Presentation for Workshop on Mining Cobalt-rich Ferromanganese Crusts
and Polymetallic Sulphides in the Area, Aug. 1, 2006, Kingston, Jamaica

Technological issues associated with commercializing polymetallic sulphides deposits in the Area

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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

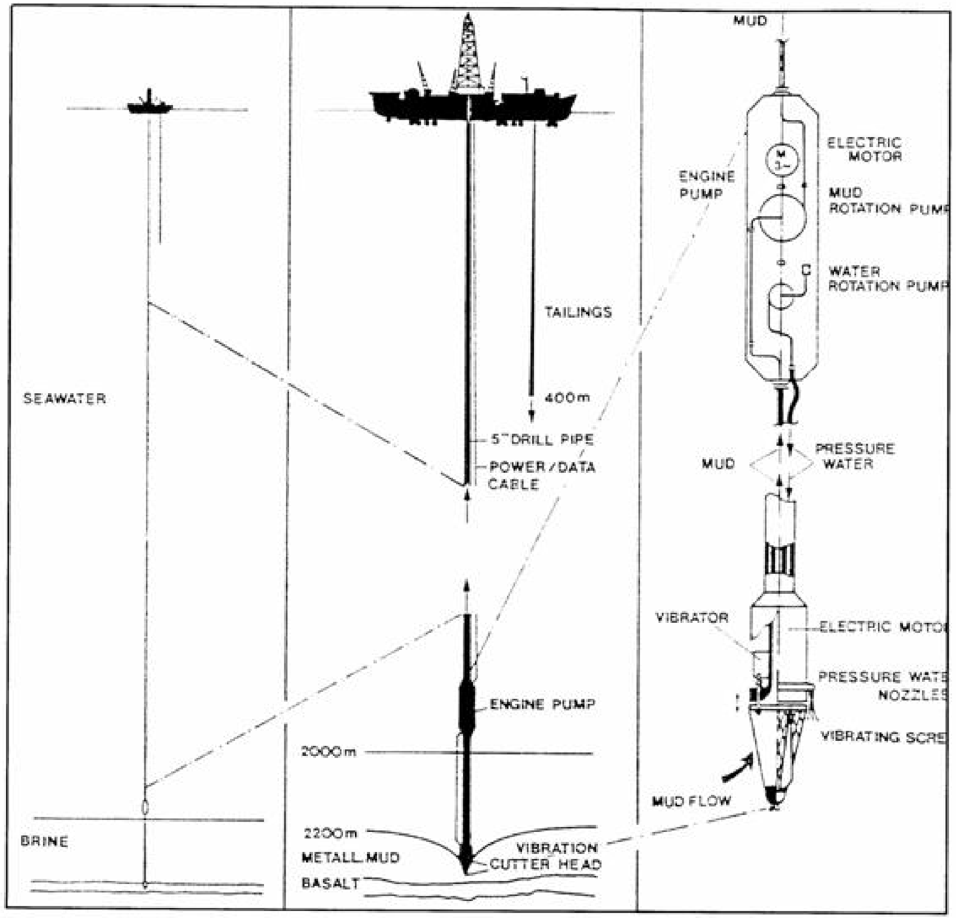
Fundamentals

Saudi Arabia-Sudan cooperation in 1982

Nawab, Z. (2001). “Atlantis II Deep: A Future Deep Sea Mining Site,” *Proc. Proposed Technologies for Mining Deep-seabed Polymetallic Nodules*, ISA, pp.301-313.

- 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.

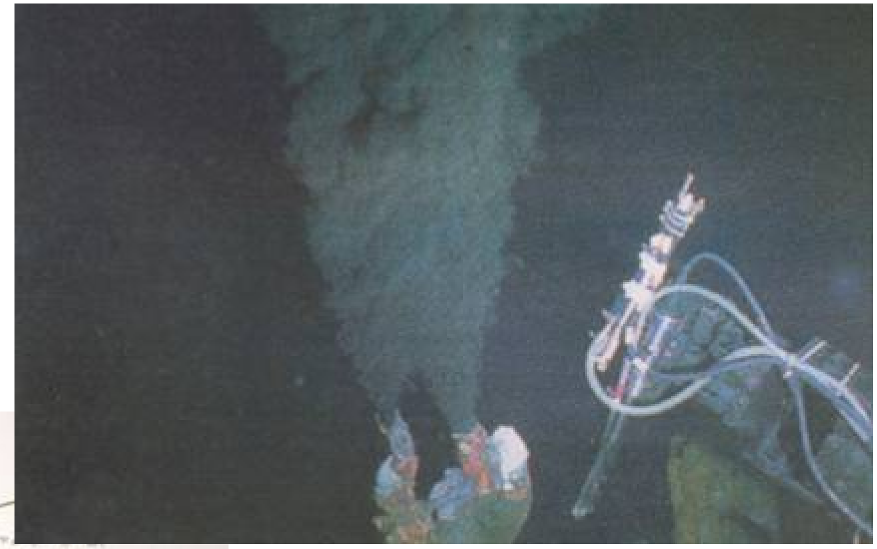


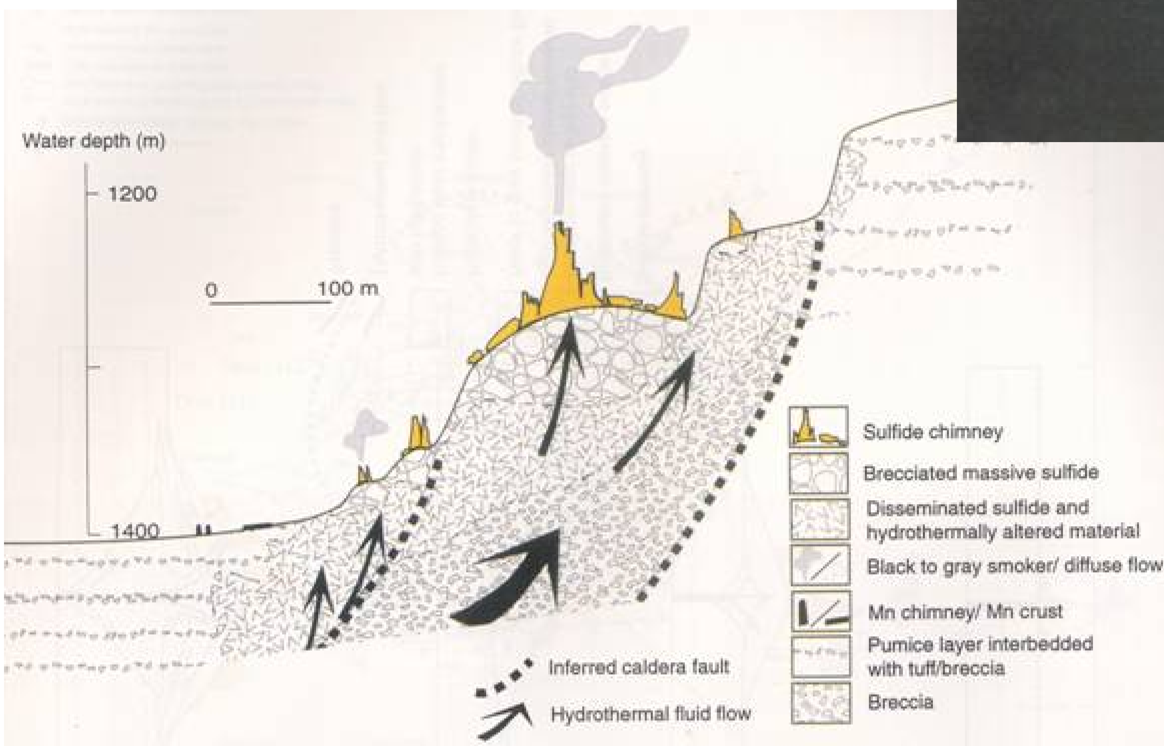
Distribution aspect of Kuroko-type SMS (K-SMS)

Fundamentals

Active black smoker in PACMANUS, PNG

Photographed by Shinkai 6500





Schematic cross section of Sunrise in Myojin Knoll, Japan

From Iizasa (2000)

