Polymetallic Nodules Resource Classification

French effort 1970 - 2014

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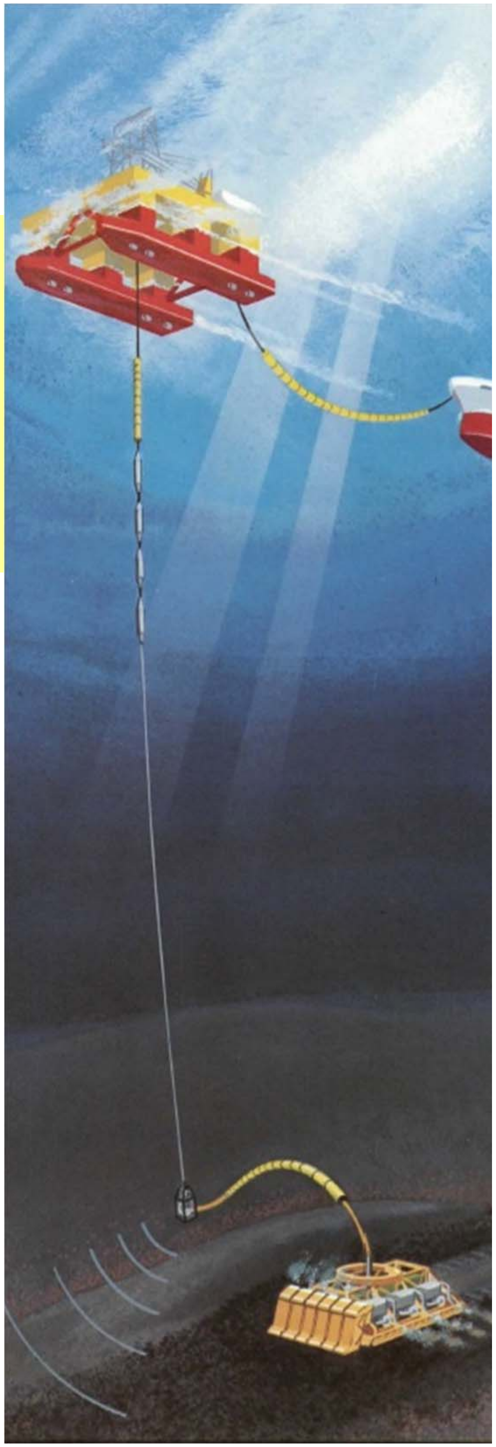
+ GEMONOD consortium

ISA Workshop Goa 2014

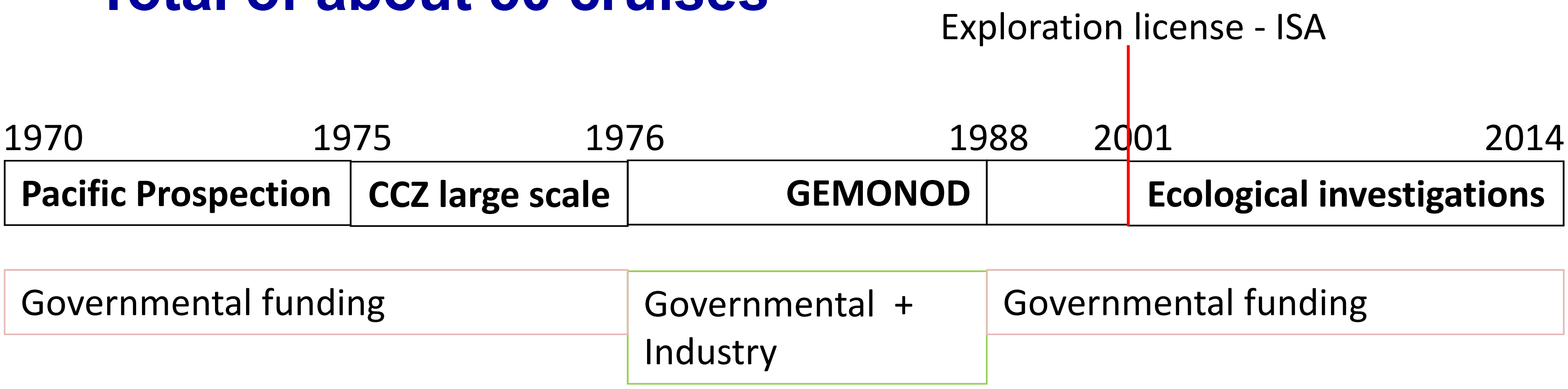


Historical Background

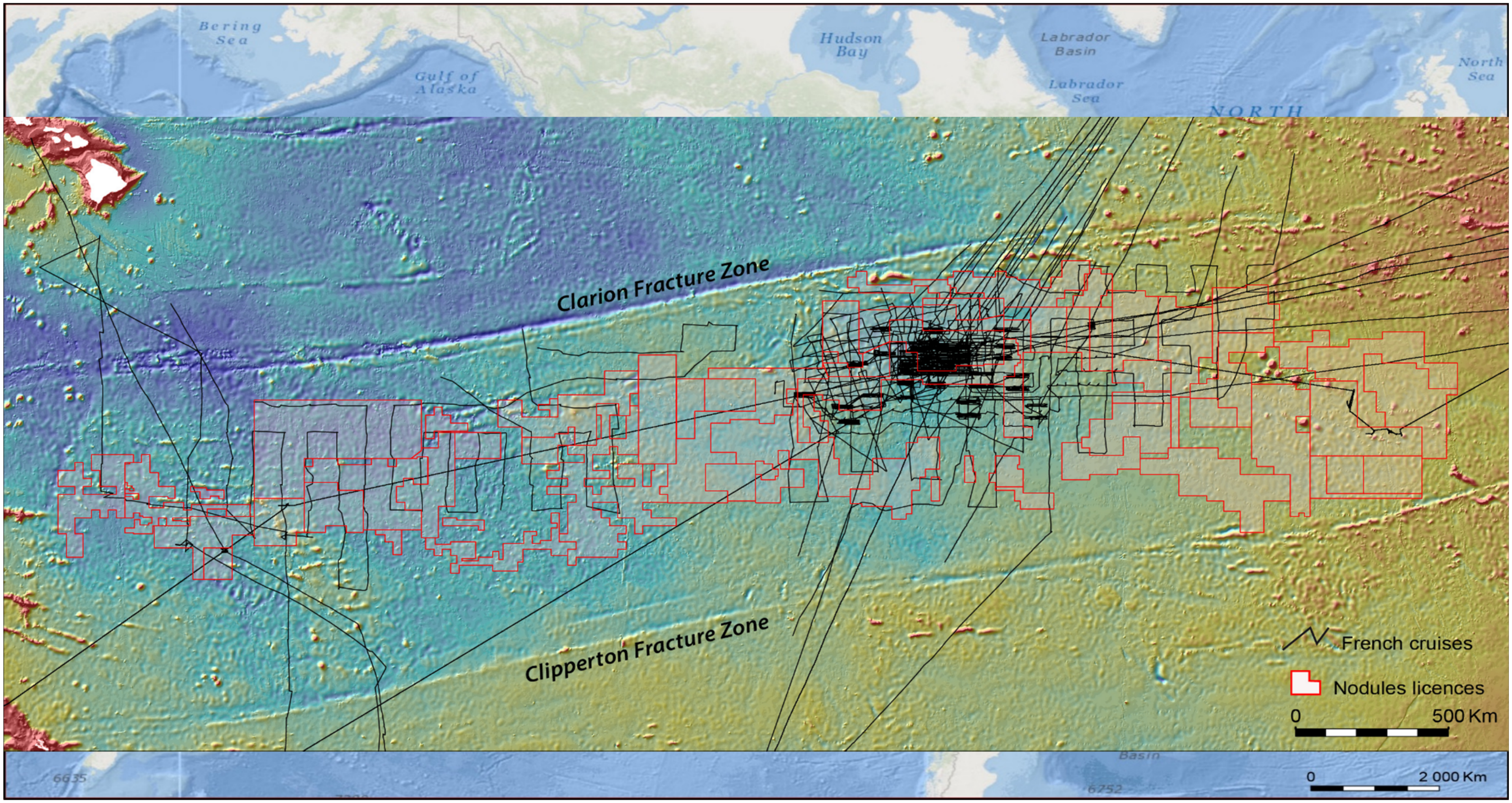
- 1970 – 1975 Regional prospection: EEZ + Pacific
- 1975 – 1976 large scale exploration: CCZ
- 1976 – 1988 local scale central CCZ

