds (Namibia), cassiterite tin (SE Asia) and gold (North America, though intermittent)[3], and other projects (e.g. ironsands, New Zealand) are in the final stages of development and currently seeking approval to begin production[58]. The focus of this paper is on deep-sea (>200 m water depth[59]) solid mineral resources. These include: SMS (polymetallic sulphides), manganese or polymetallic nodules, so-called "cobalt-rich" ferromanganese crusts, and phosphorite (Figure 1). An overview of the typical characteristics of these deposits is in Table 2.

Overview of Current Seabed Resources

This section presents an overview of reported mineral resources of known deep-sea (>200m water depth) seabed projects, arranged by deposit type. These are divided into *code-compliant* and *other* mineral resources.

All but one of the deposit types in Table 2 can also occur at water depths <200 m, which means that there is some overlap with shallow-water settings. In particular, one phosphorite project is located at depths <200 m, but has been included in this discussion alongside other phosphorite projects located in deeper waters for the sake of completeness.

While efforts have been made to ensure the information presented is as accurate and up to date as possible, it is necessarily limited to that which is available in the public domain.

Seafloor Massive Sulphides

Though volcanic massive sulphide (VMS) deposits have long been known and exploited in terrestrial settings, their marine analogues were not discovered until the late 1970s in the form of active hydrothermal vents on the East Pacific Rise[3,60,61]. The vast majority of work since then has been conducted by academic researchers. Exploration has focused on actively forming SMS deposits due to the comparative ease of locating them compared to inactive centres. However, extinct centres have the potential to be much larger, more numerous and less environmentally sensitive to exploit than deposits associated with active venting[62].

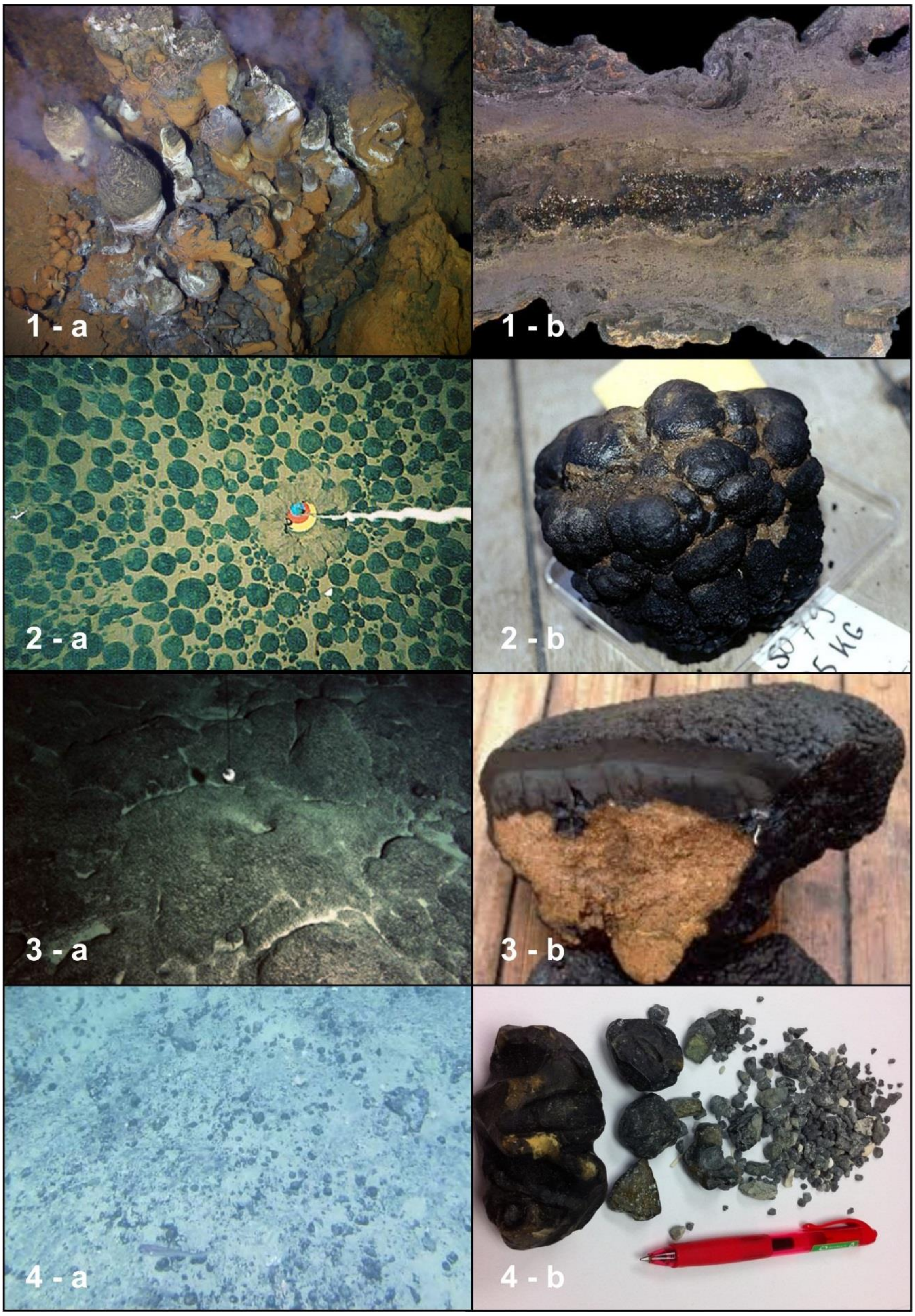

Figure 1: Types of seabed mineral deposit. 1. Seafloor massive sulphides a) in situ, and b) in section. 2. Polymetallic nodules a) in situ, and b) large recovered nodule. 3. Ferromanganese crusts a) in situ, and b) in section, attached to substrate. 4. Phosphorite nodules a) in situ, and b) collected. (Images courtesy of: 1-a Maurice Tivey, WHOI/NSF/ROV Jason © 2006 Woods Hole Oceanographic Institution, 1-b GNS Science, 2-a Deep Green Resources, 2-b BGR, 3-a JOGMEC, 3-b BGR, 4-a and 4-b CRP).

