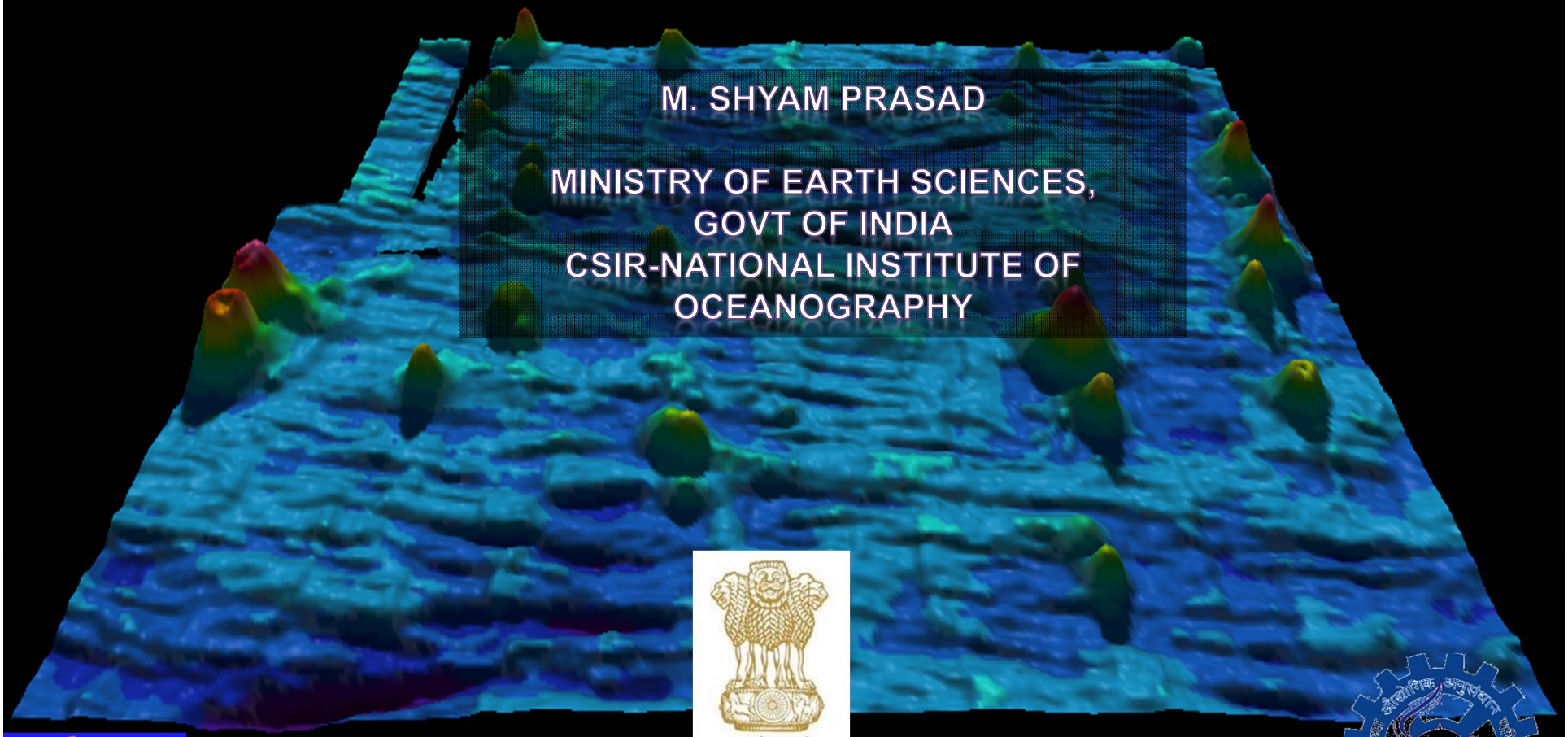
Indian Polymetallic Nodules program - RESOURCE EVALUATION

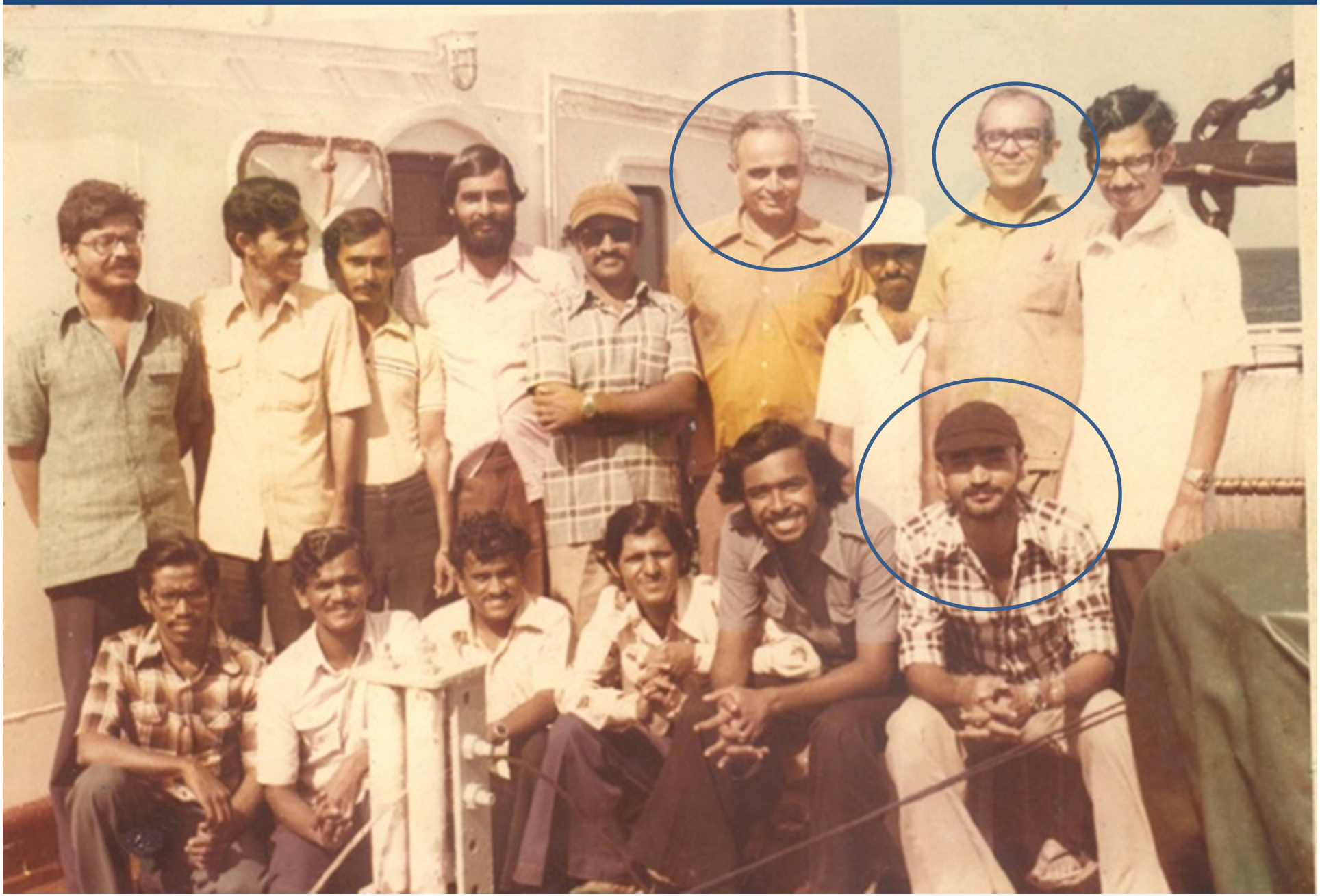


M. SHYAM PRASAD

MINISTRY OF EARTH SCIENCES,
GOVT OF INDIA
CSIR-NATIONAL INSTITUTE OF
OCEANOGRAPHY

सत्यमेव जयते
Ministry of
Earth Sciences

26TH January, 1981……..



Indian nodule catch stuns big powers

NEW DELHI, March 15 (PTI)

INDIA'S oceanographic adventure in January has stunned the big powers and some multinationals.

They are carefully watching India's next move in the Indian Ocean floor from where the research ship, "Gavesha", of the National

India to launch a venture similar to its off-shore oil hunt.

Currently India imports all its nickel and cobalt and some 60 per cent of the copper it needs. The NIO

India to exploit seabed nodules in Ocean floor

PANAJI, August 2 (UNI)

India strikes polymetallic nodules search geared up

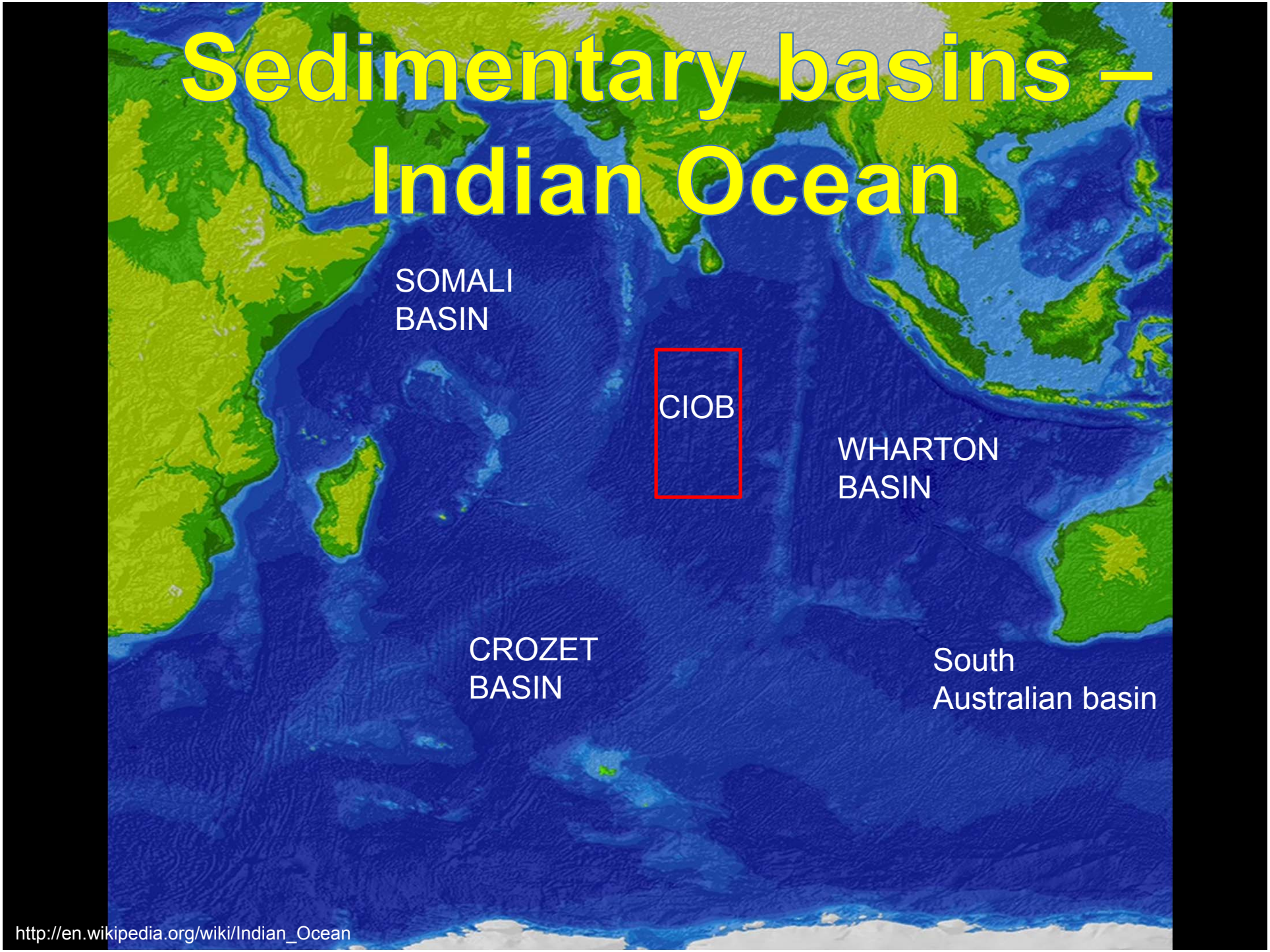
ભારતના સાયન્ટિસ્ટો તરફથી મહા-
સાગરના ખનિજ પદાર્થોના સંશોધનની
તેજ બનાવાયેલી પ્રવૃત્તિ

अनेक धातूंच्या मिश्रणाचे हिंदी महासागरात खडे

'गवेषणी'वरील वैज्ञानिकांची शोध मोहीम

पणजी, दि. १६ (वीटोमात)–

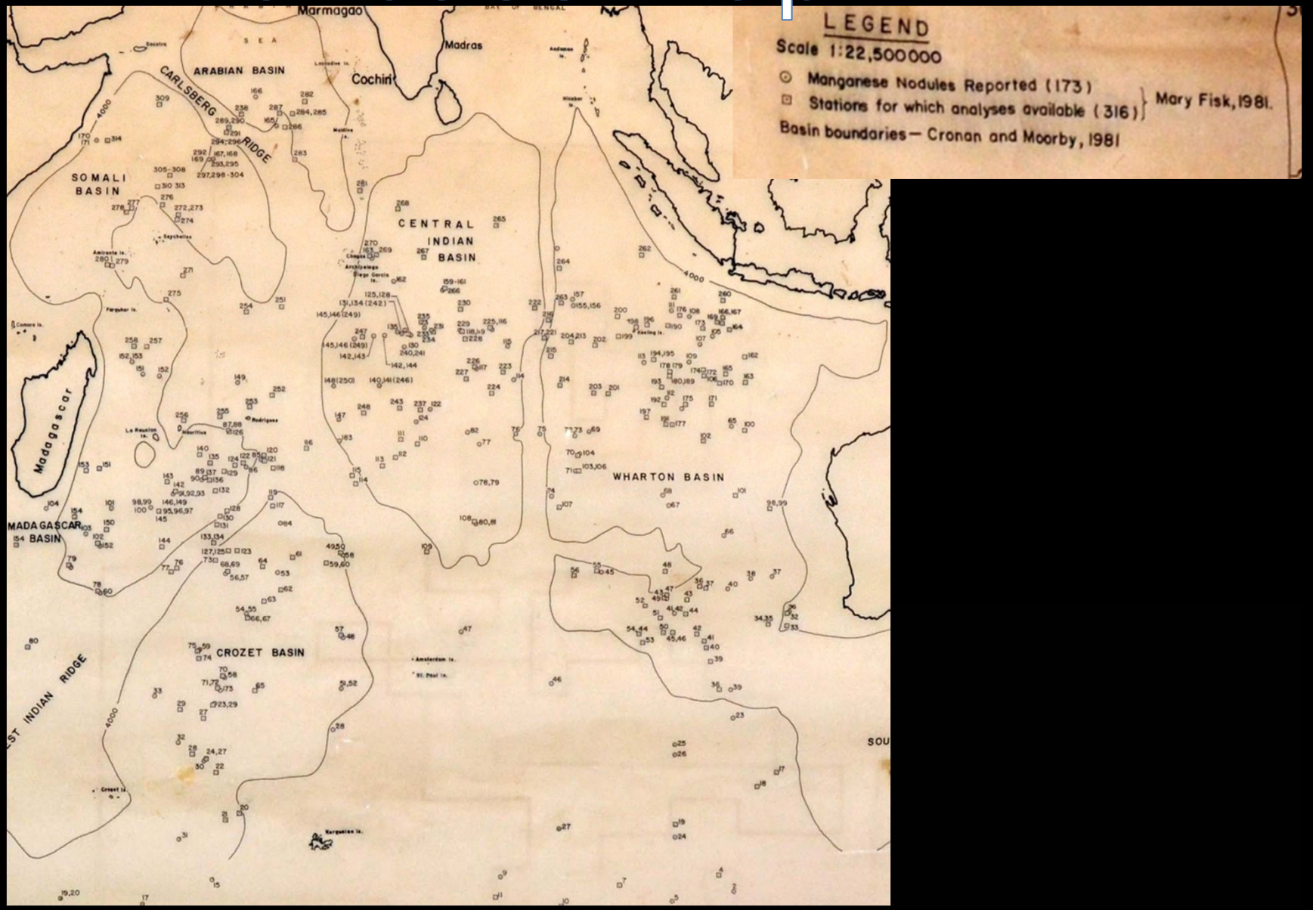
Sedimentary basins – Indian Ocean



http://en.wikipedia.org/wiki/Indian_Ocean


LEGEND
Scale 1:22,500000
Manganese Nodules Reported (173)
Stations for which analyses available (316)
Mary Fisk, 1981.
Basin boundaries — Cronan and Moorby, 1981
ARABIAN SEA
BAY OF BENGAL
Marmagao
Madras
Cochin
ARABIAN BASIN
CARLSBERG RIDGE
SOMALI BASIN
CENTRAL INDIAN BASIN
WHARTON BASIN
MOZAMBIQE CHANNEL
Madagascar
MADAGASCAR BASIN
MOZAMBIQUE RIDGE
AGULHAS PLATEAU
SOUTH WEST INDIAN RIDGE
CROZET BASIN
SOUTH AUSTRALIAN BASIN
4000

Initial base map



Milestones….

- First nodule sample collected by Indian scientists on 26 Jan.1981
- April, 1982 :India recognised as Pioneer Investor
- December, 1982 : India Signed UNCLOS III
- August 1983 : First metal from nodules extracted and 2 mil. Sq.km area explored (the exploration and the metallurgy teams were in working in tandem)

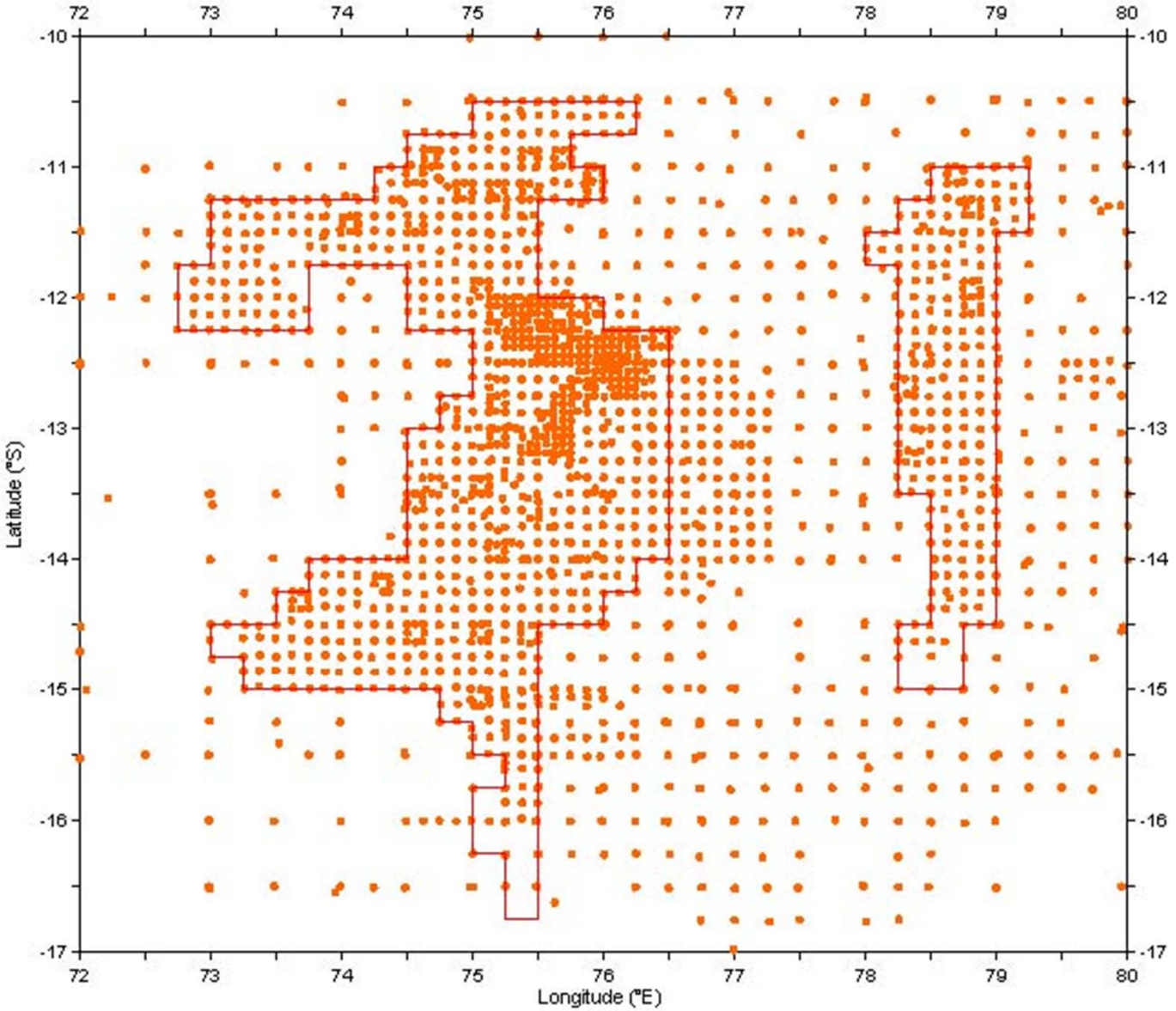
Milestones.....

- **August 1987:** Pioneer Area Allocated(150,000 sq.km)
- **July 1994:** 20% area relinquished (block size 25 km)
- **June 1995:** India Ratified UNCLOS III
- **October 1996:** 10% area relinquished (block size 12.5 km).
- **2002 :** 20% final relinquishment
- **2009-10** : Identification of First Generation Mine Site
- **2013 :** Identification of Test Mine Site

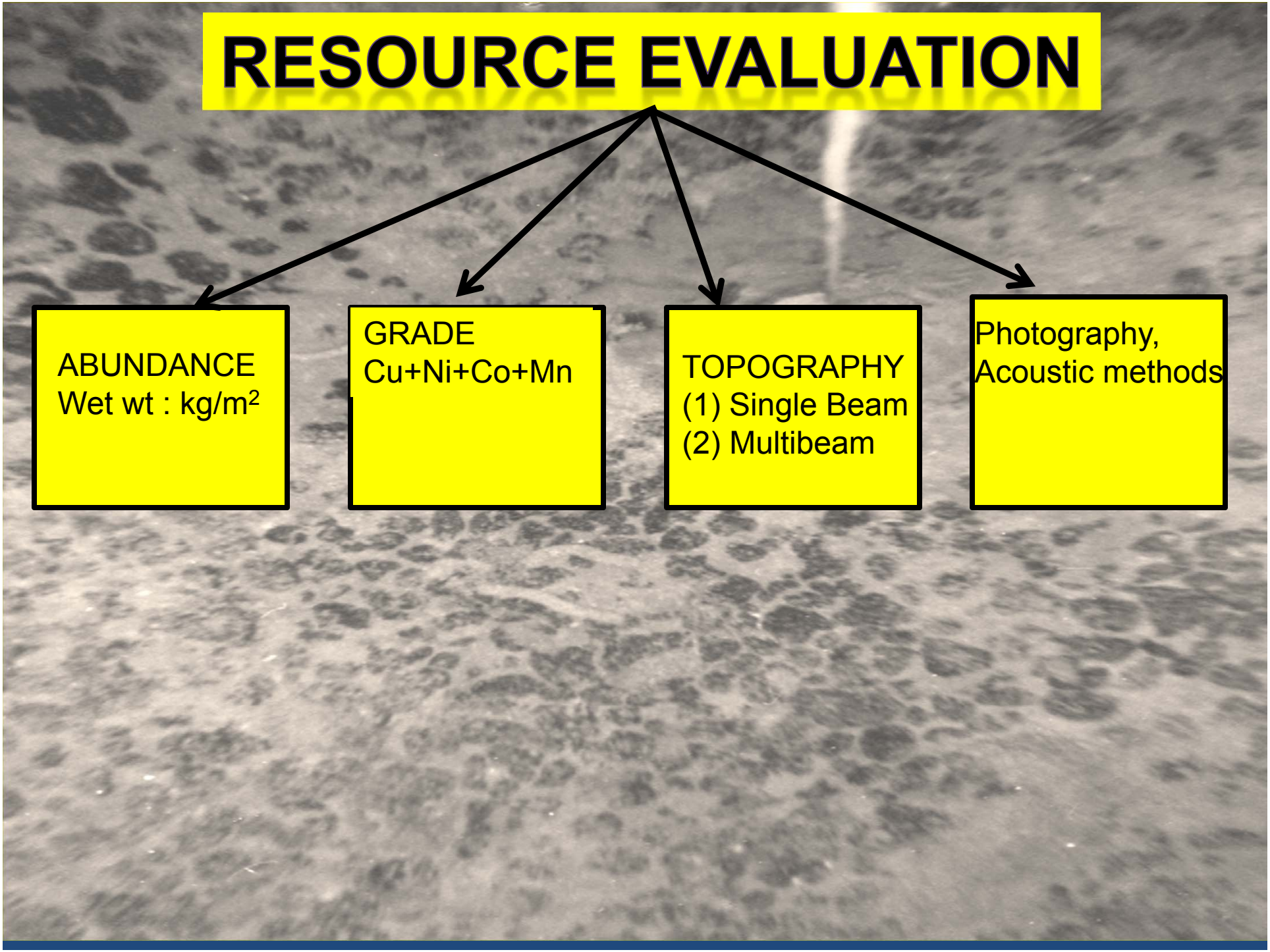
QUANTUM OF DATA OBTAINED FROM THE CENTRAL INDIAN OCEAN

Area Surveyed	~3 Million Sq.km
Nodule sampling Equipment used- Free fall grab,Photo grab, Van veen grab, Okean grab etc.	Over 2500 locations with 5-7 operations in each station.
Total number of sampling operations	~ 10,900
Grid of sampling	Completed 0.125° (~14 km) km grid in entire Pioneer area, and 0.0625° (~7 km) grid in a part of the area measuring approximately 18,400 km^2
Total Bulk nodules Collected (by Dredging)	300 tons
Seabed photographs	>50,000
Echosounding (12 and 3.5 Khz echosounder)	500000 lkm
Multibeam Swath bathymetry	300000 sq.km
High resolution Multibeam swath bathymetry	12,000 lkm
Sediment Coring (Box/spade cores)	~ 50 stations.
No of expeditions	76
Ships used (8)	RV Gaveshani, ORV Sagarkanya, MV Farnella, DSV Nand Rachit ,MV GA Reay, MV Skandi Surveyor, RV AA Sidorenko, Akademik Boris Petrov
Scientific Publications (in national and international journals)	>350 (>25 Ph.D.s)

