Goa, India
October 2014

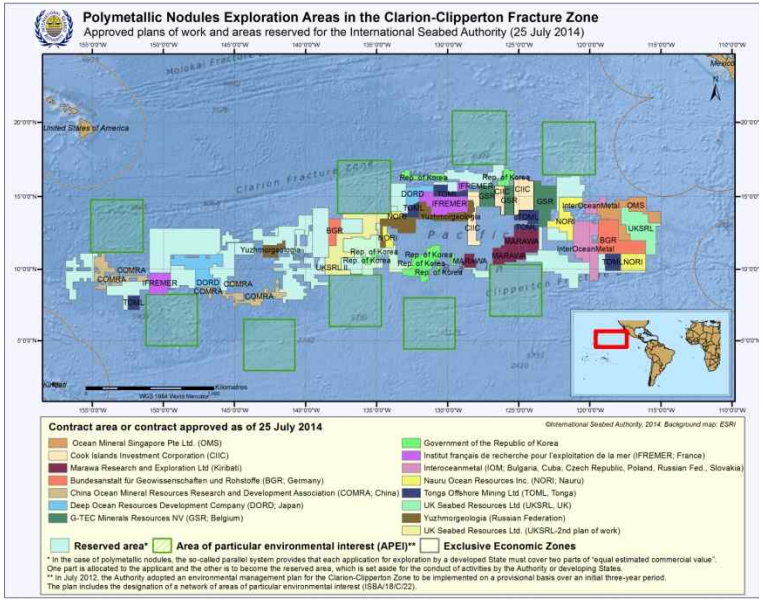
STATUS OF KOREA ACTIVITIES IN RESOURCE ASSESSMENT & MINING TECHNOLOGIES

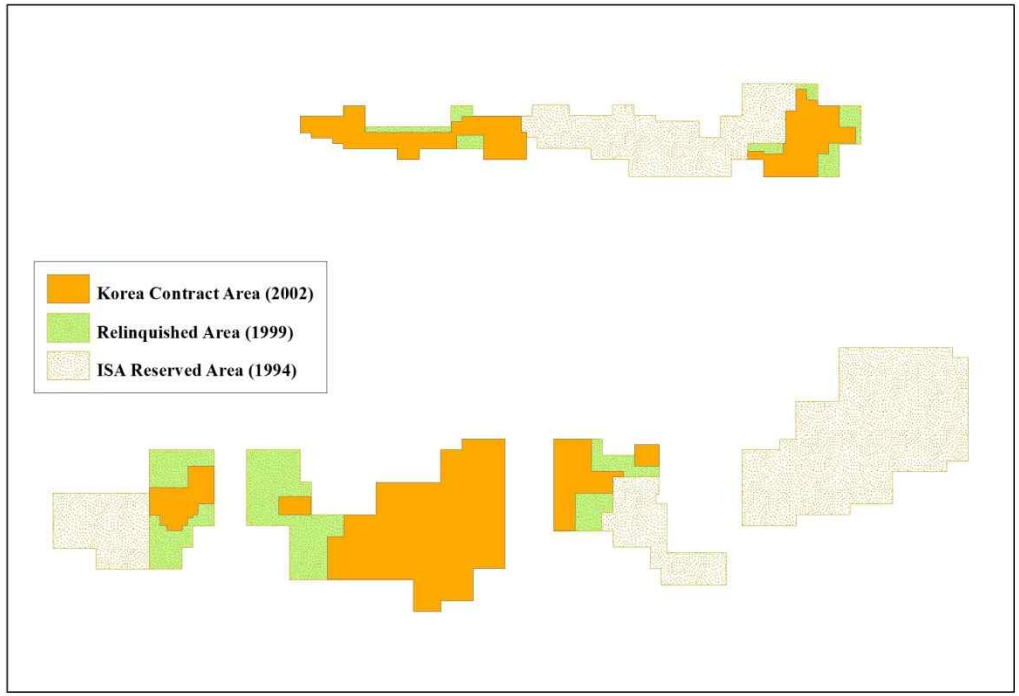
Ministry of Oceans and Fisheries, Republic of Korea
Korea Institute of Ocean Science & Technology

Contents

- Brief history of exploration activities
- General characteristics of contract area
- Resource assessment
- Selection of mineable area
- Priority mining area
- Future work
- Miner robot ‘MineRo’ (Dr. Hong)

Korea Contract Area





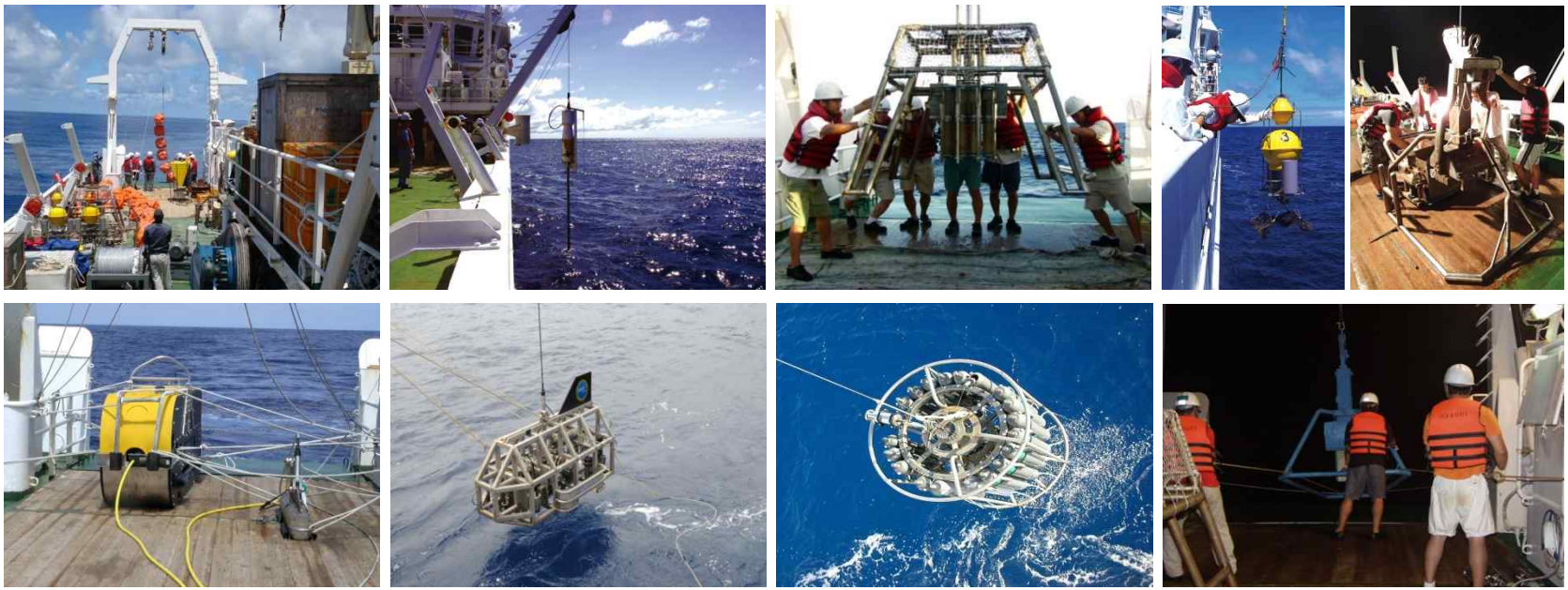
- **1994 :** Registration as a pioneer investor (150,000 ㎢)
- **1997 :** 1st relinquishment (30,000㎢)
- **1999 :** 2nd relinquishment (15,000㎢)
- **2002 :** Selection of final contract area (75,000㎢)

Exploration Summary

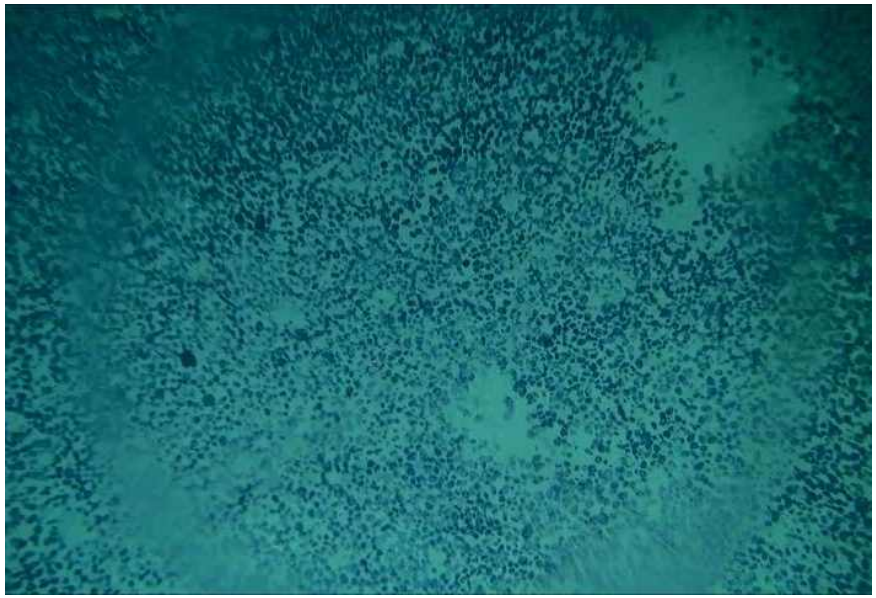
- **Stage I (1994-2010) : Resource assessment and environmental baseline study**

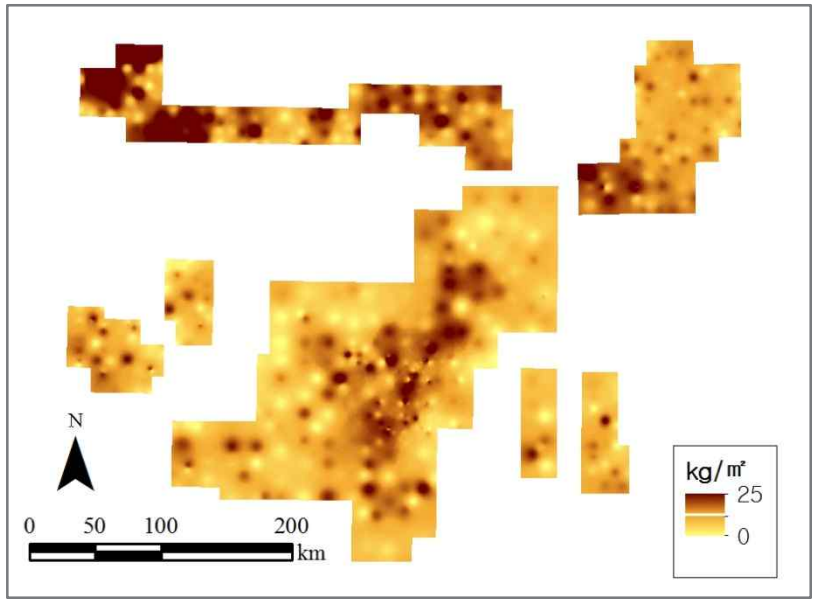
  - 925 days (ave. 62 days/year)