Table 2: Seafloor Solid Mineral Deposit Types

Deposit Type	Description	Dimensions	Growth Rate	Where Found	Optimal Environment	Commodities	Key Deposits
Seafloor massive sulphides	concentrated deposits of sulphide minerals (>50-60%) derived from hydrothermal venting on the seafloor; include SMS and "black smoker" chimneys[1,2,3]. Analogous to terrestrial VMS deposits[2]	tens of m^2 to several km^2; several metres thick	accumulate over hundreds of thousands to millions of years	active and extinct seafloor spreading ridges, island arcs and back-arc basins; down to 3,700 m water depth[2]	long-lived seafloor hydrothermal centres discharging high-temperature fluids	Pb, Zn, Cu +/- Au, Ag[1]	Red Sea[10], Manus Basin[3] and Mid-Atlantic Ridge[1]
Polymetallic (manganese) nodules	concretions of layered Fe and Mn hydroxides precipitated around a core (shell or rock fragment)[5]	Individual Grains: microscopic to >20 cm nodules, typically 5-10 cm. Nodule Deposits: several tens to hundreds of km^2; ≤0.5 m thick[5,6]	1-10 mm per million years[6]	upper ≤45 cm seafloor sediment. Any water depth[5,6]	4,000 - 6,000m water depth, gentle slopes with low sedimentation rates (abyssal plains)[5,6]	Mn, Ni, Cu, Co +/- Mb, Zn, Zr, Li, Pt, Ti, Ge, Y, REEs[5,7]	Clarion-Clipperton Zone (CCZ), also Peru Basin and north Indian Ocean[5,8]
Ferro-manganese crusts	typically laminated crusts of Mn and Fe oxide +/- quartz & feldspar, up to 25 cm thick. Precipitate from seawater onto hard rock substrates[9]	up to several km^2; ≤0.3 m thick[9]	1-6 mm per million years[9,10]	bare rock, flanks and summits of seamounts; 400 - 4,000 m water depth[9]	extensive hard substrate, low oxygen, 800 - 2,500 m water depth[9]	Mn, Co, Ni, Cu, Te, Mb, Zr, Ti, Bi, Ni, Pt, W, REEs[11,12]	Central equatorial Pacific and equatorial Indian Ocean[2,12]
Phosphorite	composed of sediment, typically nodules but occasionally crusts, containing significant amounts of P_2O_5. Form diagenetically from replacement of carbonate within anoxic sediments close to the sediment-water interface[13]	Individual Grains: microscopic to ~15 cm nodules[14,15] Nodule Deposits: tens to hundreds of km^2; typically <2 m[14,15]	poorly constrained; phosphatisation and accumulation over hundreds of thousands to millions of years	~2 - 600 m water depth[16] along continental margins off South Africa, Gulf of California, South America, Eastern Australia and New Zealand[14]	low oxygen, low sedimentation rate, gentle slopes, proximal to nutrient-rich upwellings/high primary productivity in surface waters[10]	P_2O_5[14,15]	continental shelves of New Zealand, Namibia, South Africa and Mexico[14,15,17]

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Code-Compliant Publicly Reported Mineral Resources

To date there are only two projects that have published Code-compliant polymetallic sulphide resource reports: the Solwara Project in the Bismarck Sea, and the Atlantis II Deep project in the Red Sea.

<u>Solwara</u>

Nautilus Minerals' Solwara project comprises 17 different SMS deposits in the Manus Basin, Bismarck Sea, within the EEZ of Papua New Guinea. Hydrothermal vents were first discovered in the area in 1985 and Nautilus acquired its first exploration licence in 1997[23].

Nautilus was the first explorer to publish a code-compliant seabed resource report. The Solwara 1 deposit is a flat-lying 1.4 km long SMS associated with active hydrothermal venting on the flanks and crest of a volcanic mound rising 150 – 200 m from the seafloor in ~1,550 m water depth. The main mineralised horizon is up to 29 m thick and consists predominantly of pyrite and chalcopyrite with variable amounts of anhydrite and barite. The chalcopyrite content tends to diminish with depth[23].

The 2008 resource report stated an inferred resource of 1,300 kt at average grades of 7.5% Cu, 7.2 g/t Au, 37 g/t Ag and 0.8% Zn, and an indicated resource of 870 kt at average grades of 6.8% Cu, 4.8 g/t Au, 23 g/t Ag and 0.4% Zn, both at a cut-off grade of 4% Cu[22]. Further drilling in 2010/2011 increased the available geological knowledge at Solwara 1 and the additional core data enabled the resource model to be updated. Dated 23 March 2012 the updated resource estimate comprised an inferred resource of 1,540 kt at average grades of 8.1% Cu, 6.4 g/t Au, 34 g/t Ag and 0.9% Zn, and an indicated resource of 1,030 kt at average grades of 7.2% Cu, 5.0 g/t Au, 23 g/t Ag and 0.4% Zn, both at a cut-off grade of 2.6% Cu-equivalent[23]. The resource was estimated by a qualified person, used ordinary kriging estimation of ROV-mounted drilling (average drill spacing ~35 m) and spot samples of sulphide chimneys. The mineral resource was subdivided into three separate domains: consolidated sediment, sulphide dominant and chimneys[23].

The 2012 report also presented a maiden resource statement for the neighbouring Solwara 12 deposit where detailed mapping identified an area of inactive sulphide chimneys including a central cluster of copper-rich chimneys surrounded by zinc-rich chimneys. Subsequent drilling identified a domain of Zn-rich sulphide mineralisation dominated by sphalerite and chalcopyrite, with lesser galena, barite and pyrite, occurring below unconsolidated sediment and extending to a depth of 10.3 m. The sulphide-dominant domain contains pyrite with chalcopyrite with lesser sphalerite and galena and has an average depth of 6 m and a maximum depth of 17 m[23]. The resource statement for Solwara 12 comprises an inferred resource of 230 kt at average grades of 7.3% Cu, 3.6 g/t Au, 56 g/t Ag and 3.6% Zn, at a cut-off grade of 2.6% Cu-equivalent[23].

