“Mineral Resources Potential and Mining in the Pacific Islands Region: Lessons Learned”

Pacific-ACP States Regional Training Workshop on Geological, Technological, Biological and Environmental Aspects of Deep Sea Minerals

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Secretariat of the Pacific Community
Presentation Outline

• Minerals and uses of minerals
• History of Mining Globally and in the Pacific Islands Region
• Mineral Exploration and Mining Processes
• Nature of Mining Projects – Economic, Social and Environmental
• Mineral Potential of PNG
• A Case Study: Porgera Gold Mine
• Solwara 1 Project
• Seabed Mineral Potential in the Region
Why are we talking about Terrestrial Minerals and Mining?

- All the metals contained in offshore mineral deposits have been mined on-land for many years (Cu, Au, Ag, Zn, Pb, Co, Ni, Pt and REEs)

- Volcanogenic Massive Sulphides – the onland analogue of SMS have been mined on-land for hundreds of years;

- Although Manganese Nodules and Cobalt-rich Crusts mining have never occurred on-land, processing facilities for terrestrial minerals can be modified to extract the target minerals.

- Many terrestrial minerals issues are similar to marine minerals issues hence the new deep sea minerals industry has a lot to learn from on-land mining (exploration, exploitation, policy and law, environmental, societal impacts, fiscal regime, revenue management ,etc).
Uses of Minerals

...we use them in everyday life...

Minerals

- Buildings
- Vehicles
- Jewelleries
- Alloys
- Renewable energy applications
- Fertilizers
- Weapons
- Dentistry
- Electrical applications
- Communication Technologies
- Drinks
- Food
- Planes
- Equipments
- Infrastructure

Dentistry

Communication Technologies
Terrestrial Mining…

- On-land mining methods:
  1. Alluvial Mining: PNG, Solomon Islands
  2. Underground mining:
     - higher grade,
     - low tonnage,
     - high waste-to-product ratio.
     - e.g. Vatukoula Gold Mine, Fiji
  3. Open pit mining:
     - low grade,
     - high tonnage,
     - very high waste-to-product ratio.
     - e.g. Ok Tedi Copper Mine (PNG); Gold Ridge Mine (Solomon Islands).
Trend of Marine Mining

• Marine mining is a relatively new method of developing mineral deposits and ongoing since the 1960s;

• Nearshore mining in the forms of aggregates extraction / dredging is common in PICs;

• Shallow marine mining of placer diamond has occurred in Southern Africa since the 1960s;

• Deep sea mining is a new frontier in mineral development – expected to commence in the Pacific region soon.
Mining History in the Pacific

• On-land mining for metallic minerals is restricted to the Melanesian Countries – Papua New Guinea (PNG), Fiji, Solomon Islands and New Caledonia.

• Large-scale nickel mining commenced in New Caledonia in the second half of the 19th century.

• Phosphate extraction in Banaba and Nauru started at the beginning of the 20th century.

• Mining in Fiji has been dominated by gold mining at Vatukoula, commenced in 1933.
Mining History in the Pacific (cont’)

- Solomon Islands has a recent mining history with the opening of the Gold Ridge Mine in 1998.

- Small to medium scale alluvial gold and silver mining was reported in the last quarter of the 19th century and continued in the best part of the 20th century.

- PNG has been on the world mineral map since the early 1970s after the Bougainville Copper Mine came into production.

- To date, PNG has eight operating mines, three of which are world class in terms of mineral deposit size.
PNG, Solomon Islands, Vanuatu, Fiji and Tonga are part of the Rim of Fire;

They host world class mineral deposits:
- Porphyry Cu-Au (e.g. Ok Tedi, Panguna);
- Epithermal Au (e.g. Lihir, Porgera, Vatukoula, Gold Ridge)

Significant potential for SMS deposits in:
- Back-arc Basins (Manus Basin, North Fiji Basin, Lau Basin);
- Fore-arc Basins (Kemadec Ridge North of NZ).
Mining in New Caledonia

- Longest history of mining in the Pacific Islands region;
- Large scale nickel mining started in 1875;
- New Caledonia is the world’s fifth largest nickel producer;
- 2009 production: 107,000 tonnes Nickel;
- 2009 reserve estimates: 6,600,000 tonnes Nickel (USGS, 2010);
- Nickel mining is a major sector of the country’s economy;
Phosphate Mining in Banaba

- Phosphate mining on Banaba Island started in 1900 and was completed in 1979;

- Phosphate extracted from Banaba Island were estimated at 20 million tonnes;

- In 2009, SOPAC conducted an assessment of the phosphate remnants on Banaba.
Phosphate Mining in Nauru

• Mining in Nauru started in 1908 and ceased in 2000;

• Nauru gained independence in 1968 and took control of the phosphate mining operations;

• 80% of the island’s surface have been strip-mined;

• Since independence in 1968, the Nauru government has earned about AU$100-AU$120 million yearly by exporting the phosphate (Pukrop, 1997);
Phosphate Mining in Nauru (cont’)

- Mining re-commenced on a smaller scale in 2006;

- Mining of primary phosphate is expected to be completed in 2014;

- Mining of secondary phosphate will take 20-30 years.