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

Fundamentals

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

Fundamentals

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

From Yamazaki et al., 1990

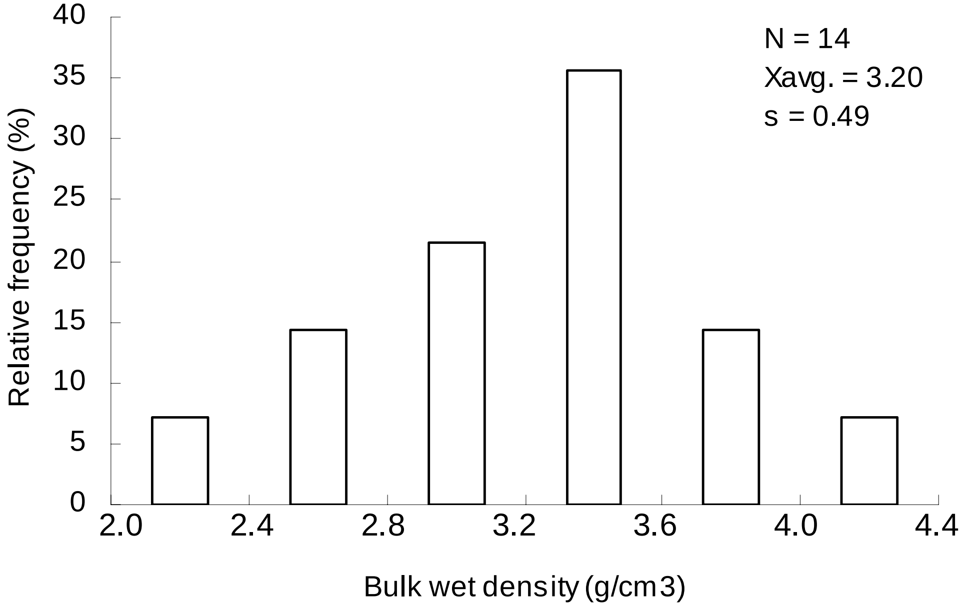
Fundamentals

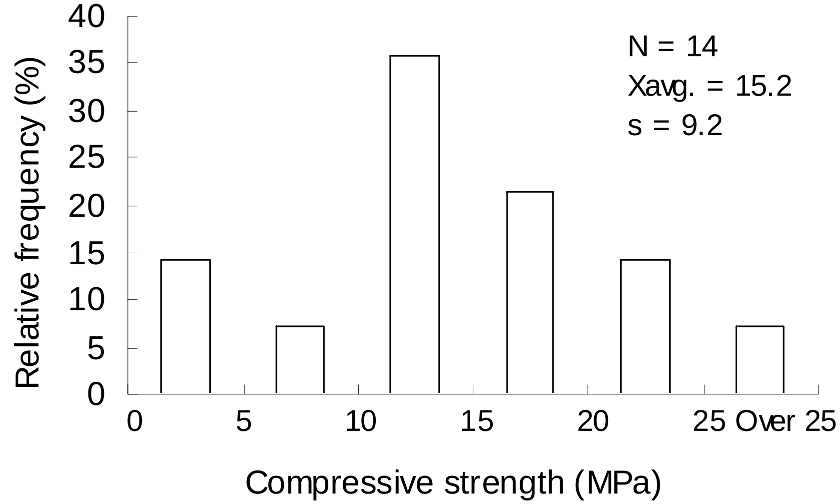
Geotechnical properties of K-SMS in Japan’s EEZ #2

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

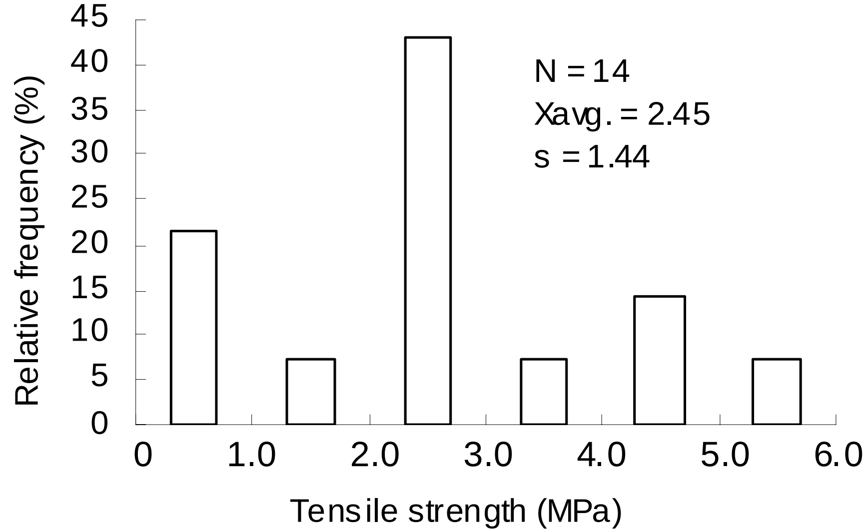
From Yamazaki and Park, 2003

Fundamentals

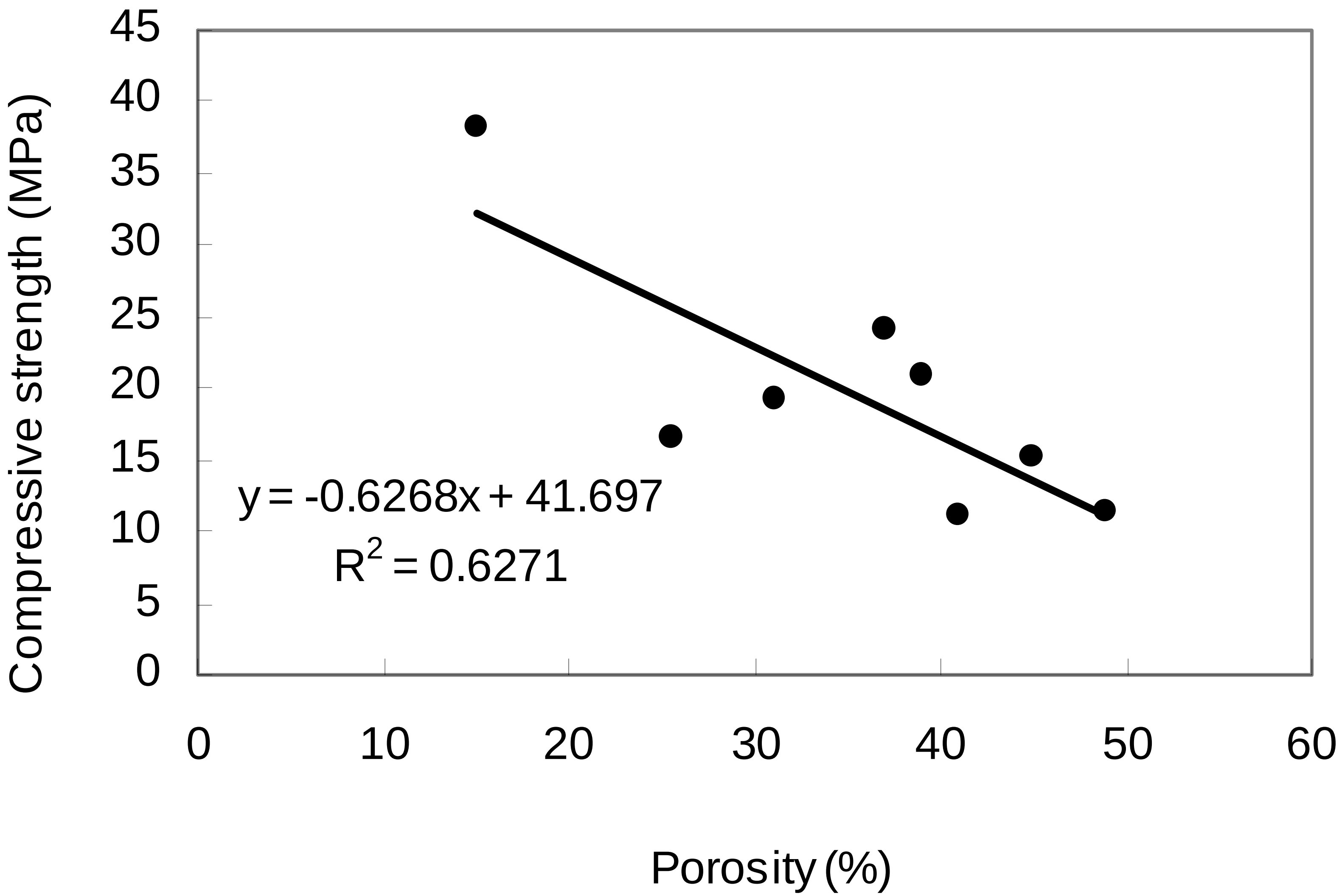




Frequency distribution of bulk wet density, compressive strength, and tensile strength of K-SMS



