New Method of Mapping Sub-Volcanic Geology Using Magnetic Data*

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Abstract

The Gawler Range Volcanics (GRV) province of the Western Gawler Craton in South Australia is an under-explored area covered by good quality, open file magnetic data. Using these data, a test study was conducted for the government of South Australia to map the thickness of volcanics and sub-volcanic geology over an area of 220km by 75km. The test area was chosen over the southern margin of the GRV where the thickness of volcanics was unknown, outcropping basement and basement with thin cover. Beneath the volcanic cover, basement configuration is unknown as there are a limited number of holes drilled, with only one penetrating through the volcanics. The main aim of this study was to map the base of volcanics, depth to sub-volcanic basement and delineation of structures underlying the GRV from the magnetic data. This test was also used to assess our new technique together with other methods concurrently being used to map subsurface geology, such as passive seismic.

To map base of volcanics and underlying basement, the Automatic Curve Matching (ACM) method was applied to located magnetic data. This method detects magnetic sources within different rock units of the crust, such as volcanics and the underlying basement. The ACM method was used to analyse and interpret millions of individual magnetic anomalies along profiles, detecting causative magnetic sources providing depth, location, geometry and magnetic susceptibility. To image the GRV in 3D, the high-frequency component of the magnetic field was targeted. The Total Magnetic Intensity (TMI) data was analysed using separate geophysical algorithms to simulate subhorizontal volcanic lava flows, and to model complex basement geology more effectively. The magnetic susceptibilities detected by ACM indicated the geochemistry of volcanics of different

ages. This allowed the imaging of separate lava flows and differentiation of the volcanics from the underlying basement. Using different visualisation techniques for the results from each algorithm, the base of volcanics was mapped along 75km NS profiles, spaced 1km apart over a distance of 220km, covering an area of 16,500km^2. The results were gridded, and an image of the base of volcanics was generated.

This procedure was used to map the top of the sub-volcanic magnetic basement. The Proterozoic basement magnetic susceptibilities and the magnetic source distribution pattern were used as key determinants to interpret the depth to the top of basement. The results were gridded and an image of the basement configuration was generated. In some areas, the base of volcanics coincides with the basement, whereas in other areas, there is a difference between the two, which could be due to the presence of sub-volcanic sediments. The results show that the volcanics are on average 700m-900m thick with a very thick section exceeding 3.4km in the east, and around 1.5km in the west of the study area.

The mapped volcanics thickness was validated by comparison with numerous drill holes (intersecting the base of volcanics or terminating within the volcanics). All the results matched the drill-hole data extremely well. After project completion, a passive seismic survey was conducted at the eastern end of the test area, indicating a base of volcanics of about 4km, which further confirms our results. The results achieved show that this process of mapping sub-volcanic basement can be applied in other volcanic provinces worldwide, and provide valuable and, perhaps, crucial information for mineral and petroleum exploration. Based on the imaged base, thickness and magnetic susceptibilities of volcanics, the magnetic influence of volcanics can be modelled and subtracted from the acquired magnetic data, thus enabling interpretation of magnetic anomalies arising from sub-volcanic crust. This can be done over sedimentary basins where thick volcanics mask seismic signals and prevent mapping of sub-volcanic geology. Our new method can assist solving challenges in sub-volcanic petroleum exploration in India.

Selected References

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Agenda

I. **Introduction**
II. Description of the New Method
III. ACM Method
IV. Imaging Volcanics in 3D
V. Stripping off Volcanics from Total Magnetic Field
- 3D-voxel Synthetic Model of Volcanics
- Magnetic Field of Volcanics
- Sub-volcanic Magnetic Field

VI. Examples of Mapping Sub-volcanic Geology
IV. Conclusions

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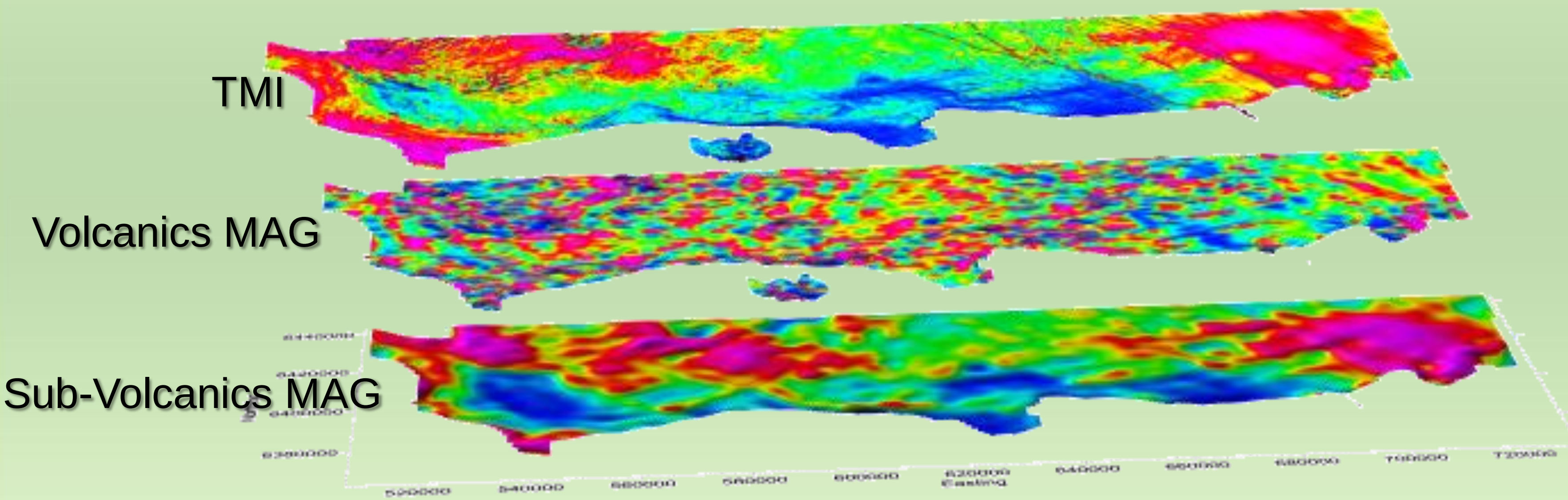
How we can Map Sub-volcanic Geology?

Description of the New Method

To uncover the Sub-Volcanic Geology, Magnetic Anomalies from Volcanics have to be attenuated & subsequently Magnetic Field of Sub-Volcanic Crust computed

<u>TMI –‘Volcanics MAG’ = ‘Sub-Volcanic MAG’</u>



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ACM Method
Imaging Volcanics in 3D
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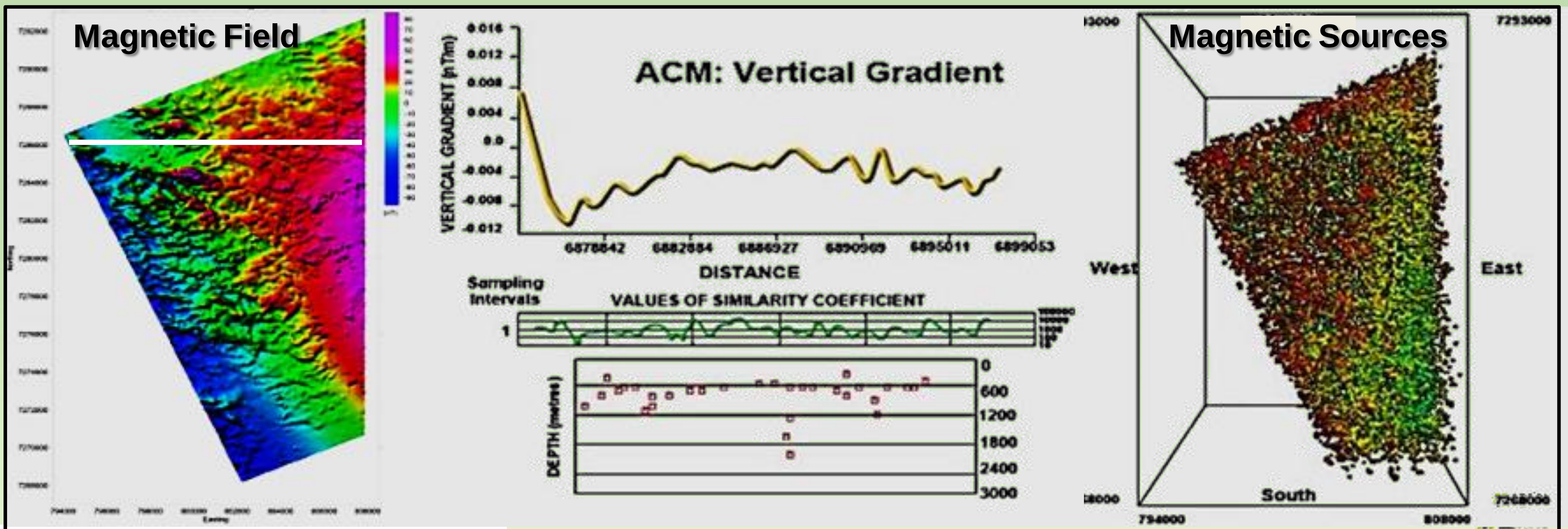
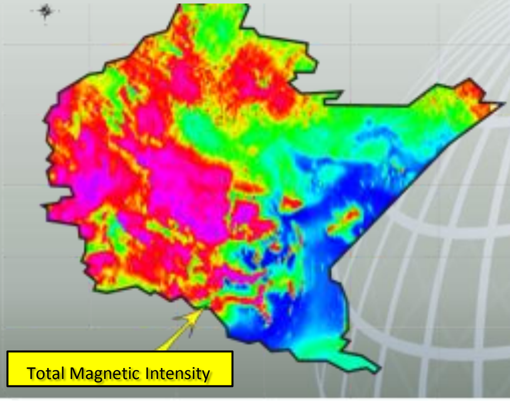
ACM: Automatic Curve Matching Method

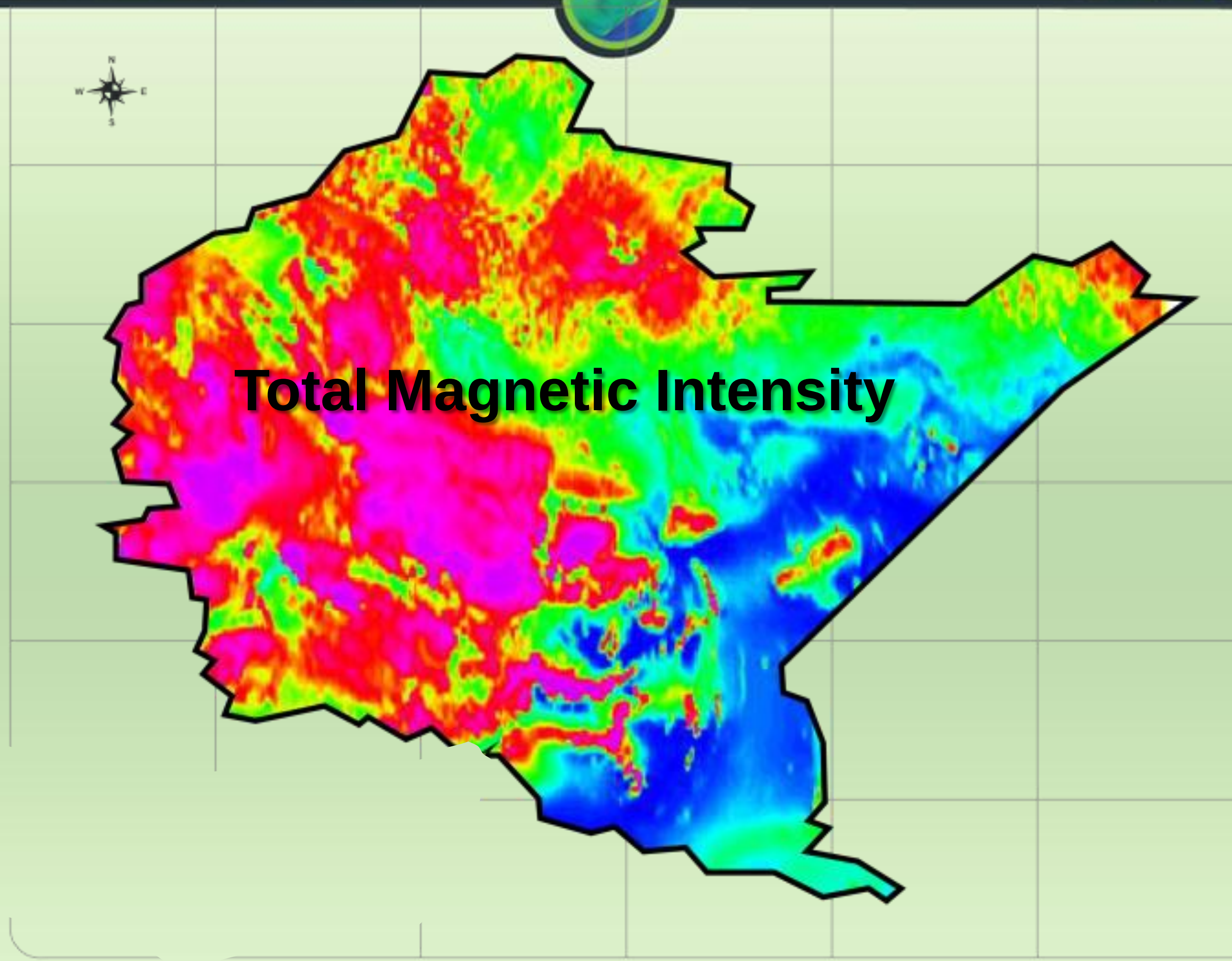
- The ACM method is applied to located magnetic data
- Analyses individual magnetic anomalies in purely automatic manner
- For each anomaly, ACM detects Magnetic Source: depth to the top, geometry & magnetic susceptibility
- Magnetic Sources visualise magnetisation of the crust: sediments, basement, intrusions & volcanics.



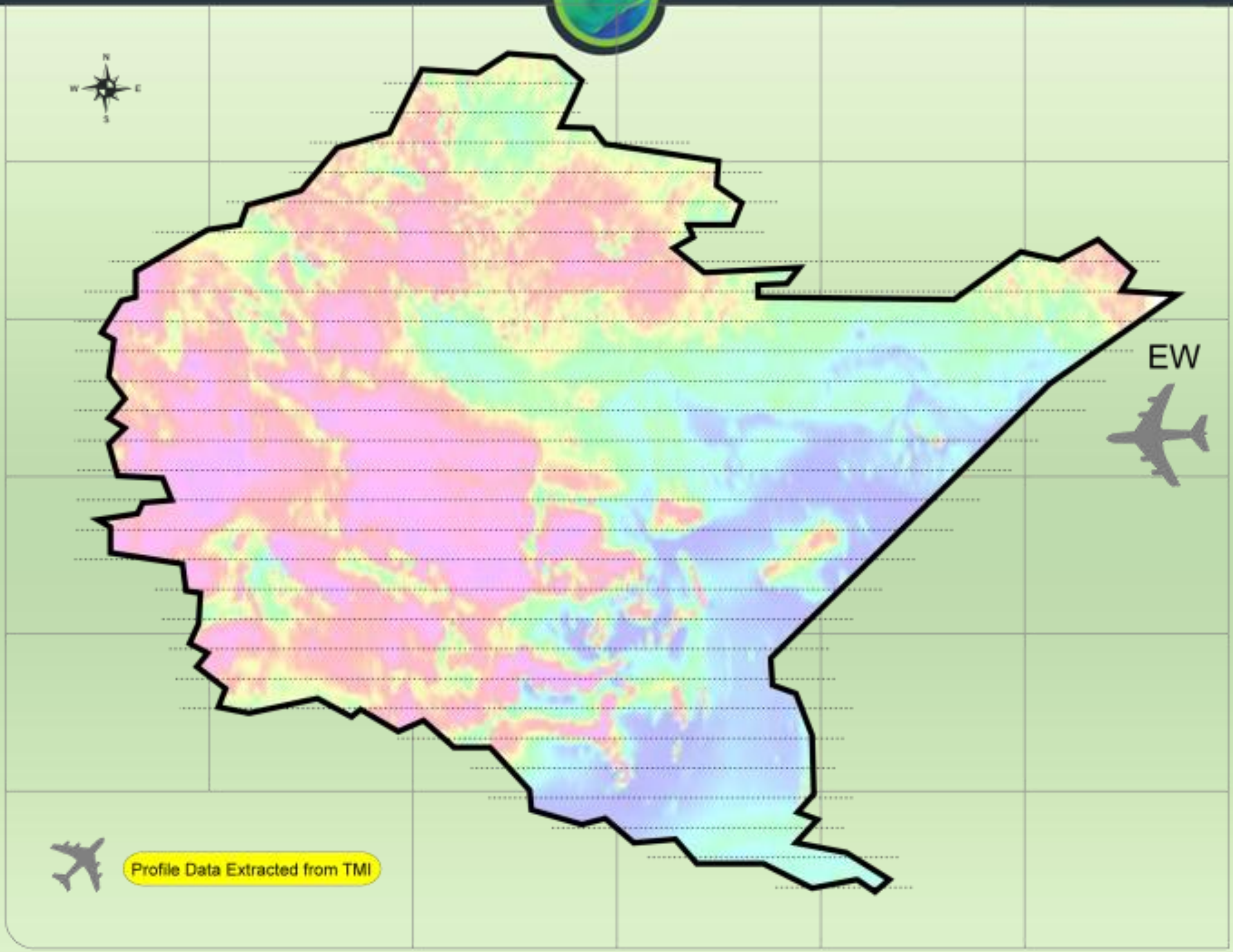
ACM
Basic Principles



Automatic Curve Matching: Theory



Profile Extraction for ACM



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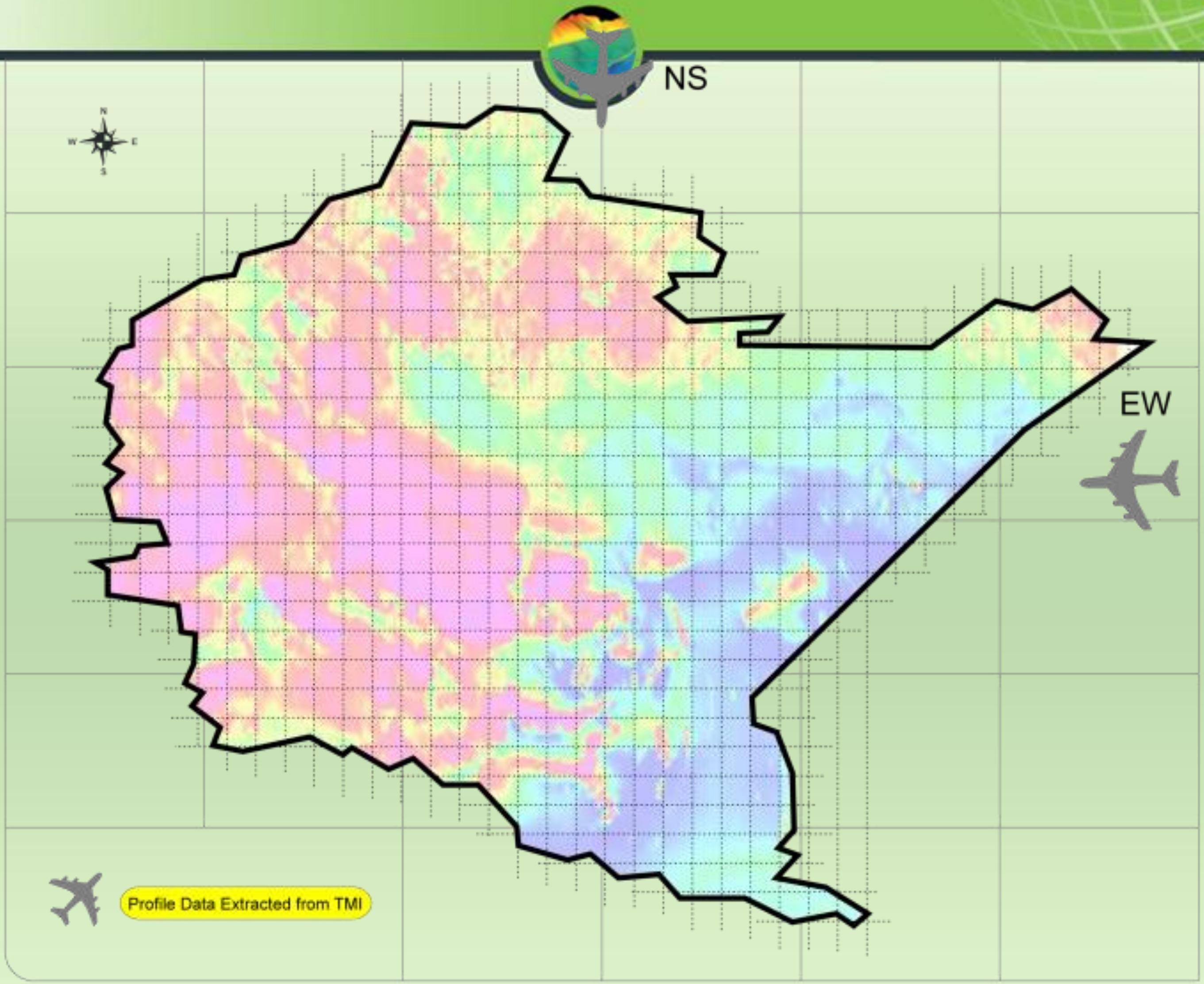
Profile Extraction for ACM



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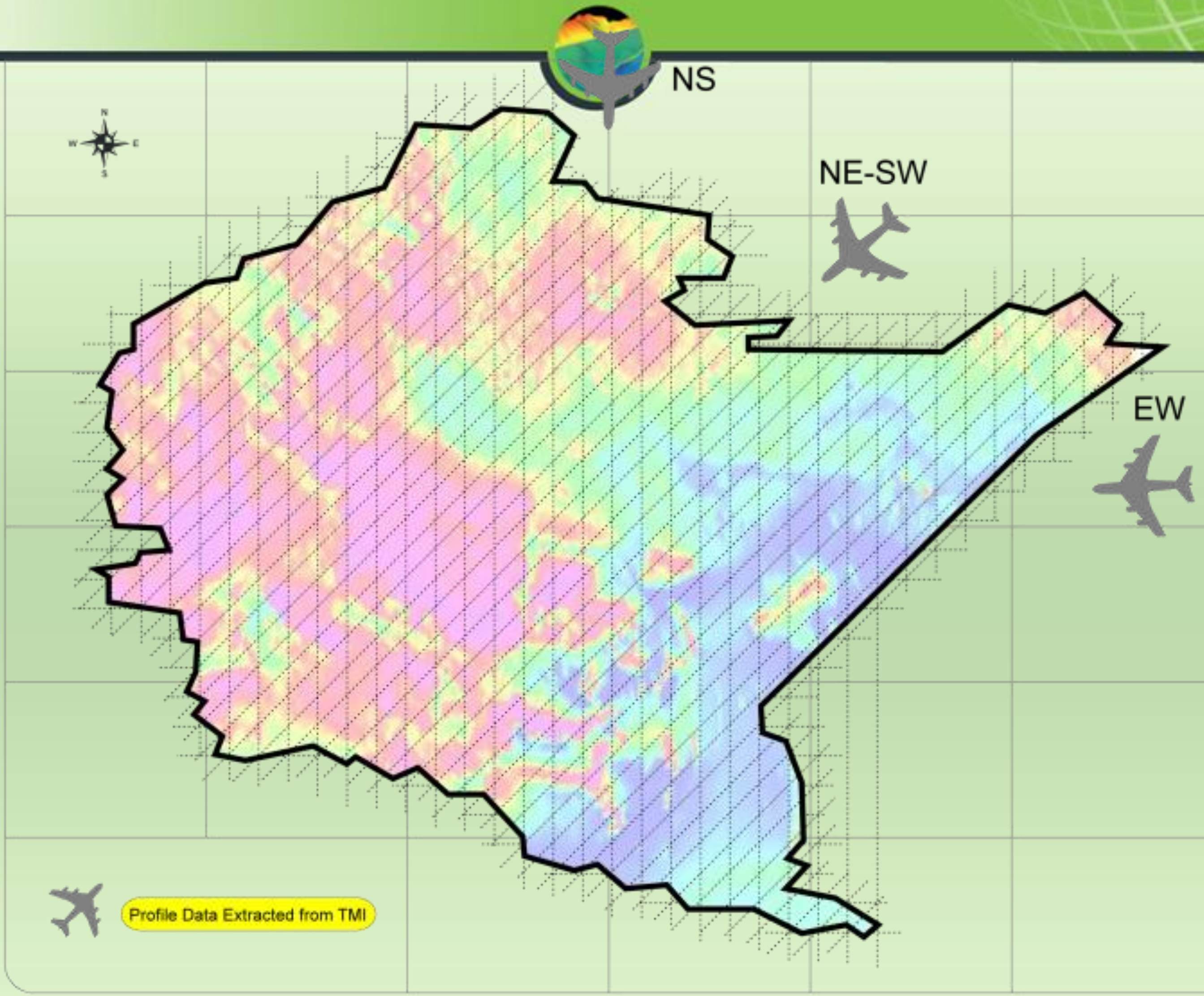