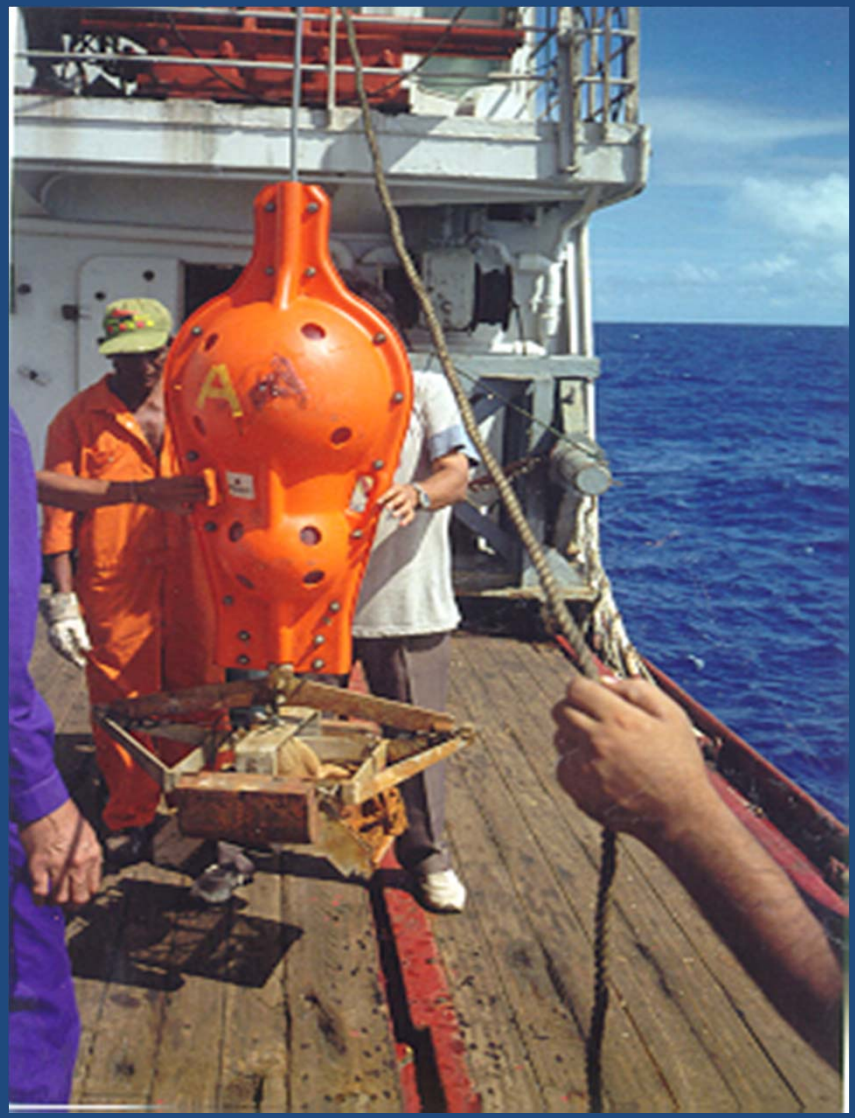
Sampling density in the Central Indian Ocean



RESOURCE EVALUATION

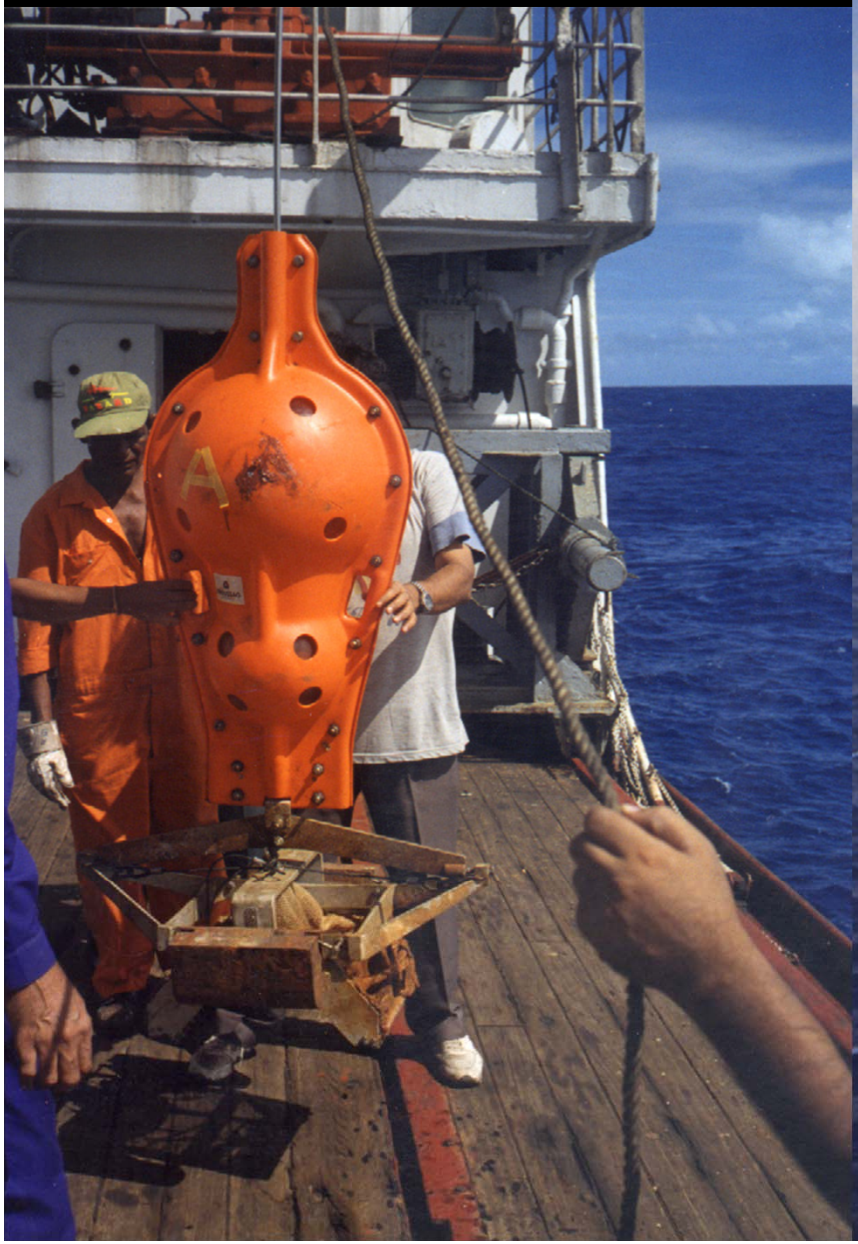


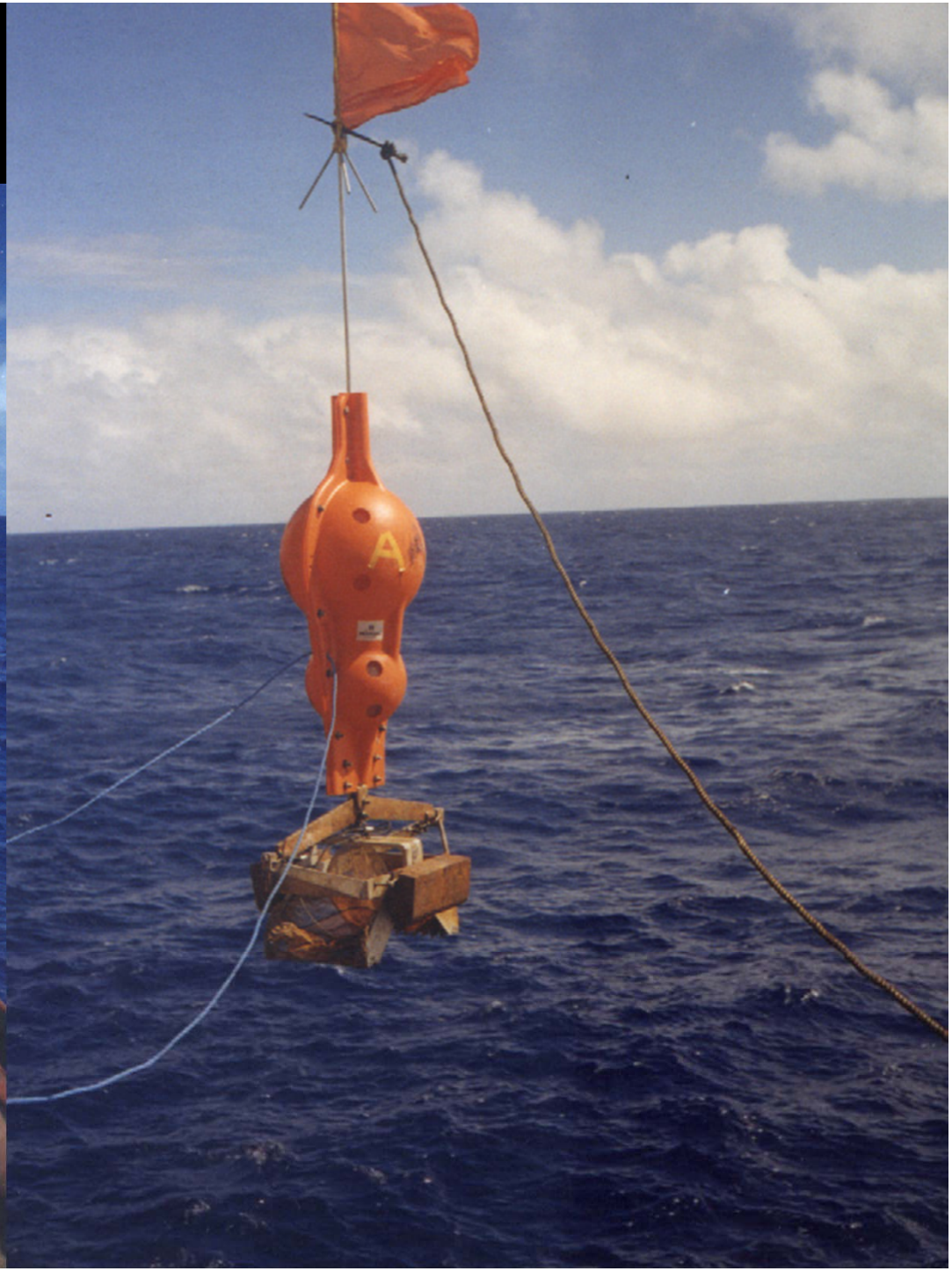
Exploration methods : SPOT SAMPLING



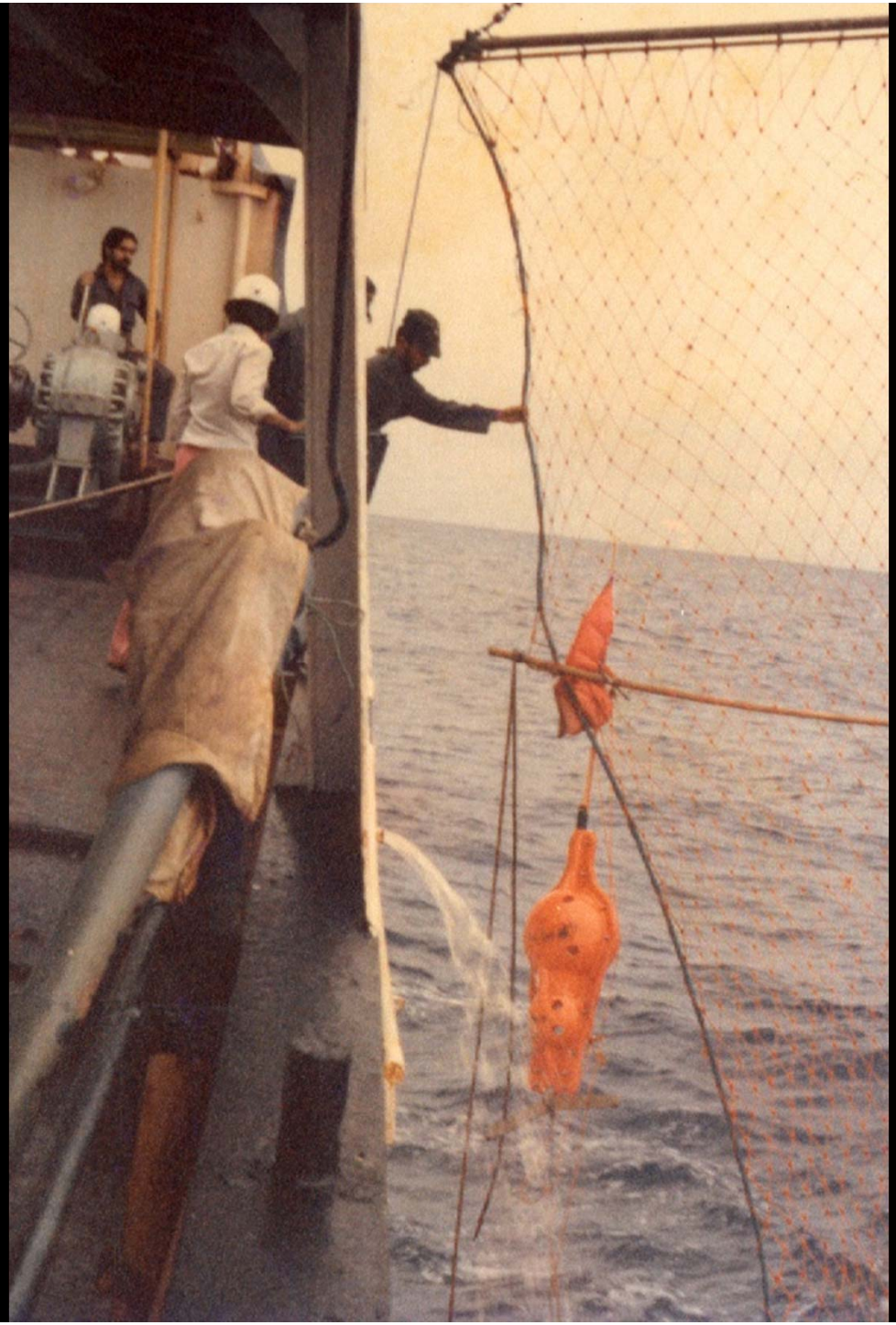
A Free fall grab –ready for launch

Free fall grab launching





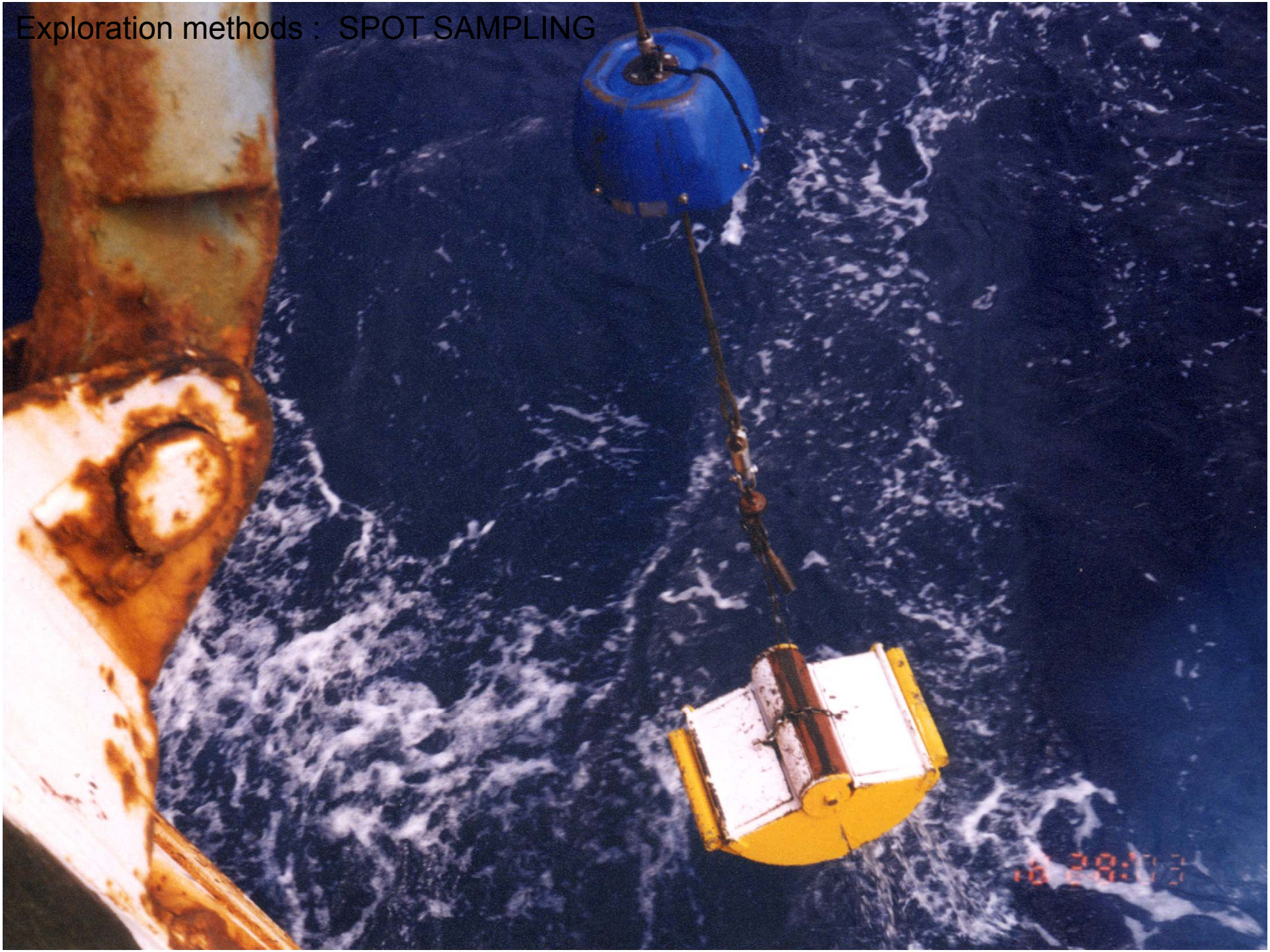
Free fall grab recovery



Spot Sampling : Pettersson Grab launching

Exploration methods :
SPOT SAMPLING – OKEAN GRAB

Exploration methods : SPOT SAMPLING



Exploration methods : SPOT SAMPLING


Exploration methods : SPOT SAMPLING

Exploration methods : SPOT SAMPLING

Bulk Sampling

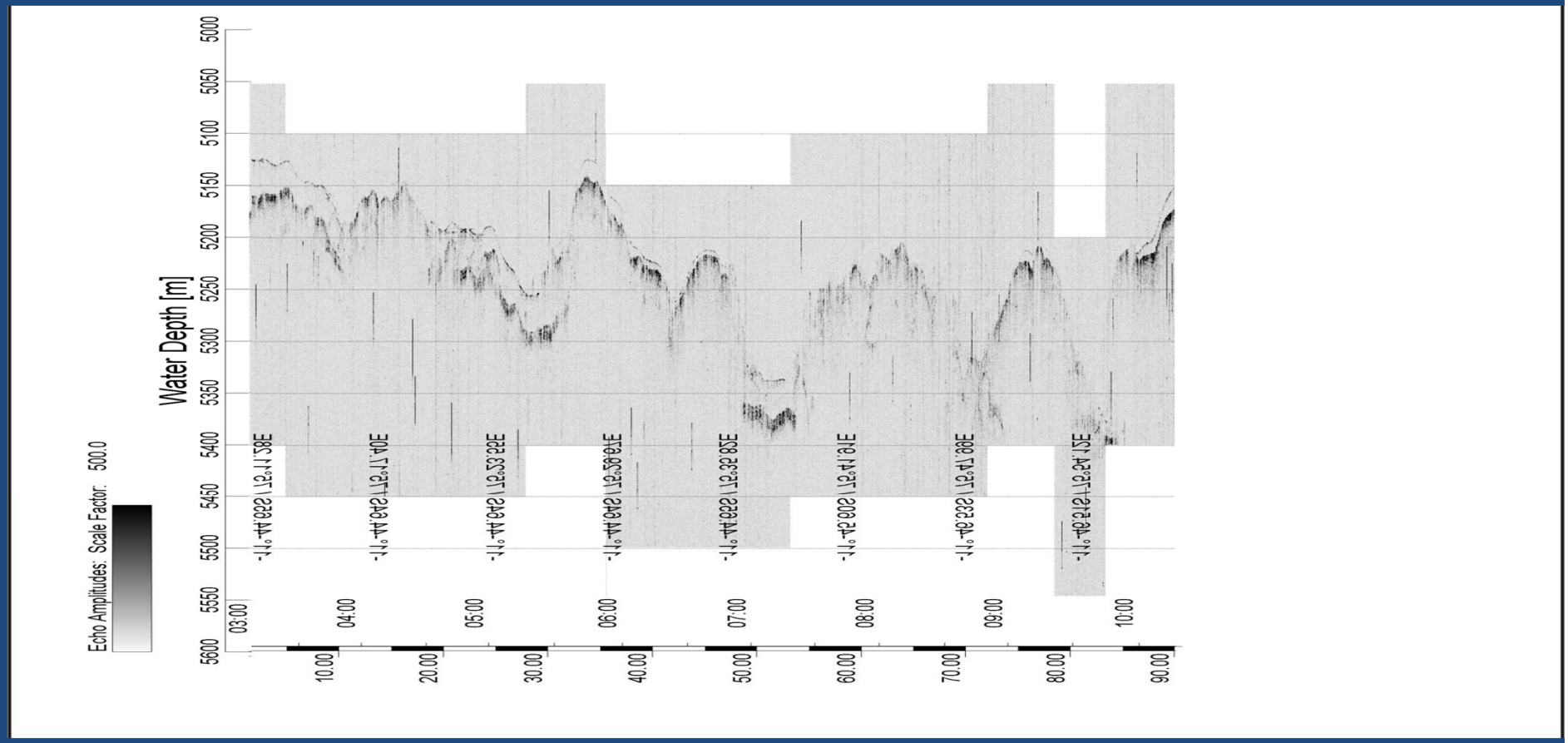

Bulk Sampling

Bulk Sampling

Bulk Sampling

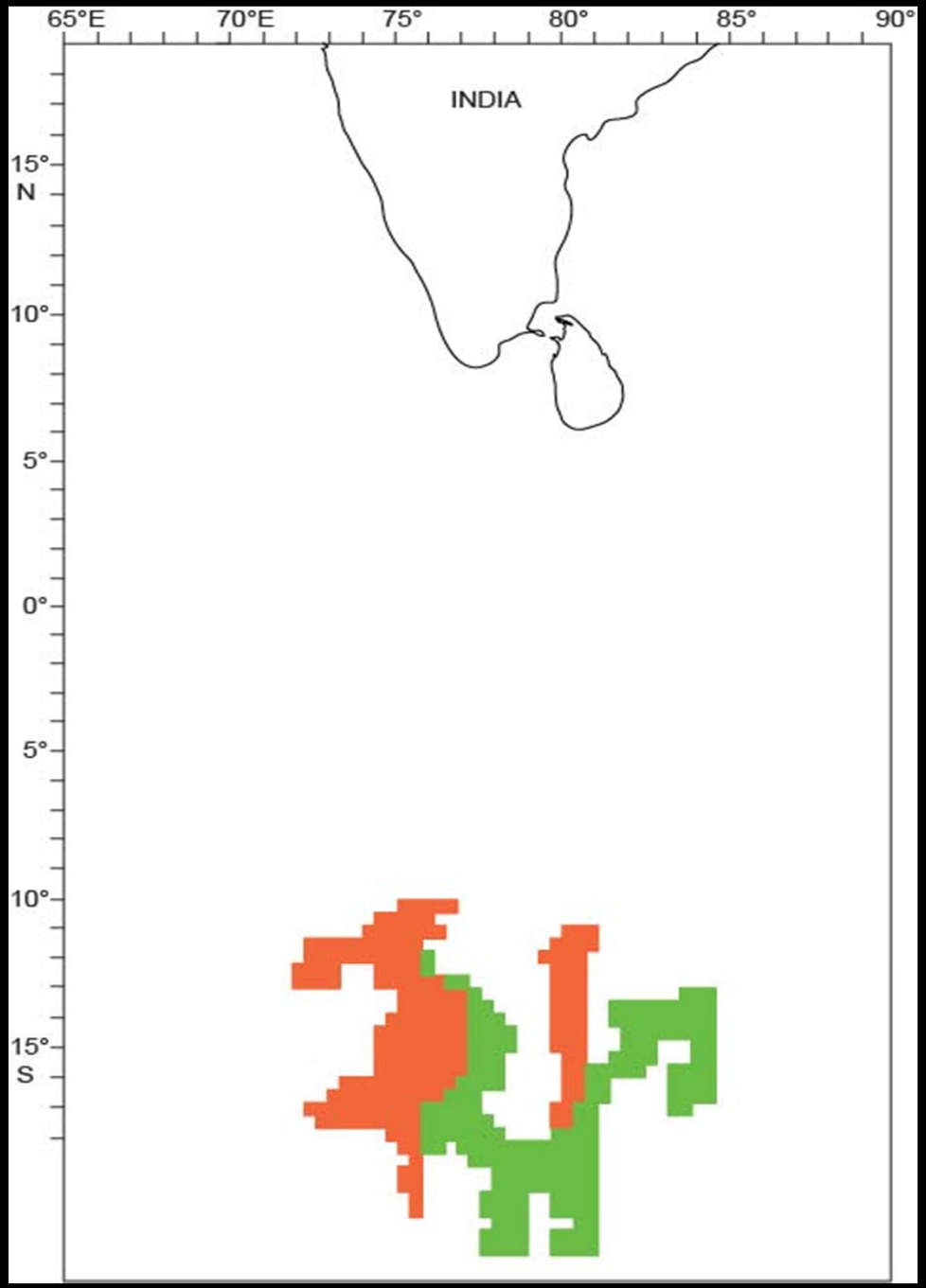
Bulk Sampling

Exploration … : **Echosounding, subbottom profiling**



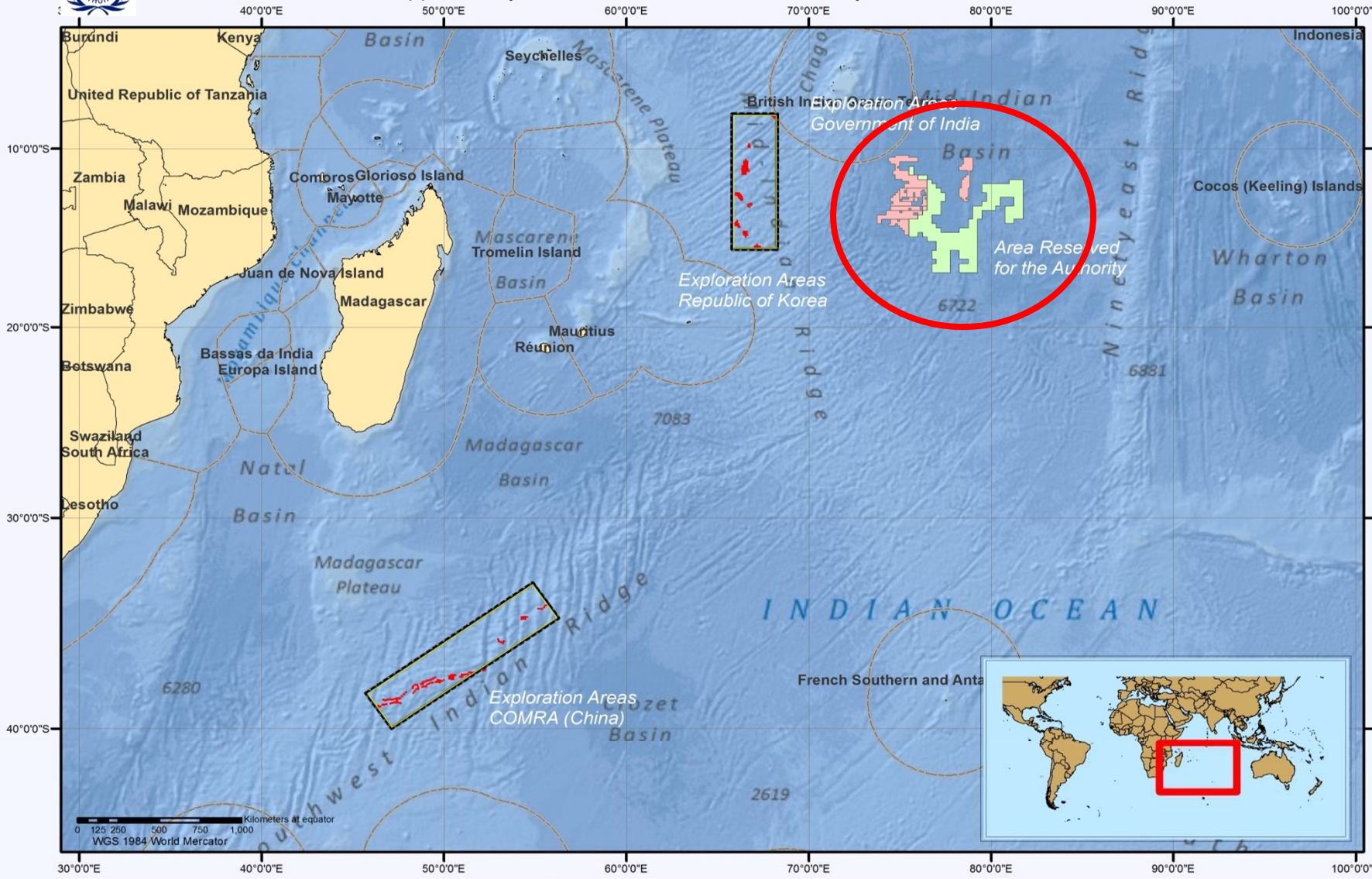
1987

Identification of Pioneer Area (orange) Reserved Area (green)