- Phosphate was/is Nauru’s main export revenue earner.

- Nauru has sponsored NORI to conduct seabed exploration in the Area.
Mining in Fiji

- Gold mining in Vatukoula dominates Fiji’s mining history;

- Mining in Vatukoula started in 1933 and had been under the management of a number of companies;

- Mining was suspended in December 2006 and reopened in April 2008;

- Vatukoula has produced about 7 million ounces of gold in the last eighty years;

- Mt Kasi was the other gold mine in Fiji but mining has ceased since 1998;

- Other mining developments – Nawailevu Bauxite, Namosi Copper Project, and others.
Mining in the Solomon Islands

• Gold Ridge Mining Limited commenced mining in 1998;

• Mine was closed due to civil unrest in June 2000;

• August 1998 – June 2000: A total of 210,000 ounces of gold;

• Allied Gold Mining recommenced mining at Gold Ridge in March 2011;

• Numerous exploration projects underway including the Isabel Nickel Project.
From Exploration to Mining…

1. Exploration
   - Exploration license

2. Advanced Exploration

3. Feasibility
   - EIA, Environmental approval
   - Mining license

4. Construction

5. Extraction
   - Permits, enforcement, consent conditions, monitoring, EIA commitments

6. Rehabilitation

7. Use
   - Processing (milling, smelting, refining)
Onland Exploration Procedures...

Prospecting and Discovery → Resource Evaluation

Feasibility Study → Mine Design

Environmental Impact Assessment → Resource Definition

Mining
Deep Sea Exploration Procedures...

- Prospecting and Discovery
- Resource Evaluation
- Feasibility Study
- Mine Design
- Environmental Impact Assessment
- Resource Definition
- Mining
Mining Process...

1. Rock body (ore and host rock)
2. Mining
3. Ore
4. Processing
5. Target minerals
6. Overburden, waste rock
7. Tailings, processing waste
Mining Process...

- Extraction
- Haulage
- Waste Stockpile
- Milling
- Tailings Disposal
Proposed treatment of SMS ore

SMS ore will be de-watered and transferred to a ship to be transported to China for metallurgical treatment.
Nature of Mining Projects...

- Long exploration history,
- Huge investment – multi-million dollar,
- Significant physical footprint,
- Huge infrastructure development,
- Non-renewable,
- Environmental impacts can be significant,
- Can be marginal, profitable or very profitable,
- Support economic development of any country,
- Generate huge amount of waste materials (overburden, tailings, leachates)
- Use huge amount of power (E.g. Lihir power requirement: 75 MW).
Nautilus Minerals – Solwara 1 Project

• First exploration license was granted in 1997;
• Nautilus Minerals has spent more than K100 Million (US$60 Million)
• Surveys Conducted – high resolution bathymetry, side-scan sonar, geophysical surveys (magnetic, electromagnetic and seismic), grab surface sampling (using ROVs), video camera (using ROVs); drilling (diamond core); geotechnical testing of drill core; metallurgical testwork of ore, independent resource estimation, EIS.
• Mining License was issued on Jan 2011.
Economic Impacts and Benefits of Mining

- Significant contribution to any country’s economy (taxes & royalty);
- Employment;
- Stimulate direct and indirect economic activities;
- Infrastructure Development.
- Enable government to support other economic sectors.
- Positively contribute to local communities’ economic activities and living standards (multiplier effect).

PNG as an example:
- Generates more than 50% of PNG’s export revenue,
- Significantly contribute to the increase in GDP.
- A total of K7.9 billion was recorded for the mineral export in PNG in 2007,
- Forecast of K12 – K16 billion per annum worth of mineral export between 2014 and 2018.

(Temu, 2008)
## GDP and Export Earning of Mining

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GDP (%)</td>
<td>64</td>
<td>10</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Export Earning (%)</td>
<td>72</td>
<td>80</td>
<td>7.7</td>
<td>16</td>
</tr>
</tbody>
</table>

* (SMI, 2011)

^ (Ackley, 2008) – these are pre-mine closure figures. Mining was suspended at Vatukoula between December 2006 - April 2008.

