Technological issues associated with commercializing polymetallic sulphides deposits in the Area

Tetsuo YAMAZAKI
National Institute of Advanced Industrial Science and Technology
AIST Tsukuba West, 16-1 Onogawa, Tsukuba, 305-8569, Japan
E-mail address: tetsuo-yamazaki@aist.go.jp

Today’s topics:
1. Fundamentals (background and technical findings)
2. Economic evaluation of mining Sunrise Deposit
3. Discussions and problems to be solved

Key words: Benthic multi-coring system, Customer smelter, Desalting, Economic analysis, Geophysical survey, Kuroko, Massive ore body, Polymetallic sulphide, Sensitivity analysis
Old FS for sulfide mud in Red Sea

Saudi Arabia-Sudan cooperation in 1982


- Atlantis II Deep in Red Sea
  Zn 2.1%, Cu 0.45%, Ag 28 ppm
- Ore production rate: 3 million tons/year
  Zn 60,000t, Cu 10,000t, Ag 100t
- Ore dressing with froth flotation
- Hydrometallurgical processing with chloride solutions

DCF (Discount Cash Flow) was calculated as 17% for 20-year mining venture.
Distribution aspect of Kuroko-type SMS (K-SMS)

Active black smoker in PACMANUS, PNG
Photographed by Shinkai 6500

Attractive assay: Au 10-100 ppm and Ag 100-500 ppm

Schematic cross section of Sunrise in Myojin Knoll, Japan
From Iizasa (2000)
Technical findings useful for mining of K-SMS

- Mechanical excavation of ore body and in-situ gravity separation of mined ore are applicable.
  (From measurements of geotechnical properties)

- Sulfide customer smelter accepts some amount of chlorine in concentrates.
  (From review of processing technologies)

- Physical desalting of ore is possible.
  (From physical desalting experiment)

- Ore shoot is there in ore body.
  (From core sample of Benthic Multi-coring System)
## Geotechnical properties of K-SMS in Japan’s EEZ #1

<table>
<thead>
<tr>
<th>Engineering properties</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk wet density (g/cm³)</td>
<td>3.298</td>
<td>4.022</td>
<td>3.1406</td>
<td>2.801</td>
<td>2.914</td>
<td>2.387</td>
</tr>
<tr>
<td>Water content</td>
<td>0.1155</td>
<td>0.0384</td>
<td>0.1467</td>
<td>0.165</td>
<td>0.141</td>
<td>0.207</td>
</tr>
<tr>
<td>Solid density (g/cm³)</td>
<td>4.63</td>
<td>4.55</td>
<td>4.49</td>
<td>4.25</td>
<td>4.17</td>
<td>3.64</td>
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<tr>
<td>Porosity (%)</td>
<td>37</td>
<td>15</td>
<td>39</td>
<td>45</td>
<td>40</td>
<td>48</td>
</tr>
<tr>
<td>P-wave velocity (km/sec)</td>
<td>3.4</td>
<td>3.5</td>
<td>3.1</td>
<td>1.9</td>
<td>2.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>24</td>
<td>38.2</td>
<td>21</td>
<td>3.45</td>
<td>6.37</td>
<td>3.13</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>2.23</td>
<td>4.09</td>
<td>3.04</td>
<td>0.61</td>
<td>0.8</td>
<td>0.14</td>
</tr>
<tr>
<td>Young's modulus (GPa)</td>
<td>21.9</td>
<td>35.2</td>
<td>18.5</td>
<td>5.7</td>
<td>7.8</td>
<td>22.5</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.15</td>
<td>0.28</td>
<td>0.47</td>
<td>0.31</td>
<td>0.27</td>
<td>0.31</td>
</tr>
<tr>
<td>Shore hardness</td>
<td>10.2</td>
<td>18.3</td>
<td>14.6</td>
<td>1.6</td>
<td>9.4</td>
<td>5.2</td>
</tr>
<tr>
<td>Micro-Vickers hardness</td>
<td>162</td>
<td>218</td>
<td>154</td>
<td>0</td>
<td>59</td>
<td>0</td>
</tr>
</tbody>
</table>