Polymetallic Nodules and Polymetallic Sulphides Exploration Areas in the Indian Ocean

Areas under contract or approved by the International Seabed Authority



Exclusive Economic Zones (VLIZ 2011)

Polymetallic Nodules Exploration Area

Area reserved for the Authority

Exploration block (approx. 10 x 10 km)

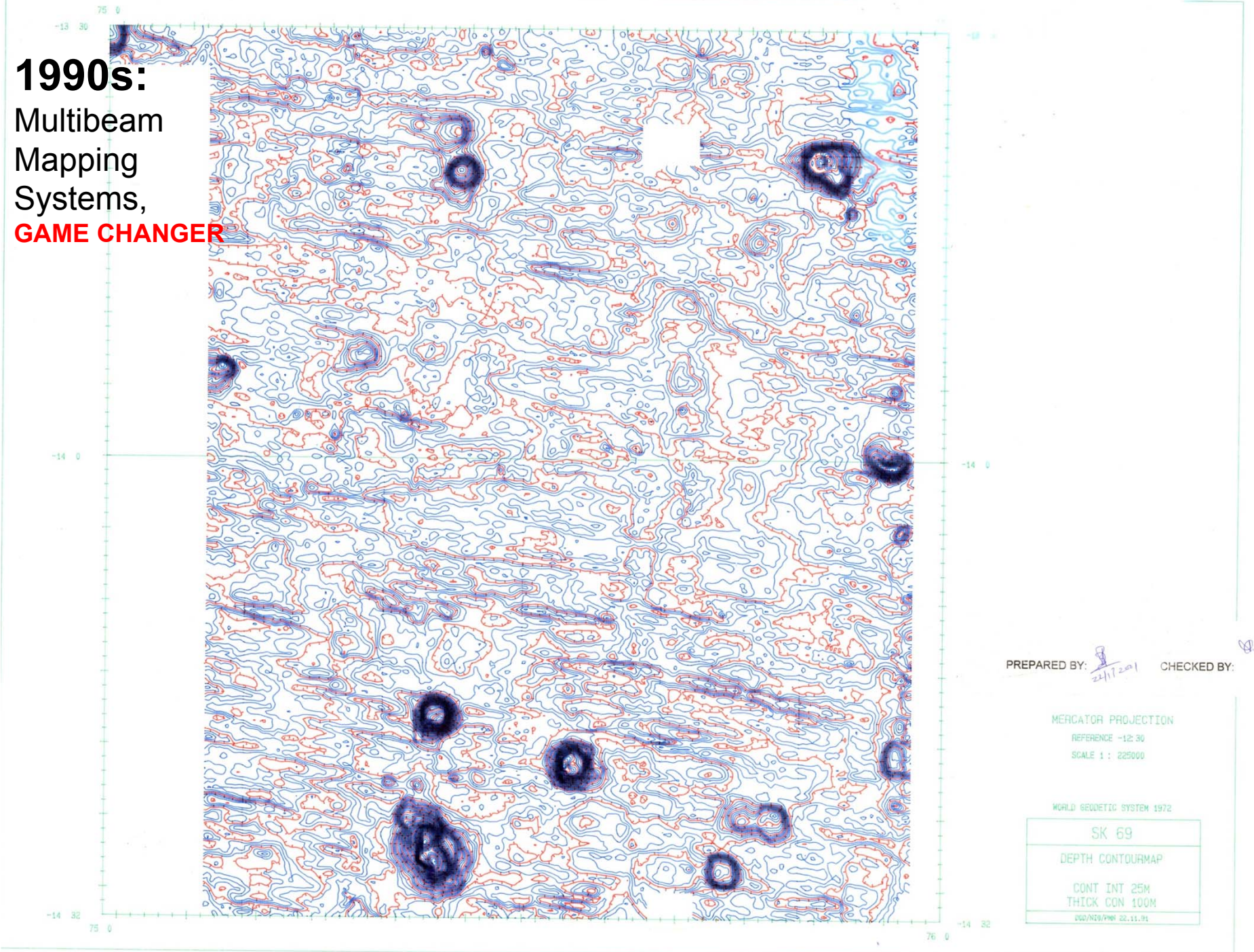
Confinement area containing 100 polymetallic sulphides exploration blocks*

* According to the Regulations on prospecting and exploration for polymetallic sulphides, a maximum of 100 exploration blocks (not exceeding 100 sq. km) must be arranged in clusters with at least five contiguous blocks. Custers need not to be contiguous, but shall be confined within a rectangular area, where the longest side does not exceed 1,000 km.

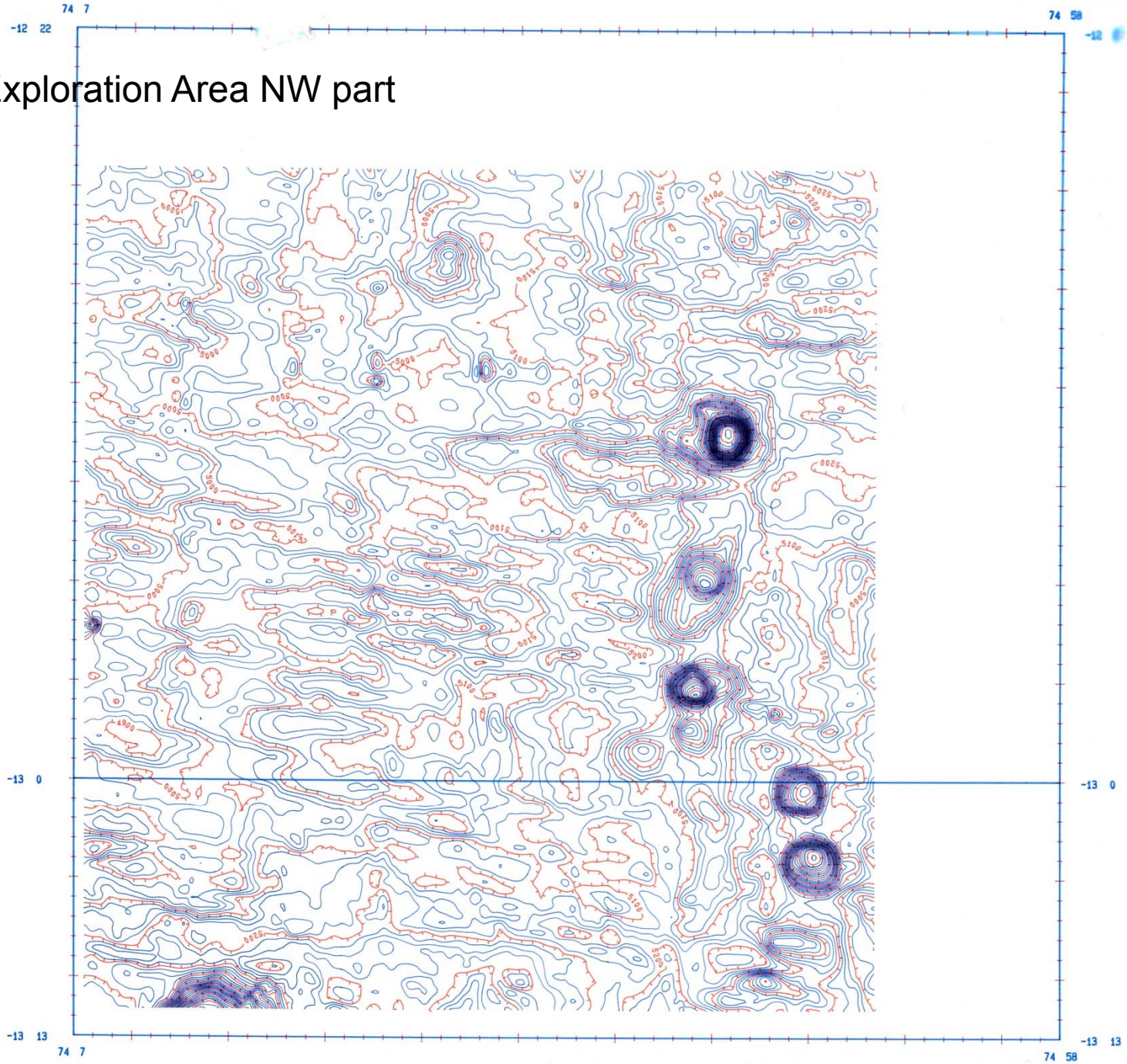
1990s:

Multibeam Mapping Systems,

GAME CHANGER



Exploration Area NW part



MERCATOR PROJECTION

REFERENCE + 0:00

SCALE 1 : 200000

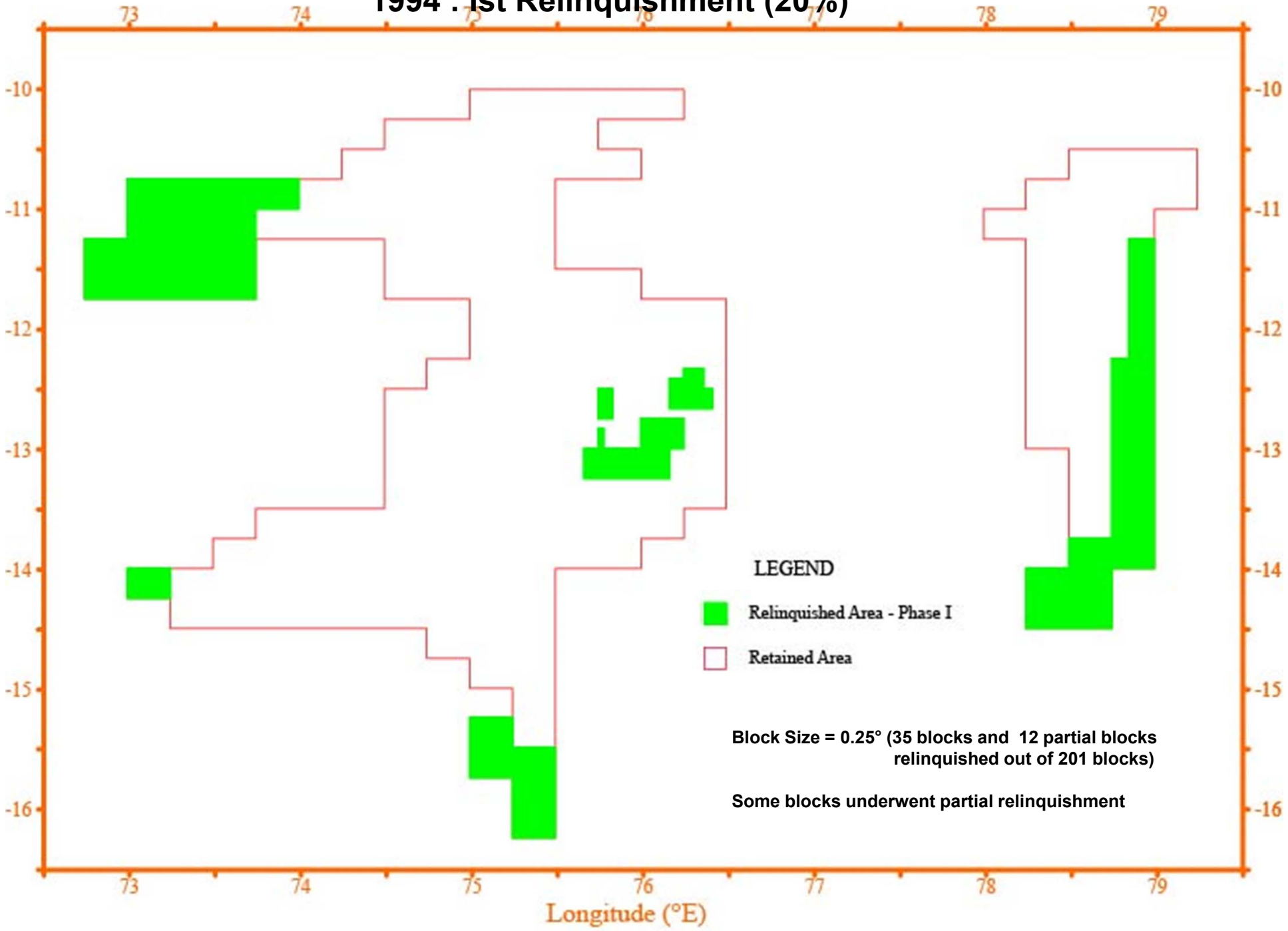
WORLD GEODETIC SYSTEM 1972

SK73E3

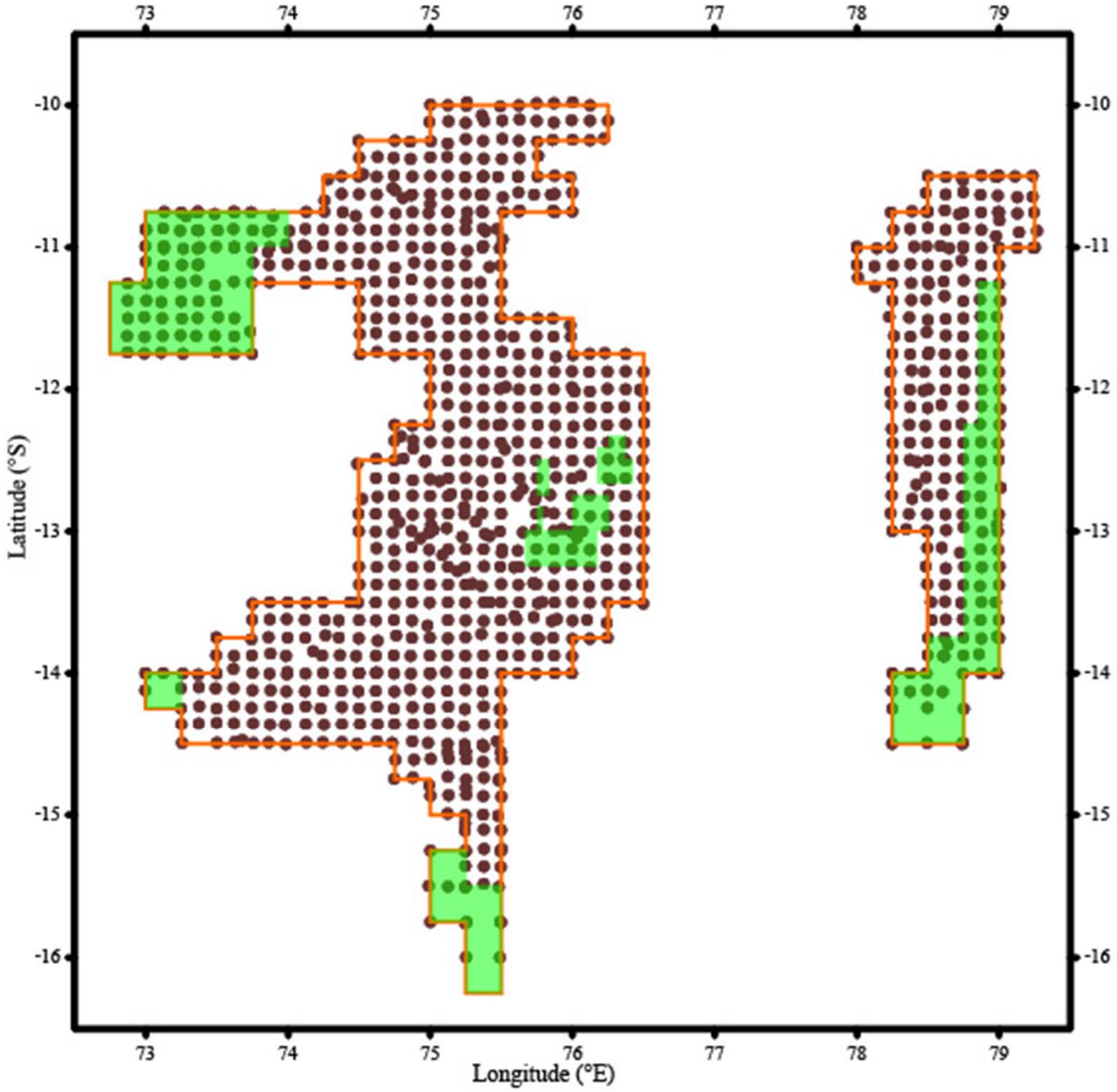
DEPTH CONTOUR MAP
CONTOUR INT. 25M
TICKED COTOUR 100M
APP. AREA A1

DOD/HIO/PMM 25. 5.92

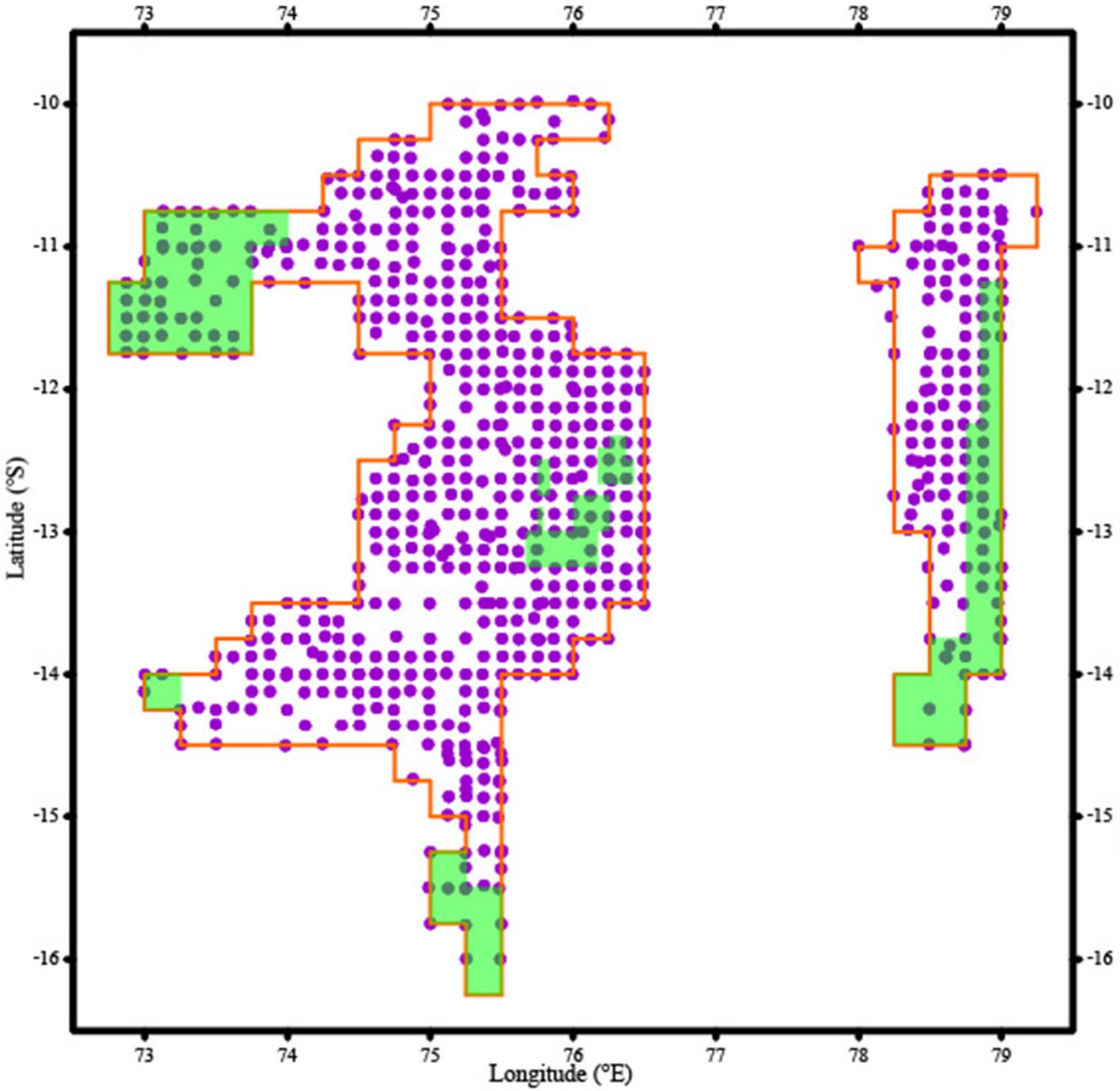
1994 : Ist Relinquishment (20%)

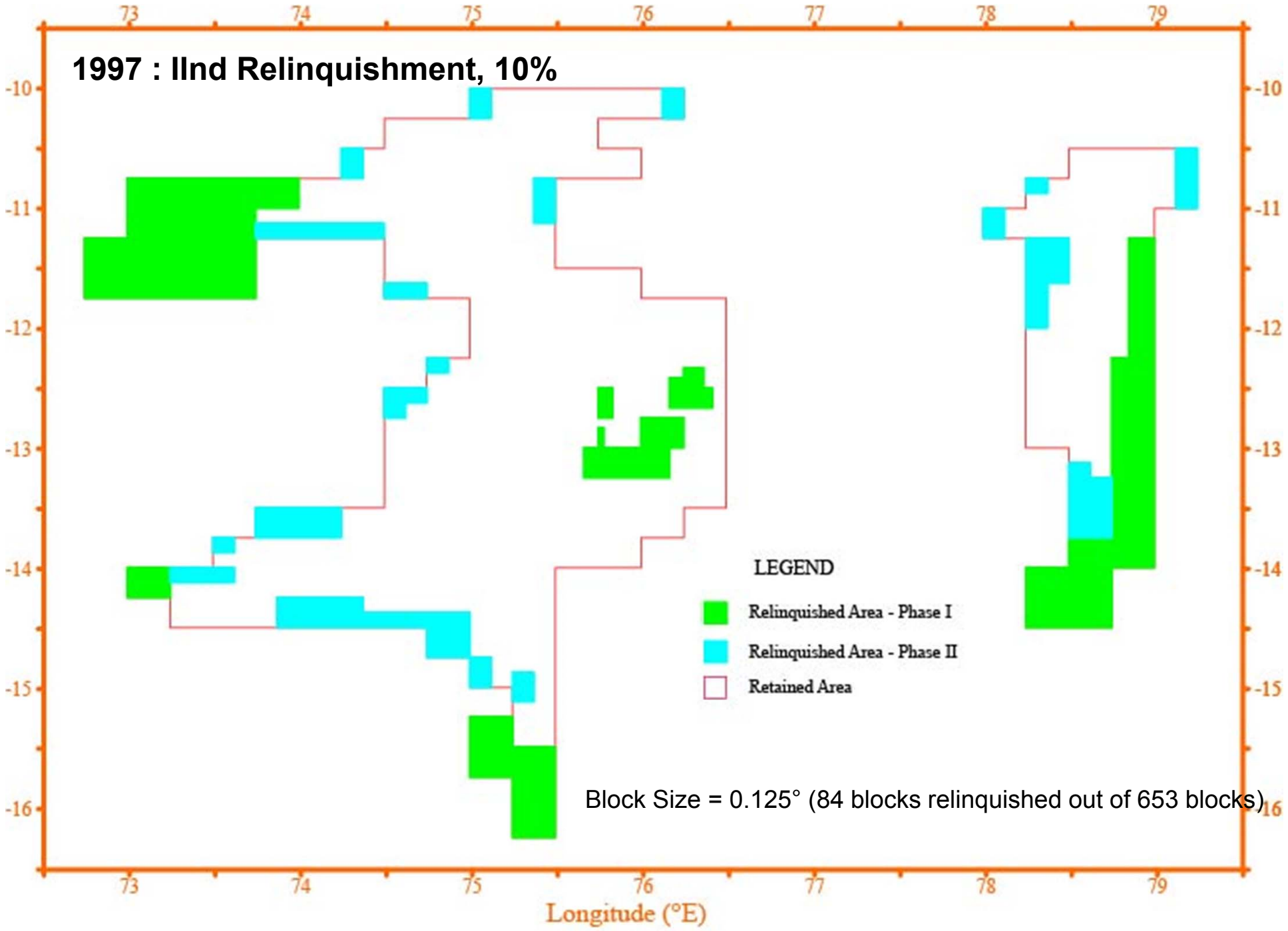


Sampling stations before IInd Relinquishment (0.125° grid; n=1025)