^^ (EITI, 2012) – mining at Gold Ridge was suspended between June 2000 – March 2011.
Socio-Economic Impacts

• Employment for the local people;
• Business opportunities for the local communities;
• Compensation and royalty payment to resource owners;
• Raising living standards:
  - improved health care and facilities;
  - construction of new houses;
  - education facilities and scholarships.
• Infrastructure development (water supply and sanitation, roads and bridges).
Example: Community Resettlement at Gold Ridge Mines Solomon Islands

Traditional Villages in the Mine Area

Relocation Villages built by GRML
Adverse Impacts of Mining

- Significant footprint;
- Significant waste materials (waste rock and tailings) are generated that are generally toxic;
- Unsafe disposal of waste materials and that can cause long-term environmental impacts;
- Breakdown of traditional structures and values;
- Increase in cash flow and economic activities can contribute to social problems such as increase in drunkenness and family related problems;
- Rapid social change associated with mine development widens the gap between the ‘haves’ and ‘have-nots’.
Mineral Potential of PNG

Map showing the location of mineral potential in PNG, with major sites such as Grasberg, Frieda, Porgera, Ok Ted, Yandera, Tolukuma, Harmony Projects, Lihir, Panguna, and Misima. The map includes markings for Porphyry Copper Belt, Major Faults (Landsat Linear), and Minor Copper Occurrence.
Known Gold Resources of PNG

- Frieda River – 9.3Moz
- Mt Kare
- Wafi/Golpu – 20Moz
- Grasberg – 88Moz
- Ok Tedi – 17Moz
- Porgera – 28Moz
- Hidden Valley – 6.4Moz
- Lihir – 45Moz
- Simberi – 3.5Moz
- Bougainville – 16Moz
- Misima – 5Moz
## Production at Major Mines in PNG

<table>
<thead>
<tr>
<th>Name of Mine</th>
<th>Year Started</th>
<th>Mining Method</th>
<th>Annual Production</th>
<th>Waste Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porgera Gold Mine</td>
<td>1990</td>
<td>Open pit/Underground</td>
<td>845,000oz Au</td>
<td>Riverine</td>
</tr>
<tr>
<td>Ok Tedi Mining Ltd</td>
<td>1984</td>
<td>Open pit</td>
<td>180,000t Cu 500,000oz Au</td>
<td>Riverine</td>
</tr>
<tr>
<td>Lihir Gold Mine</td>
<td>1997</td>
<td>Open pit</td>
<td>770,000oz Au</td>
<td>DSTP</td>
</tr>
<tr>
<td>Bougainville Copper Mine</td>
<td>1972 – 1989</td>
<td>Open pit</td>
<td>165,000t Cu 450,000oz Au</td>
<td>Riverine</td>
</tr>
</tbody>
</table>
Quantitative analysis of the mined commodity and mining waste

- E.g. a gold mine that contains an average grade of 10g/t Au, a ton of rock (ore) contains:
  - 10g of Au
  - 999,990g of waste

- If the mill recovery is 90%:
  - 9g of gold will be recovered
  - 1g will be lost with the tailings.
  - A total of 999,991g of waste material needs to be managed.

- More than 99% of mined material is waste.
Porgera Gold Mine: A Case Study

Wire Gold specimen, Porgera Gold Mine PNG (Corbett, 2005)
Porgera Gold Mine: Background

- A major resource development in PNG
- A major contributor to PNG’s GDP
- Both open pit and underground mining operations
- Employing more than 2,500 people
- 500 more people are employed with contractors
- 93% of the workforce are PNG nationals
- Construction of roads, bridges, hospitals and schools in the Porgera region,
- Improving the quality and availability of education
- Provides significant support to medical clinics and hospitals in the Porgera region.
- The mine’s doctors conduct health patrols to remote communities with no access to health care
Example: Production at Porgera Gold Mine

<table>
<thead>
<tr>
<th>Year</th>
<th>Material moved (Mt)</th>
<th>Ore milled (Mt)</th>
<th>Gold Produced (oz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>69.2</td>
<td>5.6</td>
<td>755,000</td>
</tr>
</tbody>
</table>

- Average head grade: 5.4g/t Au (Au equivalent grade)
- 5.6Mt of ore is milled,
- 63.6Mt of waste materials produced.
- Stripping ratio (waste to ore): 11 : 3
1999 Porgera Ore Value Estimation...

- 1 tonne of Ore at the following Grades: Au = 5.4g/t; Ag = 1.0g/t

- 1999 commodity prices: Au = US$300/oz; Ag = US$6.00/oz (1oz = 31.1035g)

  - Au: \( \frac{31.1035}{300} = \frac{5.4}{x} \); \( x = 52.08 \)
  - Ag: \( \frac{31.1035}{6} = \frac{1}{x} \); \( x = 0.19 \)

- So, in 1999 a tonne of ore is worth US$52.08 (Au) and US$0.19 (Ag);

- Therefore the value of 1 tonne of ore at Porgera: US$52.27
2011 Porgera Ore Value Estimation...