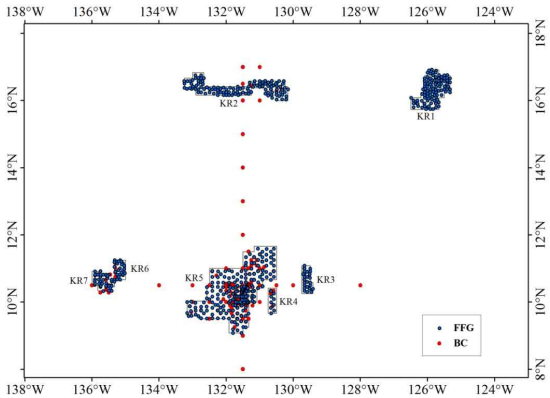
- **Stage II (2011-2015) : High resolution topographic and acoustic seafloor mapping in a prospective area and environment data collection for BIE (195 days)**



Nodule Resources



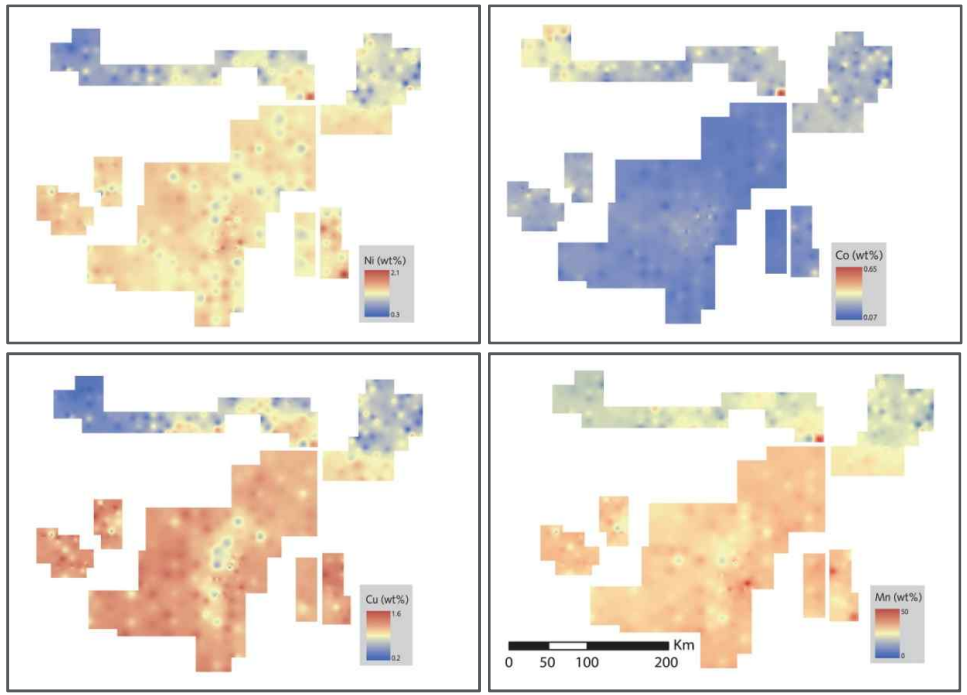




- **Collection of Mn-nodule : 1,354 sites**
  (FFG 1,062 (4 deployments at a site); BC 292)
- **Average abundance : 7.5kg/㎡**
- **High in north central (10.5kg/㎡), and low in southwest (6.3kg/㎡)**

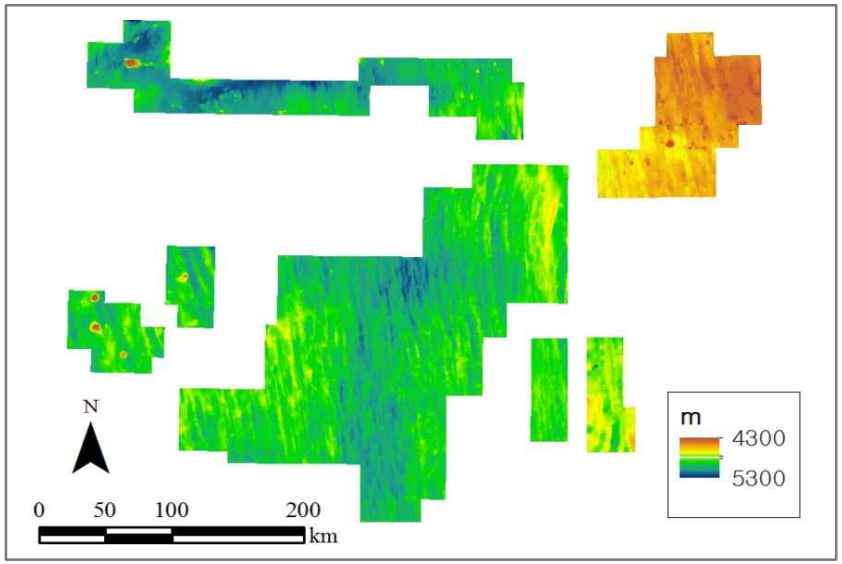
Mineral Resources

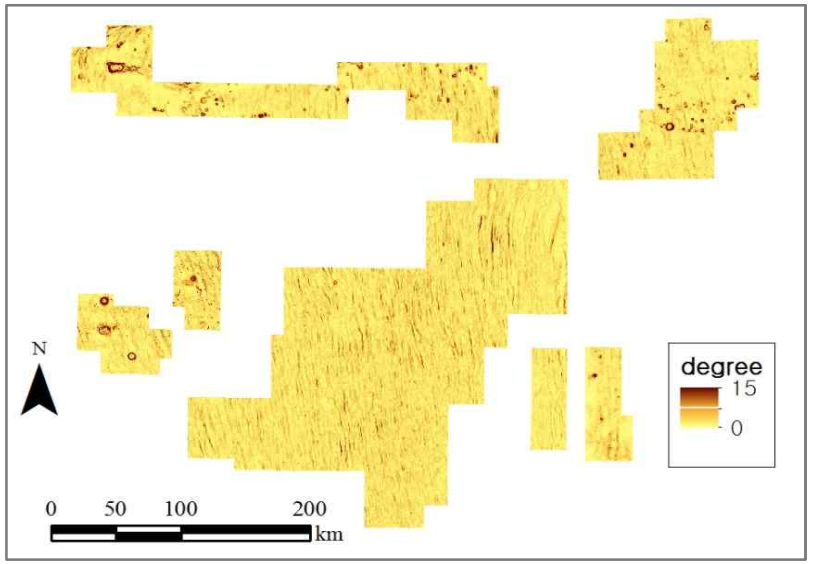
- Mineral resources are estimated from 451 samples
- Average contents of Ni, Co, Cu, and Mn are 1.19, 0.22, 1.02, and 27.7%.

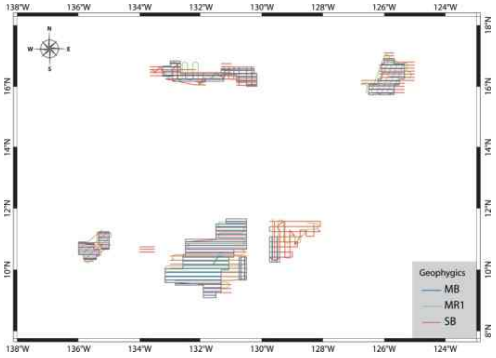


Variable	#Samples	Min.	Max.	Ave.	Median	S.D.
Ni	451	0.28	2.09	1.19	1.25	0.26
Co	451	0.07	0.65	0.22	0.21	0.07
Cu	451	0.22	1.64	1.02	1.09	0.31
Mn	451	4.7	47.7	27.7	28.7	5.1

Topographic Survey _ Water Depth & Slope

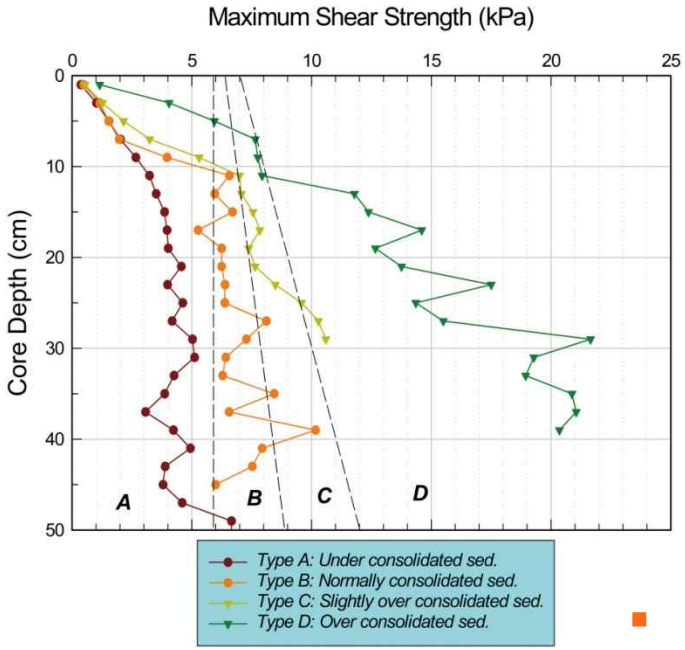


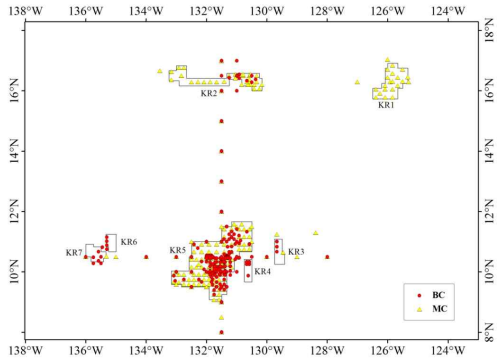


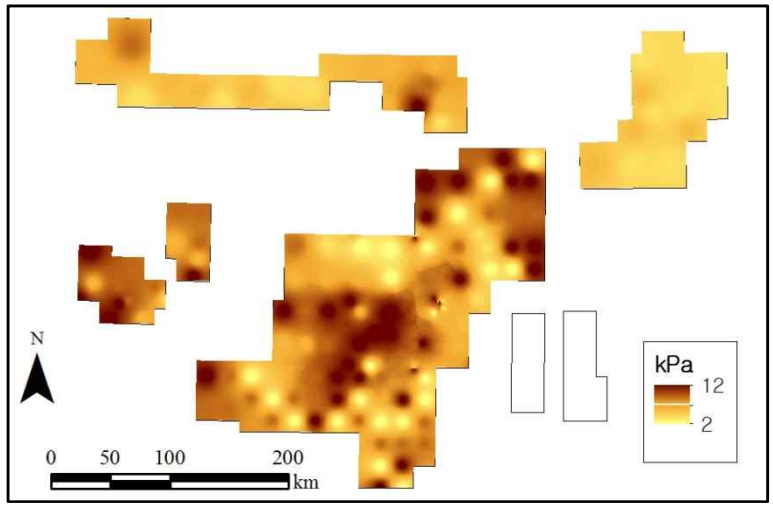


- **Equipment : Multi-Beam Echo Sounder, Side Scan Sonar (MR1)**
- **Water depth ranges from 4,800m to 5,100m**
- **Slopes are less than 5° in 90% of Korea contract area**