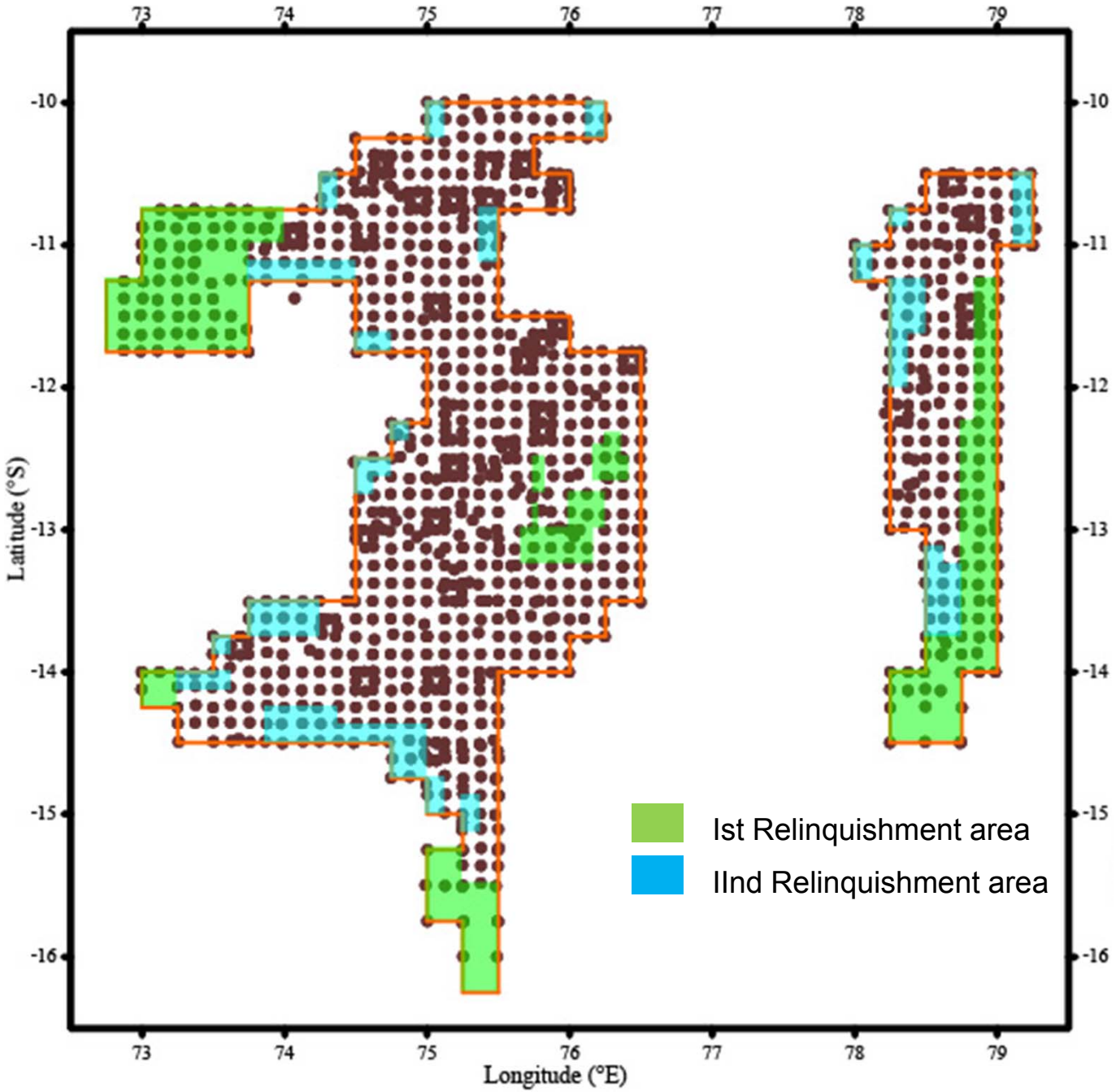


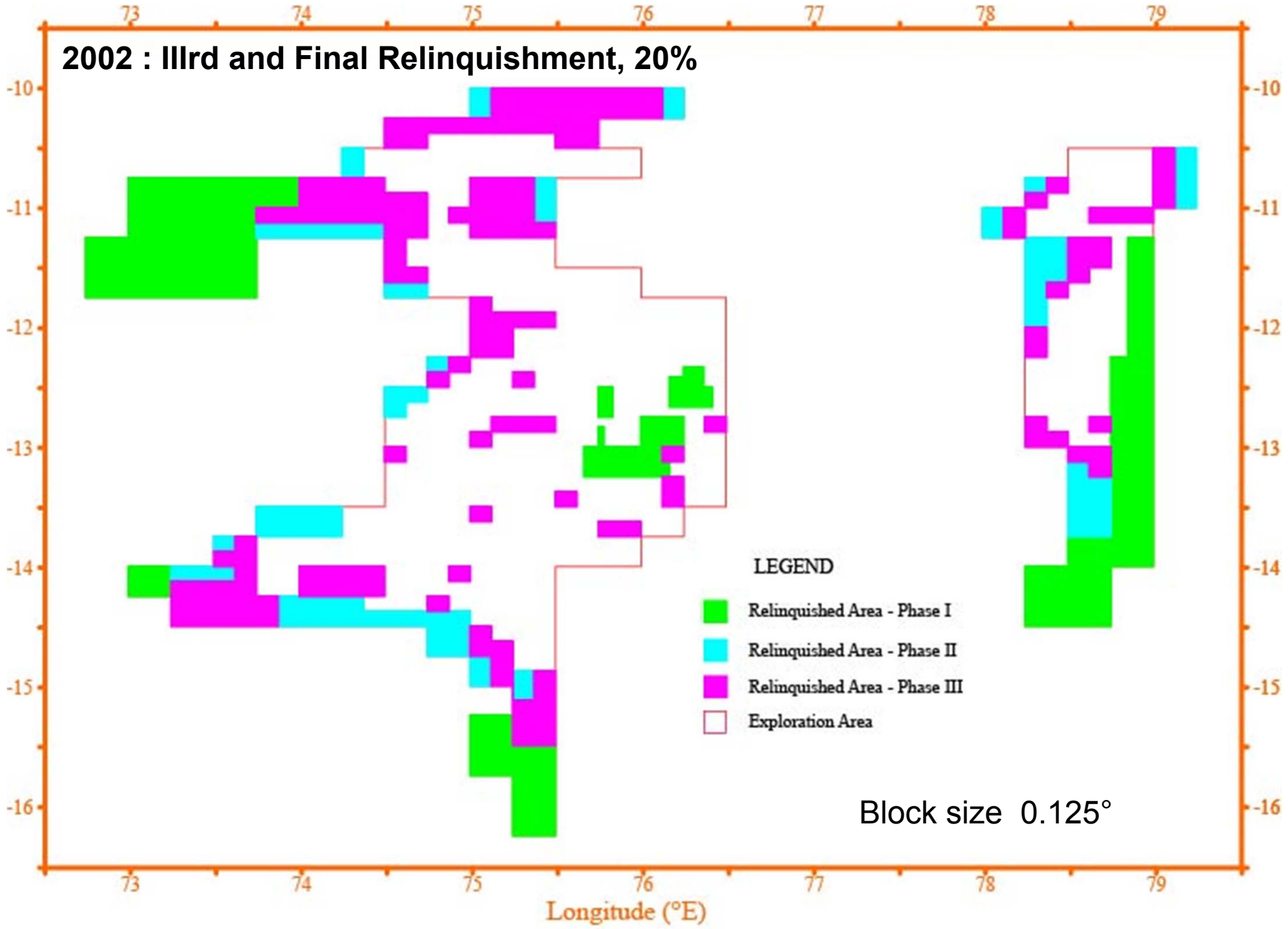
Chemical analysis stations before IInd Relinquishment (n=732)



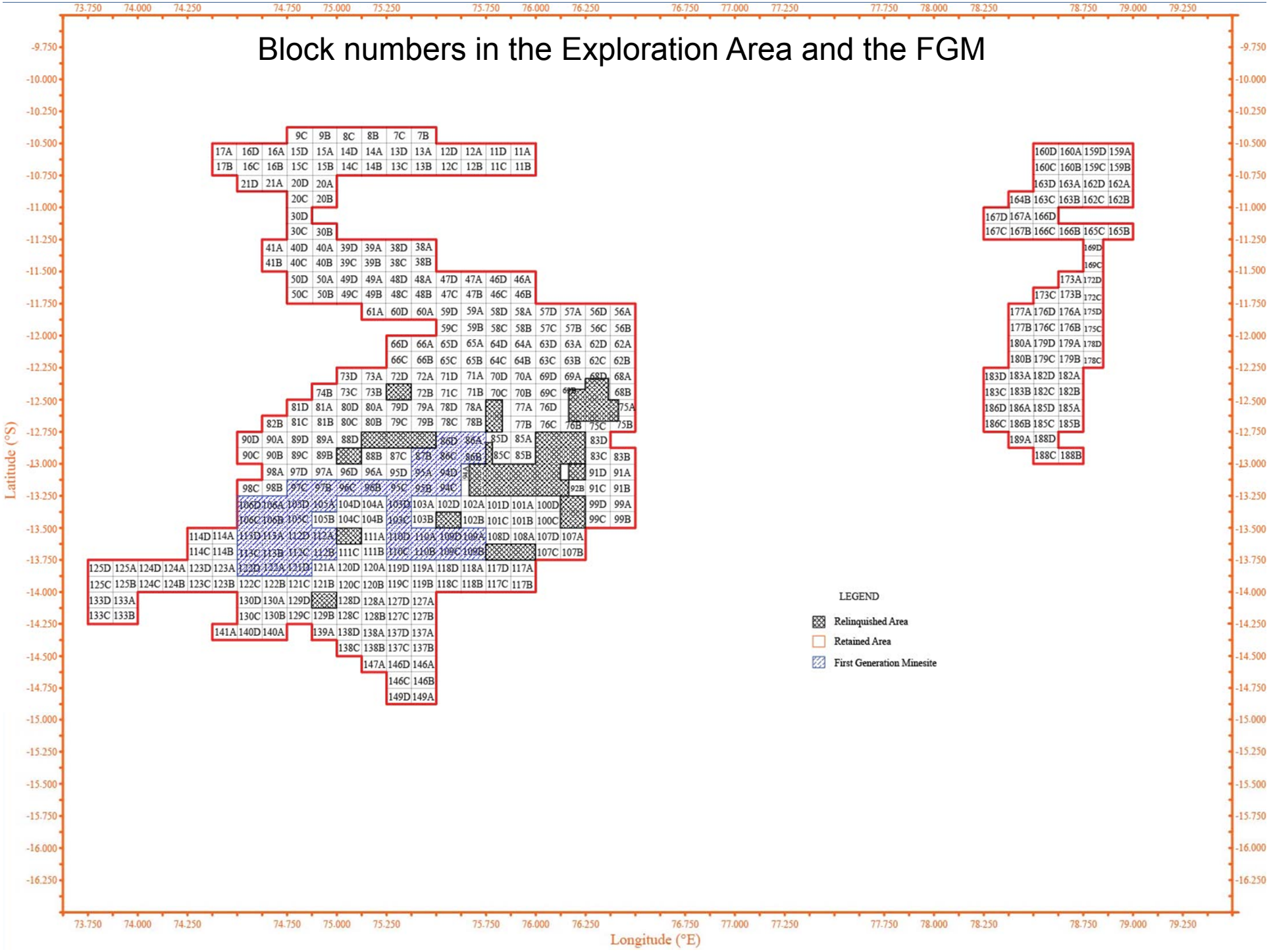

1997 : IInd Relinquishment, 10%
73
74
75
76
77
78
79
-10
-11
-12
-13
-14
-15
-16
LEGEND
Relinquished Area - Phase I
Relinquished Area - Phase II
Retained Area
Block Size = 0.125° (84 blocks relinquished out of 653 blocks)
Longitude (°E)

Sampling stations before final 20% relinquishment (n=1246)




2002 : IIIrd and Final Relinquishment, 20%
73
74
75
76
77
78
79
-10
-11
-12
-13
-14
-15
-16
LEGEND
Relinquished Area - Phase I
Relinquished Area - Phase II
Relinquished Area - Phase III
Exploration Area
Block size 0.125°
Longitude (°E)

Block numbers in the Exploration Area and the FGM



Ist Gen Mine Site

Pathway :

- Identify a candidate area
- Close-grid Sampling
- High resolution mapping
- Resource Evaluation

Establishment of Criteria for Mine Site

A) RESERVE CONTENT

- The mine site should be able to sustain a process plant for 20 years

B) EXTENT OF EXPLORATION

- Should have at least 20% of the area sampled at close grid (i.e at 0.0625° or ~7 Km grid) interval

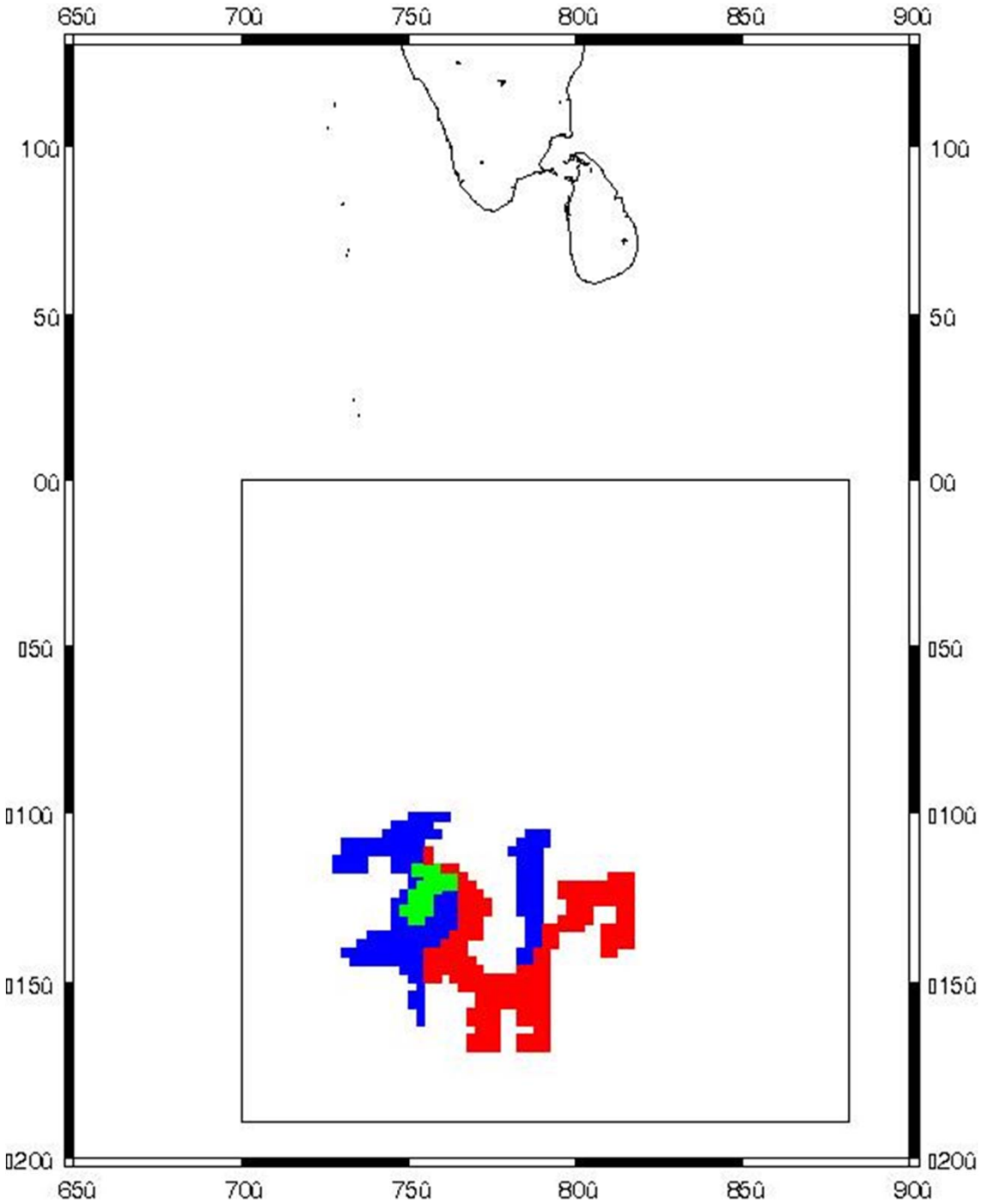
C) TOPOGRAPHIC INFORMATION

- Available topographic information should indicate minimal area occupied by sea mounts and adverse topography

Pioneer Area :

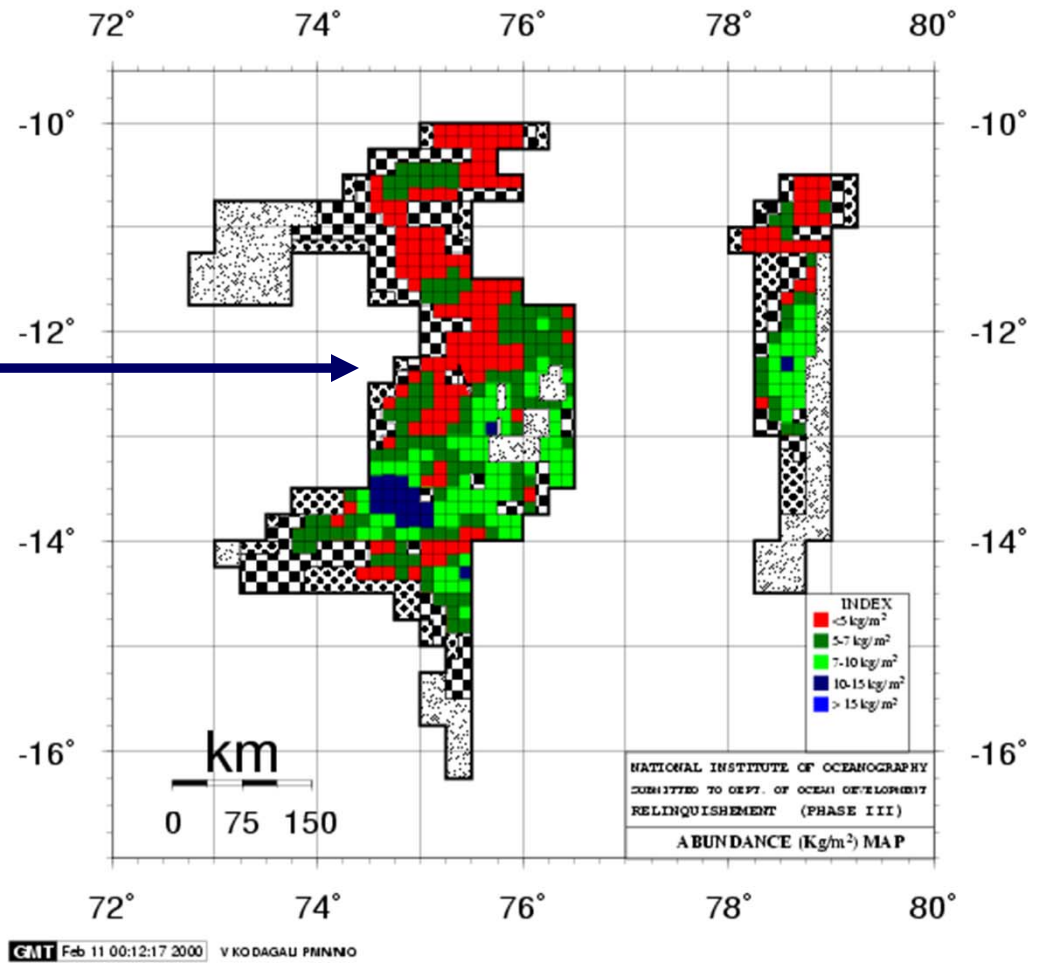
Reserved Area:

First gen. mine
Site candidate
Area (18400 km^2):



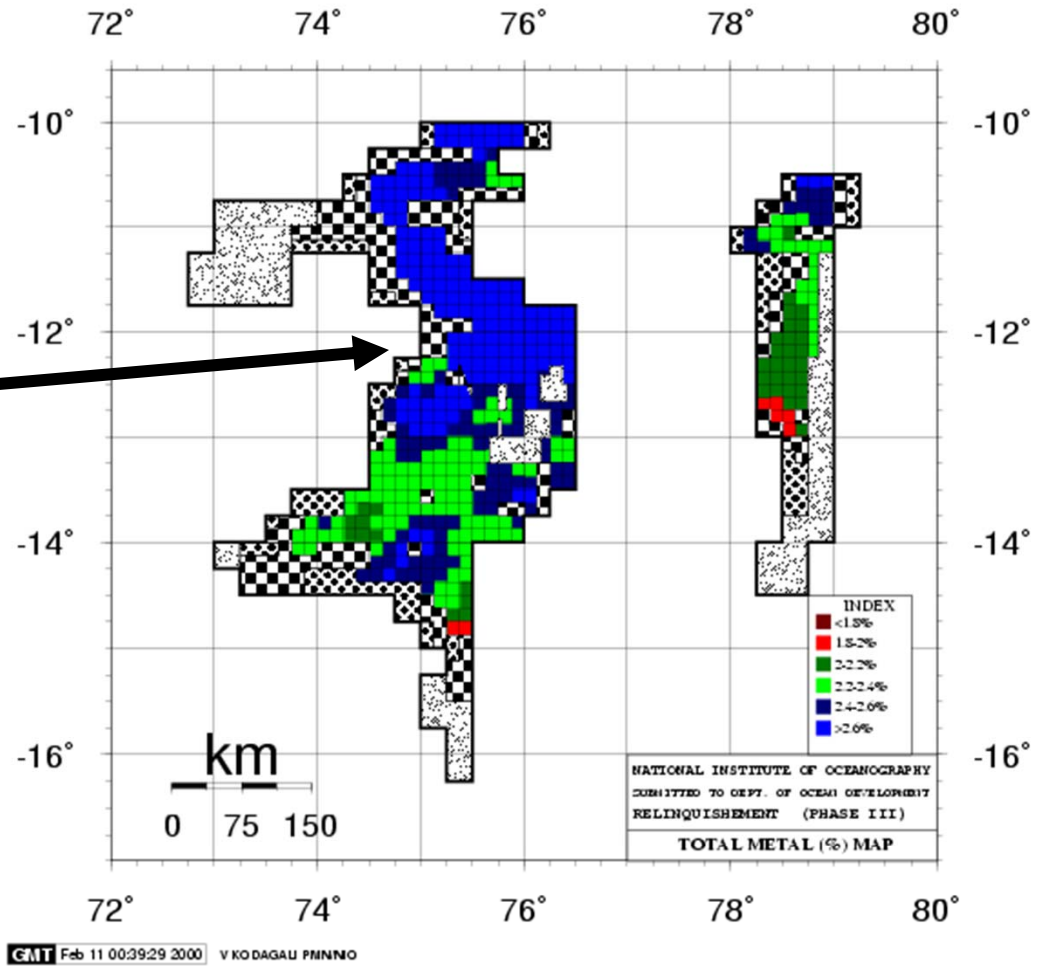
Pioneer Area Block wise Abundances Kg/m^2

- Consistently high abundances
- Contiguous blocks
- Highest grade

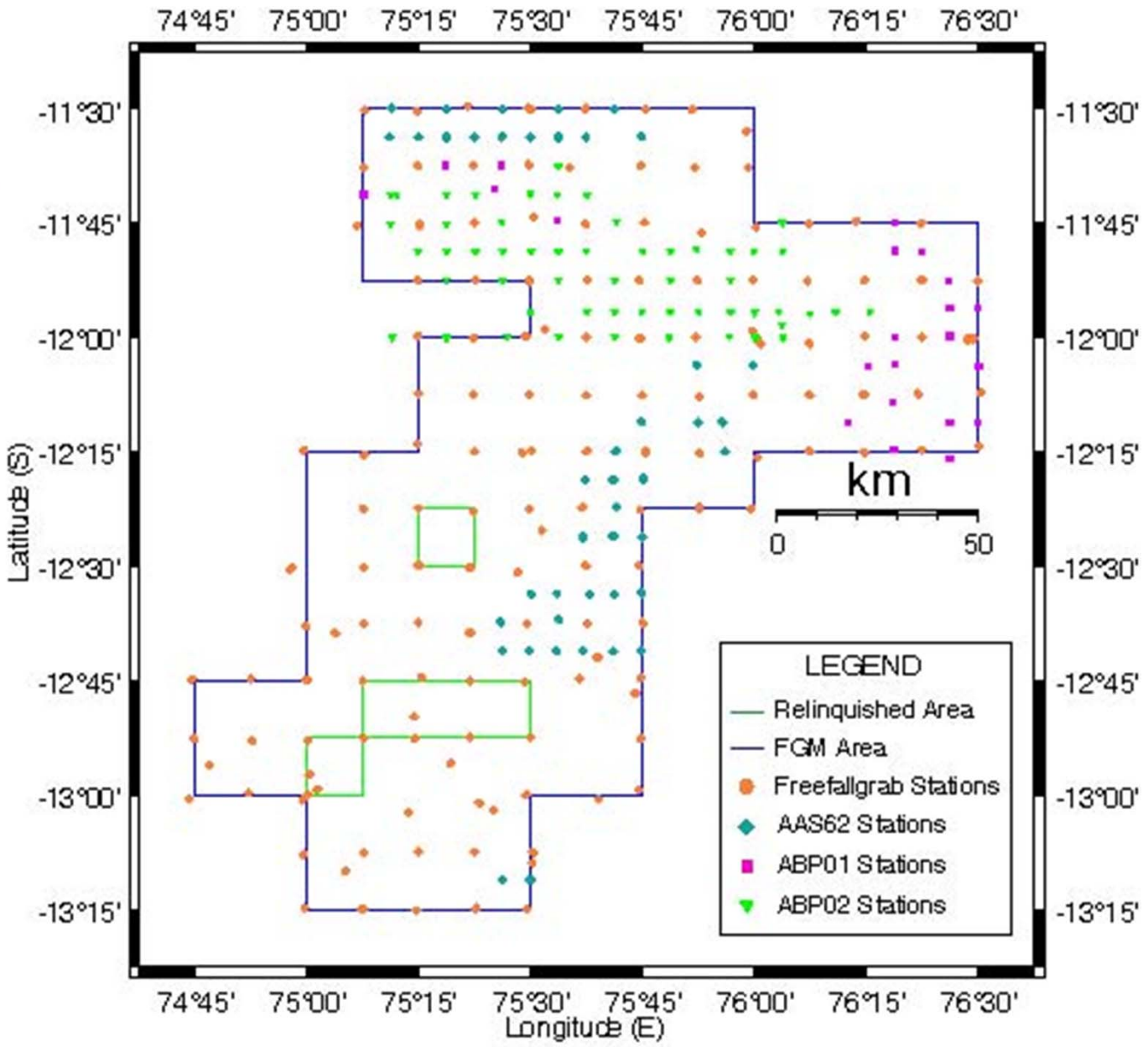


Pioneer Area Grade map

Metal contents
In the Retained
Area
Cu + Ni + Co



58 BLOCKS COVERED BY 0.0625° (~7 KM) GRID SAMPLING



Relative ranking of blocks

- Each block was assigned a rating(R) between -2 to +2 (including 0), for all the parameters
- Nett score for each of the 411 blocks was computed as

$$\text{Overall Score} = \sum_{i=1}^{5} W_i R_i$$

Where Wi = Weight assigned for parameters and
Ri = Rating for the block for parameters.

Parameter	Weightage
No. of contours	200
Area of Seamounts	100
Local gradients	100
Abundance (kg/sq.m)	300
Grade (Cu+Ni+Co)	300
	1000

- The blocks were finally ranked based on their nett score.

Ranking of blocks for FGM identification

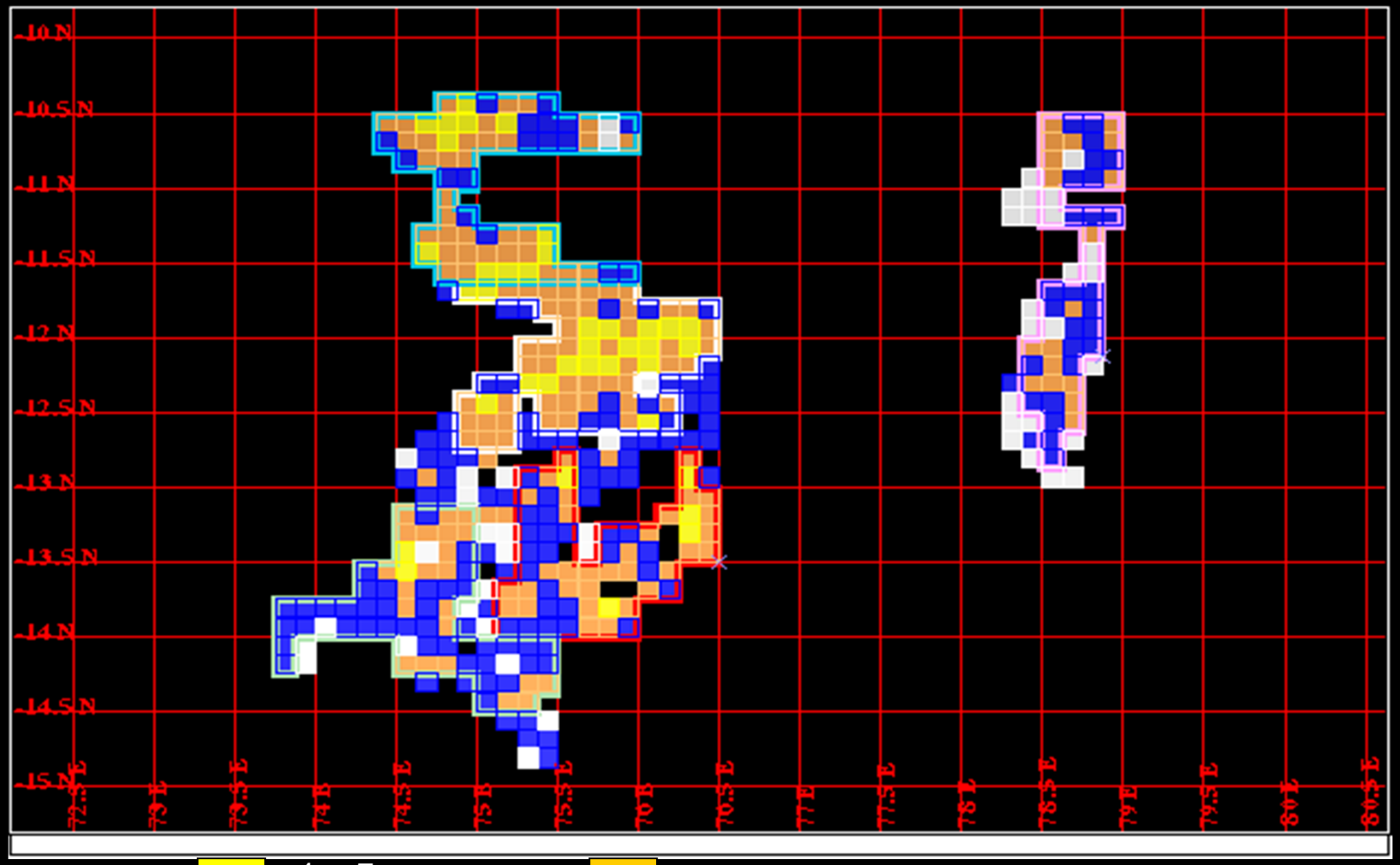
- The blocks further categorised (1 to 20) and finally into four groups of blocks which were colour coded yellow (best), orange, deep blue and white (poorest) to help identify clusters.