From Yamazaki et al., 1990
Geotechnical properties of K-SMS in Japan’s EEZ #2

<table>
<thead>
<tr>
<th>Engineering properties</th>
<th>G</th>
<th>H1</th>
<th>H2</th>
<th>I1</th>
<th>I2</th>
<th>J1</th>
<th>J2</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk wet density (g/cm³)</td>
<td>3.358</td>
<td>2.554</td>
<td>2.668</td>
<td>3.861</td>
<td>3.682</td>
<td>3.388</td>
<td>3.349</td>
<td>3.364</td>
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<tr>
<td>Water content</td>
<td>0.126</td>
<td>0.214</td>
<td>0.174</td>
<td>0.059</td>
<td>0.081</td>
<td>0.128</td>
<td>0.148</td>
<td>0.095</td>
</tr>
<tr>
<td>Solid density (g/cm³)</td>
<td>4.976</td>
<td>4.273</td>
<td>4.008</td>
<td>4.66</td>
<td>4.765</td>
<td>5.095</td>
<td>5.49</td>
<td>4.413</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>41</td>
<td>53</td>
<td>45</td>
<td>22</td>
<td>29</td>
<td>42</td>
<td>48</td>
<td>31</td>
</tr>
<tr>
<td>P-wave velocity (km/sec)</td>
<td>3.55</td>
<td>2.76</td>
<td>2.49</td>
<td>3.2</td>
<td>2.93</td>
<td>2.45</td>
<td>2.65</td>
<td>2.56</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>11.05</td>
<td>10.26</td>
<td>12.58</td>
<td>18.1</td>
<td>14.93</td>
<td>18.52</td>
<td>11.69</td>
<td>19.22</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>2.4</td>
<td>2.54</td>
<td>1.81</td>
<td>4.54</td>
<td>2.42</td>
<td>5.21</td>
<td>2.18</td>
<td>2.33</td>
</tr>
<tr>
<td>Young's modulus (GPa)</td>
<td>1.448</td>
<td>1.794</td>
<td>3.836</td>
<td>4.51</td>
<td>5.108</td>
<td>4.859</td>
<td>1.745</td>
<td>5.813</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>-0.022</td>
<td>0.009</td>
<td>0.133</td>
<td>0.025</td>
<td>0.053</td>
<td>0.032</td>
<td>0.01</td>
<td>0.039</td>
</tr>
<tr>
<td>Shore hardness</td>
<td>39.01</td>
<td>1.8</td>
<td>7.65</td>
<td>23.32</td>
<td>14.41</td>
<td>12.3</td>
<td>16.94</td>
<td>10.54</td>
</tr>
<tr>
<td>Micro-Vickers hardness</td>
<td>635</td>
<td>137</td>
<td>0</td>
<td>188</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>291</td>
</tr>
</tbody>
</table>

From Yamazaki and Park, 2003
Frequency distribution of bulk wet density, compressive strength, and tensile strength of K-SMS

From Yamazaki and Park, 2003
Relationship between porosity and compressive strength of K-SMS

\[ y = -0.6268x + 41.697 \]

\[ R^2 = 0.6271 \]

From Yamazaki and Park, 2003
Relationship between bulk wet density and assay of K-SMS

\[ y = 0.0154x + 2.5472 \]

\[ R^2 = 0.6968 \]

From Yamazaki and Park, 2003
Metal recycling from printed circuit boards etc.