- 2001 – 2014 Ecological + Geochemical investigations

- Total of about 50 cruises

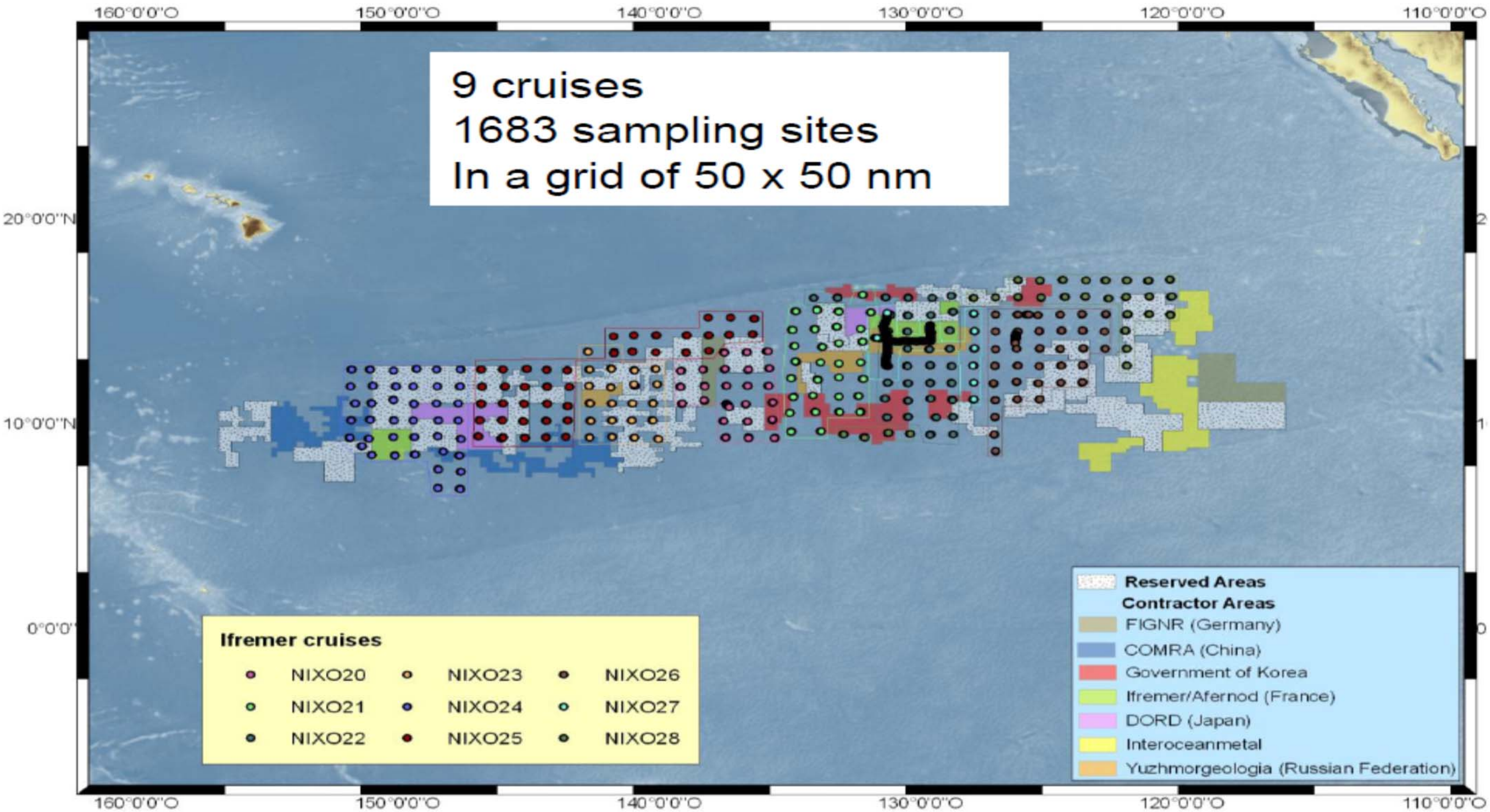


Regional Prospection



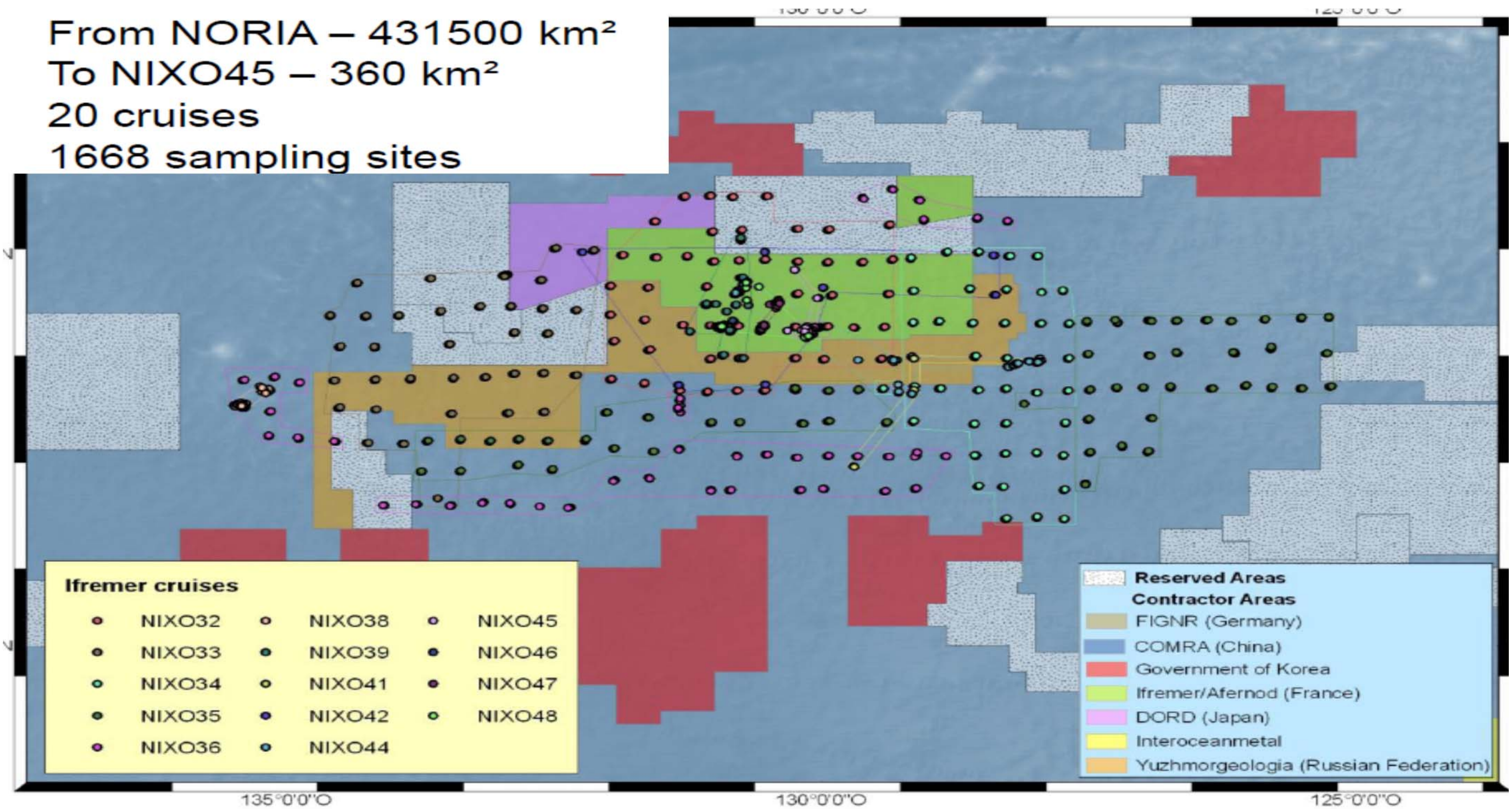
1970	1975	1976	1988	2001	2014
Pacific Prospection	**CCZ large scale**	**GEMONOD**		**Ecological investigations**	

Large scale geological exploration



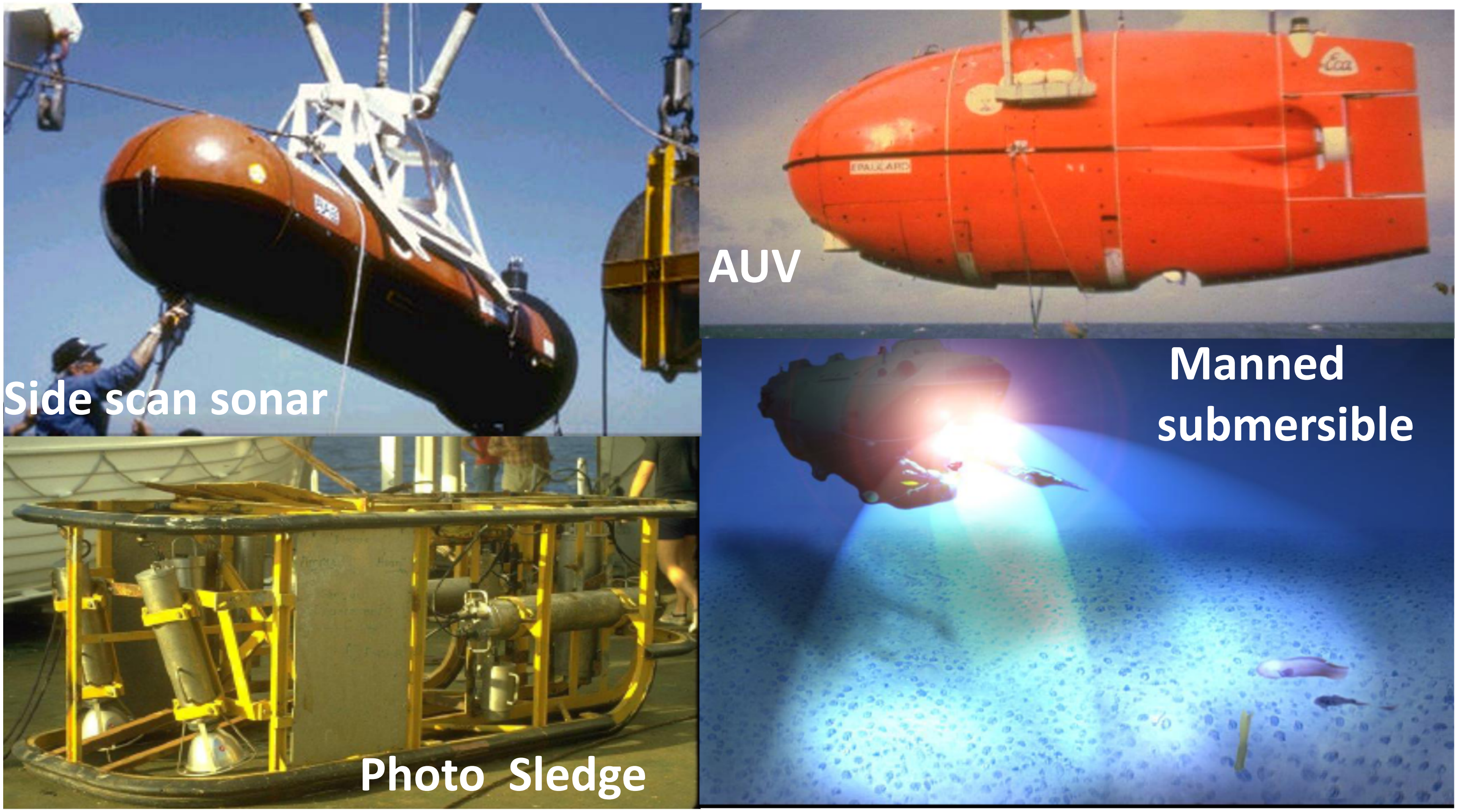
1970	1975	1976	1988	2001	2014
Pacific Prospection	**CCZ large scale**	**GEMONOD**		**Ecological investigations**	

local scale geological exploration



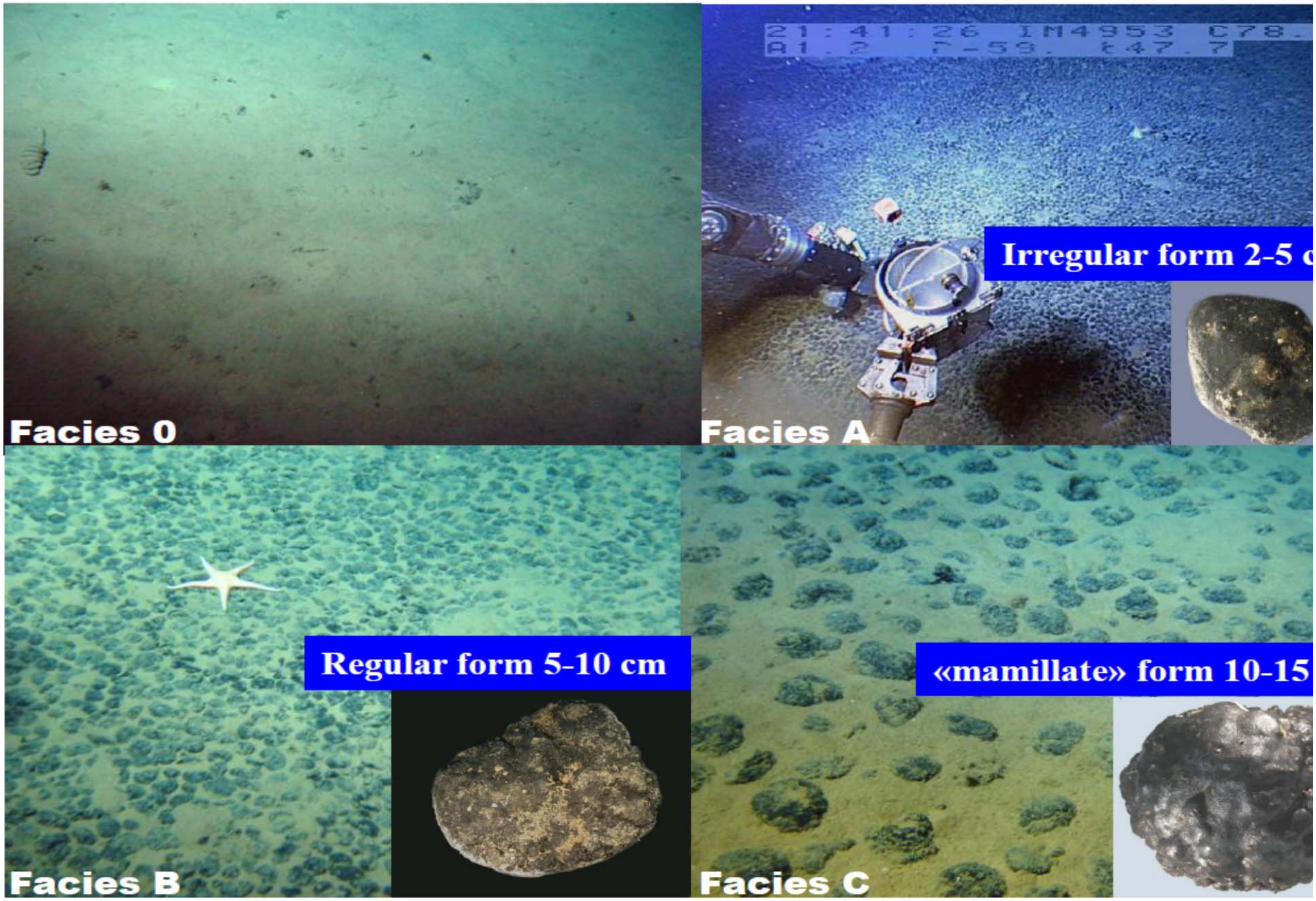
1970	1975	1976	1988	2001	2014
Pacific Prospection	**CCZ large scale**	**GEMONOD**		**Ecological investigations**	