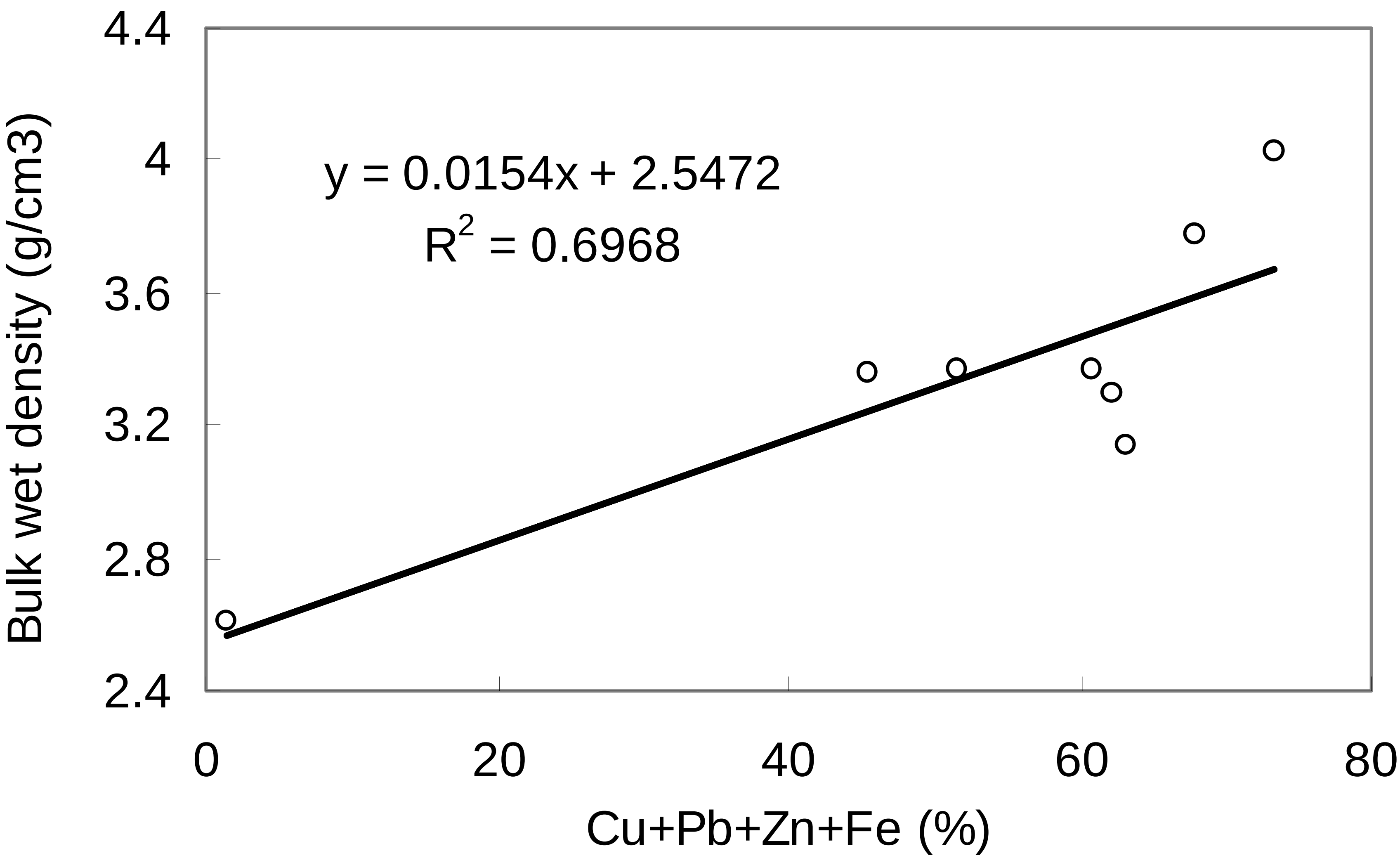
From Yamazaki and Park, 2003



Relationship between porosity and compressive strength of K-SMS

From Yamazaki and Park, 2003

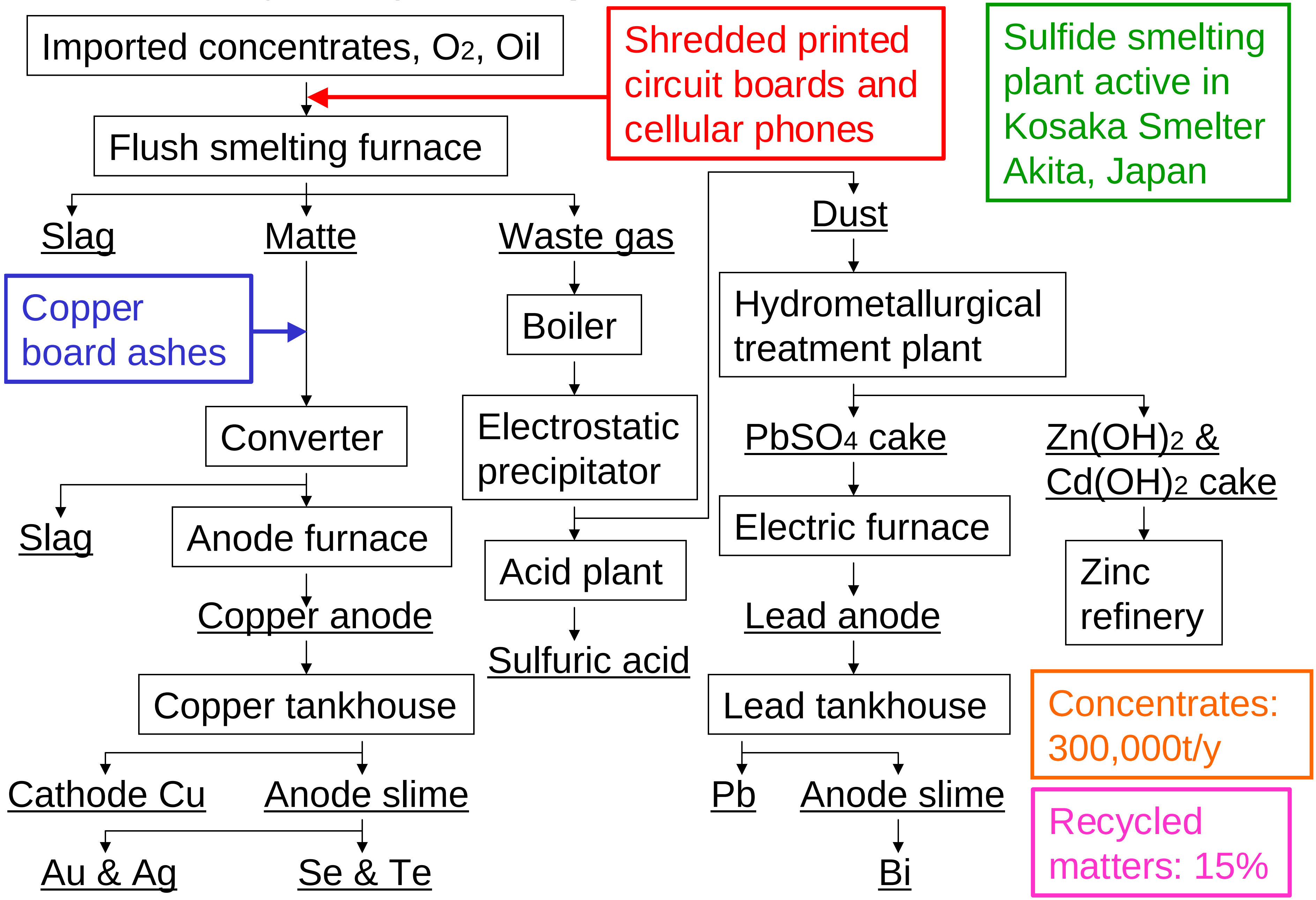
Fundamentals



Relationship between bulk wet density and assay of K-SMS

From Yamazaki and Park, 2003

Metal recycling from printed circuit boards etc.



Fundamentals

Results of physical desalting experiment

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

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.