Imported concentrates, O₂, Oil

Flush smelting furnace

- Slag
- Matte

Copper board ashes

Converter

- Slag
- Anode furnace

- Copper anode

Copper tankhouse

- Cathode Cu
- Anode slime
  - Au & Ag
  - Se & Te

Converter

Electrostatic precipitator

Boiler

Waste gas

Hydrometallurgical treatment plant

- PbSO₄ cake
- Zn(OH)₂ & Cd(OH)₂ cake

Electric furnace

Lead anode

Lead tankhouse

- Pb
- Anode slime
  - Bi

Anode furnace

Copper anode

Copper tankhouse

- Cathode Cu
- Anode slime
  - Au & Ag
  - Se & Te

Shredded printed circuit boards and cellular phones

Sulfide smelting plant active in Kosaka Smelter Akita, Japan

Concentrates: 300,000t/y

Recycled matters: 15%
### Results of physical desalting experiment

<table>
<thead>
<tr>
<th>Step</th>
<th>Size</th>
<th>Dry weight (g)</th>
<th>Dissolved salt (g)</th>
<th>Sum of dissolved salt (g)</th>
<th>Desalt efficiency (%)</th>
<th>Cumulative efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>50-60 mm (original)</td>
<td>608</td>
<td>0.46</td>
<td>0.46</td>
<td>13.4</td>
<td>13.4</td>
</tr>
<tr>
<td>No. 2</td>
<td>10-20 mm</td>
<td>604</td>
<td>0.56</td>
<td>1.02</td>
<td>16.3</td>
<td>29.7</td>
</tr>
<tr>
<td>No. 3</td>
<td>1-2 mm</td>
<td>595</td>
<td>0.83</td>
<td>1.85</td>
<td>24.0</td>
<td>53.7</td>
</tr>
<tr>
<td>No. 4</td>
<td>0.1-0.2 mm</td>
<td>594</td>
<td>0.75</td>
<td>2.60</td>
<td>21.8</td>
<td>75.5</td>
</tr>
<tr>
<td>No. 5</td>
<td>under 200 µm</td>
<td>591</td>
<td>0.85</td>
<td>3.46</td>
<td>24.5</td>
<td>100</td>
</tr>
</tbody>
</table>

After crushing the K-SMS samples and soaking the products in distilled water for 5 minutes with stirring 10-15 seconds, the amount of salt dissolved into the water was measured by a salinity meter.

In total 4 steps of crushing and 5 steps of soaking were conducted from the original size, 50-60 mm in equivalent diameter, to less than 200 µm in diameter.

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From Yamazaki et al., 2003
Benthic Multi-coring System (BMS)

from iizasa
A core sample recovered by Benthic Multi-coring System

Recovered was 100 cm in 757 cm coring length.

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Drilled length: 757 cm Recovered core length: 146 cm</th>
<th>Cu (%)</th>
<th>Pb (%)</th>
<th>Zn (%)</th>
<th>Au (g/t)</th>
<th>Ag (g/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>about 46 cm in 0-757 cm</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>about 10 cm in 163-351 cm</td>
<td>1.44</td>
<td>0.91</td>
<td>45.40</td>
<td>18.60</td>
<td>656.00</td>
</tr>
<tr>
<td>C</td>
<td>about 15 cm in 351-553 cm</td>
<td>28.90</td>
<td>0.01</td>
<td>0.40</td>
<td>1.40</td>
<td>28.20</td>
</tr>
<tr>
<td>D</td>
<td>about 30 cm in 553-757 cm</td>
<td>0.21</td>
<td>0.18</td>
<td>5.76</td>
<td>3.30</td>
<td>44.90</td>
</tr>
<tr>
<td>E</td>
<td>about 35 cm in 553-757 cm</td>
<td>2.59</td>
<td>1.86</td>
<td>20.60</td>
<td>8.20</td>
<td>945.00</td>
</tr>
<tr>
<td>F</td>
<td>about 10 cm in 553-757 cm</td>
<td>0.22</td>
<td>0.92</td>
<td>2.59</td>
<td>0.38</td>
<td>285.00</td>
</tr>
<tr>
<td>Average of 146 cm</td>
<td></td>
<td>5.56</td>
<td>0.65</td>
<td>12.46</td>
<td>5.31</td>
<td>326.52</td>
</tr>
<tr>
<td>Average of 100 cm</td>
<td></td>
<td>6.67</td>
<td>0.78</td>
<td>14.95</td>
<td>6.38</td>
<td>391.82</td>
</tr>
</tbody>
</table>