Near-seafloor geological mapping

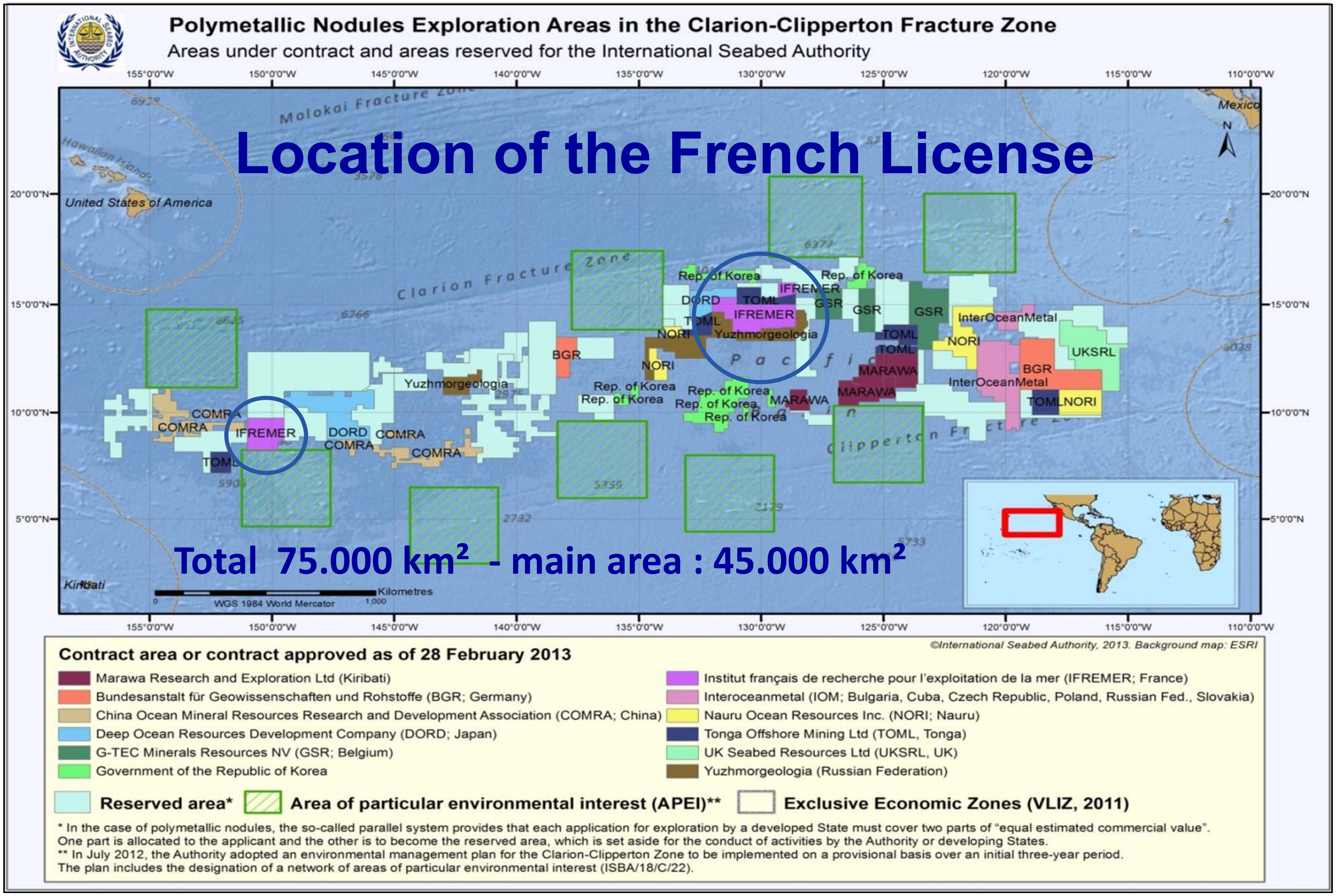


1970	1975	1976	1988	2001	2014
Pacific Prospection	CCZ large scale	GEMONOD		Ecological investigations	

Nodule facies



Location of the French License

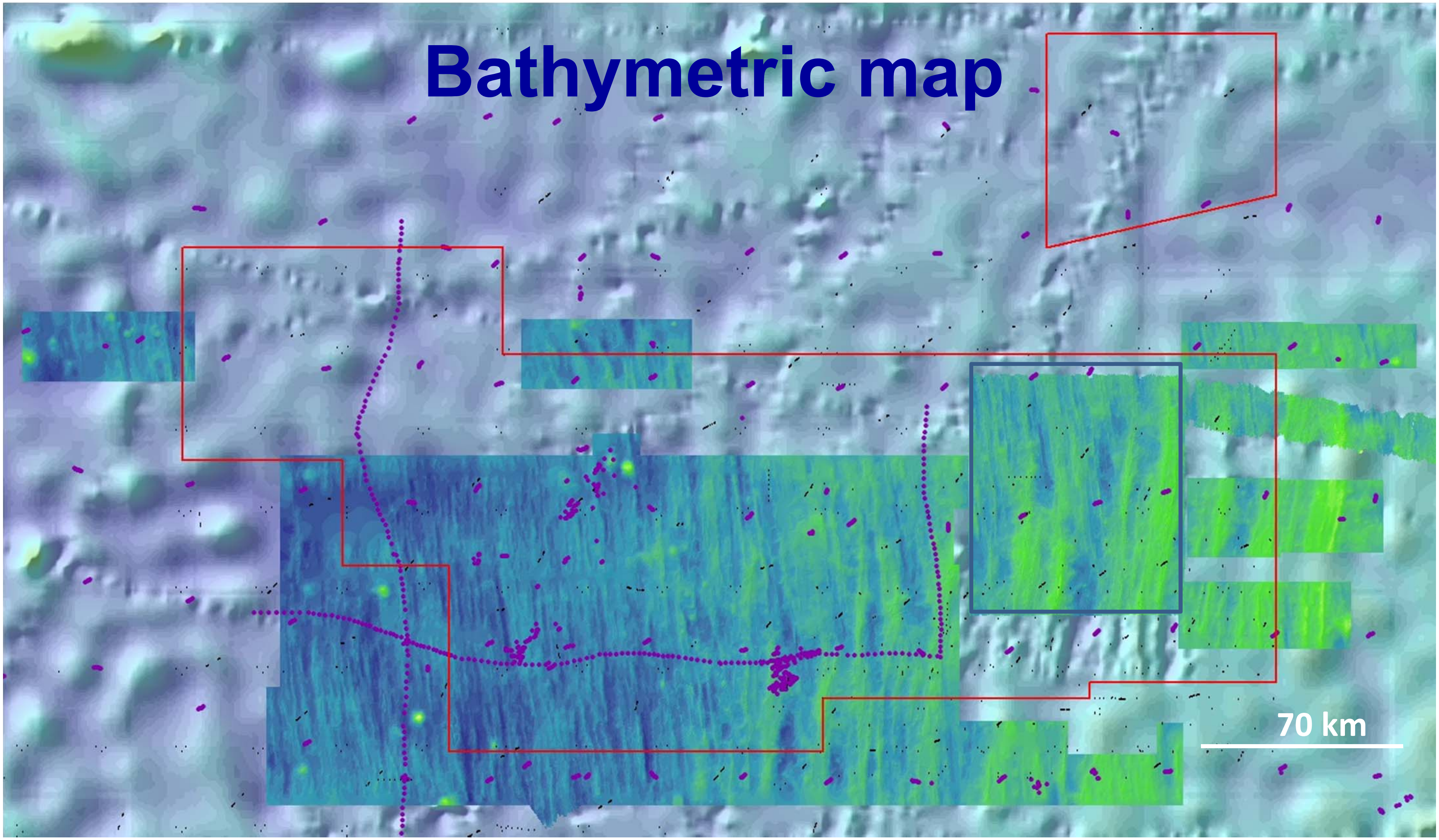


Total 75.000 km² - main area : 45.000 km²

1970	1975	1976	1988	2001 – 2014
Pacific Prospection	**CCZ large scale**	**GIP GEMONOD**		**Ecological investigations**

Ifremer

Bathymetric map



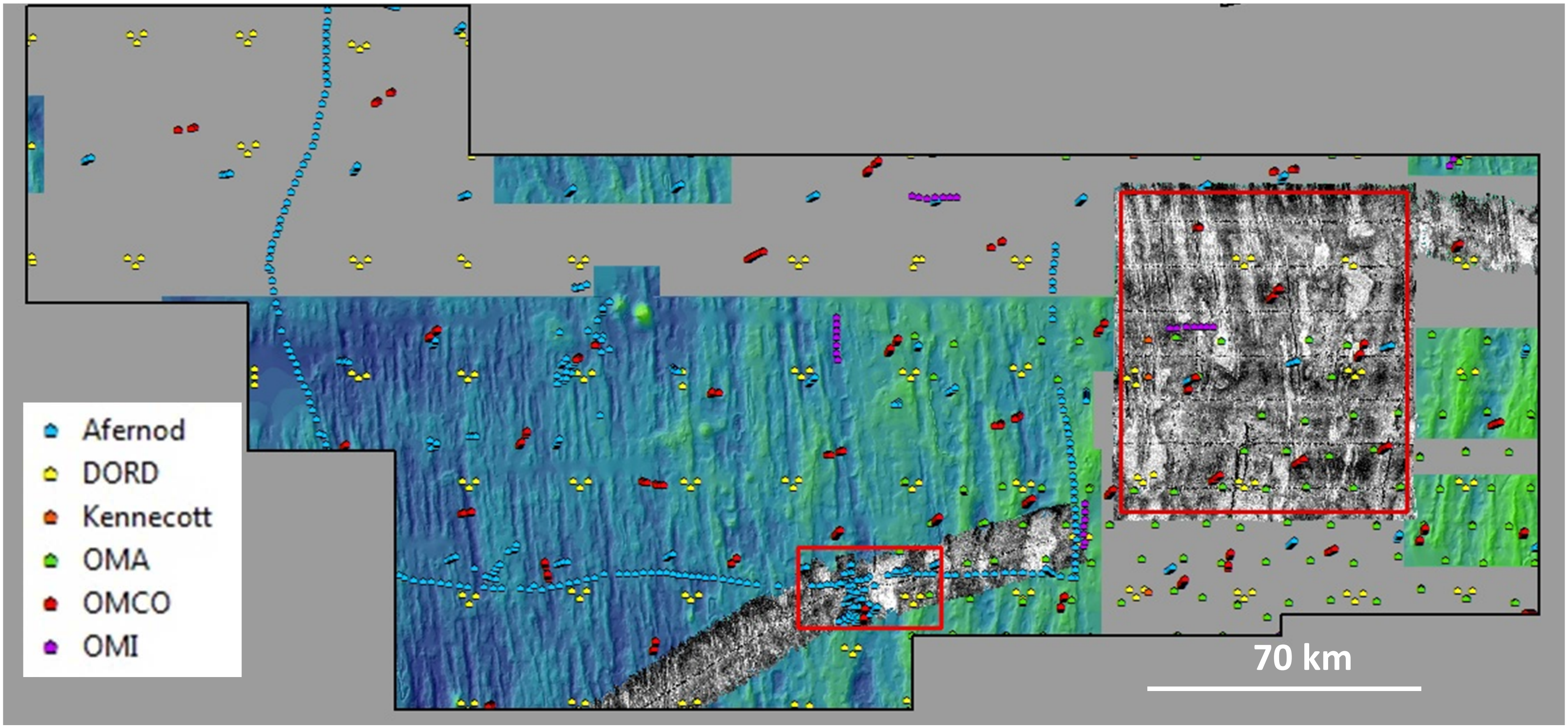
Study of small scale variability and anisotropy :

- NS and EW cross with 2 km spacing
- Clusters of 5 points with 500 m spacing

Bathymetry : 150 m and 75 m resolution.
Gebco (1 km res.)

Bathymetry + regional acoustic imagery

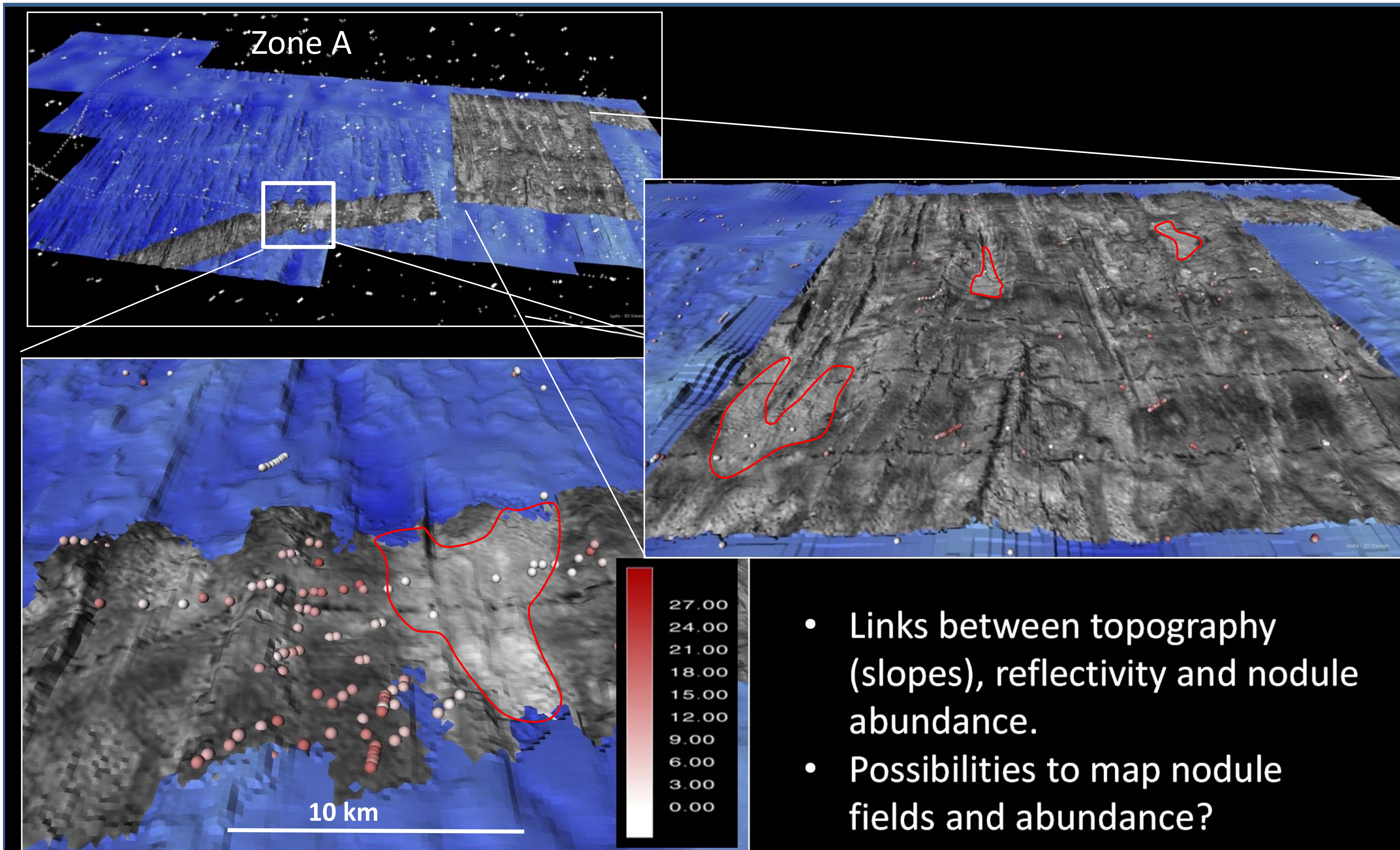
- Over 1400 samples (abundance, grades, pictures, facies…)
- BIONOD 2012 area. 70x80 km with 30 m resolution reflectivity map
- Environmental cruise. Bathymetry and backscatter.
- Historical area of interest : NIXO 45. 35x20 km. Nautile dives.