Sediment Property _ Shear Strength



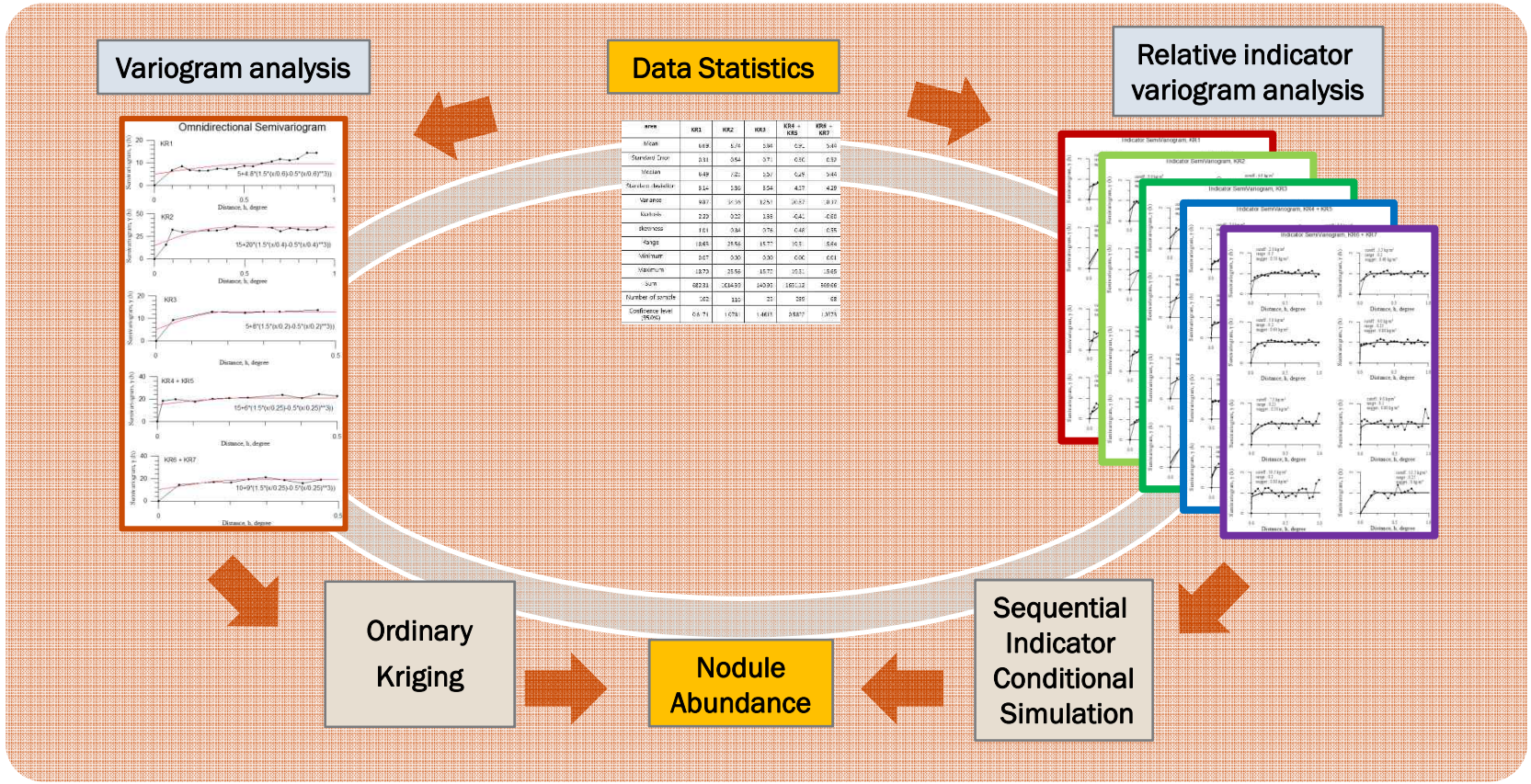




- **Sediment samples were collected at 227 sites using BC & MC**
- **Shear strength : averaged from 10cm to 40cm**
- **86.8% of total area : > 5kpa (Normally to Over consolidated)**
- **Blocks in southern part are covered with more consolidated sediments**

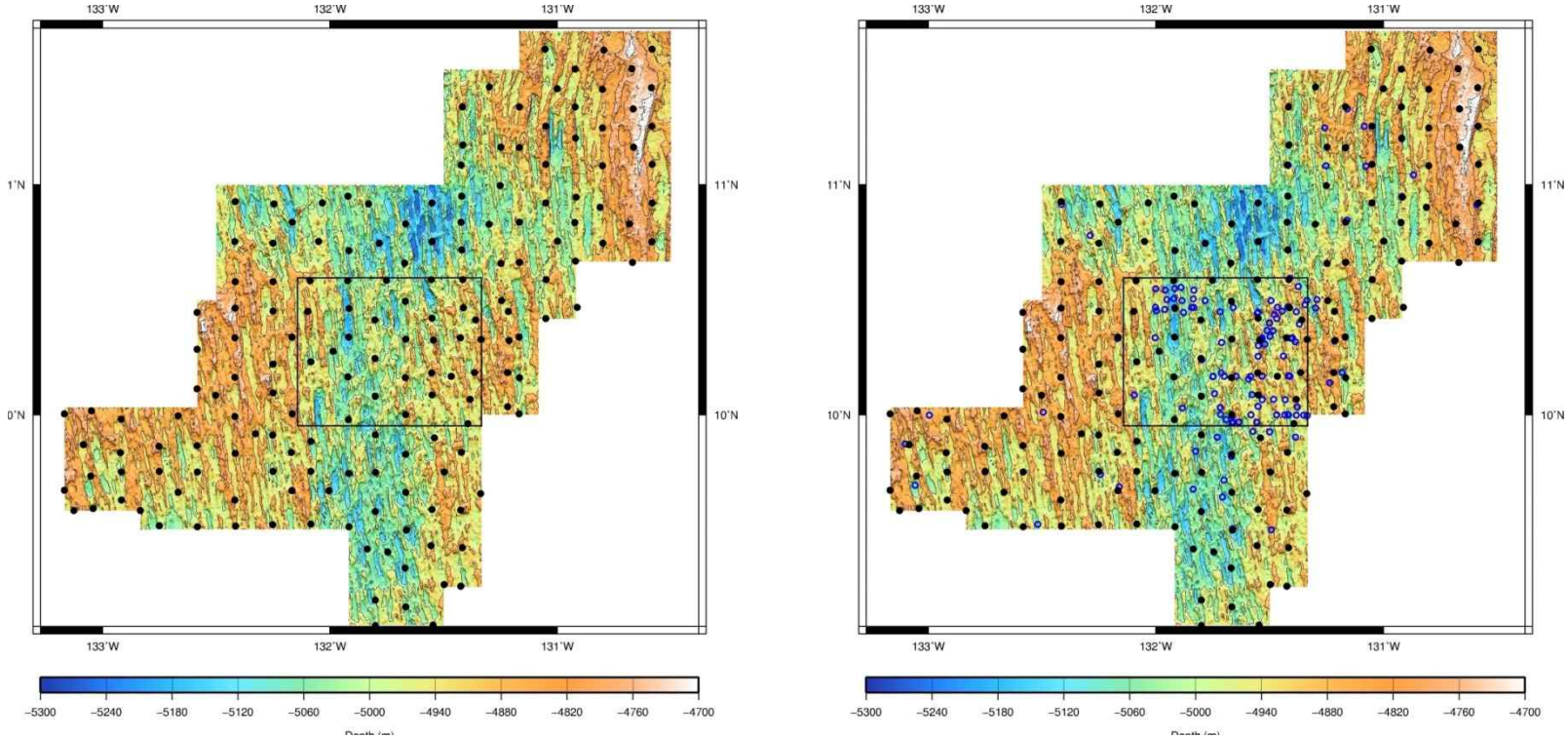
Estimation of Nodule Abundance

- **Ordinary Kriging Method & Sequential Indicator conditional Simulation Method**
- **Variogram analysis for Ordinary Kriging Method**
- **Relative indicator variogram analysis for SIS Method**



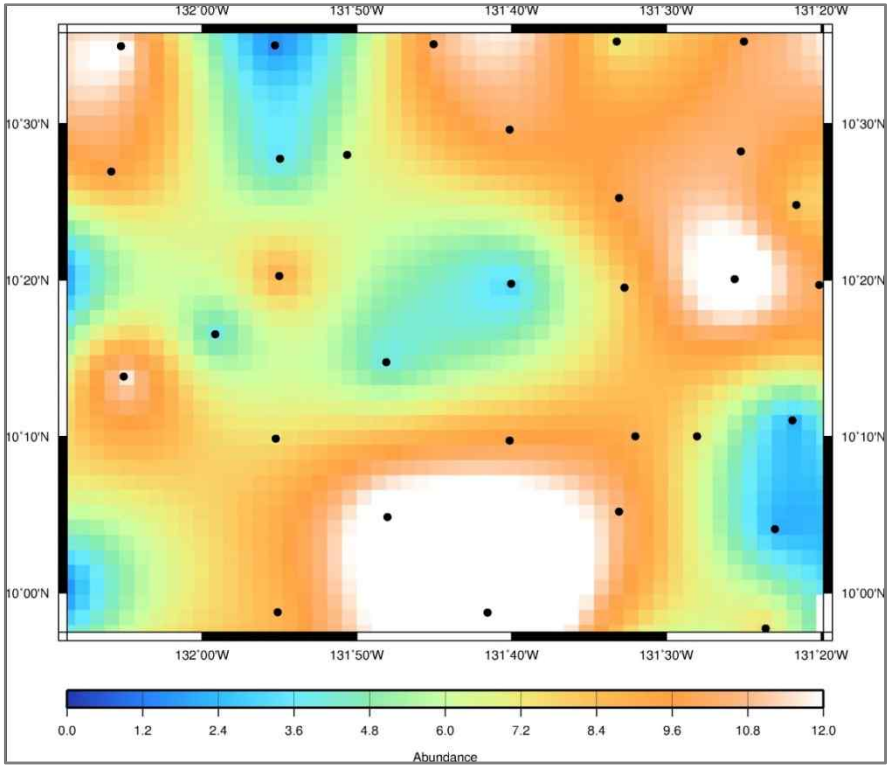
Nodule Abundance of KR5 Area

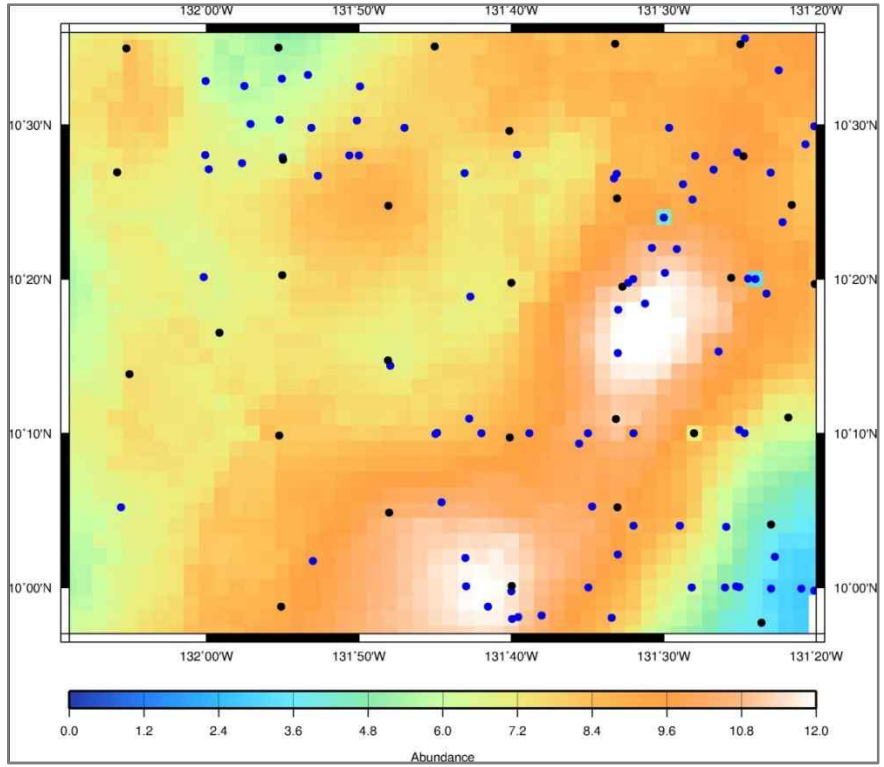
- **Evenly spaced samples in all contract area : ~14.4 km**
- **High density samples in a selected area : ~3.6 km**
- **Comparison of nodule resources estimated from evenly spaced low density sampling data and high density sampling data in a selected area**