From Yamazaki et al., 2003
Sunrise Deposit in Myojin Knoll

on Izu-Ogasawara Oceanic Island arc
474km south from Tokyo
1,400m deep

From Iizasa, 2000
Factors used for technical model and economic evaluation of Sunrise Deposit

<table>
<thead>
<tr>
<th>Name of factor</th>
<th>Factor used for model and evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site location</td>
<td>N32°06', E139°52'</td>
</tr>
<tr>
<td>Site depth</td>
<td>1,400 m</td>
</tr>
<tr>
<td>Amount of ore body</td>
<td>9,000,000 metric tons in wet weight</td>
</tr>
<tr>
<td>Metal yields (example data of on-land Kuroko ore mined)</td>
<td>1.66 % in Cu, 10.5 % in Zn, 2.45 % in Pb, 1.4 ppm in Au, and 113 ppm in Ag in dry weight</td>
</tr>
<tr>
<td>Ore density</td>
<td>3.2 in wet bulk</td>
</tr>
<tr>
<td>Ore water content</td>
<td>0.128 in weight</td>
</tr>
<tr>
<td>Ore compressive strength</td>
<td>3.1-38 MPa</td>
</tr>
<tr>
<td>Ore tensile strength</td>
<td>0.14-5.2 MPa</td>
</tr>
</tbody>
</table>

Information about the resource potential of the targeted K-SMS deposit, such as the amount of ore body, the inside structure, the mean metal yields, and the geographical details are necessary.
Mining system selected for 300,000 t/y

Recovery on seafloor is assumed 2/3. 20-year mining operation is assumed.

- Originally designed for cobalt-rich manganese crust (Yamazaki et al., 1996)
- Self-propulsive miner with mechanical excavation unit
- Modified to fit to distribution and geotechnical features of K-SMS.
- Buffer unit with gravity separation
- Hydraulic lift in steel pipe
Mining system selected for 50,000 t/y

Recovery richer zones only is assumed. 20-year mining operation for 13% is assumed.

- Originally designed for manganese nodules in India’s R&D project by Siegen Univ.
The shallow water test at 410m deep was completed (Deepak et al., 2001).

- Modified to fit to distribution and geotechnical features of K-SMS.

- Self-propulsive miner with mechanical excavation unit

- Hydraulic lift in flexible riser tube

(from Home Page of Siegen Univ., NIOT and Handschuh: personal communication)
**Economic evaluation of K-SMS mining**

**Case 1**

**Seafloor massive sulfides**

- **Miner**
  - Metal content
    - Cu: 1.66%, Pb: 2.45%, Zn: 10.5%
    - Au: 1.4ppm, Ag: 113ppm
  - 300,000t/y 9 million tons

- **Ore dressing efficiency**
  - Cu: 74.5%, Au: 34.5%, Ag: 58.7%
  - Pb: 64.6%, Au: 3.6%, Ag: 10.0%
  - Zn: 76.0%, Au: 25.4%, Ag: 13.4%

- **Dewatering efficiency**
  - 98%

- **Drying efficiency**
  - 87.2%

- **Transportation**
  - 474km from Tokyo 1,400m deep

- **Pick-up**
  - Picked up copper smelter
  - Dewatering efficiency 98%

- **Offshore ore dressing**
  - Desalting
  - To sell customer smelter

- **Onboard ore dressing**

- **Desalting**

- **To sell customer smelter**

**Purchased smelters**

- **Lead smelter**
  - Pb concentrate: 8,204t/y
  - Cu concentrate: 14,691t/y
  - Zn concentrate: 43,120t/y

- **Copper smelter**
  - Cu concentrate: 14,691t/y
  - Pb concentrate: 8,204t/y
  - Zn concentrate: 43,120t/y