NODULE ABUNDANCE

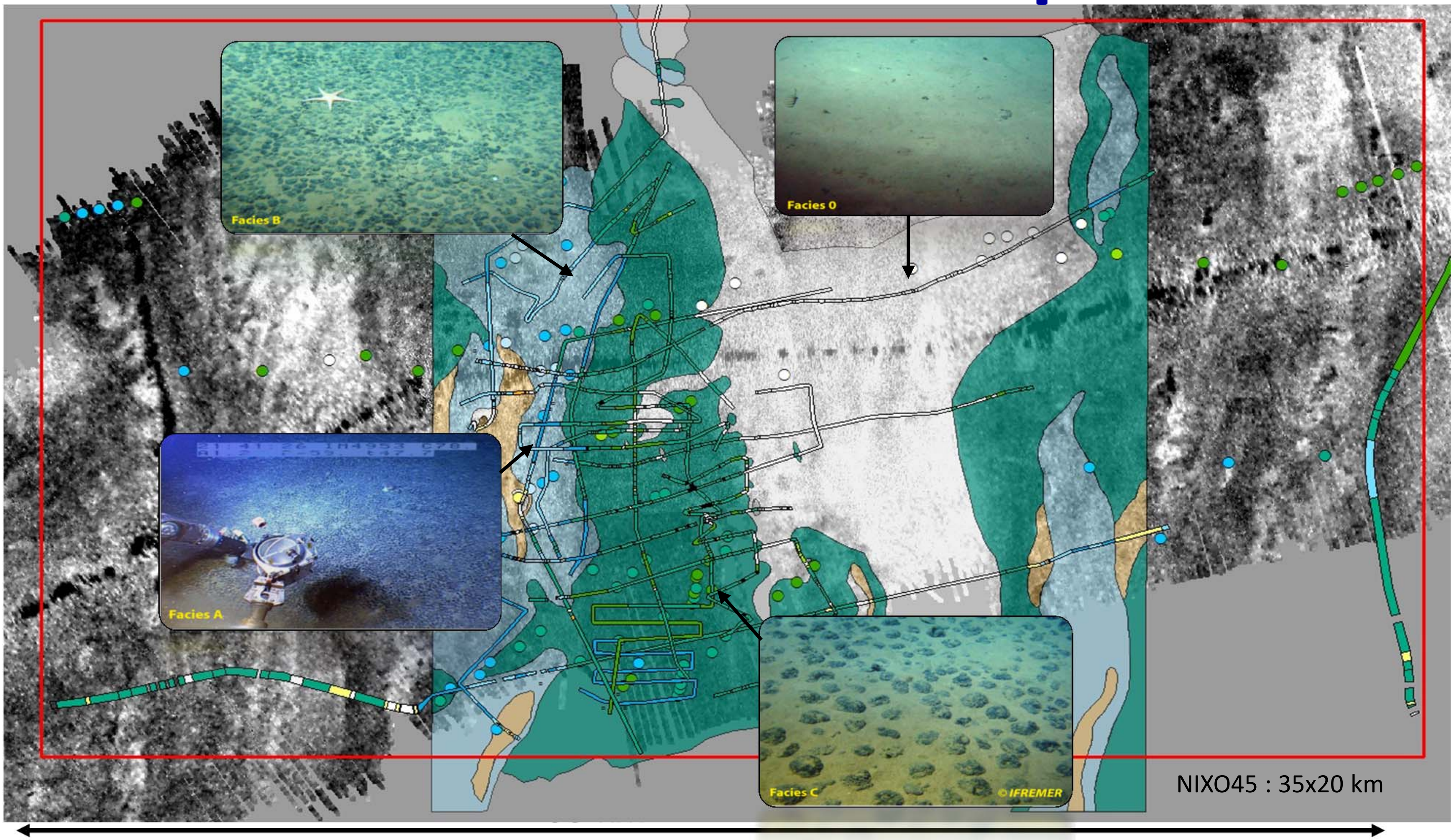
Small scale abundance and facies variability

Reflectivity and density of Nodules



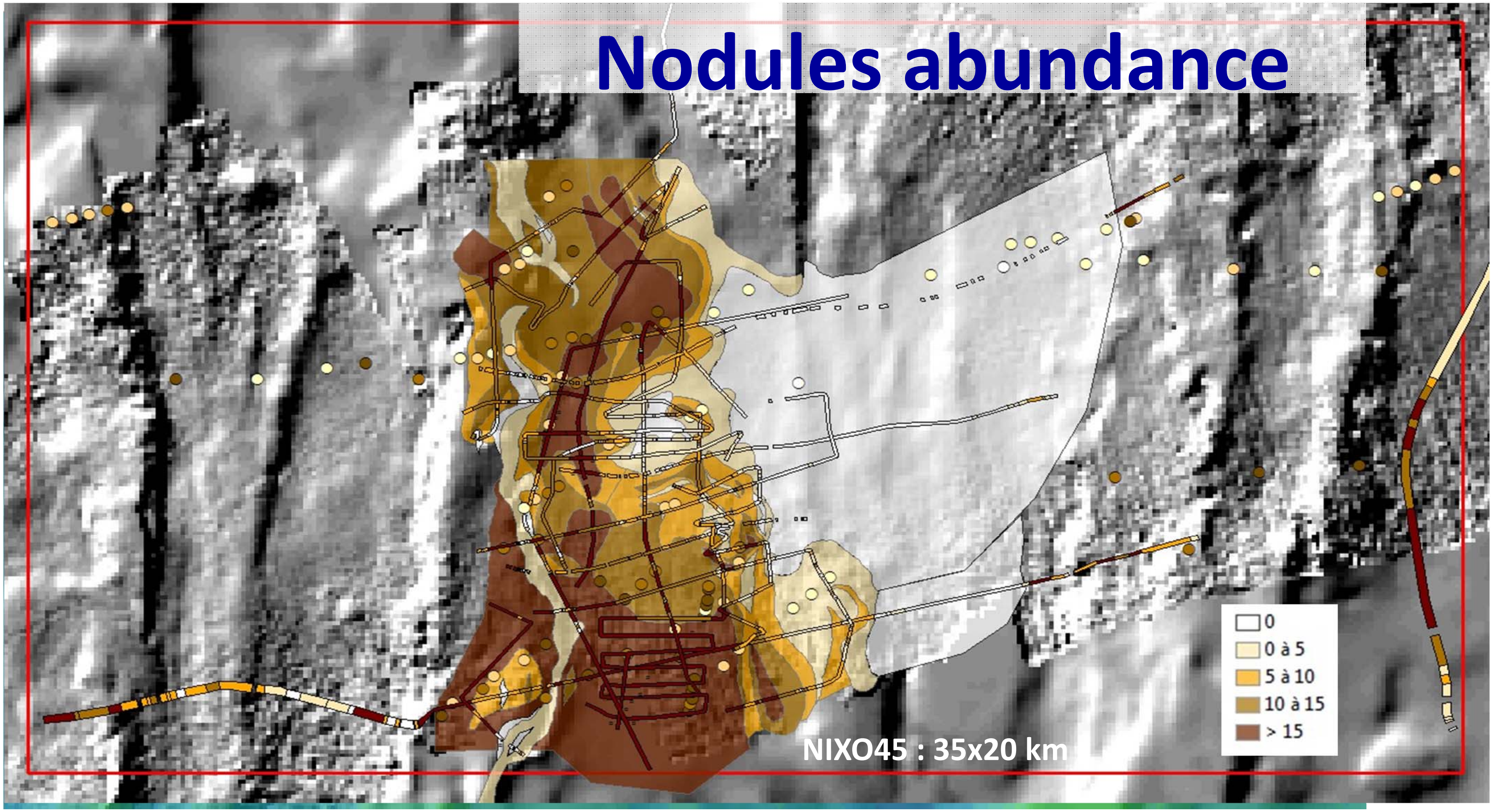
- Links between topography (slopes), reflectivity and nodule abundance.
- Possibilities to map nodule fields and abundance?

Detailed nodules facies map (photo + dives)



- **Small hydrogenetic type A and B nodules dominating on slopes.**
- **Facies C large nodules field on the plateau.**
- **Facies O in the deeper basin with low reflectivity.**
- **Links between facies and abundance distribution.**

Nodules abundance

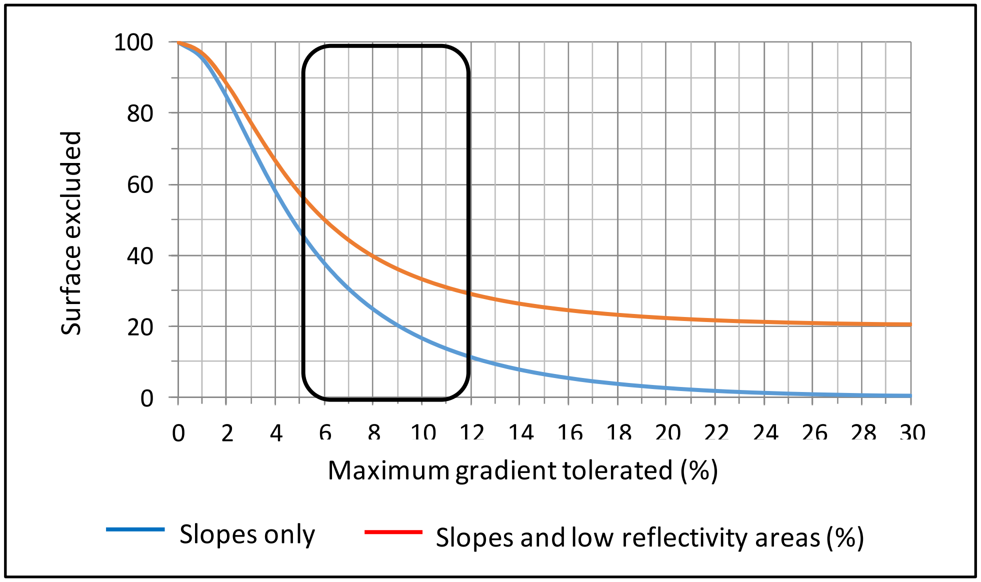


- **Interpreted nodule abundance map (photography and Nautile dives)**
- **High abundance over 15 kg/m² on the plateau, lower abundance on slopes and no nodules in the deeper basin.**
- **Small scale abundance variations not understood with a kilometer scale sampling**