A Mining Lease for Solwara 1 was granted in December 2011, following the issuing of an Environmental Permit in December 2009. Development of the project is taking place in collaboration with the government of Papua New Guinea (via state nominee Eda Kopa (Solwara) Ltd.) which has a 15% interest in the project until the first production. Most recently this saw the balance of the state's interest (US$113M) released from escrow as Nautilus fulfilled its contractual requirements to secure intellectual rights and charter a mining vessel[63]. This is due to be delivered in 2017[64], whilst construction of seafloor production tools is already 90% complete[20,24].

<u>Atlantis II Deep</u>

The Atlantis II Deep deposit lies at ~2,000 m water depth and is located within the joint EEZ of Saudi Arabia and Sudan in the Red Sea. It is the largest marine sulphide deposit known[10]. First discovered in 1963[35], the deposit is the largest of several normal fault-bounded bathymetric depressions (“deeps”) containing pooled brine fluids derived from active hydrothermal venting associated with a spreading ridge[10,35]. The high salinity of the fluids (up to 27%) compensates for their thermal expansion, resulting in density stratification of fluid layers within the depression, from which sulphide minerals precipitate and settle on the seafloor[3,35]. The resulting metalliferous muds, rich in fine-grained sphalerite, chalcopyrite and iron oxides, average 11 m thick but may exceed 25 m thickness in places[35].

Early sampling was conducted by Preussag A.G. from 1969 – 1972. A 30-year development contract was issued to Manafa International Trade Company in 2011, who entered into a JV with Diamond Fields International Ltd.[35]. A number of historic resource estimates have been made for the deposit, but the resource was first published in a NI 43-101-compliant report on 14 July 2011, and was compiled by qualified persons from ACA Howe International Ltd. This report was subsequently updated (28 October 2011) to include an estimate of Mn resources. An amended version of the report (dated 22 August 2014) incorporated updates to some sections of the report; however, the resource estimate remained unchanged (effective date 28 October 2011). The resource statement for Atlantis II Deep comprises an inferred resource of 604.21 Mt at dry salt free (DSF) average metal grades of 2.03% Zn, 0.46% Cu 41.14 g/t Ag and 2.69% Mn. No cut-off grade is reported in the resource statement, however, subsequent tables report average metal grades corresponding to those in the resource statement as being calculated assuming cut-off grades for each metal of: 0% Zn (for Zn grade), 0% Cu (for Cu grade), 0% Ag (for Ag grade) and 0% Cu (*sic*) (for Mn grade). The tables also report a range of alternative average grades for each metal, corresponding to a range of other cut-off grades >0%, but these are not reported in the resource statement. The authors note that, as mentioned previously, the technical correctness of resource reporting is not the subject of this paper and these numbers are simply quoted from the available information. The resource was estimated using omnidirectional ordinary kriging, based on historic box core, piston core and gravity core sample data[35].

Historic work on the deposit also included an environmental impact study (the first of its kind) and a pre-pilot mining test[35]. Further development of the project is currently on hold due to a contractual and performance dispute between Diamond Fields and its JV partner Manafa International[65].

Other Mineral Resources

At the time of writing there are no other publicly reported and code-compliant marine polymetallic sulphide resources; however, several other explorers are currently exploring various deposits around the world, including Neptune Minerals (with offshore tenements in Japan, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Tonga and New Zealand)[66] and ISA contractors. Polymetallic sulphide contractors currently are the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER; Mid-Atlantic Ridge), the Government of the Republic of Korea (Central Indian Ridge), the Government of the Russian Federation (Mid-Atlantic Ridge) and the China Ocean Mineral Resources Research and Development Association (COMRA; Southwest Indian Ridge)[67].

Polymetallic Nodules

While polymetallic nodules can occur at any water depth, the greatest concentrations found to date are within the Clarion-Clipperton Zone (CCZ) in the central northwest Pacific[68]. This zone is effectively one huge nodules deposit covering an area of some 5.2 million km^2, bounded to the north and south by the NNE-SSW trending Clarion and Clipperton fracture zones (respectively) and ranging from ~4,000 – 6,000 m water depth[14,69]. The vast majority of the deposit lies within international waters and is under the jurisdiction of the ISA; however, significant exploration for polymetallic nodules was conducted across the CCZ by so-called "pioneer explorers" prior to the introduction of the ISA as a regulatory body.

Currently the ISA has granted 13 contractors polymetallic nodule exploration licences, 12 within the CCZ and one in the Indian Ocean. To date one of these contactors has made public a resource report compliant with a CRIRSCO-affiliated code. Four others state that their mineral resource statements are compliant with a code, but have not made the documentation or material information publicly available.

Code-Compliant Publicly Reported Mineral Resources

<u>TOML</u>

Tonga Offshore Mining Limited (TOML), a 100% subsidiary of Nautilus Minerals sponsored by the Kingdom of Tonga, executed a 15-year exploration contract with the ISA on 11 January 2012. The licence area incorporates six separate areas totalling 74,713 km^2 within the CCZ, 98% of which comprise abyssal hill province with slopes <20%[2]. The areas were part of the Reserved Area set aside by the ISA for exploration by developing nations[70].

TOML released a maiden resource statement, including resource estimates for four of their six exploration areas in a NI 43-101-compliant report dated 24 September 2012. The resource was classified as an inferred resource of 440 Mt (wet) at average grades of 1.2% Ni, 0.24% Co, 1.1% Cu and 26.9% Mn, at a cut-off nodule abundance of 4 kg/m^2[71]. This report, the first for this type of deposit, was reviewed by the British Columbia Securities Commission (BCSC)[70] and following their feedback an updated report was prepared dated 20 March 2013; however, the resource statement itself remained unchanged[2,70]. The resource was estimated using ordinary kriging for a single domain, and was based on historic data in four of the six TOML exploration areas, collected by pioneer explorers from Japan, France and Russia (two areas had insufficient sample coverage to estimate resources). The majority of samples were collected using free-fall grab samplers, the remainder using box core samplers. Sample spacing varies from 5 – 30 km, but averages 20 km across the TOML exploration areas[2].

