Imaging Basement & Intra-Sedimentary Horizons with Spectral Methods Applied to HRAM Data in Sirt Basin

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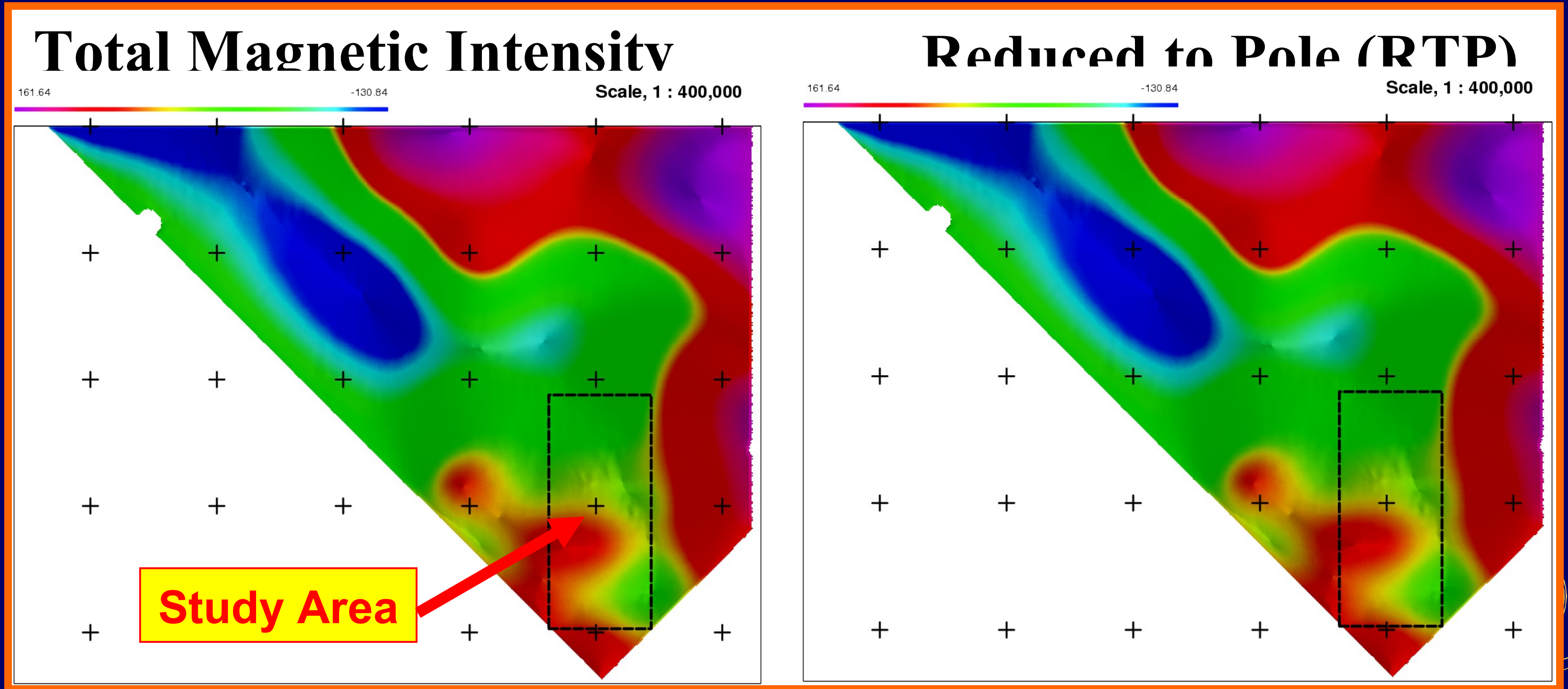
Outline

- Introduction
- Methodology
- Horizon Interpretation
  - Basement
  - Top Nubian
  - Unit 4 of Nubian SST
- Comparison with Well and Seismic data
- Conclusions

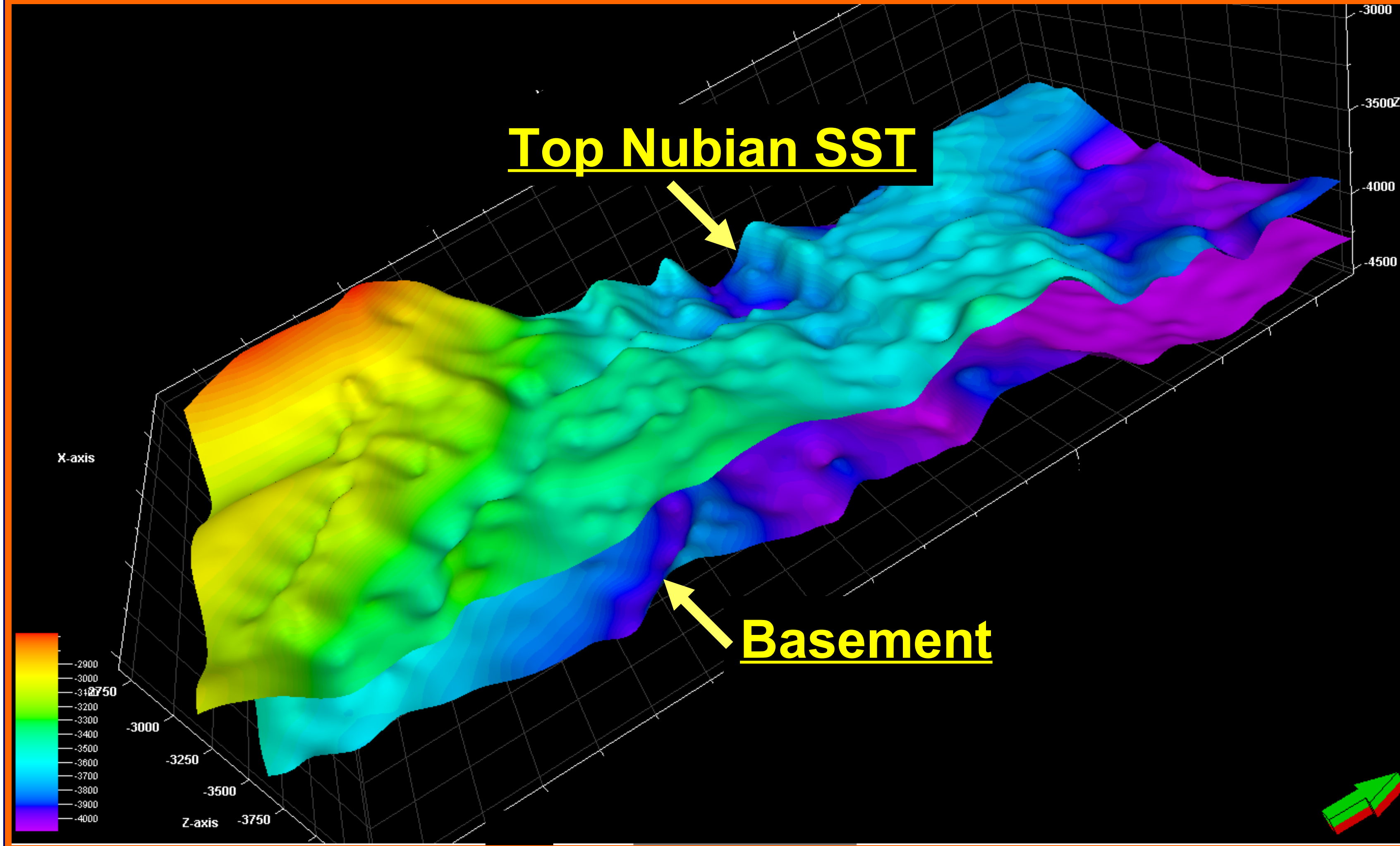
Introduction

- HRAM data was analysed over part of the Sirt Basin to image the Magnetic Horizons
- Survey Parameters:
  - Flight Line Spacing 500m
  - Tie Line Spacing 2500m
  - Flight Altitude 100m
  - Flight Line Direction NE-SW



Introduction

- **Spectral methods were used to map Basement & Top of Nubian SST Intra-Sedimentary Horizon.**



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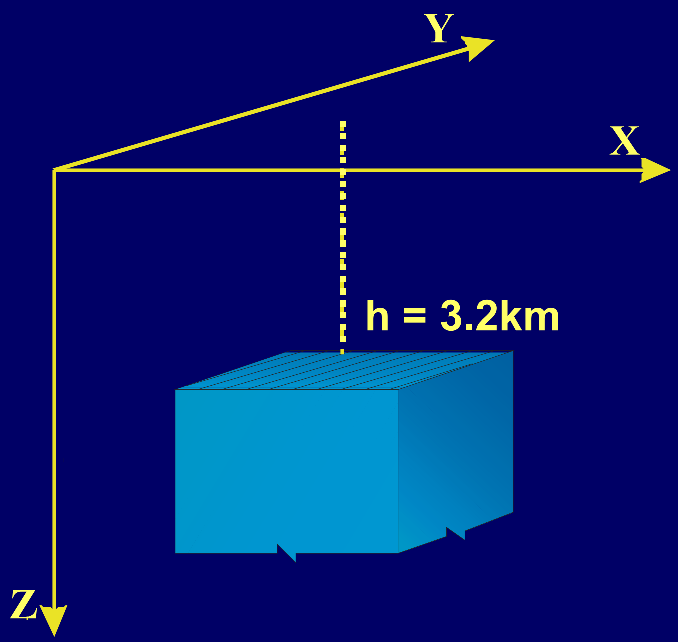
Methodology