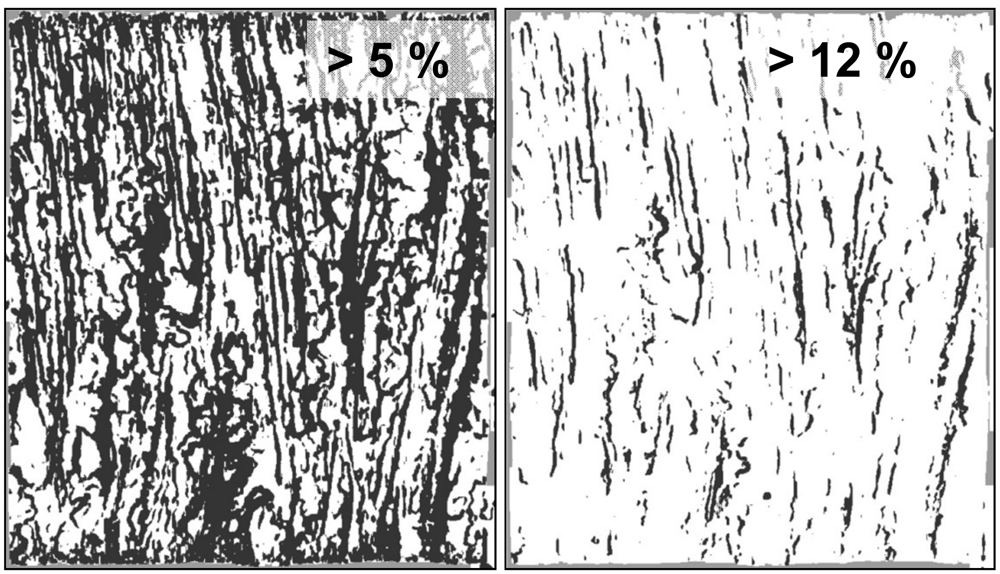
SEAFLOOR CHARACTERISTICS

Slopes, nodule free areas and smaller obstacles
Geotechnical measurements

Slope and Nodule free areas

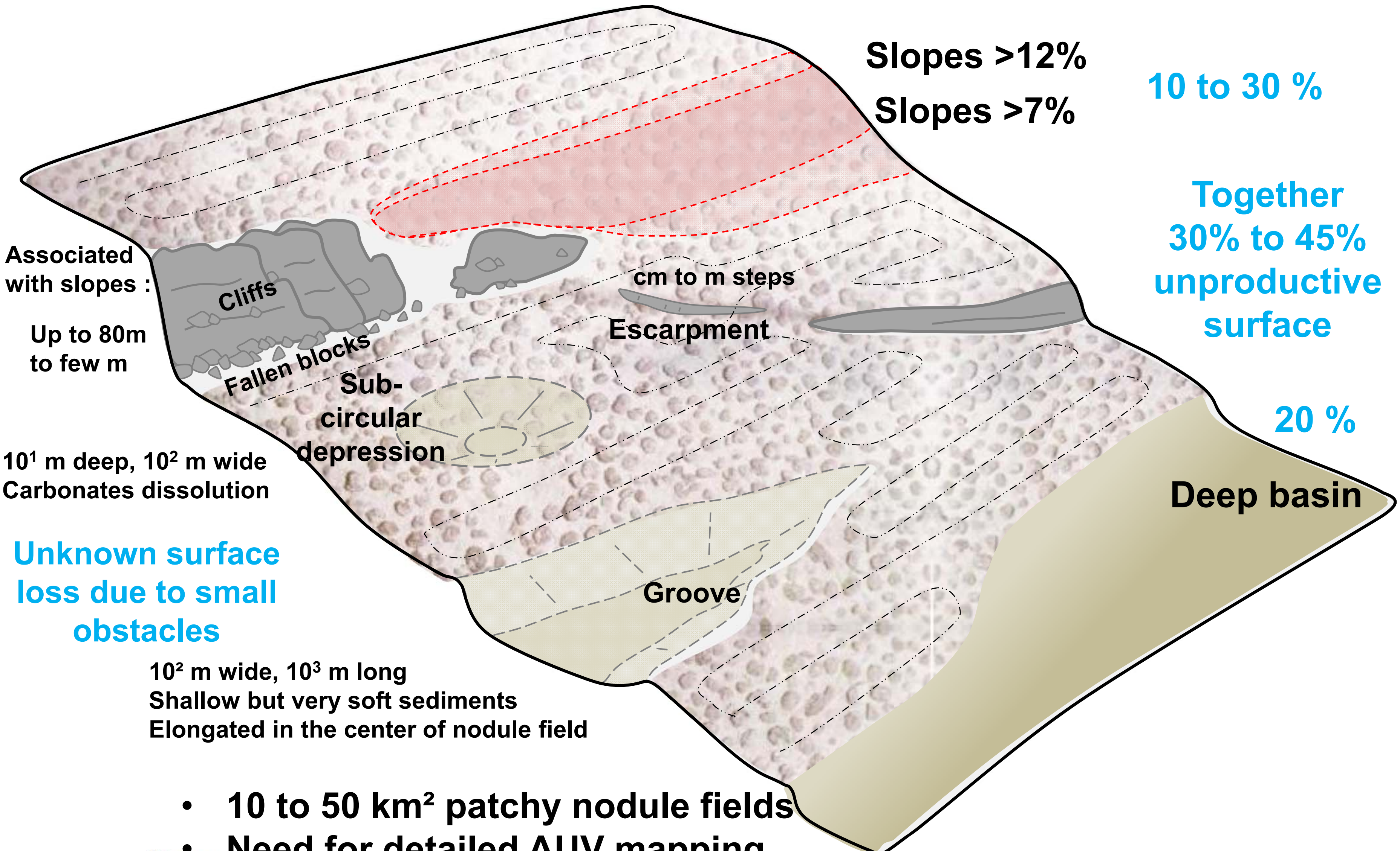


- Low reflectivity (white) and slopes above 7% (dark gray) on the BIONOD area (70x80 km).
- Over 40% of the total surface is lost.
- Excluded areas will hardly be below 30%



Gradients above 5% (left) and 12% (right)on the BIONOD area

Known obstacles on the seafloor



- 10 to 50 km² patchy nodule fields
- Need for detailed AUV mapping

Ifremer

Not to scale

Geotechnical measurement

- **86 % of superficial core samples in the CCFZ are siliceous clays.**
- **14 % are hard outcrops or crusts.**

Geotechnical parameters retained by GEMONOD :

Depth	10 cm	40 cm
Water content	250 % [160 – 280]	220 % [160 – 240]
Cu peak	3,5 kPa [2 – 6]	5,0 kPa [2 – 8]
Cu after rework	0,8 kPa	1 kPa

Cu : Cohesion undrained
Cu of hard outcrops and crusts to be crossed are over : 30-80 kPa

- **Soft siliceous clay.**
- **Cu increases rapidly with depth.**
- **Dramatic loss of cohesion after rework.**

In situ geotechnical measurement

Near seafloor side scan sonar image ~ 1 m resolution

+ near seafloor Acoustic profiles => thickness of sediment coverage

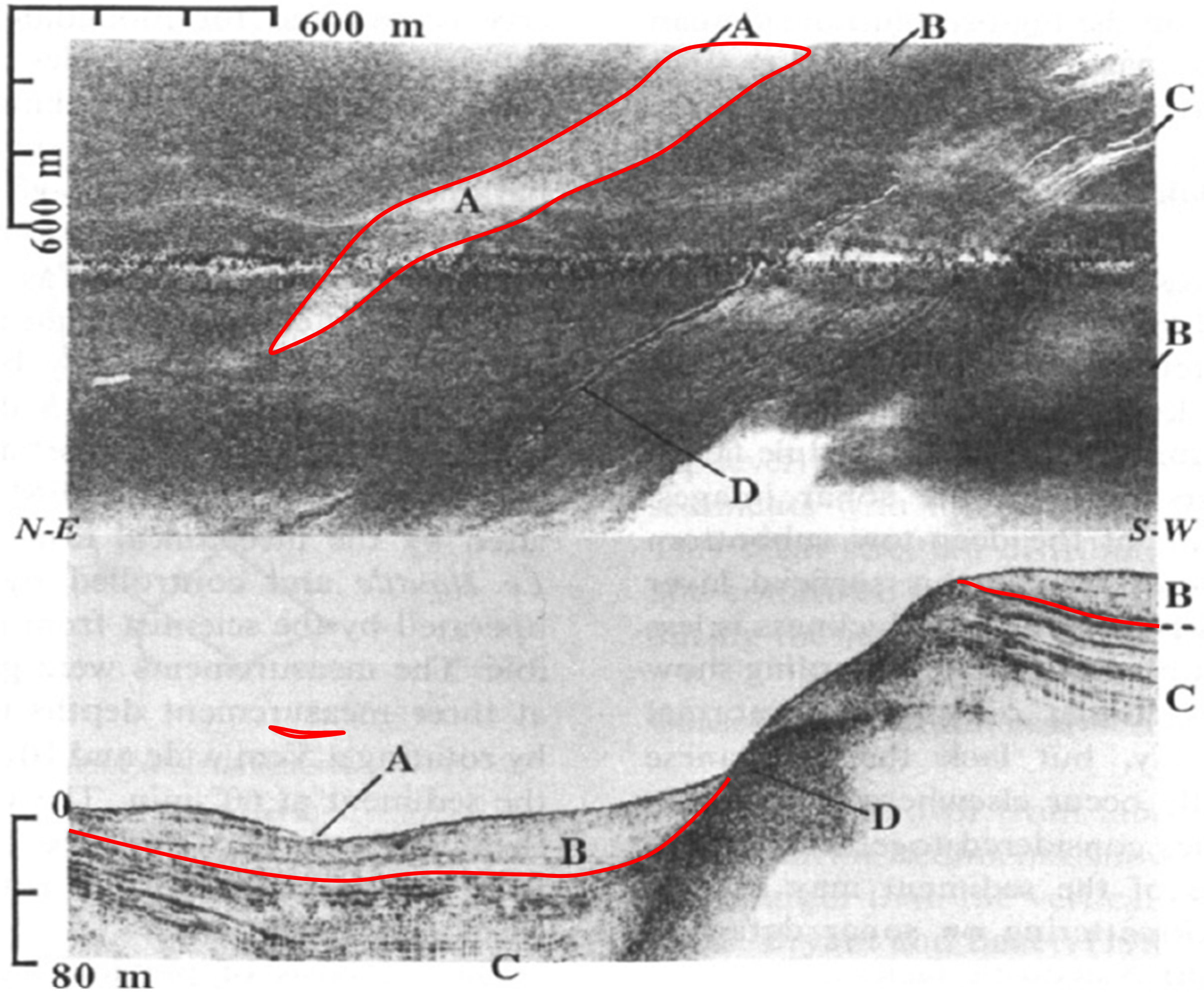


Fig. 2. Sidescan sonar data and associated subbottom profile acquired with the deep-towed acoustic system SAR showing the acoustic units existing in one of the investigated areas (14°35'N–130°42'W). Selected images which exhibit all the sedimentary sequences existing in the study area. A = low acoustic reflectivity facies of the seafloor (grey pattern on sonar image); B = transparent unit; C = stratified unit; D = acoustic basement.

P. Cochonat et al. 1992.
First in situ studies of nodule distribution and geotechnical measurements of associated deep-sea clay

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Geotechnical measurement

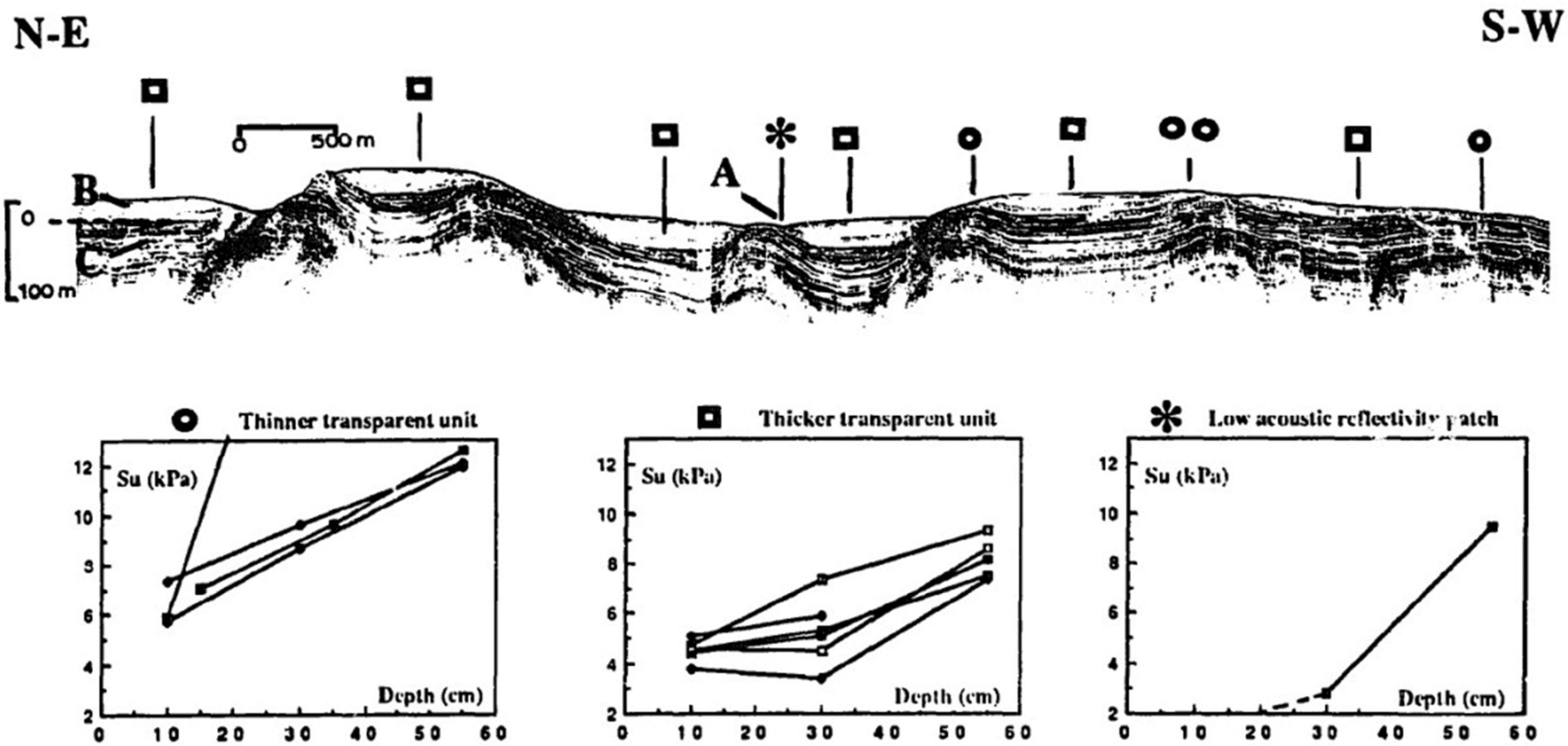


Fig. 5. Results of in situ vane shear measurements showing the three geotechnical facies distribution and the measurement stations in their morphological framework exhibited on a high resolution seismic profile. A = low acoustic reflectivity sonar facies; B = transparent unit; C = stratified unit; S_u = undrained shear strength (in situ vane shear strength in kPa).