Nodule Abundance of Selected Area

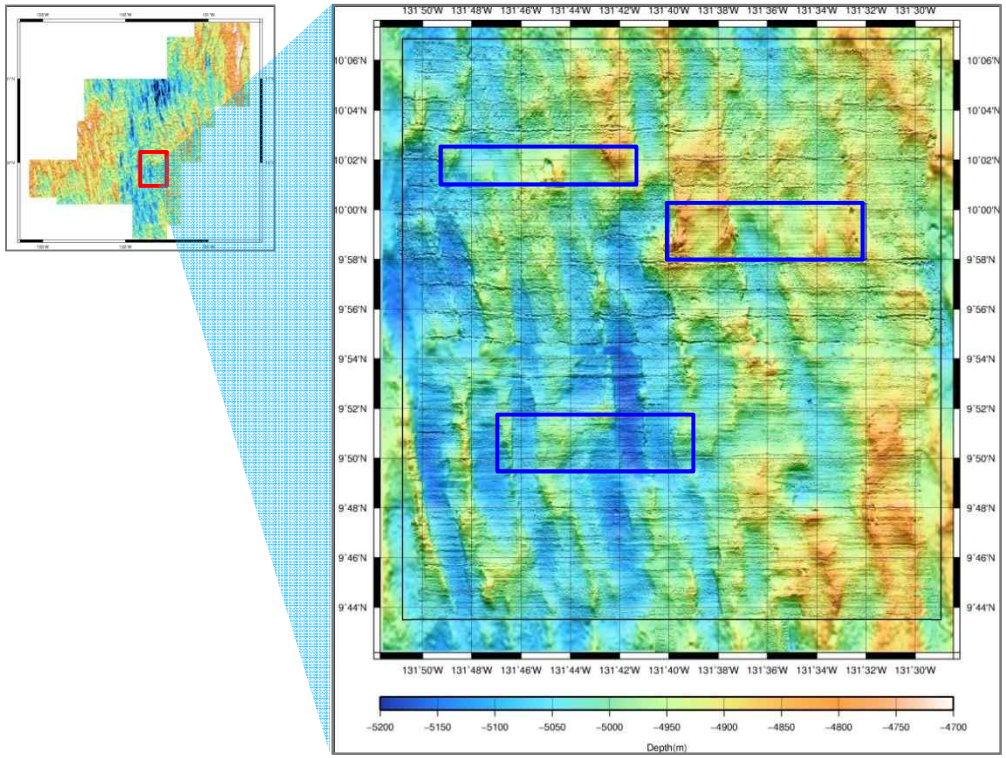
- **Evenly spaced low density data (32 points) :** 8.0 ± 2.7 kg/㎡
- **All available data (116 points) :** 8.3 ± 1.7 kg/㎡





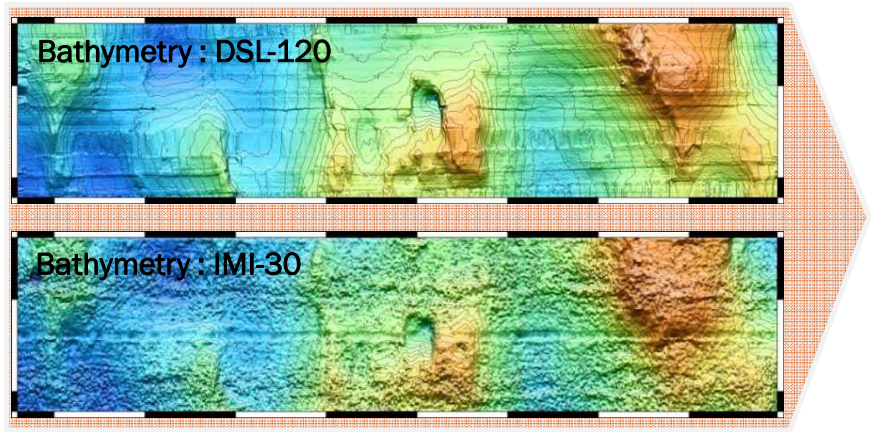
Mapping of Mineable Area _ seafloor acoustic survey

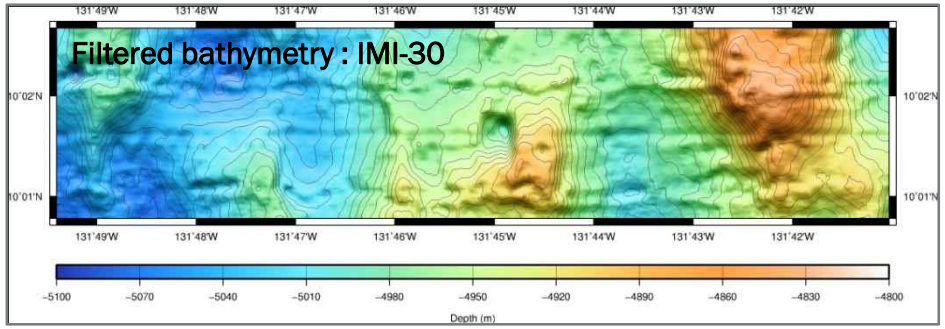
- **Equipment :** IMI-30 (25x25m), DSL-120 (5x5m)
- **Locates the obstacles for miner operation**
- **Covered area :** key prospective mining area of 1,613.3 ㎢

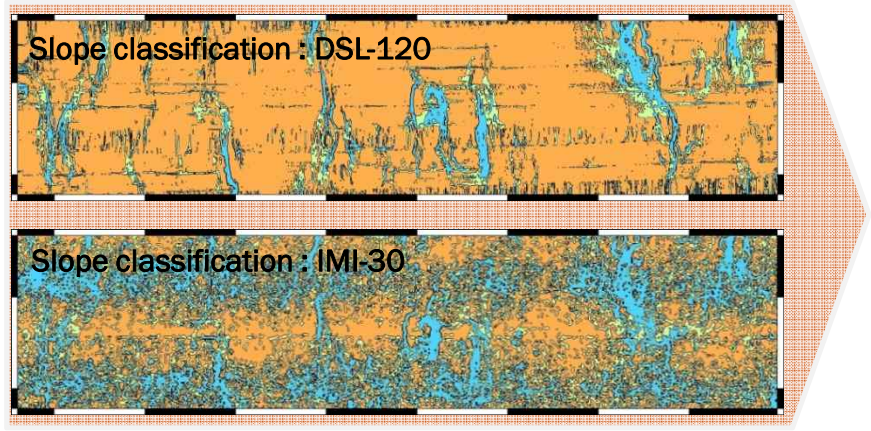


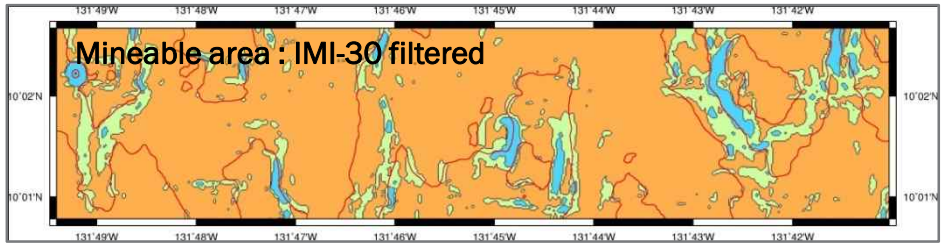
Mapping of Mineable Area _ seafloor acoustic survey

- Filtering IMI-30 data based on DSL-120 data
- Slopes are divided into three categories : <5° , 5-8° , >8°
- Mineable area is defined by slope gradient and obstacle continuity