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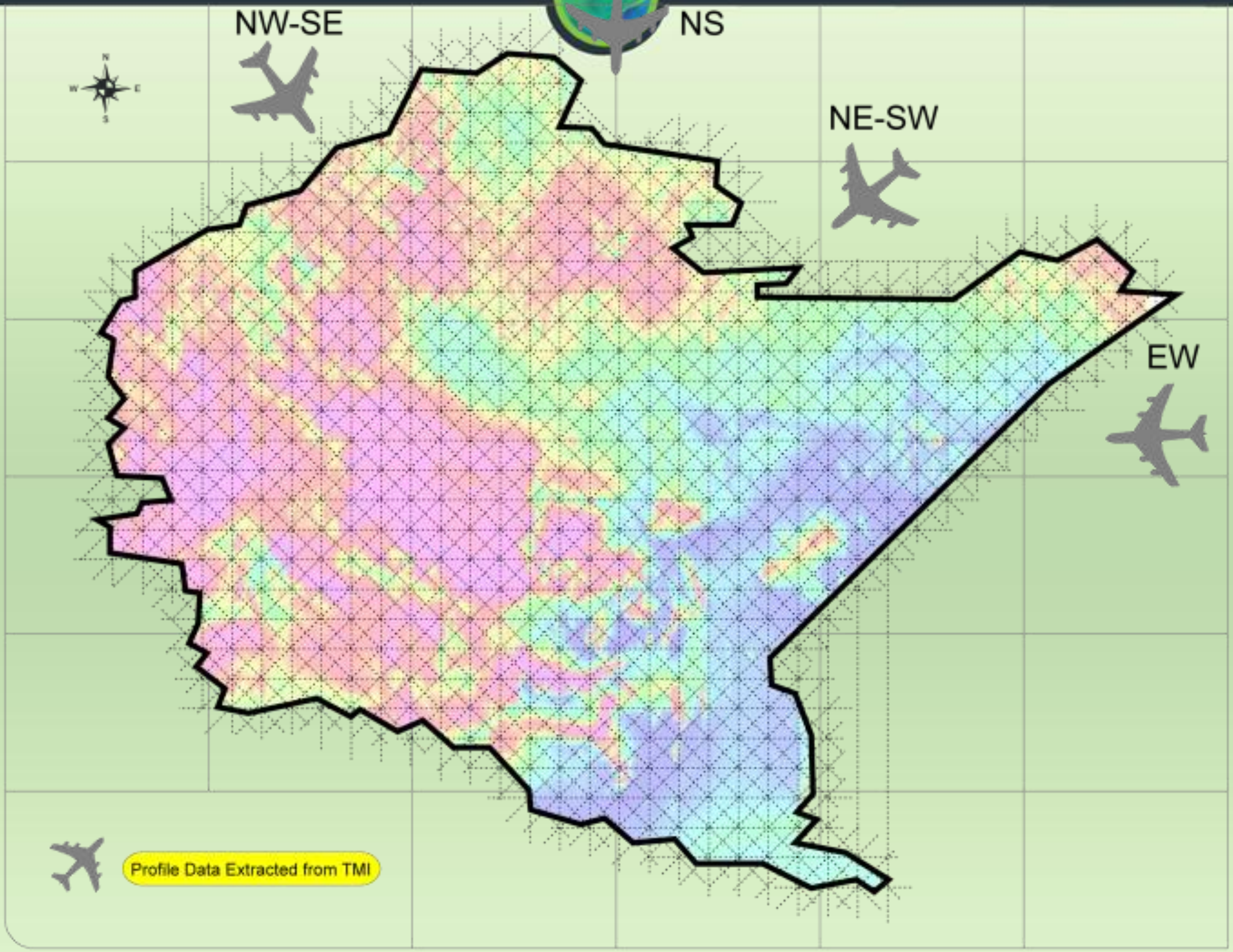

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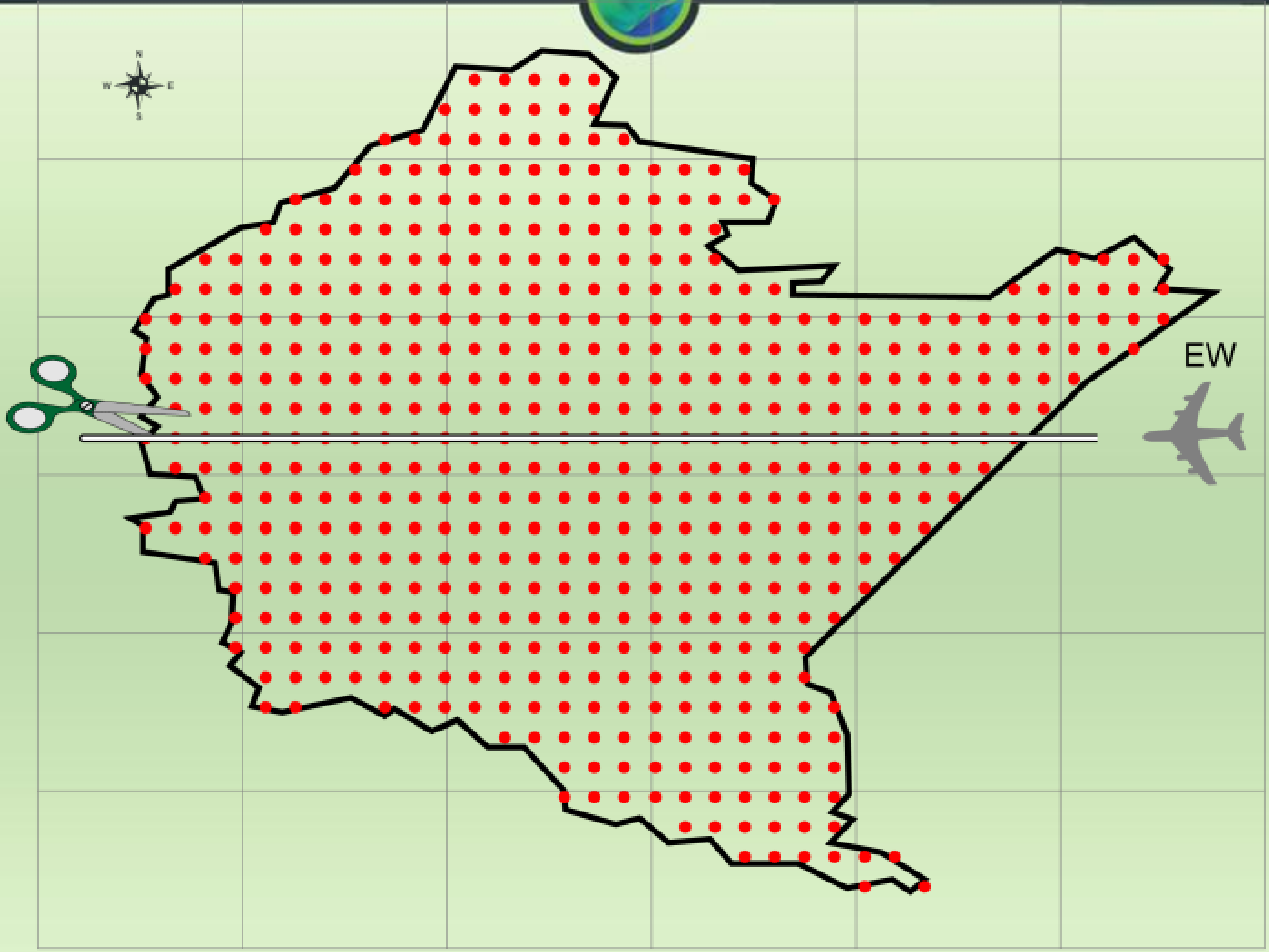

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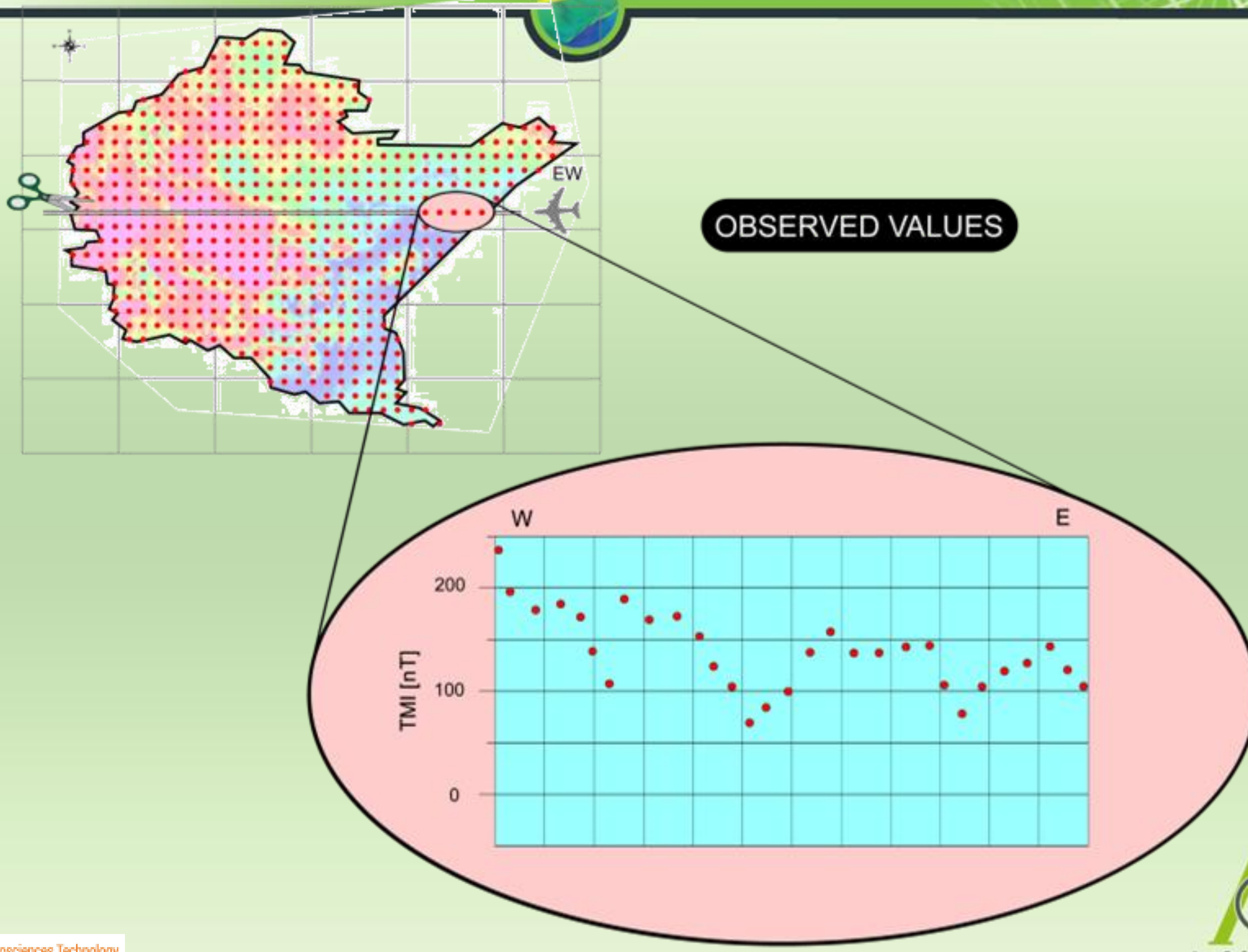

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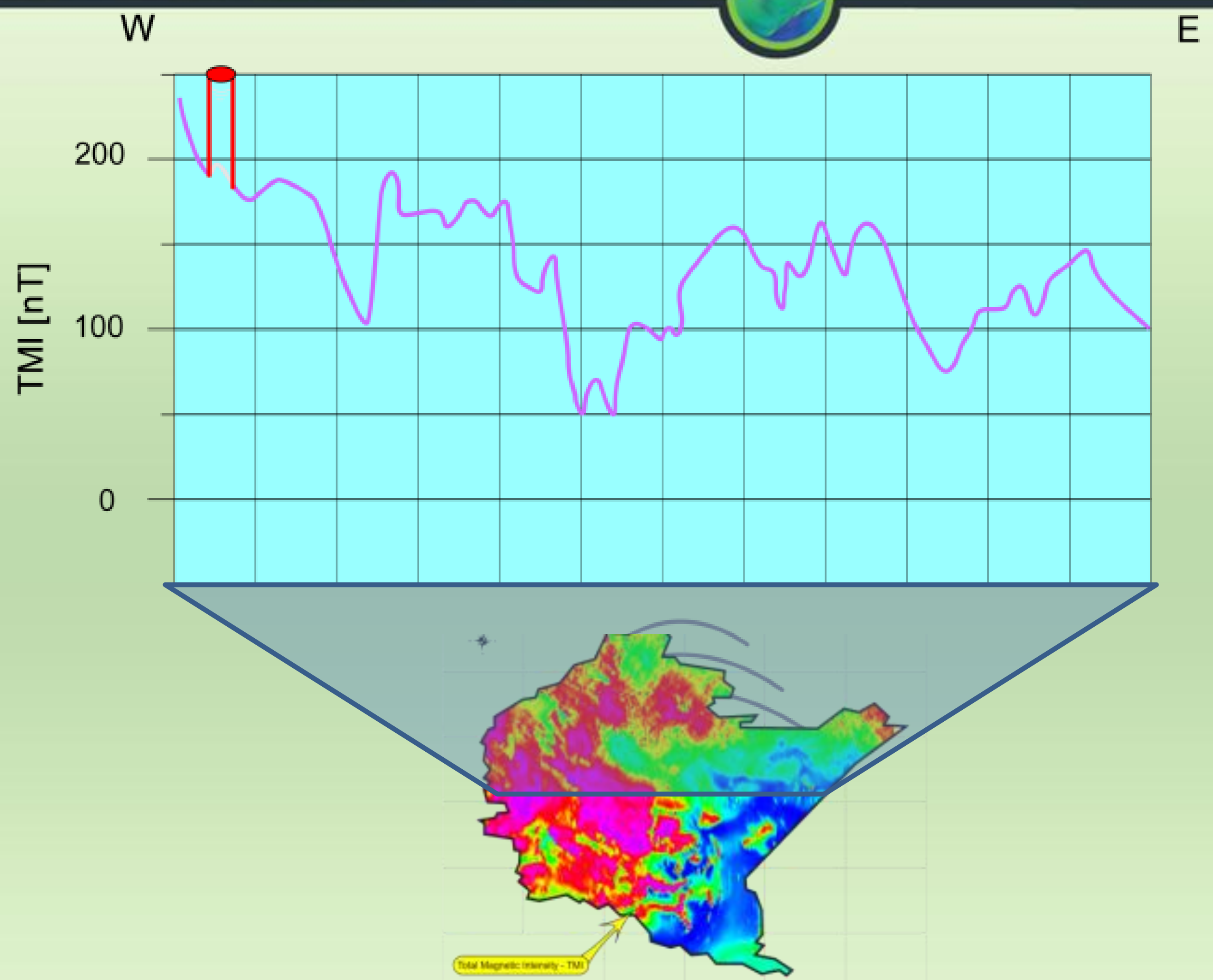
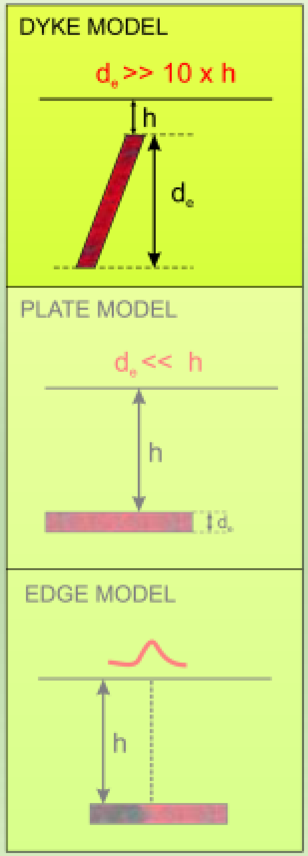
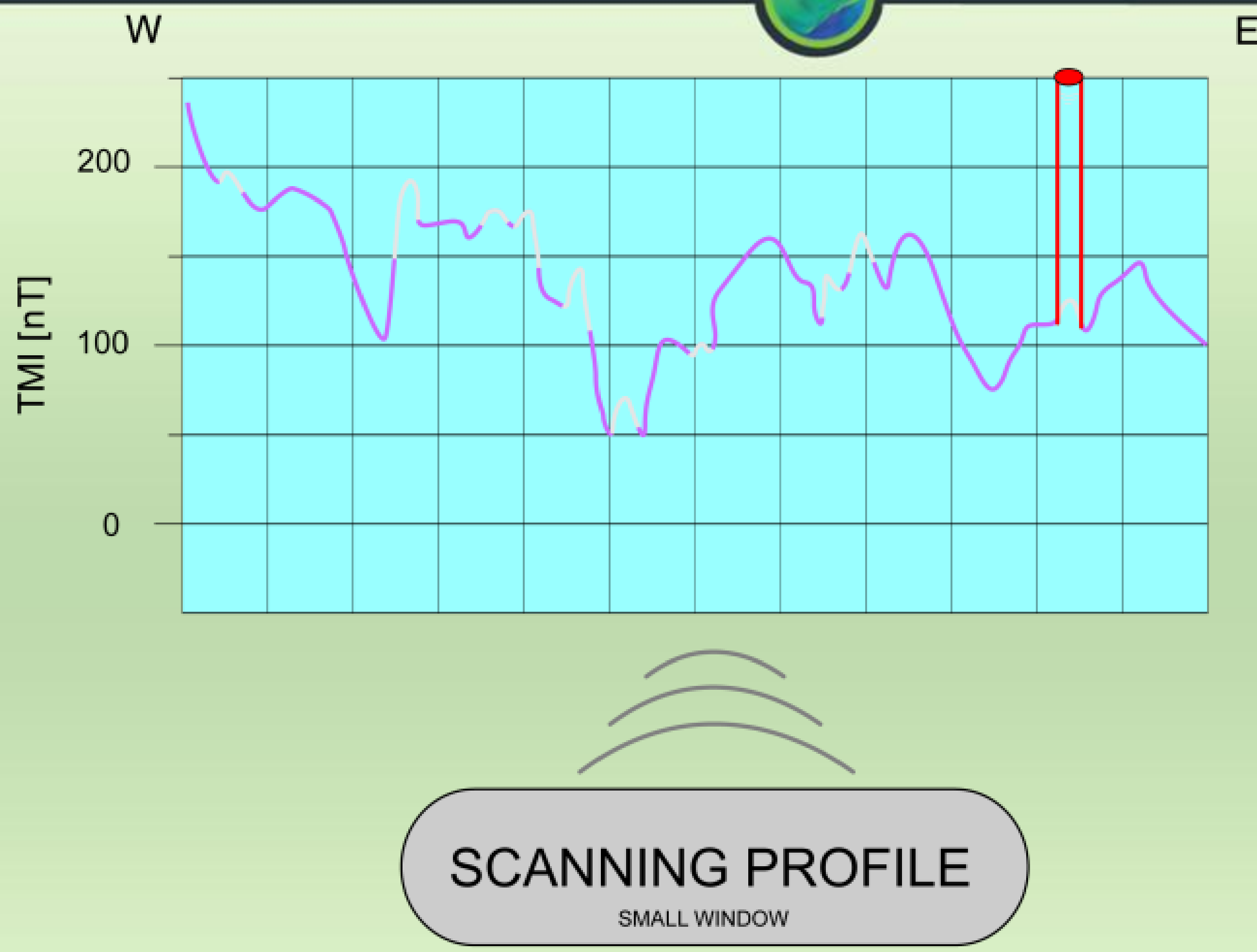
Automatic Curve Matching: Theory

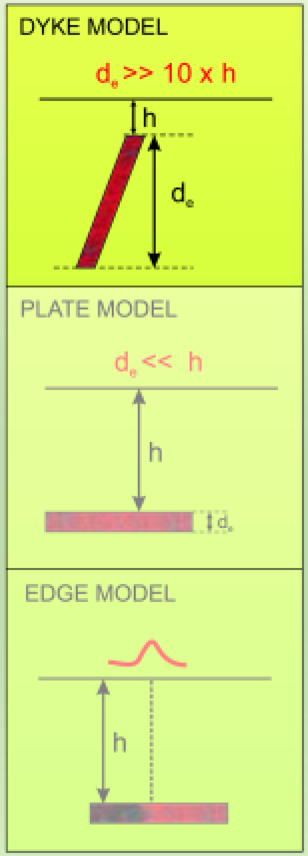




Individual magnetic anomalies of short wave-length are defined along the profiles.