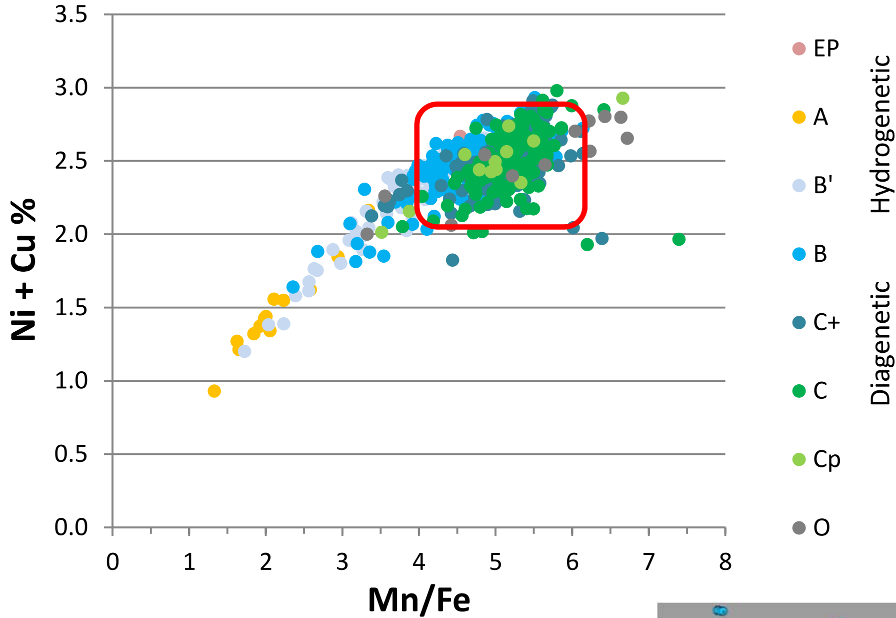
Cochonat et al. 1992.

Geotechnical measurement

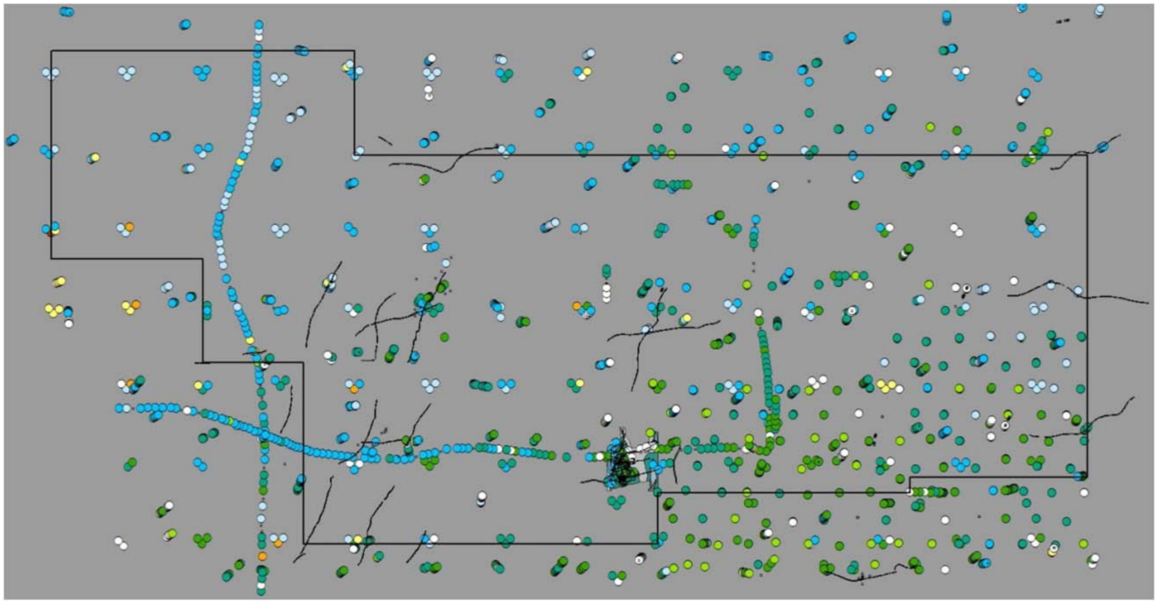
- **Cu is linked to sedimentation rates (thickness of unit B) :**
  - High sedimentation rates have lower Cu
  - Cohesion due to clay bounding and not to compaction.
- **Nodule free grooves with low Cu (A) are easily visible with low reflectivity on the side scan sonar but not on the sediments profiles (very thin unit).**
- **Expected small scale Cu variability (similar to nodule abundance) also linked to sedimentation rates**

METAL GRADES

Metal grades and facies



- **Hydrogenetic nodules less present on the area A (mainly in NW corner).**
- **Grades linked to facies (shape and size of nodules).**
- **Low variability of grades on the French permit in regards to abundance variations.**