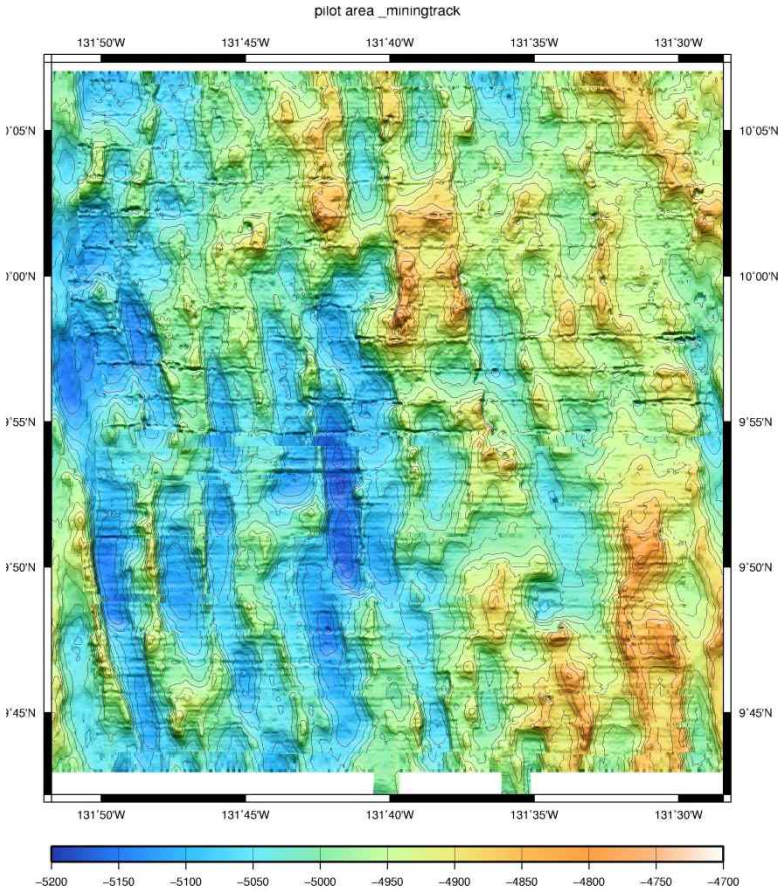


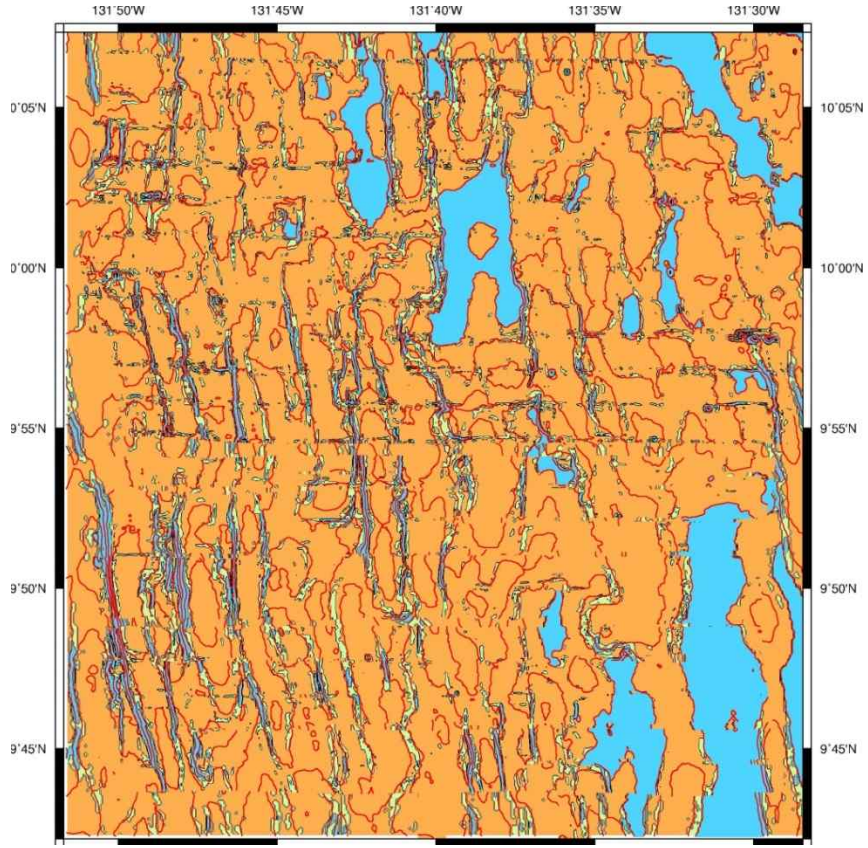




Mapping of Mineable Area _ seafloor acoustic survey

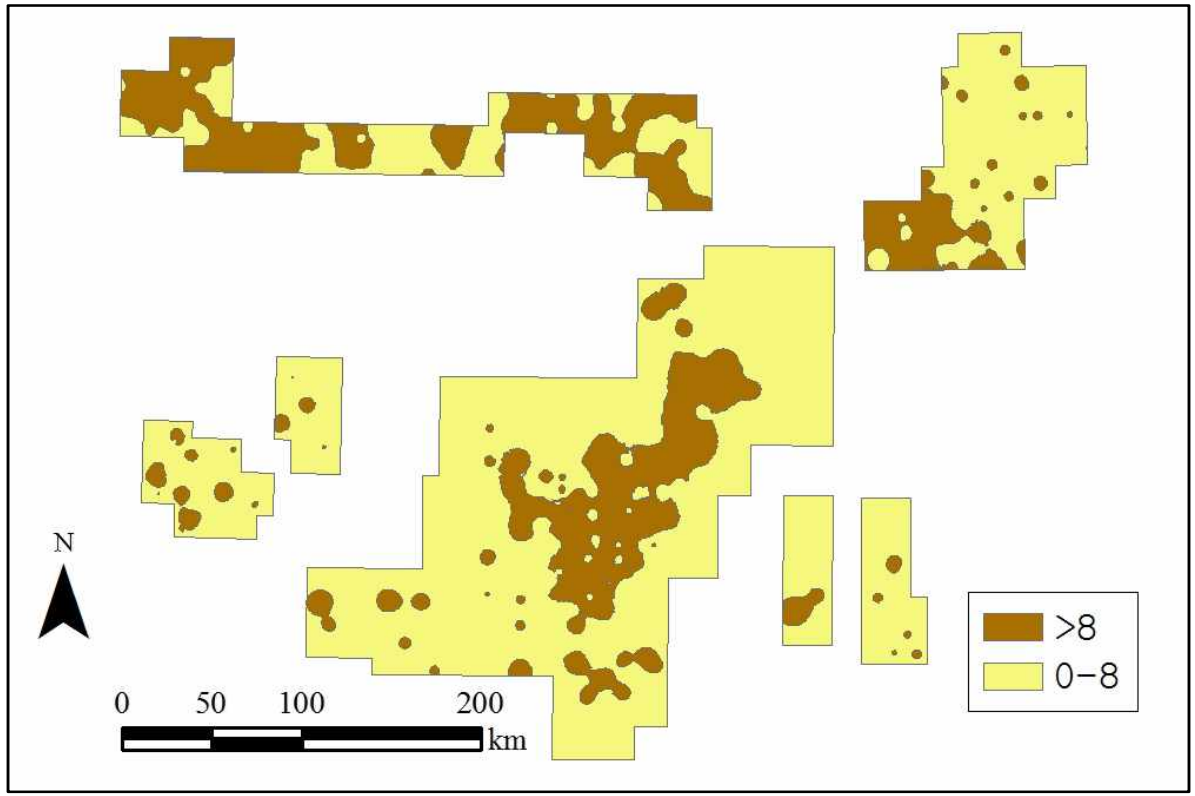
- **High bathymetric map using filtered IMI-30**
- **Mineable area taking account of miner maneuverability : ~75%**





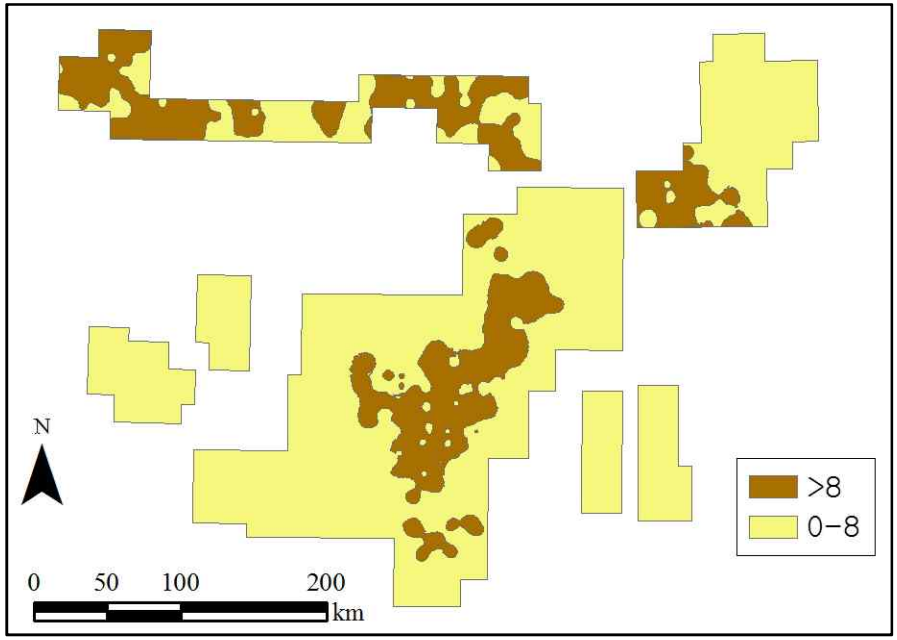
Selection of Priority Mining Area

- **Tentative production plan for Mn-nodule :** 3M ton/year, 30 years
- **Approximate cut-off value :** 8kg/㎡



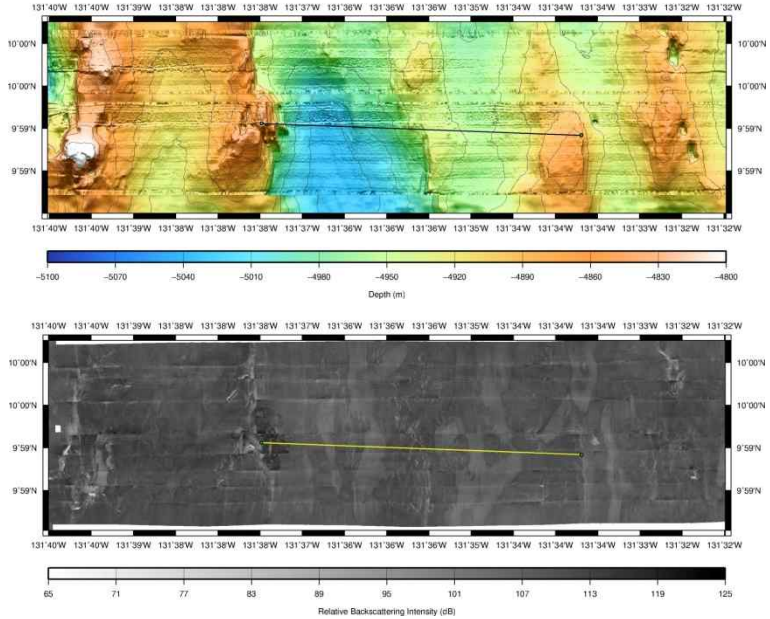
Resource within Priority Mining Area

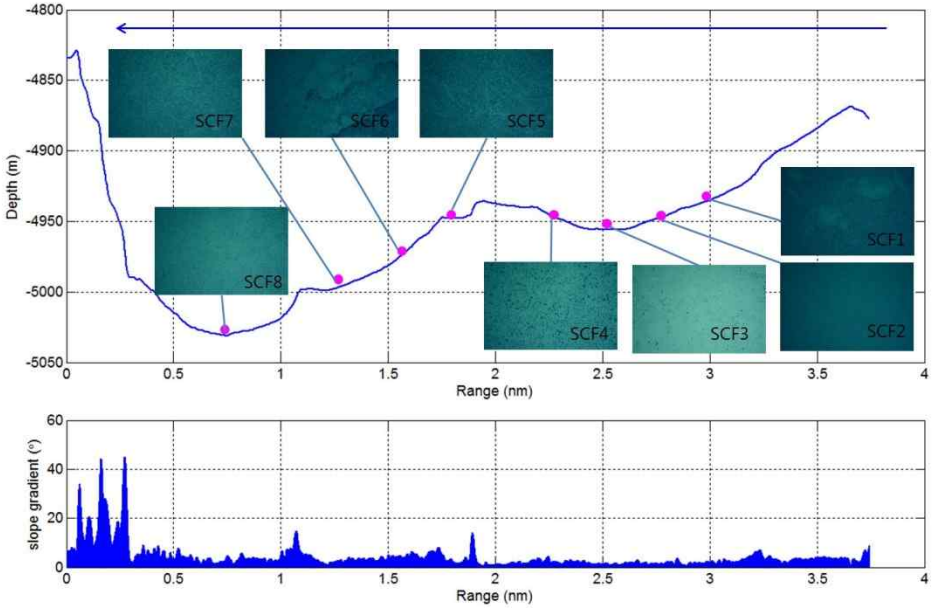
- **Factors considered for selection of priority mining area :** Cut-off Abundance(8㎏/㎡), Slope(<5°), Continuity
- **Estimated resource of priority mining area**
  - Area : 18,113 ㎢
  - Measured Resource : 188.4M ton (avg. 10.4 ㎏/㎡)
  - Mineable Resource : 113.8M ton



Future Work Plan for Resource Assessment

- **Acquisition of continuous nodule abundance data in a representative area**
  - Processing of backscatter intensity data from IMI-30 & DSL-120
  - Comparison of backscatter data with seafloor image (deep-sea camera system and AUV) and nodule abundance data collected with a TV-guided box corer
- **Mapping of mining obstacles in a representative area**





ISA Workshop 2014
Goa, India

Resource Assessment & Mining Technology
: Safe and Eco-Friendly Mining

Korea Research Institute of Ships & Ocean Engineering

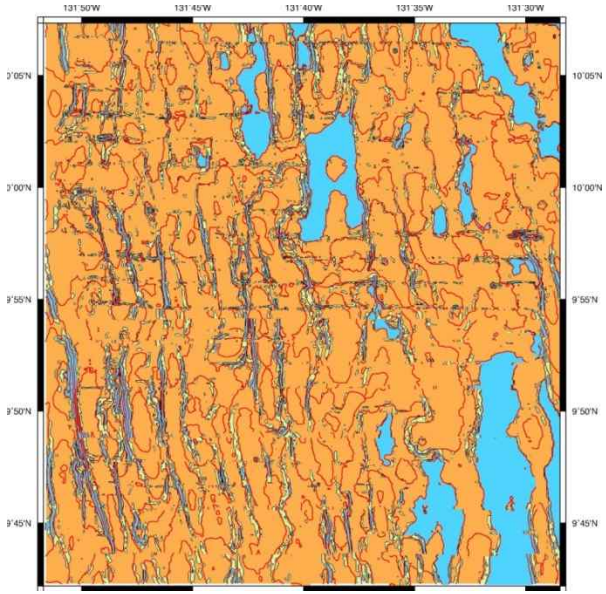
KIOST

Resource Assessment & Mining Technology (1/2)