From Yamazaki et al., 2003

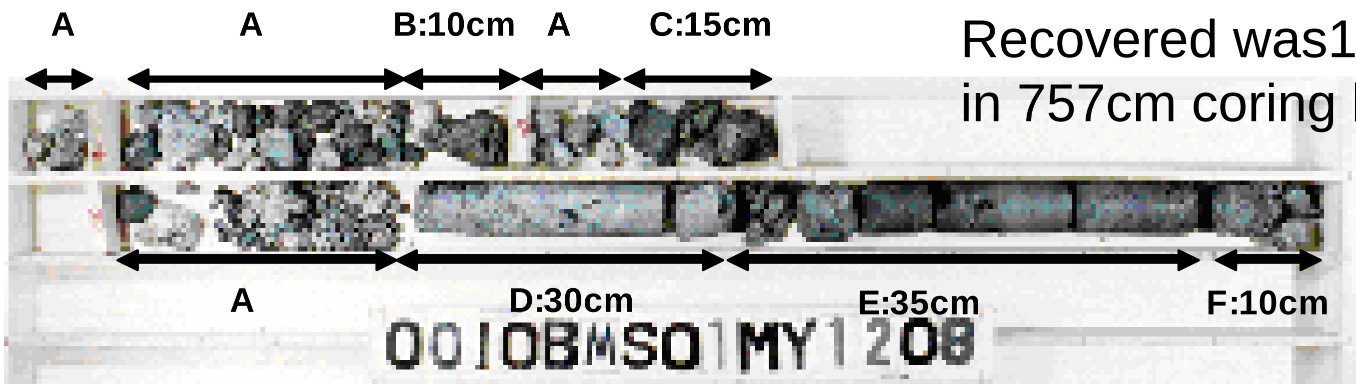
Fundamentals

Benthic Multi-coring System (BMS)

from Iizasa

A core sample recovered by Benthic Multi-coring System

Fundamentals



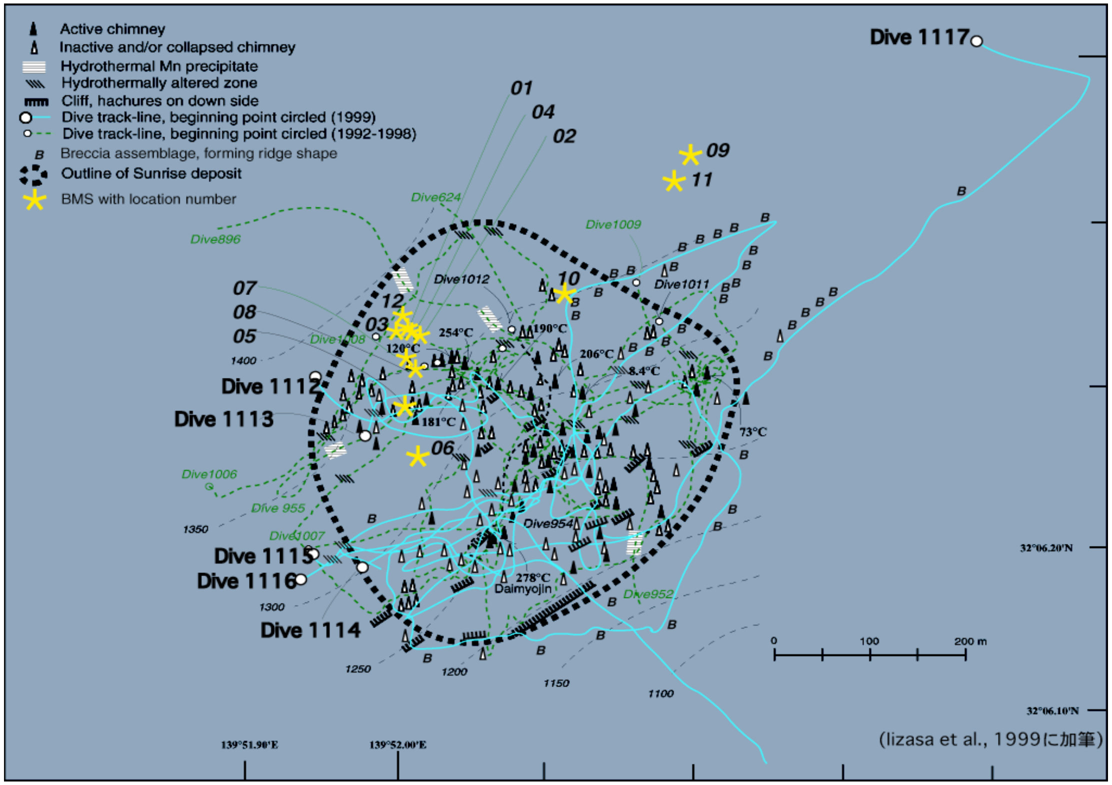
Recovered was100cm in 757cm coring length.

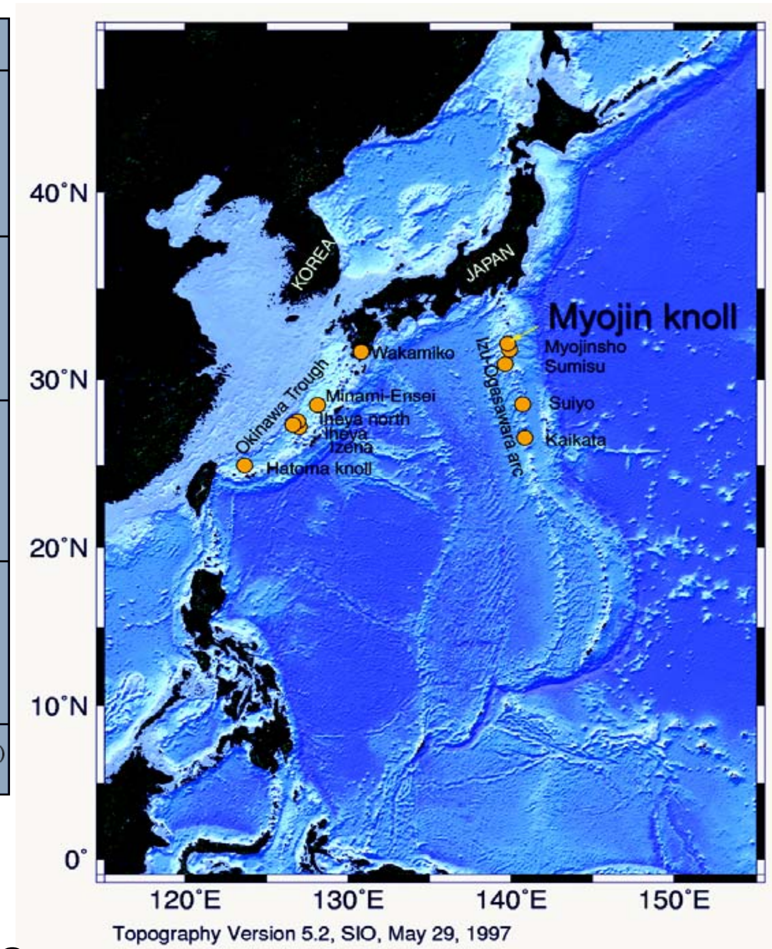
Sample name	Drilled length: 757cm Recovered core length: 146cm	Cu (%)	Pb (%)	Zn (%)	Au (g/t)	Ag (g/t)
A	about 46cm in 0-757cm	0	0	0	0	0
B	about 10 cm in 163-351cm	1.44	0.91	45.40	18.60	656.00
C	about 15cm in 351-553cm	28.90	0.01	0.40	1.40	28.20
D	about 30 cm in 553-757cm	0.21	0.18	5.76	3.30	44.90
E	about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

From Yamazaki et al., 2003

Evaluation

Sunrise Deposit in Myojin Knoll





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

From Iizasa, 2000

Evaluation

Factors used for technical model and economic evaluation of Sunrise Deposit

Name of factor	Factor used for model and evaluation
Site location	N32º06', E139º52'
Site depth	1,400 m
Amount of ore body	9,000,000 metric tons in wet weight
Metal yields (example data of on-land Kuroko ore mined)	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
Ore density	3.2 in wet bulk
Ore water content	0.128 in weight
Ore compressive strength	3.1-38 MPa
Ore tensile strength	0.14-5.2 MPa

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.