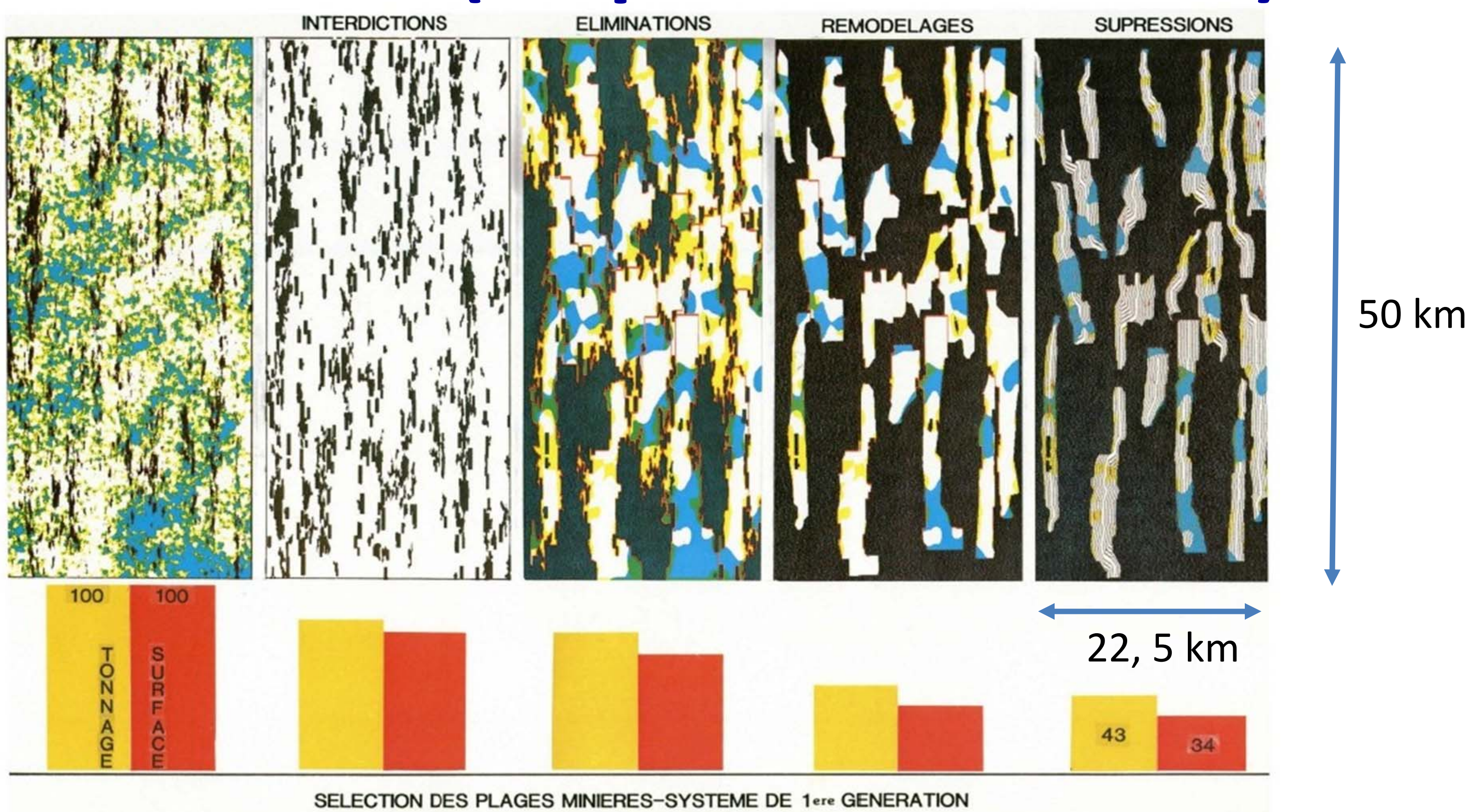
Average concentration

- Ni: 1,37%
- Cu: 1,25%
- Co: 0,25%
- Mn: 30%

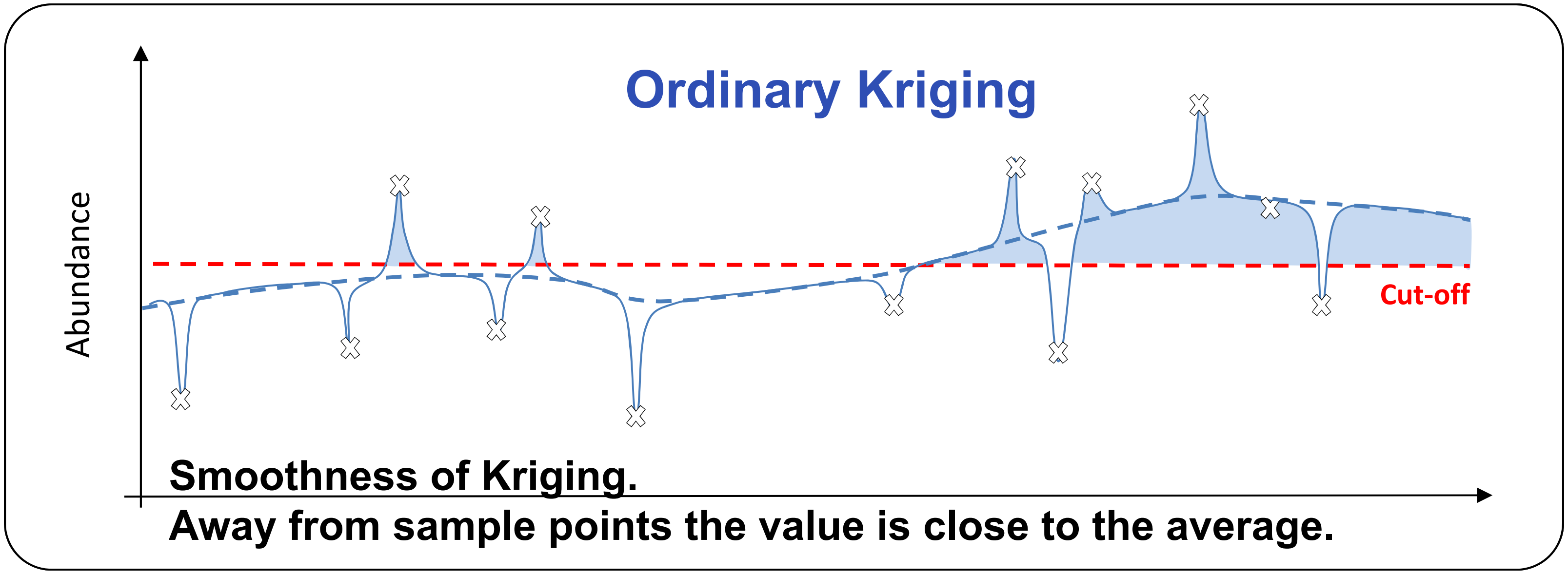
RESOURCE ESTIMATION

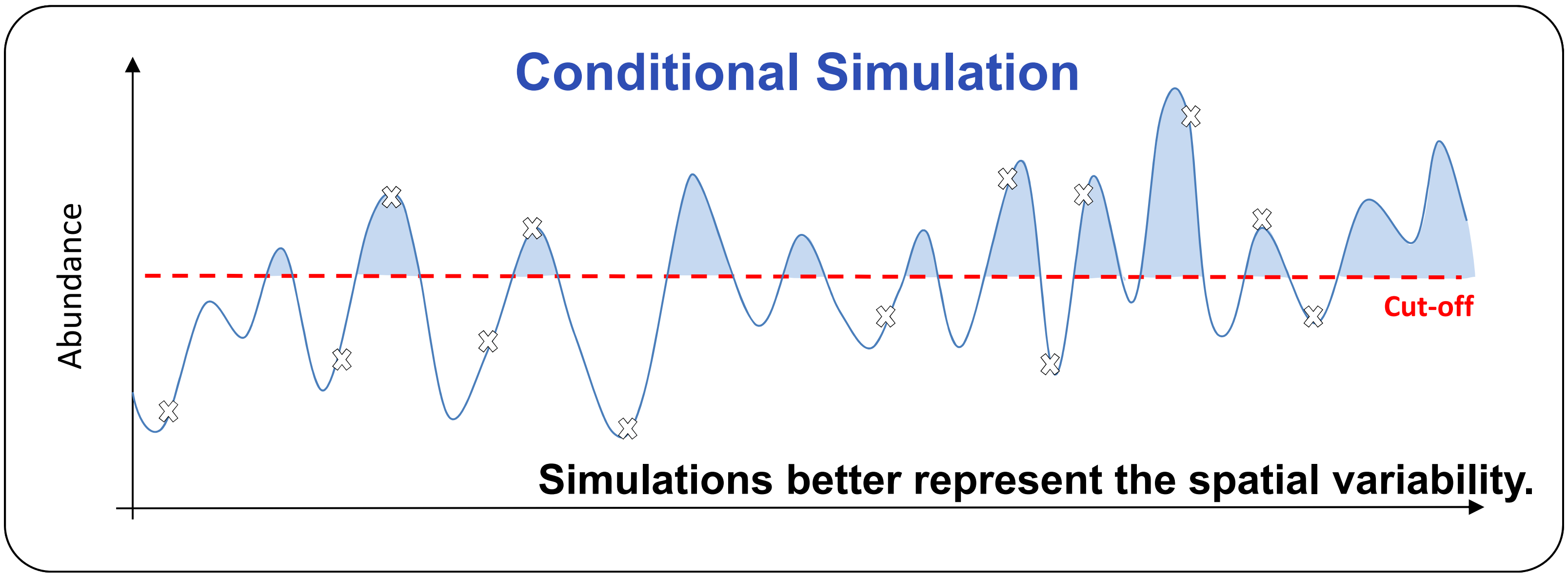
Historic GEMONOD and current work
Ordinary Kriging and Conditional Simulations

Simulation (Slope + abundance)

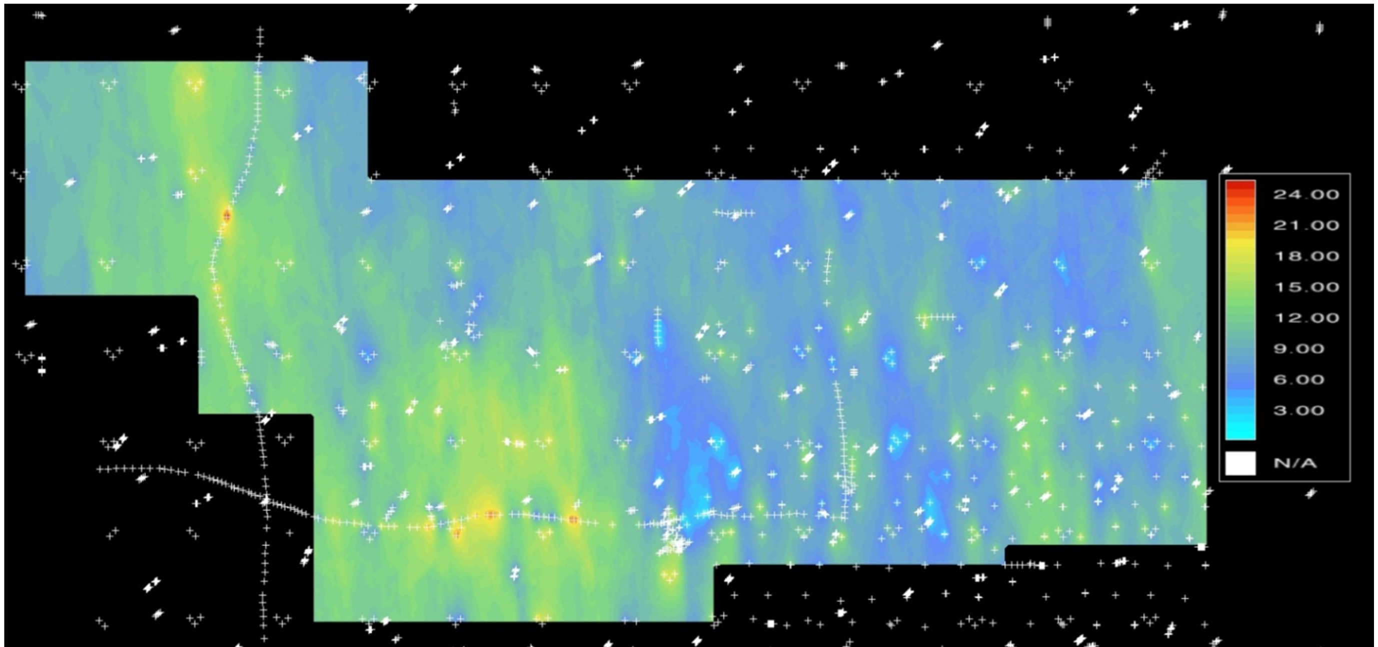


- **Exploitable fields selection process and corresponding losses in surface and tonnage.**
- **65 % surface loss expected (could be exploited by a collector of 2nd generation)**
- **Mineable areas = 1,2 to 5,2 km in width and 9,7 to 18.3 km long (N-S)**

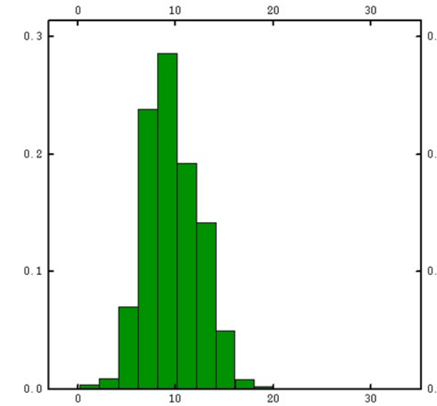

Ordinary Kriging
Abundance
Cut-off
Smoothness of Kriging.
Away from sample points the value is close to the average.


Conditional Simulation
Abundance
Cut-off
Simulations better represent the spatial variability.

Kriging (1 km blocks)

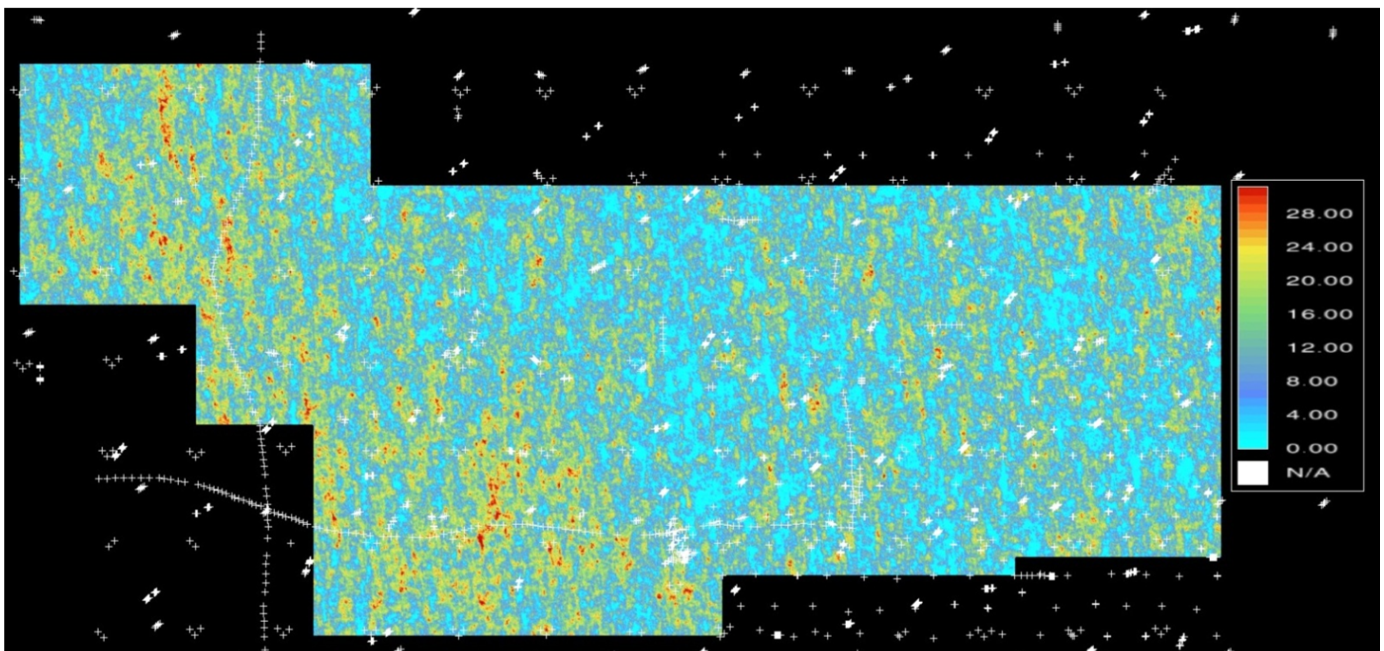


Contouring kriged abundance above cut-off doesn't give a realistic view of the resource

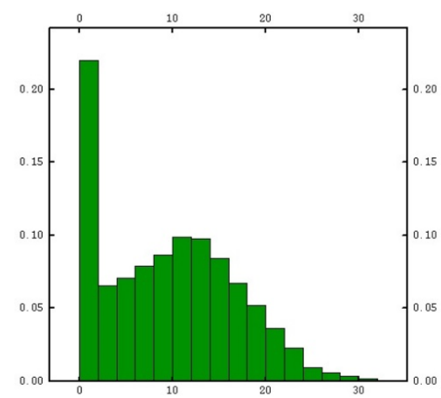


Loss of extreme values. Most of the values are close to the average.