Due to the historic nature of the sample data, accompanying original records detailing standard quality assurance (QA) and quality control (QC) procedures and sample location accuracy parameters were lacking. Consequently, in isolation the historic data from within the TOML licence areas would not have met the current standards required for code-compliant reporting. However, TOML were able to compare the data from their exploration area to the ISA data for the entire CCZ[69], and to a completely independent dataset from the Scripps Institute of Oceanography, both of which showed that there was no material difference between the various datasets for their exploration areas. In the qualified person's opinion, this provided sufficient confidence in the historic data for TOML to define an inferred resource. TOML now plans to upgrade its resource to the indicated category, which will require sampling to be conducted on a ~7.5 km spacing[70].

Other Mineral Resources

<u>ISA</u>

In 2010, the ISA published a non-code-compliant resource report containing a resource estimate of the entire CCZ based on all of the available pioneer exploration data. The assessment, encompassing 4.85 million km^2 estimated a total CCZ resource of 27.1 Mt of nodules containing 7.3 Mt Mn, 58 Mt Co, 340 Mt Ni and 290 Mt Cu[69].

BGR

Bundesanstalt für Geowissenschaften und Rohstoffe (the Federal Institute for Geosciences and Natural Resources of Germany; BGR) first explored the CCZ for polymetallic nodules from 1976 – 1978[72]. On 16 July 2006 BGR signed a contract with the ISA which granted them an exploration licence comprising two separate areas within the CCZ[67]. From 2008 – 2013 five cruises were undertaken to collect data by remote sensing and physical sampling. Acoustic backscatter data was interpreted to identify 10 – 14 prospective nodule fields (totalling 16% of the licence area). These are separated by regions interpreted to have low to zero nodule abundance[73].

Physical sampling during the recent cruises included gridded box core sampling that was used to ground-truth acoustic backscatter interpretations of nodule abundance. The data were used to estimate a "CIM-compliant indicated mineral resource"[74]; however, there is no publicly available NI 43-101-compliant report or documentation to support this estimate. Details of the resource estimate remain confidential; however, certain information about the general abundance of the nodule fields is publicly available. The nodule field currently considered by BGR to have the most economic potential is ~2,000 km^2 in area, 34% of which is dominated by medium-sized nodules (>4 cm diameter) with an average abundance of 22.4 kg/m^2, and 44% of which is dominated by small nodules (<4 cm diameter) with an average abundance of 17.5 kg/m^2. The combined total resource for this field is stated by BGR to be >30 Mt nodules (wet weight)[73].

COMRA

China Ocean Mineral Resources Research and Development Association (COMRA), signed an exploration contract with the ISA on 22 May 2001 for an exploration licence comprising four separate blocks within two general areas of the eastern CCZ[67]. Based on sampling on a 9.8 km grid spacing, COMRA states it has defined an inferred resource with nodule abundance >5 kg/m^2 and Cu+Co+Ni grade >1.8%[75]. The resource is reported using a system that is comparable to the United Nations Framework Template (UNFC)[75]. CRIRSCO-affiliated codes can be mapped to the UNFC (and vice versa)[76], however, the UNFC itself is a project classification system and not a widely accepted reporting code, and is not recognised by the International Security Advisory Board (ISAB)[56]. In addition, supporting documentation containing material information for the resource estimate has not been made publicly available.

DORD

Deep Ocean Mineral Resources Development Co. Ltd. (DORD), sponsored by Japan, signed a contract with the ISA on 20 June 2001, granting them a polymetallic nodule exploration licence comprising two separate areas within the CCZ[67]. Most physical sampling to date has been that conducted by pioneer explorers, the majority consisting of free fall grab samples collected in sets of three samples (triangular array with 2.6 – 3.7 km sample spacing) per sample station (~10 – 25 km station spacing)[77].

DORD reported an inferred resource in accordance with the JORC Code[56], however, neither details of the resource, information supporting the resource or JORC-compliant documentation have been made publicly available. As with many ISA contractors, DORD is actively conducting feasibility studies concurrent with exploration work (see *Discussion* below). In a recent presentation at the ISA Goa Workshop on Polymetallic

Nodules Resource Classification, DORD described a “mineable resource” as having an average nodule abundance of 12.31 kg/m^2 with a cut-off abundance of 7.5 kg/m^2. DORD further states that 92.5% of the total resource is mineable due to having a slope gradient of <5°[77]. "Mineable resource" and "total resource" are not terms endorsed by CRIRSCO-affiliated codes and so it remains unclear whether the resource has been estimated and documented by a Competent Person as defined by the JORC Code.

Government of the Republic of Korea

The Government of the Republic of Korea signed an exploration contract with the ISA on 27 April 2001. The exploration licence comprises seven separate blocks in three general areas of the CCZ[67] and project work has primarily been conducted through the state-owned Korean Institute of Ocean Science and Technology (KIOST) (formerly Korean Ocean Research and Development Institute (KORDI). In a presentation to the recent ISA Workshop on Polymetallic Nodules Resource Classification, KIOST described a “measured” resource of 188.4 Mt averaging 10.4 kg/m^2, and a “mineable” resource of 113.8 Mt[78]. However "mineable resource" is not a term defined by a code and it does not appear that "measured" is used within the strict definition of the term, as there is no reference to either indicated or inferred resources estimated with lower levels of confidence. No mention was made of whether these resources were estimated or documented by a Competent Person as defined by a CRIRSCO-affiliated code.

IFREMER

The Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), sponsored by France, signed an exploration contract with the ISA on 20 June 2001, for an exploration licence consisting of two separate areas within the CCZ[67,79]. Work conducted so far has identified several 10 – 50 km^2 nodule fields. Preliminary resource assessments have been conducted using both ordinary kriging and conditional simulation; however, conditional simulation was found to provide a better representation of the spatial variability in the deposit. IFREMER is currently working towards defining an inferred resource which is anticipated to be in the order of 200 Mt (wet)[79].

IOM

The Interoceanmetal Joint Organisation (IOM), a collaboration by the states of Republic of Bulgaria, the Czech Republic, the Republic of Cuba, the Republic of Poland, the Russian Federation and Slovakia, signed a contract with the ISA on 29 March 2001, granting them an exploration licence comprising two areas within the eastern CCZ[67,80]. Based on box core sampling and photo profiling data IOM has estimated a resource of 48.1Mt (wet) for a contained 11 Mt Mn, 0.44 Mt Ni, 0.43 Mt Cu and 0.05 Mt Co; however, the estimate does not appear to have been publicly reported under a code, or estimated by a Competent Person as defined by a CRIRSCO-affiliated code[81].