Categories	Group	No of Blocks
I	1 to 5	1 to 53
II	6 to 10	54 to 234
III	11 to 15	235 to 395
IV	16 to 20	395 to 411

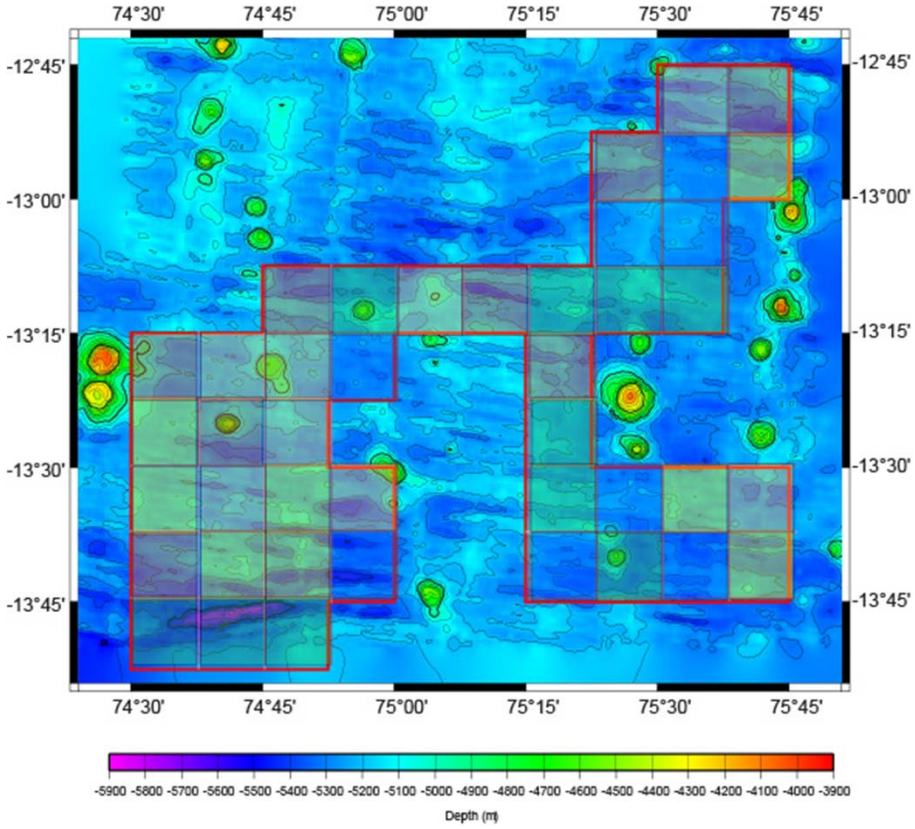
- After colour coding the blocks, the entire retained area was visually scanned to identify clusters of rich (yellow) blocks

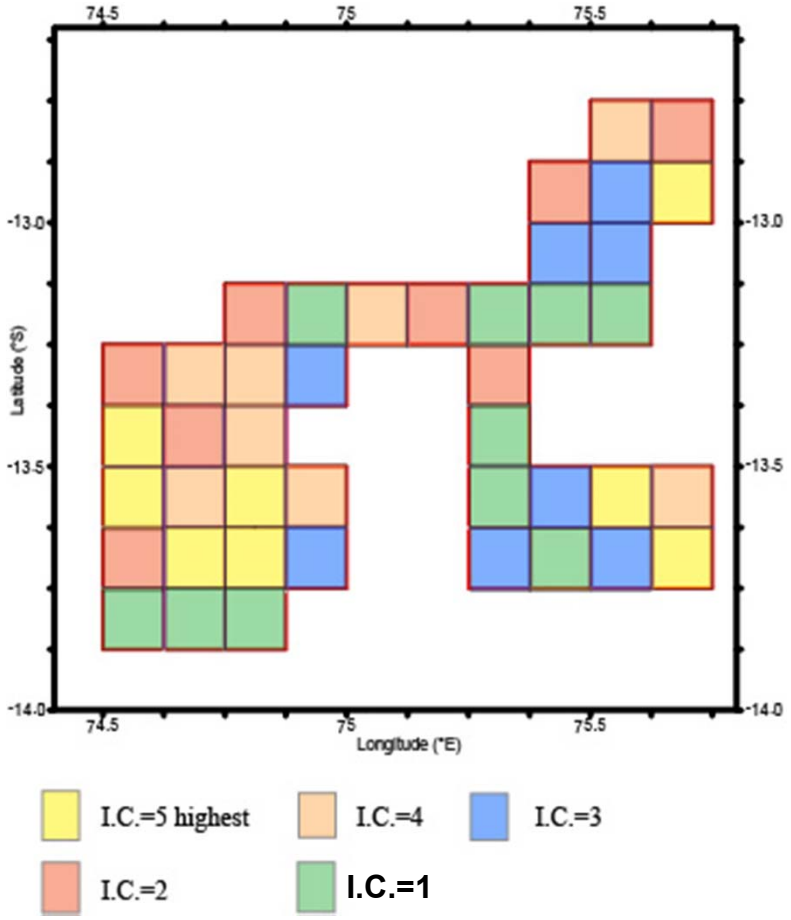
- Such clusters were identified to zero in on the First Generation Mine Site

Retained Area Showing the colour coded blocks



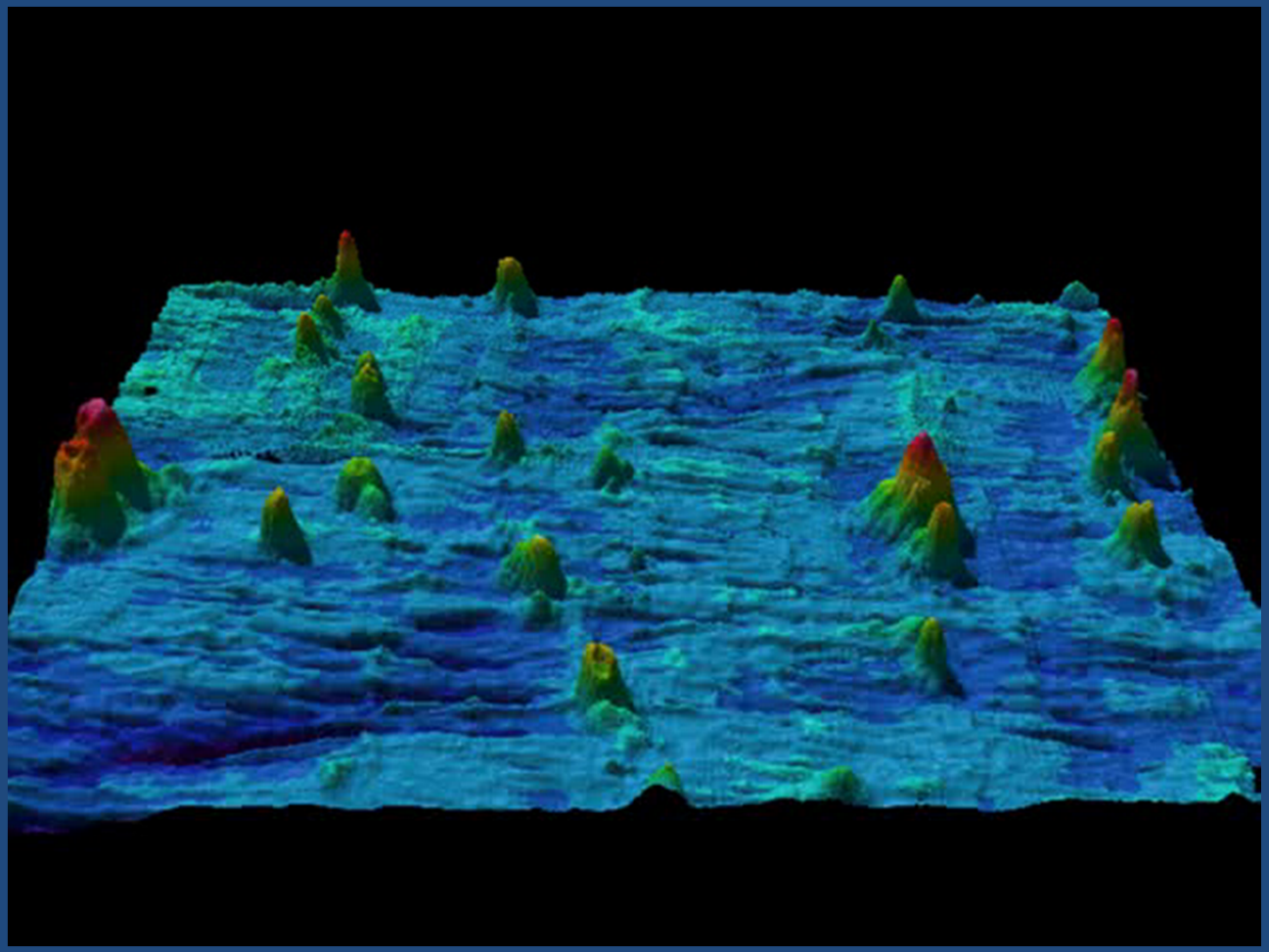
First Generation Mine Site
(42 blocks 0.125° grid)





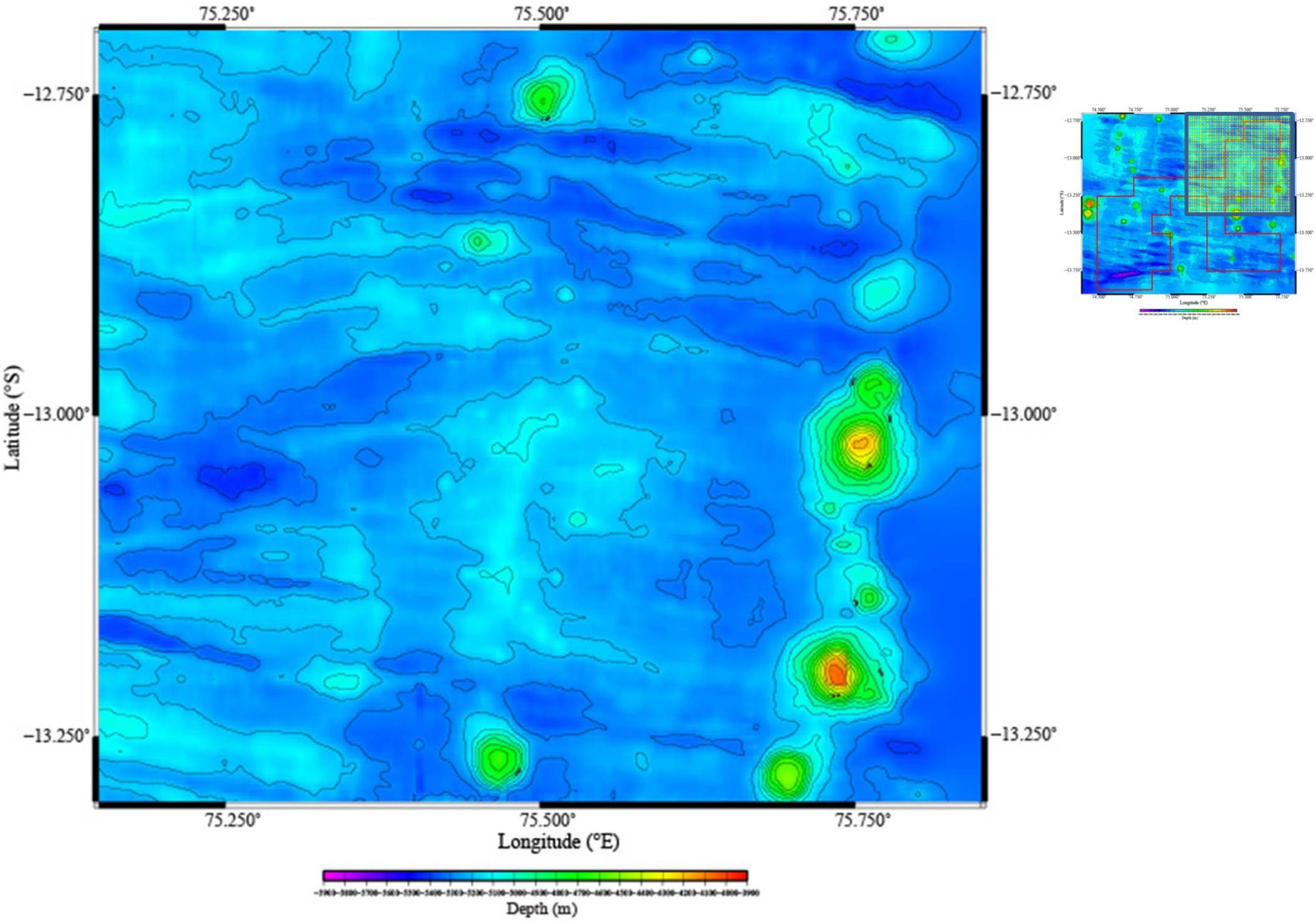
Exaggeration Factor:
12 times

Profile Paths:
Southwest-Northwest
Northwest-Northeast
Northeast-Southeast
Southeast-Southwest
Southwest-Northeast
Northeast-Northwest
Northwest-Southeast
Southeast-Southwest

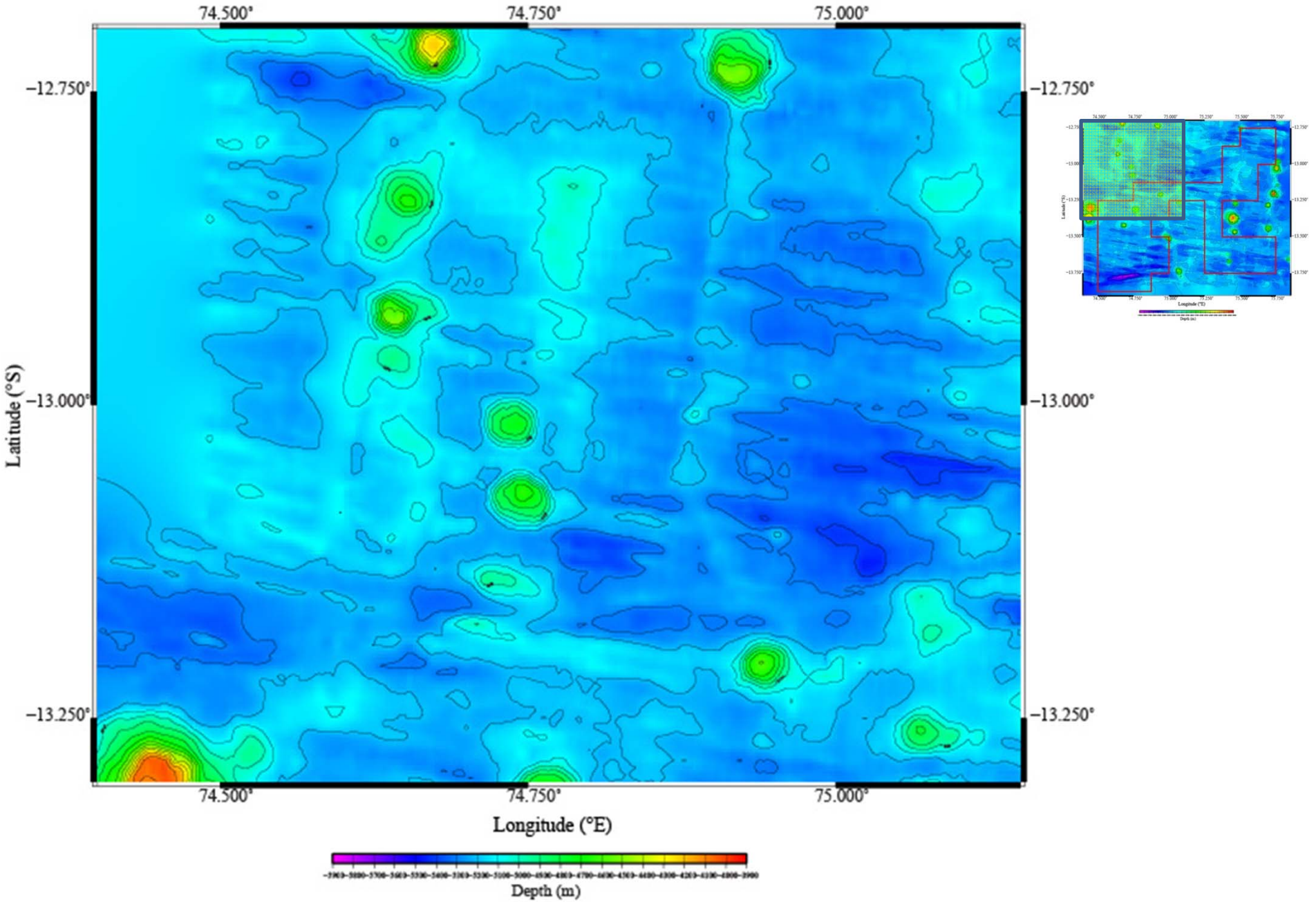


Present FGM Virtual Flythru

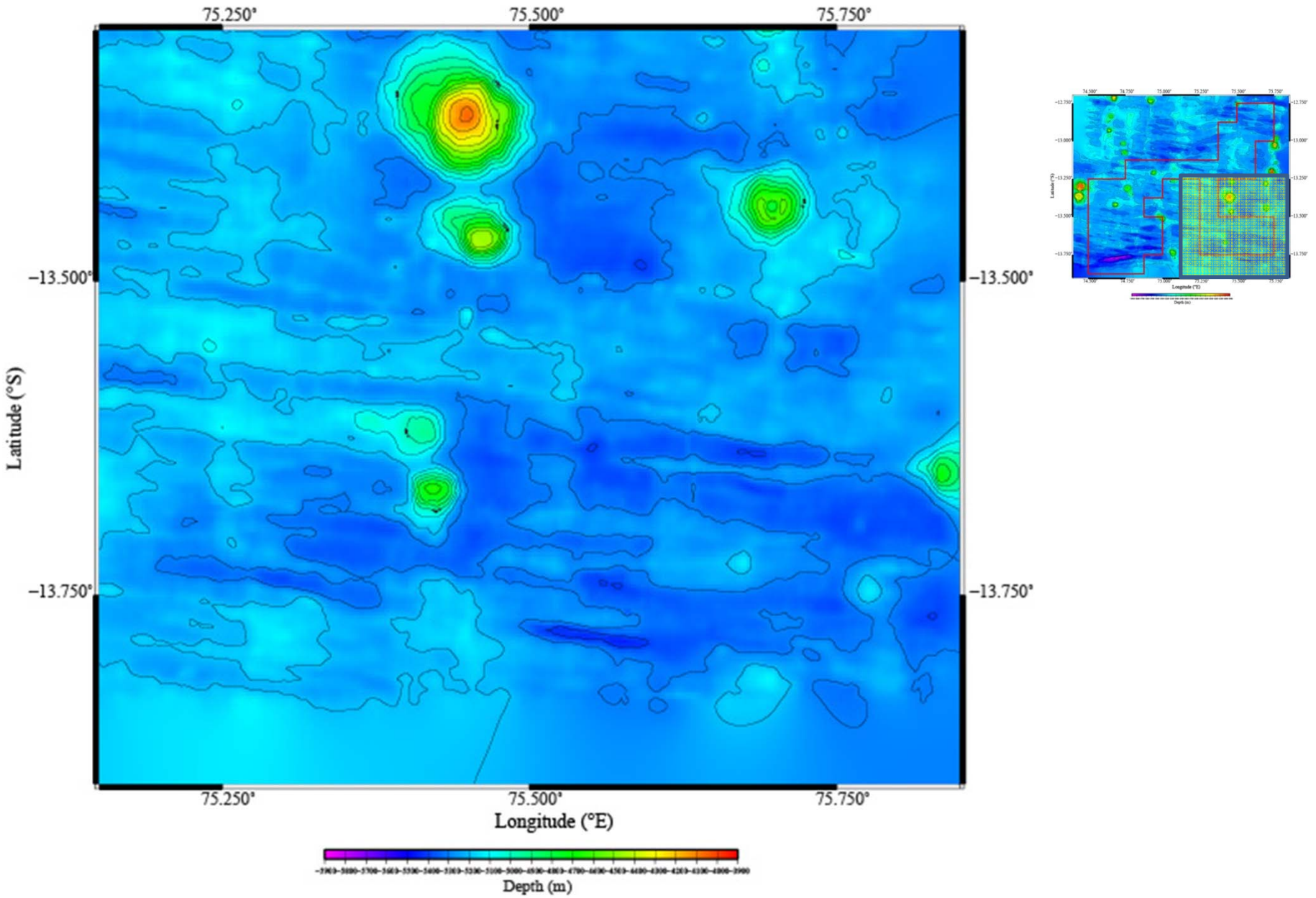
FGM - NE


75.250°
75.500°
75.750°
−12.750°
−13.000°
−13.250°
Latitude (°S)
Longitude (°E)
Depth (m)

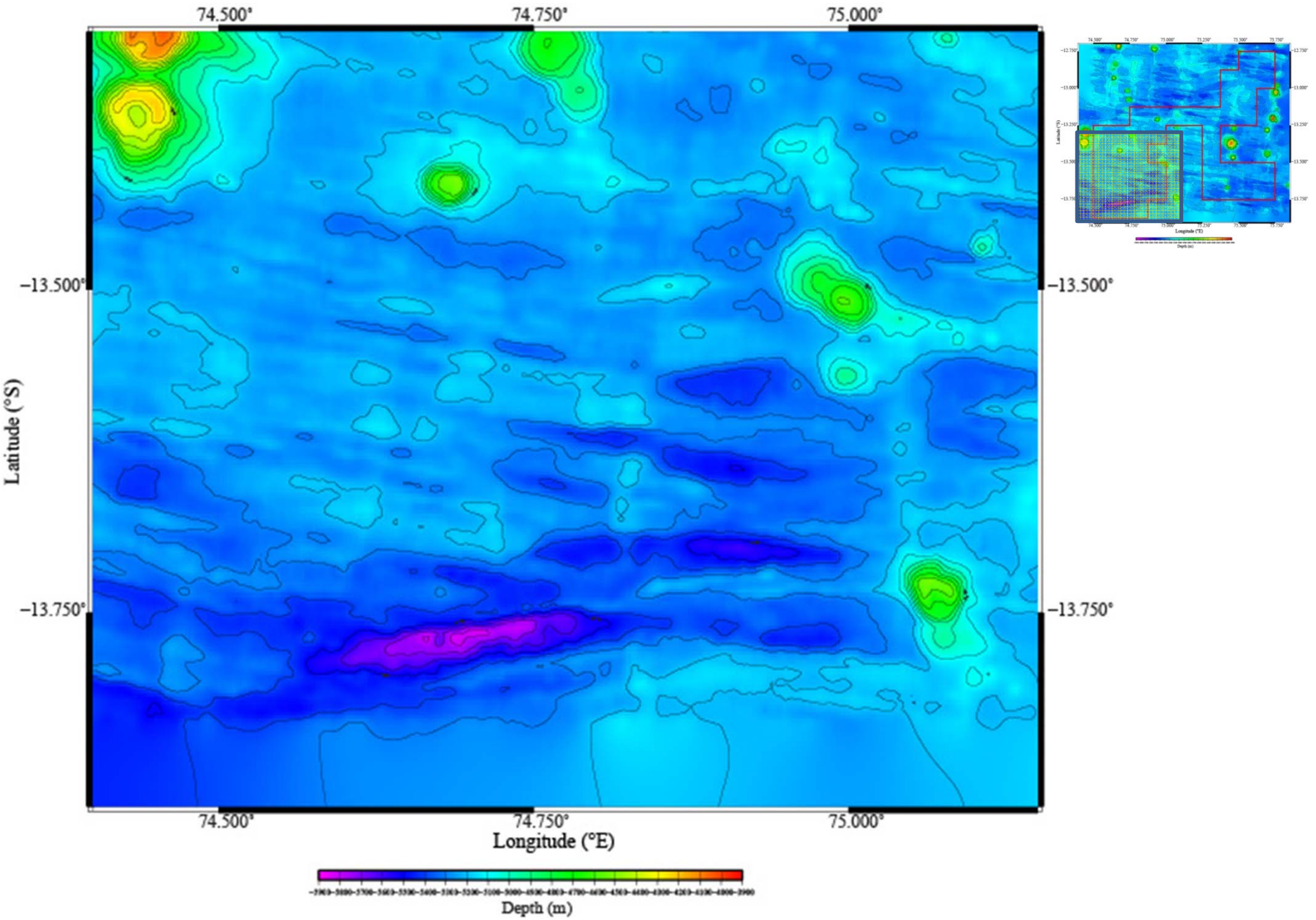
FGM NW

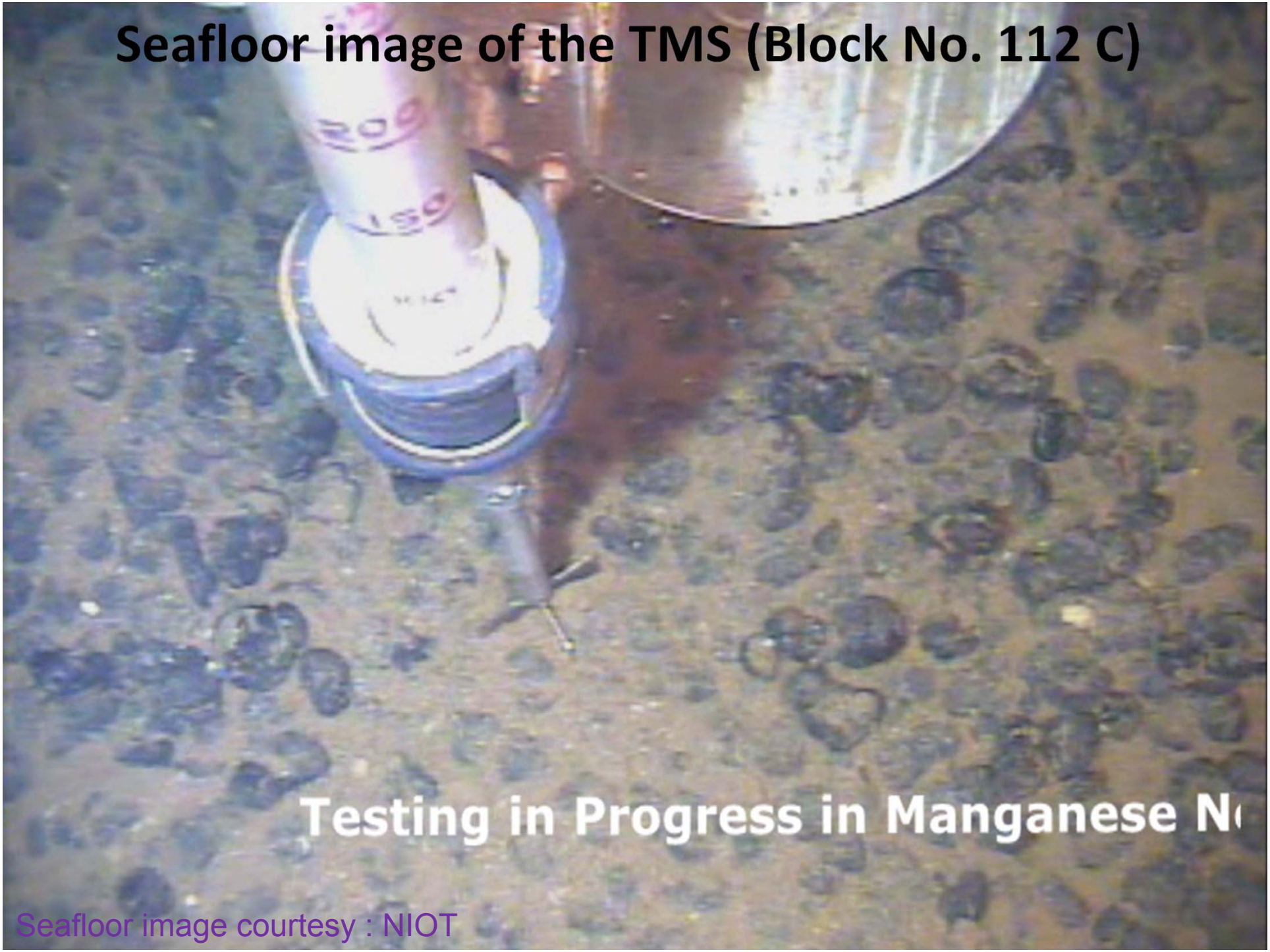

74.500°
74.750°
75.000°
−12.750°
−13.000°
−13.250°
Latitude (°S)
Longitude (°E)
Depth (m)