- **Zinc smelter**
  - Cu concentrate: 14,691t/y
  - Pb concentrate: 8,204t/y
  - Zn concentrate: 43,120t/y
Economic evaluation of K-SMS mining

Case 2

Seafloor massive sulfides

Metal content
Cu: 6.67%, Pb: 0.78%, Zn: 14.95%
Au: 6.38 ppm, Ag: 391.82 ppm

Au: 6.4 ppm, Ag: 392 ppm
50,000 t/y 1.2 million tons

Dewatering efficiency 98%
Drying efficiency 87.2%

Ore dressing efficiency
Cu: 82.5%, Au: 34.5%, Ag: 58.7%
Pb: 53.4%, Au: 3.6%, Ag: 10.0%
Zn: 69.7%, Au: 25.4%, Ag: 13.4%

Onboard ore dressing
Desalting
To sell customer smelter

50,000 t/y 1.2 million tons

Mining Vessel

Fragmentation
Pick-up
Lifting
Dewatering
Drying
Ore dressing (Flotation)
Transportation
Desalting

Transportation

50,000 t/y
49,000 t/y
42,728 t/y

Cu concentrate: 10,029 t/y
Pb concentrate: 398 t/y
Zn concentrate: 8,689 t/y

Purchased lead smelter
Purchased copper smelter
Purchased zinc smelter

474 km from Tokyo
1,400 m deep

Evaluation
Comparison of economic factors and metal prices used in validation analyses

Prices of main cost elements in 1999 and 2004

<table>
<thead>
<tr>
<th>Items</th>
<th>1999</th>
<th>2004</th>
<th>Changing ratio</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy oil (3%C)</td>
<td>113 US$/kl</td>
<td>238 US$/kl</td>
<td>▲2.11</td>
<td>Whole system</td>
</tr>
<tr>
<td>Coal</td>
<td>30.0 US$/t</td>
<td>35.9 US$/t</td>
<td>▲1.20</td>
<td>Processing</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.086 US$/kWh</td>
<td>0.11 US$/kWh</td>
<td>▲1.28</td>
<td>Whole system</td>
</tr>
<tr>
<td>Calcined lime</td>
<td>66.6 US$/t</td>
<td>85.5 US$/t</td>
<td>▲1.28</td>
<td>Processing</td>
</tr>
<tr>
<td>Material (Others)</td>
<td></td>
<td></td>
<td>▲avg. 1.25</td>
<td>Processing</td>
</tr>
<tr>
<td>Foreign exchange</td>
<td>1 US$ = 121 Yen</td>
<td>1 US$ = 112 Yen</td>
<td>▼0.93</td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>2,350 US$/month 8%</td>
<td>2,327 US$/month 3%</td>
<td>▼0.99</td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td></td>
<td></td>
<td>▼0.38</td>
<td></td>
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</tbody>
</table>

Prices of metals in 1995-1999 and 2004

<table>
<thead>
<tr>
<th>Metal</th>
<th>in 1995-1999</th>
<th>2004</th>
<th>Changing ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>US$ 3.3/lb</td>
<td>US$ 6.28/lb</td>
<td>▲1.26</td>
</tr>
<tr>
<td>Copper</td>
<td>US$ 1/lb</td>
<td>US$ 1.26/lb</td>
<td>▲1.26</td>
</tr>
<tr>
<td>Lead</td>
<td>US$ 0.45/lb</td>
<td>US$ 0.37/lb</td>
<td>▼0.82</td>
</tr>
<tr>
<td>Zinc</td>
<td>US$ 0.55/lb</td>
<td>US$ 0.47/lb</td>
<td>▼0.85</td>
</tr>
<tr>
<td>Gold</td>
<td>US$ 336.4/oz</td>
<td>US$ 407.5/oz</td>
<td>▲1.21</td>
</tr>
<tr>
<td>Silver</td>
<td>US$ 5.2/oz</td>
<td>US$ 6.76/oz</td>
<td>▲1.30</td>
</tr>
</tbody>
</table>
Result of economic evaluation: Case 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Capital costs</th>
<th>Operating costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining system</td>
<td>55.0</td>
<td>6.6</td>
</tr>
<tr>
<td>Mineral processing</td>
<td>19.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Transportation</td>
<td>9.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Sub-total</td>
<td>84.1 M$</td>
<td>12.2 M$</td>
</tr>
<tr>
<td>Continuing expenses</td>
<td></td>
<td>18.9</td>
</tr>
<tr>
<td>Working capital</td>
<td></td>
<td>9.1</td>
</tr>
<tr>
<td>Total investments</td>
<td></td>
<td>112.1 M$</td>
</tr>
</tbody>
</table>