Evaluation

Mining system selected for 300,000 t/y

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

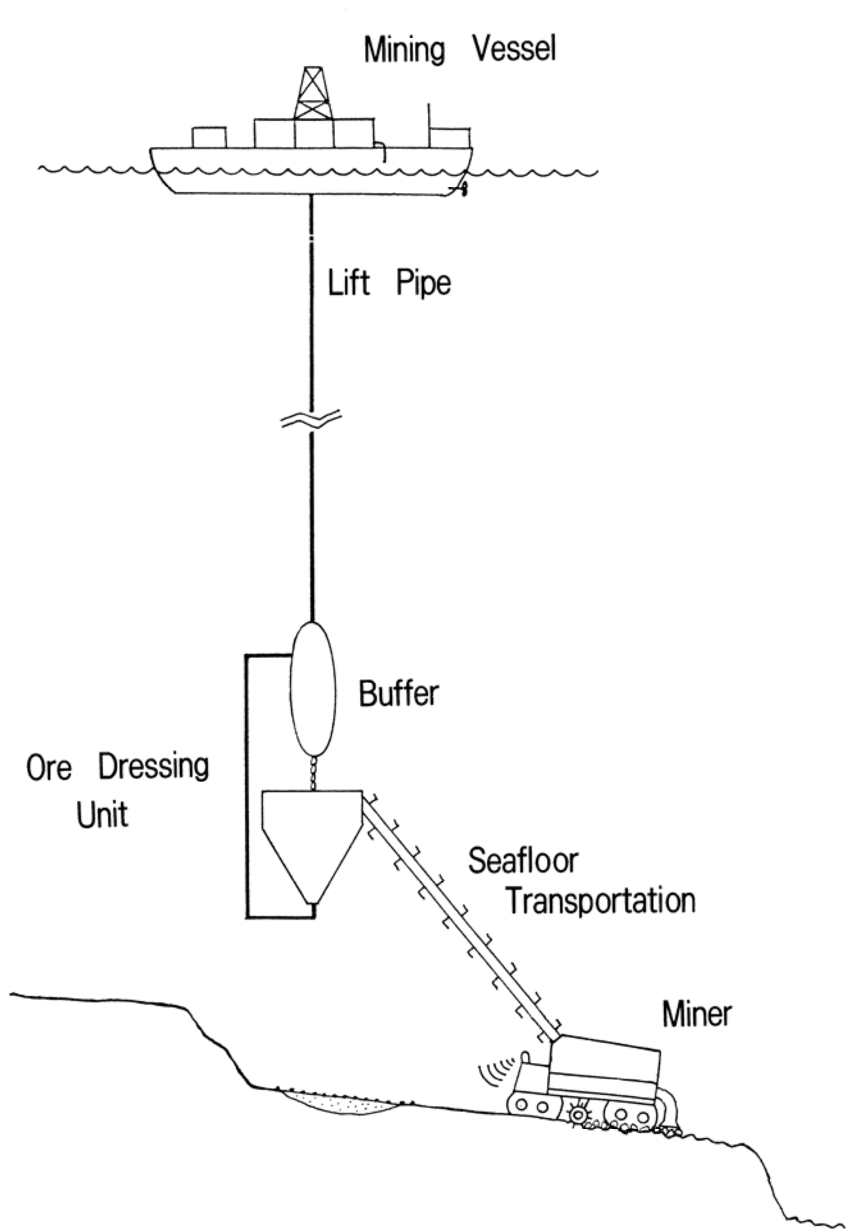
-Originally designed for cobalt-rich manganese crust (Yamazaki et al., 1996)