Automatic Curve Matching: Theory





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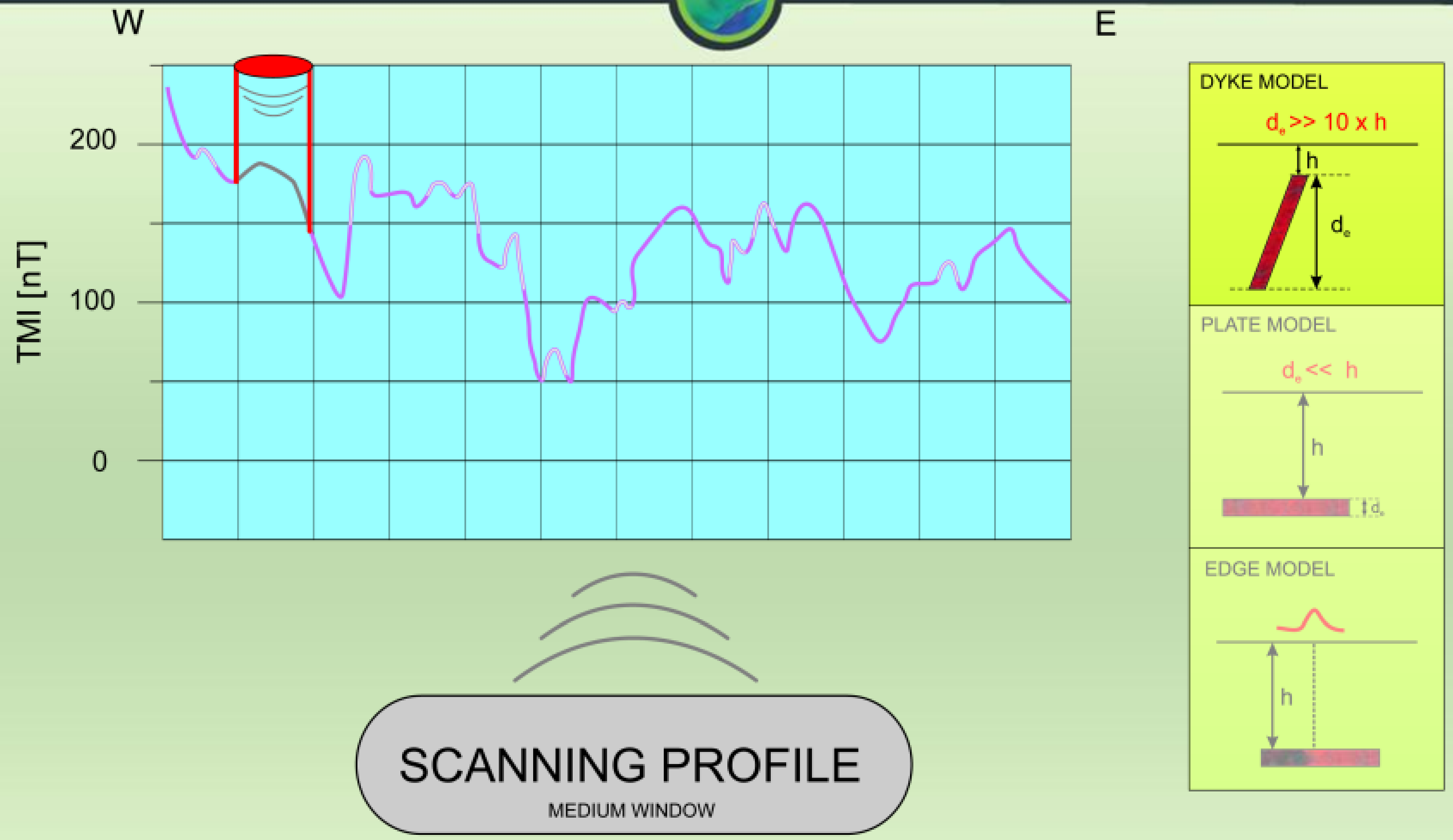
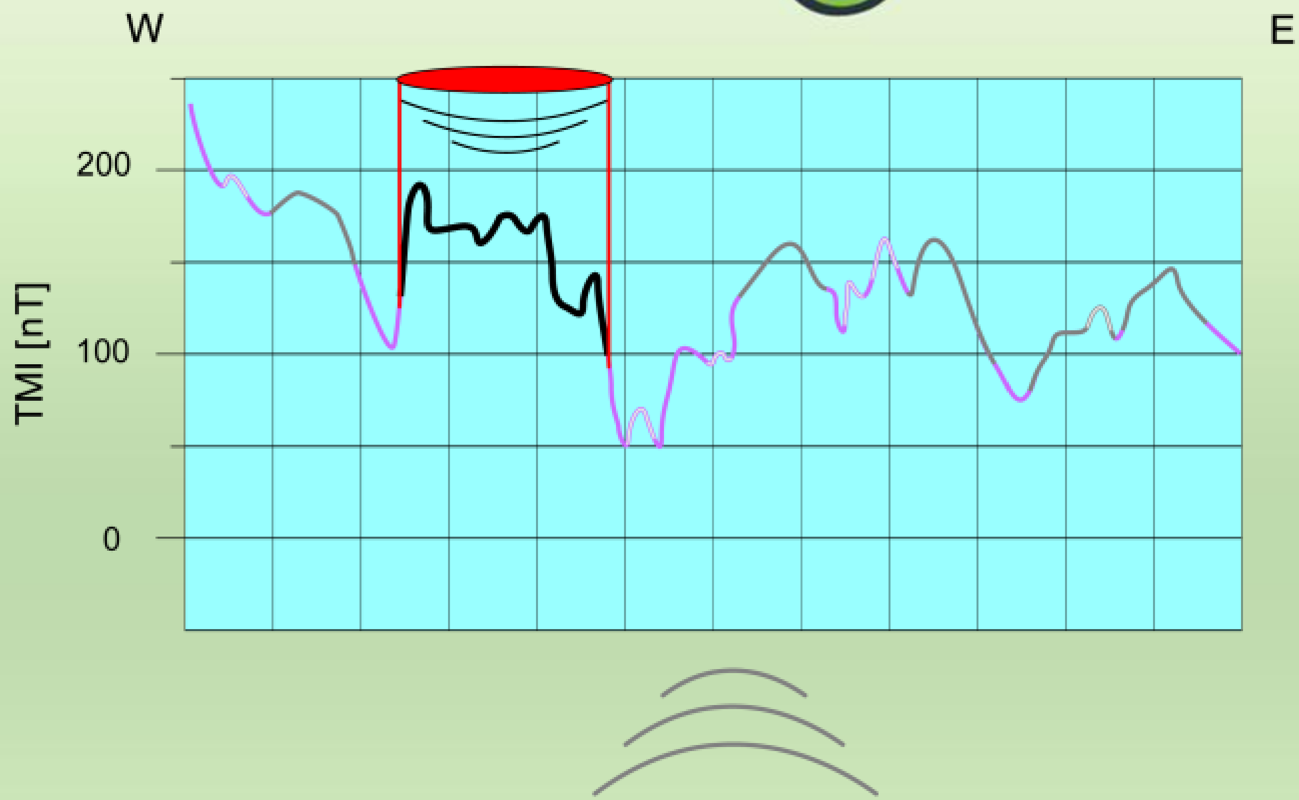
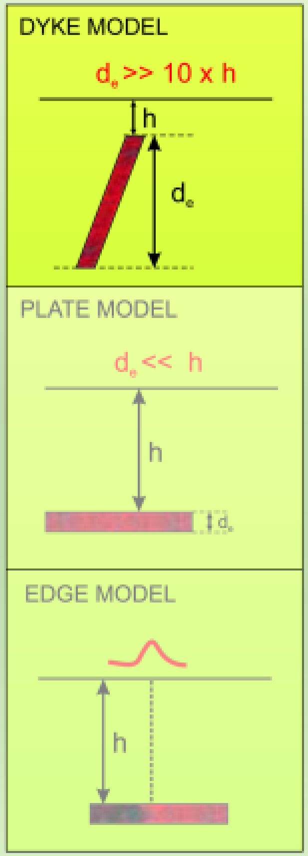
Automatic Curve Matching: Theory



Individual magnetic anomalies of medium wave-length are defined along the profiles.

Automatic Curve Matching: Theory



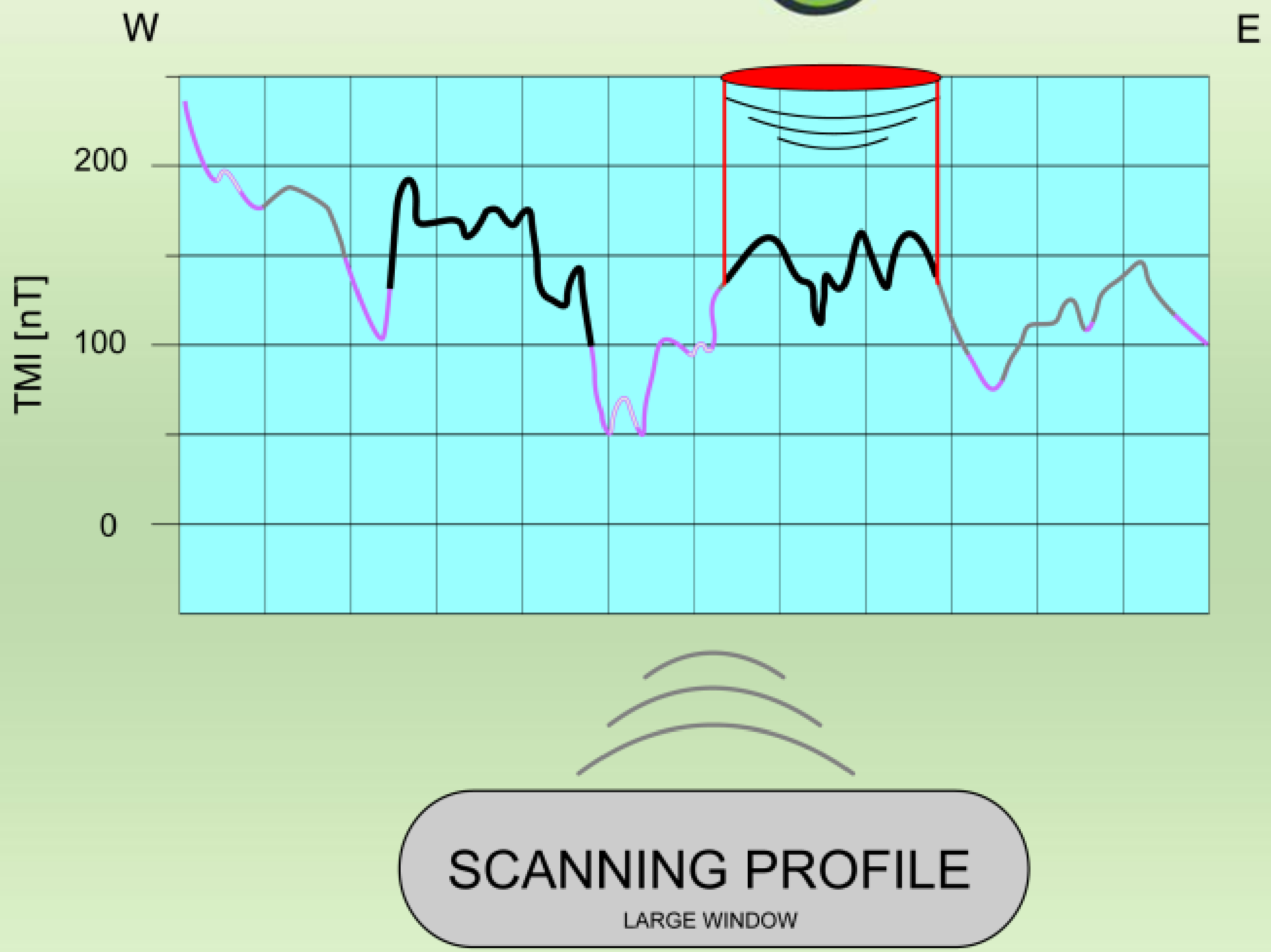


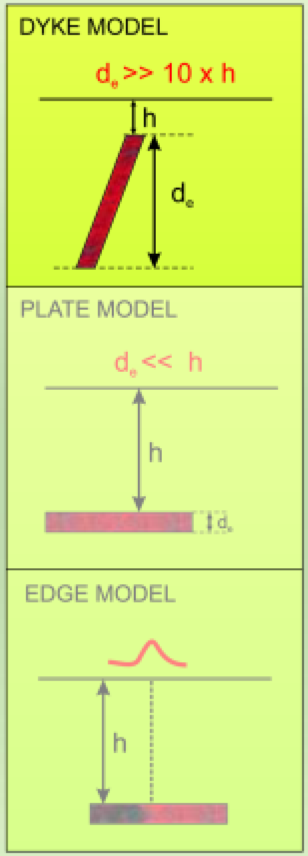
SCANNING PROFILE

LARGE WINDOW

Individual magnetic anomalies of long wave-length are defined along the profiles.

Automatic Curve Matching: Theory

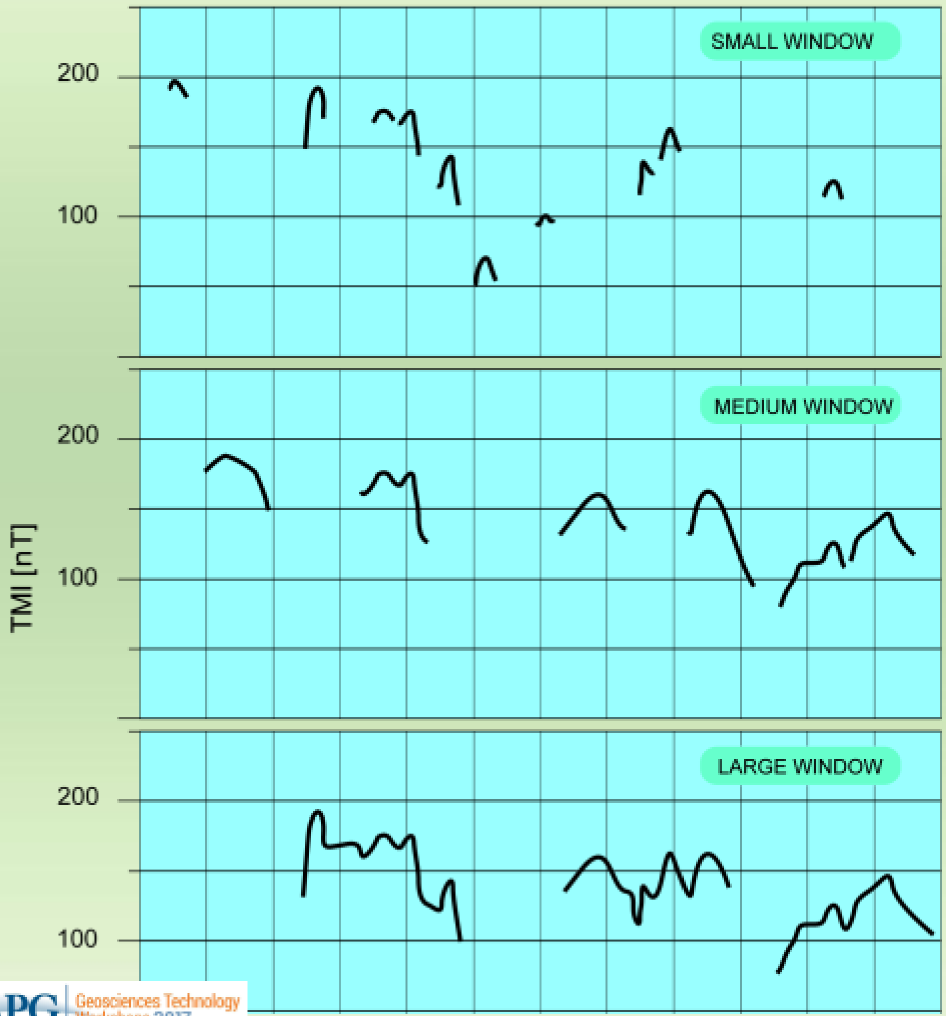


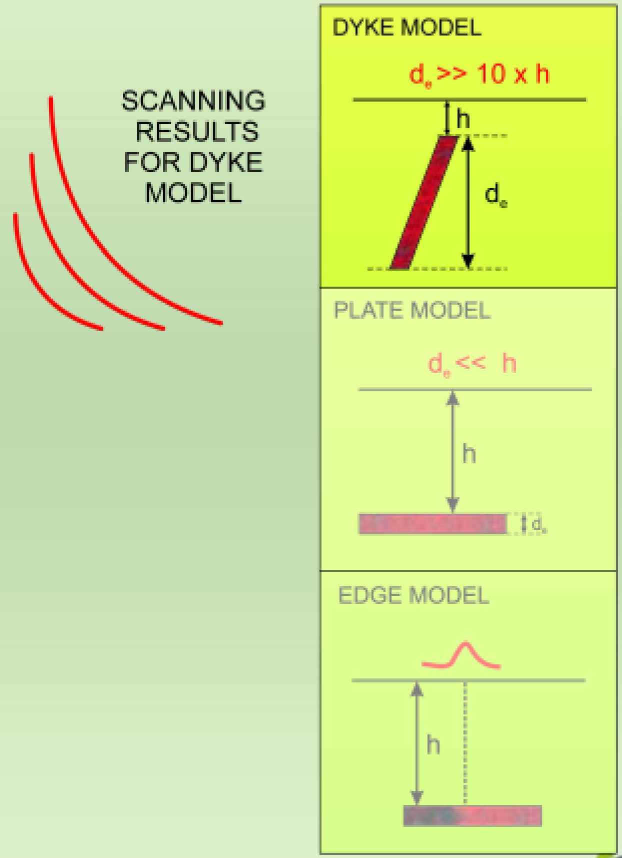


Individual magnetic anomalies of long wave-length are defined along the profiles.

Automatic Curve Matching: Theory

Individual magnetic anomalies of different wave-length are defined along the profiles.





Automatic Curve Matching: Theory

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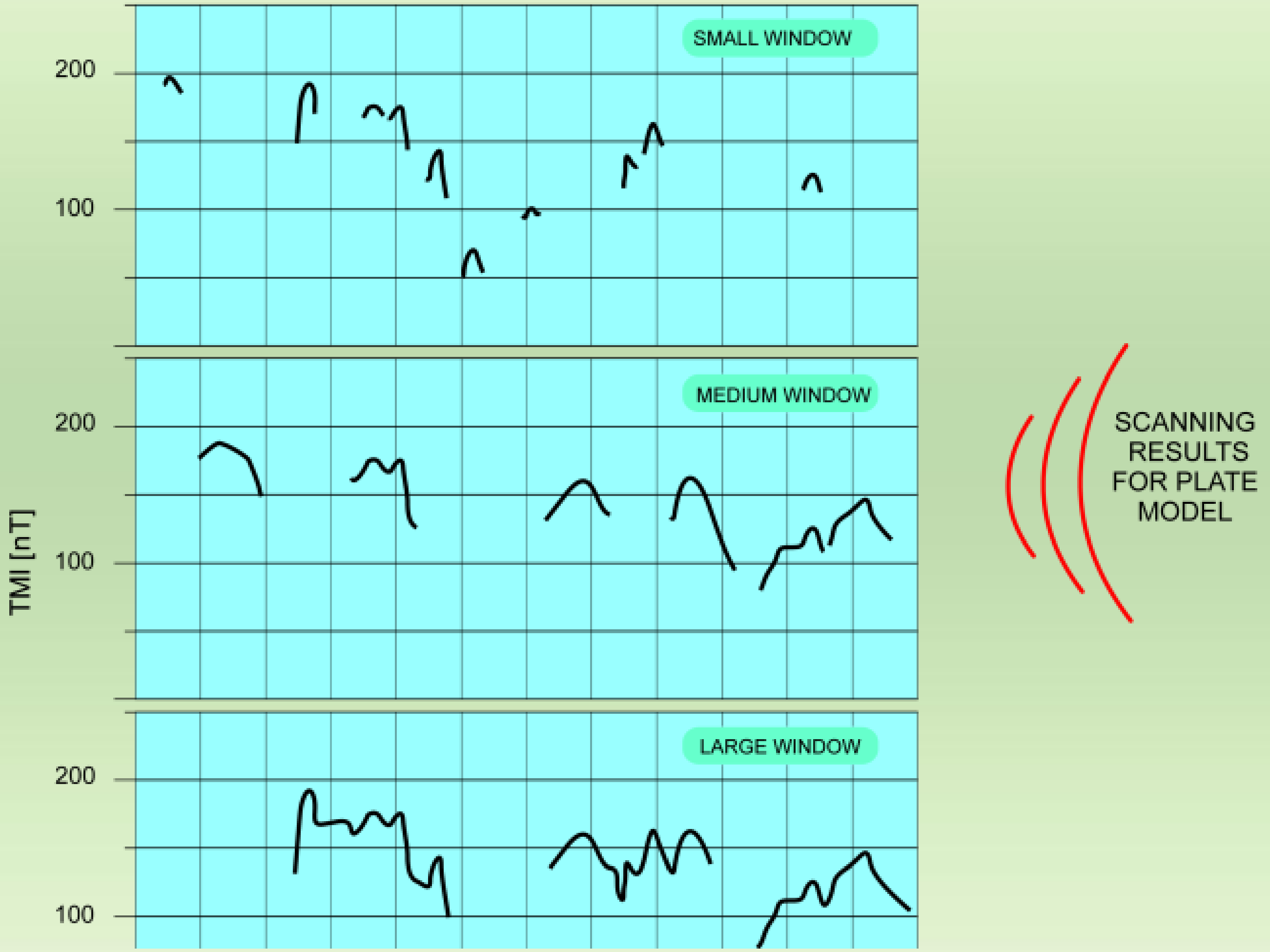

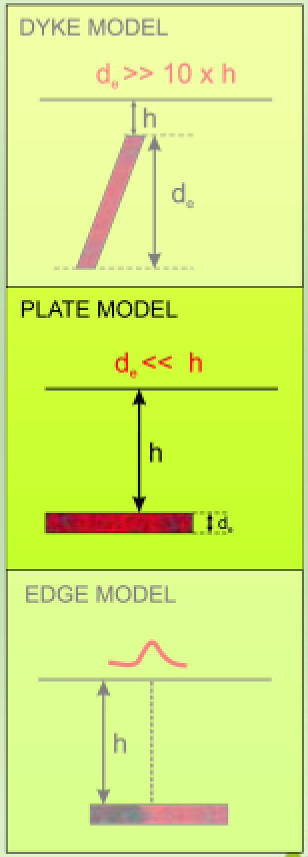

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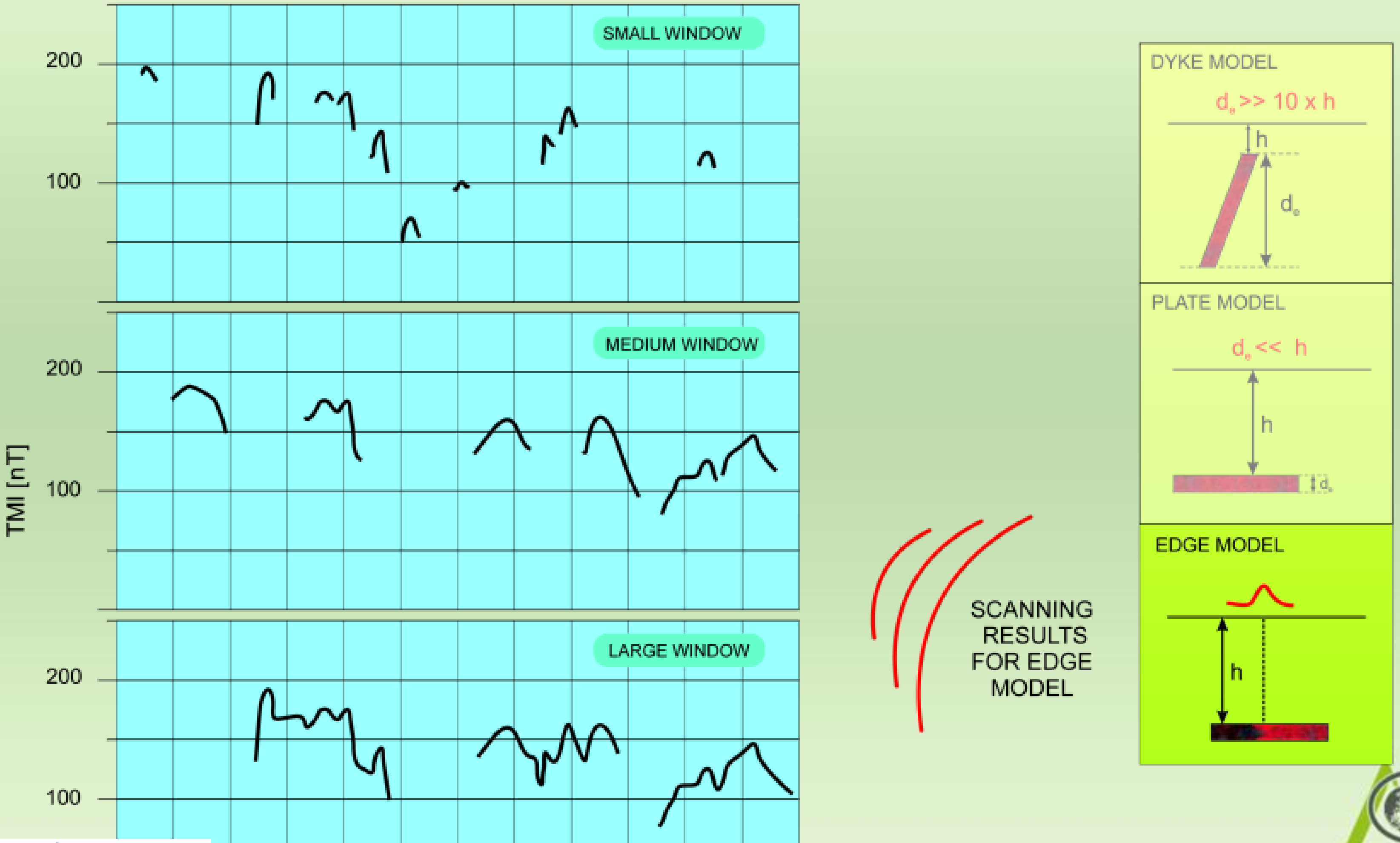
Automatic Curve Matching: Theory

Individual magnetic anomalies of different wave-length are defined along the profiles.