Simulation (100 m blocks)

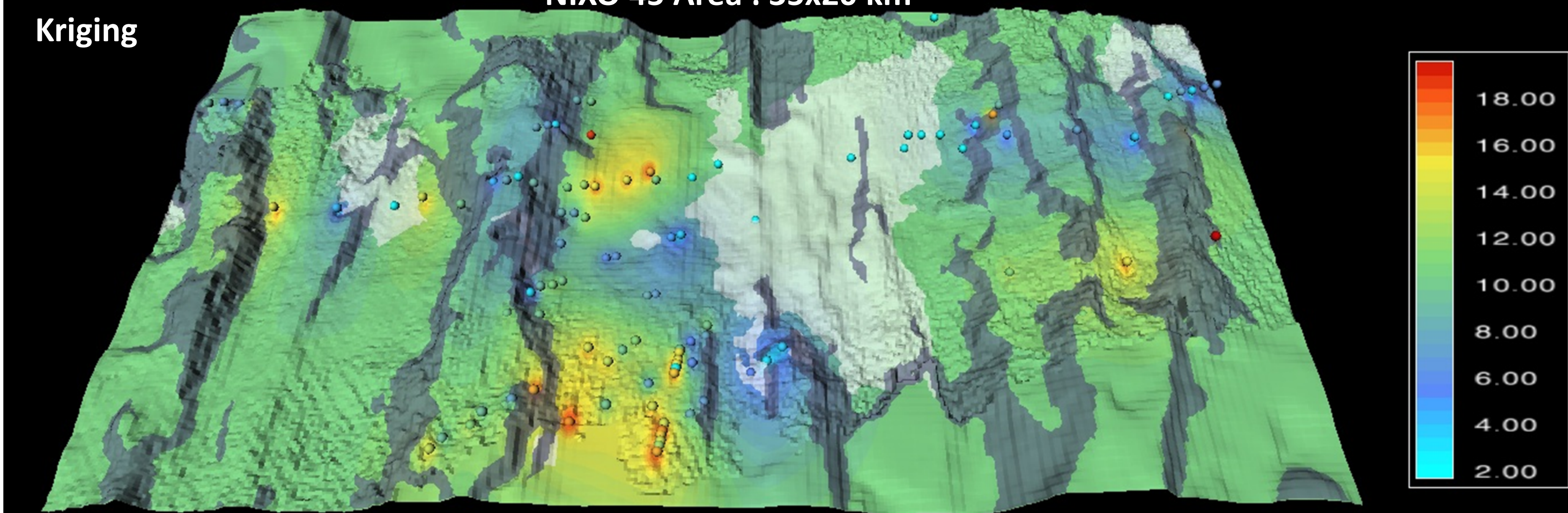


Contouring simulated abundance above cut-off is more realistic but doesn't give the true location

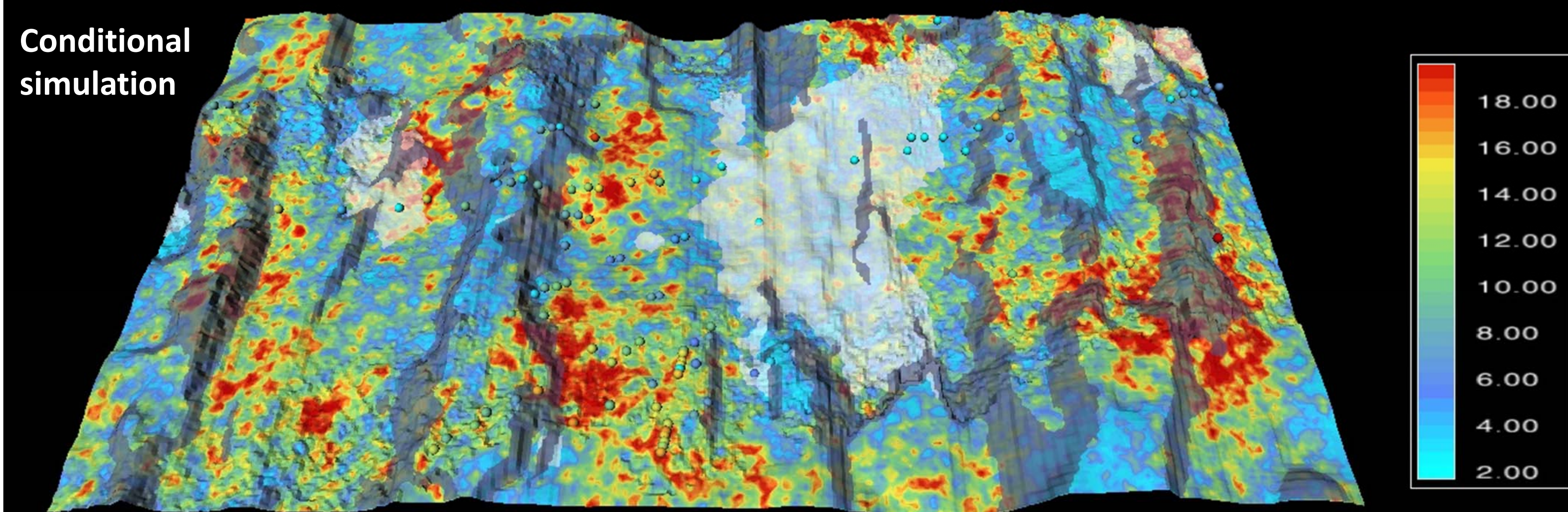


Closer to the data histogram.

NIXO 45 Area : 35x20 km



Most of the area without sampling has a value close to the average. Not representative of the reality.



Better representation of the spatial variability, but not correlated yet to slopes, reflectivity, sedimentation or others.

ANNUAL PRODUCTION AND DURATION OF MINING

Gemonod technical studies

1 - Geological and Meteorological environment

2 - Collecting strategy and technical specification

3 - Pipe study : rigid + flexible parts (corrosion/abrasion studies)

4 - Hydraulic lift (comparison of air lift and pumps)

5 - Surface operation and ship for transportation

6 - Processing technologies (hydrometallurgy and pyrometallurgy)

7 -Technical and economic studies

8 -Preliminary study of a pilot (France and Japan)

Technical and Economical study

- **Annual production: 1,5 Mt / year of dry nodules @ 14 kg/m² (GEMONOD) as a compromise between 3 factors :**
  - **Metal market (essentially French and European)**
  - **A collector strategy of (~350 t/h, 250 d/year)**
  - **Production costs**

- **Duration of Mining:**
  - **GEMONOD estimated from the simulation that 30.000 km² would provide enough nodules for over 50 years of mining (at 1,5 Mt/year).**
  - **Current work on inferred resource, expected to reach about 200 Mt of wet nodules (150 Mt dry) on the 45.000 km² (Zone A) for 50 to 100 years of mining.**

Collecting system

1- Dredging equipment

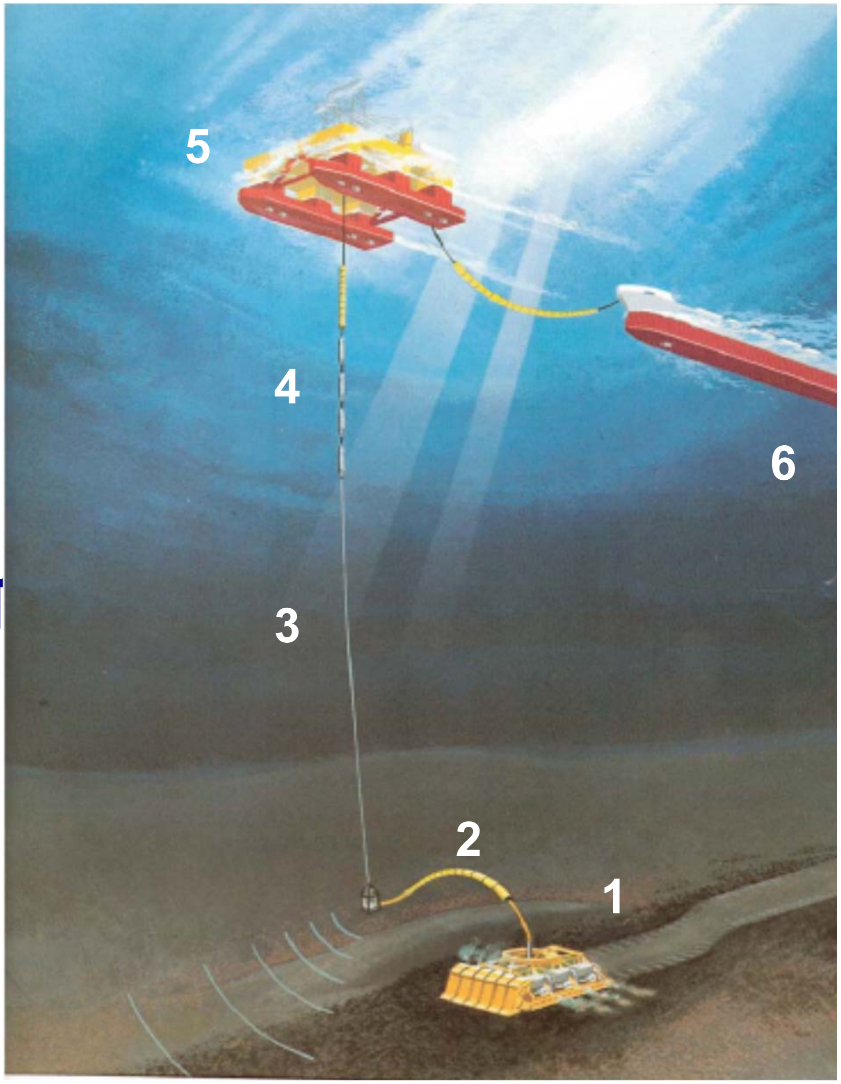
2- Flexible pipe 600m

3- Rigid pipe 4800 m

4- 4 pumps

5- Semi-submersible platform

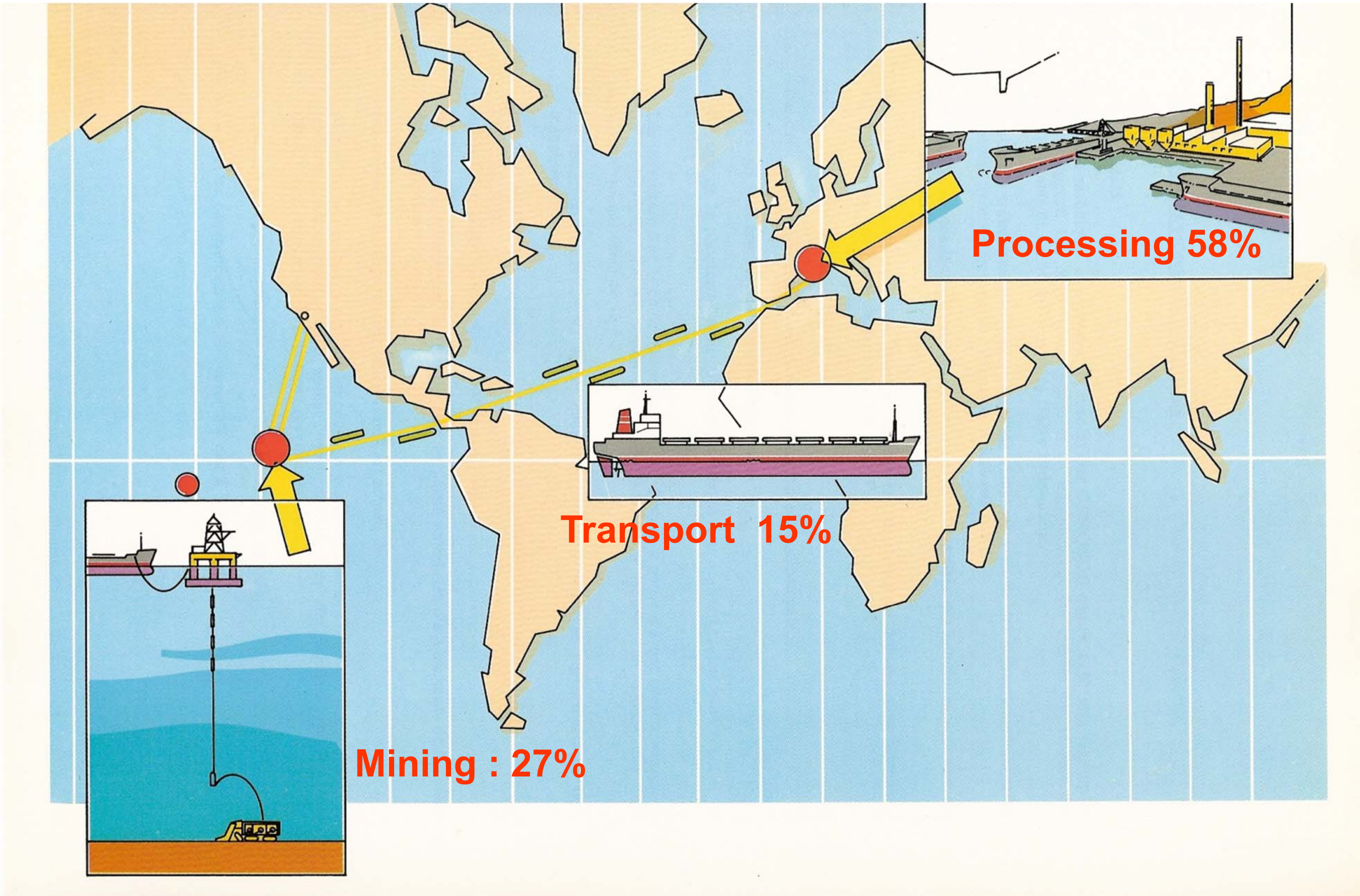
6- Transportation ship 60 000T



Operation stopped after 1990 before the pilot test, because of :

- Low metal prices
- Technological risk
- Funding

Estimation of mining operation costs



Some conclusions and perspectives

- **Importance of slopes on the resource estimation : need for a choice on the maximum slope .**
- **Unknown surface loss due to small obstacles: need for detailed mapping.**
- **Important local abundance variability: need for correlations with continuous parameters (bathymetry, reflectivity, pictures, slopes, sedimentation rate…) => need for AUV detailed mapping and box-corers for calibration + geotechnical parameters.**
- **Resource upgrade: inferred resource supports decades of mining. Upgrade to indicated resources on the whole license area is costly and not necessary at this stage.**

= > Detailed evaluation of resources and environmental strategy during mining to be validated by high resolution (1 m) mapping and acoustic imagery with new technology (deep AUV). Need of a pilot mining test .

Thank you for your attention