- **Delineation of Mineable Area** depends directly on mining technology, in particular, on the performance of miner robot and it's integrated controllability, taking into account the coupled dynamics of robot vehicle and the rest subsea systems, i.e. flexible conduit, buffer and lifting pipe/pump.

$$MP = NC \times WC \times SC \times PE \times TE \times LE \times HE \times T$$

MP: Mining Production,
NC: Nodule Coverage
WC: Width of Collector,
SC: Speed of Collector
PE: Pick-Up Efficiency,
TE: Time Efficiency
LE: Lifting Efficiency,
HE: Handling Efficiency
T: Time



Resource Assessment & Mining Technology (2/2)

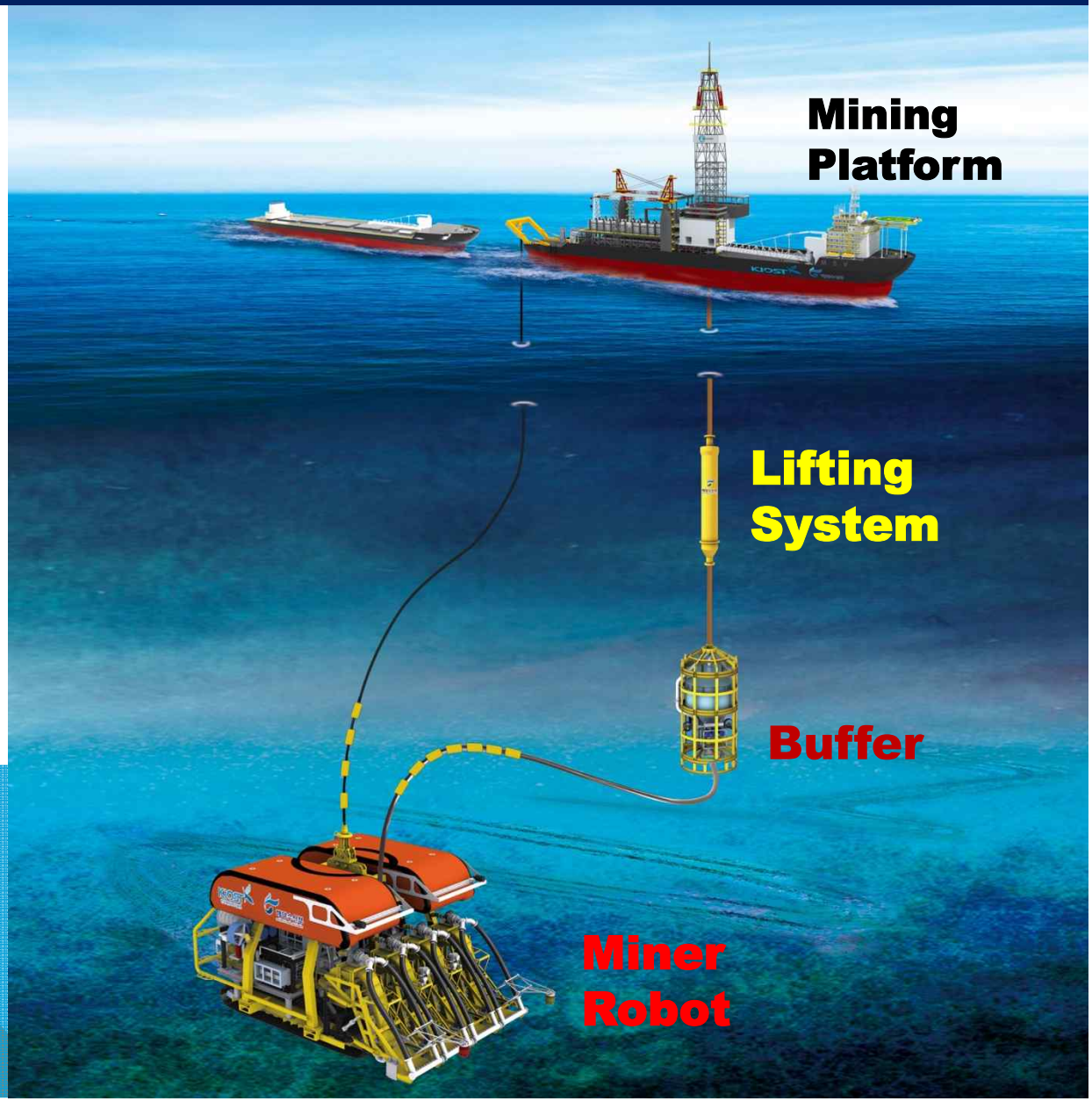
❖ Mineable Resources and Mining Technology

- **Pick-Up Efficiency**
- **Areal Coverage Performance**

- **Automatic Control** of miner robot is indispensable in commercial mining operation, because manual operation of mining machine (or collector) will be extremely restrained in sediment plumes by mining operation.
- **Robotics of Seafloor Miner** is of substantial meaning for realization of deep-seabed mining industry.
  - ***Driving Performance*** of robot vehicle on extremely soft-and-cohesive soil and in conditions of abyssal terrains
  - ***Performance of Automatic Path Tracking***
  - ***Performance of Pick-up/Crushing/Discharging of nodules***

Concept of Total Mining System

Proposed
Continuous
Mining
Concept



Development Points of Pilot Miner Robot

- **Final Goal**
  - **To reach TRL of 6 through PMT**
- **Extrapolation to Commercial Scale**
  - **Combination robot concept**
- **Mining Efficiency & Productivity**
  - **Collecting efficiency**
  - **Areal coverage perform**
    - Underwater localization
    - Driving performance
    - Automatic path tracking
- **Environmental Issue**
  - Low penetration into seafloor sediment
  - Sediment separation at robot
  - Sediment separation at buffer

HSE
(Health, Safety, Environment)

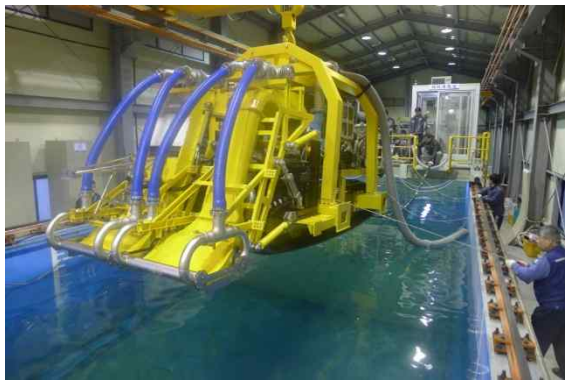
Pilot Mining Robot, *MineRo*

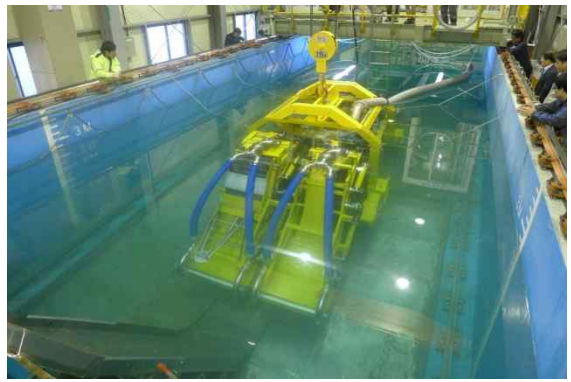
- Mining Capacity: 30t/h
- Pick-up
  - Hybrid(hydraulic + mechanical)
  - Hydraulic
- Four-Track Vehicle

- Weight : 28ton(Air), 11.5ton(Water)
- Size : 6.5m(L) x 5m(W) x 4m(H)
- Contact pressure(mean) : 9.82kPa
- Power : 550kW
- Working Depth : 6,000m

Combination Robot Concept

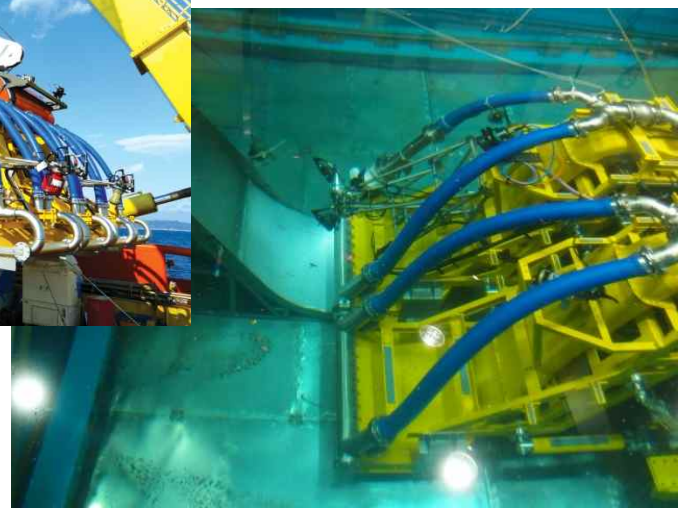
- **Unit robot module**
  - Two pick-up devices, two tracks and one discharging pump
  - Robot functions fully implemented
  - On road transportation and maintenance
  - Expandability to commercial mining robot (multiple unit robot modules)

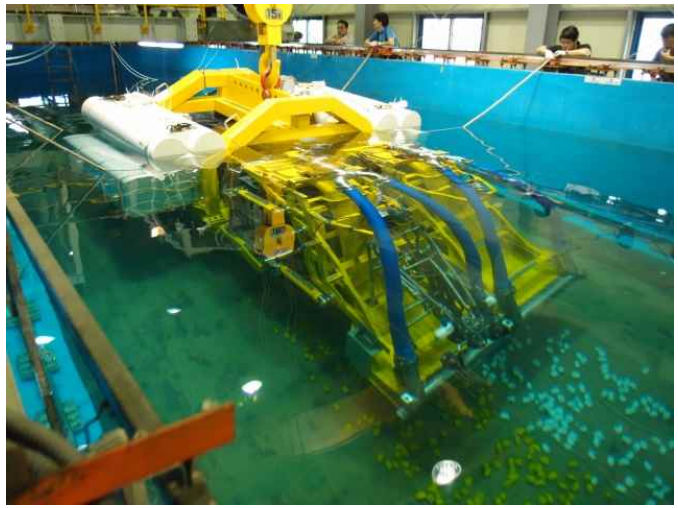




Collecting Efficiency (Lab Test)

- **Pick-Up Type :** hydraulic (Coanda + Transport)
- **Propulsion :** tracked vehicle
- **Design parameters :** **Gap, Nozzle shape, Flow-rates of waterjet, etc.**
- **Efficiency :** **max. 95% with manual gap setting**