-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

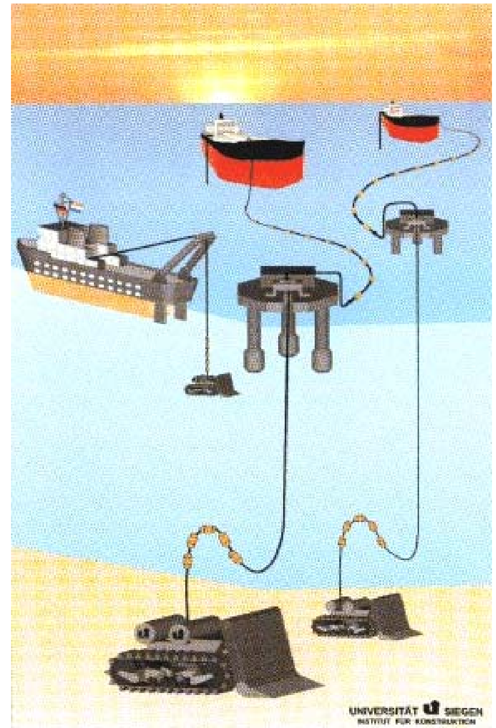


Evaluation

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

Evaluation

Case 1

Metal content
Cu:1.66%, Pb:2.45%, Zn:10.5%
Au:1.4ppm, Ag:113ppm

Au:1.4ppm, Ag: 113ppm
300,000t/y 9 million tons

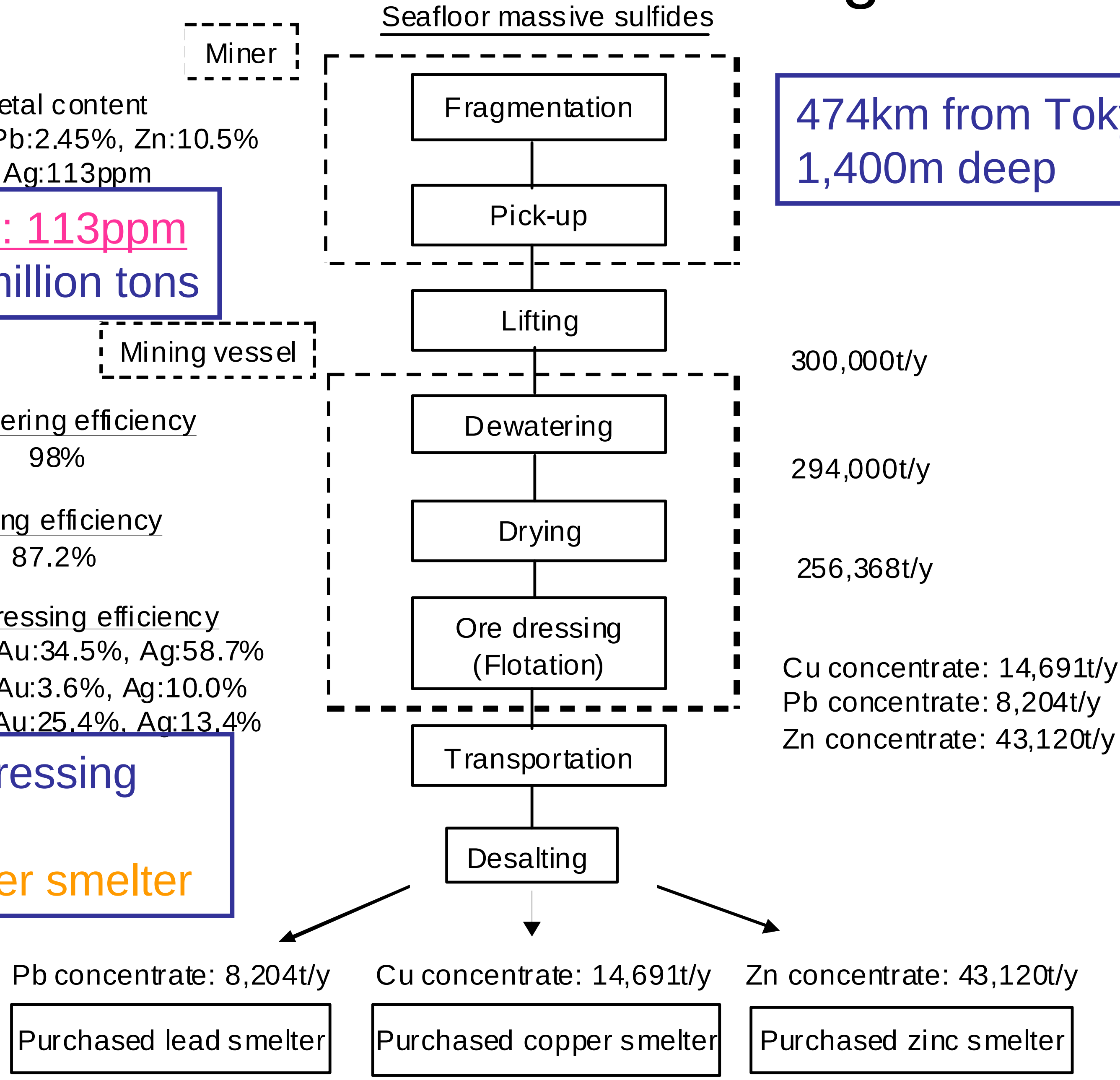
474km from Tokyo
1,400m deep

Dewatering efficiency
98%

Drying efficiency
87.2%

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%

Onboard ore dressing
Desalting
To sell customer smelter



Economic evaluation of K-SMS mining

Evaluation

Case 2

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

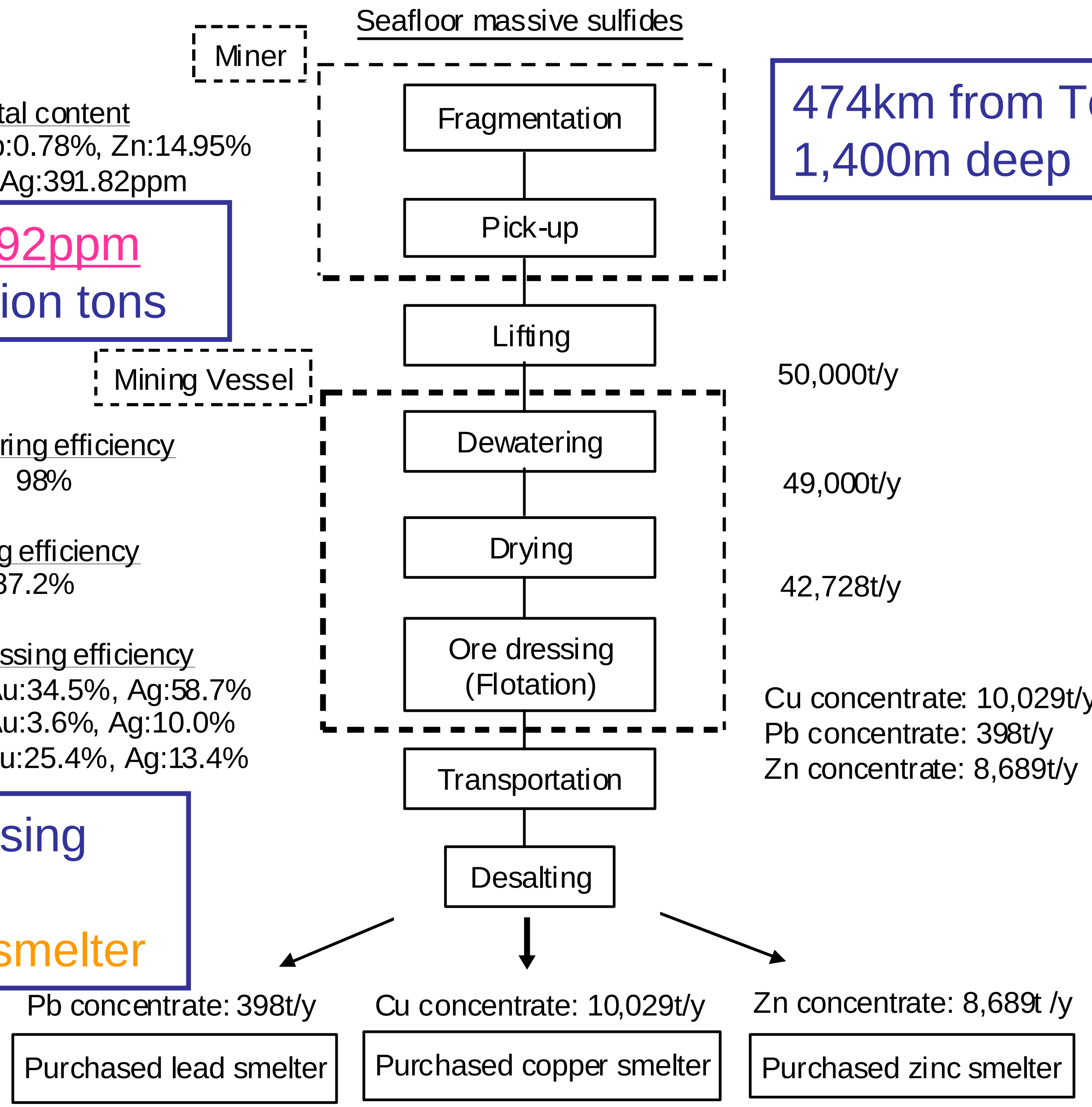
Au:6.4ppm, Ag: 392ppm
50,000t/y 1.2 million tons

474km from Tokyo
1,400m deep

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

Comparison of economic factors and metal prices used in validation analyses

Evaluation

Prices of main cost elements in 1999 and 2004

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

Prices of metals in 1995-1999 and 2004

Metal	in 1995-1999	2004	Changing ratio
Cobalt	US$ 15/lb, US$ 20/lb, US$ 25/lb, US$ 30/lb	US$ 26.8/lb	
Nickel	US$ 3.3/lb	US$ 6.28/lb	▲1.90
Copper	US$ 1/lb	US$ 1.26/lb	▲1.26
Lead	US$ 0.45/lb	US$ 0.37/lb	▼0.82
Zinc	US$ 0.55/lb	US$ 0.47/lb	▼0.85
Gold	US$ 336.4/oz	US$ 407.5/oz	▲1.21
Silver	US$ 5.2/oz	US$ 6.76/oz	▲1.30

Evaluation

Result of economic evaluation: Case 1

Item	Production scale: 300,000 t/y	
	Capital costs	Operating costs
Mining system Mineral processing Transportation	55.0 19.5 9.6	6.6 2.2 3.4
Sub-total	84.1 M$	12.2 M$
Continuing expenses Working capital	18.9 9.1	
Total investments	112.1 M$	

Sensitivity factor	Production scale: 300,000 t/y		
Purchased price	Payback periods (year)	NPV($)	IRR(%)
Metal sales in 75% Metal sales in 70%	9.4 10.5	23M 13M	13.2 11.1

with economic factors in 1999

Evaluation

Result of economic evaluation: Case 2

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

Sensitivity factor	Production scale: 50,000 t/y		
Purchased price	Payback periods (year)	NPV($)	IRR(%)
Metal sales 75% Metal sales 70%	7.3 8.0	17M 14M	20.4 18.1

with economic factors in 1999

Evaluation

Comparison of investment costs and results of economic evaluation in 1999 and 2004

Subsystem	Production scale: 300,000 t/y with operating costs in 1999 and metal prices in 1995-1999		Production scale: 300,000 t/y with the operating costs in 2004 and metal prices in 2004	
	Capital costs	Operating costs	Capital costs	Operating costs
Mining system Mineral processing Transportation Metallurgy	55.0 19.5 9.6 -	6.6 2.2 3.4 -	55.0 19.5 9.6 -	11.0 3.0 4.0 -
Sub-total	**84.1 M$**	**12.2 M$**	**84.1 M$**	**18.0 M$**
Continuing expenses Working capital	18.9 9.1		20.0 13.4	
Total investment	**112.1 M$**		**117.5 M$**	

Case	Production scale: 300,000 t/y (with Kuroko grade)		
	Payback periods (year)	NPV ($)	IRR (%)
Metal prices in 1995-1999	**9.4**	**23M**	**13.2**
Metal prices in 2004	**12.9**	**-1 M**	**7.7**

Clarified topics through the preliminary evaluation of K-SMS mining

Discussions

- 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.

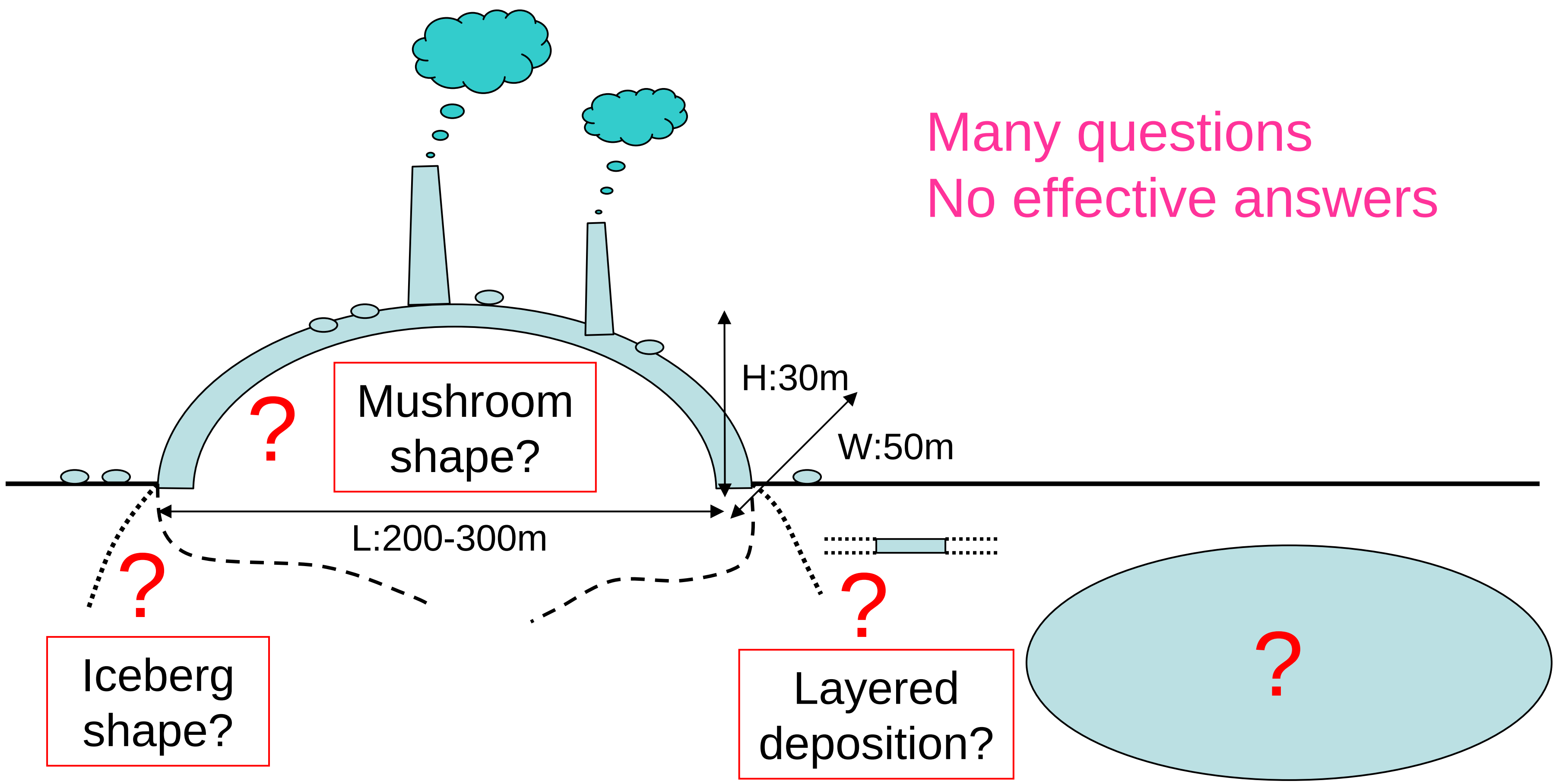
Many uncertain factors, such as the amount of ore body, the inside structure, the mean metal yields, and the geographical details, are assumed and used in the evaluation.