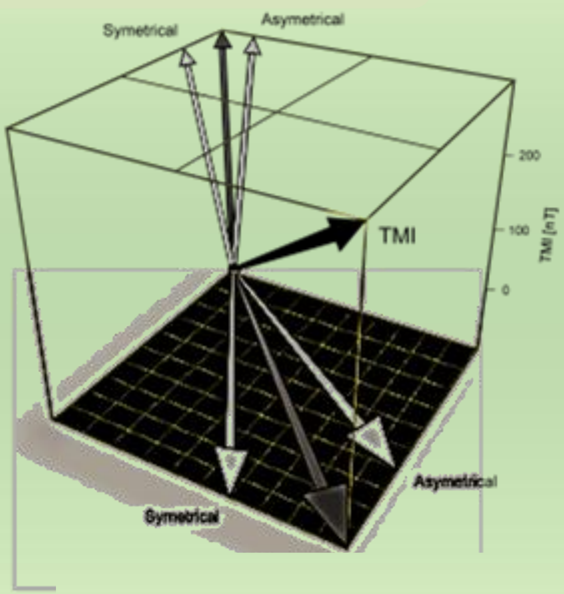


ACM: Theory

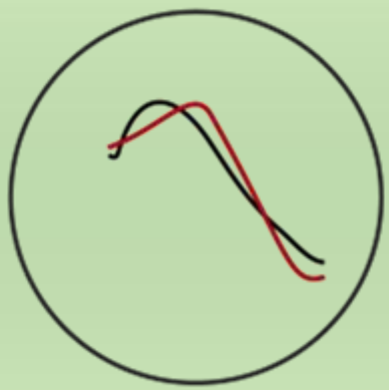
OBSERVED

CALCULATED

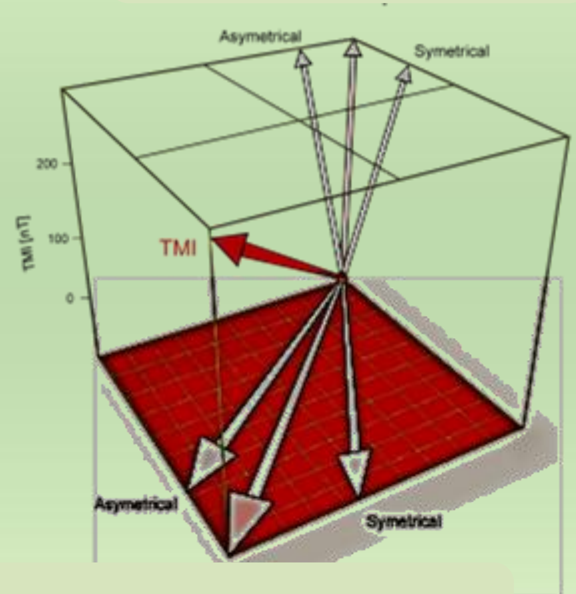
Vertical Component



Horizontal Component



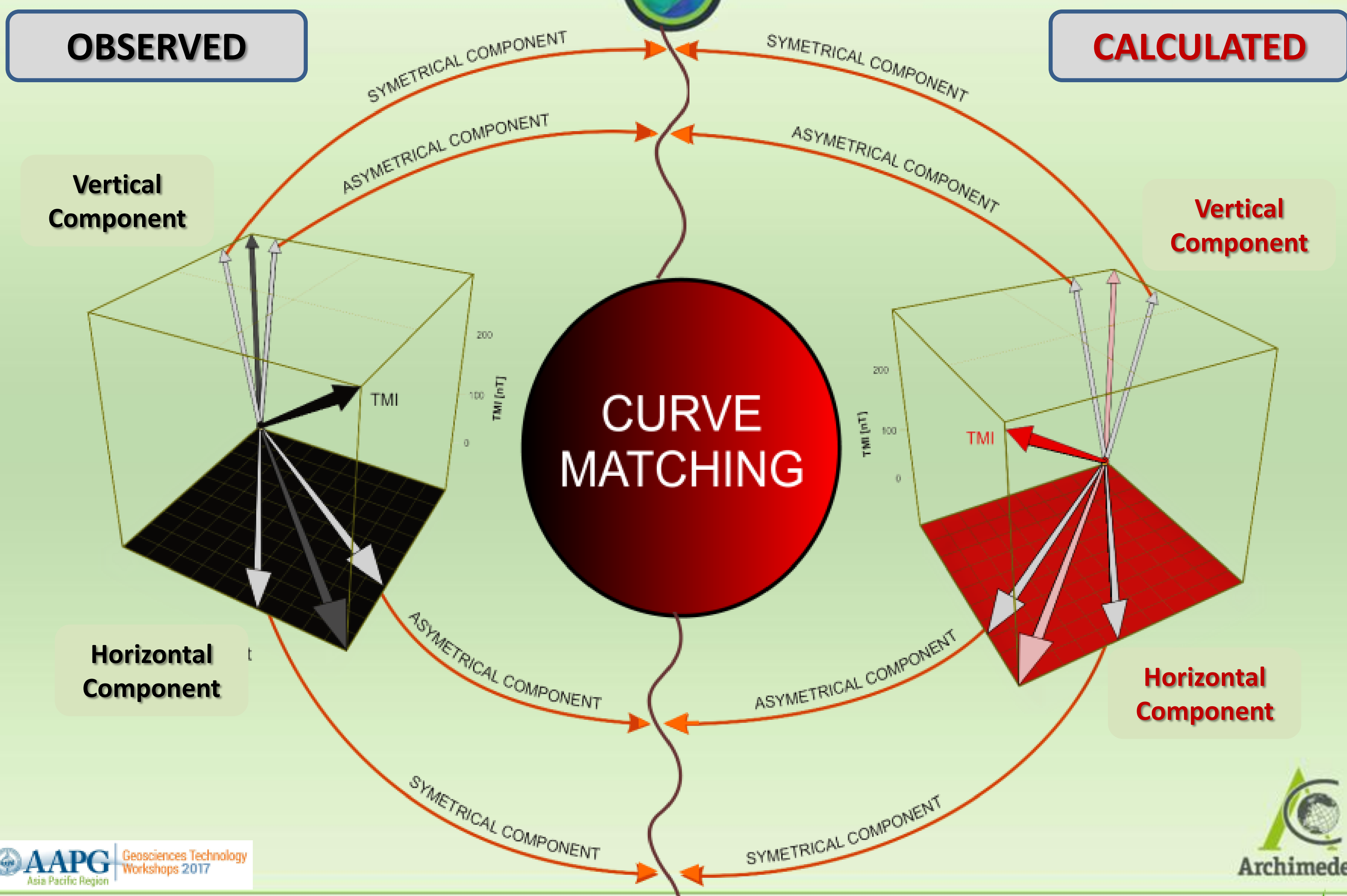
Vertical Component



Horizontal Component

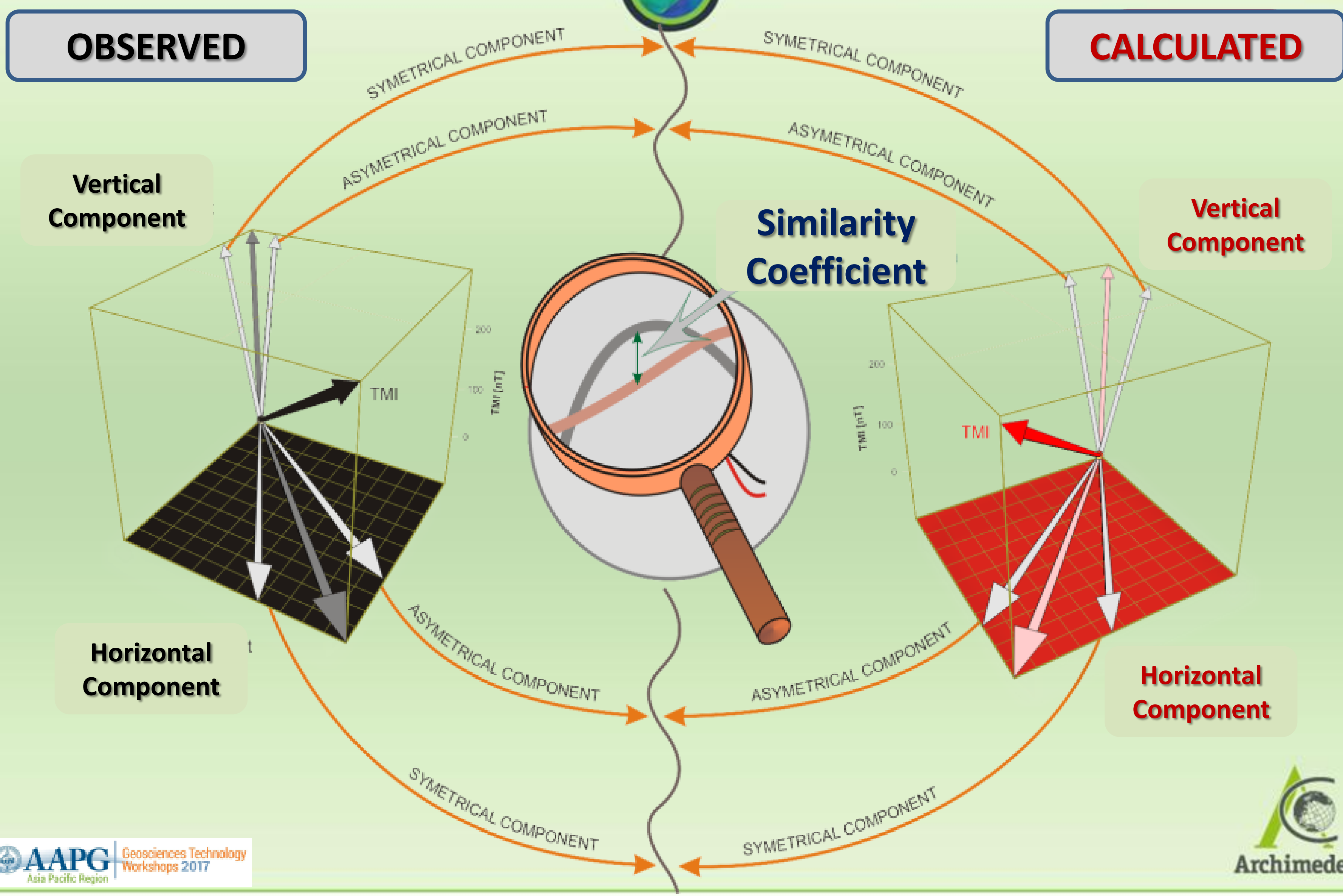
Single anomaly is split into vertical & horizontal components, which are then represented by a pair of symmetrical & asymmetrical functions.

ACM: Theory

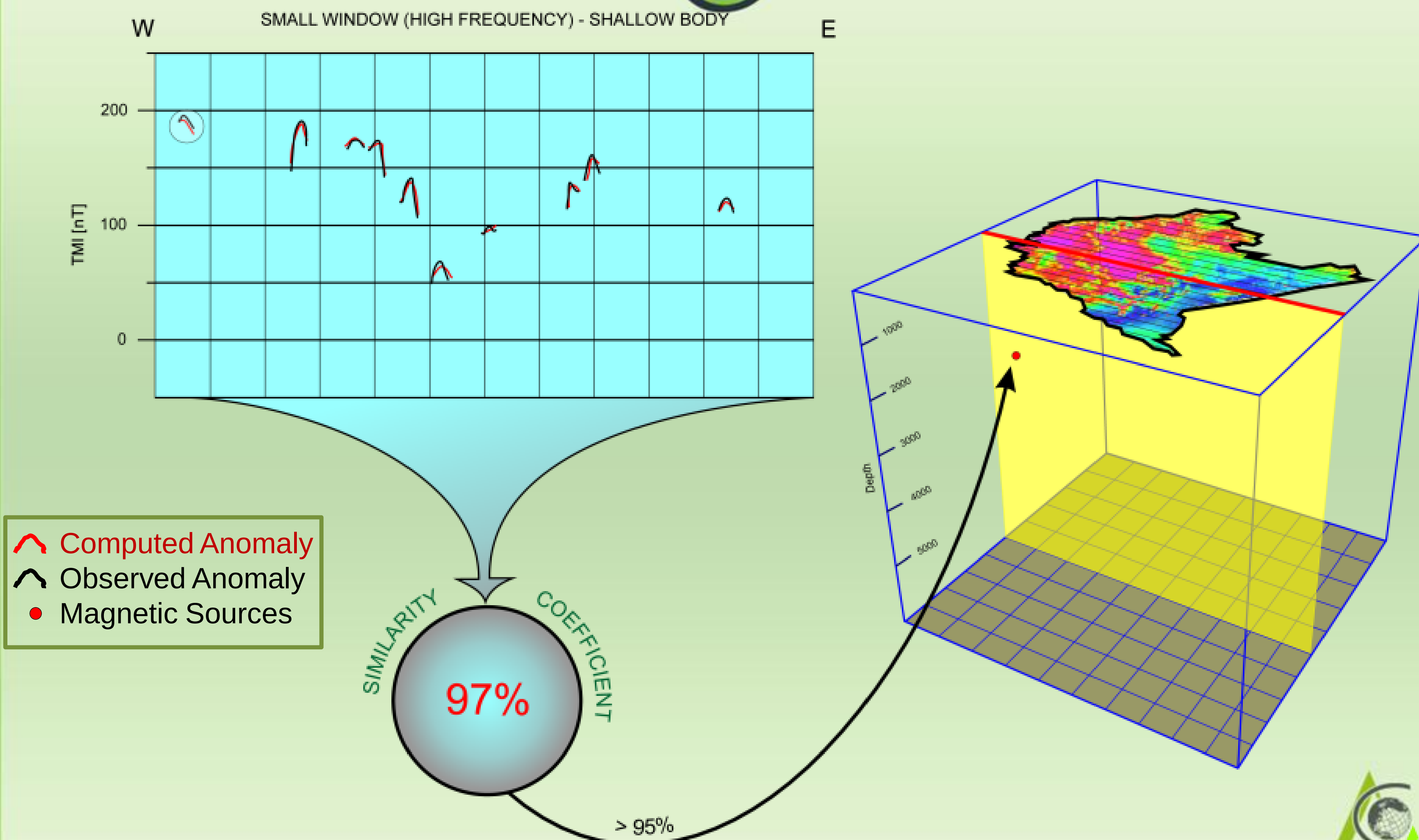


OBSERVED
CALCULATED
SYMETRICAL COMPONENT
ASYMETRICAL COMPONENT
Vertical Component
Horizontal Component
TMI
200
100
0
TMI [nT]
CURVE MATCHING
Vertical Component
Horizontal Component
TMI
200
100
0
TMI [nT]
ASYMETRICAL COMPONENT
SYMETRICAL COMPONENT

ACM: Goodness of Fit



Automatic Curve Matching: Goodness of Fit



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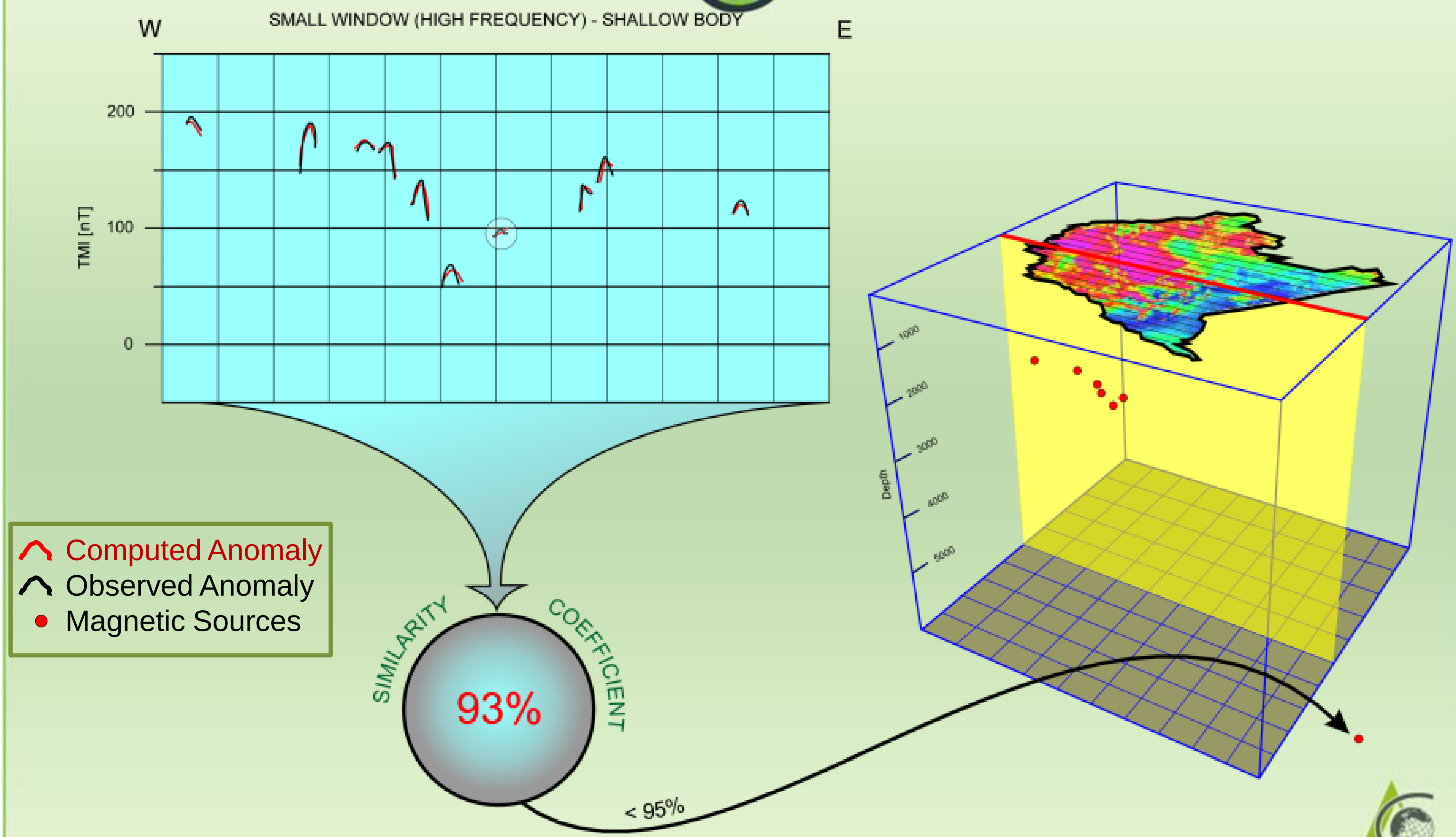
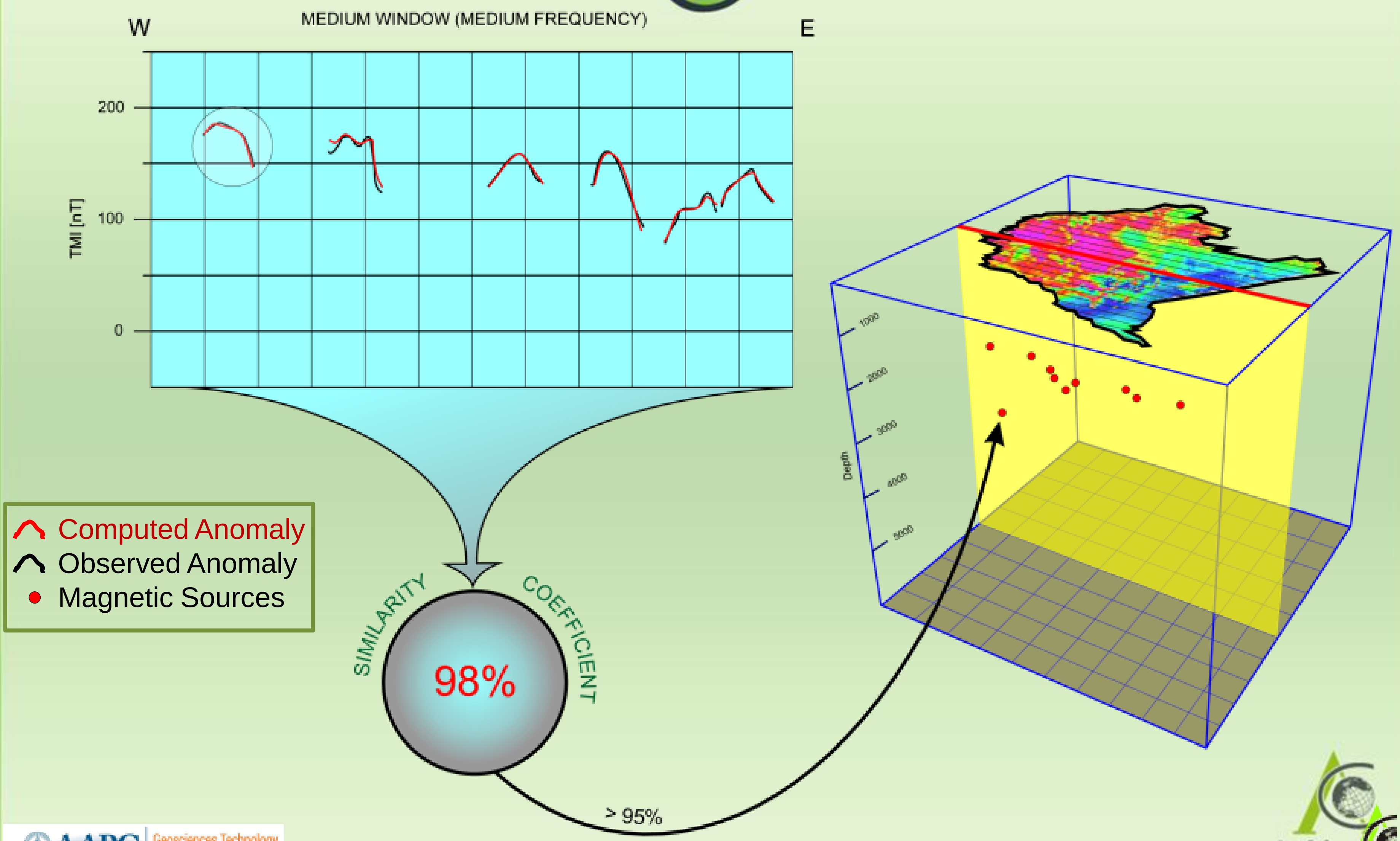
Automatic Curve Matching: Goodness of Fit