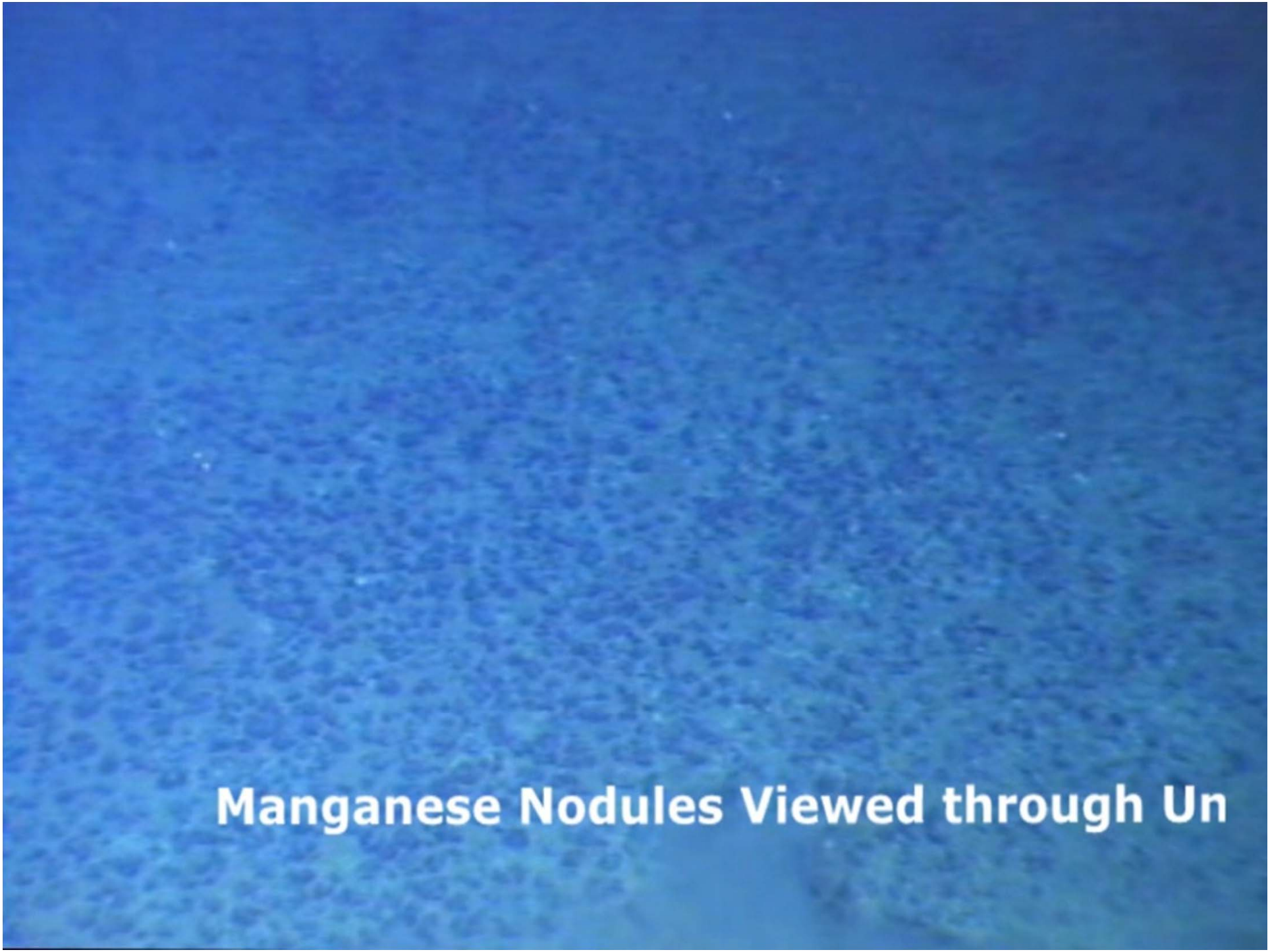
FGM SE

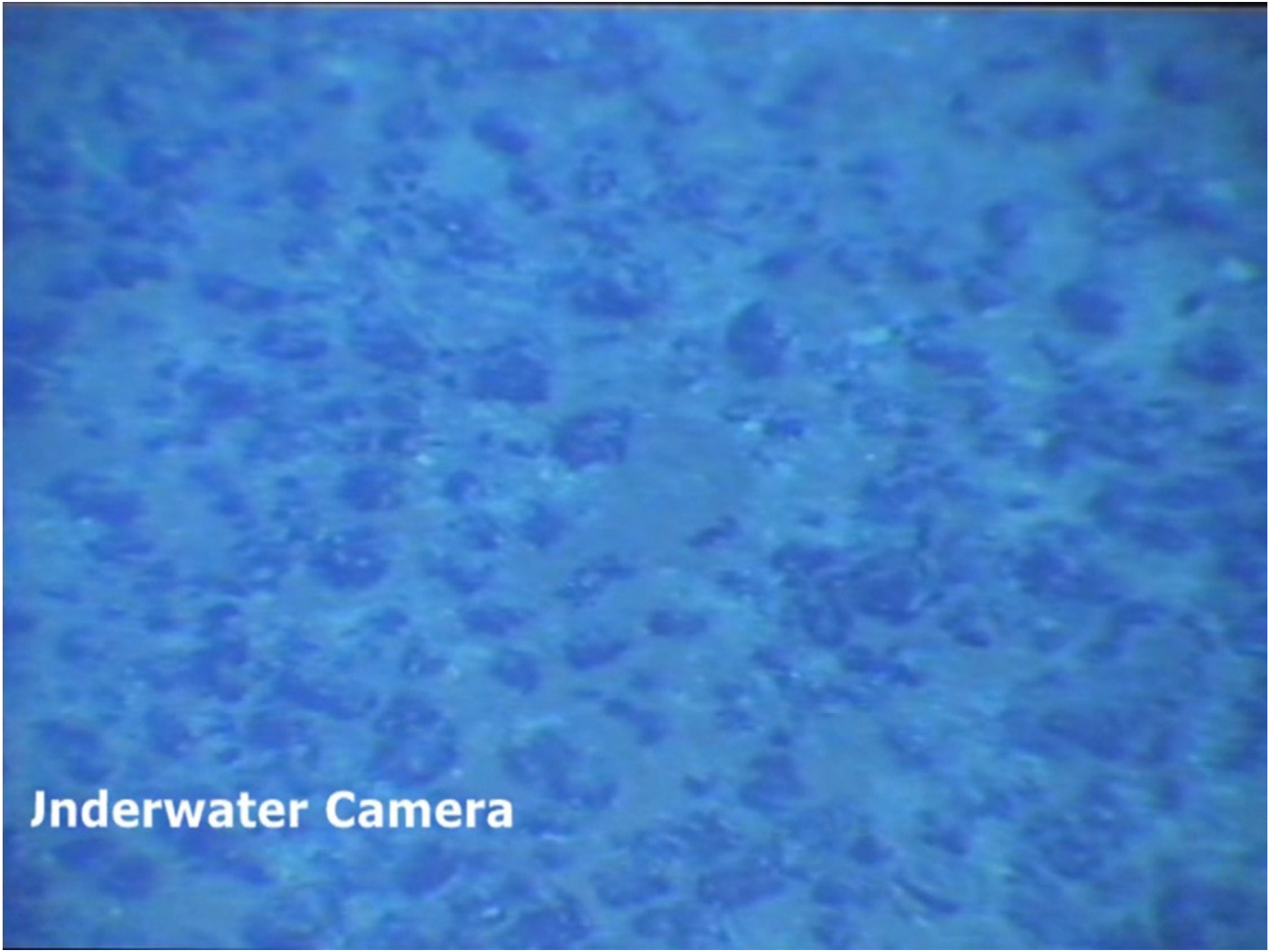

75.250°
75.500°
75.750°
−13.500°
−13.750°
Latitude (°S)
Longitude (°E)
Depth (m)

FGM SW


74.500°
74.750°
75.000°
−13.500°
−13.750°
Latitude (°S)
Longitude (°E)
Depth (m)


Seafloor image of the TMS (Block No. 112 C)
Testing in Progress in Manganese N
Seafloor image courtesy : NIOT


Manganese Nodules Viewed through Un


Jnderwater Camera

Seafloor image courtesy : NIOT

Identification of Test Mine Site(TMS)

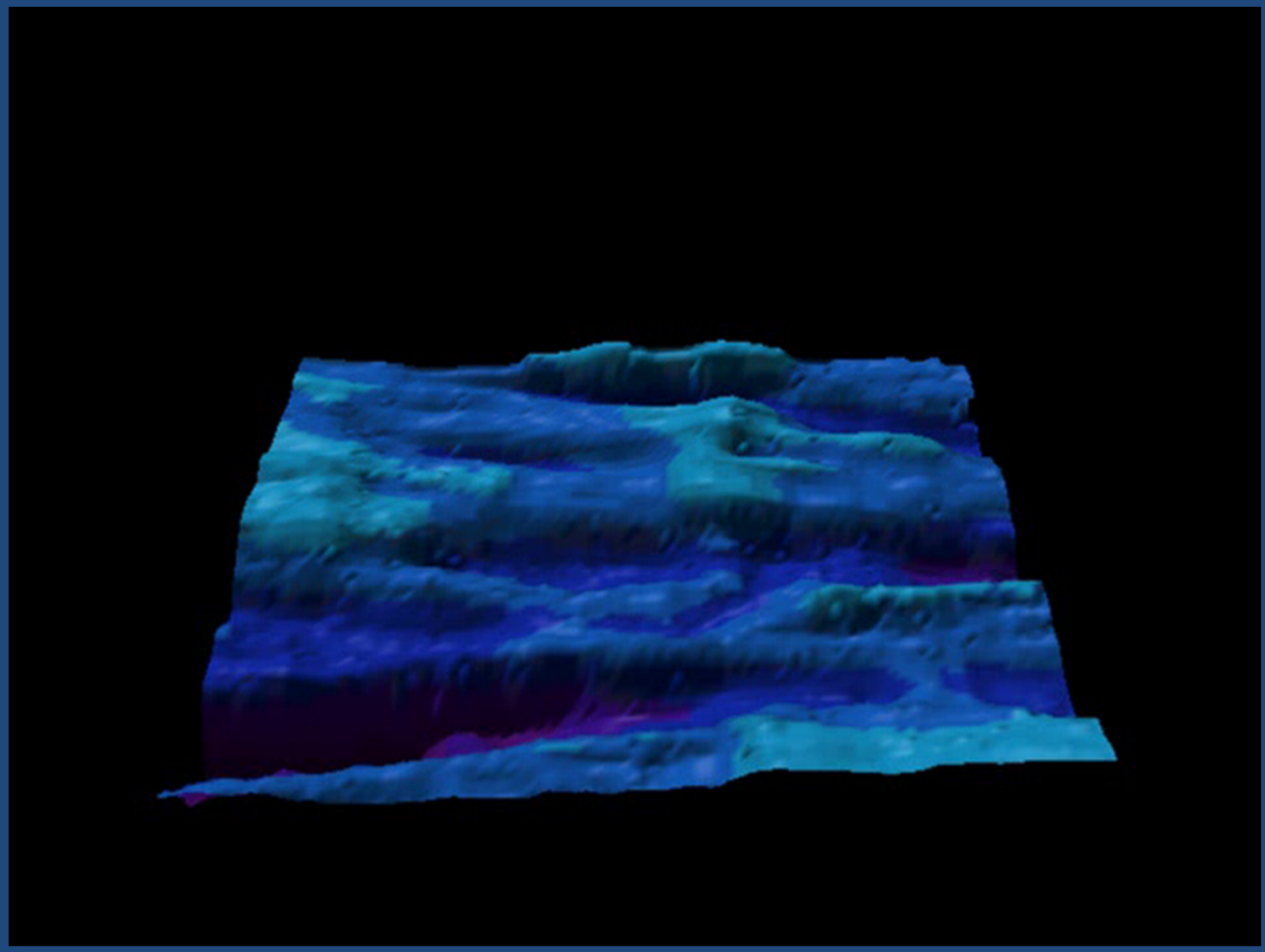
- Ranking of blocks of the FGM, and identify one block of 0.125° X 0.125° (i.e. ~14 km x 14 km)

Criteria for ranking -

1. Bathymetry (weightage high 500)
2. Abundance (weightage 250)
3. Grade (weightage 250)

Exaggeration Factor:
6 times

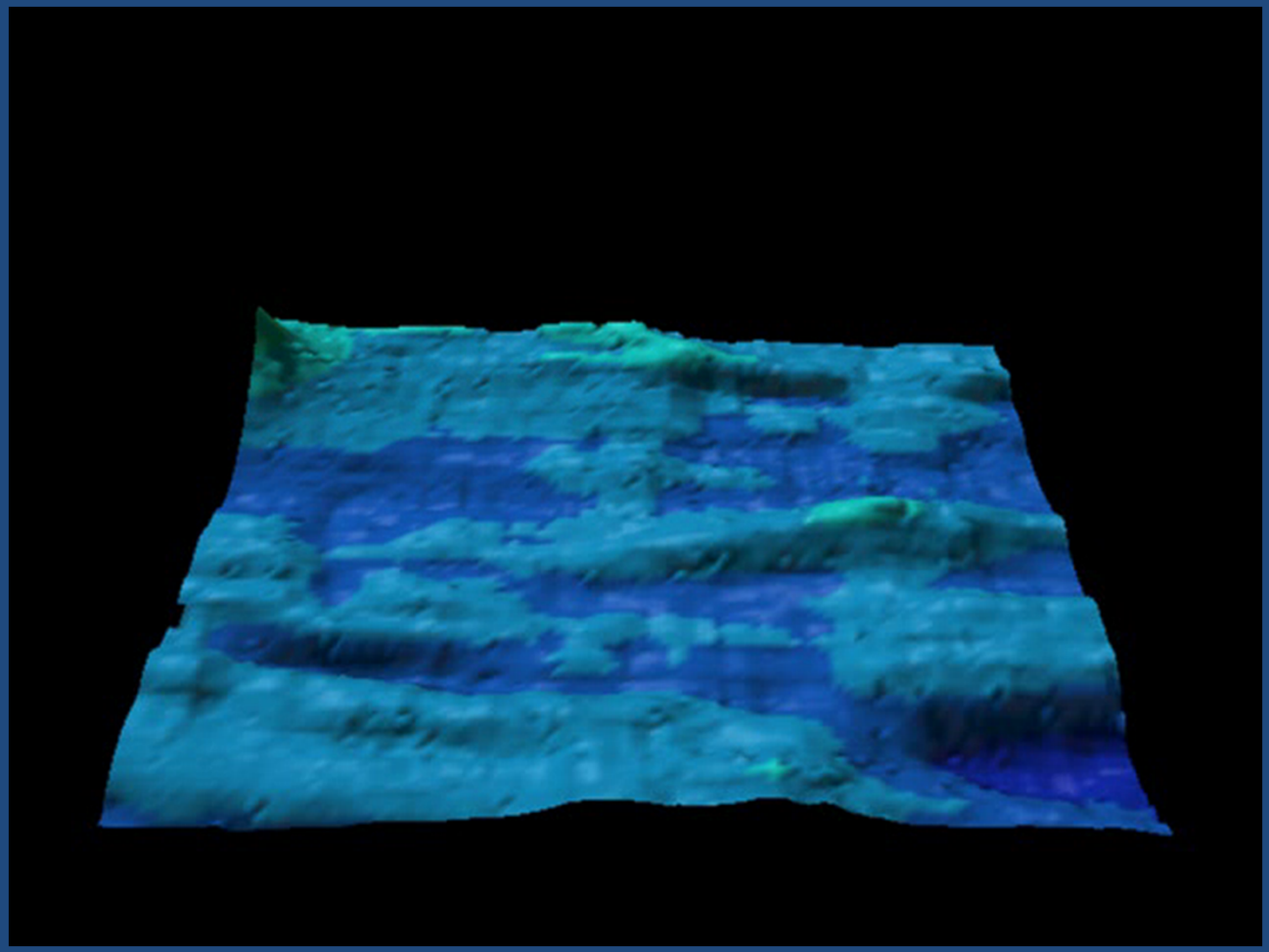
Profile Paths:
Southwest-Northwest
Northwest-Northeast
Northeast-Southeast
Southeast-Southwest
Southwest-Northeast
Northeast-Northwest
Northwest-Southeast
Southeast-Southwest



Block in FGM : Virtual Flythru

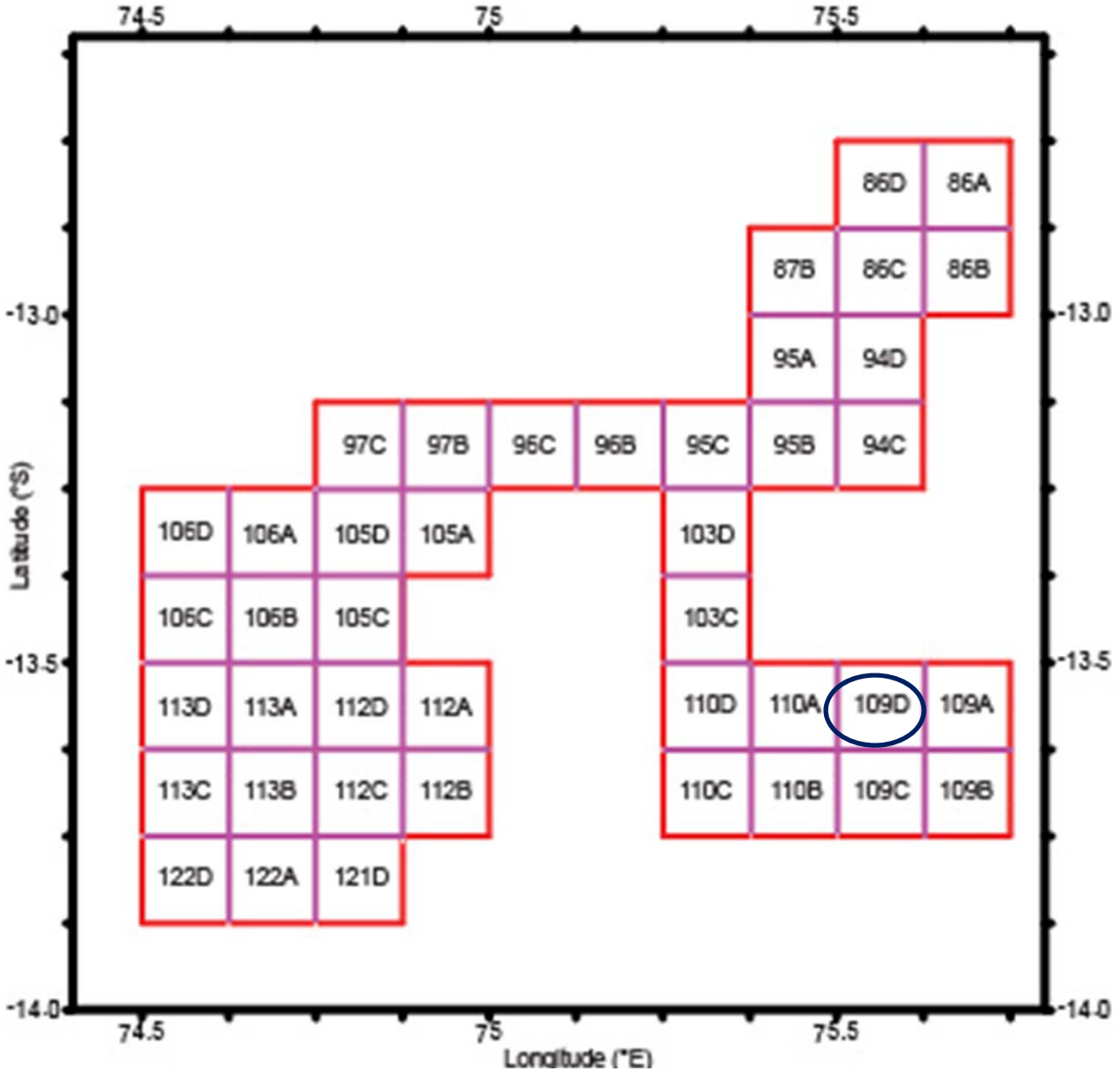
Exaggeration Factor:
6 times

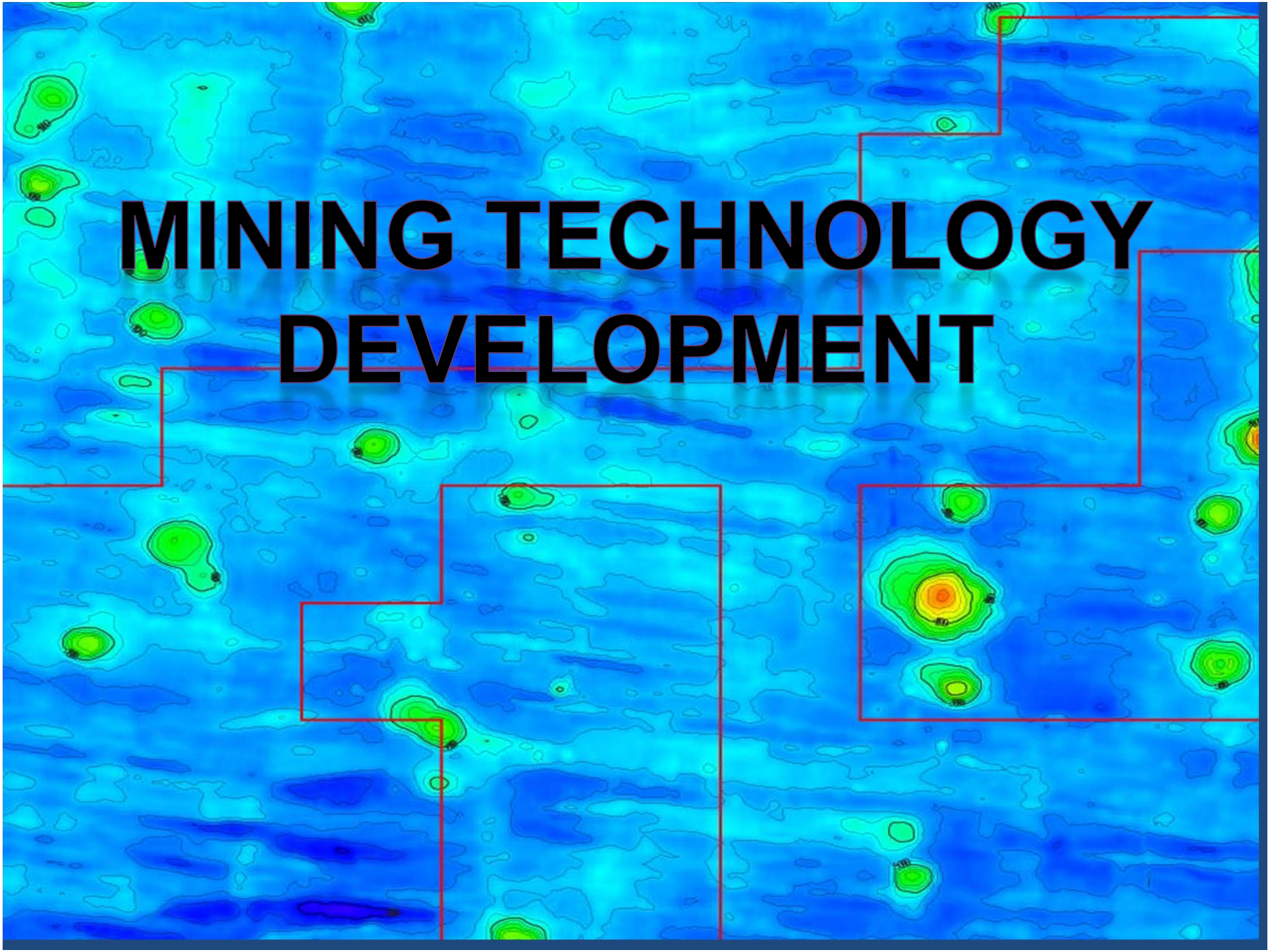
Profile Paths:
Southwest-Northwest
Northwest-Northeast
Northeast-Southeast
Southeast-Southwest
Southwest-Northeast
Northeast-Northwest
Northwest-Southeast
Southeast-Southwest



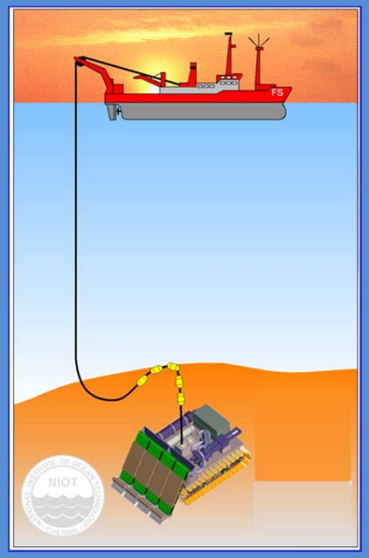
Block in FGM : Virtual Flythru

TEST MINE SITE




MINING TECHNOLOGY
DEVELOPMENT

Polymetallic Nodule Programme of India
Technology developed so far for nodule mining and the plan of work during the next few years



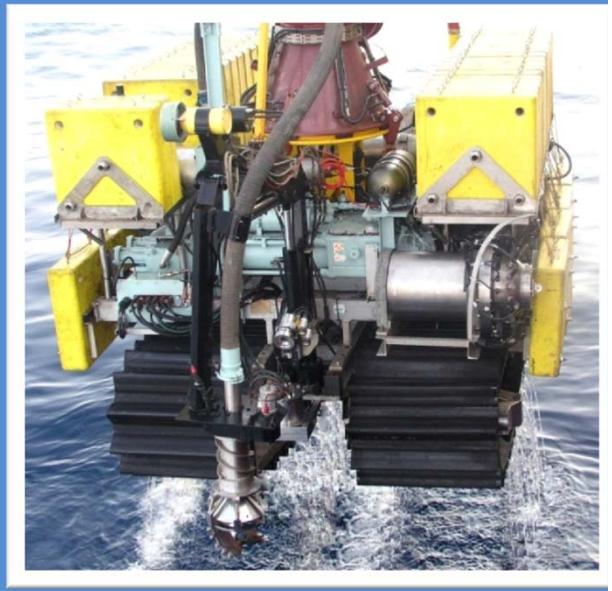
National Institute of Ocean Technology
Ministry of Earth Sciences, Govt of India

Technologies developed

- **Underwater mining machine for 500 metres**
- **Development of underwater collector and crushing system for manganese nodules mining in shallow water**
- **Development of Unmanned Remotely Operated Vehicle for 6000 m water depth**
- **Development of in-situ Soil Tester for 6000 metres depth**
- **Integrated Deep-sea Mining System for mining of Polymetallic nodules up to 6000m depth – in progress**

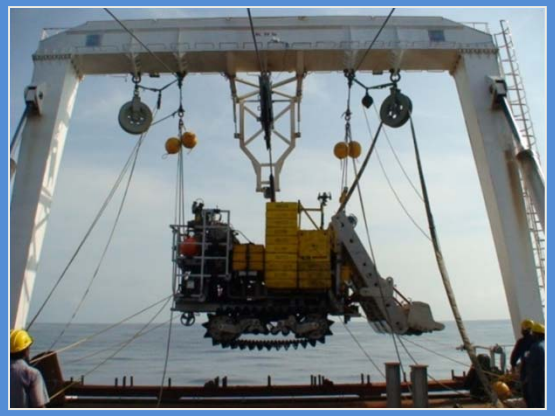
Highlights of work done

- Objective was to realize a pilot scale mining system along with the collector and crusher system and demonstrate the shallow bed mining capability in water depths up to 500metres in the Indian waters.
- The performance of the systems developed during this period and the analysis of results formed the basis for scaling up for the technology for the deep sea application.
- As a demonstration platform, a technology demonstration vessel was acquired



Development of Underwater Collection and Crushing Systems

- Design and Development of Collector, Crushing Systems, Undercarriage, Enhanced Hydraulics, Buoyancy packs Electronics and Control Systems
- A Remotely operable artificial nodule laying system was and tested off Chennai coast in 2007 at 500 m depth.