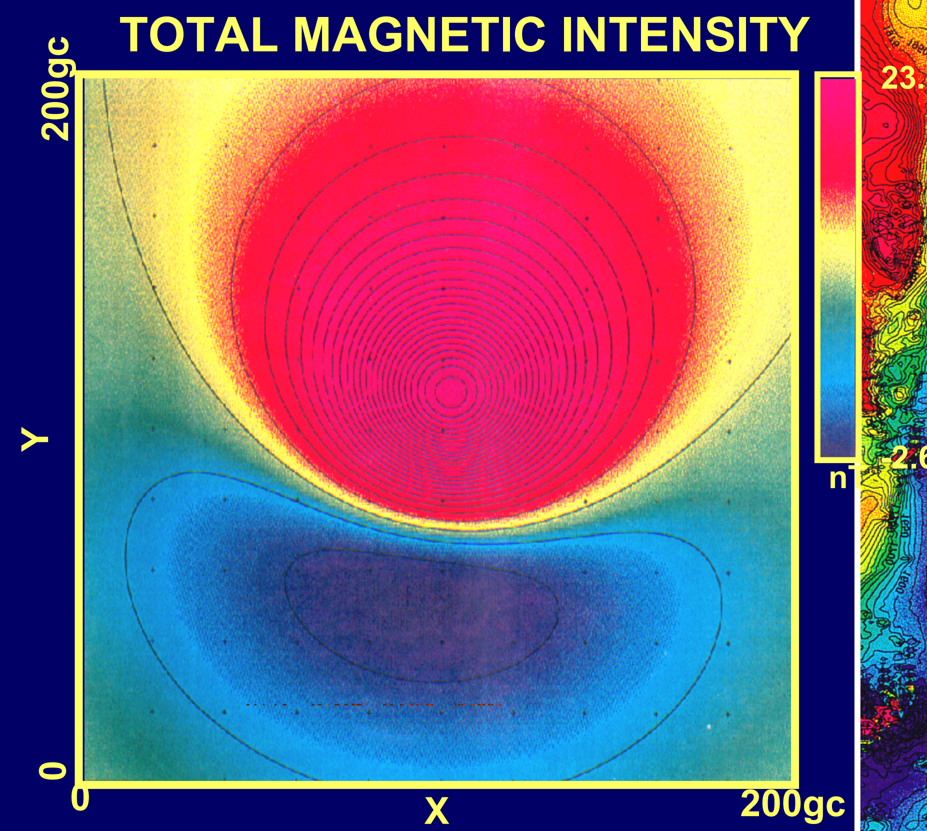
Energy Spectral Analysis

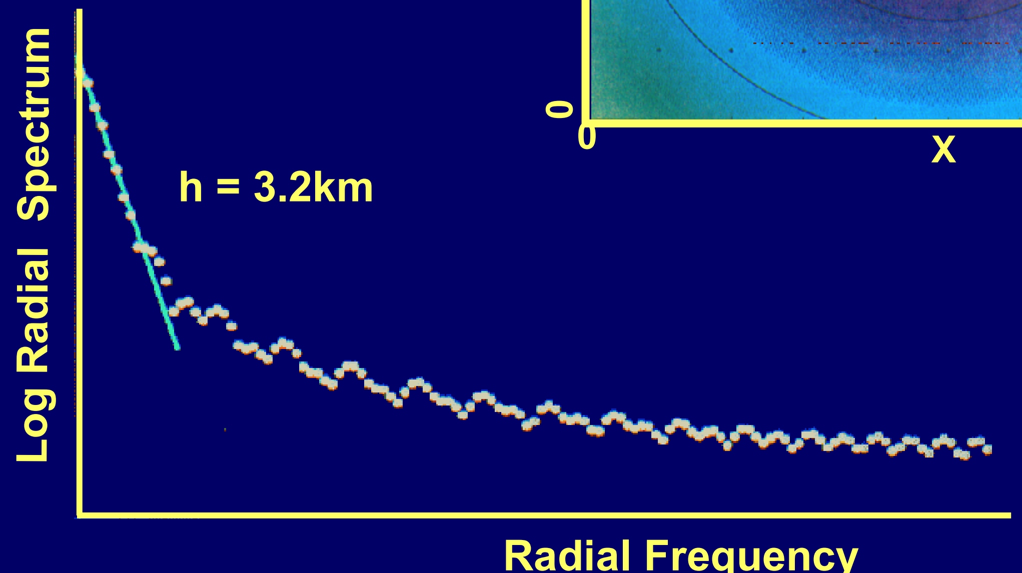
Basic Principles

- Theoretical Models
  - Single Vertical Prism
  - Multi-prisms Model

SINGLE PRISM MODEL







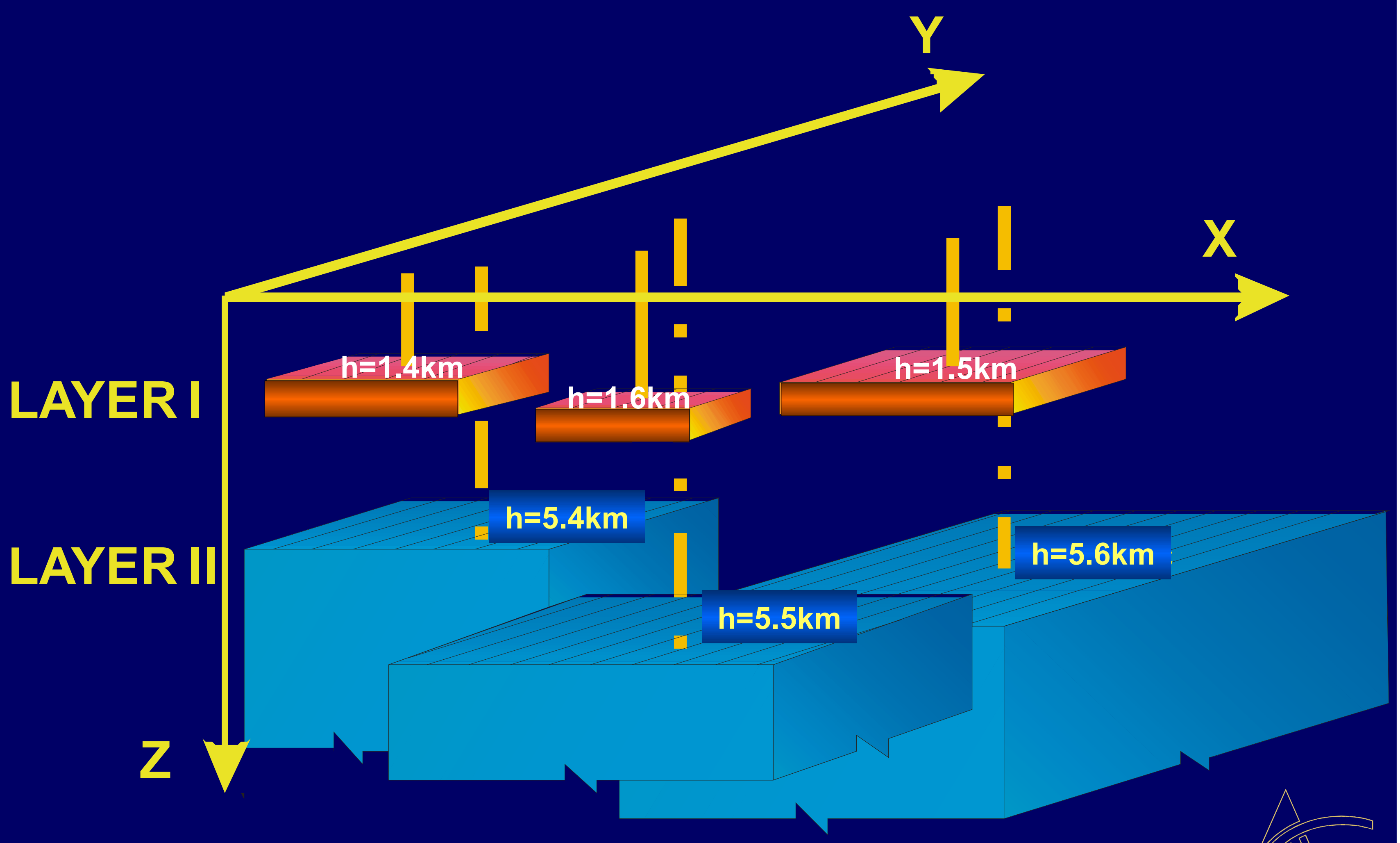
Methodology

Energy Spectral Analysis

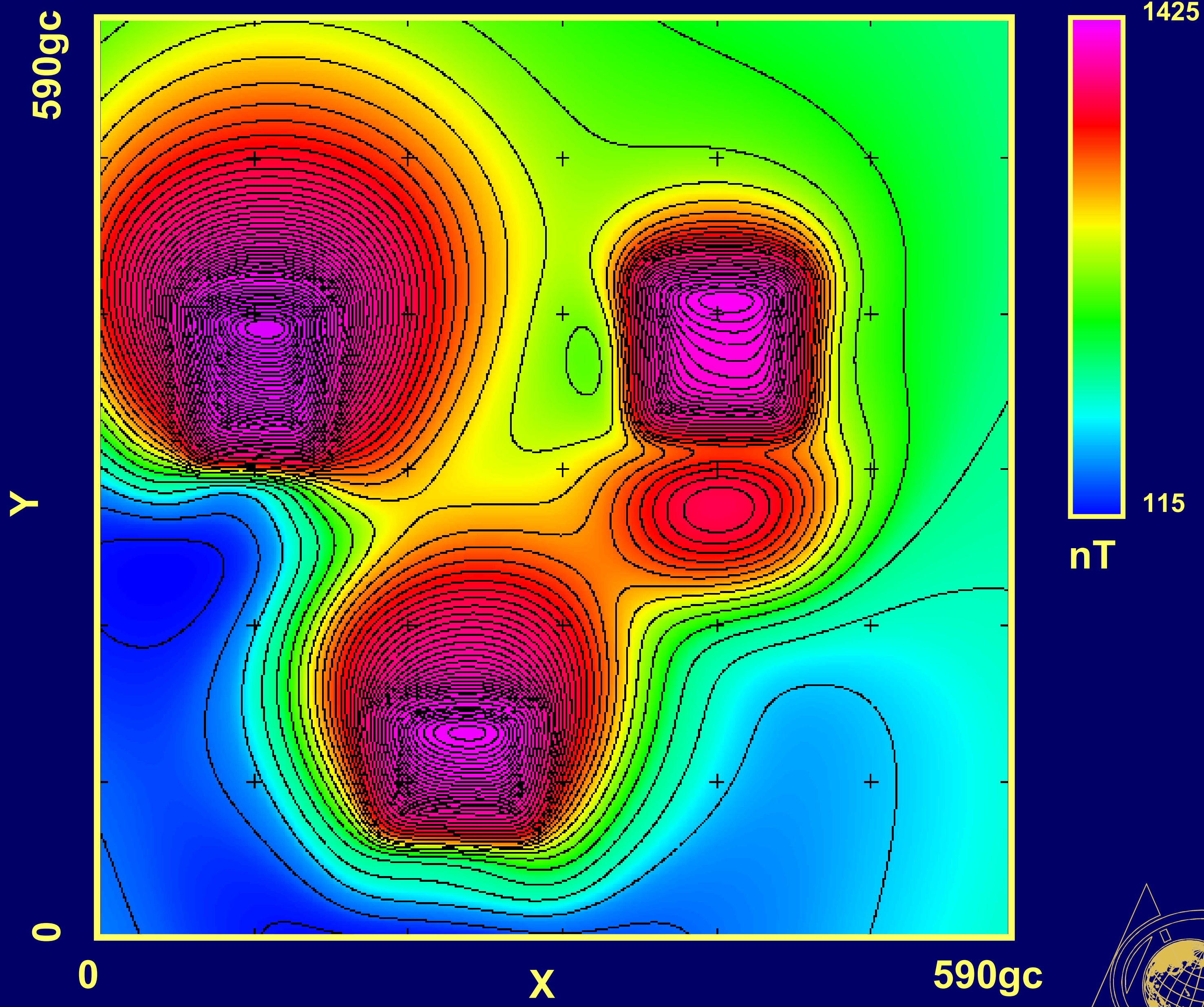
Basic Principles

- Theoretical Models
  - Single Vertical Prism
  - Multi-prisms Model

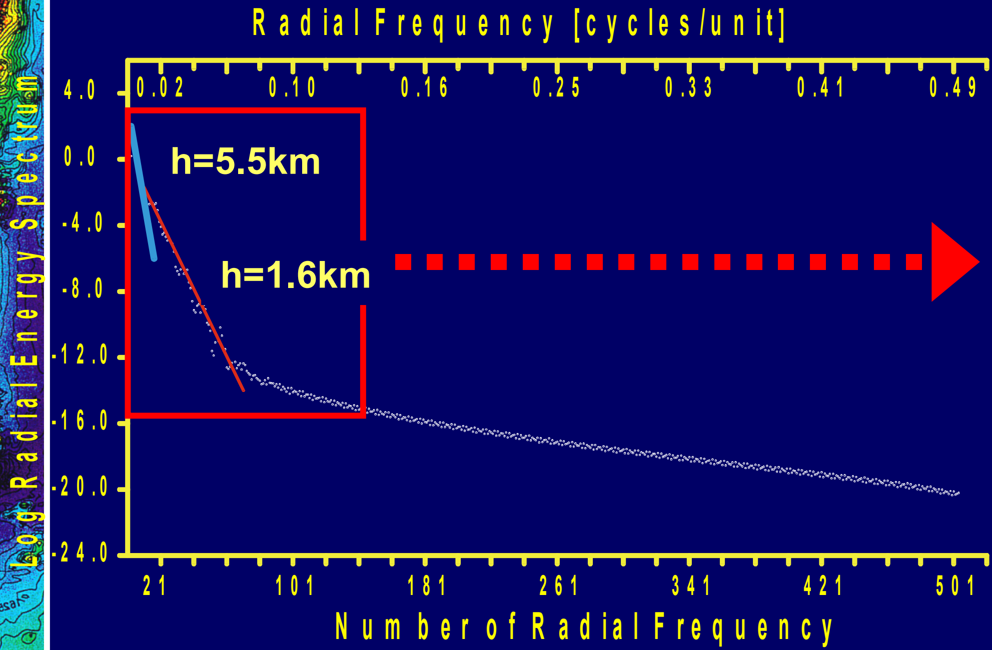
Methodology: Multi-Prism Model

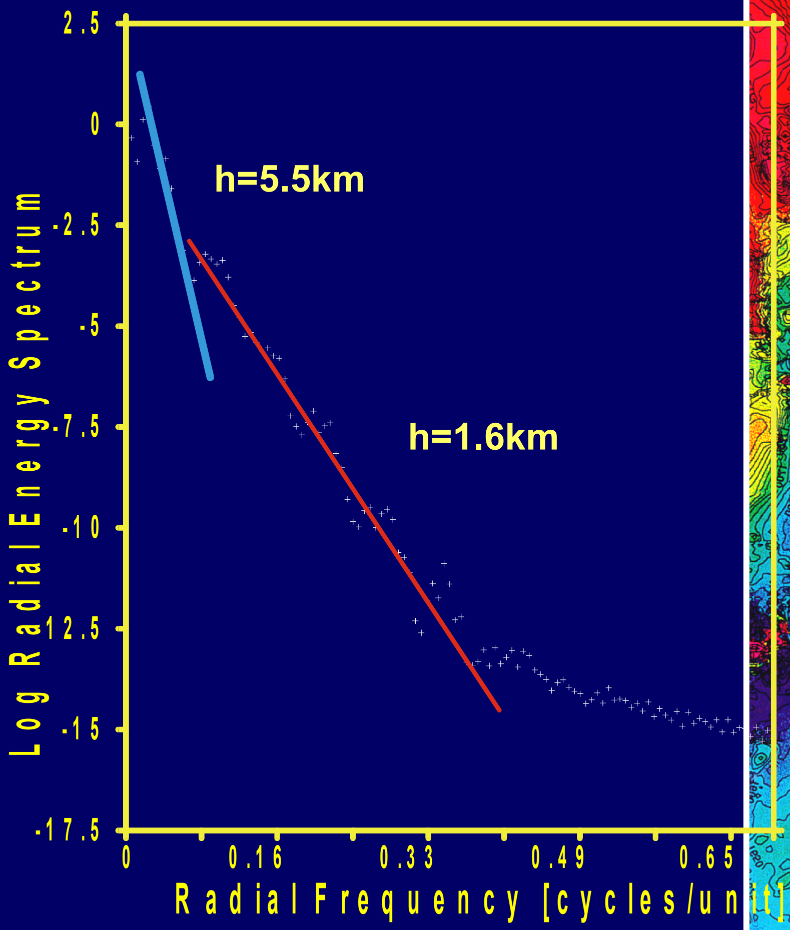


MULTI-PRISMS MODEL - TMI



MULTI-PRISMS MODEL: ENERGY SPECTRUM

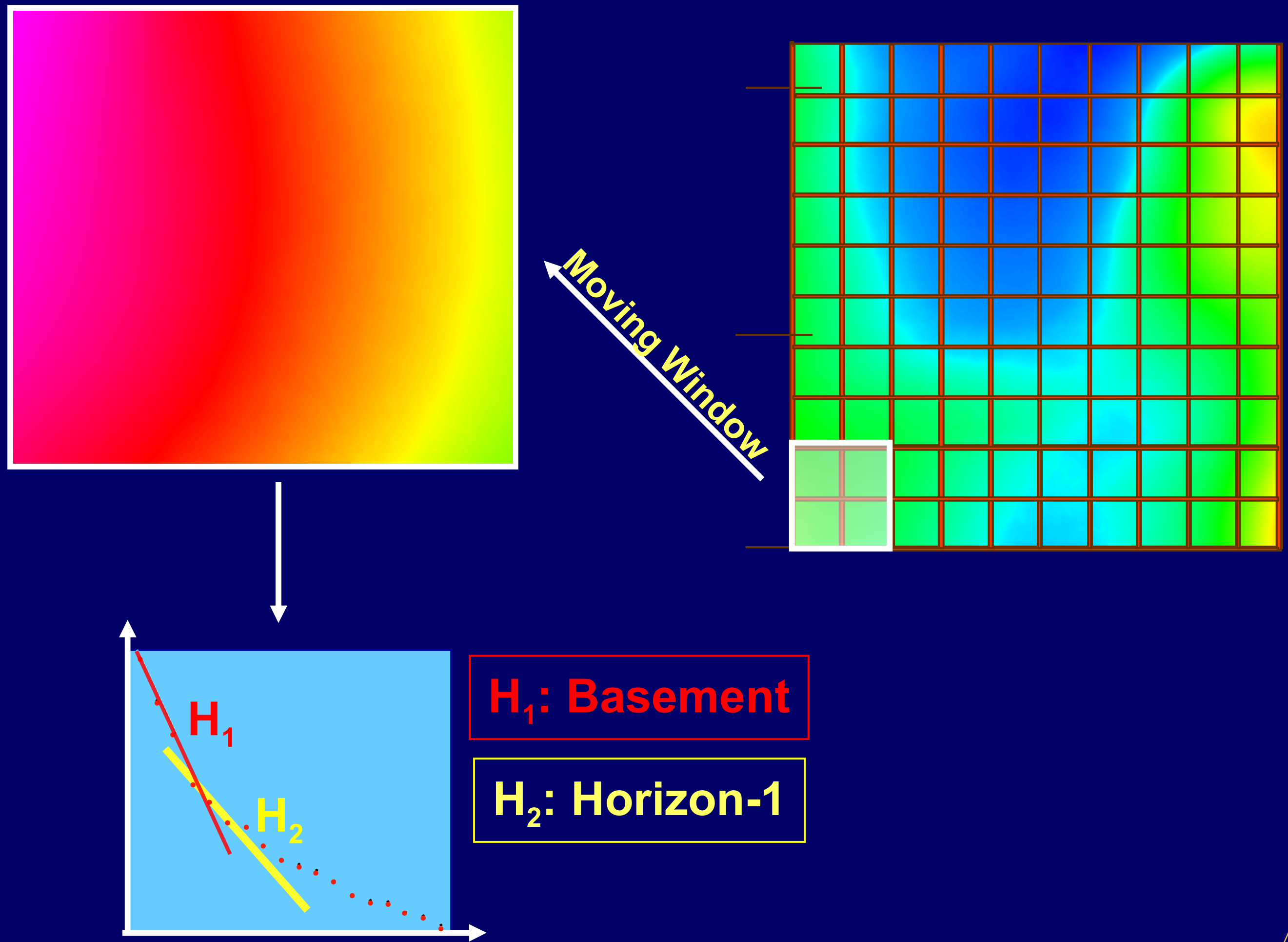




DETAIL OF LOW FREQUENCIES

Methodology

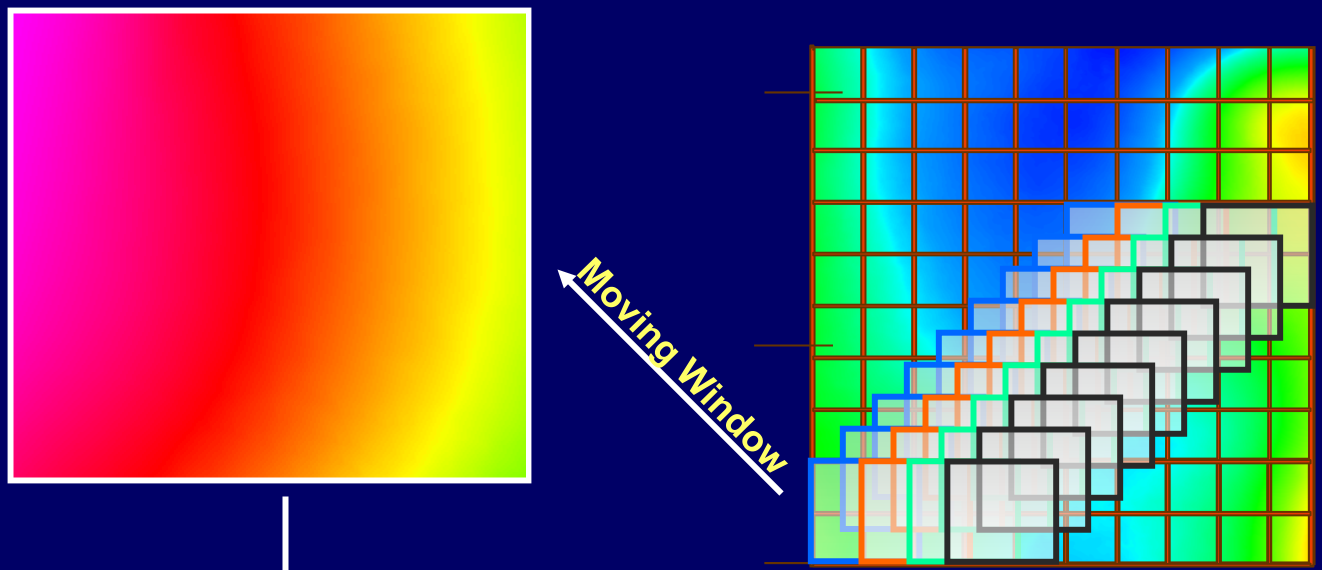
ESA Moving Window

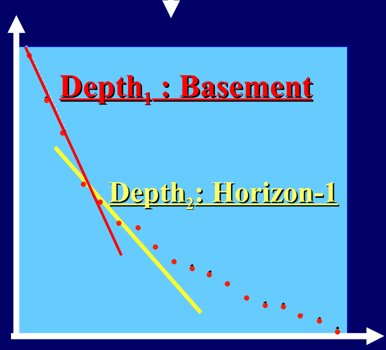


Spectrum: Row-1, Column-1

Methodology

ESA Moving Window





Spectrum: r-1, c-1

- Moving-Window increment e.g. 1x1gc
- Depth to Horizons every gc

Methodology: ESA-MW

Depth to Magnetic Horizons

- A large number of spectra are computed for each interpreted horizon
- Each horizon is imaged using
  - Semi-automatic depth calculation
  - Fully-automatic depth calculation - AutoESA

Methodology: ESA-MW

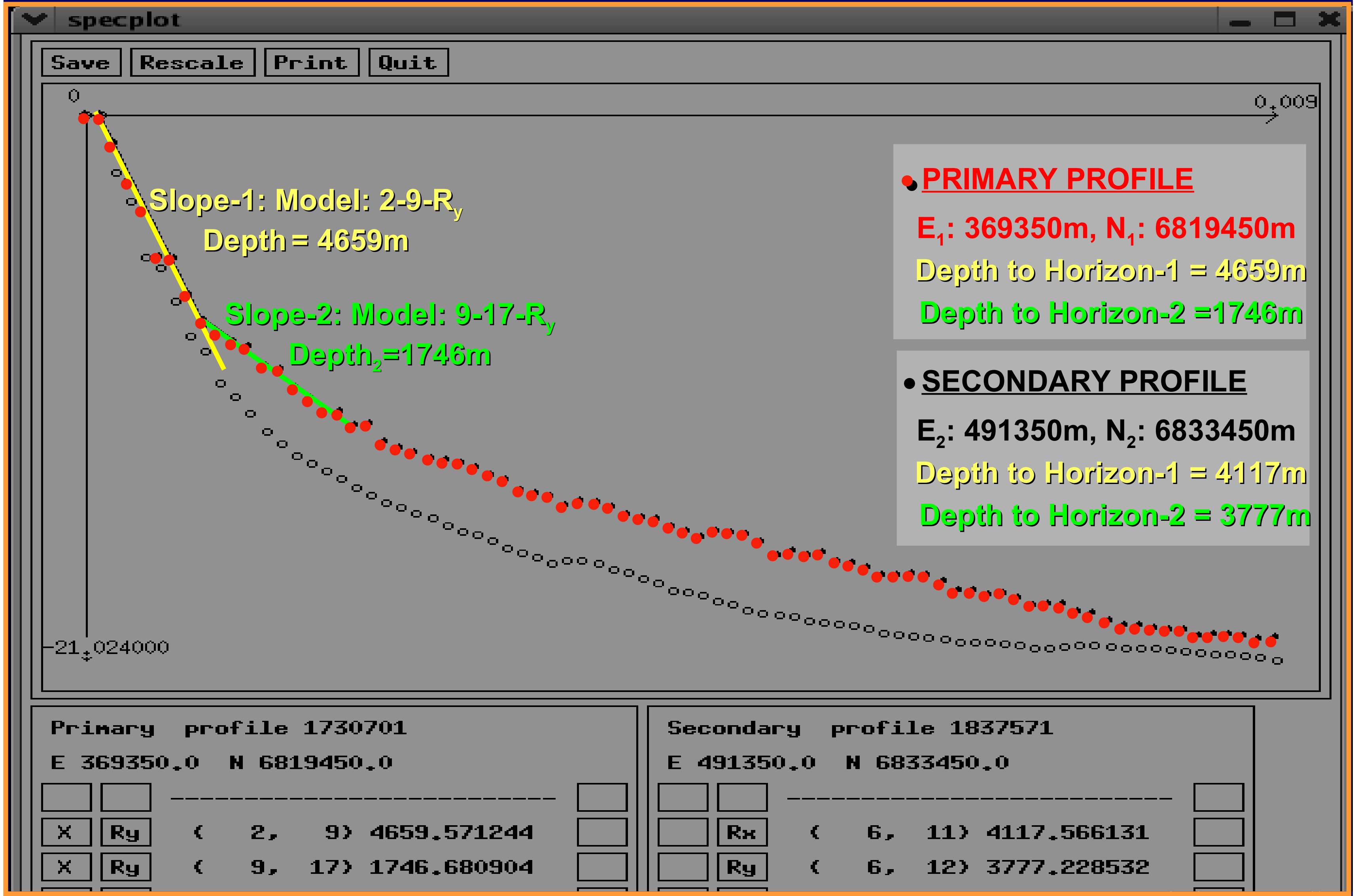
Depth to Magnetic Horizons

- Semi-Automatic Depth Calculation
- AutoESA: Fully-automatic Depth Calculation

Sedimantary Basin

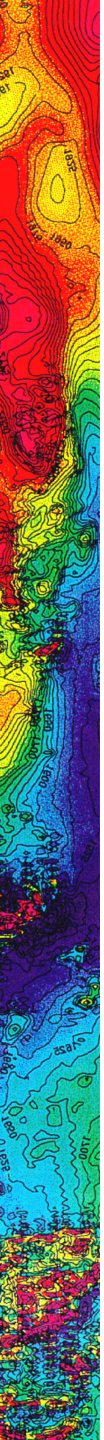
ESA-MW: Semi-Automatic Depth Interpretation

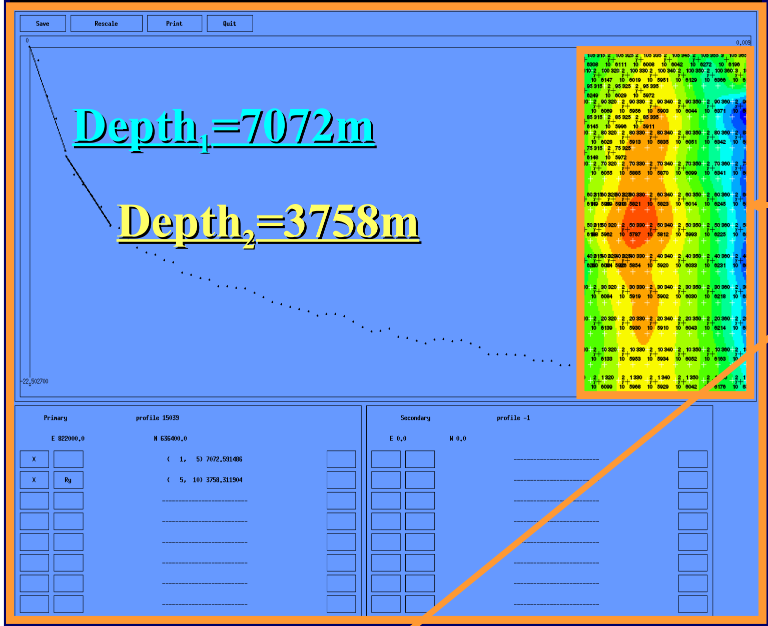
Spectra Window 12.8x12.8km: Horizon-1 & Horizon-2



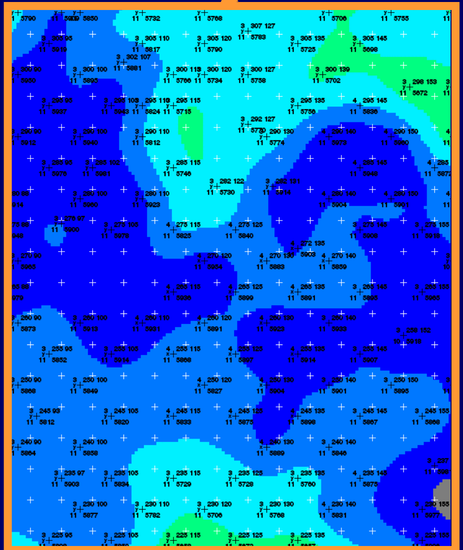
ESA 'Moving Window'

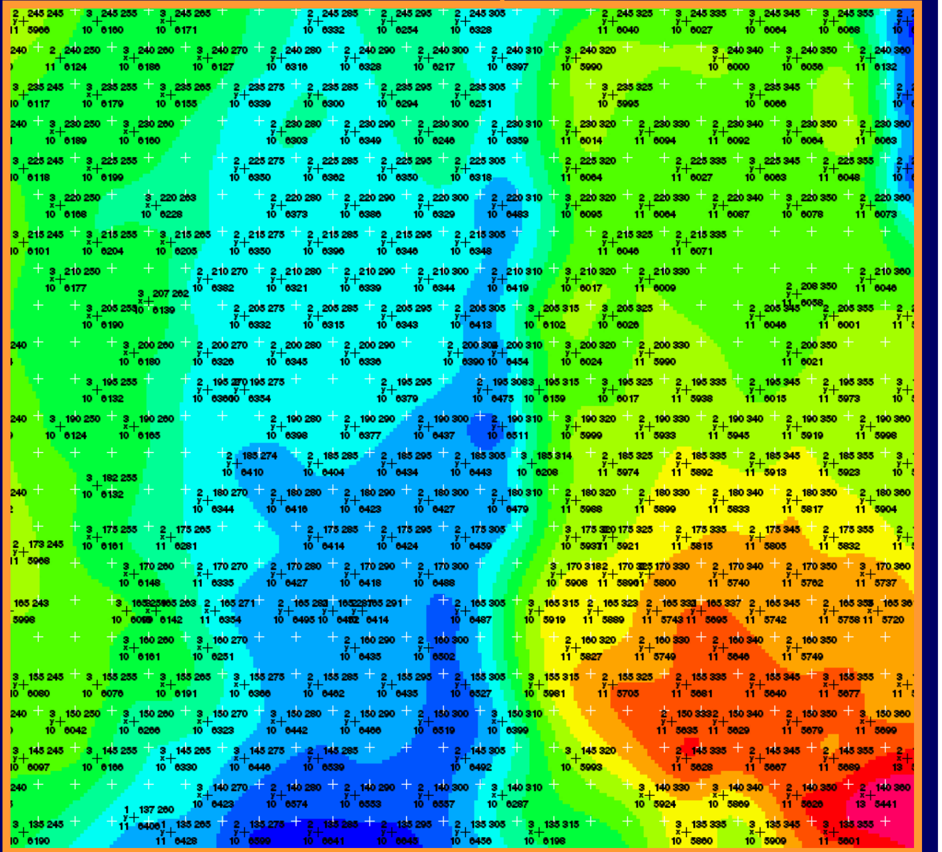
Semi-Automatic Depth Calculation

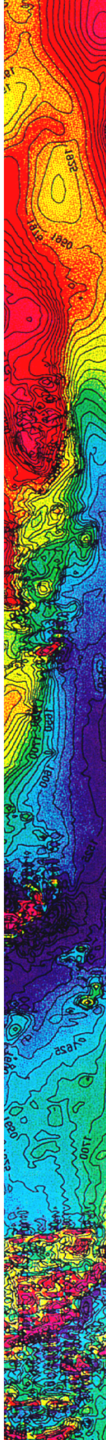




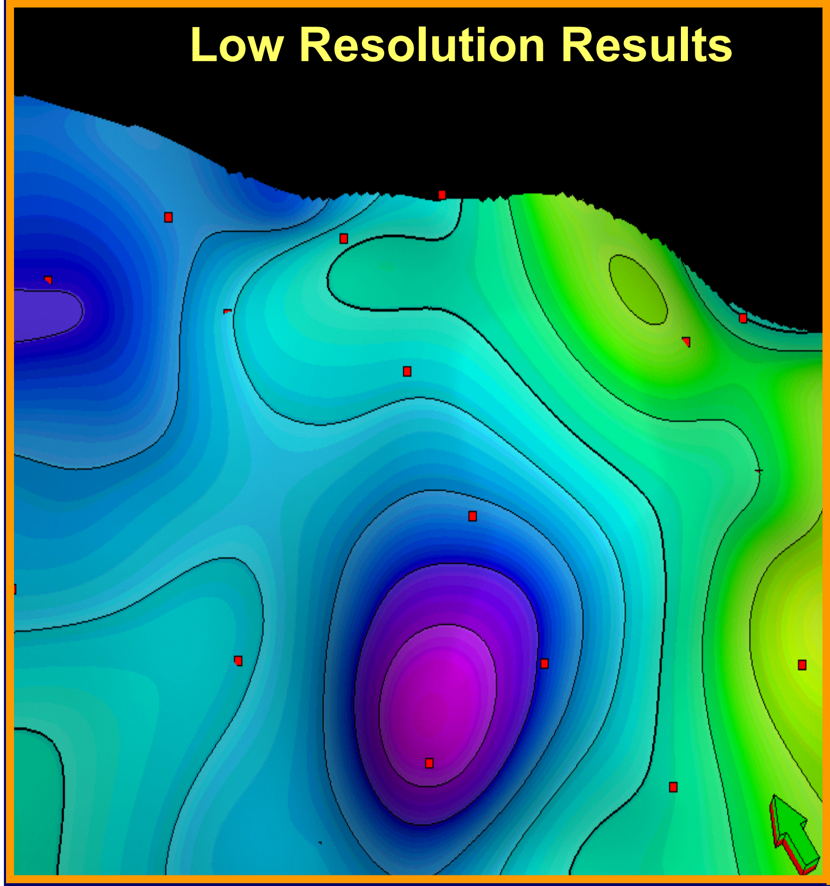
Live Image of Interpreted Magnetic Basement