Automatic Curve Matching: Goodness of Fit



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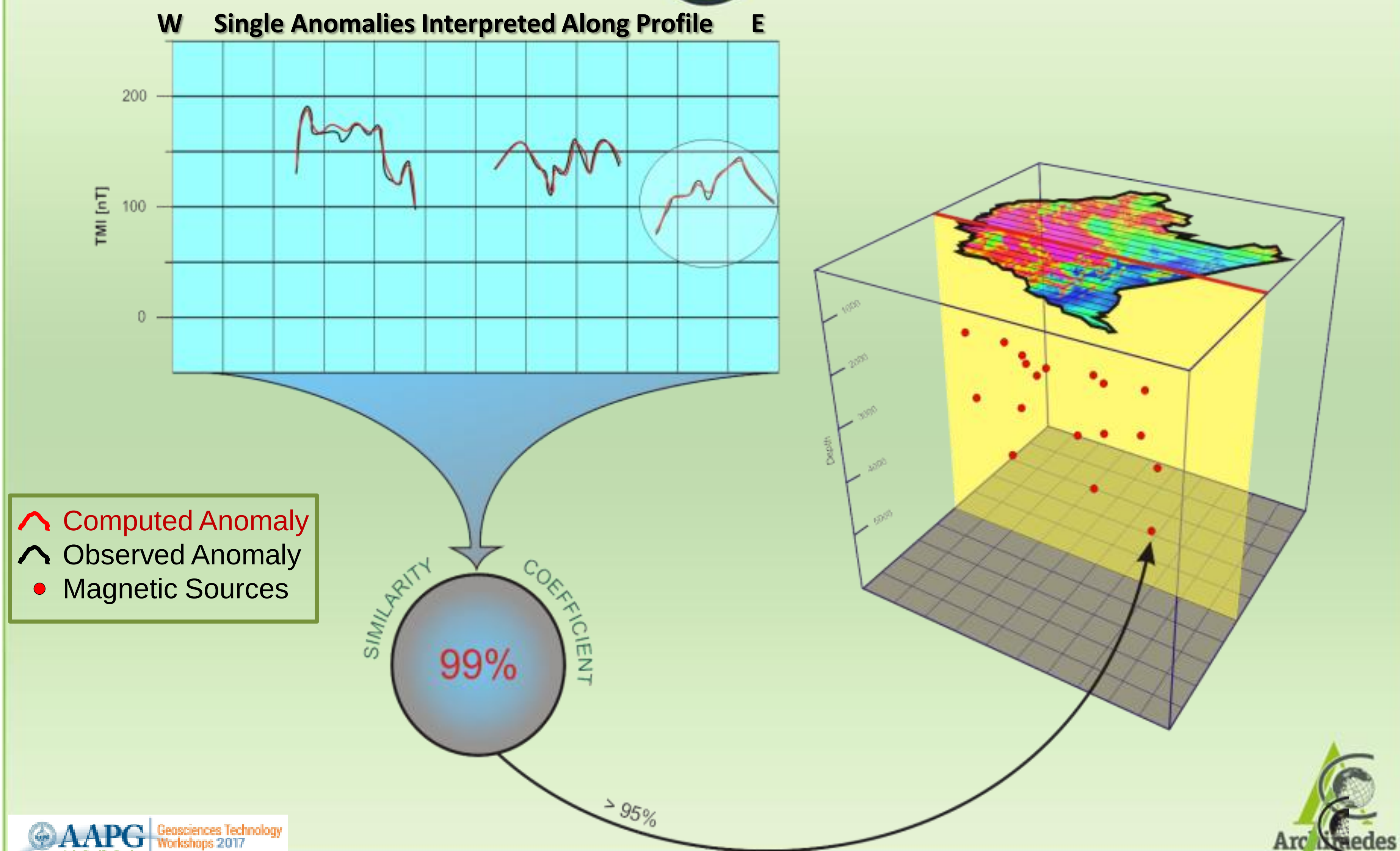
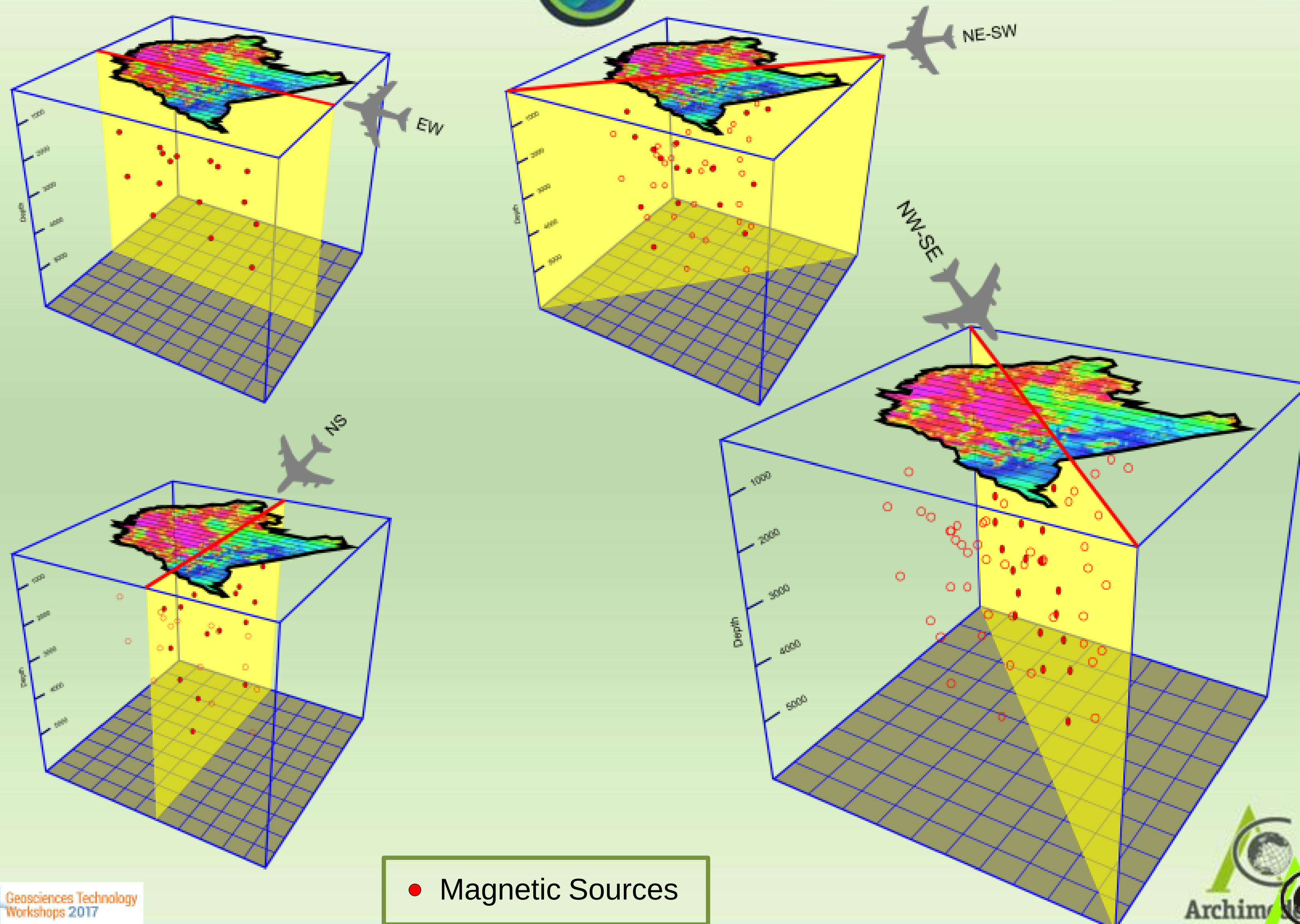
Automatic Curve Matching: Goodness of Fit



Magnetic Sources along EW, NS, NE, NW Profiles



● Magnetic Sources

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  - Sub-volcanic Magnetic Field

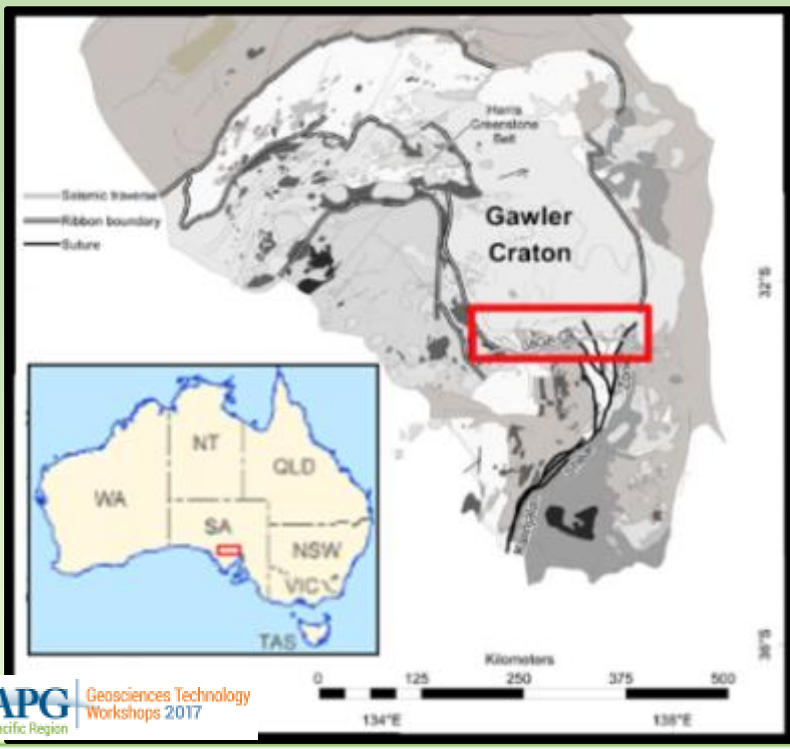
VI. Examples of Mapping Sub-volcanic Geology
VII. Conclusions

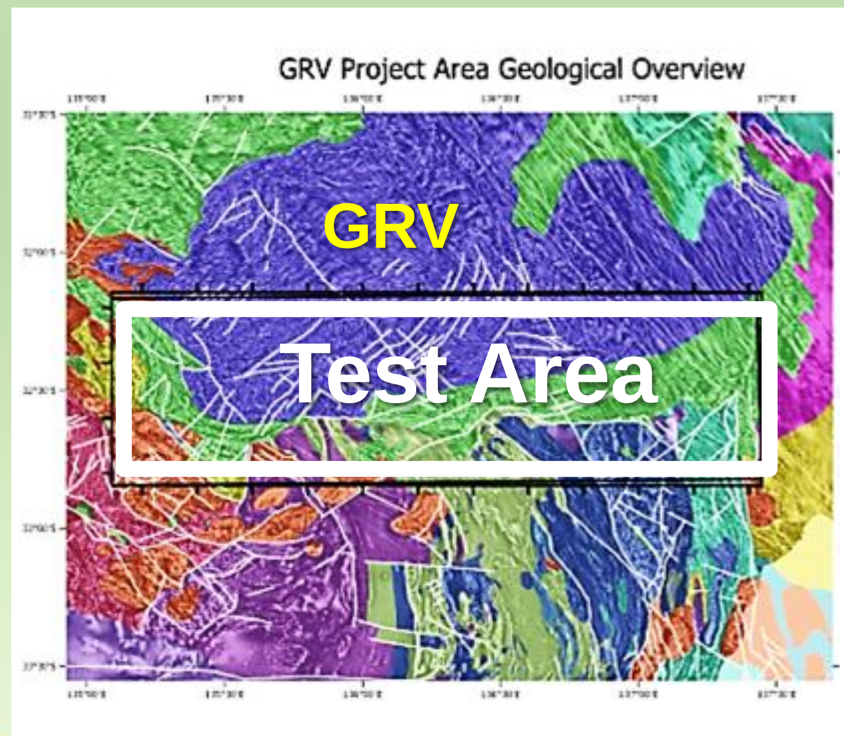
Imaging Volcanics

Gawler Range Volcanics Province

Mapping Base of the Gawler Range Volcanics

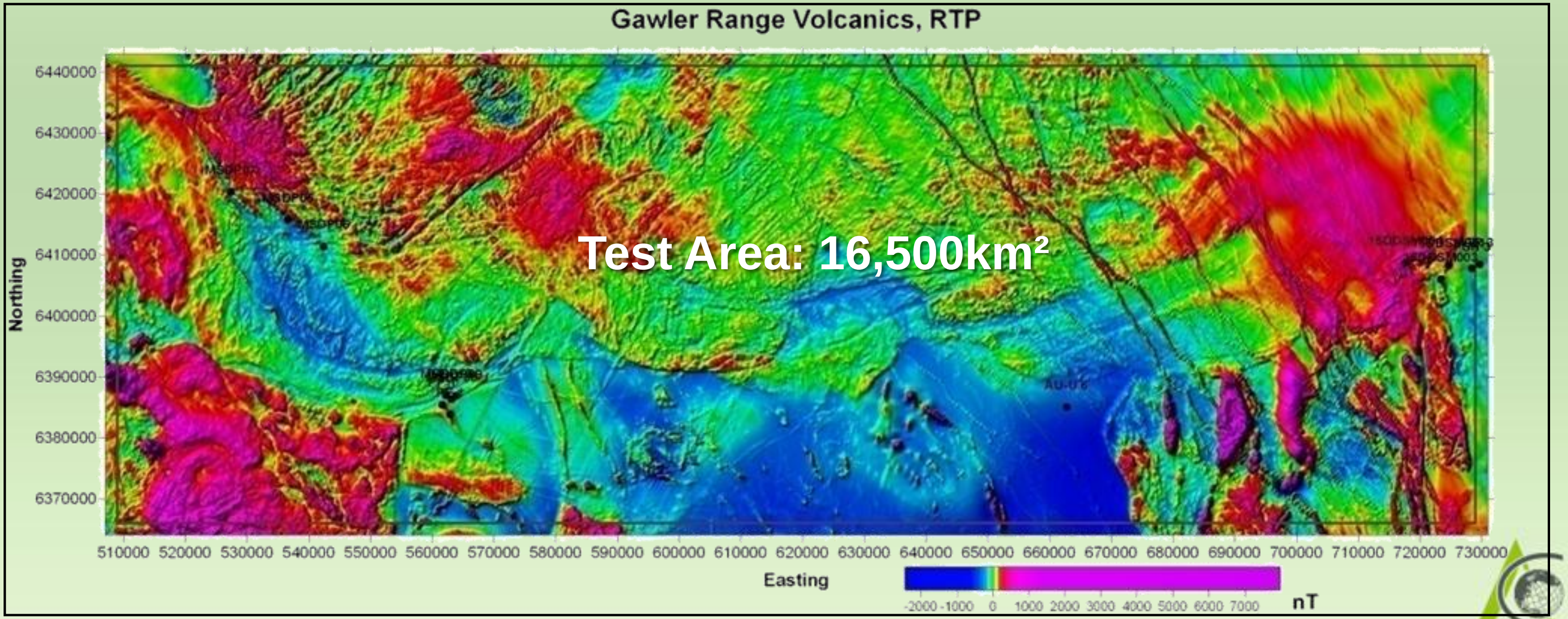
- Test Project in the Gawler Range Volcanics province was conducted for the South Australian government.
- GRV province is located on the Western Gawler Craton in South Australia.
- GRV erupted ~1592Ma in two episodes over 100,000km² area
  - Lower GRV, felsic lavas, minor mafic at base
  - Upper GRV, felsic lavas





Mapping Base of the Gawler Range Volcanics

- Study area is covered by good quality magnetic data, used to map Base Volcanics.
- Northern part is covered by thick GRV while in the south, basement is outcropping.
- Thickness of the GRV was unknown, as there are a limited number of drill holes penetrating the volcanics.



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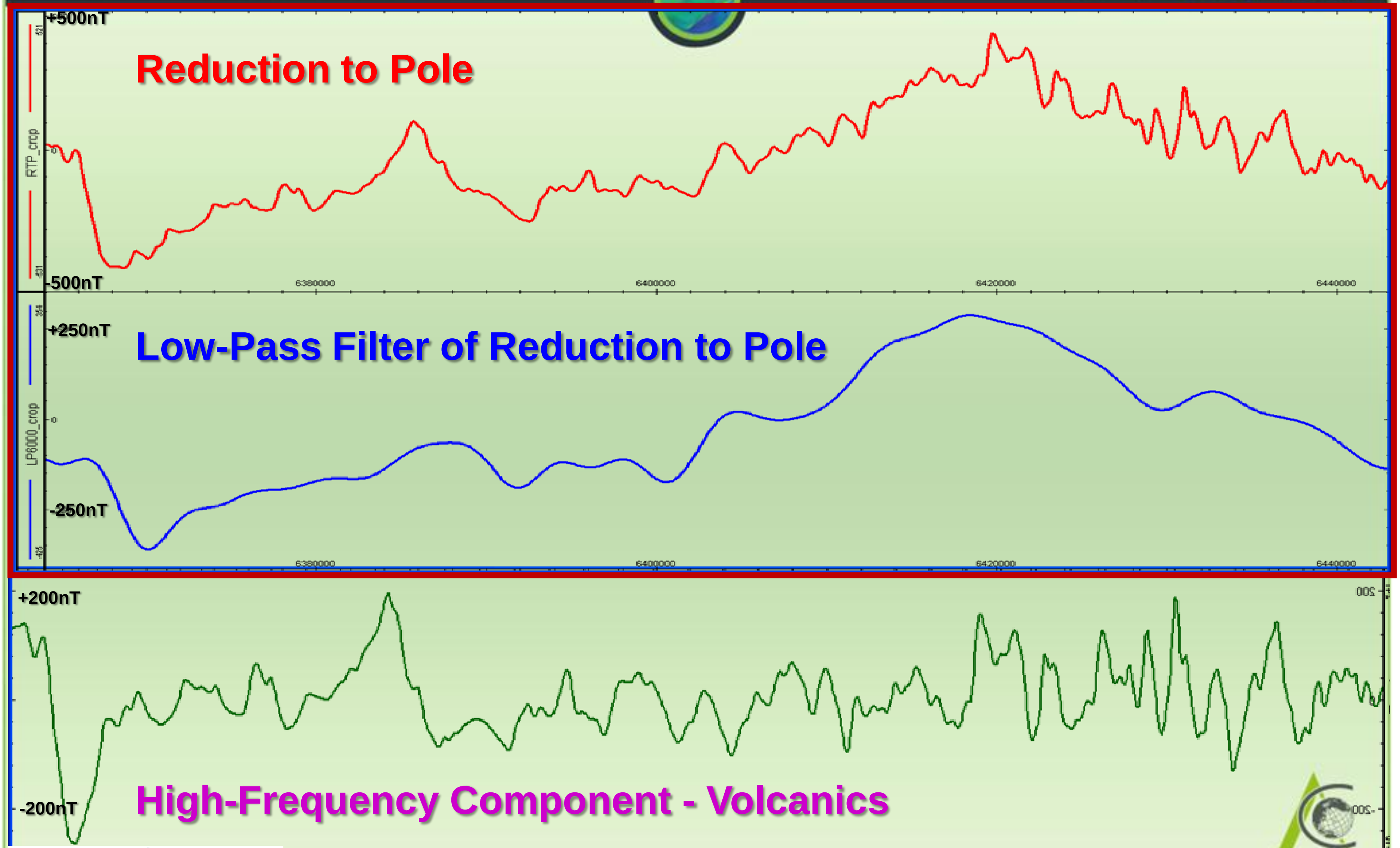
GRV - Test Project

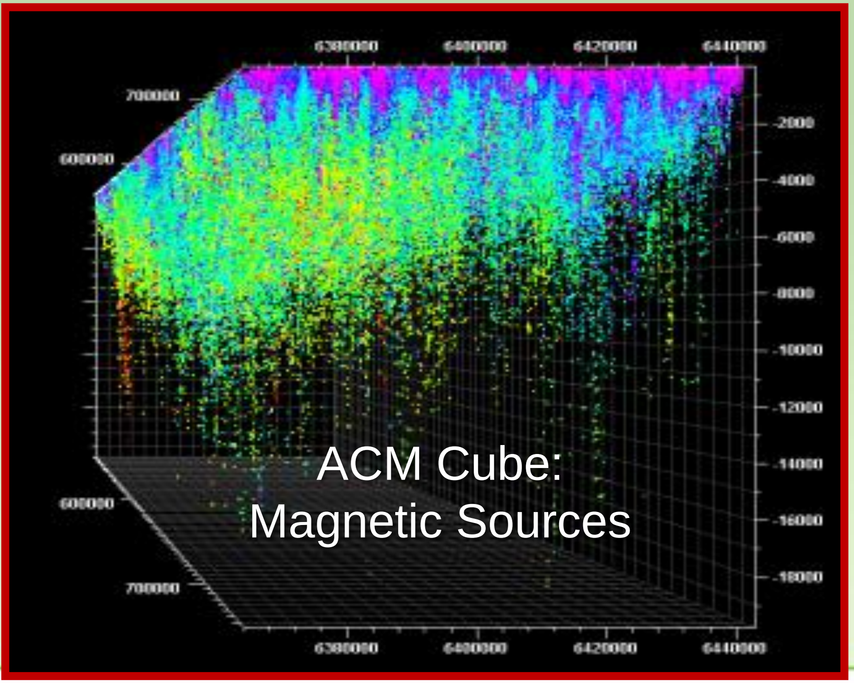
- Aim of this study was to develop a method to map Base Volcanics
- ACM was applied to located magnetic data to detect Magnetic Sources within volcanics, underlying sediments & basement.
- Millions of individual magnetic anomalies were analysed along profiles extracted from the TMI grid along rows, columns & diagonally.
- ACM analysed individual anomalies along:
  - EW & NS profiles, 100m apart; total 660,000km
  - NE & NW profiles, 71m apart; total 930,000km
- High & medium-frequency components of magnetic field generated by GRV were analysed using algorithms designed to simulate volcanic lava flows, and to model basement geology.