- 1 tonne of ore at the following Grades:
  Au = 3.2g/t ; Ag = 0.6g/t

- 2011 commodity prices: Au = US$1600/oz; Ag = 27.90/oz (1oz = 31.1035g)

- Au: \( \frac{31.1035}{1600} = \frac{3.2}{x} \); \( x = 164.61 \)

- Ag: \( \frac{31.1035}{27.9} = \frac{0.6}{x} \); \( x = 0.54 \)

- So, in 2011 a tonne of ore is worth US$164.61 (Au) and US$0.54 (Ag);

- Therefore the value of 1 tonne of ore at Porgera: US$165.15
Global Gold Grade and Discovery

Average grade of gold mined in USA + Canada + Australia + South Africa

- 7.3 g/t in 1979
- 2.08 g/t

Average grade of gold discovered in the World

- 1.8 g/t in 2009
- 0.76 g/t

Significant decline in grade mined ... are we running out of high grade deposits?

Modest decline in discovery grades
A total of 146 diamond drill holes (2006 – 35; 2007 – 111);
38% of drill holes ended in mineralisation indicating potential at depth.
## Resource Estimates Comparison

<table>
<thead>
<tr>
<th>Potential and Existing Mines</th>
<th>Type of Deposit</th>
<th>Resource (Mt)</th>
<th>Average Grade</th>
<th>Cu (%)</th>
<th>Zn (%)</th>
<th>Pb (%)</th>
<th>Au (g/t)</th>
<th>Ag (g/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triple Junction (Fiji) SMS</td>
<td>0.5 (Inferred)</td>
<td>6.93</td>
<td>0.61</td>
<td></td>
<td>-</td>
<td>0.85</td>
<td>24.39</td>
<td></td>
</tr>
<tr>
<td>Solwara 1* (PNG) SMS</td>
<td>0.87 (Indicated)</td>
<td>6.8</td>
<td>0.4</td>
<td></td>
<td>-</td>
<td>4.8</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3 (Inferred)</td>
<td>7.5</td>
<td>0.8</td>
<td></td>
<td>-</td>
<td>7.2</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Whim Creek ~ VMS</td>
<td>3.4</td>
<td>1.6</td>
<td>1.3</td>
<td></td>
<td>0.2</td>
<td>-</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>Kidd Mine ^ VMS</td>
<td>115</td>
<td>2.2</td>
<td>5.77</td>
<td>0.25</td>
<td>-</td>
<td></td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Ok Tedi Mine Porphyry Cu-Au</td>
<td>910 (resource &amp; reserve)</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td></td>
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</tr>
</tbody>
</table>

* (Golder Associates, 2008); ~ (Collins et al, 2004); ^ (Wilton, 1998)
Solwara 1 Ore Value Calculations...

Based on Indicated Mineral Resource:

- 1 tonne of SMS Ore at the following Grades:
  (Cu = 6.8%; Au = 4.8g/t; Zn = 0.4%; Ag = 23g/t);

- Recent commodity prices:
  Cu = US$9,000/ton; Au = US$1600/oz; Zn = US$2,000/ton; Ag = US$27.00/oz

- Value of 1 tonne SMS ore by individual minerals:
  [US$612.00 (Cu) + US$246.00 (Au) + US$8.00 (Zn) + US$20.00 (Ag)]

- Total value of 1 tonne of SMS ore: US$886.00

- Less 10% (Assume 90% metal recovery): US$797.00/ton
## Seabed Mineral Occurrence/Potential in the Region

<table>
<thead>
<tr>
<th>Country</th>
<th>MN</th>
<th>CRC</th>
<th>SMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiribati</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Cook Islands</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuvalu</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Samoa</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonga</td>
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<td></td>
<td>✓</td>
</tr>
<tr>
<td>PNG</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solomon Islands</td>
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<td>✓</td>
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</tr>
<tr>
<td>Vanuatu</td>
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<td>✓</td>
<td></td>
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<tr>
<td>Fiji</td>
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<td>✓</td>
<td></td>
</tr>
<tr>
<td>Marshall Islands</td>
<td></td>
<td>✓</td>
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<tr>
<td>Federated States of Micronesia</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Palau</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Niue</td>
<td>✓</td>
<td>✓</td>
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</tr>
</tbody>
</table>

- No economic potential for Metalliferous Sediment, Precious Coral and Phosphate
Deep Sea Mining a Possibility?

- Viability of offshore mining hinges on:
  - world demand;
  - commodity prices;
  - technological development;
  - sound environmental management.

- Any offshore mining operation has to compete with terrestrial mining;

- Recent studies of SMS deposits have indicated excellent potential for mining.

- If SMS mining is successfully proven, the interests in manganese nodules and cobalt-rich crusts will increase.