Sensitivity factor

<table>
<thead>
<tr>
<th>Sensitivity factor</th>
<th>Production scale: 300,000 t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased price</td>
<td>Payback periods (year)</td>
</tr>
<tr>
<td>Metal sales in 75%</td>
<td>9.4</td>
</tr>
<tr>
<td>Metal sales in 70%</td>
<td>10.5</td>
</tr>
</tbody>
</table>

with economic factors in 1999
## Result of economic evaluation: Case 2

<table>
<thead>
<tr>
<th>Item</th>
<th>Production scale: 50,000 t/y</th>
<th>Capital costs</th>
<th>Operating Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining system</td>
<td>15.3</td>
<td></td>
<td>2.05</td>
</tr>
<tr>
<td>Mineral processing</td>
<td>6.6</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>4.5</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Sub-total</td>
<td>26.5 M$</td>
<td>3.31 M$</td>
<td></td>
</tr>
<tr>
<td>Continuing expenses</td>
<td></td>
<td>4.60</td>
<td></td>
</tr>
<tr>
<td>Working capital</td>
<td></td>
<td>2.48</td>
<td></td>
</tr>
<tr>
<td>Total investments</td>
<td></td>
<td>33.6 M$</td>
<td></td>
</tr>
</tbody>
</table>

### Sensitivity factor

<table>
<thead>
<tr>
<th>Purchased price</th>
<th>Payback periods (year)</th>
<th>NPV($)</th>
<th>IRR(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal sales 75%</td>
<td>7.3</td>
<td>17M</td>
<td>20.4</td>
</tr>
<tr>
<td>Metal sales 70%</td>
<td>8.0</td>
<td>14M</td>
<td>18.1</td>
</tr>
</tbody>
</table>

with economic factors in 1999
### Comparison of investment costs and results of economic evaluation in 1999 and 2004

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Production scale: 300,000 t/y with operating costs in 1999 and metal prices in 1995-1999</th>
<th>Production scale: 300,000 t/y with the operating costs in 2004 and metal prices in 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capital costs</td>
<td>Operating costs</td>
</tr>
<tr>
<td>Mining system</td>
<td>55.0</td>
<td>6.6</td>
</tr>
<tr>
<td>Mineral processing</td>
<td>19.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Transportation</td>
<td>9.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Metallurgy</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub-total</strong></td>
<td><strong>84.1 M$</strong></td>
<td><strong>12.2 M$</strong></td>
</tr>
<tr>
<td>Continuing expenses</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Working capital</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td><strong>Total investment</strong></td>
<td><strong>112.1 M$</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Case

<table>
<thead>
<tr>
<th>Case</th>
<th>Production scale: 300,000 t/y (with Kuroko grade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payback periods (year)</td>
<td>NPV ($)</td>
</tr>
<tr>
<td>Metal prices in 1995-1999</td>
<td>9.4</td>
</tr>
<tr>
<td>Metal prices in 2004</td>
<td>12.9</td>
</tr>
</tbody>
</table>
Clarified topics through the preliminary evaluation of K-SMS mining

- Mechanical excavation of ore body and in-situ gravity separation of mined ore are applicable for mining of K-SMS.
- Existing sulfide customer smelters can accept K-SMS after physical desalting.
- Small scale production rate is applicable for mining of K-SMS in Japan’s EEZ.