NS Magnetic Profile - Test Area



GRV - Test Project

- ACM detected ~80 million Magnetic Sources within GRV & Basement
- For each Magnetic Source, ACM calculated:
  - Depth to Top
  - Model Geometry
  - Magnetic Susceptibility
  - Similarity Coefficient Factor (Goodness of Fit)
- Magnetic Sources were visualised & interpreted in 3D using *Petrel*



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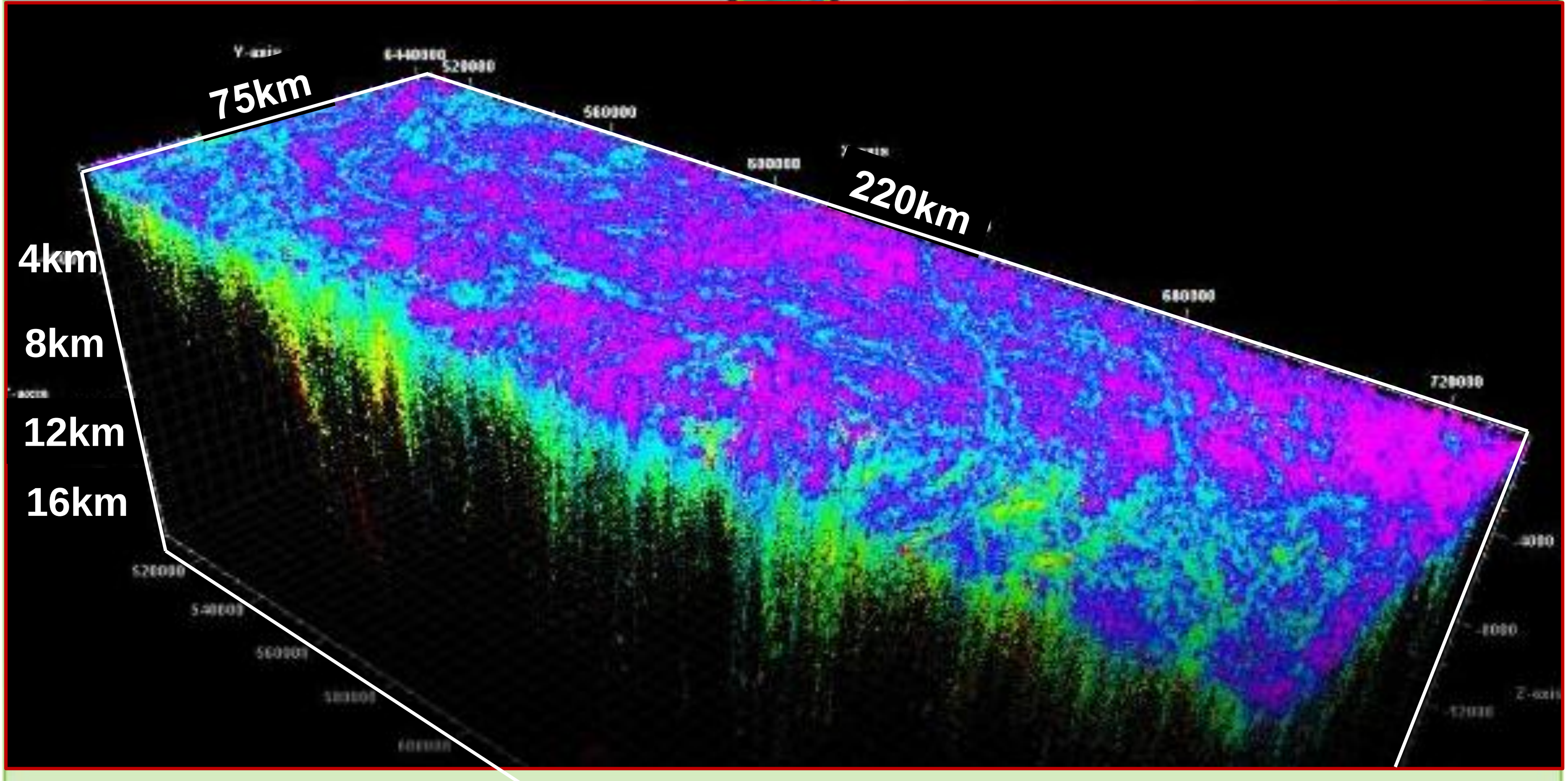
Test Area: Magnetic Sources



ACM Cube: Magnetic Sources

Magnetic Susceptibilities shown in colour

80 million Magnetic Sources detected by ACM

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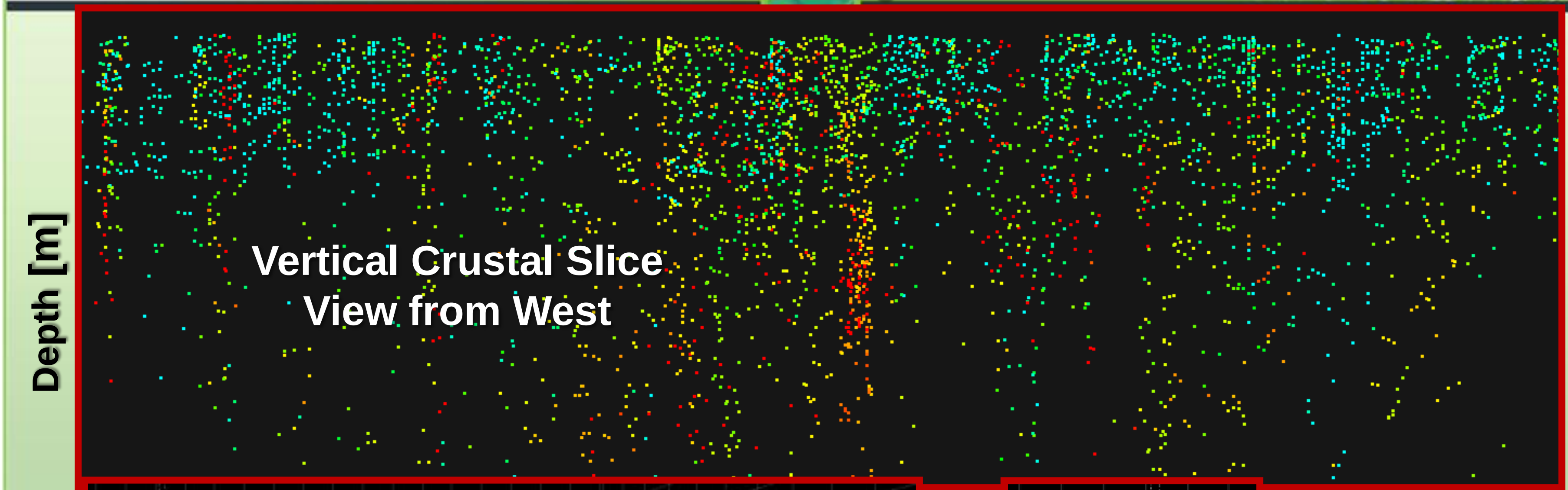
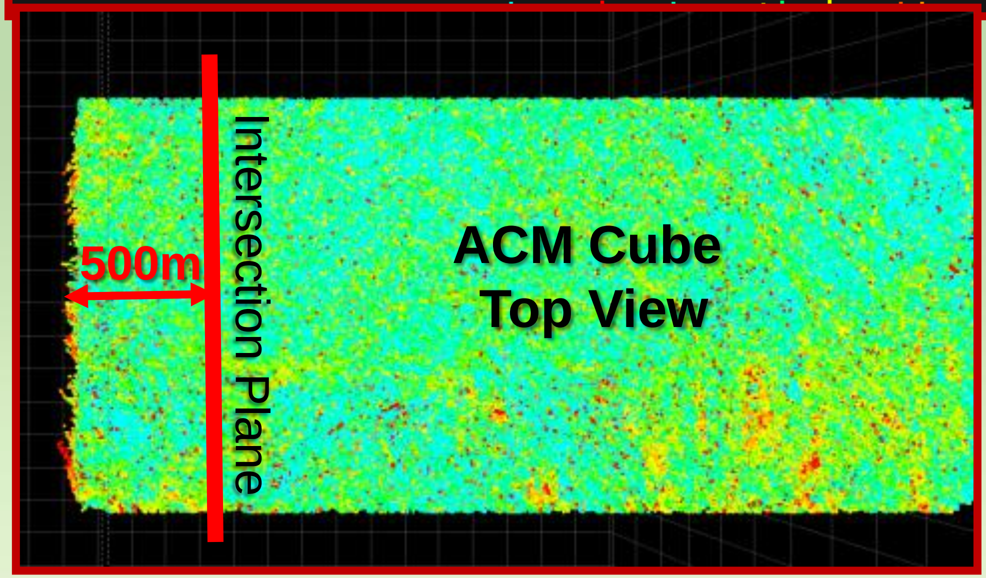
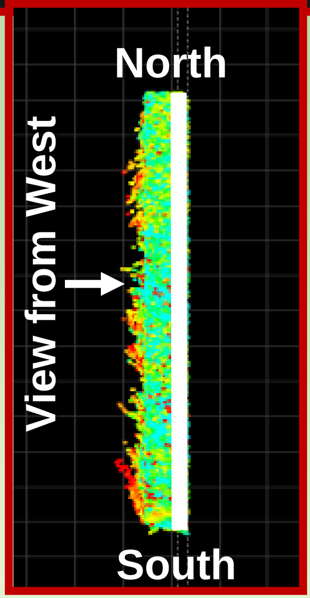
Vertical Crustal Slices of Magnetic Sources

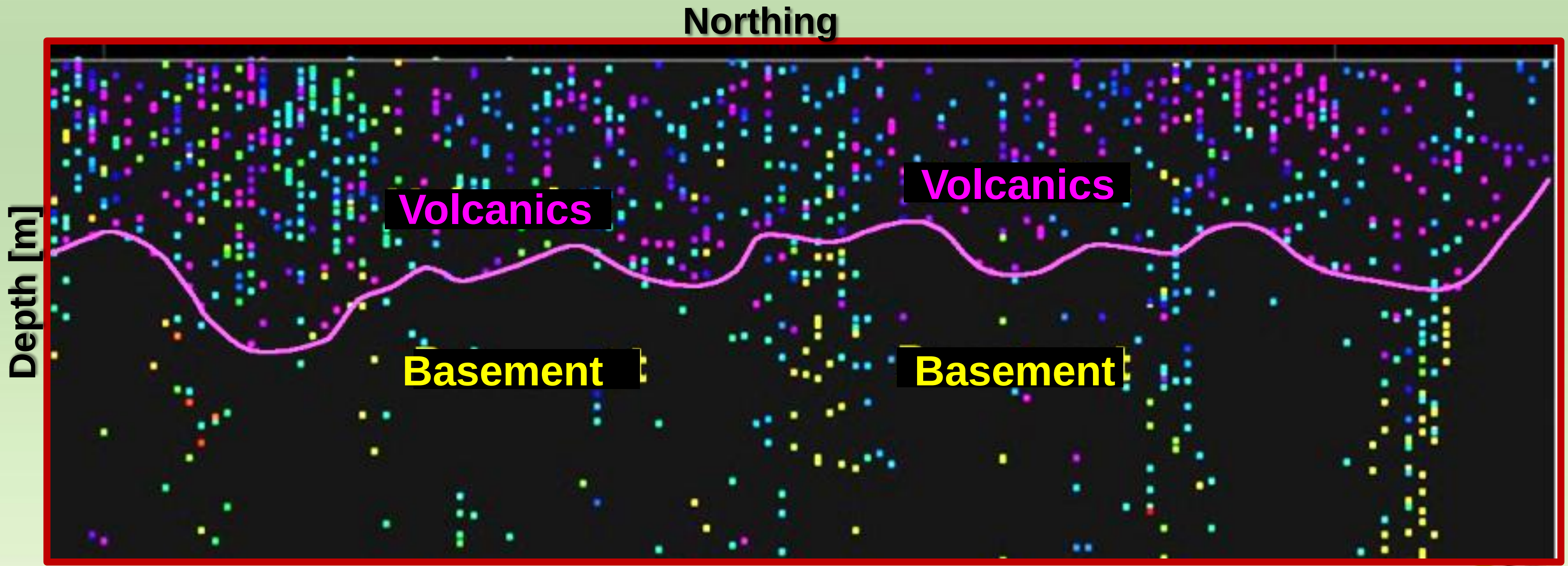




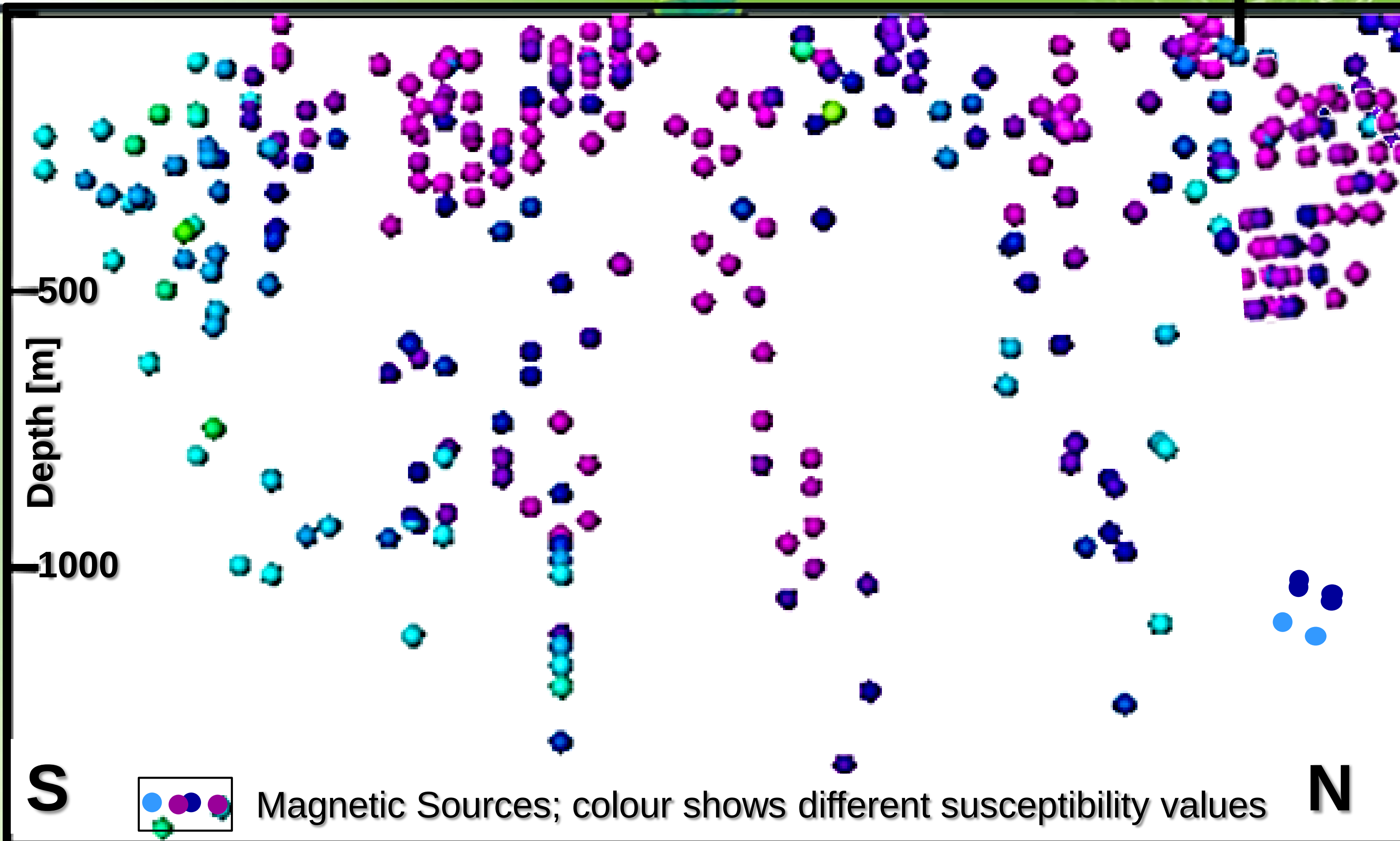


Interpretation of VCS

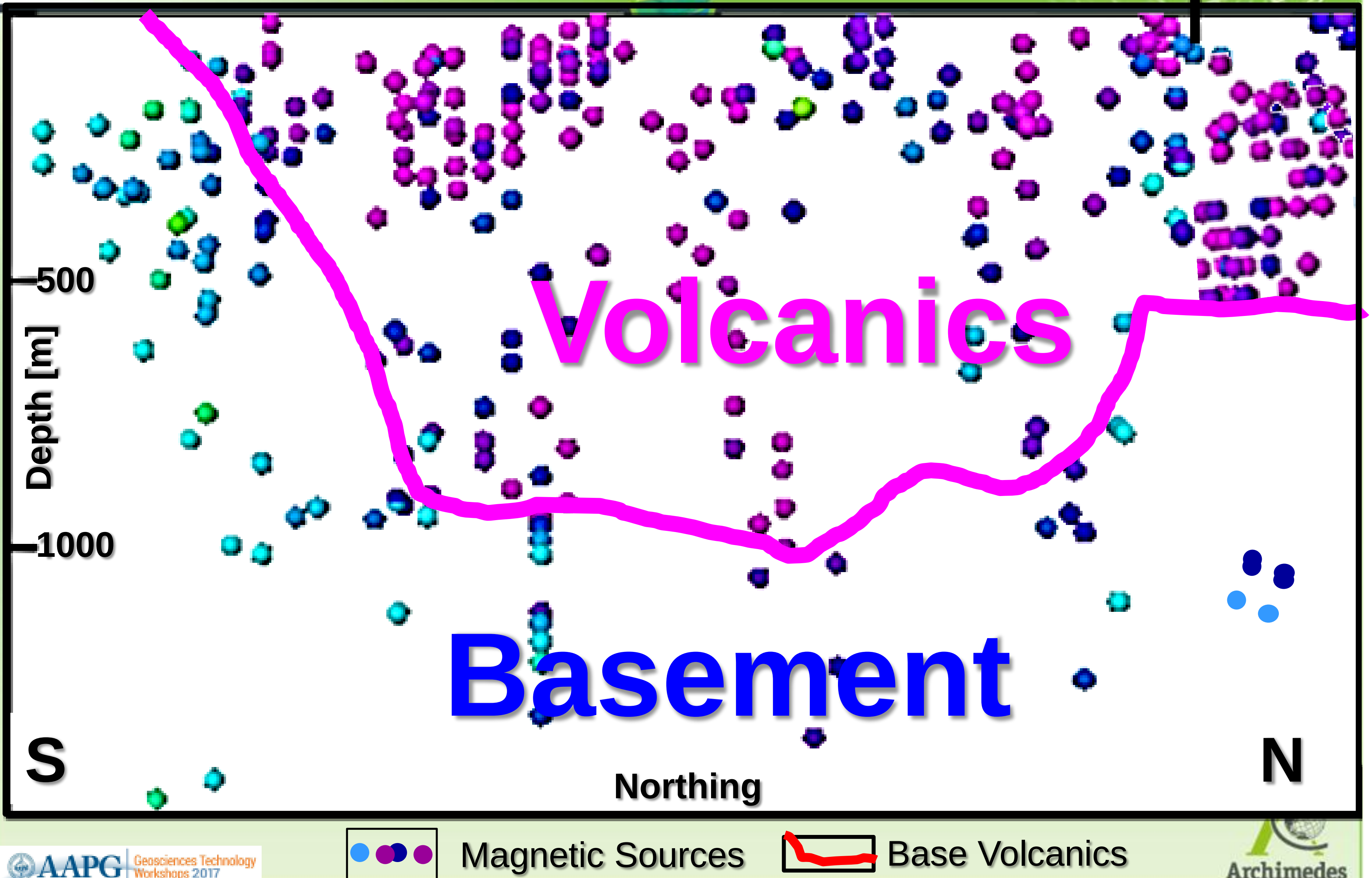
- Key criteria used to map Base Volcanics
  i. Magnetic Susceptibility of Magnetic Sources within Volcanics are different than within Basement.
  ii. Distribution patterns of Magnetic Sources & abundance within Volcanics is different than within Basement rocks.
- Distinct boundary between Base Volcanics & Basement can be seen



VCS: Magnetic Sources

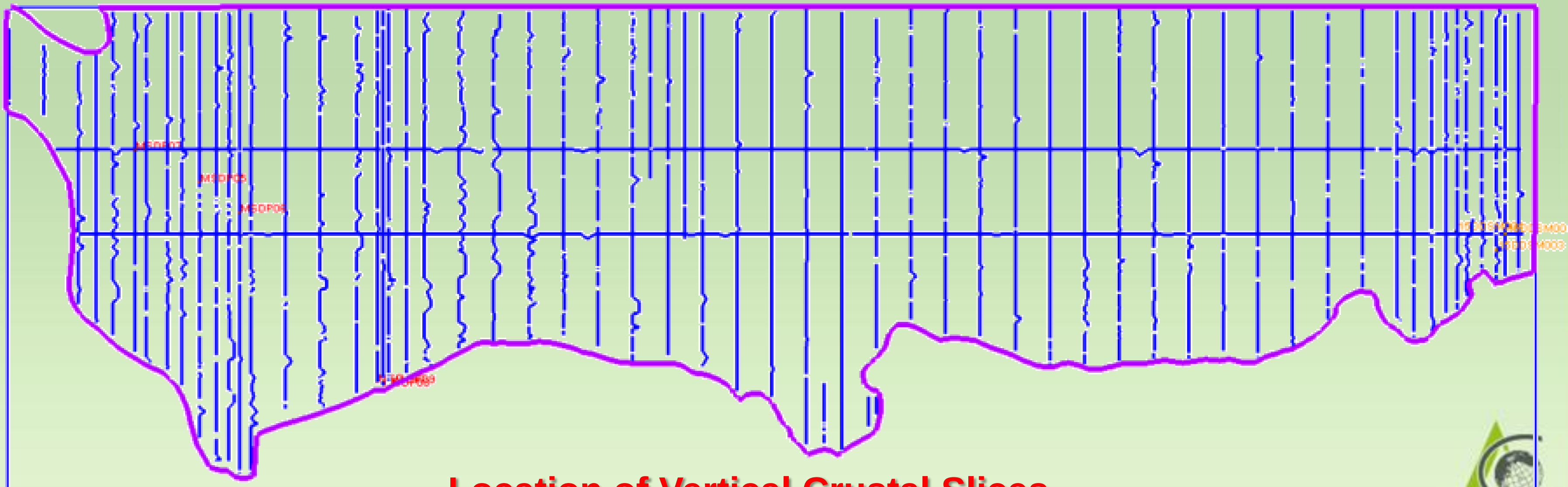


VCS: Base Volcanics



Base Volcanics along NS Profiles

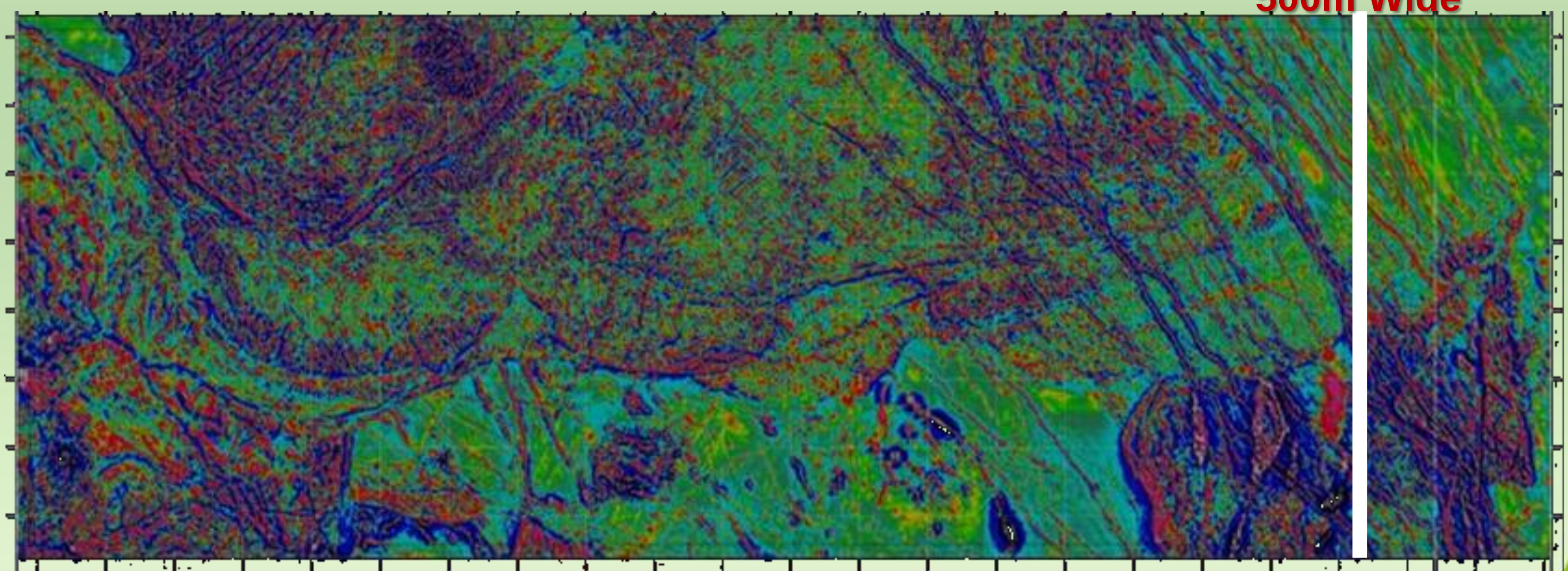
- Boundary between Base Volcanics & Basement was mapped along NS profiles & selected EW controlling profiles
- The NS Profiles were 1km to 5km apart
- Results were gridded to produce a map of Base Volcanics