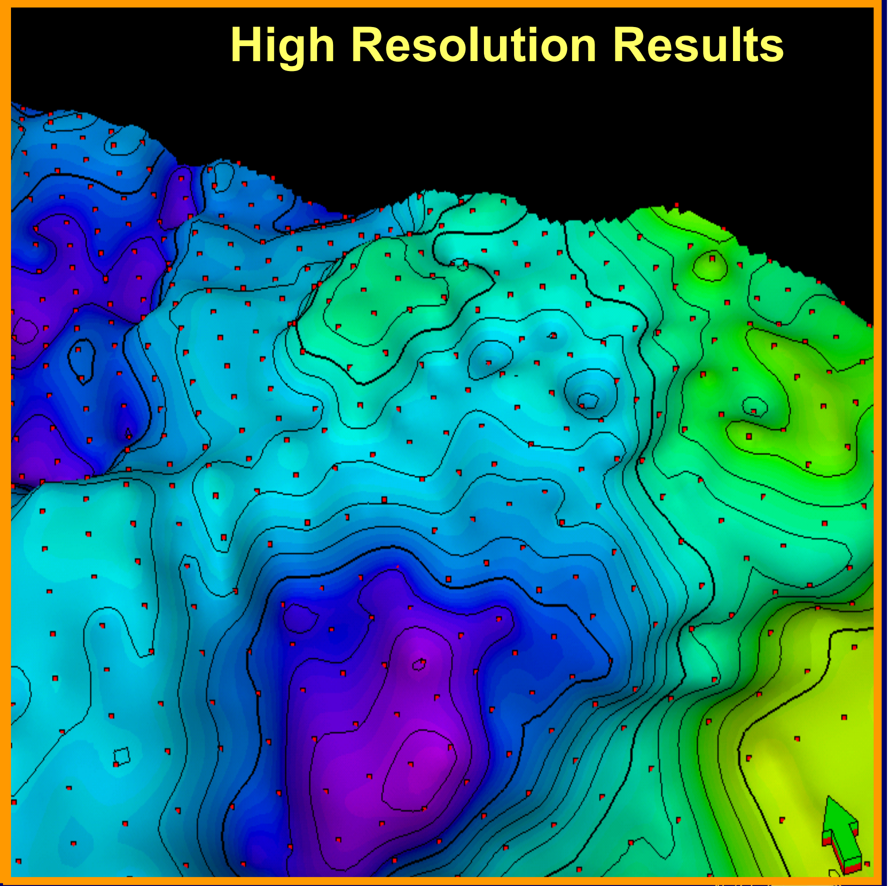






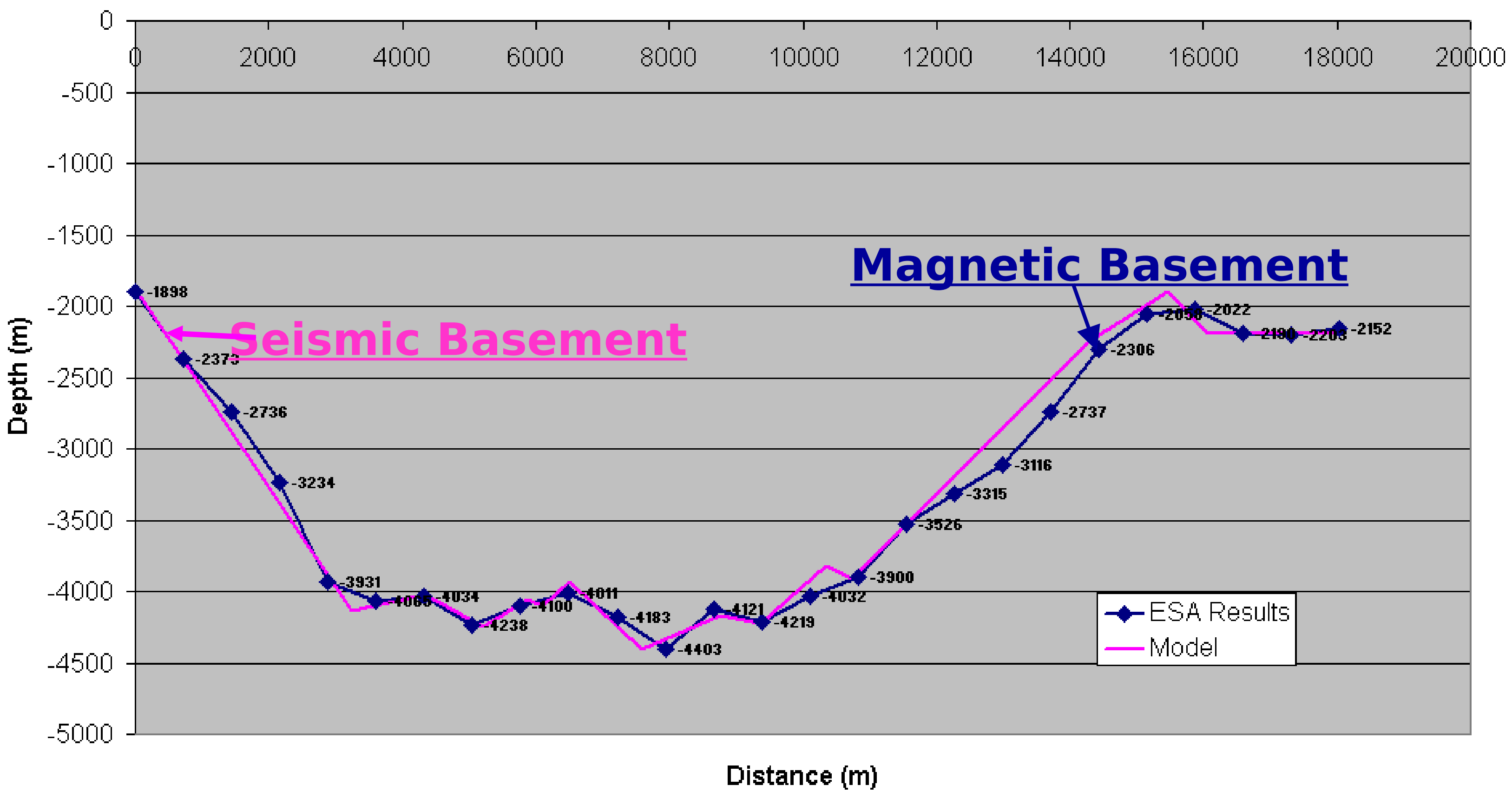
Low & High Resolution Interpretation of HRAM Data





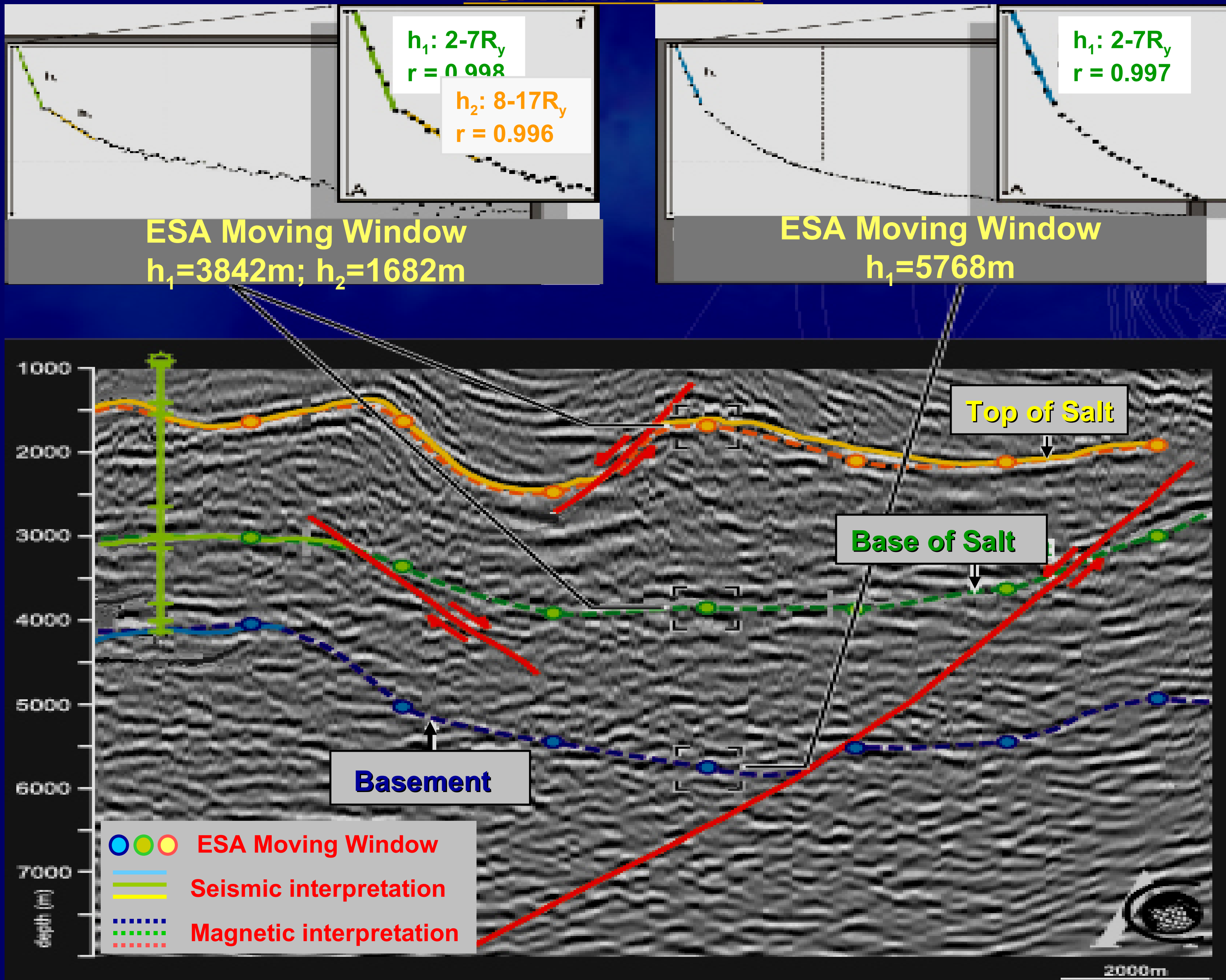
ESA 'Moving Window'

Depth to Magnetic Basement



Top Salt, Base Salt, Basement

ESA-MW of TMI

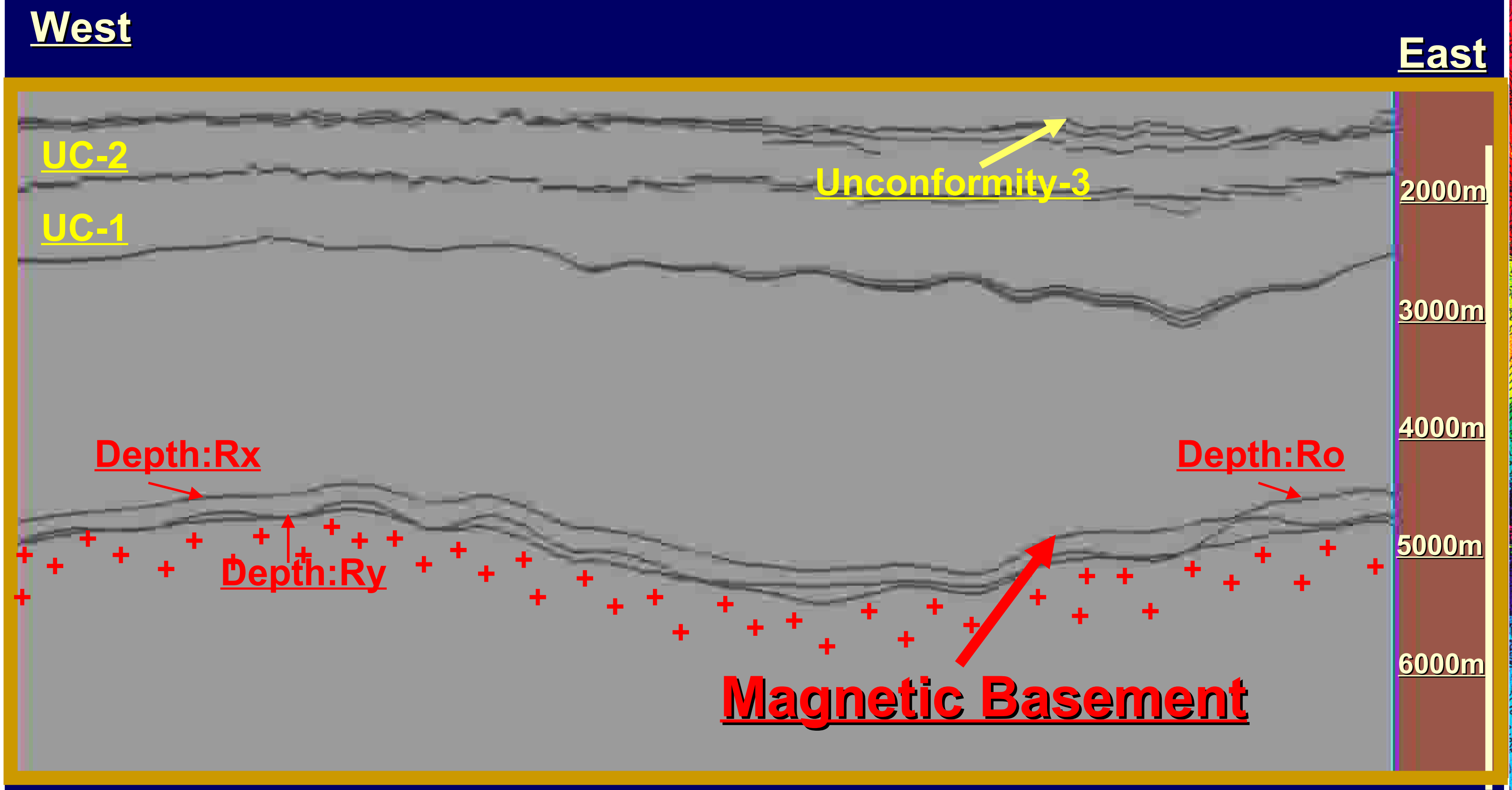


ESA 'Moving Window' Technique

– Depth to Magnetic Horizons
  - Semi-automatic Depth Calculation
  - AutoESA: Fully-automatic Depth Calculation

Basement & Intra-Sedimentary Horizons

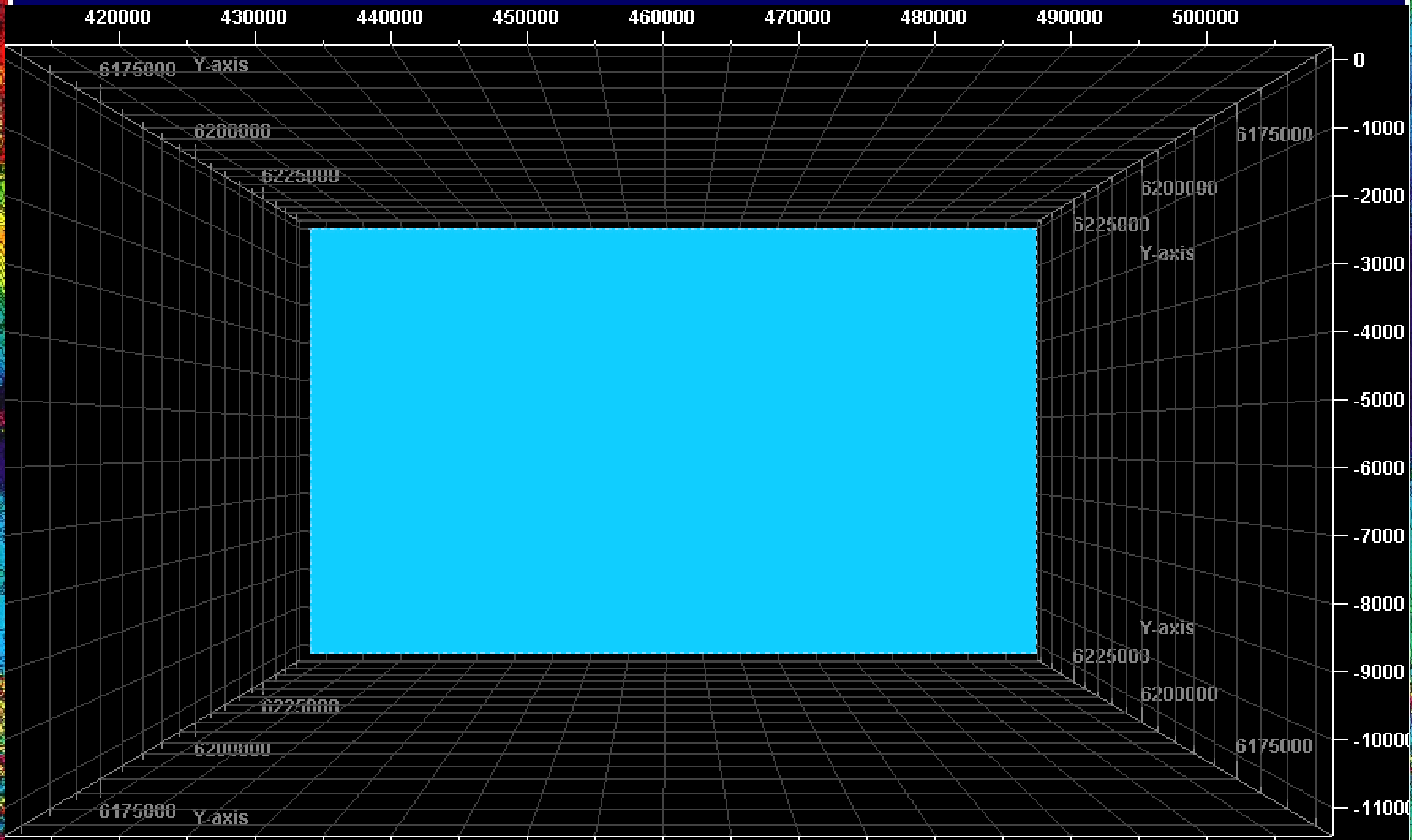
Detected by AutoESA of TMI



Comparison of AutoESA & Semi-Automatic

Basement Interpretation

EW Cross-Section in 3D-Volume



ESA ‘Moving Window’ Window Size

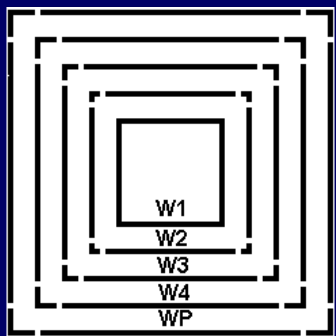
- Calculated depth can depend on the window size
  - too small window will not properly cover the anomalies
  - too large window will introduce averaging and possibly image a deeper structure
- Optimal size of each window is detected using the Multi-Window Test