MOES

The only ISA contractor currently exploring for polymetallic nodules outside the CCZ is the Indian Ministry of Earth Sciences (MOES). MOES has undertaken a large amount of exploration work in the Indian Ocean since 1981 and signed a contract with ISA on 25 March 2002[67]. MOES has completed a 13 km^2 sampling grid over the entirety of their 75,000 km^2 licence area, further containing 58 blocks sampled on a ~7 km^2 grid spacing. Sampling has been conducted using box cores and a range of free fall grab samplers[82]. MOES has advanced to the stage of identifying a test mine site, however, their exploration plan has been largely informed by the United Nations Ocean and Technology Branch (UNOET) *Delineation of Mine Sites and Potential in Different Sea Areas* (1987)[83], which pre-dates the development of regulated guidelines for the classification and reporting of resources. Consequently, while MOES has estimated a resource[82], they have not yet released a code-compliant resource report.

NORI

Nauru Ocean Resources Inc., a Nauruan company, signed a contract with the ISA on 22 July 2011 to explore for polymetallic nodules in a licence comprising four separate blocks within the CCZ[84]. In July and August 2012 NORI carried out its first polymetallic nodule survey cruise and conducted extensive geophysical mapping of the seafloor and polymetallic nodule sampling within NORI Areas C and D. Further successful polymetallic nodule surveying and nodule sampling was carried out across NORI Areas A and B in October 2013 using a multi-beam echo sounder system to map seafloor topography and delineate nodule fields[5].

Based on historic data and interpretation of geological and geophysical data collected during 2012, NORI has generated a nodule distribution model. This correlates nodule distribution with seafloor topography and sediment characteristics, and was used to estimate an inferred mineral resource in 2012[56]. This estimate was updated in 2013 based on additional data[85]. Details of the resource estimates have not been made public, however they were reportedly carried out by a qualified/Competent Person as defined by either the NI 43-101 standard or the 2012 JORC Code[56,85].

Yuzhmorgeologia

Yuzhmorgeologia, sponsored by the Russian government, signed a polymetallic exploration contract with the ISA on 29 March 2001, granting them a licence comprising two separate areas within the CCZ[67,86]. Yuzhmorgeologia has reported a resource under the CRIRSCO-affiliated 2011 NAEN Code[81]; however, it is not clear whether a Competent Person carried out the resource estimate. Although specific information supporting the resource estimate has not been made publicly available, it comprises an inferred resource of 414.3 Mt (wet) based on a 50 km x 50 km sampling grid, and an indicated resource of 144.2 Mt (wet; unknown sample spacing)[86] . The grade and abundance cut-off of these resources is not publicly available. The "cumulative" resource for the Yuzhmorgeologia licence area is reported as 448 Mt (dry) at an average grade of 1.39% Ni, 1.1% Cu, 0.23% Co and 9.3% Mn[86]; however it is not clear whether or not this is based on the NAEN-classified resources.

Polymetallic Crusts

Only two exploration contracts for polymetallic (ferromanganese) crusts have so far been granted by the ISA, both signed in 2014. Both licences are located in the western Pacific Ocean: one belonging to Japan Oil, Gas and Metals National Corporation (JOGMEC) and the other to COMRA[67]. While no resources have been reported, JOGMEC has been conducting exploration utilising a seabed drill[87] and in August 2014 COMRA completed a 52-day expedition utilising a deep-diving manned submersible (or human occupied vehicle—HOV) which, among various water and biological samples, collected 100 kg of ferromanganese crust[88].

Phosphorite

To date, two seabed phosphorite resources reported under a CRIRSCO-affiliated code and prepared by a Competent Person have been made public and one further resource has been reported under a CRIRSCO-affiliated code; however, it lacks the required disclosure of supporting information that is necessary to be considered code-compliant. At least one other seabed phosphorite resource is also currently being explored.

Code-Compliant Publicly Reported Mineral Resources

Chatham Rise

Phosphorite nodules were first discovered on the Chatham Rise in 1952. The deposit lies in 350 – 450 m of water ~450 km off the coast of eastern mainland New Zealand, and is composed of nodules up to 15 cm in diameter in a surficial layer averaging 0.3 m thick. The bulk of sediment sampling to date has been conducted by a collaboration between the West German Government and the New Zealand Department of Scientific and Industrial Research (DSIR) during two extensive sampling surveys undertaken in 1978 and 1981, primarily utilising large pneumatic and Van-Veen style wireline grab samplers[33].

Chatham Rock Phosphate Ltd. (CRP) was granted an exploration licence over the deposit in 2010 and was issued a Mining Permit on 6 December 2013. A maiden Resource statement for the project, compliant with the JORC Code (2012) was prepared by a Competent Person and made public on 3 March 2014. The Inferred Resource comprised 80 million m^3 with an average phosphorite grade of 290 kg/m^3 for a contained 23.4 Mt of phosphorite[33]. P_2O_5 assay data for the deposit are limited, however the general tenor of the phosphate grade for the phosphorite Resource may be reasonably expected to be in the order of 17.5% - 19.0% P_2O_5[89].

CRP submitted a draft Marine Consent application to the New Zealand Environmental Protection Agency (EPA) on 31 March 2014[90], and subsequently provided updated draft conditions on 12 November 2014[91]. The hearing closed on 12 December 2014 and a decision on whether CRP will be granted an environmental permit to mine is anticipated in February 2015[92].

Sandpiper

The Sandpiper project lies ~60 km off the coast of Namibia in 200 – 300 m water depth, and is composed of predominantly fine-sand-sized phosphorite ooliths. Phosphorite deposits were initially discovered in the area in the 1970s and early sampling was conducted by Gencor and later Bonaparte Diamond Mines (Namibia) Pty Ltd[34]. Bonaparte formed a JV with Union Resources and Tungeni Investments and founded Namibia Marine Phosphate Pty Ltd. (NMP), but was bought out by Minemakers Ltd. in 2009. NMP is now a subsidiary of Union Resources (42.5%), Mawarid Mining (42.5%) and Tungeni Investments (15%)[34,93].