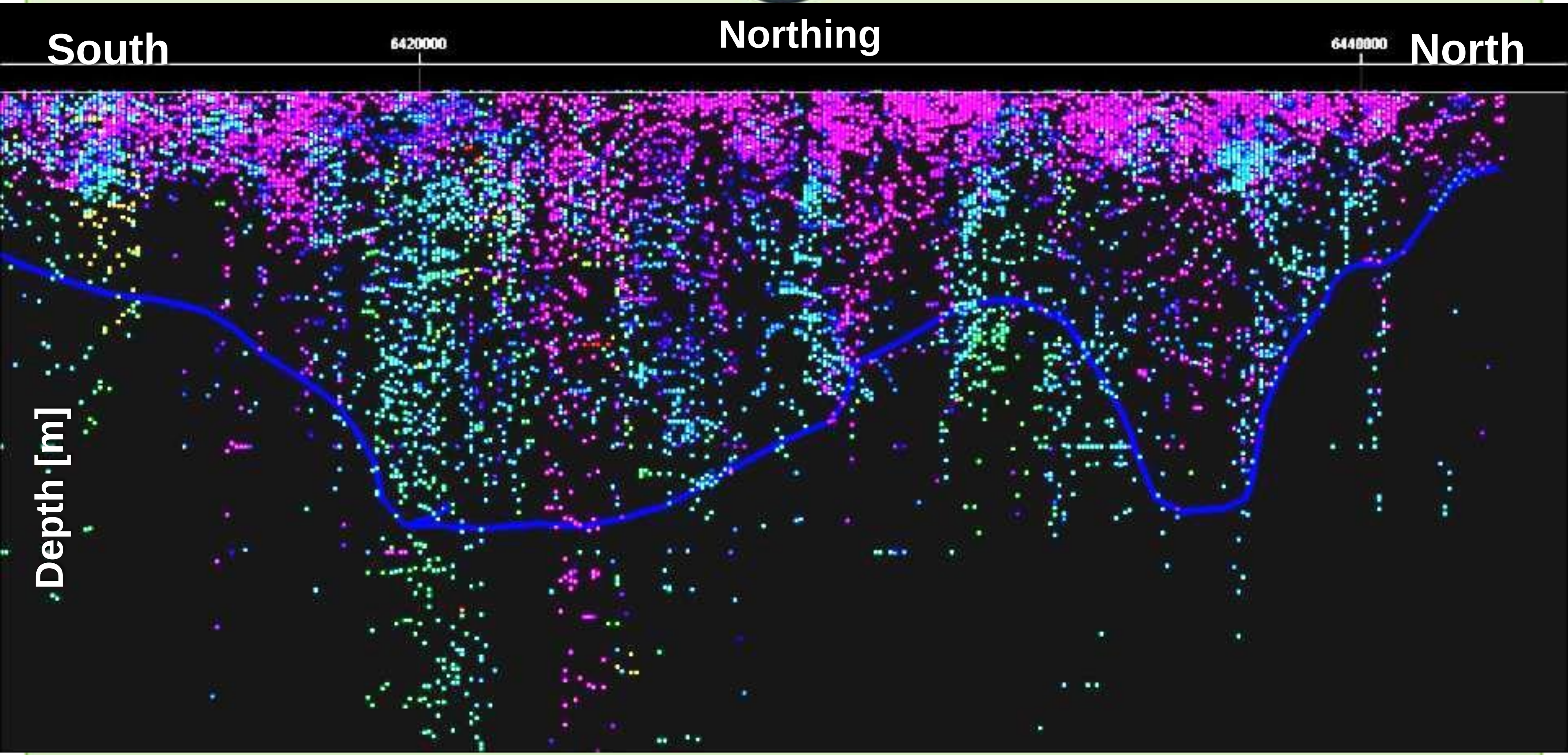
Location of Vertical Crustal Slices

GRV - Test Project

- Base Volcanics was mapped using several different attributes such as:
  - TMI & VG(TMI)
  - Geophysical Model: Dyke, Plate, Edge
  - Profile Direction: EW, NS, NW-SE, NE-SW
  - Similarity Coefficient Factor
- Drill hole data was used as a guidance & to validate the interpreted results



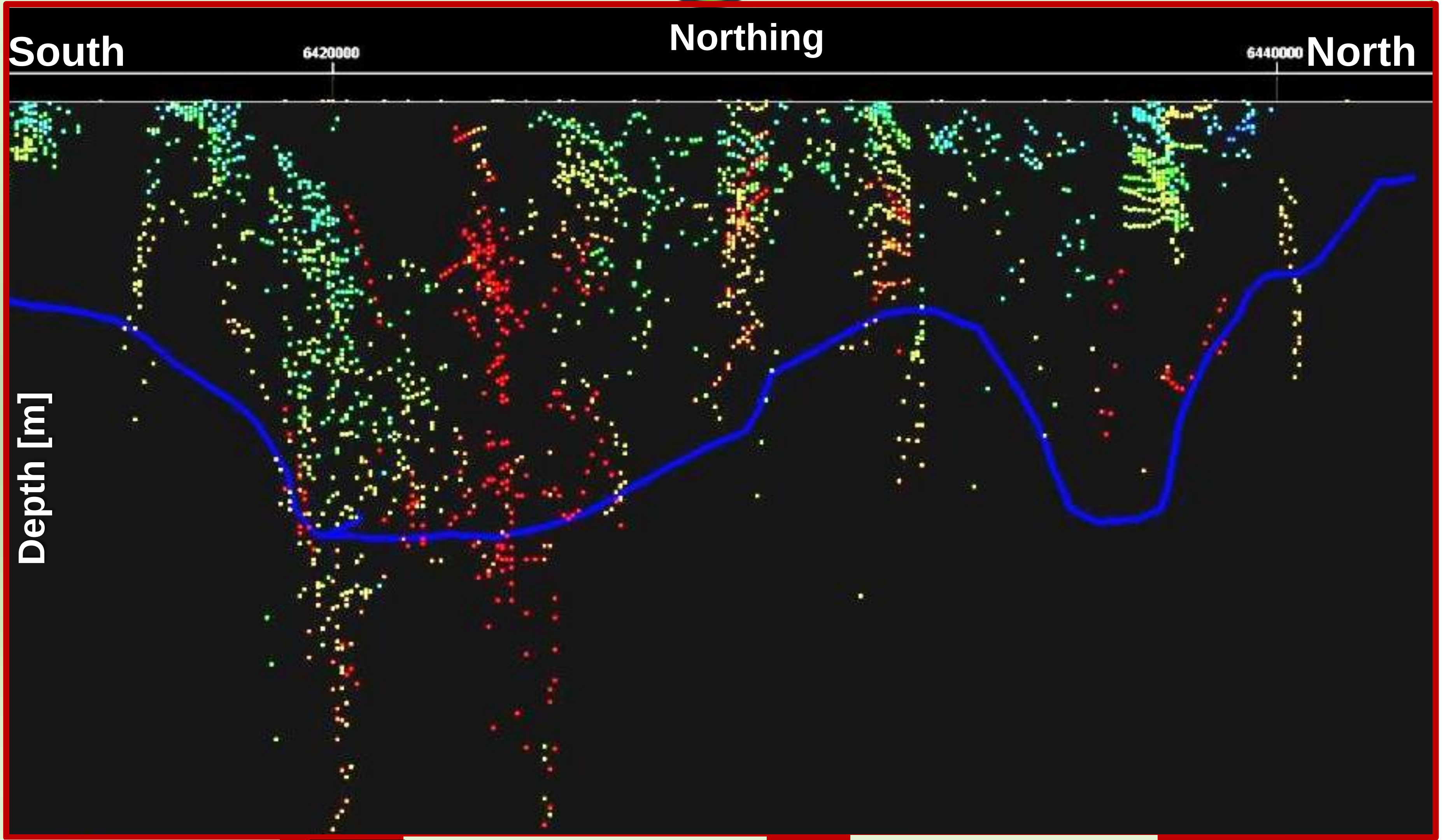
GRV Project – VCS at 714050mE
Base Volcanics with VG(TMI) & Dyke+Plate+Edge Models



Magnetic Sources | Base Volcanics

GRV Project – VCS at 714050mE

Base Volcanics with TMI & Dyke+Plate Model



Magnetic Sources

Base Volcanics

Boundary of Lower & Upper GRV

Boundary of Upper & Lower GRV

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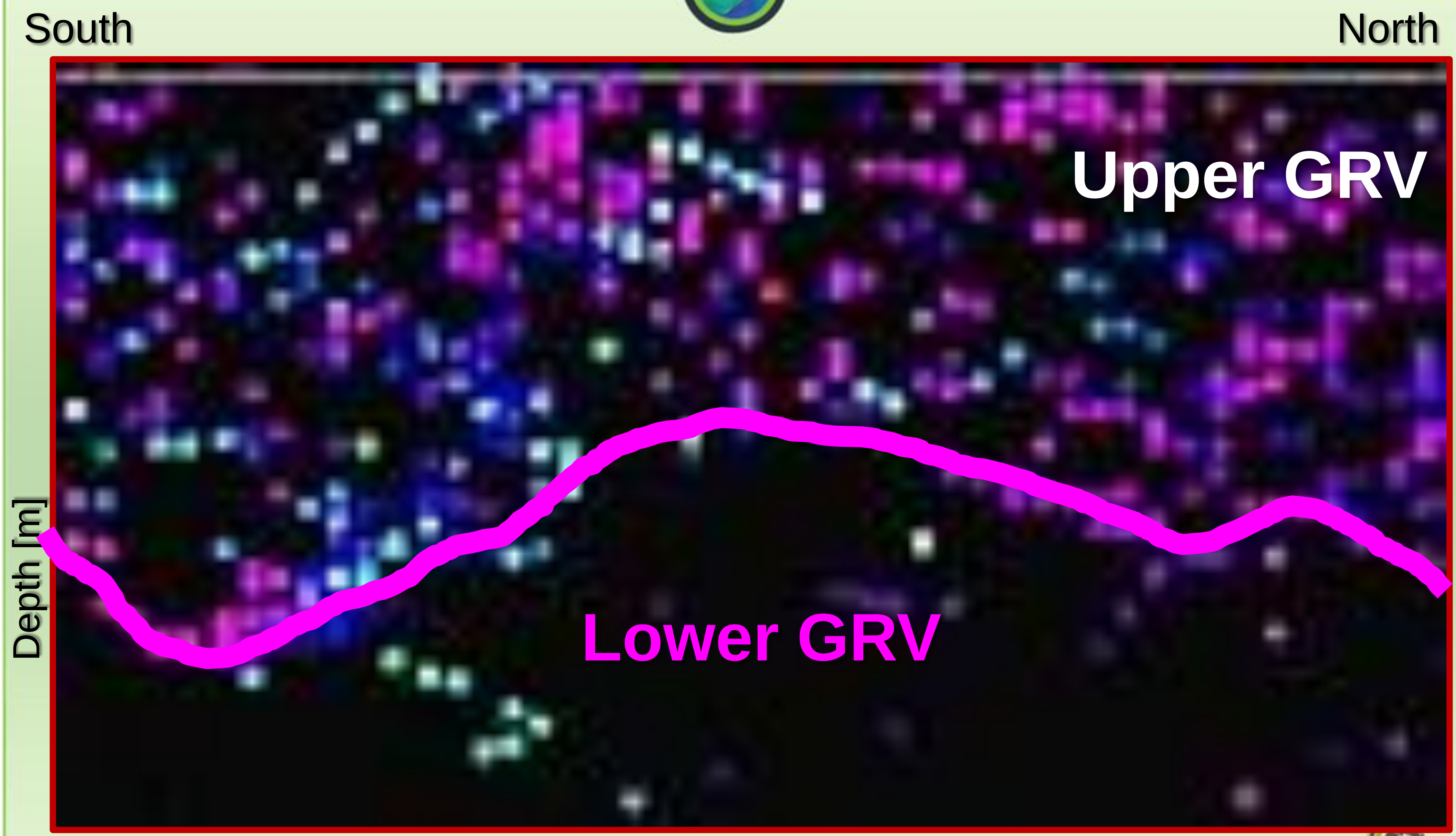
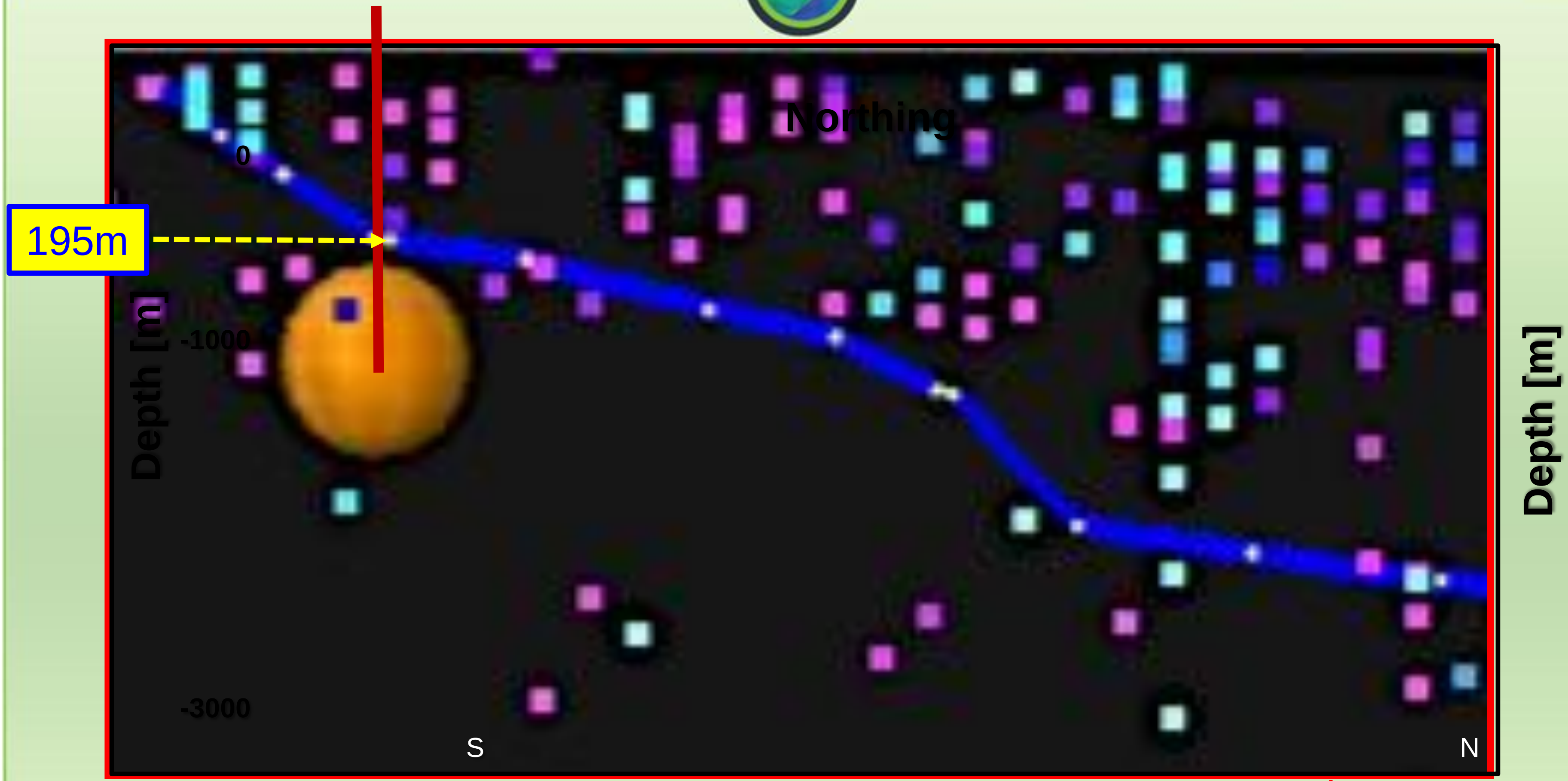
Boundary of Upper & Lower GRV



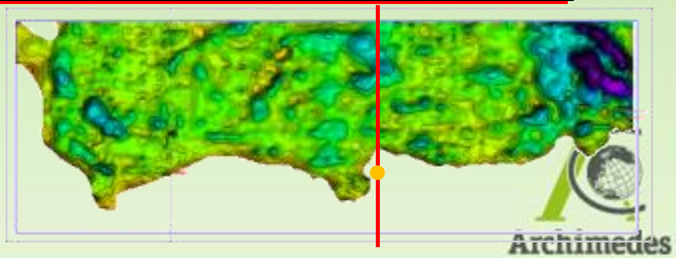
Base Volcanics vs Drill-hole Data

Base Volcanics - Drill Hole MSDPO9

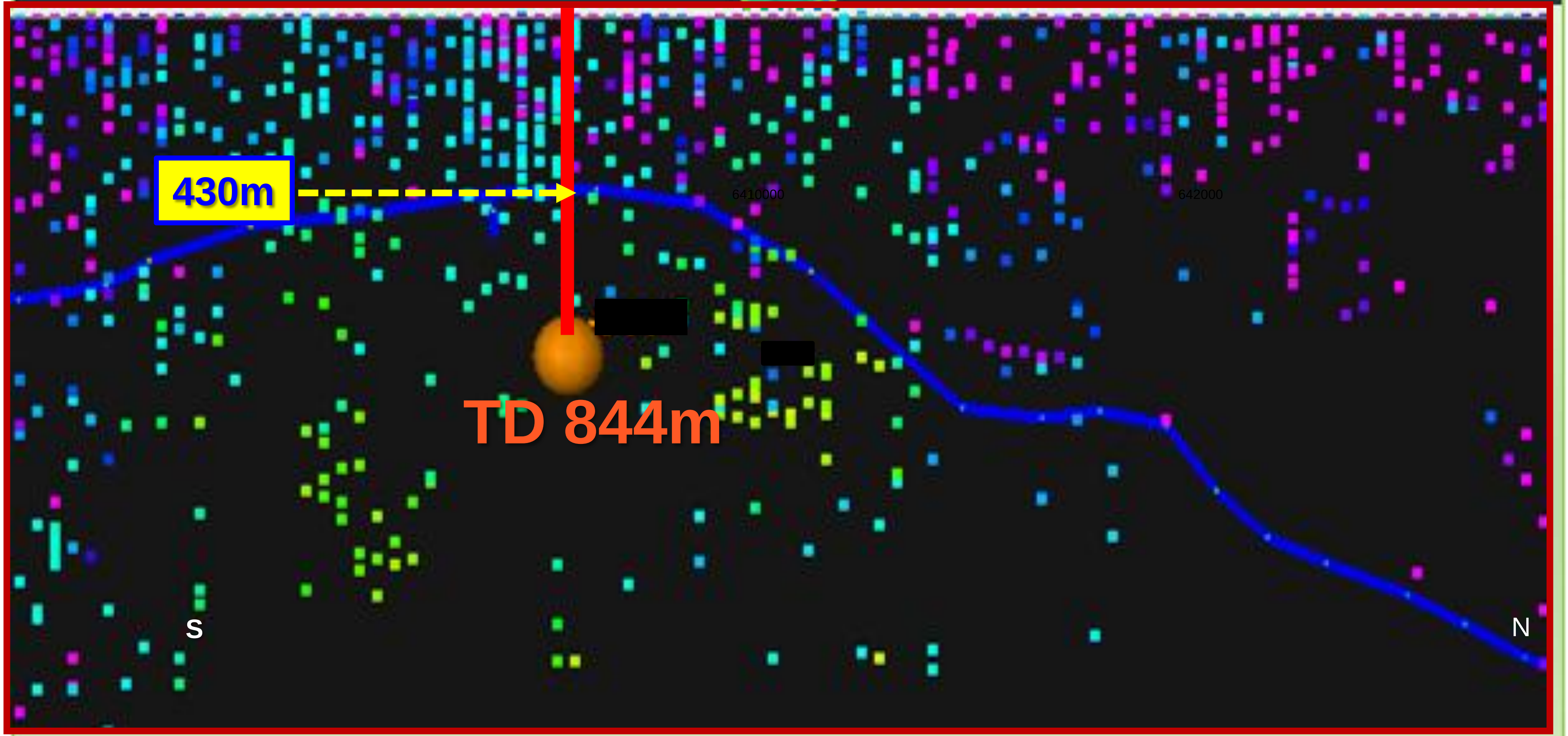


Drill hole MSDPO9 TD = 319m
Base Volcanics = 174m

Base Volcanics = 195m



Base Volcanics - Drill Hole M004

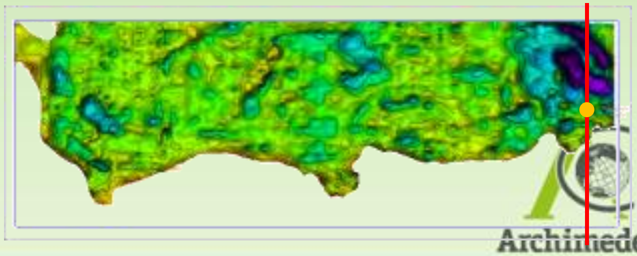


Drill hole MOO4: TD=844m

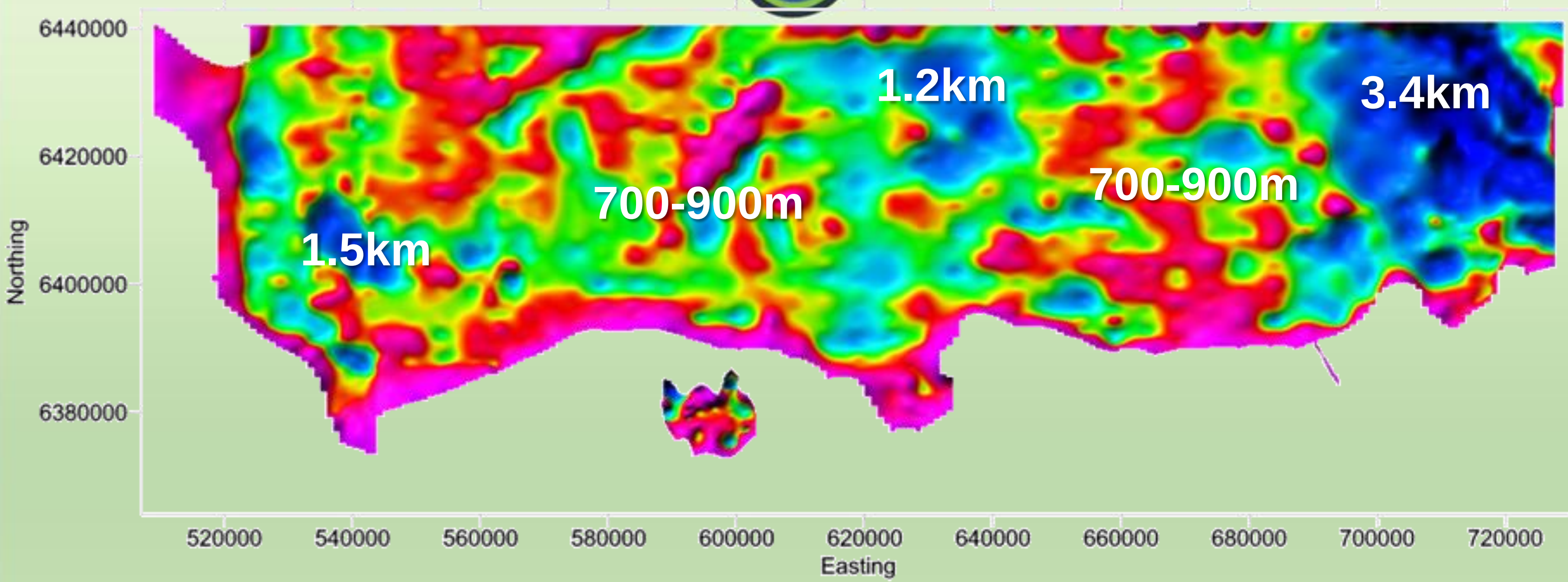
Base Volcanics = 437m

Magnetic Sources

Base Volcanics = 430m



Base of Gawler Range Volcanics



- Map of the Base Volcanics generated from NS Profiles.
- Volcanics are on average 700m-900m thick
- Very thick section exceeding 3.4km in the east & ~1.5km in the west.