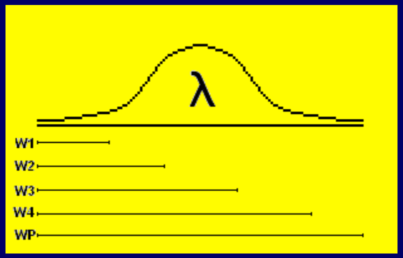
AutoESA
Multi Window Test

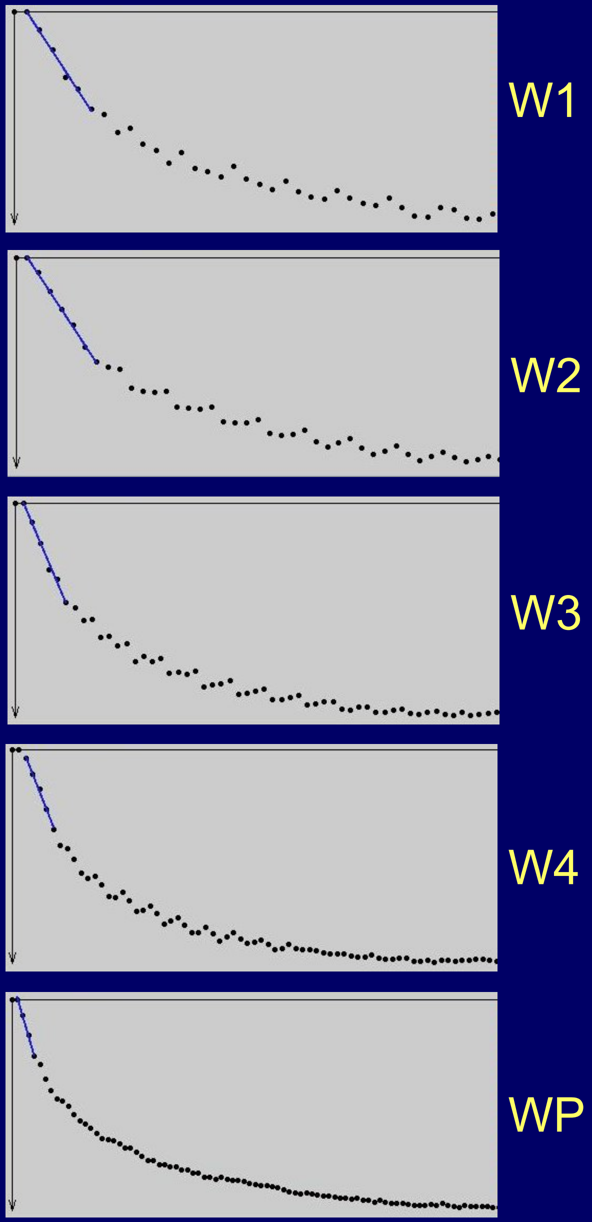
(AutoESA-MWT)

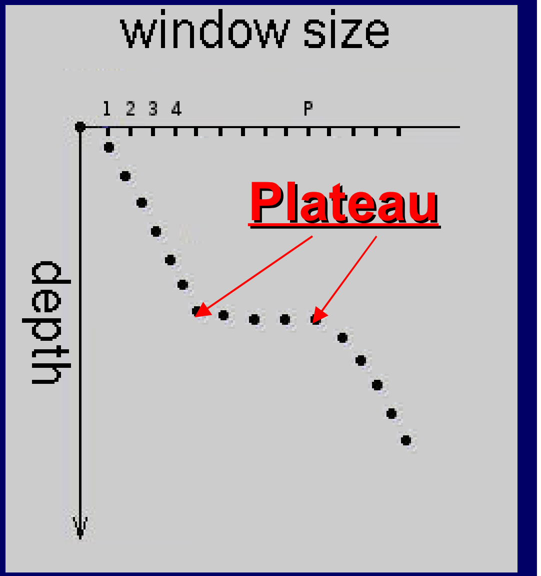
AutoESA MWT

Depth Plateau Indicating Optimal Window Size









AutoESA-MWT
Procedure

- Spectra calculated using
  - Window Size
    - Minimum, for example 20gc
    - Maximum related to targeted depth
    - Increment usually 2gc
  - MWT stations
    - Regular grid e.g. 1x1gc
    - Profiles across the study area

AutoESA-MWT
Procedure

- For each MWT station is computed
  - Window density of plateaus
  - Spectra shape parameters at each window size
  - Statistical goodness of fit

AutoESA-MWT
Window Density

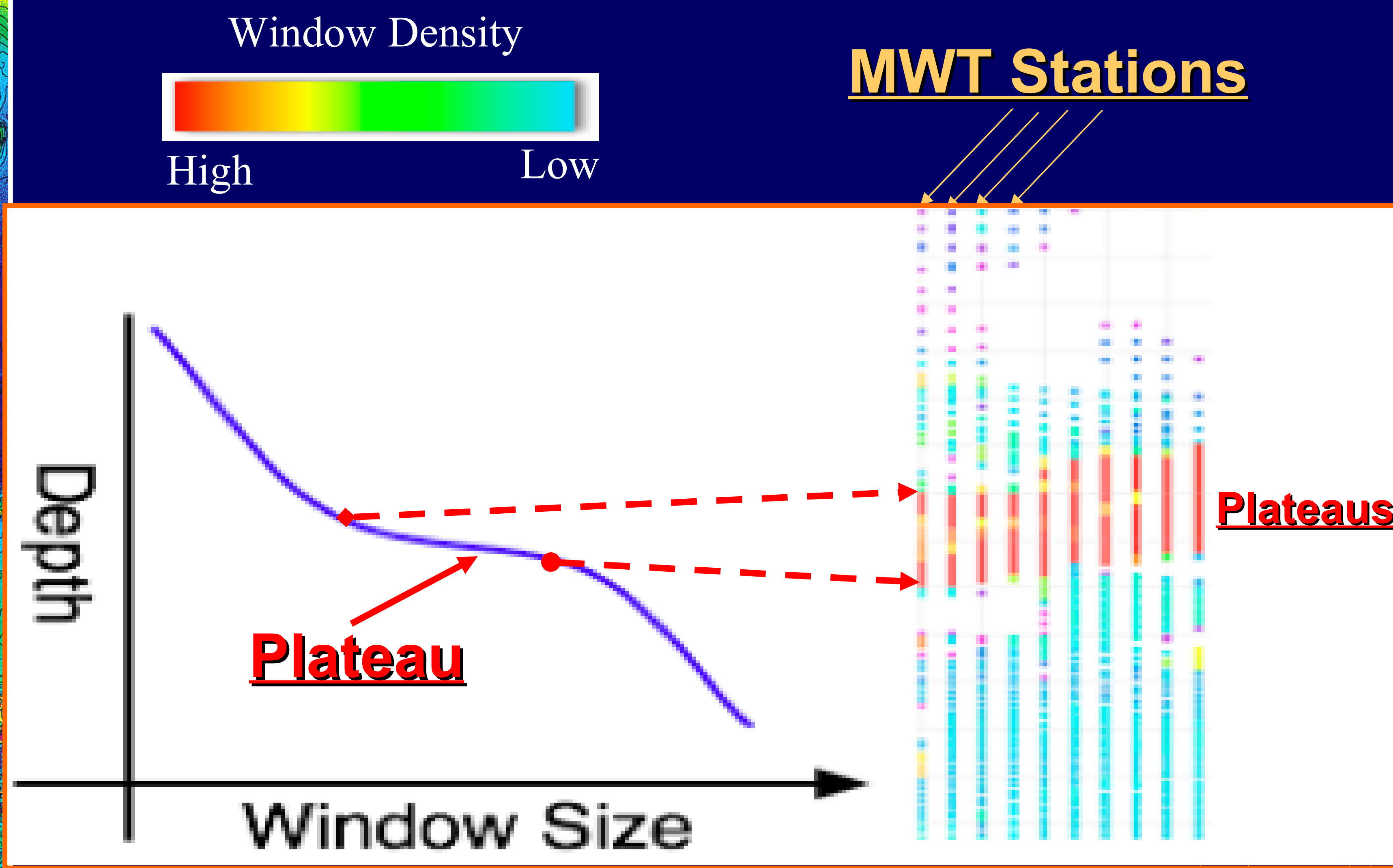
- For each depth plateau

Window Density
=
Number of windows forming plateau

- High Window Density implies robust depth estimation

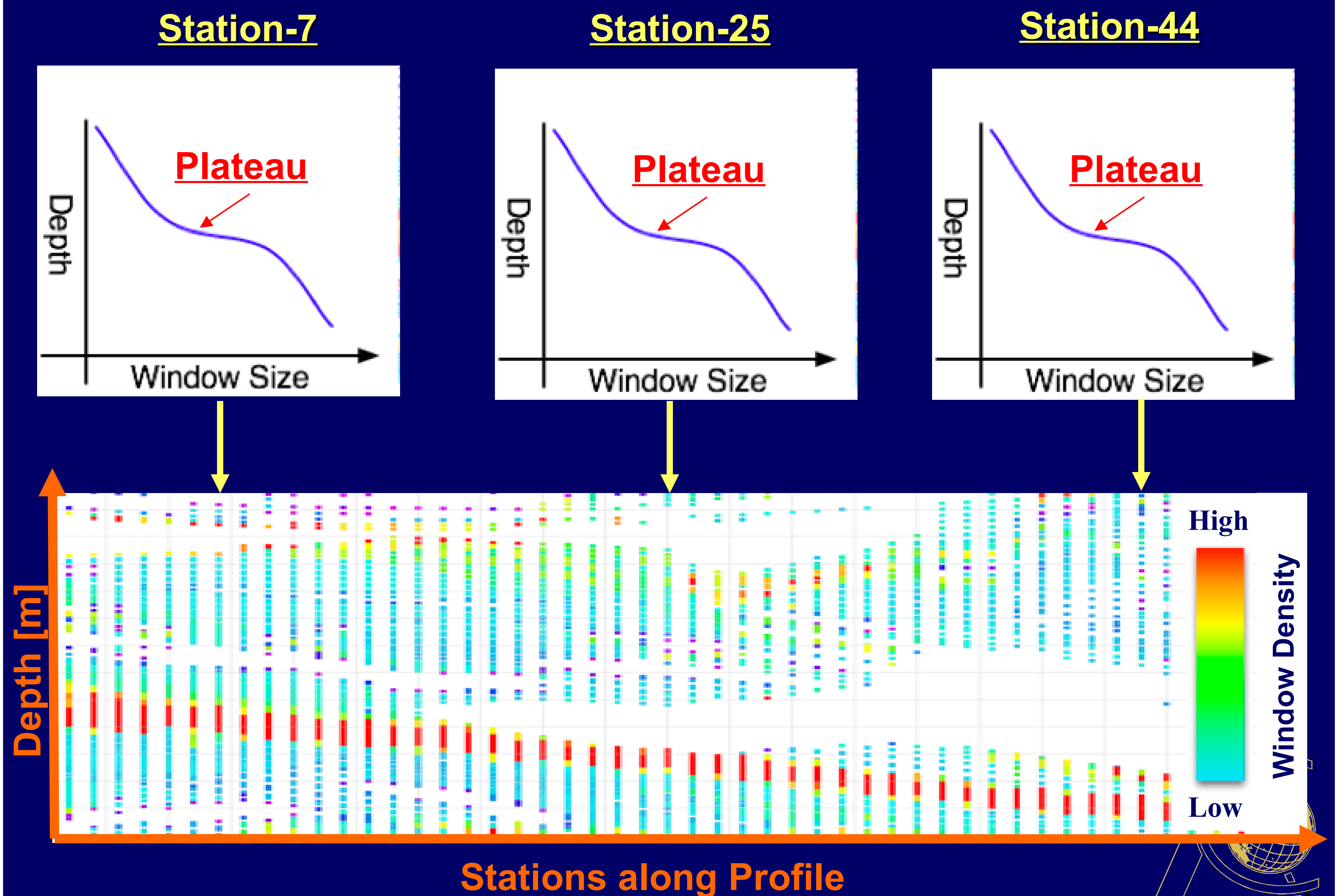
AutoESA MWT

Window Density of Plateaus



AutoESA MWT

Window Density of Plateaus along Profile Images Horizon



AutoESA-MWT
Procedure

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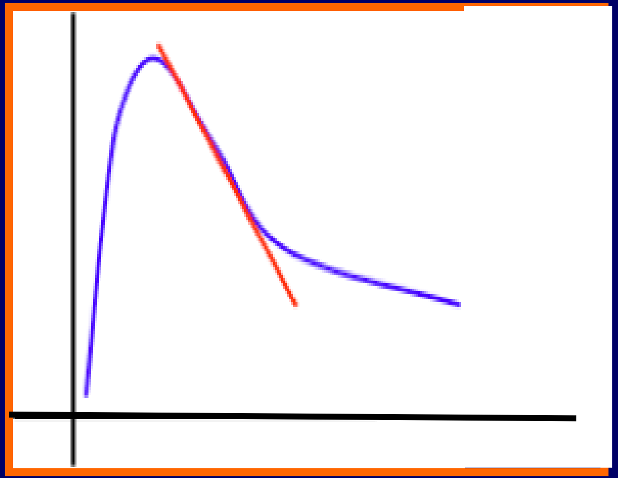
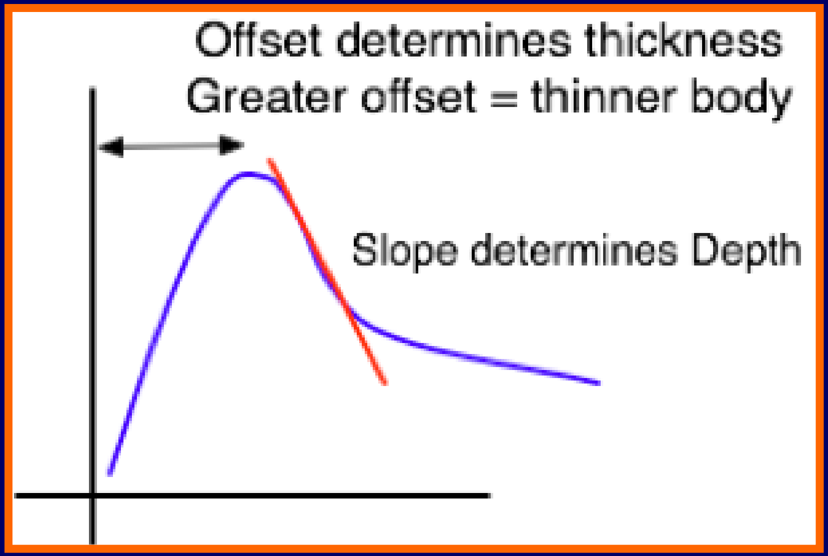
AutoESA MWT

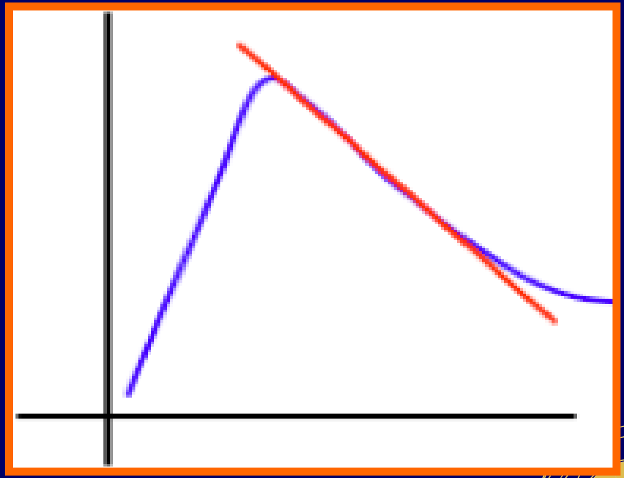
Analysis of Spectra Shape



Thick deep body



Geometry of Body influences Spectrum Shape



Shallow thin body

AutoESA-MWT

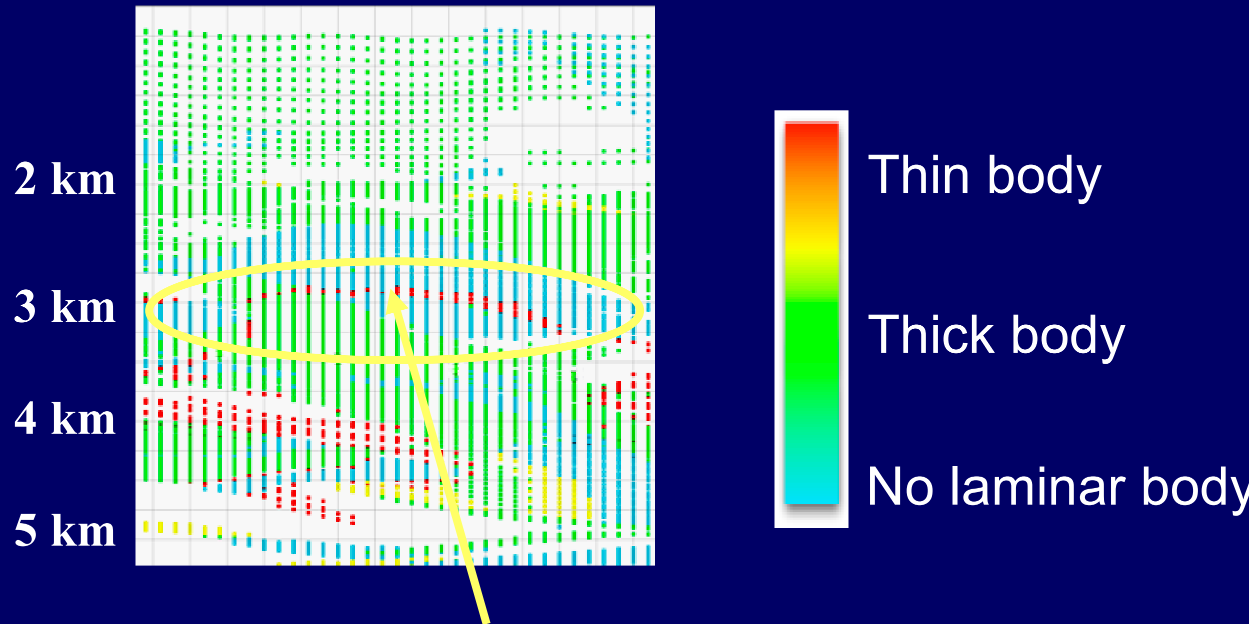
Analysis of Spectra Shape

- For each spectrum:
  - the shape is quantified
  - depth of the 1st slope is computed
- Spectra shape parameter is plotted vs computed depth
  - For visualization along a profile, high values of the spectra shape parameter are represented by hot colours
- High values of the spectra shape parameter correspond to thin bodies

AutoESA-MWT

Analysis of Spectra Shape

Spectra Shape Parameter vs Depth along Profile



Detecting Laminar Bodies

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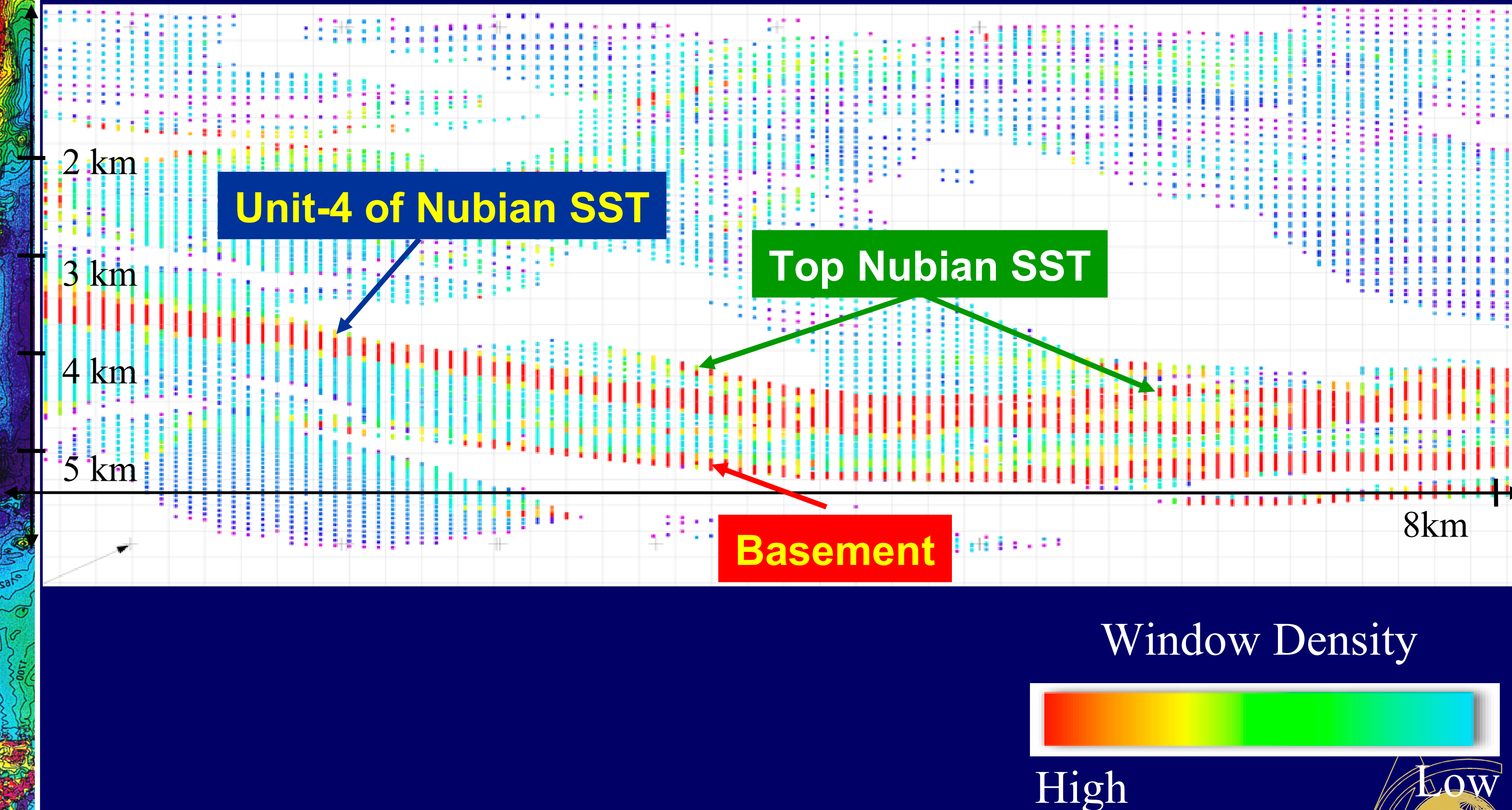
AutoESA-MWT: Horizon Mapping