- Mining machine with collection and crusher system was realized and tested in the test pond in March 2010.
- The remotely operable artificial nodule laying system was used for nodule laying tested off Malvan coast at 512 m depth in September 2010.
- A 500 metre test mining system was launched at the at Angria bank, off Malvan coast at 512 m depth

Infrastructure Development :

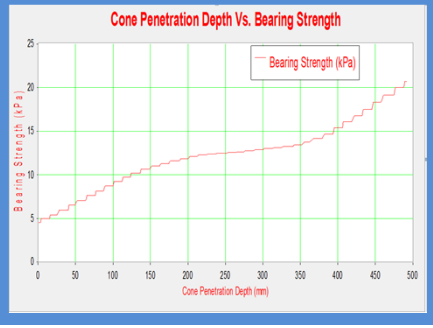
- Installation and commissioning of Hyperbaric chamber.
- Hydrotransport test facility commissioned.

Development of in-situ Soil Tester

- In order to validate the compact fully electrical in situ soil tester, test was conducted off Ennore port at around

  14m depth in July 2010.

- Subsequently, the modified in-situ soil tester was tested successfully at 5462m depth at CIOB during October 2011.



POLYMETALLIC NODULES MINING PROGRAMME

SOIL TESTER TESTING AT CIOB - 2011

- The modified in-situ soil tester was tested successfully at **5462m depth at CIOB during October 2011**.
- The indigenously developed sub-sea motor successfully demonstrated.
- The new sub-sea termination assembly for the in situ soil tester cable was used for the first time at 5462m water depth and qualified the same.

Launching of In-situ Soil tester

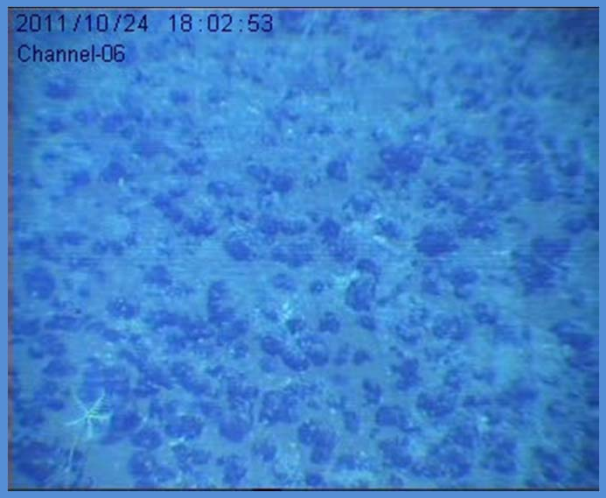


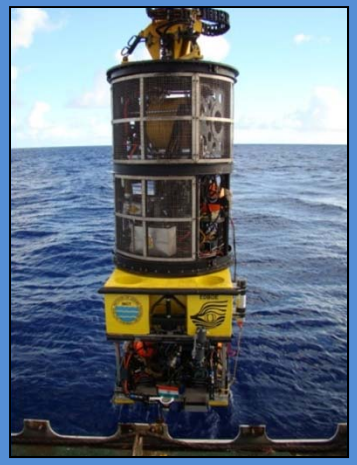
Image of Nodule field at CIOB

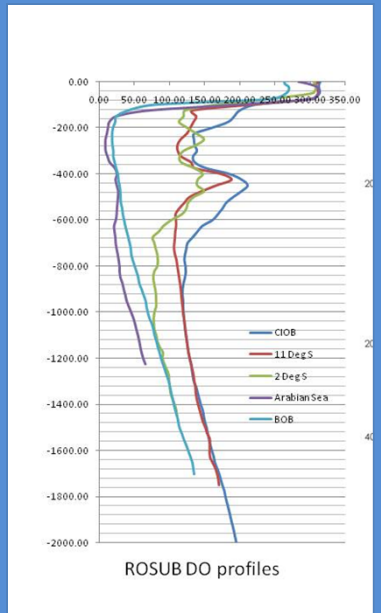
Vane operation on the sea bed at 5462 m depth

In-situ Soil tester in splash zone

Development and Testing of Deep Ocean ROV (Remotely Operable SUBmersible – ROSUB- 6000)

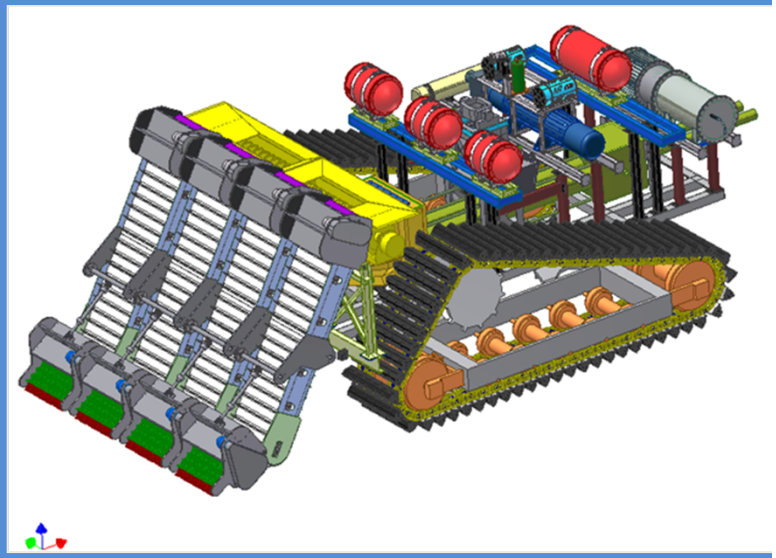
- A Deep Ocean Remotely Operated Vehicle (ROSUB 6000was developed and tested at PMN site in Central Indian Ocean at a water depth of 5289 metres
- Scientific data such as Sound Velocity, Dissolved Oxygen, Conductivity were collected. Water samples, bottom video and still pictures and short core samples were also collected at the PMN site





Concept development for Integrated Deep-sea Mining system for 6000m depth

- Design phase initiated with preliminary design calculation/drawing for various sub-systems.
- Studies on Acoustic Positioning System (APOS) for positioning the mining system at 6000 metres depth.
- Initial testing of hydraulic closed circuit pumps for 600 bar pressure in hyperbaric chamber




Environmental
Impact Assessment

EIA studies for nodule mining in CIB

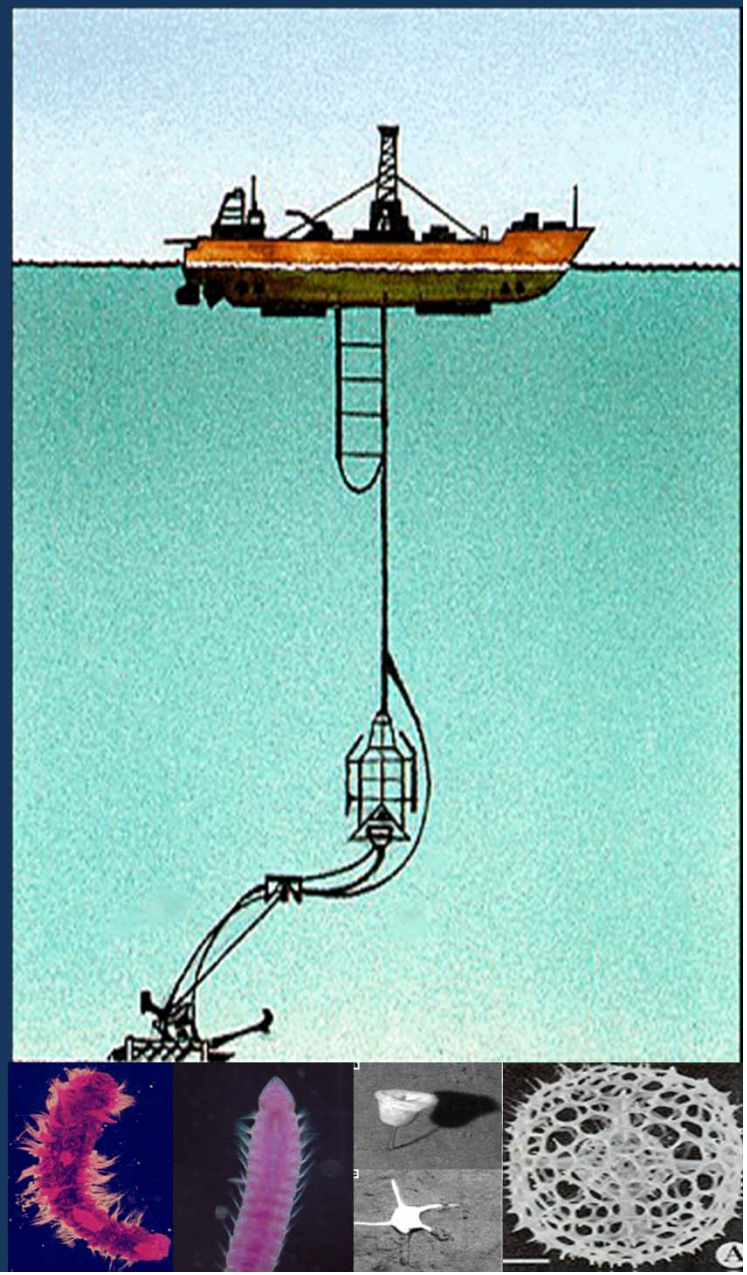
Objectives

- To establish baseline conditions in nodule areas
- To assess potential environmental impact
- To understand processes of restoration
- To prepare Environment Impact Statement

Schedule of major activities

Baseline data in EDS and PRS	1996-1997
Benthic impact experiment in EDS	1997-2001
Monitoring the impact in EDS and PRS	1997-2005
Environmental variability study	2005-2012
Baseline environmental studies at TMS	2012-2015

EDS-Experimental disturbance site
PRS-Preservation reference site,
TMS-Test Mining Site

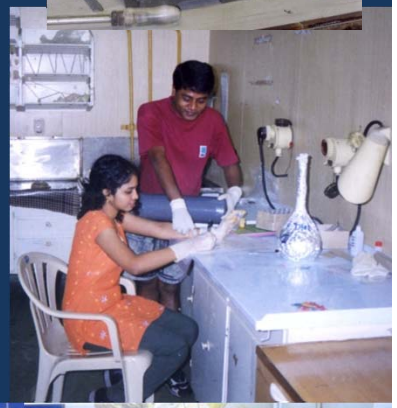


STAGES AND PARAMETERS FOR ENVIRONMENTAL STUDY

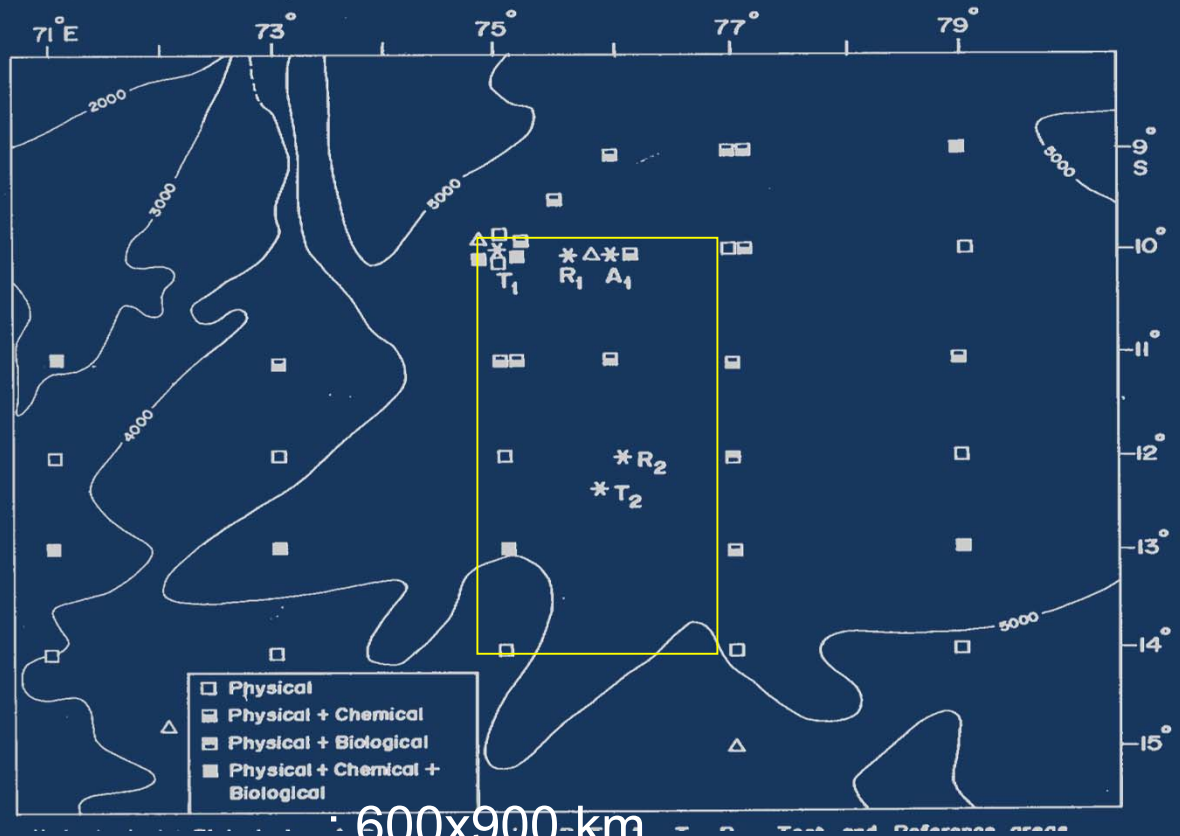
Baseline (1996)
Pre-mining (1997)
Post-mining (1997)
Monitoring-1 (2001)
Monitoring-2 (2002)
Monitoring-3 (2003)
Monitoring-4 (2005)
Env. Variability-1 (2003)
Env. Variability-2 (2005)
Env. Variability-3 (2006)
Env. Variability-4 (2009)

Parameters analysed

- Sediment sizes
- Water content
- Shear strength
- Sediment geochemistry
- Macrofauna diversity and abundance
- Meiofaunal diversity and abundance
- Bacterial diversity and abundance
- Currents and sediment flux



Collection of baseline water column data in CIB



Data collection

- Areal
- Seasonal
- 3-dimensional

Parameters

- Meteorology : 600x900 km
- Temperature, salinity : 600x900 km
- Currents (3 levels/locations) : ~200 days
- Bottom currents in test area : ~200 days
- Productivity and chlorophyl : 600x900 km
- Chemical characteristics : 600x900 km
  (metals, DOC, POC)

Collection of baseline benthic data

Sediment + nodule + benthos:

64 stations (in 5 candidate test and reference areas)

26 stations (in application area)

All stations sampled over multiple sampling schedules

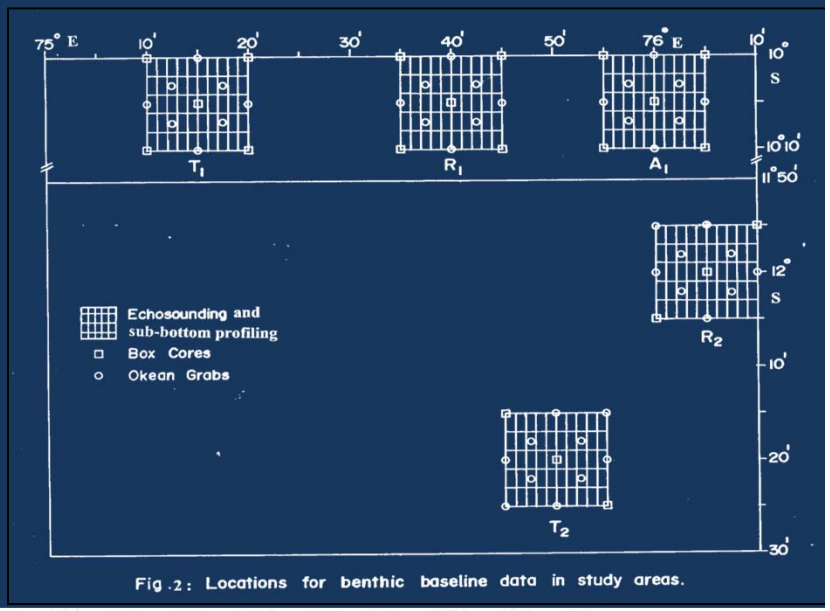
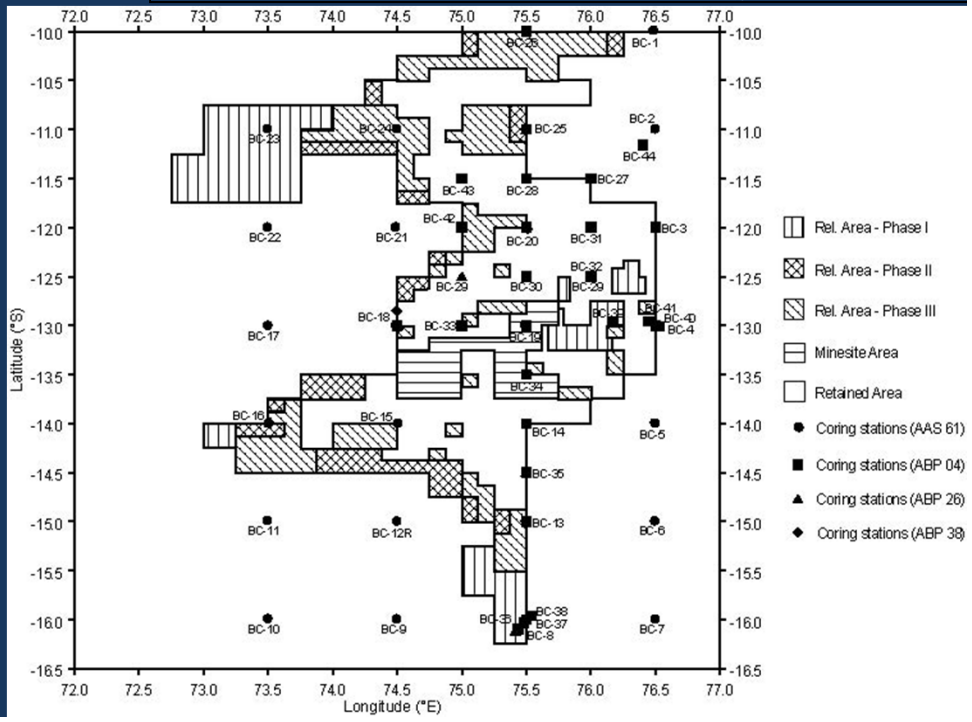


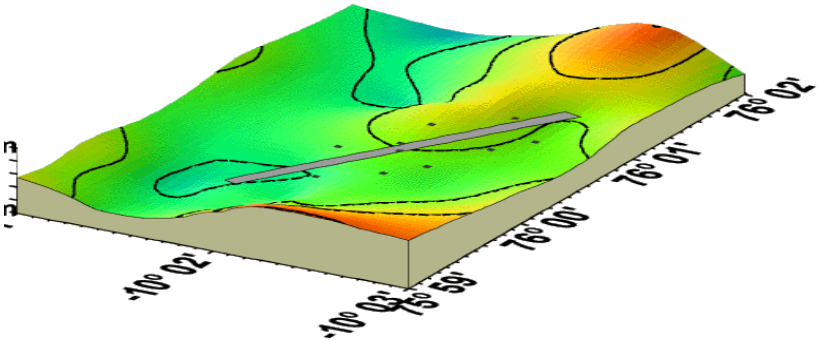
Fig .2: Locations for benthic baseline data in study areas.



Simulated ‘mining’ experiment (1997)

Hydraulic suction device used

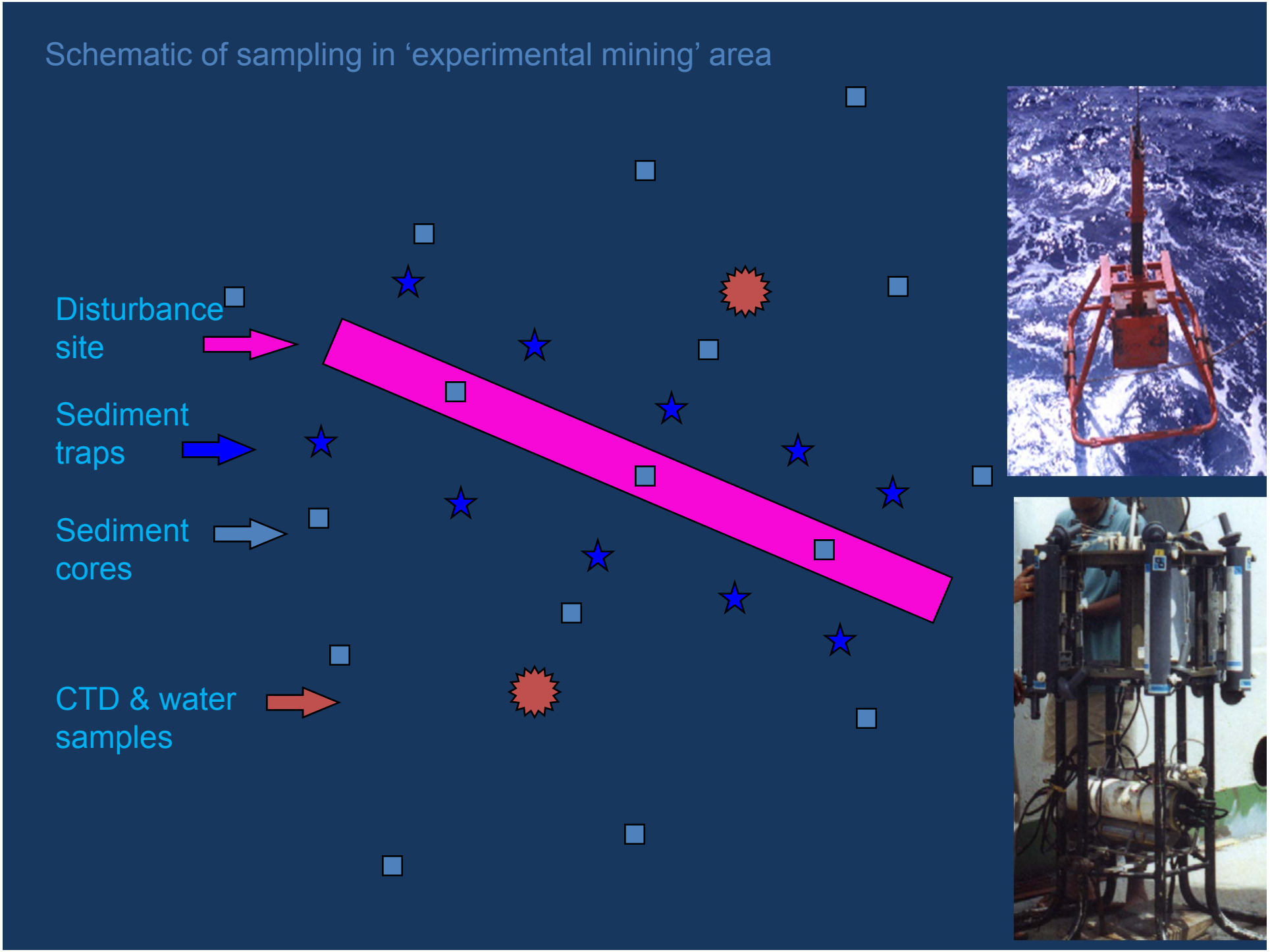
- No. of tows : 26 tows
- No. of days : 9
- Operation time: 47 hrs
- Operation distance : 88 km
- Sediment resuspended : 580 t (dry)