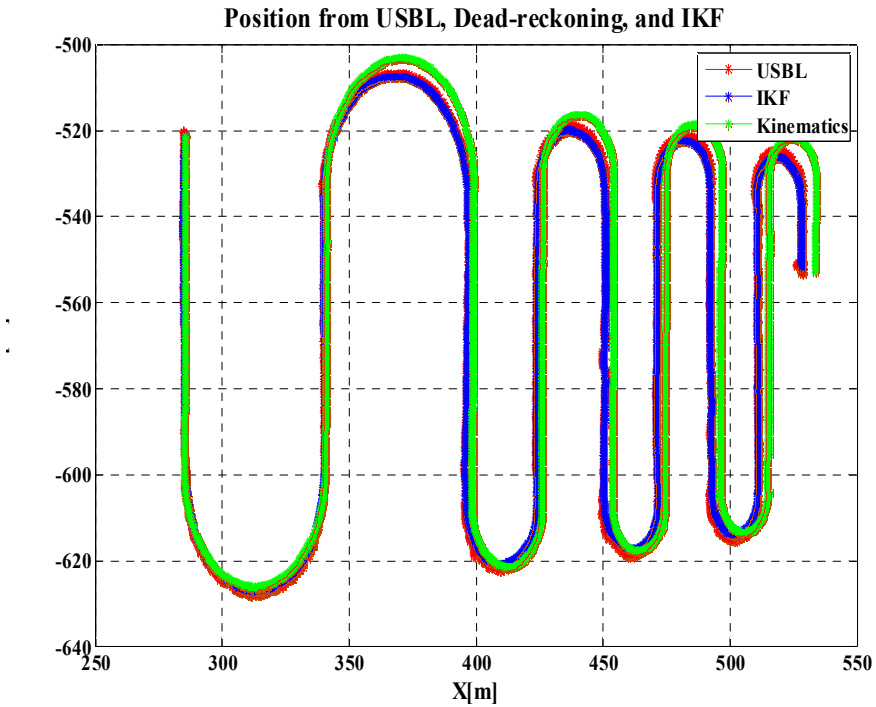


Collecting Efficiency (Sea Test)

- **Sea trials at 130m depth in 2012 & 2013**
- **Nodule collecting with crushing**
- **Collecting efficiency: N/A (nodule coverage unknown)**

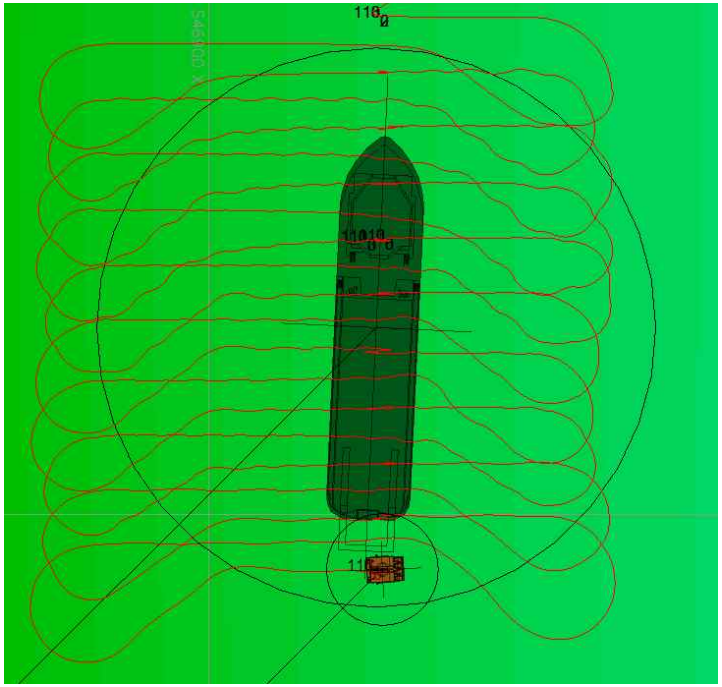
Underwater Localization

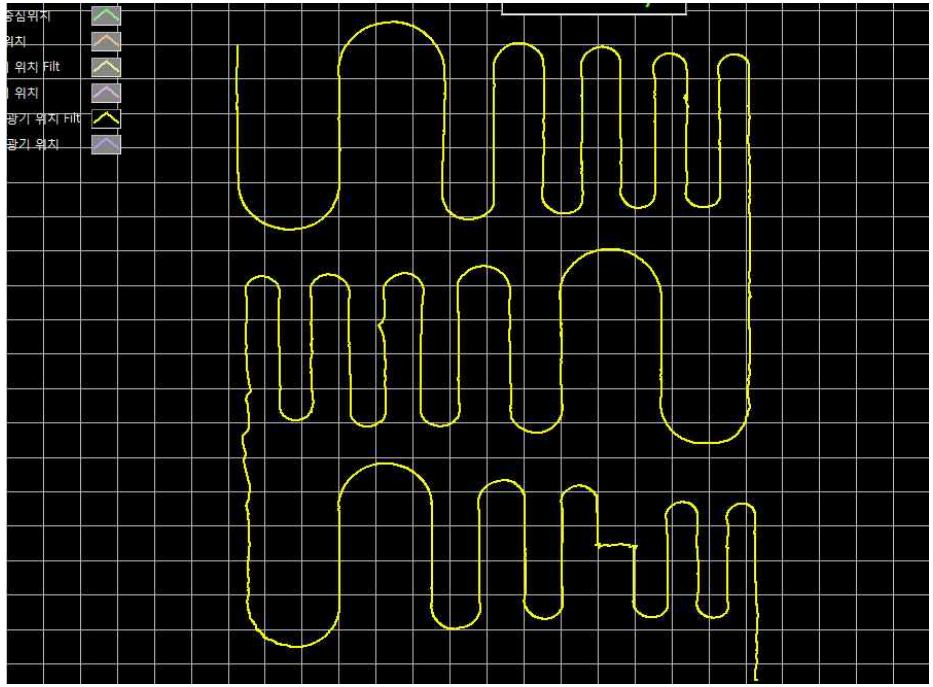
- **Localization algorithm**
  - Pre-filtering of USBL position data
  - Dead-reckoning using inner sensors data and vehicle kinematics
  - Indirect Kalman Filter : sensor-fusion algorithm (USBL data and dead-reckoning data)



Driving Performance

- **Steering characteristics on soft-cohesive soil**
  - Velocity control of four tracks (in parallel array)
  - Steering performance tests with respect to various steering ratios
  - **Performance parameters** : ***forward speed, angular velocity, track slip, slip angle, turning radius, sinkage, etc.***



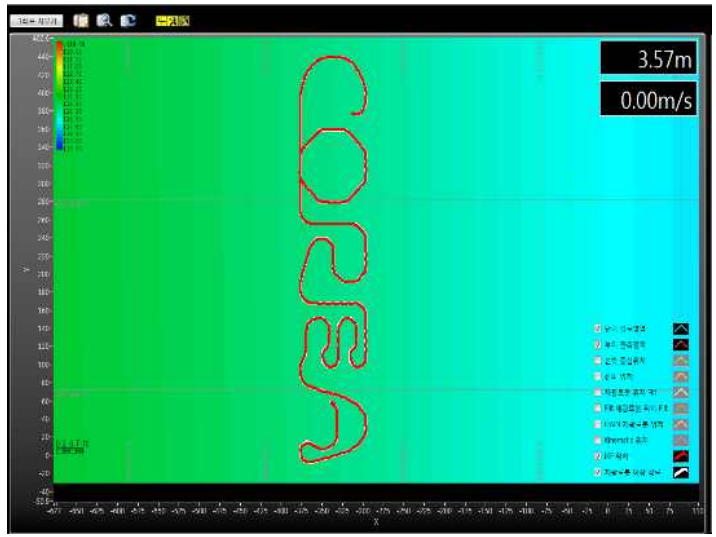


Areal Coverage Performance

- **Vacuum Cleaner vs. Vacuum Cleaner Robot**

  In order to harvest nodules at every corner, the areal coverage capacity of robot vehicle stands before the pick-up efficiency. The delineation of mining sectors and the optimum design of mining paths are closely related with the performance of driving control of robot vehicle.

  Automatic path tracking of miner robot is a prerequisite for profitable mining of polymetallic nodules.

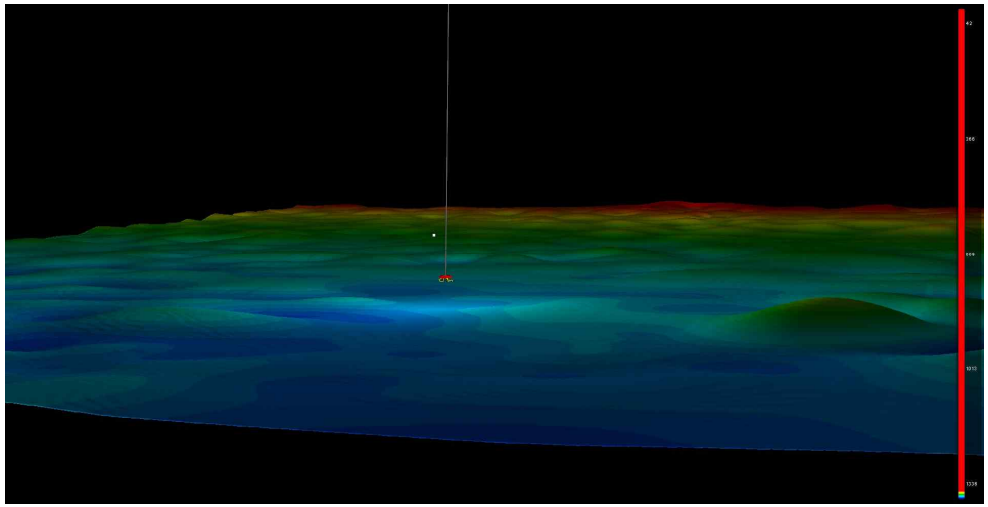


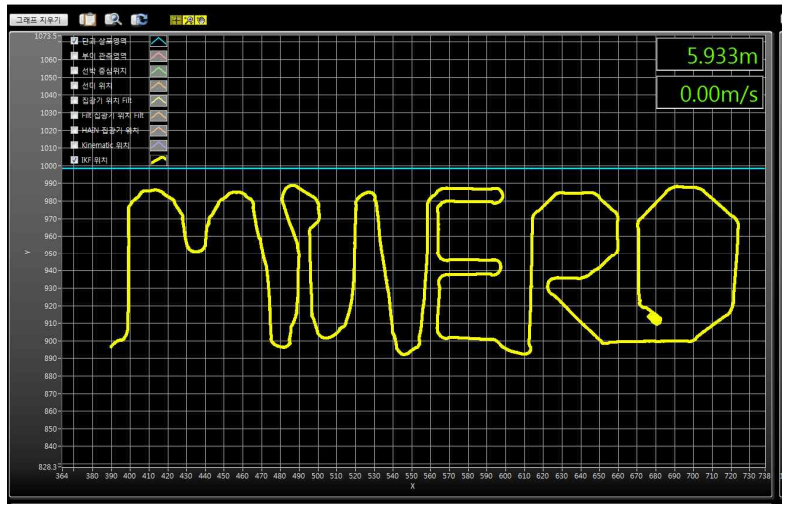
Path Tracking Tests (2013)