Window Density

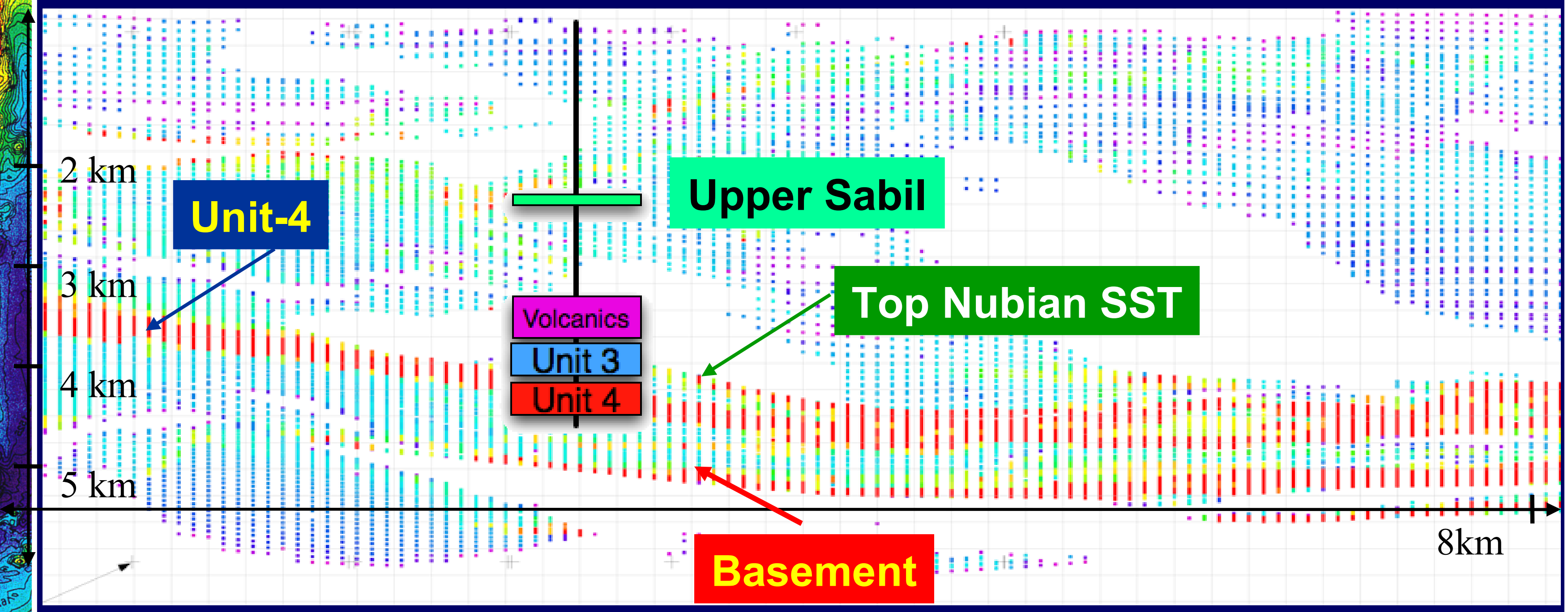
Sirt Basin: Libya

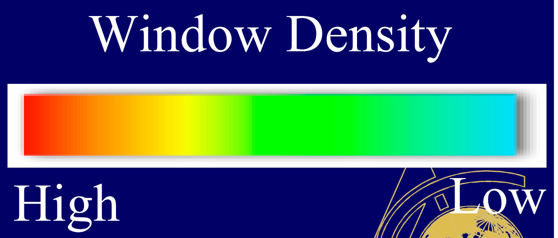


AutoESA-MWT: Horizon Mapping

Window Density

Sirt Basin: Libya

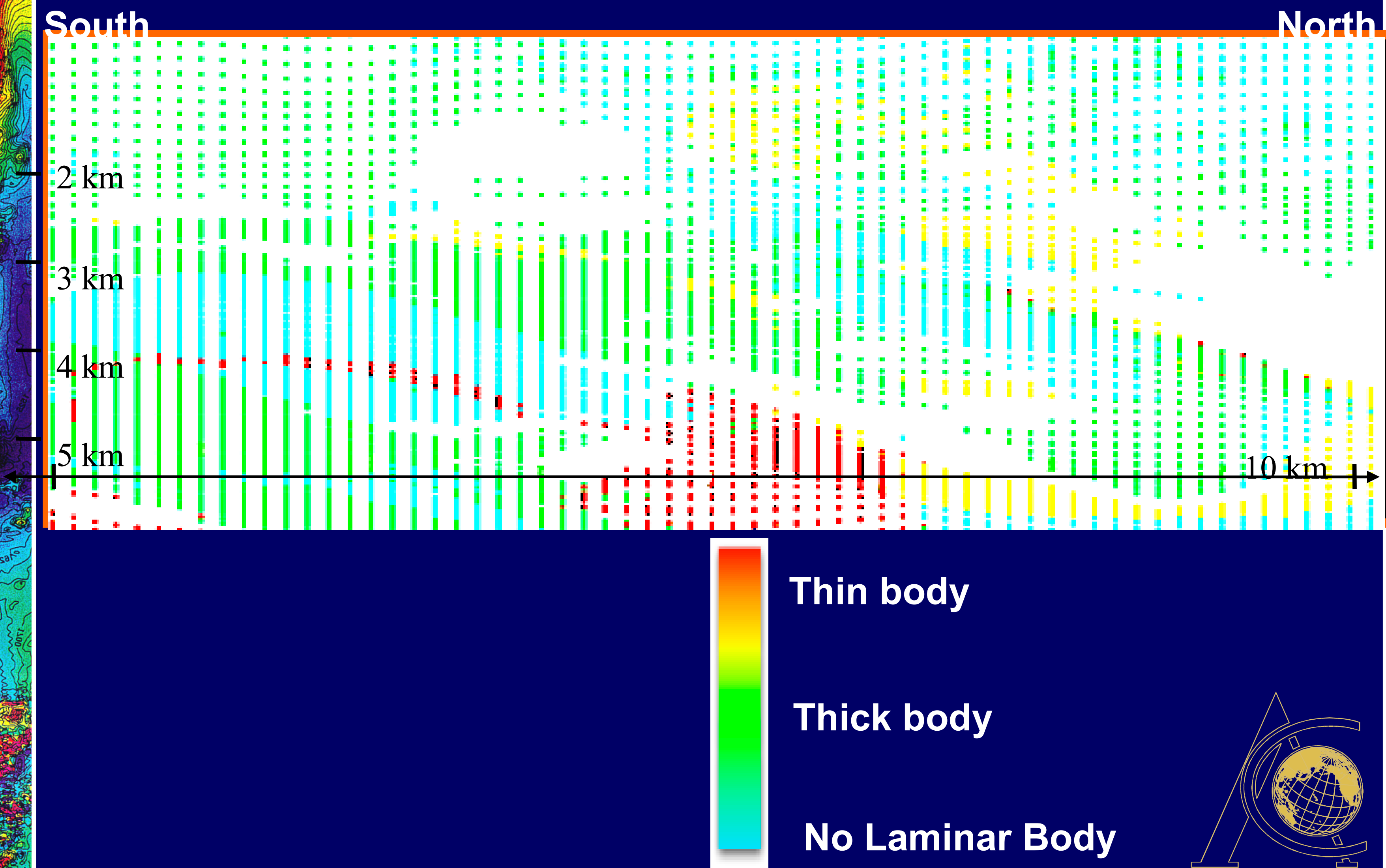




AutoESA-MWT: Horizon Mapping

Spectra Shape: Detecting Laminar Bodies

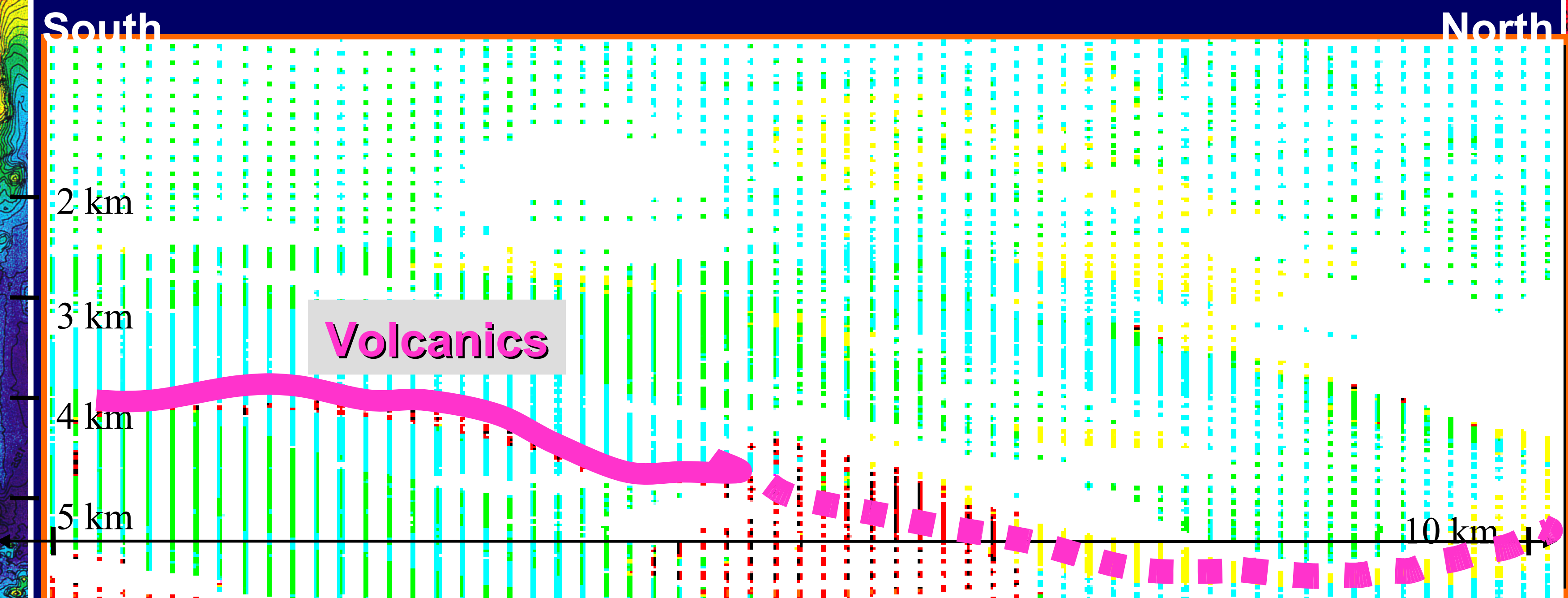
Sirt Basin: Libya



AutoESA-MWT: Horizon Mapping

Spectra Shape: Detecting Laminar Bodies

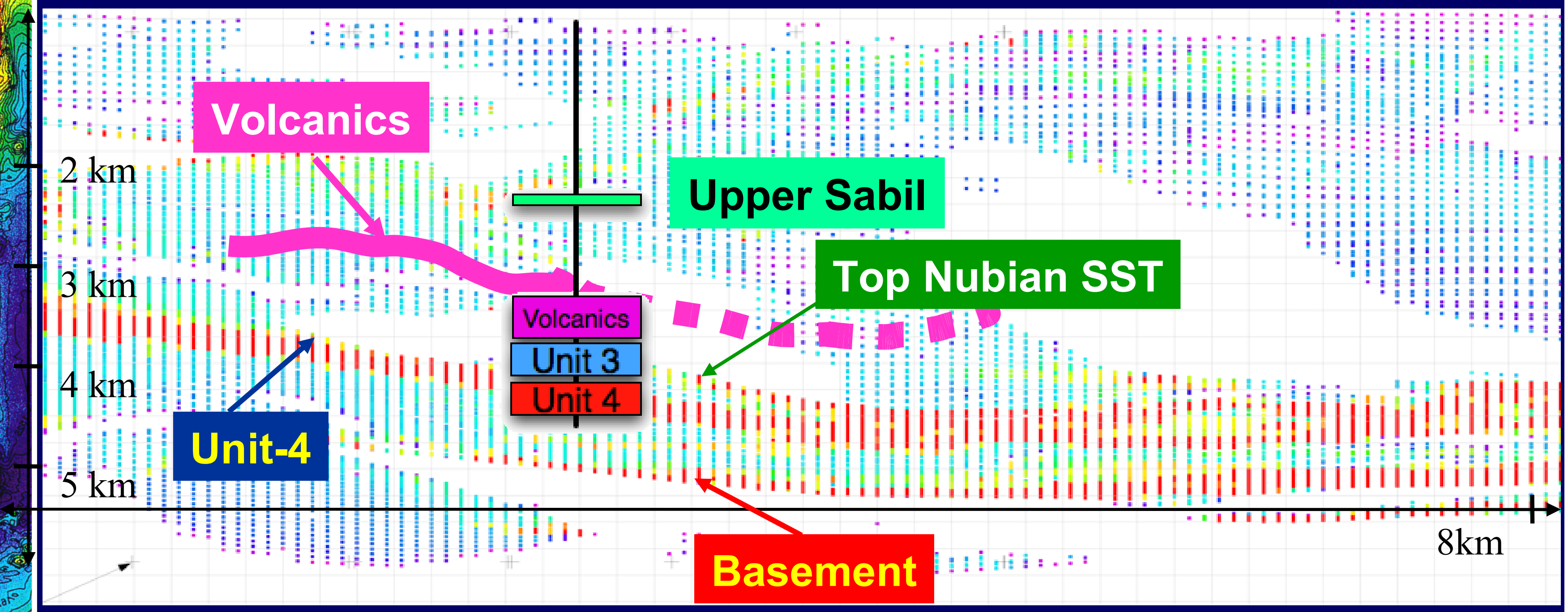
Sirt Basin: Libya

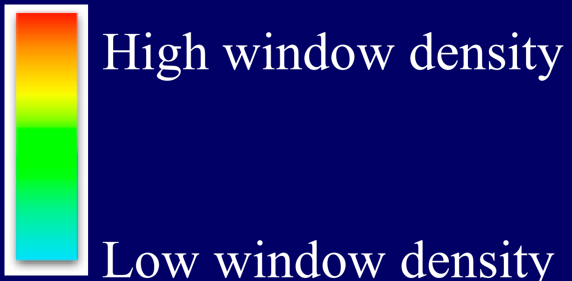


AutoESA-MWT: Horizon Mapping

Window Density

Sirt Basin: Libya





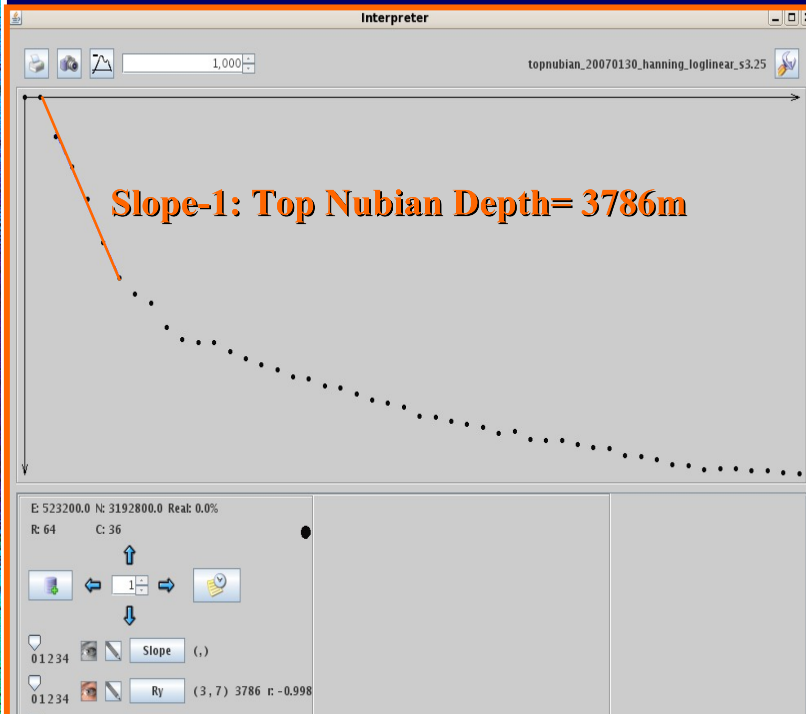
ESA-MW

Top Nubian Horizon

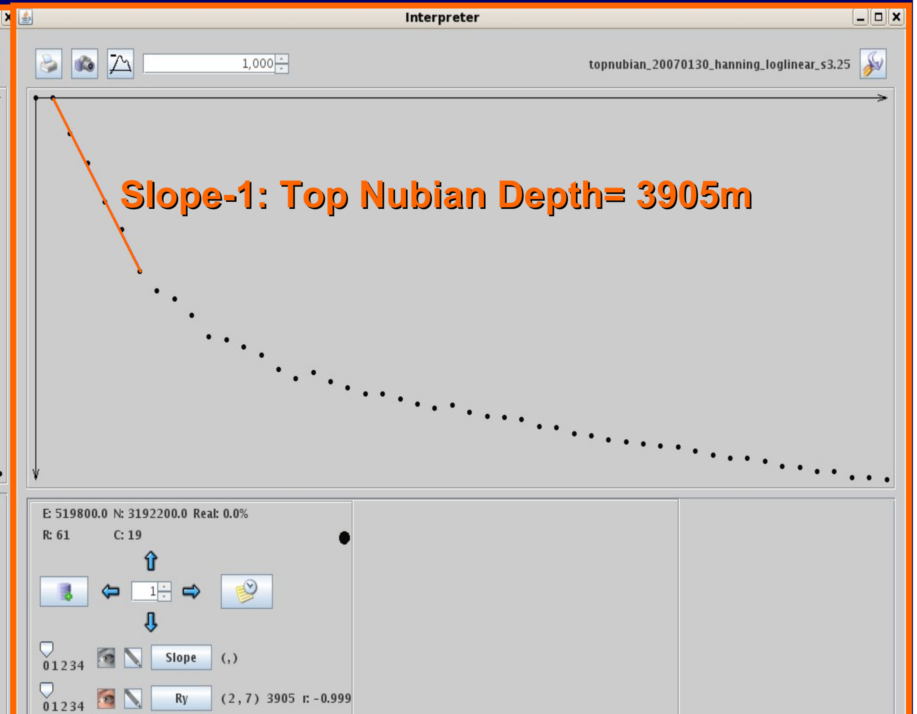
Top Nubian: ESA-MW

Example of Interpreted Spectra
Semi-automatic Depth Calculation

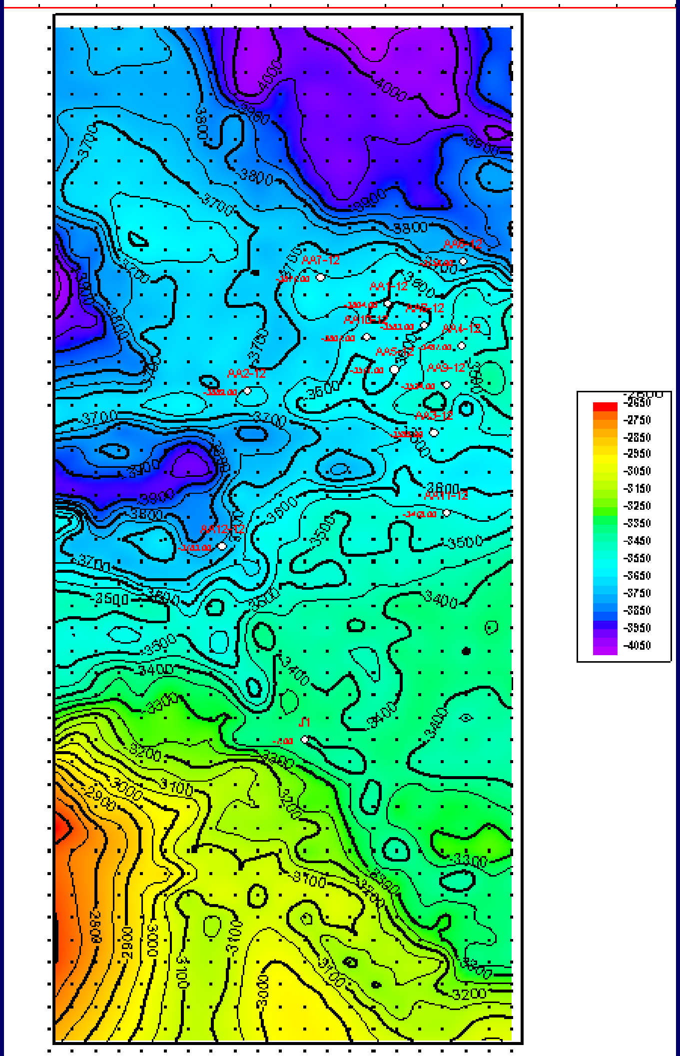
Location-1