Many uncertain factors, such as the amount of ore body, the inside structure, the mean metal yields, and the geographical details, are assumed and used in the evaluation.
Is K-SMS actually massive or not?

Many questions
No effective answers

Is mound core sulfides? Is the surface layer crust-like thin one?

Mushroom shape?

Iceberg shape?

Layered deposition?

Are there buried mounds?
Information necessary for improving the technical models and the economic evaluation of K-SMS mining

1. Vertical extent of the massive body
2. Metal concentration contour lines in the massive body

- Estimation of the economic reserve is necessary.
  Some metal-rich zones were recognized in cases of on-land Kuroko deposits in Japan. The structural data are necessary for the estimation. The gold and silver contents affect the economic evaluation of targeted area, though they are by products.

Combination analysis of geophysical surveys (acoustic, electric, gravity, etc.) and BMS core data is an example solution.
Geophysical surveys applied for K-SMS

*Nautilus* tried in PNG area.
(Source: M. Williamson’s PPF in UMI-2005)

**Program Objective:**
Test and Evaluate Effectiveness of Candidate Geophysical Methodologies to Detect/Quantify Massive Sulfide Deposits in Deepsea Environments

**Operational Area:**  Bismark Sea, Papua New Guinea

**Geophysical Methods:**
- Deeptowed Sidescan Sonar
- Interferometric Swath Bathymetry
- Subbottom Profiling
- Magnetic Gradiometry
- DC Resistivity
- Induced Polarization
- Self Potential
- Gravimetry

Discussions
Survey coring with drilling ship for K-SMS

- 32 holes on Suzette field, PNG were drilled.
- The results are opened in HP of Nautilus.

Nautilus tried in PNG area.
(Source: HP of Nautilus www.nautilusminerals.com)
Technical problems to be solved in K-SMS survey

- Combination analysis of the geophysical survey data and the survey coring results is necessary.

  The Nautilus’s trial is very important for obtaining answers to the key questions about K-SMS structure and distribution.

- Improving the ability of in-situ coring system (i.e. BMS) is required.

  Because of the wide strength variation of K-SMS ore, some parts of the ore body are easily fractured during the coring operation. It results keeping the drilling center difficult. That is the reason why increasing the core recovery length and ratio is difficult.
Optional functions proposed for improving BMS ability in K-SMS survey

1. SWD (Seismic While Drilling)-VSP (Vertical Seismic Profiling)
   - Extend to 3D geological structure from 2D core information.
   - To install geophones on BMS legs or to shoot out them on seafloor by springs around BMS.

2. Cuttings recovery
   - Extend to 100 % from about 30-50 % 2D core information.
   - Continuous or batch sampling during drilling, or once after drilling.
Example image of large scale SWD-VSP
(Schlumberger Oil field Glossary http://www.glossary.oilfield.slb.com/)
Example record of pilot sensor attached on drill pipe
Borehole Research Group, Lamont Doherty Earth Observatory

(http://www.ldeo.columbia.edu/BRG/)

Pilot sensor vertical and horizontal axis RMS amplitude data from ODP Site 1107 with core measurements from adjacent Site 757. Pilot sensor data indicated the precise location of the basement in real time in the absence of core or log data. (Source: Myers et al., 1999)
Example of cuttings recovery system
- Sampling hose and storing revolver tubes installed on ROV ROPOS
Sampling by hose and storing in revolving tubes
Technical remarks for commercializing polymetallic sulphides deposits in the Area

Are they resources?
Geological information is available, but nothing we know as resources.

- Establishing survey techniques effective for polymetallic sulphides deposits is the first.

- Evaluating the economic possibilities and estimating the potential reserve using the amount of ore body, the inside structure, and the mean metal yields are the second.

- The mining technologies are the easiest among the three deep-sea minerals, if they are massive sulphides.
End of presentation

Thank you for your attention, again!

Japanese nodule collector for ocean test on a Pacific seamount in 1997