- **Shallow Water Test & Deep Water Test**

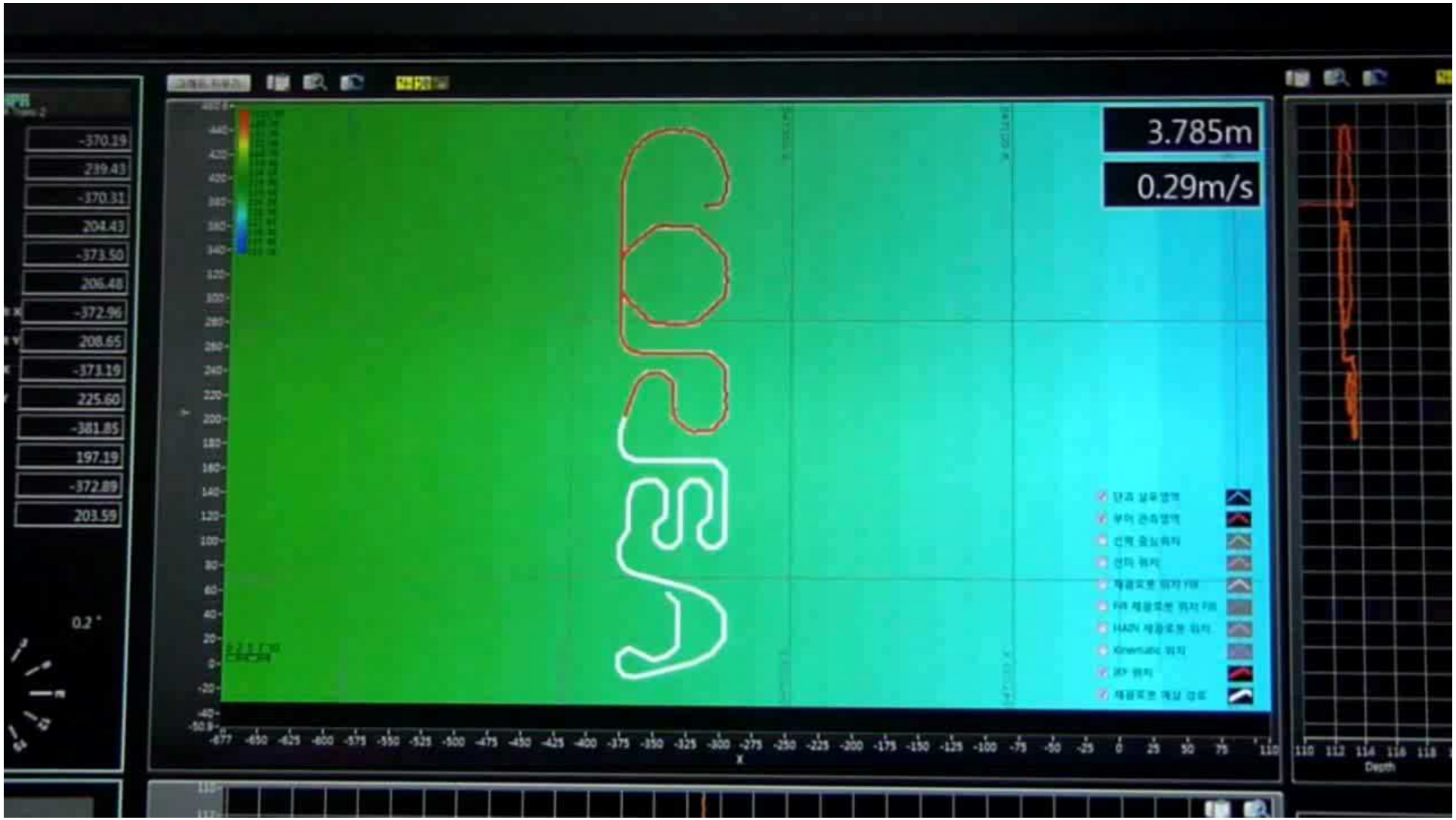
  Based on the steering characteristics of the robot vehicle, the path tracking controller has been designed taking into account of the track slips. The control parameters were tuned through ‘keyhole’ tracking tests.

  Tracking tests along complex paths on extremely soft seafloors, “**MINERO**” and “**COREA**”, were successfully performed in shallow water condition of 130m depth. Deep water test was carried out in WD of 1,370m.





Path Tracking Tests (videos)



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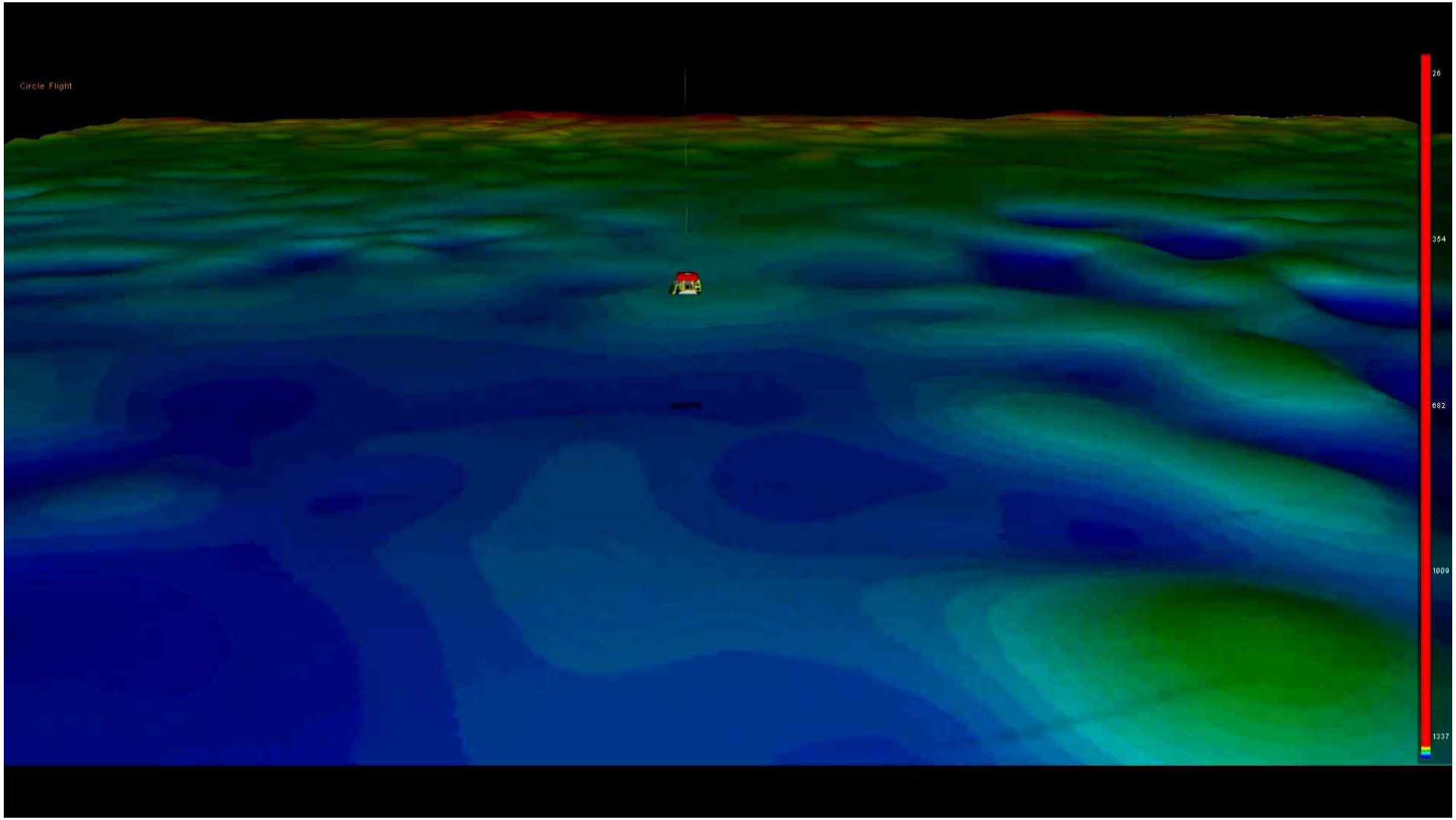


Safety & Eco-Friendliness is Profitable!

- **Eco-friendliness**
  - Minimize disturbance of benthic system
  - Suppression and control of mass transfer, *sediment and seawater*, but the minerals
  - Reduction of CO_2 emission

- **Safety**
  - Prevention of pipe clogging
  - Prevention of structure and machinery damages

- **Profitability**
  - ***Saving cost for sediment and water treatments***
  - ***Saving cost for pumping operation***
  - ***Saving cost by down-time reduction***
  - ***Maximizing performance of miner robot***

Counter-measures to Environmental Issue

- **Minimization of robot sinkage into sediment floor**

  Design of ***optimum contact pressure*** is critical for assurance of ***Floatation*** and ***Trafficability*** of the robot vehicle

- **Minimization of the sediment transportation up to the surface**

  Two-step separations of sediment were implemented:

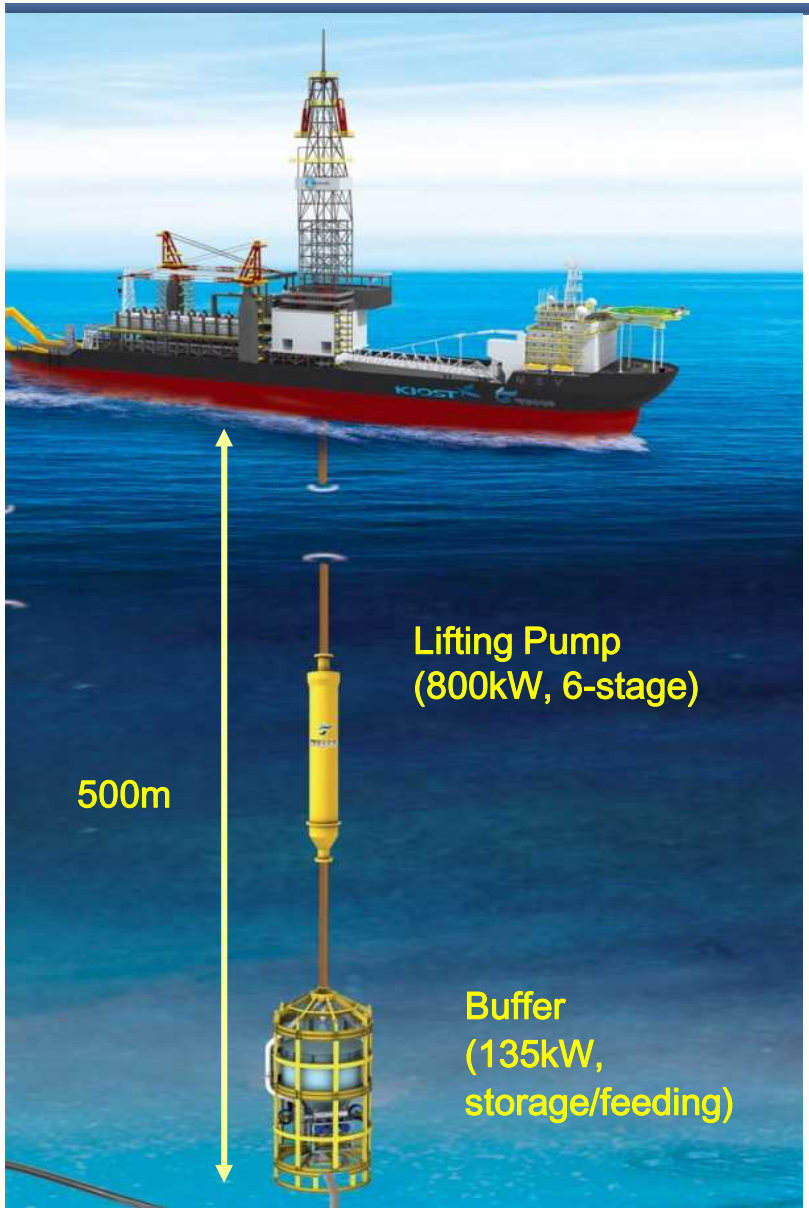
  - ***Miner robot***
  - ***Buffer***

- **Flow Assurance & Energy Reduction for Pumping Operation**

  Prevention of pipe clogging & reduction of CO_2 emission:

  - Feeder control at buffer for ***optimum volume concentration***

Pumpi & *Buffee* (to be tested in 2015)



Thank you for attention !