Location-2



Top Nubian: ESA-MW



Top Nubian Horizon

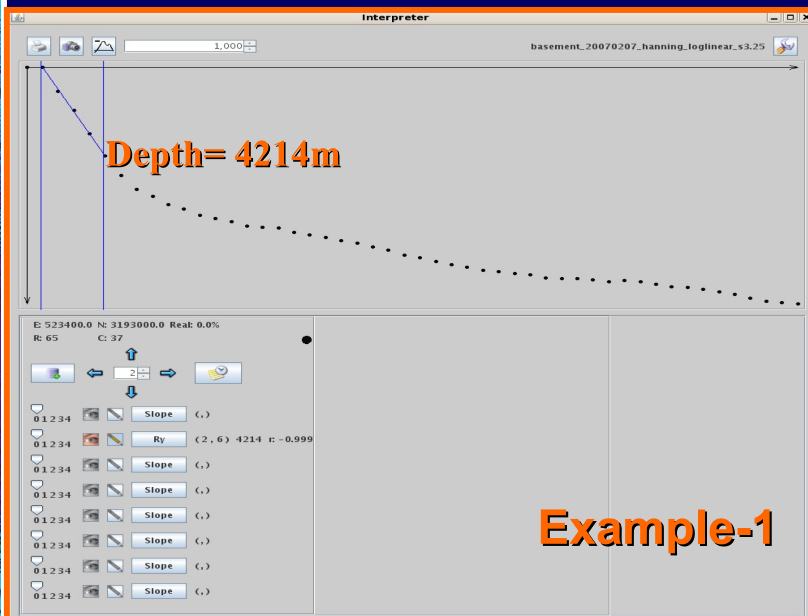
ESA-MW
3D Visualisation

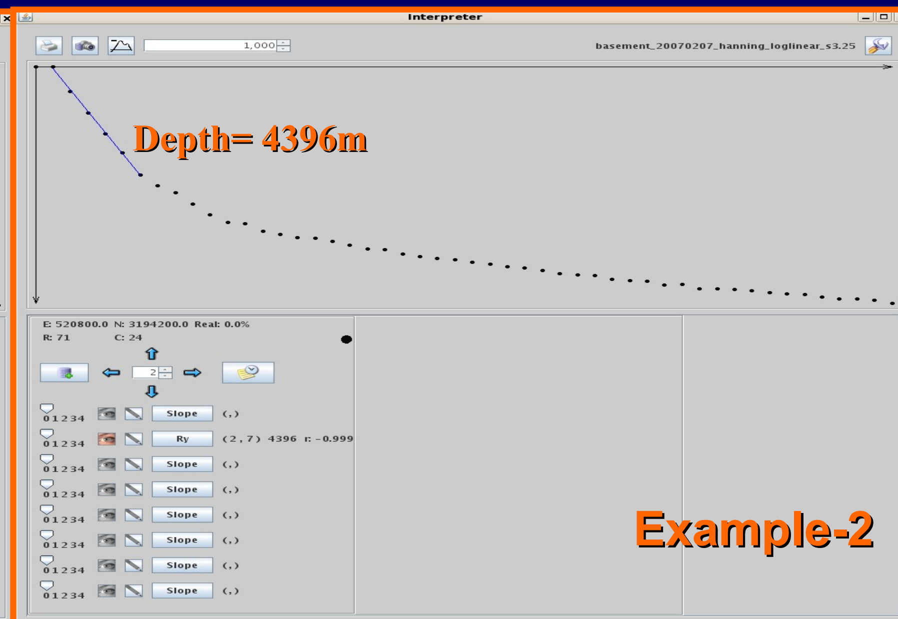
ESA-MW

Basement Horizon

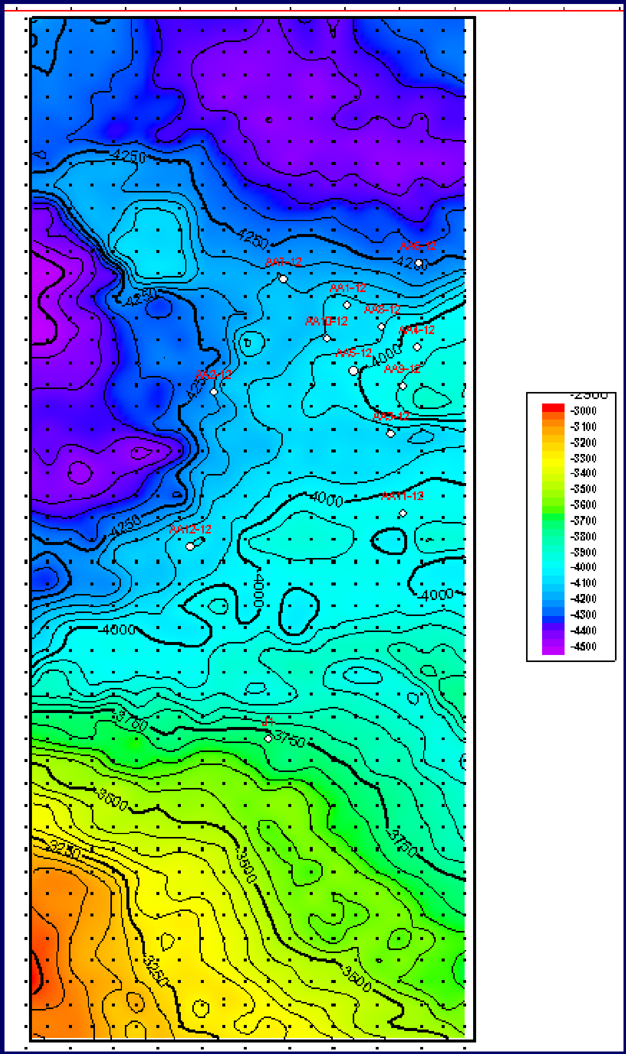
Magnetic Basement: ESA-MW

Example of Interpreted Spectra
Semi-automatic Depth Calculation

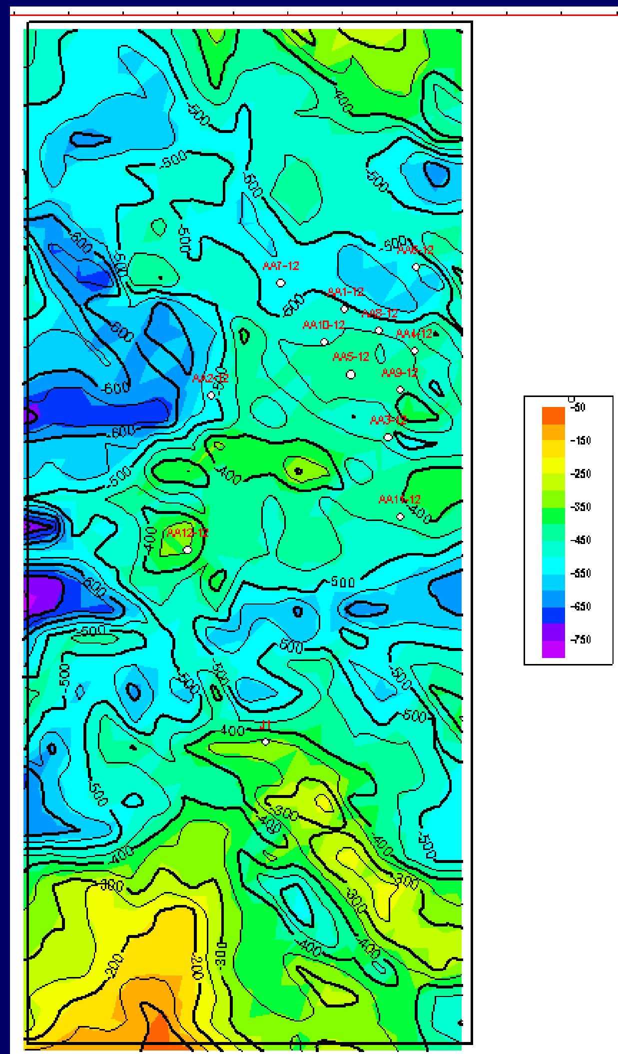




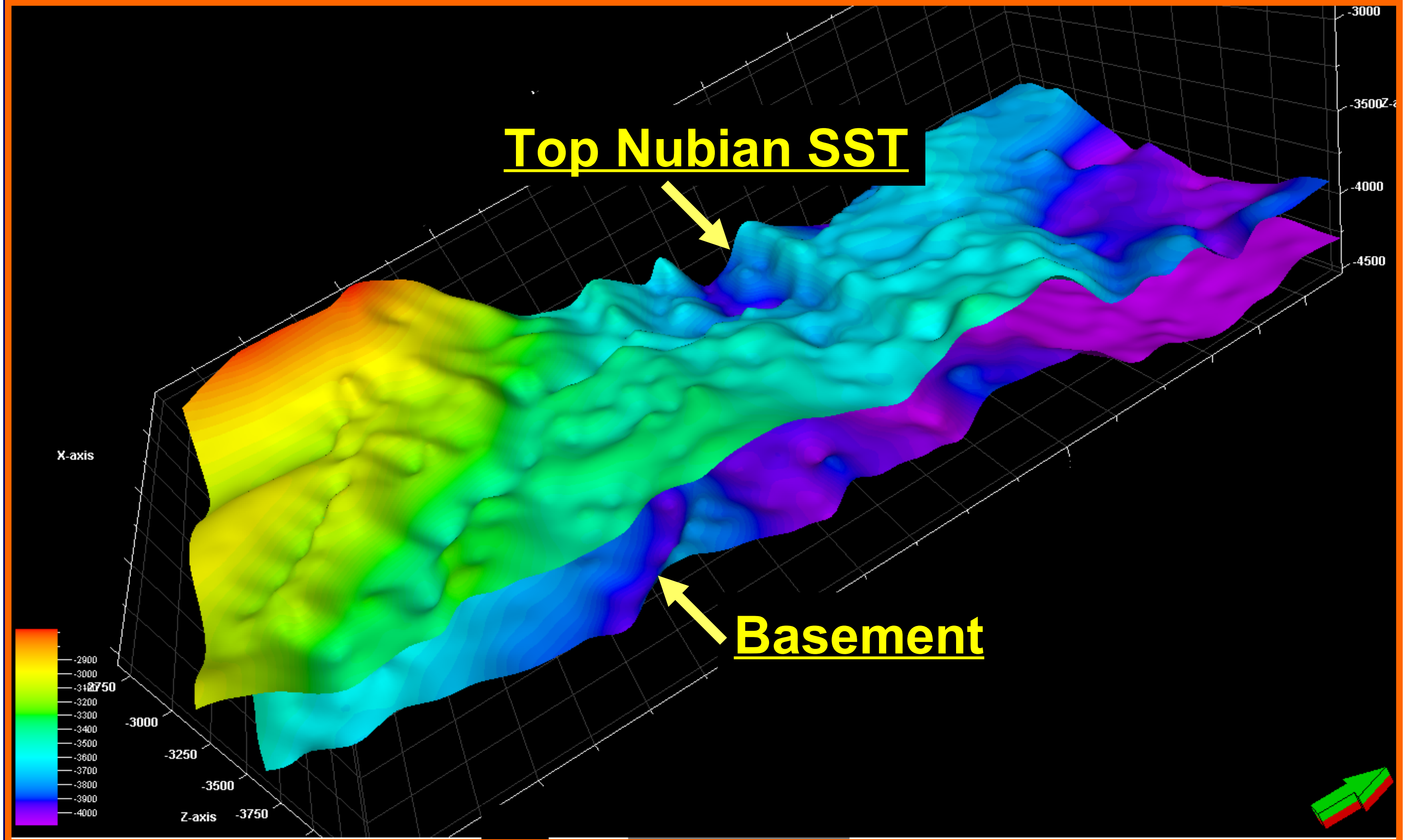
Basement: ESA-MW



Isopach map of Nubian



Horizon 3D View

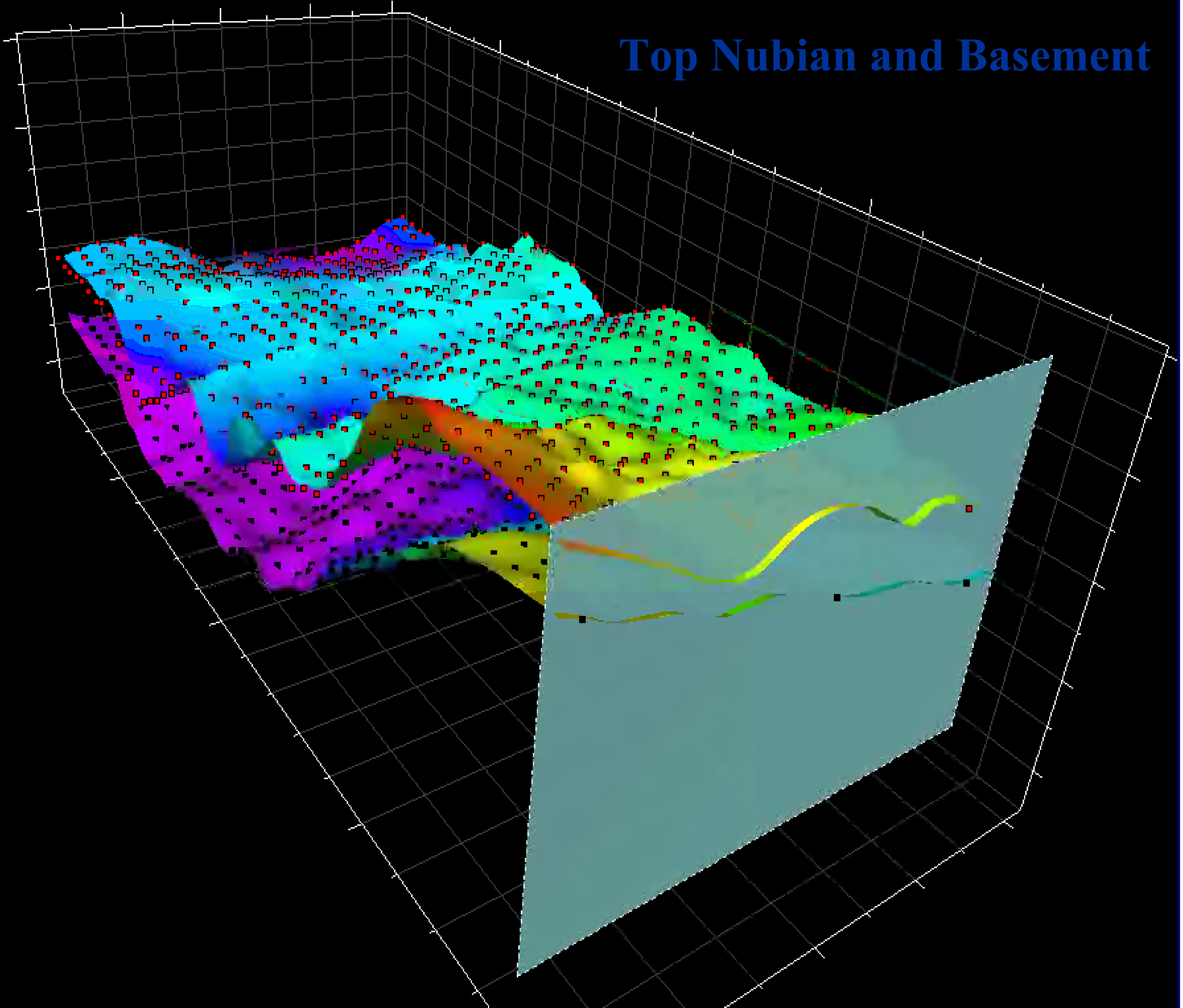


Basement & Top Nubian SST Depth Calculation from ESA-MW

Semi-automatic: Manual Picks - Points 3D Visualisation

Top Nubian & Basement
ESA-MW
3D Visualisation

Top Nubian and Basement



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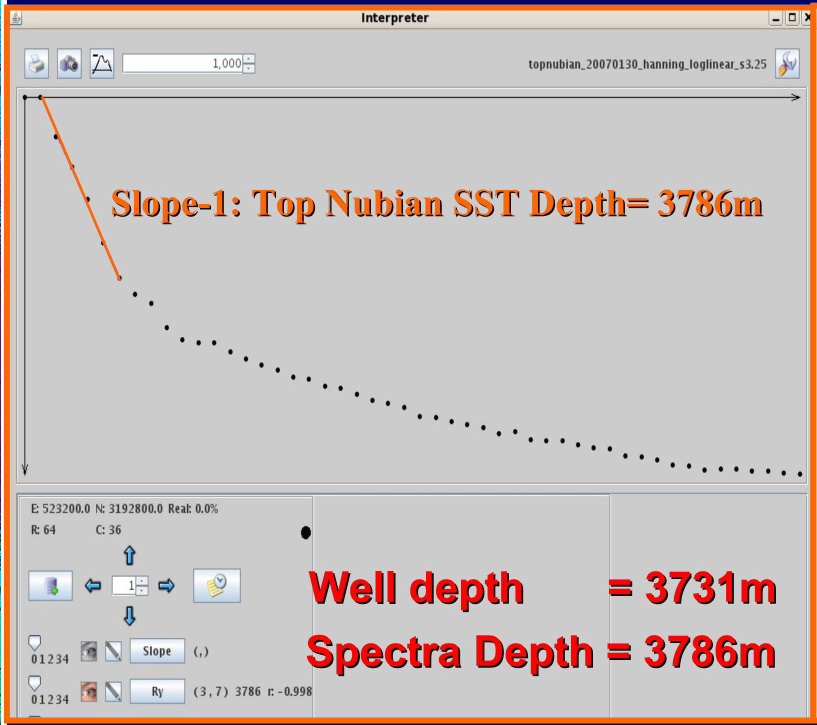
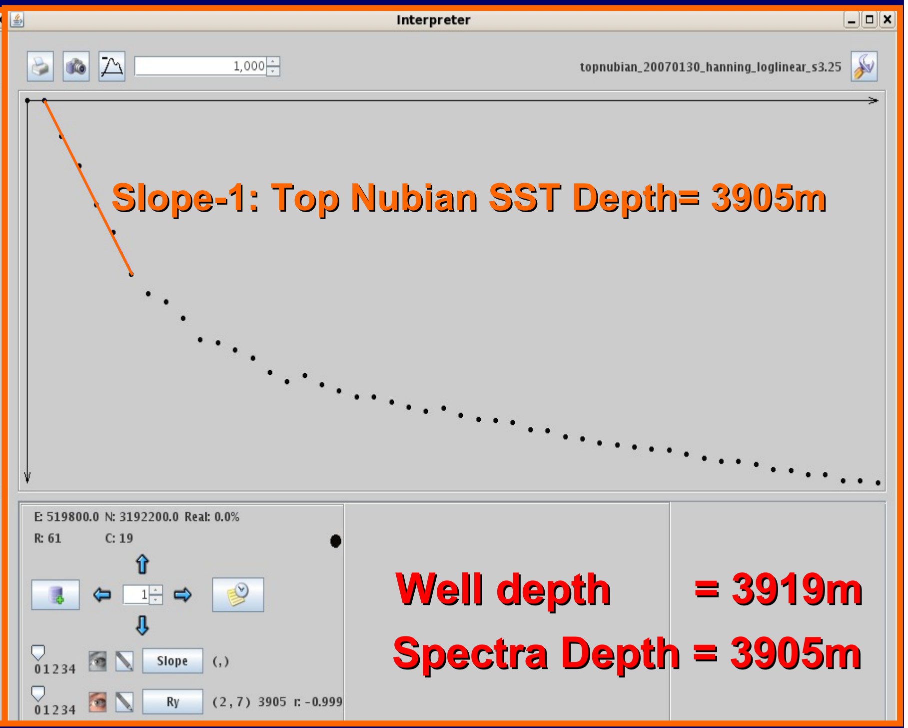
Well Correlation: ESA-MW