Discussions

Is K-SMS actually massive or not?

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

Many questions
No effective answers



Are there buried mounds?

Information necessary for improving the technical models and the economic evaluation of K-SMS mining

Discussions

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

Discussions

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

Nautilus tried in PNG area.
(Source: HP of Nautilus www.nautilusminerals.com)

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

Technical problems to be solved in K-SMS survey

Discussions

- 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

Discussions

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.

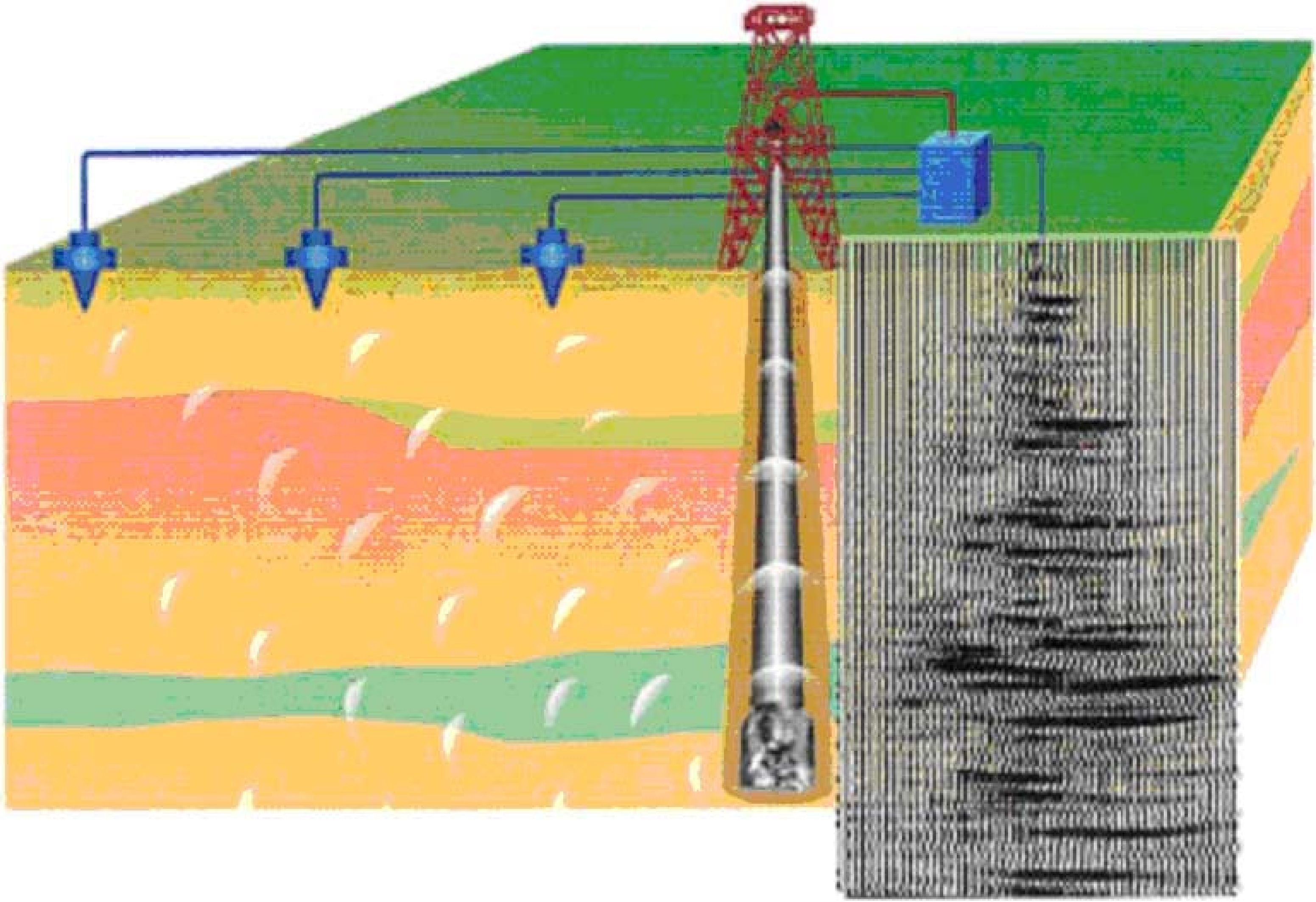
2. Cuttings recovery

- Extend to 100 % from about 30-50 % 2D core information.
- Continuous or batch sampling during drilling, or once after drilling.

Discussions

Example image of large scale SWD-VSP

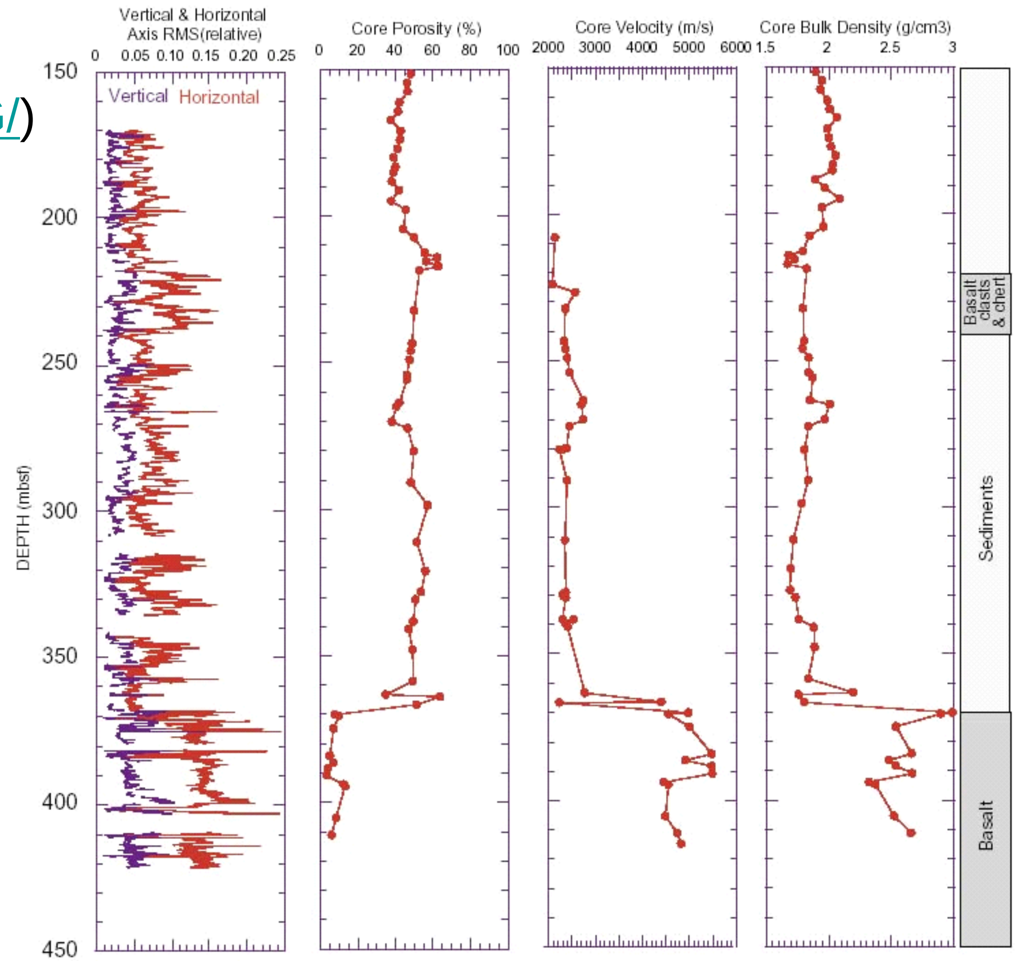
(Schlumberger Oil field Glossary http://www.glossary.oilfield.slb.com/)