A NI 43-101-compliant report, made public on 11 March 2011, was prepared by a qualified person and defined an inferred resource comprising 2009.4 Mt (wet) of phosphorite at an average grade of 18.7% P_2O_5, and an indicated resource comprising 98.9 Mt (wet) of phosphorite at an average grade of 20.57% P_2O_5. The resource estimate was based on gravity core and grab sampling conducted at 1.6 km intervals along 4.0 km spaced lines for the inferred resource and 400 m intervals along 400 m spaced lines for the indicated resource component[34].

NMP's company website presents an updated resource estimate (dated April 2012) comprising a measured resource of 60 Mt at an average grade of 20.8% P_2O_5, two separate indicated resources of 105 Mt at an average grade of 19.6% P_2O_5 and 62 Mt at an average grade of 18.9% P_2O_5 (for a combined measured + indicated resource of 227 Mt at 19.7% P_2O_5), and inferred resources of 1,608 Mt at 18.9% P_2O_5[94]; however, there is insufficient accompanying documentation for the report to be considered code-compliant. Results of a mining feasibility study are also presented, but similarly without supporting information specific to the technical work.

In a presentation to the Africa Down Under Conference 2012 NMP presented their maiden reserves statement consisting of converted measured and indicated resources to proven reserves of 54.07 Mt at 20.83% P_2O_5 and probable reserves of 78.69 Mt at 20.12% P_2O_5. The unconverted resources consisted of an indicated resource comprising 79.75 Mt at 19.82% P_2O_5 and inferred resource of 1,608 Mt at 18.0-% P_2O_5[95]. Code-compliant documentation supporting these estimations has not been made publically available.

NMP has been granted a Mining Licence Development of the Sandpiper project, however, this was put on hold in September 2013 when the Namibian Government imposed an 18-month moratorium on marine phosphate mining, pending the outcomes of an environmental impact study [96].

Other Mineral Resources

<u>Don Diego</u>

The Don Diego project is operated by Oceanica Resources S. de. R.L., a subsidiary of Odyssey Marine Exploration Inc. (OMEX) and consists of 4 – 7 m thick phosphorite sands located ~22 – 40 km off the west coast of Mexico in 50 – 90 m water depth[97,98]. The company states it has *received* an NI 43-101 report based on resource estimations carried out by a qualified person, which contained a maiden resource statement dated 11 March 2014. The statement contained a measured resource comprising 92.4 Mt at an average grade of 18.5% P_2O_5, an indicated resource comprising 181.1 Mt at an average grade of 18.8% P_2O_5, and an inferred resource of 231.9 Mt at an average grade of 20.1% P_2O_5[99]. The qualified person responsible for the report was not identified and documentation necessary for compliance with the NI 43-101 standard was not made public or filed with the System for Electronic Document Analysis and Retrieval (SEDAR).

OMEX is a NASDAQ listed company and the U.S. Securities and Exchange Commission (SEC) do not recognise CRIRSCO-affiliated reporting codes and standards such as NI 43-101[100], and therefore OMEX has no obligation to release information that is material to understanding the estimates of mineral resources. SEC only allows reporting under NI 43-101 if this standard is legally ratified in the listed company's jurisdiction. Further, SEC requires companies to disclose information in accordance with Industry Guideline 7 (IG7), a comparatively brief standard that does not require technical reports or supporting information for mineral resource estimates to be made public (however mineral reserves must be disclosed)[101]. This is contrary to all other jurisdictions using CRIRSCO-affiliated codes. There are ongoing efforts to convince the SEC of the benefits of higher standards of resource and project disclosure[102] and negotiations between CRIRSCO and SEC are ongoing[100].

An updated resource estimate for the Don Diego project was published in a press release dated 7 July 2014 which consisted of a measured resource comprising 106.9 Mt of ore, an indicated resource comprising 220.3 Mt of ore, and an inferred resource comprising 166.4 Mt of ore. While grades are not reported for the resources, the combined measured + indicated resources are stated as having an average P_2O_5 grade >18%[97]. As with the maiden resource statement, the updated resource estimate lacked the accompanying documentation for it to be considered an NI 43-101-compliant resource report.

OMEX has submitted an Environmental Impact Assessment (MIA) to the Mexican Secretariat of Environment and Natural Resources (SEMARNAT) and is awaiting a decision on environmental permitting. SEMARNAT made a request for additional information on 26 November 2014 which had the potential to stall development[103]; however, on 15 December 2014 the project received endorsement from Inpesca, a division of the Mexican Secretariat of Agriculture and Fisheries (SAGARPA), and an MIA decision is anticipated in early 2015[104].

LLNP

Adjacent to NMP's Sandpiper project is a Mining Licence held by Lev Leviev Namibia Phosphate Ltd. (LLNP), a subsidiary of Sakawe Mining Corporation (Samicor), majority owned by the Lev Leviev Group (76%). The project received environmental clearance to build a pilot processing plant in late 2013[105] and in June 2014 the company received permission from the Namibian government to proceed with construction of the US$20 million plant, in spite of the government-imposed moratorium on marine phosphate mining still being in place[106]. While there is no publicly reported resource from the company, media coverage states the phosphorite resource as being approximately 1.8 Bt[106] and that the project aims to start commercial production in 2018[107].

DISCUSSION

The deep seabed has enormous potential to offer large and high grade alternatives to land-based commodity sources. In addition, exploitation of the seabed has potentially numerous advantages over land-based mining such as the lack of overburden and mobility of mining equipment. Technological advances in recent years have made deep seabed mining a viable option and consequently numerous seabed deposits are being explored around the world. The majority of work is being conducted on polymetallic nodules, primarily within the CCZ, however a number of polymetallic sulphide and phosphorite nodule resources have also been defined. Exploration for ferromanganese crusts is also being undertaken; however insufficient work has so far been completed to define these resources.

A summary of reported deep seabed resources is in Table 3, and the location of the projects discussed by this paper in Figure 2. A thorough overview of the current state of seabed resource development is made difficult by the varying degree to which resource details are available in the public domain. This variability reflects the current non-standardised state of seabed resource reporting, especially in comparison to the land-based mining sector.