Example of Spectra & Well Depth
Semi-automatic Depth Calculation

Well-1

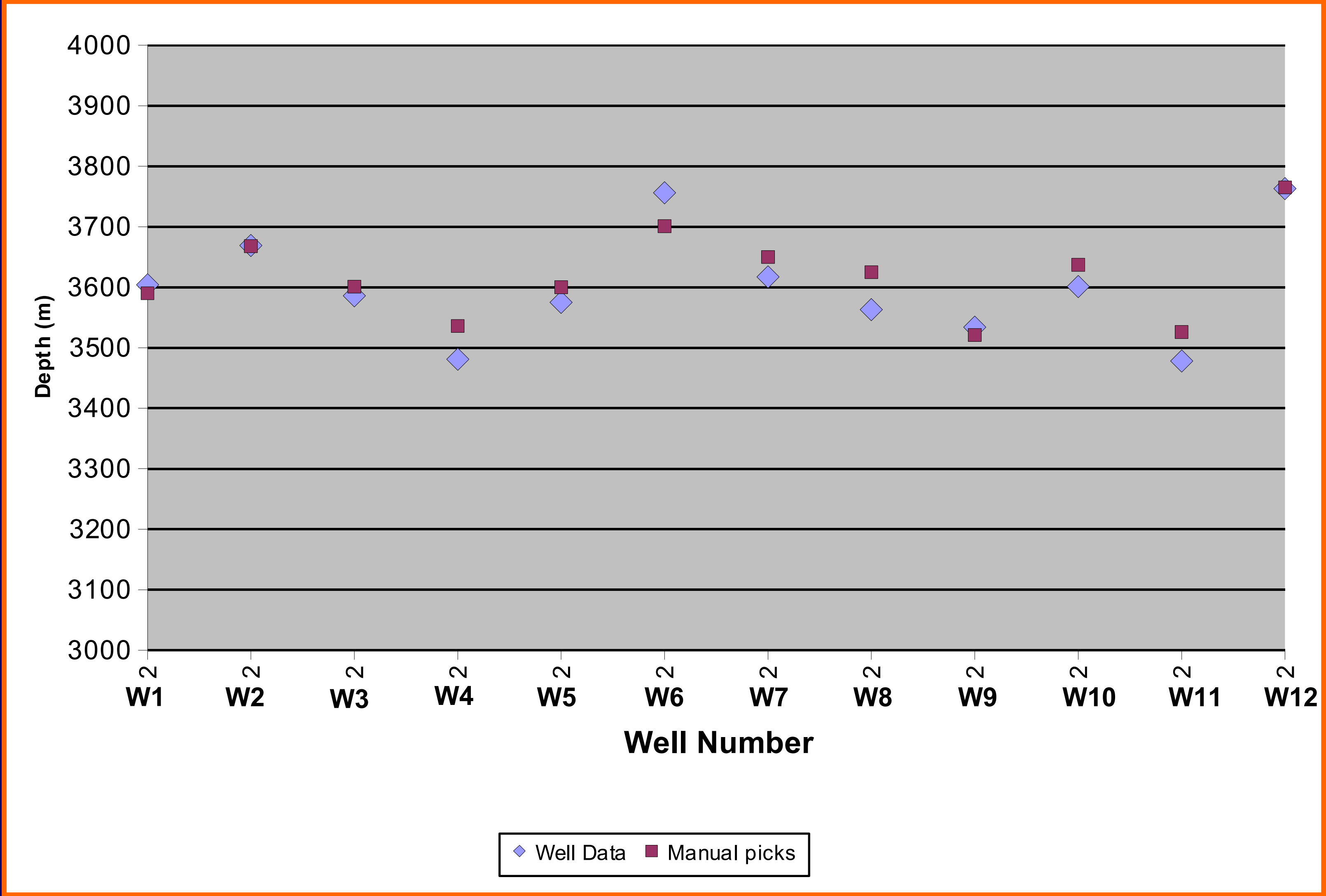


Well-2

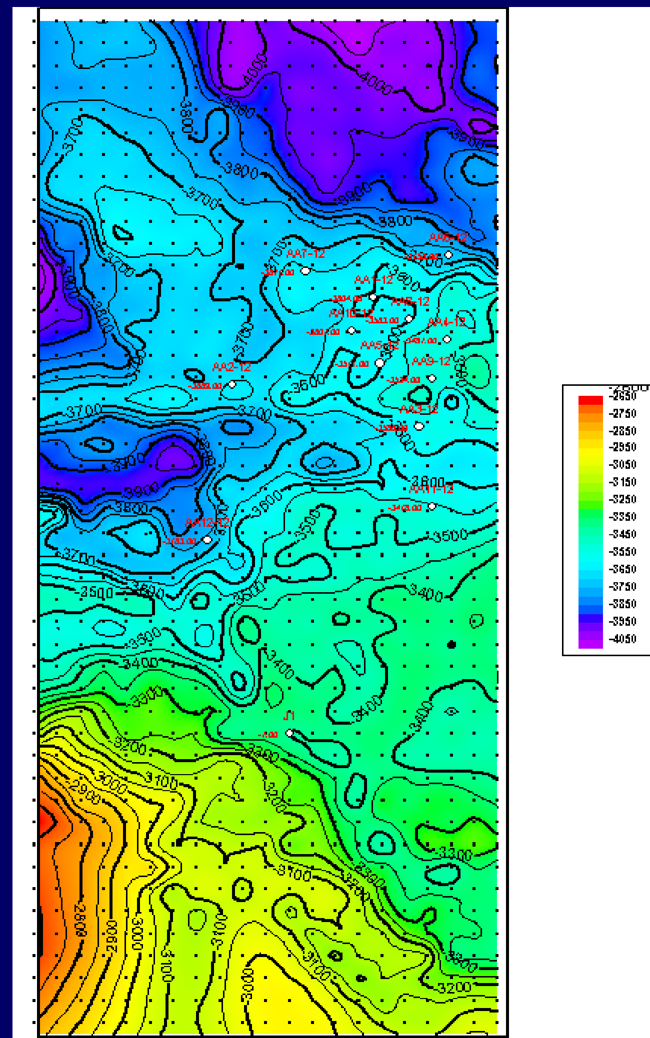


Well Depth vs Spectra Depth

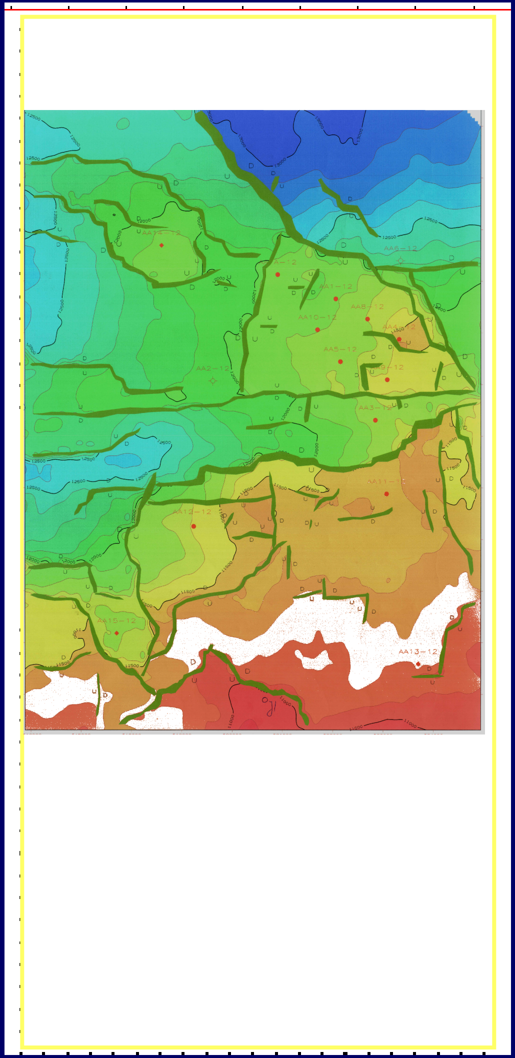
Example from Sirt Basin: Top Nubian



Top Nubian: ESA-MW

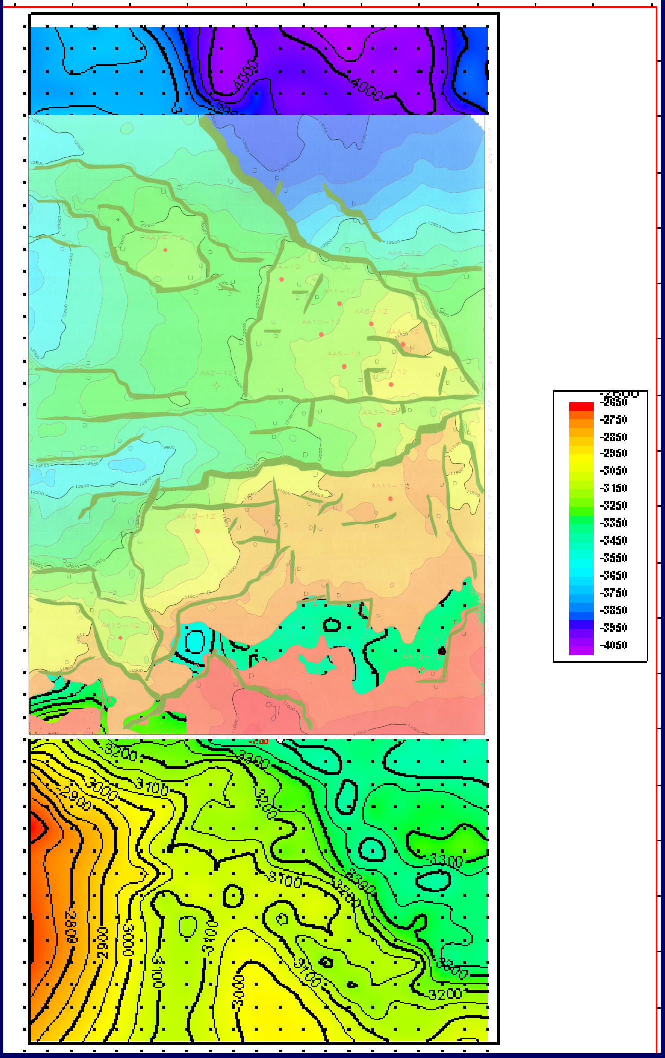


Top Nubian: Seismic



Top Nubian

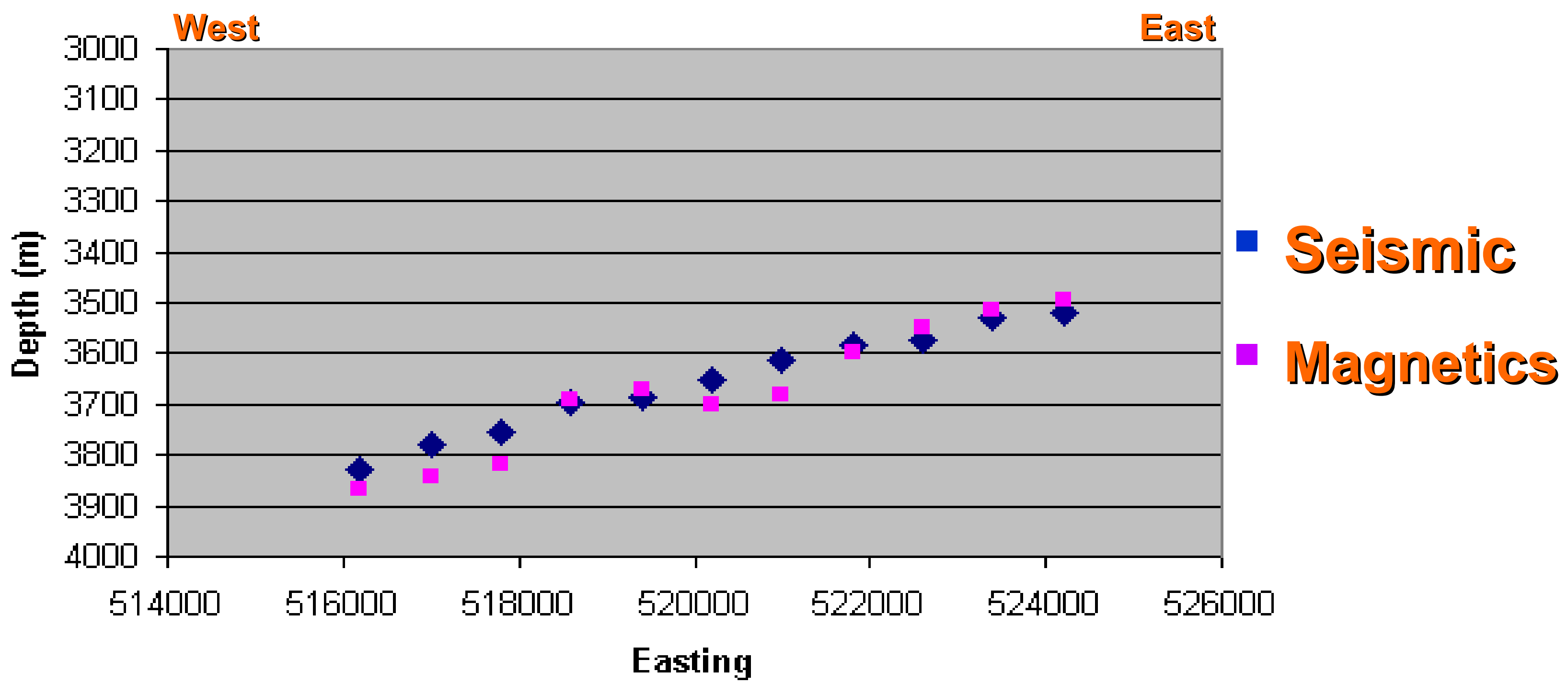
Seismic vs Magnetics



Top Nubian

Seismic vs Magnetics

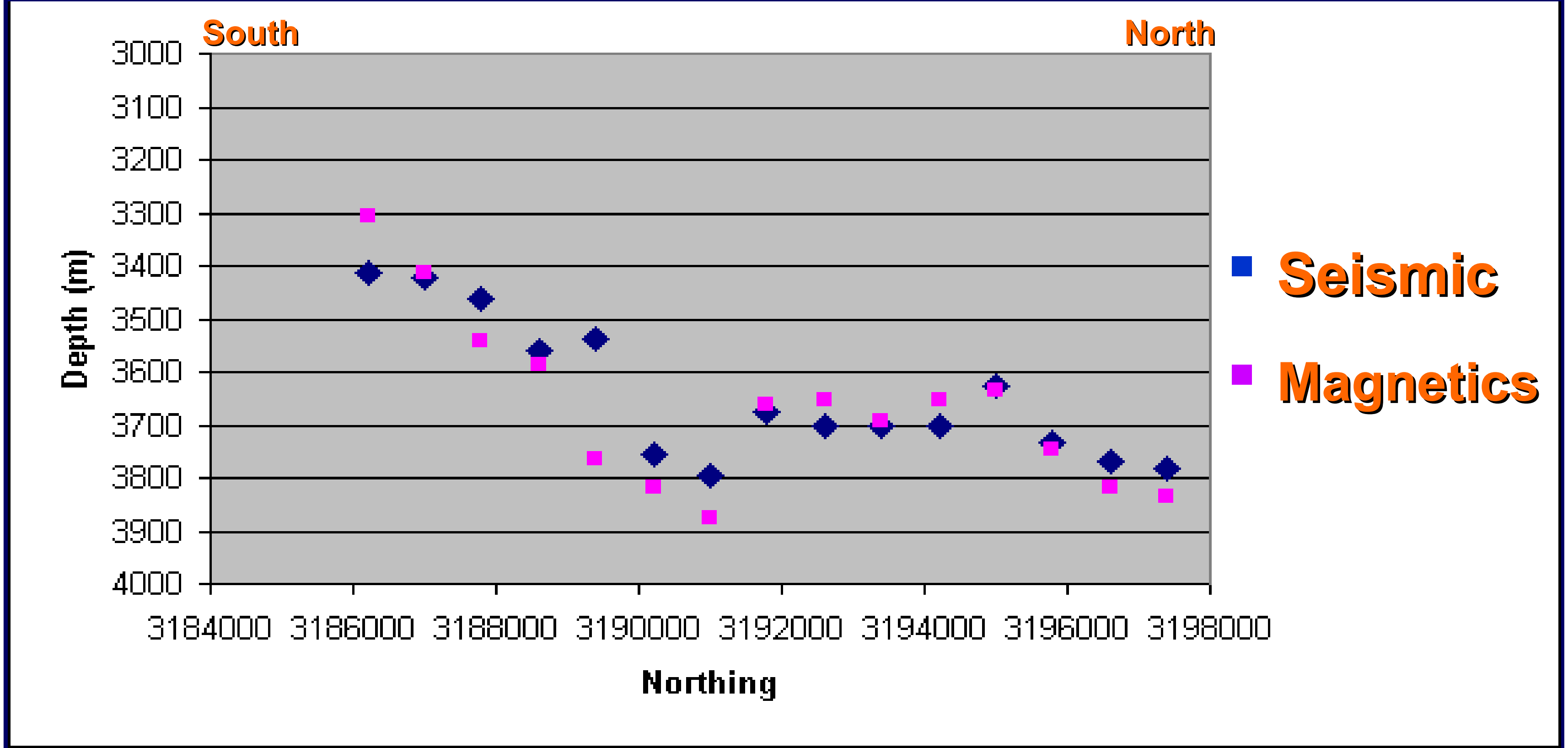
EW PROFILE
Seismic Horizon in Blue
Magnetic Horizon Purple



Top Nubian

Seismic vs Magnetics

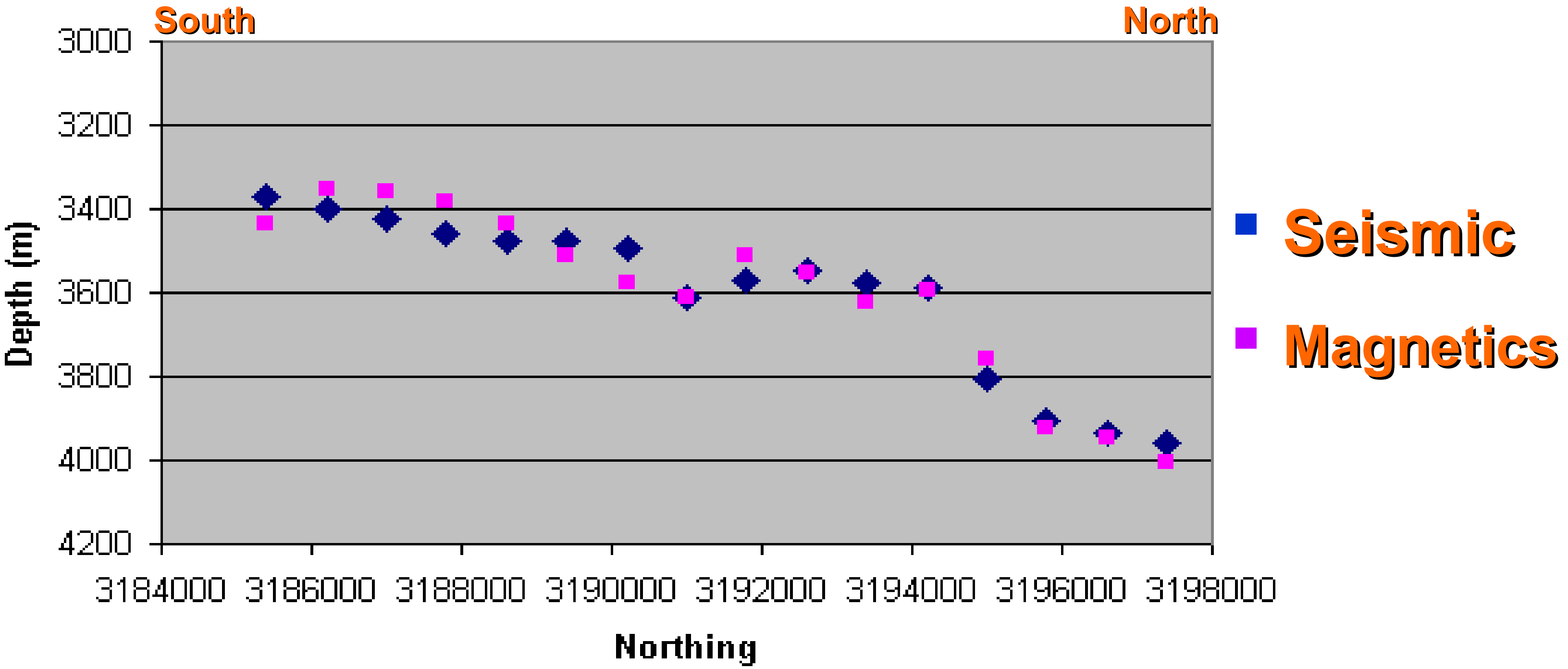
NS PROFILE-1
Seismic Horizon in Blue
Magnetic Horizon Purple



Top Nubian

Seismic vs Magnetics

NS PROFILE-2
Seismic Horizon in Blue
Magnetic Horizon Purple



Contents

Conclusions

- Spectral methods applied to HRAM data can be successfully used in Sirt Basin to image Basement and intra-sedimentary horizons

- Results from ESA Moving Window for Top Nubian SST and Unit 4 are comparable with seismic and well data.

- Multi-Window Test can be used to determine optimal window sizes for spectral analysis.

Conclusions

- Automatic spectral interpretation techniques can image multiple horizons:

  - Basement
  - Unit 4 Nubian SST
  - Volcanics
  - Upper Sabil

- Spectral shape based techniques can identify bodies of limited depth extent such as volcanic layers.

Conclusions

- Energy spectral analysis can be used as a very powerful tool in the analysis and interpretation of HRAM data for exploration in the Libyan Sirt Basin.

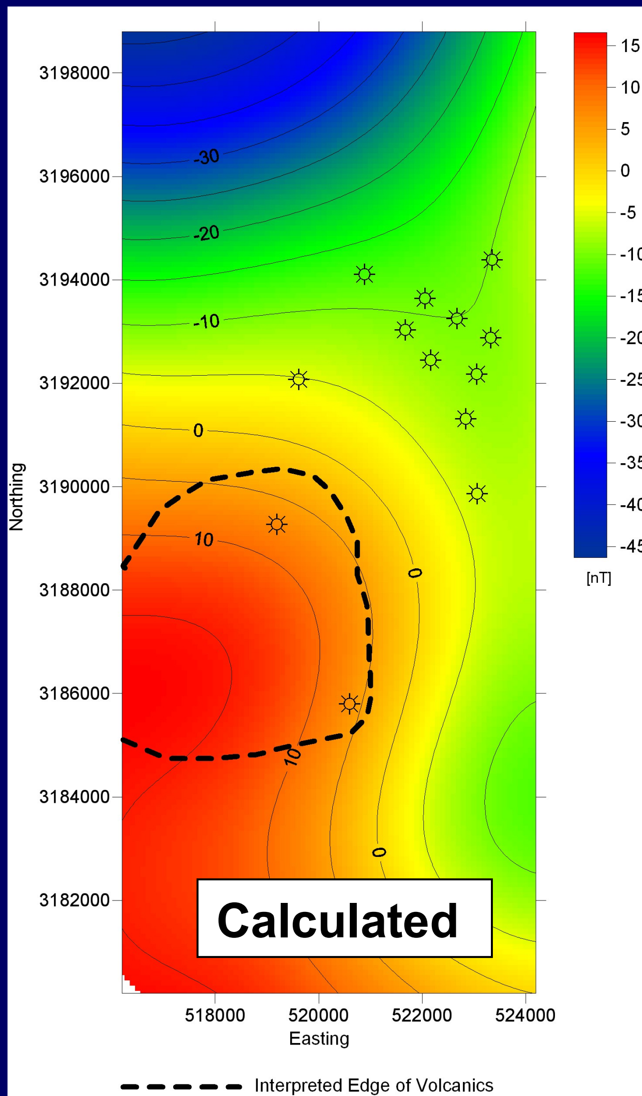
- The Multi-Window Test using window density and spectra shape parameters is a new technique which allows the detection in a purely automatic manner the top of Unit 4 of Nubian SST, which is the base of reservoir sands in the study area.