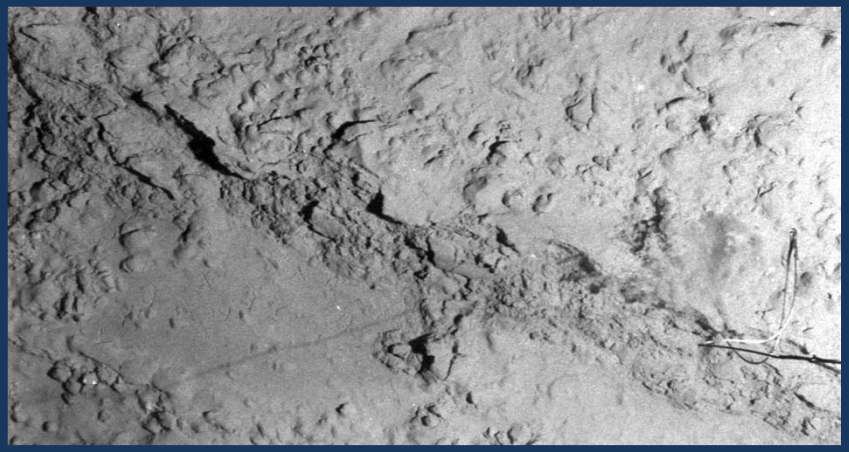
Experimental site

* Area : 200 x 3000 m
* Depth : 5400 m depth
* Location : Central Indian Basin

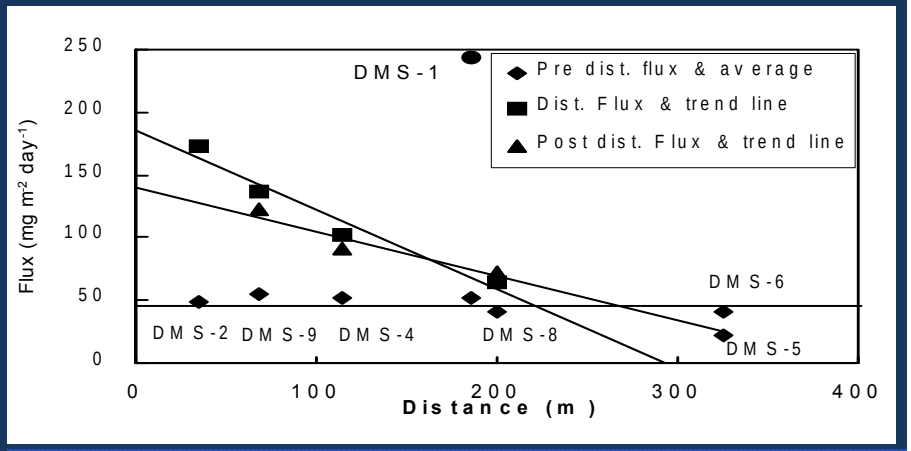
Schematic of sampling in ‘experimental mining’ area



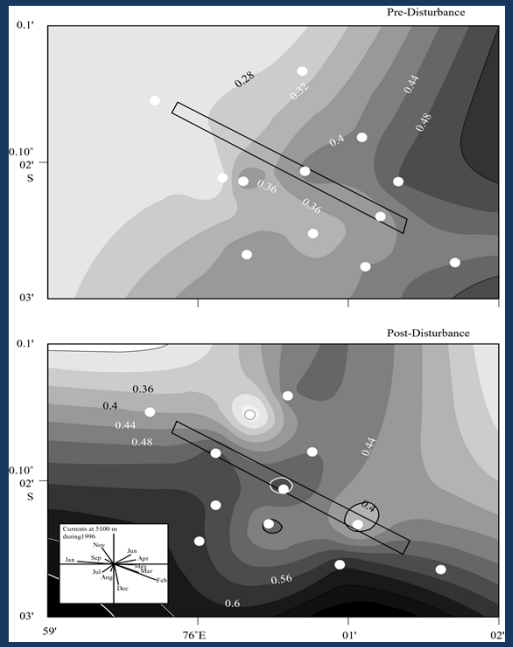
Alterations in seafloor conditions



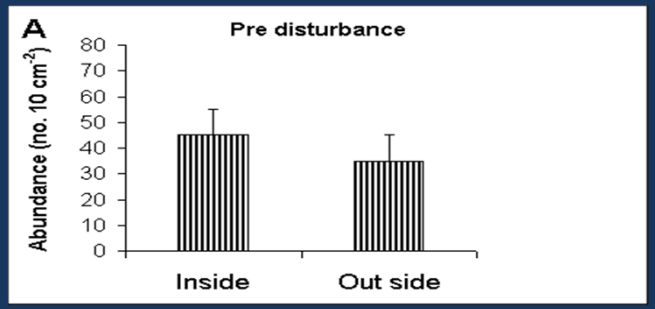
Vertical mixing of sediment

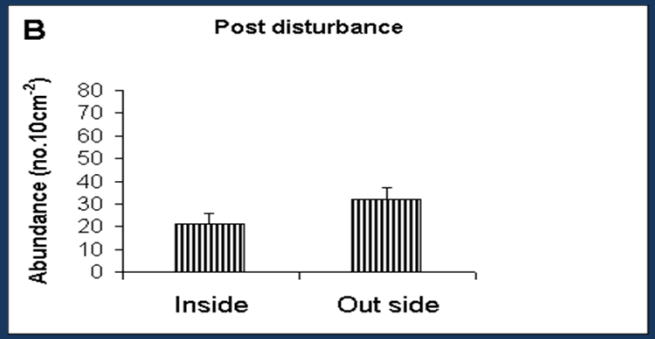


Lateral migration of sediment



Changes in physico-chemical conditions

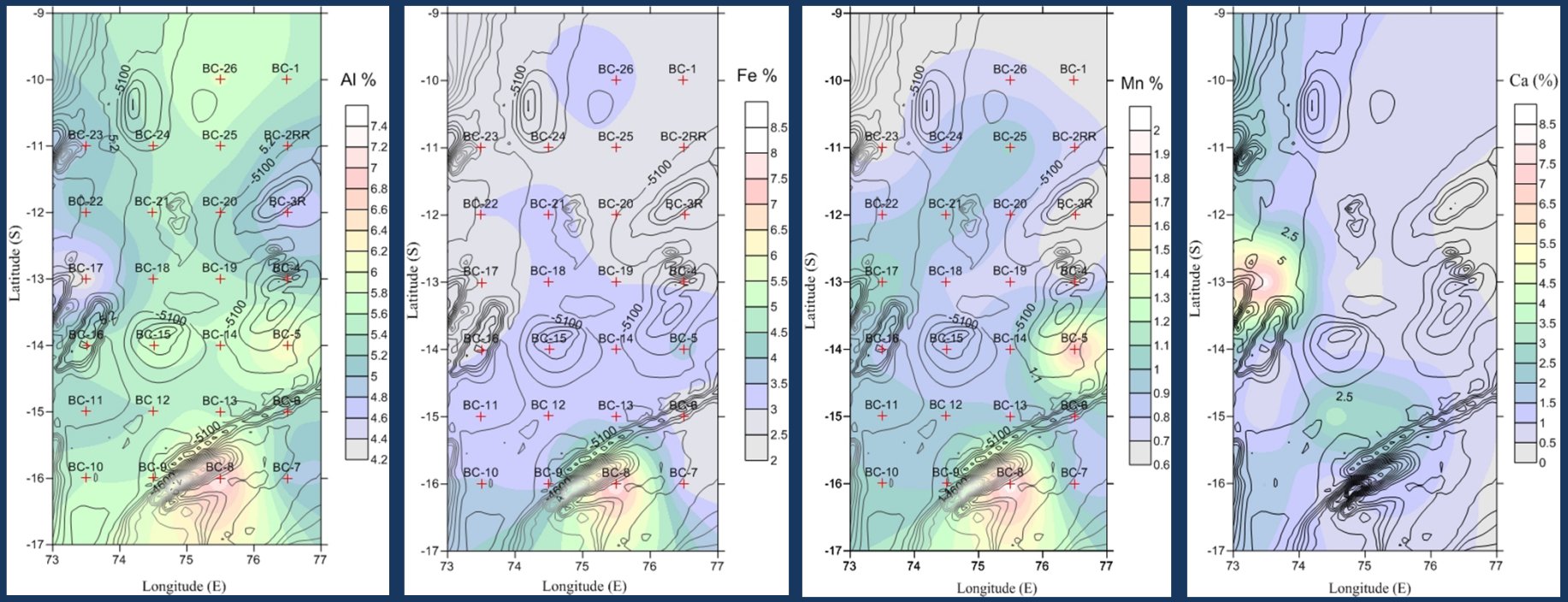




Reduction in biomass

Mapping of elemental distribution in the surface sediments

Al Fe Mn Ca

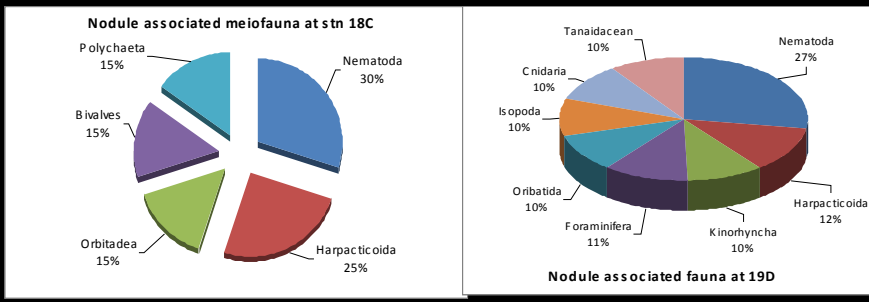


- Regional elemental distribution maps have helped in evaluating the role of local geology and bathymetry in the sediment distribution and dispersal pattern in the area.
- Geochemical tracers such as major, trace and rare earth elements were used as indicators of geological processes, provenance, and tectonic settings of basin.
- Studying the elemental composition of surface sediments allowed us to understand the fate of the terrestrial materials transported into the basins as well as the factors controlling the distribution and geochemistry of the seafloor sediments.
- Distribution patterns of these elements showed low concentration in the central part, while northern and southern parts were enriched in these elements.

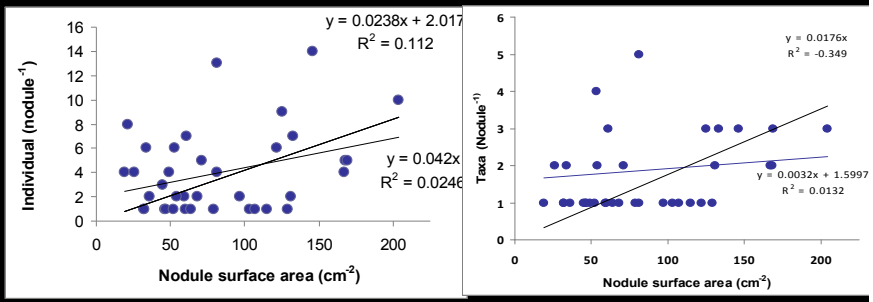
Nodule associated fauna

- 109 nodules analysed from 6 samples (2 stns.)
- 30-80% nodules (avg. 40%) have associated fauna
- 10 groups of meiofauna identified
- Nematoda (30%), herpacticoida (20%), polychaetes (15%) dominate
- 1-14 individuals per nodule
- 2-8 groups of meiofauna per nodule
- Nodule morphology plays a major role in hosting sediments with faunal groups
- Nodule surface area and faunal abundance have weak correlation

Nematode associated with nodule from CIB



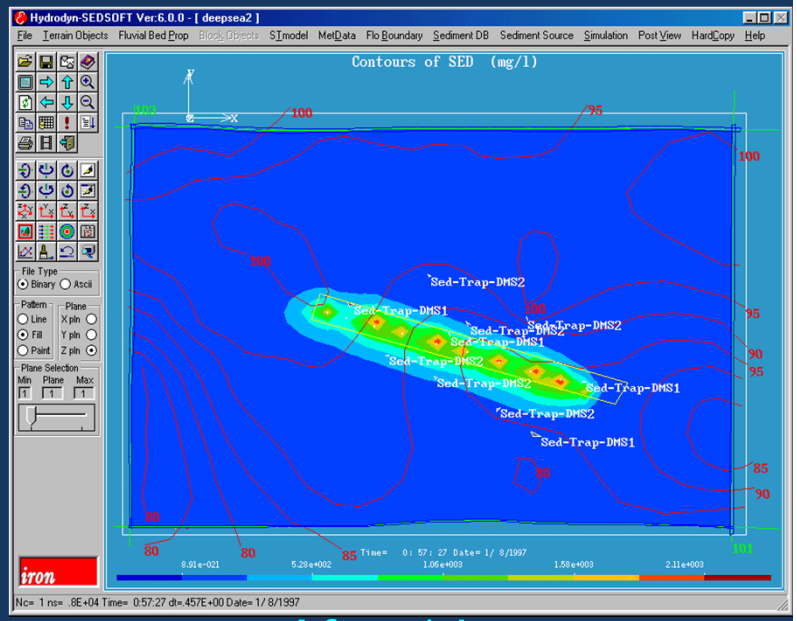
Faunal diversity associated with nodules



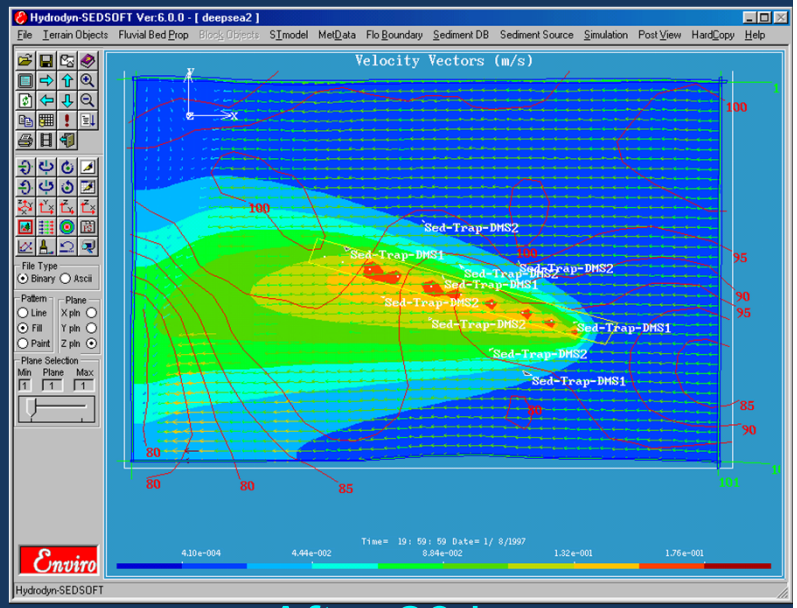
Faunal abundance with nodule surface area

Modeling of currents and sediment plume dispersion

- sediment dispersion of plume and settling
- takes into account processes including advection, dispersion
- predicts suspended and bed load sediment movement
- specialized features for graphics and post-processing



After 1 hour



After 20 hours

Overall conclusions

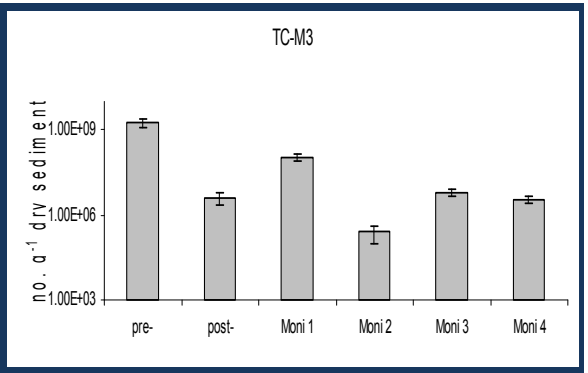
Environmental conditions

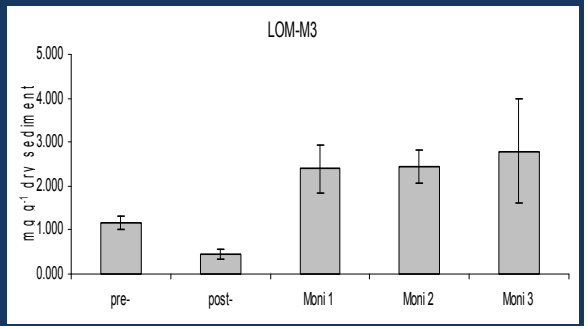
- vary over different time scales (seasonal and annual)
- on a wide range, but always follow a particular trend
- near seafloor currents very slow and in gyres

Implications

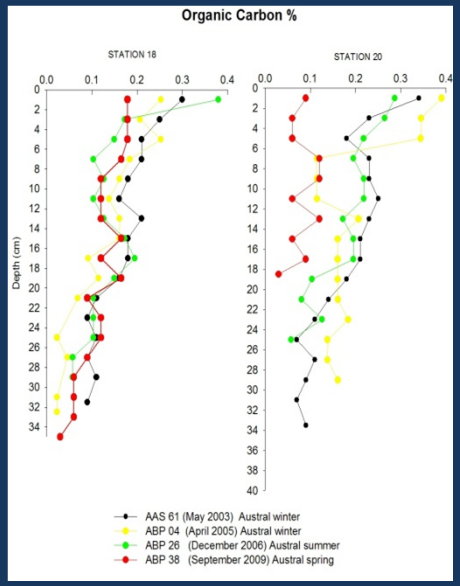
These variations could well encompass the changes in conditions created by other activities such as deep seabed mining.

As a result major environmental impact is not expected

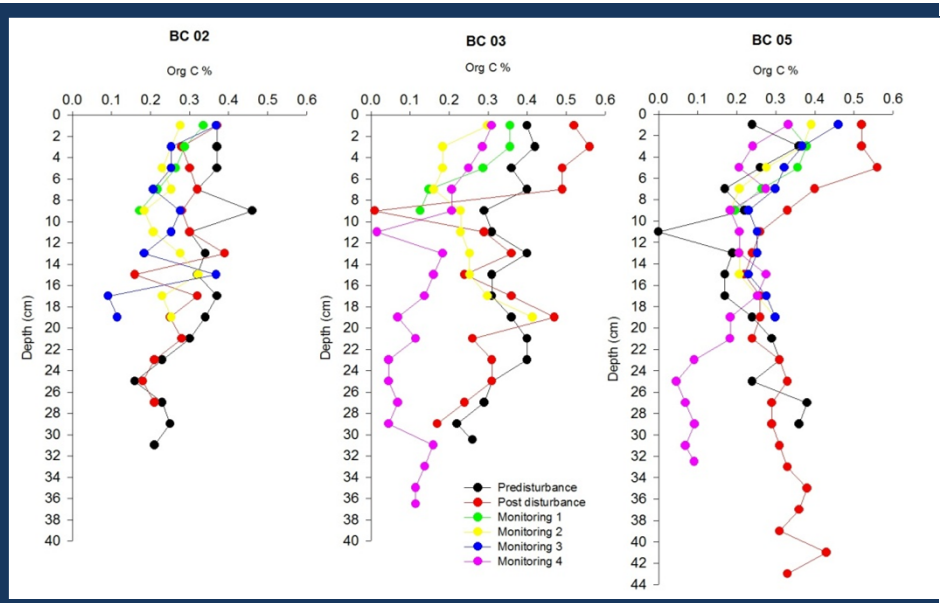




TC and LOM during monitoring phases at BC-3



Org C during EVD-I,II,III,IV



Org C during pre, pot-dist, monitoring at BC-2,3,5

Major outcomes

1. Assessing the potential impact of nodule mining on environment in test and reference areas

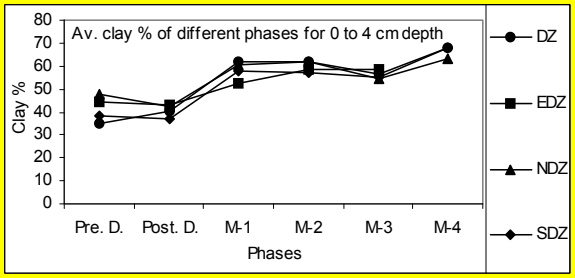
- Benthic conditions getting restored
- Degree of restoration is different
- Natural conditions taking over

2. Natural variability in nodule area

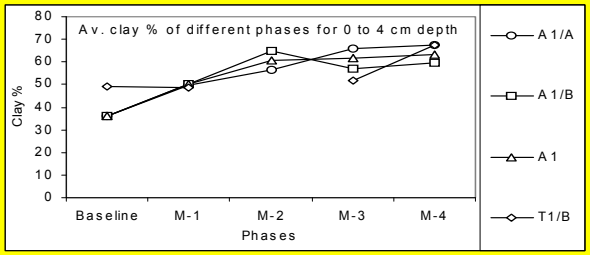
Water column : 34 stations
Physical , Chemical, Biological

Benthic : 40 stations
Geological, Biological

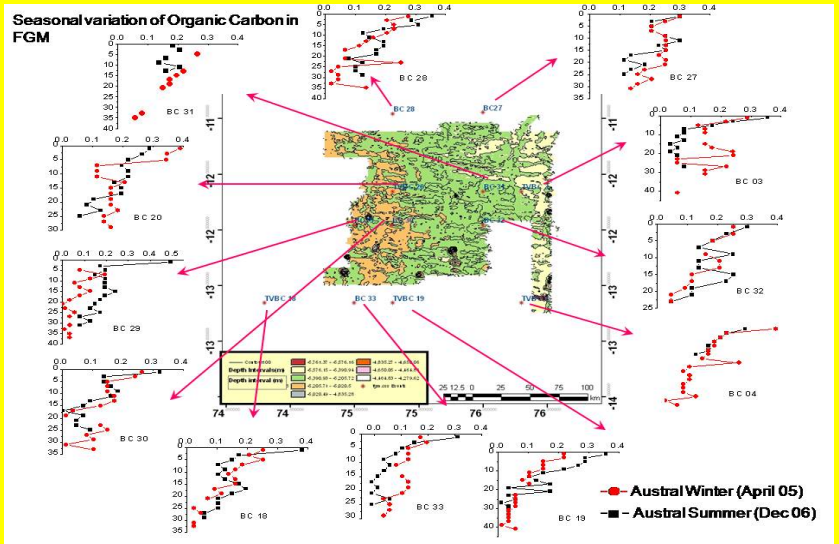
Findings
Significant seasonal and annual variability observed



Clay content in test area



Clay content in reference area

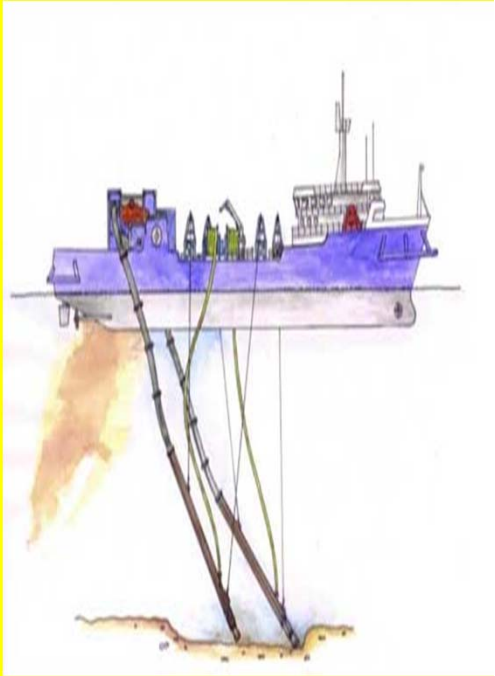


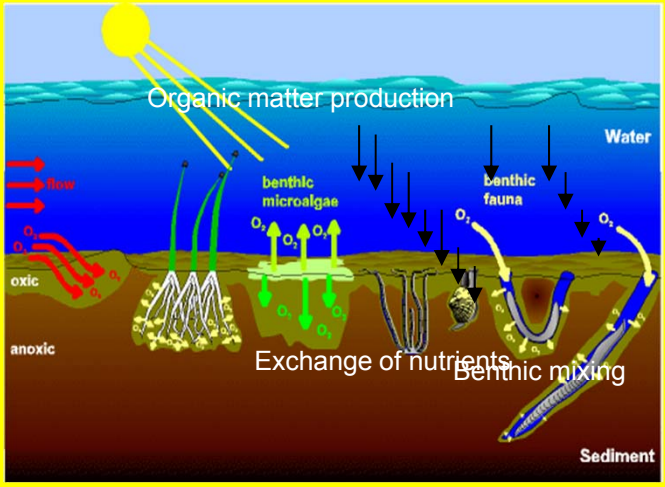
Spatial variation of Organic C in CIB

Major outcomes (contd.) :

3. Environmental data for nodule mining

Atmospheric	- wind, rainfall, cyclone
Surface	- waves, temperature, currents
Water column	- currents, temperature, pressure
Seafloor	- topography, micro-topography, slopes
Sub-seafloor	- sediment thickness, shear strength
Mineral characteristics	- abundance, grade, size
Associated substrates	- sediments, rocks, crusts





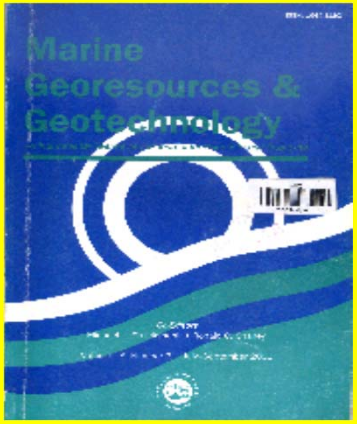
Major outputs

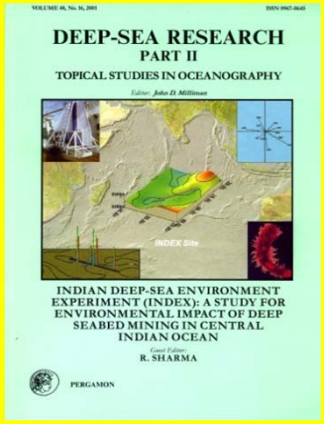
Tangible outputs — *Nodule mining*

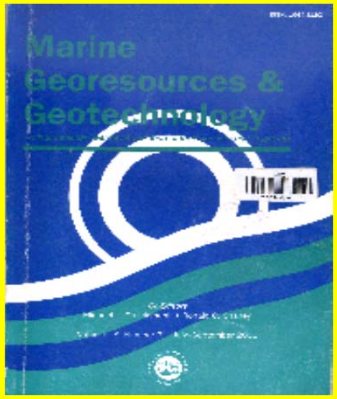
Publications	80 (Total impact factor = 90)
Symposia	60
Patents	4
Reports	26
Trainings - PAs trained	36
Foreign students	17
Ph.D students	6
Dissertations	90

Special issues of intl. journals

(2000, 2001, 2005)







Intangible outputs

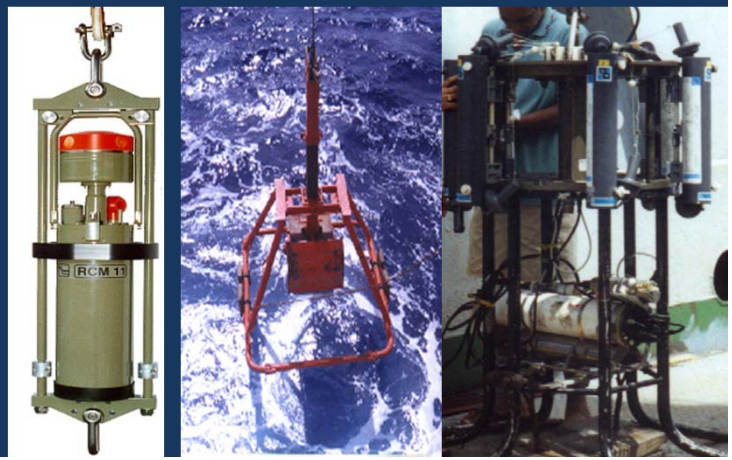
Development of multi-disciplinary research group for deep-sea environment studies

Providing advisories to International Seabed Authority (UN)

Databases generated

Database	Phases included	Parameters included	Contents (format)
PMN-EIA database - I	Baseline, Pre-disturbance, Post-disturbance	All parameters of water column and benthic environment	EIA metadata (MS Word) EIA analysed data tables (MS Access) EIA reports (Multipage compressed Tiff)
PMN-EIA database-II	Monitoring-I, Monitoring-II, Monitoring-III, Monitoring-IV	All parameters of benthic environment (no data on water column parameters collected during these phases)	EIA metadata (MS Word) EIA analysed data tables (MS Access) EIA reports (MS Word)
PMN-EIA database-III	EVD-I, EVD-II, EVD-III, EVD-IV	All parameters of benthic environment (no data on water column parameters was collected during these phases)	EVD metadata tables (MS Word) EVD analysed data tables (MS Access) EVD reports (Adobe Acrobat)

All data submitted to MoES and ISBA




THANK YOU