Standardised, code-compliant reporting arose as a means of stimulating and regulating a high standard of data analysis and disclosure within the mining industry. While the various codes differ in detail, the overarching aspect of them all is the demand for transparency, materiality and competence. That is, preparation of public reports that are based on relevant, quality data and other supporting information, and which are compiled by a Competent Person who has sufficient skill and experience to make reasonable expert judgements. These codes of reporting have helped to ensure a high standard of resource reporting and development in the terrestrial mining sector.

By contrast, the unique challenges and high cost of seabed mineral exploration, in particular deep seabed exploration, has seen the seabed mining sector develop almost independently of its terrestrial counterpart. The vast majority of early work was conducted by researchers and government-funded initiatives which have continued without necessarily applying the best practice standards and QA/QC required for modern mineral resource estimations. Consequently, it is now the relative newcomers, and companies with mining industry backgrounds, who are leading the way in terms of robust documentation of resource development.

A number of resources have been reported under the banner of CRIRSCO-affiliated codes, but often the resource statements are published without any information that is material to the

Table 3: Summary of deep seabed resources

Project	***Current Company***	***Deposit Type***	***Where***	***Jurisdiction***	***Water Depth***	***Report Code***	***Resource Classification***	***Project Status***
CRIRSCO-compliant reported resources								
Solwara	Nautilus Minerals	Polymetallic sulfide (SMS)	Bismarck Sea	Papua New Guinea	~1,500 m (S1); ~1,900 m (S12)	NI 43-101	indicated[1]	Mine development
Atlantis II Deeps	Diamond Fields International	Polymetallic sulfide (SEDEX)	Red Sea	Saudi-Sudanese Red Sea Commission	~2,000 m	NI 43-101	inferred[1]	On hold pending contractual dispute
CCZ	Tonga Offshore Mining Ltd. (TOML) (subsidiary of Nautilus Minerals)	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	NI 43-101	inferred[1]	Pursuing indicated resource
Chatham Rise	Chatham Rock Phosphate (CRP)	Phosphorite	Chatham Rise	New Zealand	350 450 m	JORC	Inferred[1]	Awaiting environmental permit decision
Sandpiper	Namibian Marine Phosphate Ltd. (NMP)	Phosphorite	East Atlantic	Namibia	~200 350 m	NI 43-101	indicated	Awaiting lifting of moratorium (?)
Other resources								
CCZ	Federal Institute for Geosciences and Natural Resources of Germany (BGR)	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	NI 43-101	indicated[2]	Pursuing resource conversion (?)
CCZ	China Ocean Mineral Resources Research and Development Assoc. (COMRA)	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	?	indicated[3]	Pursuing resource conversion
CCZ	Deep Ocean Mineral Resources Development Co. Ltd. (DORD)	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	(JORC)	inferred[2]	Pursuing Indicated Resource
CCZ	Government of Korea (KIOST)	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	?	(measured + mineable)[5]	Further exploration & conceptual development
CCZ	Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	?	(estimate)[5]	Pursuing inferred resource
CCZ	Interoceanmetal Joint Organization (IOM)	Polymetallic nodules	Central NE Pacific	ISA	3,900 - 4,750 m	?	?[6]	Re-estimation of resource
Indian Ocean	Ministry of Earth Sciences, Government of India (MOES)	Polymetallic nodules	Central Indian Ocean	ISA	~4,000 - 6,000 m	-	[unclassified]	Mining tests
CCZ	Nauru Ocean Resources Incorporated (NORI) & Deep Green Resources	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 5,000 m	NI 43-101 & JORC	inferred[2]	Further exploration & metallurgical testing
CCZ	Yuzhmorgeologia	Polymetallic nodules	Central NE Pacific	ISA	~4,000 - 6,000 m	NAEN[4]	Indicated	Pursuing Resource conversion (?)
Don Diego	Oceanica Resources (subsidiary of Odyssey Marine Exploration Inc.)	Phosphorite	Central East Pacific	Mexico	50 – 90 m	NI 43 -101	measured[6]	Awaiting environmental permit decision

Table 3 Notes: 1. Full report available in the public domain. 2. Undisclosed resource; classification level reported in Goa background document[56]. 3. Reportedly classified using a system comparable to the UNFC (see discussion). 4. NAEN Code (Russia). 5. Unclear whether resource has been formally classified according to a national code or not. 6. Resource statement published but full report undisclosed.