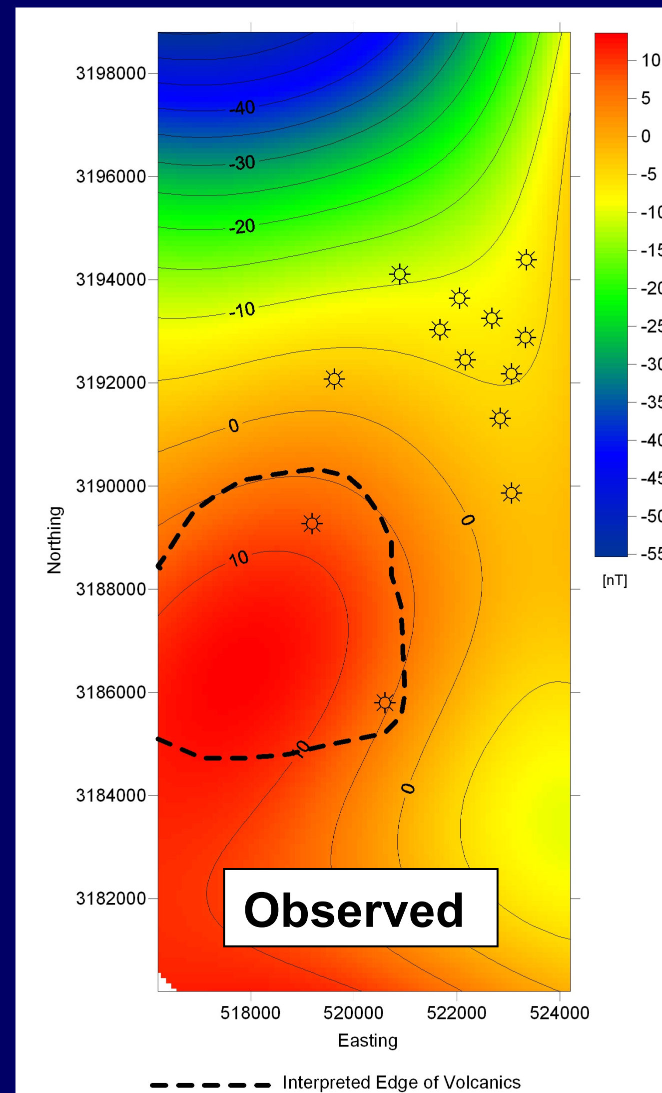
Quality Control

Quality Control: 3D Modelling

Calculated Magnetic Field vs Observed

'Lowpass Filter', Depth > 3260m





Spectral Ambiguity & Confidence Maps

- Alternative spectra interpretation based on:
  - Spectral shape
  - Consistency with nearby interpretations
  - Geological constraints such as well and seismic data.
- Spectra ambiguity maps quantifying degree to which spectra may admit alternate interpretation

Ambiguity Determination

- Set of alternate semi-automatic depth estimates for 25% spectra
- For each alternate set, interpreter estimates probability that the alternate depth would be chosen over the actual calculated depth
- This data is used to determine a standard deviation [m], that corresponds to the maximum likelihood standard deviation of the normal distribution that would give the actual and alternate depths at the corresponding selected probability ratio.

Spectral Ambiguity Maps

For each Horizon we provide two maps:

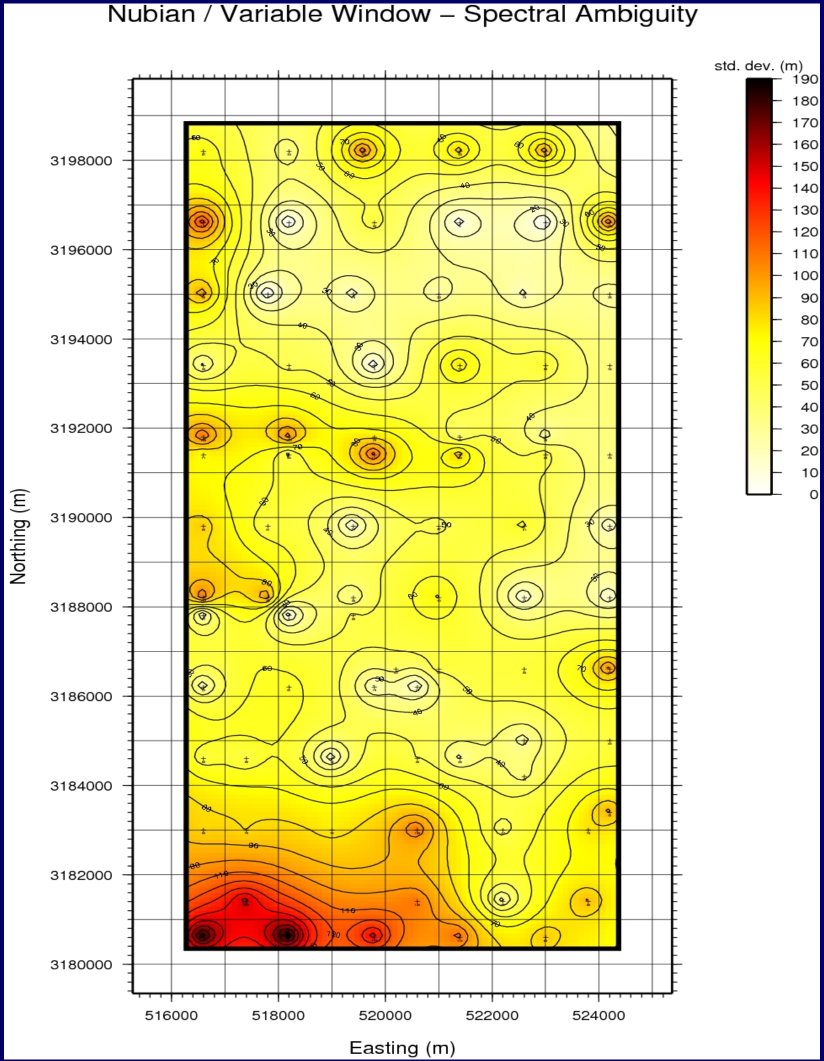
- Spectral ambiguity:

A map of the maximum likelihood estimated standard deviation derived from the actual and alternate semi-automatic depth values. This roughly corresponds to the error-bar on depth estimate that is attributable to spectral ambiguity.

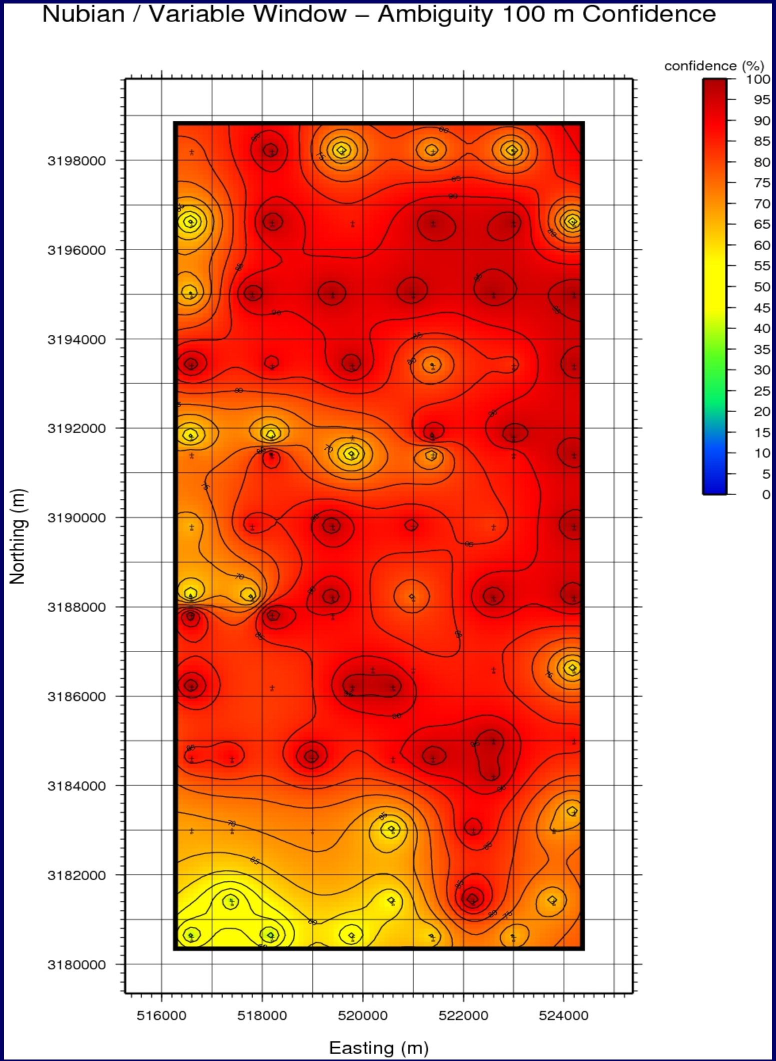
- Confidence map:

A map of the probability that a depth distributed according to the maximum likelihood normal distribution will fall within one grid-cell length of the interpreted depth.

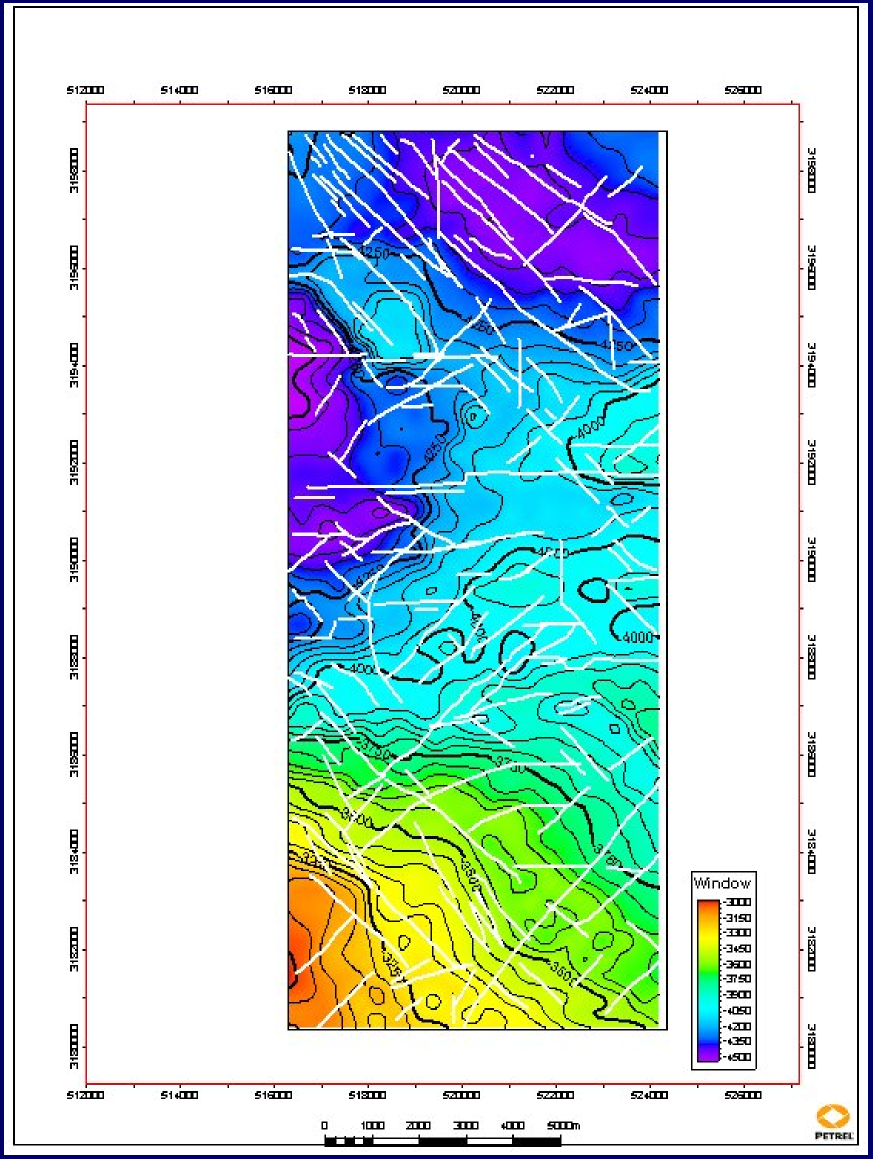
Spectral Ambiguity Map



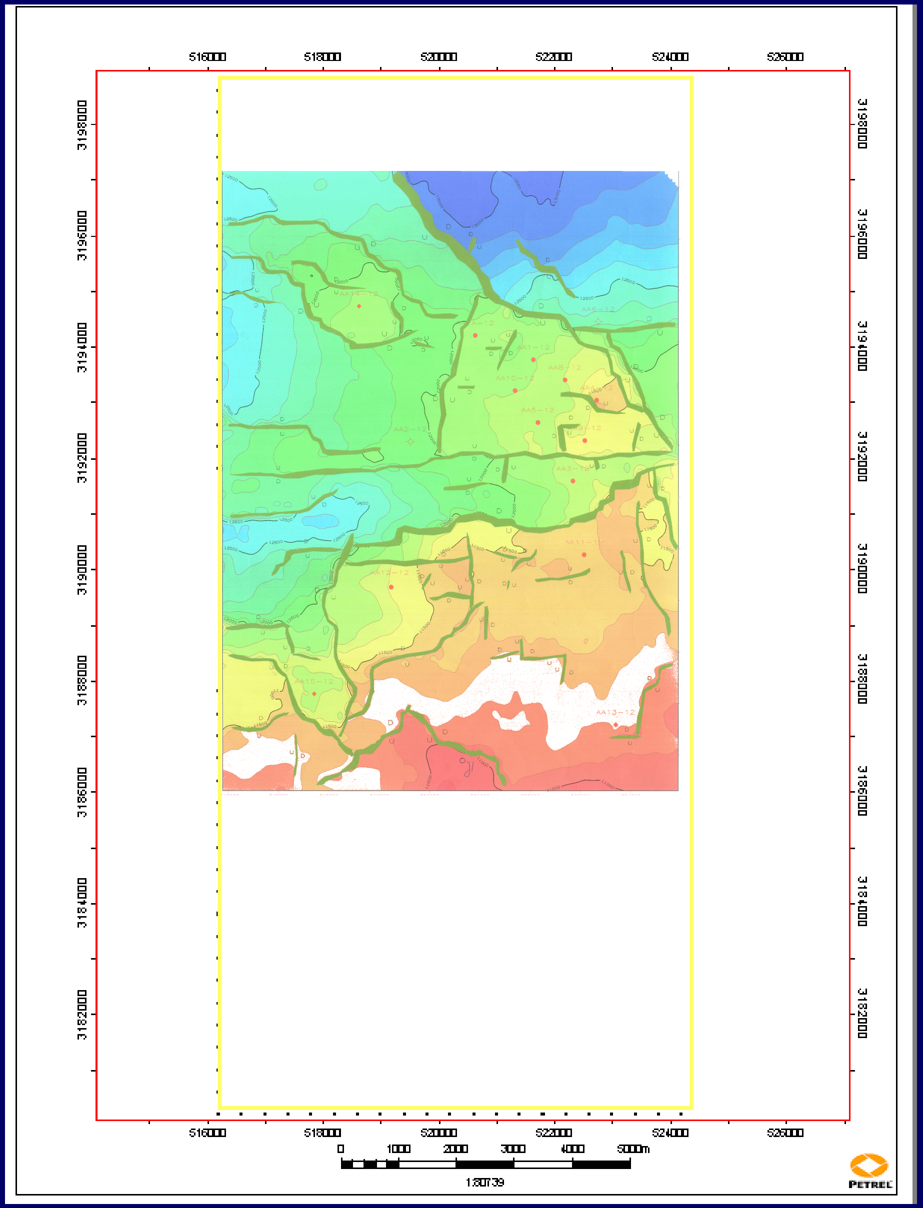
Confidence Map



Basement plus 1km magnetic lineaments overlay onto BSMT map

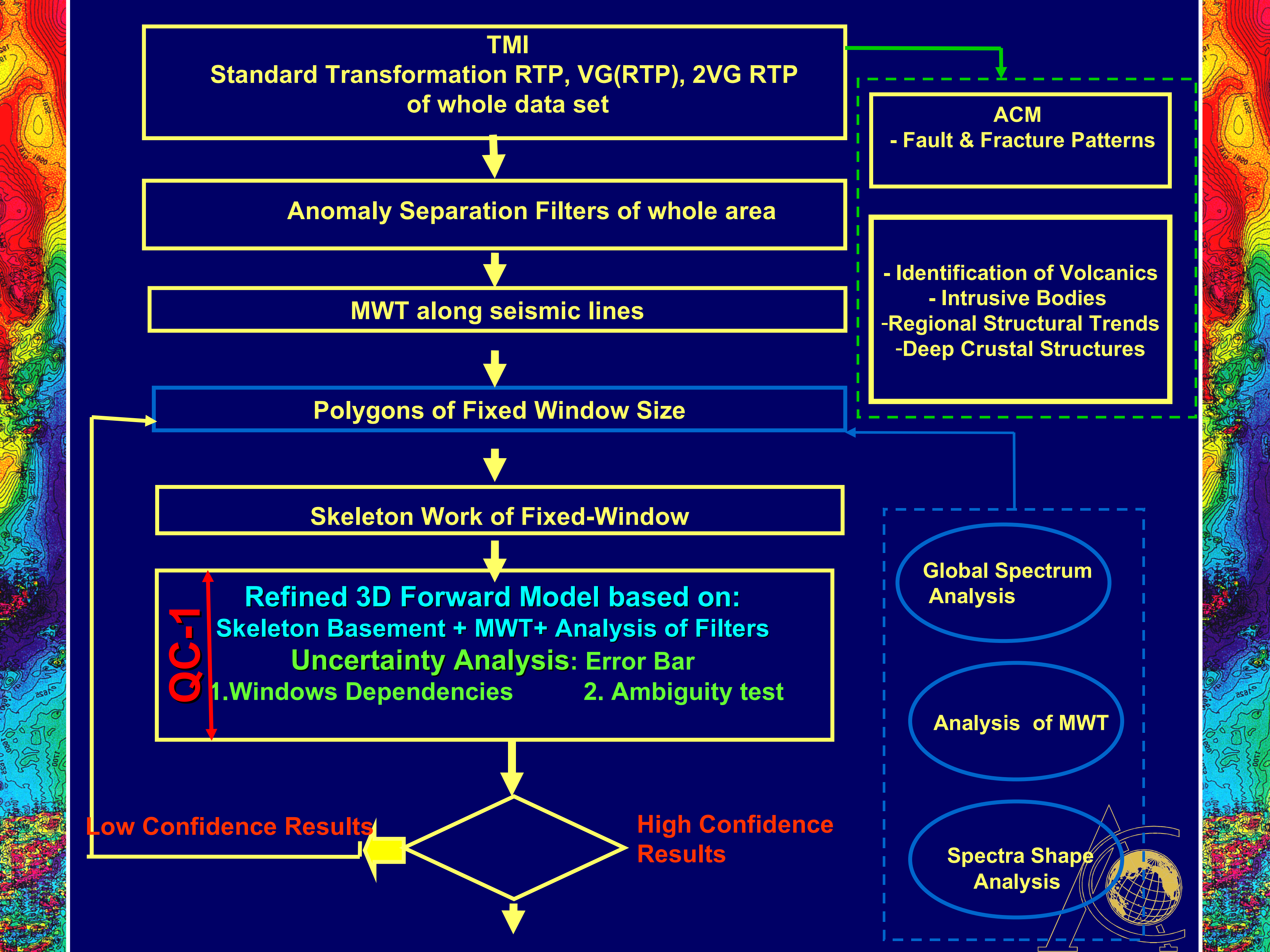


Top Nubian: Seismic



Sedimentary Basin Study

Workflow Chart


TMI
Standard Transformation RTP, VG(RTP), 2VG RTP
of whole data set
Anomaly Separation Filters of whole area
MWT along seismic lines
Polygons of Fixed Window Size
Skeleton Work of Fixed-Window
Refined 3D Forward Model based on:
Skeleton Basement + MWT+ Analysis of Filters
Uncertainty Analysis: Error Bar
1.Windows Dependencies
2. Ambiguity test
QC-1
Low Confidence Results
High Confidence Results
ACM
- Fault & Fracture Patterns
- Identification of Volcanics
- Intrusive Bodies
-Regional Structural Trends
-Deep Crustal Structures
Global Spectrum Analysis
Analysis of MWT
Spectra Shape Analysis

Fixed Window Spectra

- Semi-Automatic
- AutoESA

QC-2

Refined 3D Forward Model based on:
Skeleton of Basement + MWT+ Analysis of Filters Results

Uncertainty Analysis:
Windows Dependencies & Ambiguity test

Comparison with Seismic Data & Well Data

ACM Comparison

Low confidence results

High Confidence Results

Integration Fixed Window Results with Seismic:

- Refining Spectra calculation
- Refining Semi-Automatic Depth Calculation

Analysis of MWT to define Variable Window size

Variable Window Spectra

- Semi-Automatic
- AutoESA

QC-3

Refined 3D Forward Model based on:

- Skeleton of Basement
- MWT output
- Analysis of Filters Output

Uncertainty Analysis:

- Windows Dependencies
- Ambiguity test

Presentation and Report