Discussions

Example record of pilot sensor attached on drill pipe Borehole Research Group, Lamont Doherty Earth Observatory

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



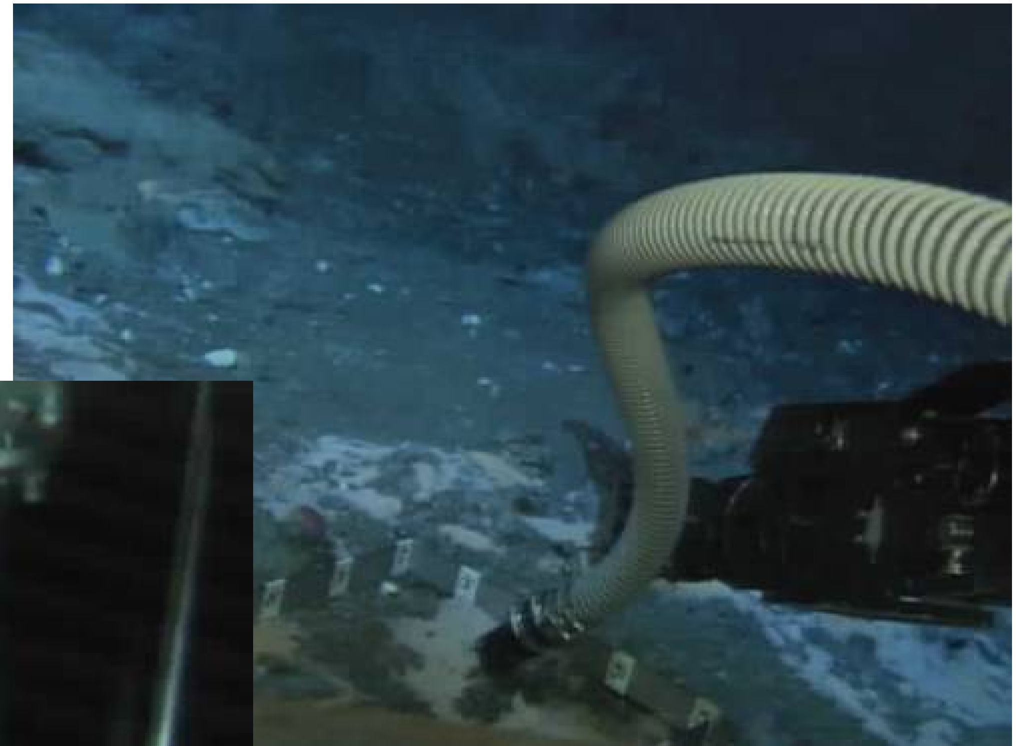
Pilot sensor vertical and horizontal axis RMS amplitude data from ODP Site 1107 with core measurements from adjacent Site 757. Pilot sensor data indicated the precise location of the basement in real time in the absence of core or log data. (Source: Myers *et. al.*, 1999)

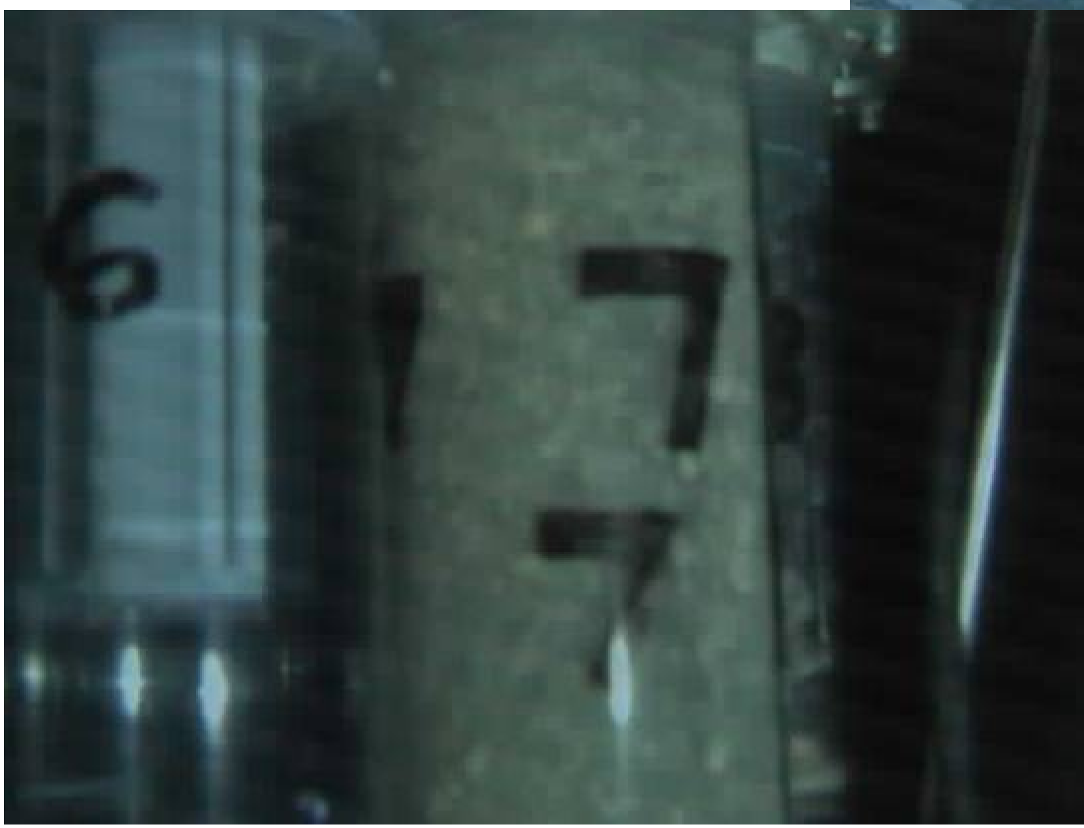
Discussions

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

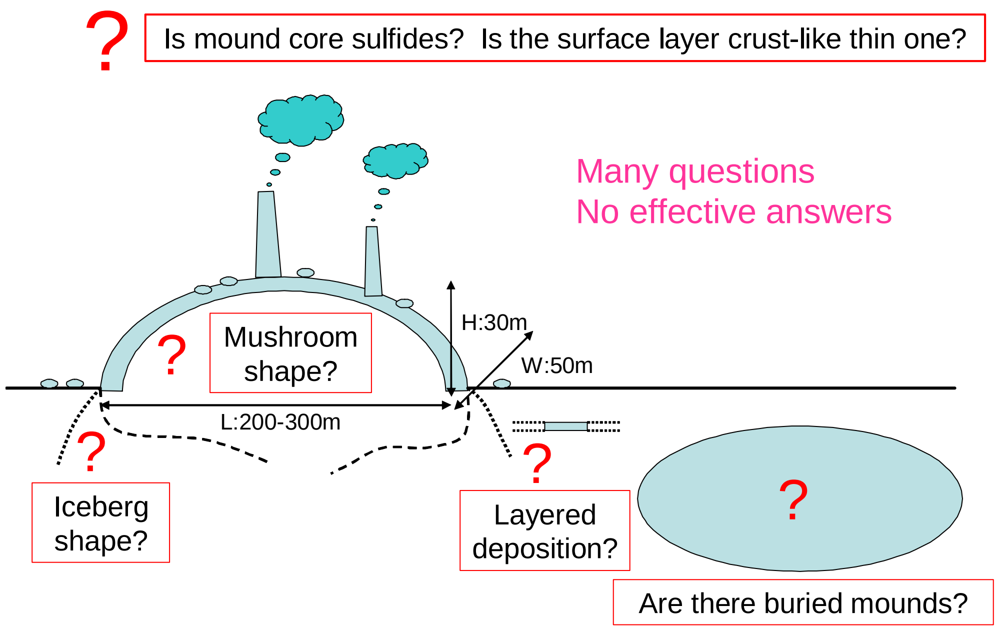
Discussions

Are they resources?

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

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

Is K-SMS actually massive or not?



- 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