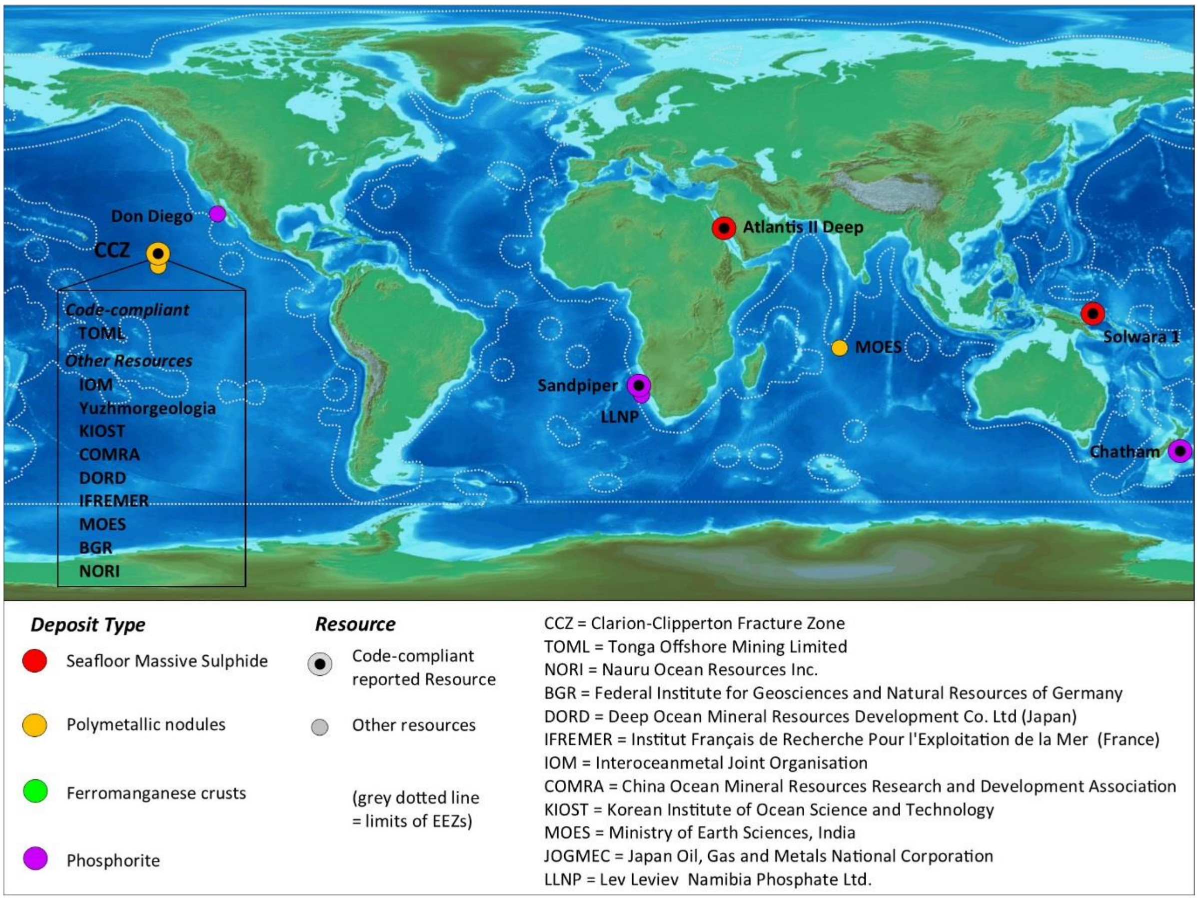

Figure 2: Location map of currently reported deep seabed resources and exploration projects.

understanding of estimates of the mineral resources. This is because these companies are private or government consortiums who have no legal (or other) obligation to report under such codes. Private operators choose not to release code-compliant reports because they consider the information in such reports too sensitive for public disclosure, and that unnecessarily disclosing intellectual property will generally be to the detriment of their efforts to raise private funds. However, non-standardised methods of disclosure make it difficult to agree on standards and hard for industry regulators to reliably assess projects—something that is already challenging given the unique and un-proven nature of seabed resource development.

With the first ISA exploration contracts due to expire in 2016, now is the time for standardised methods of data reporting to be adopted. Charged with overseeing the exploration and exploitation of seabed minerals within international waters, the ISA should be able to assess any and all projects in the Area, no matter what the deposit type, on a materially equivalent level. That is, the ISA should be able to make decisions based on data that demonstrably meet (or exceed) a standardised minimum threshold of quality and level of confidence. This is also true of other regulatory bodies that may be charged with overseeing seabed mineral exploration and exploitation projects in areas of national jurisdiction, such as the SPC.

The SPC has already put together a Regional Legislative and Regulatory Framework (RLRF 2012) for the regulation and monitoring of deep sea mineral exploration within the maritime boundaries of Pacific Island states; however this has not yet been officially implemented and does not include guidelines for how resources should be reported[108].

While adopting a standardised resource reporting format will ensure that data from various projects can be more easily assessed, adopting a standardised reporting code that also requires supporting documentation to be prepared by a Competent Person (or qualified person), who is bound by strict rules of conduct and ethics, will help ensure the data on which reports are based have been checked thoroughly for quality. This is paramount to making reliable assessments of project viability, which in turn will have a direct influence on the ultimate success or failure of project development.

There are a variety of reporting codes that could be adopted, but most are affiliated with the CRIRSCO International Reporting Template. The United Nations Framework Classification (UNFC)[109] has been proposed as an alternative, but this is not strictly a reporting code. It is not regulated and does not require data to be assessed by a Competent Person. The CRIRSCO-affiliated codes by comparison are principles based but include prescriptive guidelines for how to report data and incorporate resource and reserve classification schemes that have categories based on the level of confidence in the data on which their estimation is based. They are broadly applicable to a variety of resource types and while slightly different codes have been developed by different countries, some of the more widely utilised codes (such as JORC and NI 43-101) have been translated into different languages[30]. The established codes will undoubtedly require some minor revision to become more applicable to seabed resources, particularly in light of the unique technical and logistical challenges they present. However, the established codes are widely applicable to a variety of commodities and deposit types, and have already been used to successfully produce code-compliant and regulator-approved seabed resource reports. The authors argue that the current framework for reporting (e.g. such as the JORC Code 2012) provide sufficient support in its current form to deal with reporting of seabed resources, apart from perhaps clarification of the term "abundance" when discussing nodule deposits.

Universal adoption of a standardised reporting code for seabed resources need only require those explorers with a non-industry background to be given time (and encouragement) to become familiar with the codes. Most have collected a wealth of data and have already estimated resources. These need only be assessed and upgraded into a standardised classification system by a Competent Person and be compiled into code-compliant documentation that could be submitted to the ISA, as well as other stakeholders and regulatory bodies, as required. Irrespective of individual code-compliance, standardised reporting is in the interests of the industry to ensure quality work, unambiguous communication of information and to reinforce best practice methods of data collection and resource development.

CONCLUDING REMARKS

Whether public, state, or privately funded, it is in the interests of the seabed solid minerals industry as a whole that all explorers and prospective developers adopt high level, materially equivalent standards of reporting, including the requirement for reports to be based on documentation prepared by a Competent Person. Not only will this foster a universal understanding of the degree of uncertainty in any given resource (or reserve) estimate, it will also help improve the quality, clarity and transparency necessary for all stakeholders to be assured of the overall quality and potential value of current and future projects. Without implementing regulated standards, investment in future seabed mining may be hampered by issues like those faced by land-based mining prior to code standardisation, particularly misinterpretation (or even deliberate misrepresentation) of resources and consequently a misunderstanding of project value and viability.

The authors suggest that where mineral resources and reserves fall within its jurisdiction, an existing reporting code should be adopted and reporting monitored by a committee appointed and managed by the ISA and the SPC. This will greatly assist in activities such as regulating licence expenditure requirements, progress monitoring on each issued licence and stimulating best practice, which in turn will promote proper exploration techniques, quicker turn-over of licences that are not optimally explored and ultimately a higher chance of establishing a mine.

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