Thickness of Volcanics was validated with:

- Drillhole data showing good match
- Passive seismic in the east indicates 4km thickness

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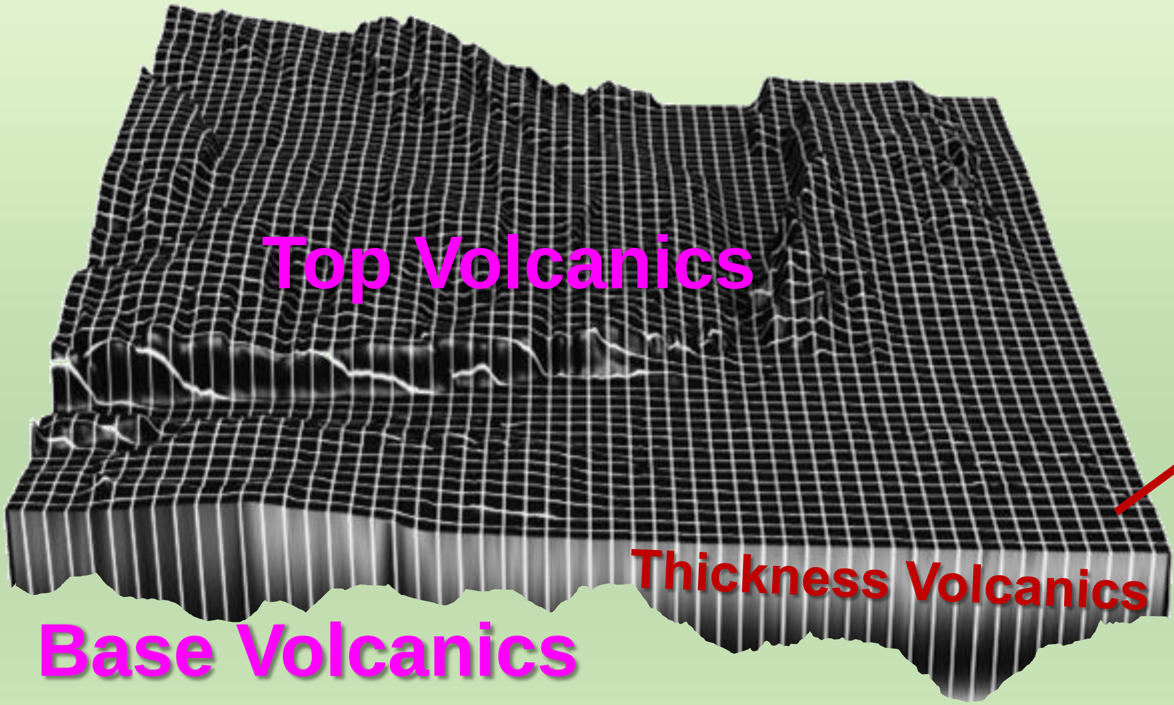
- **Magnetic Field of Volcanics**
- **Sub-volcanic Magnetic Field**

VI. Examples of Mapping Sub-volcanic Geology
IV. Conclusions

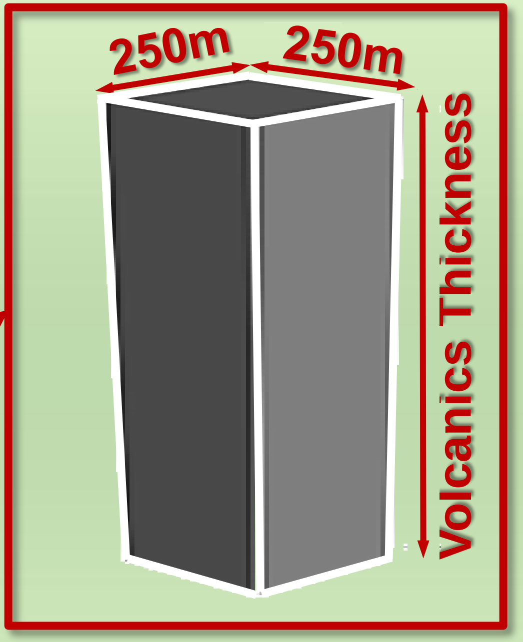
3D-Voxel Synthetic Volcanics Model

3D-Voxel Synthetic Generic Model

Simulating Volcanic Layer



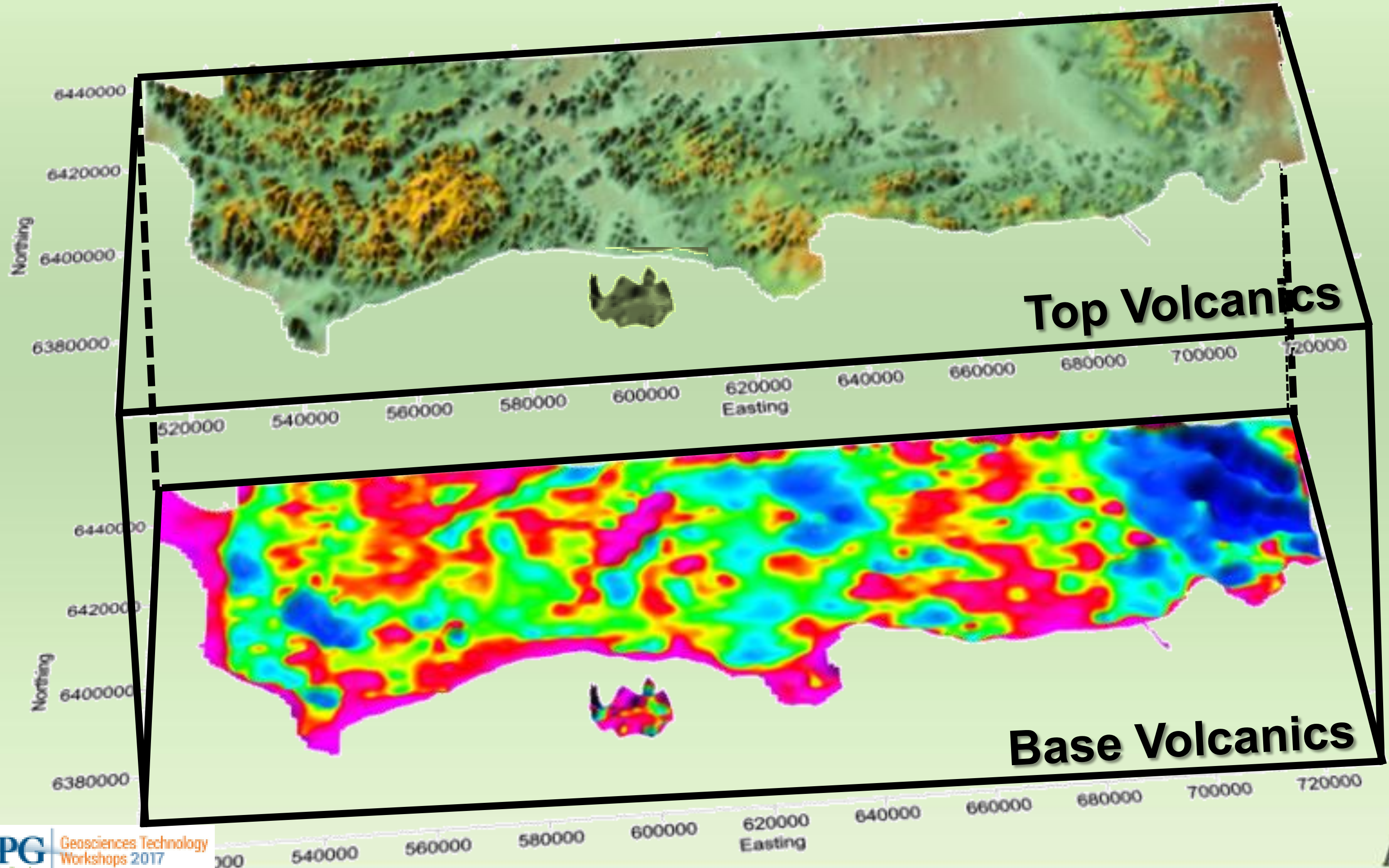
SINGLE VOXEL



Magnetic Susceptibility of individual voxels of the Volcanic Layer are assigned based on the Susceptibilities of Magnetic Sources detected by ACM

3D-Voxel Synthetic Model of GRV

Base Volcanics & Top from Topography was used to construct 3D-Voxel Synthetic Model simulating GRV.



3D-Voxel Synthetic Model of GRV

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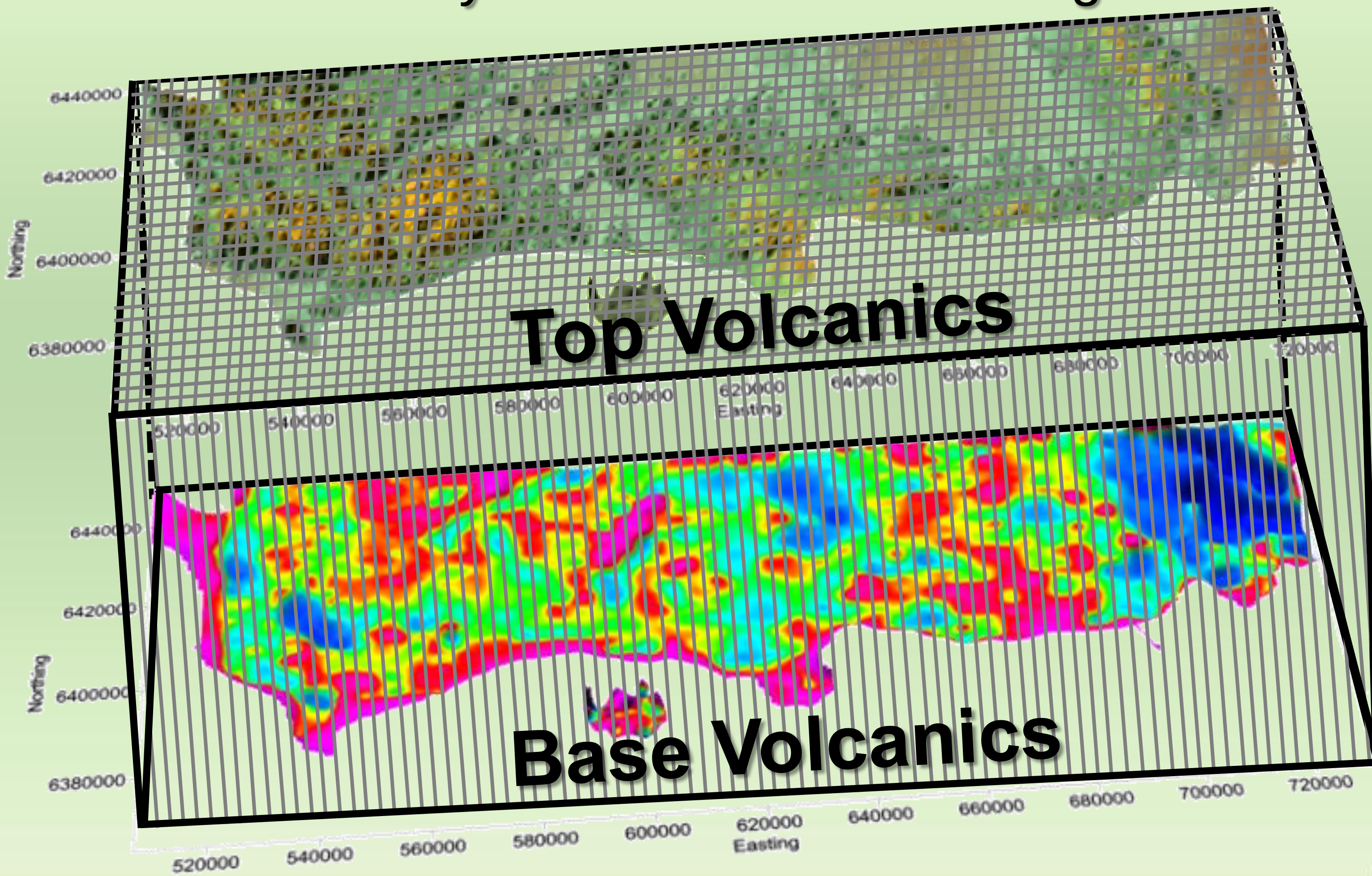

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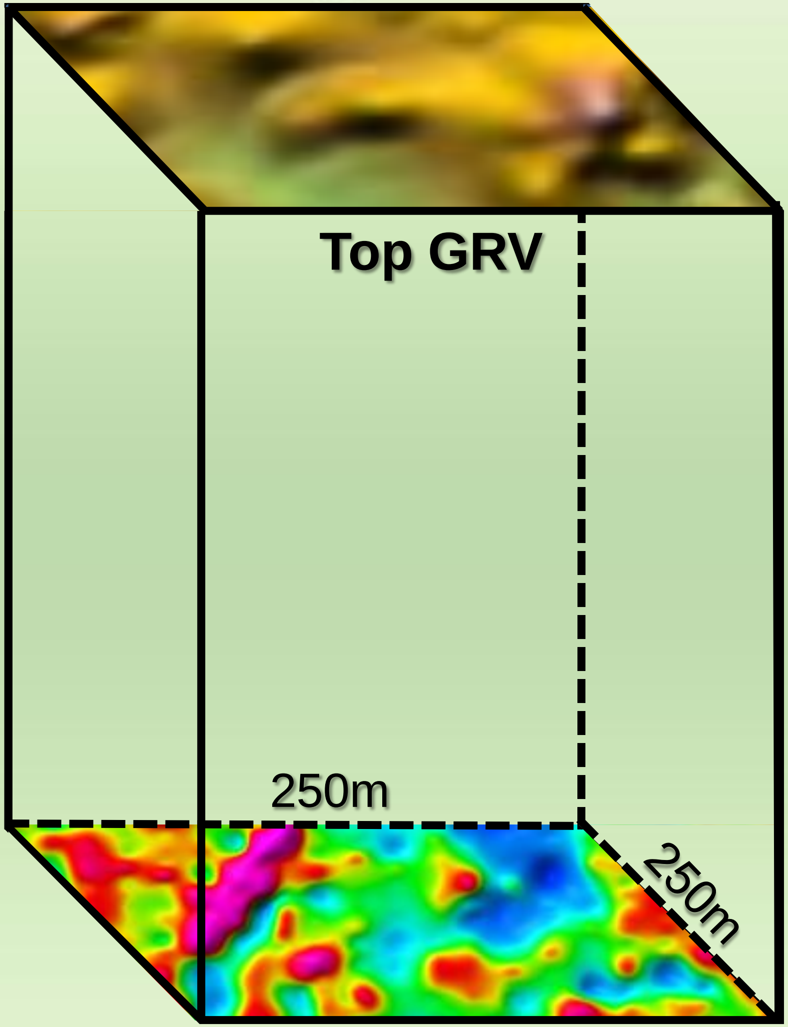
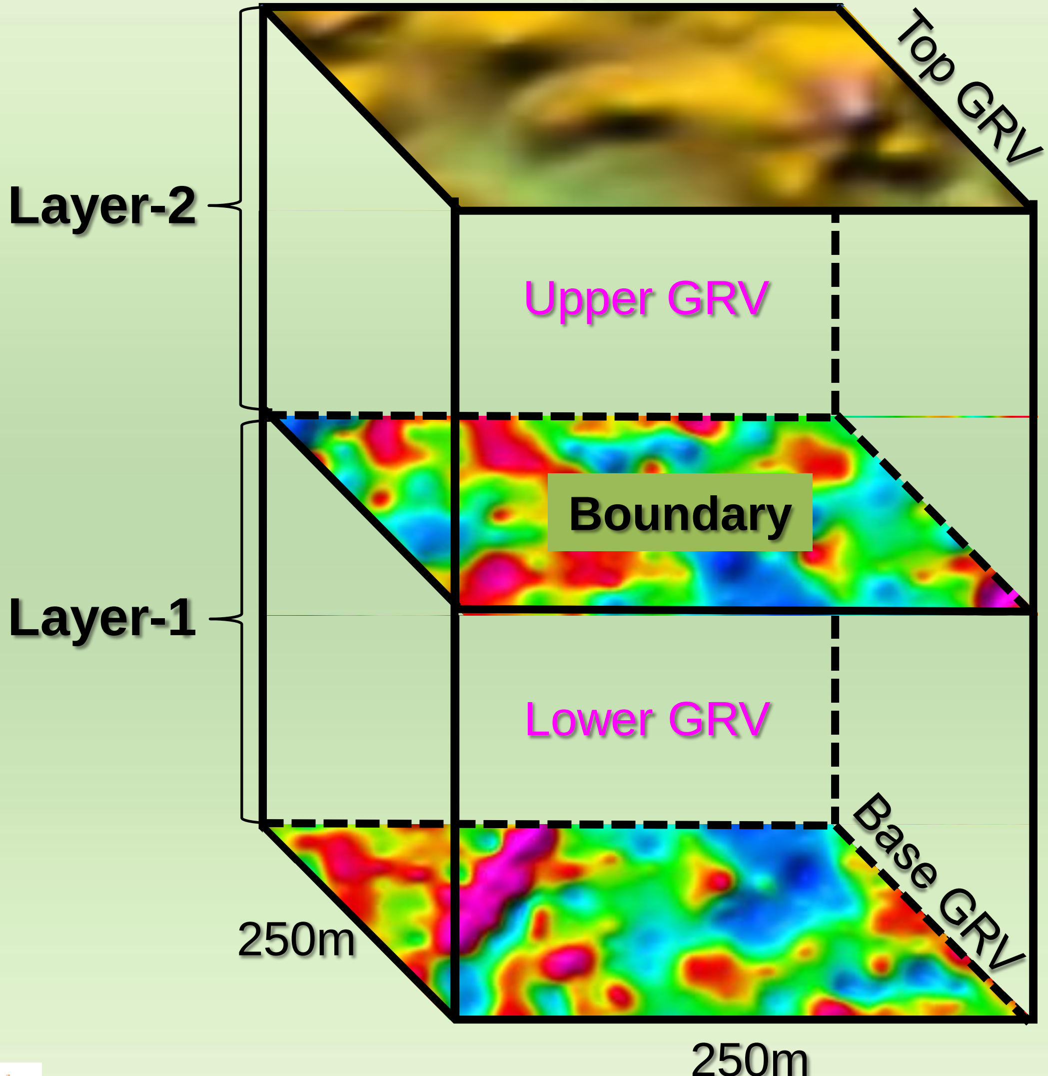
3D-Voxel of Synthetic GRV Model

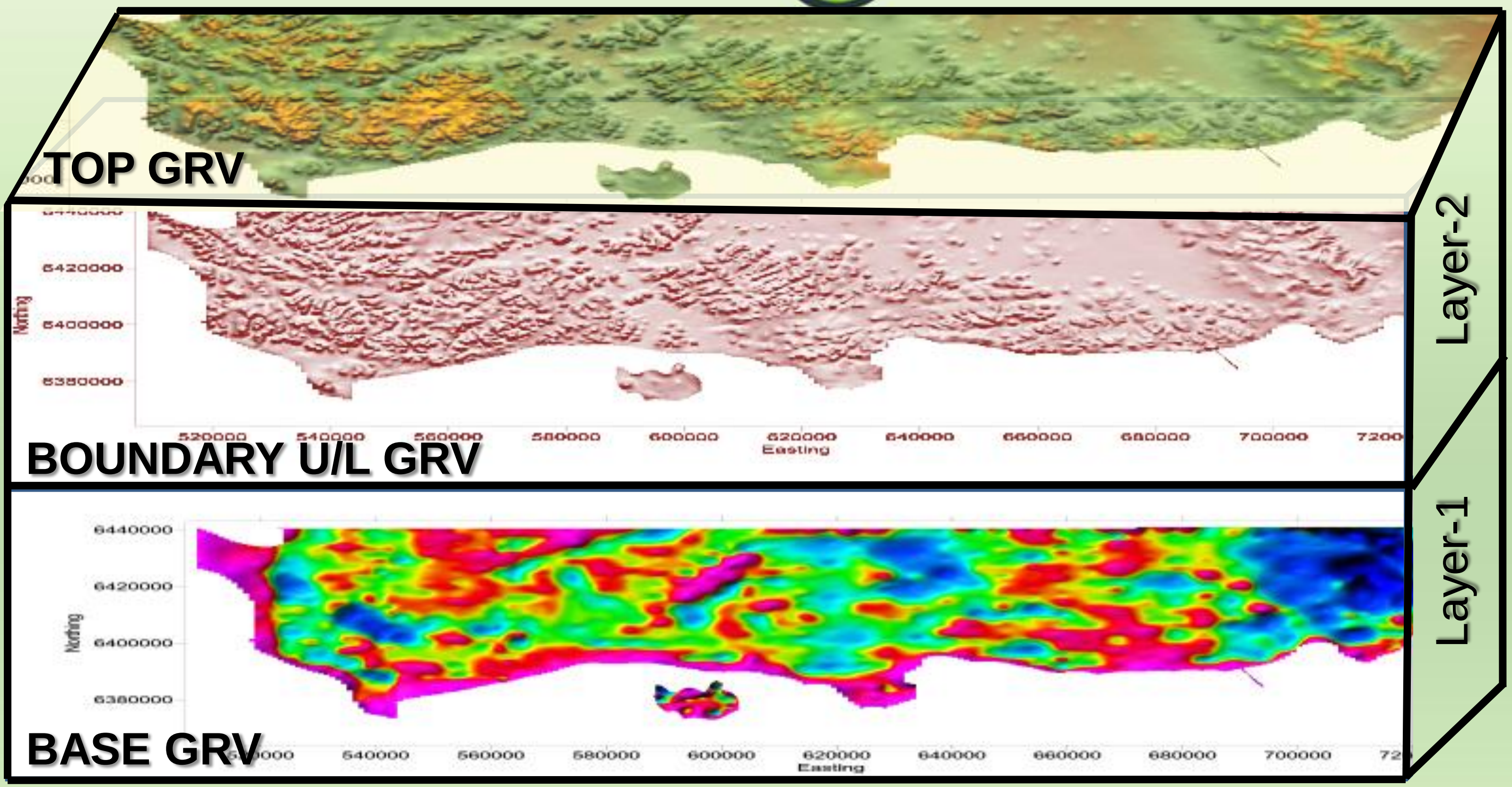
SINGLE VOXEL
Of GRV



3D-Voxels of Synthetic GRV Model



3D-Voxel Synthetic Model of GRV



Layer-1:
- Base GRV
- Top: Boundary Lower/Upper GRV

Layer-2:
- Base: Boundary Lower/Upper GRV
- Top GRV/Topography

Magnetic Field of Volcanics

‘Volcanics MAG’

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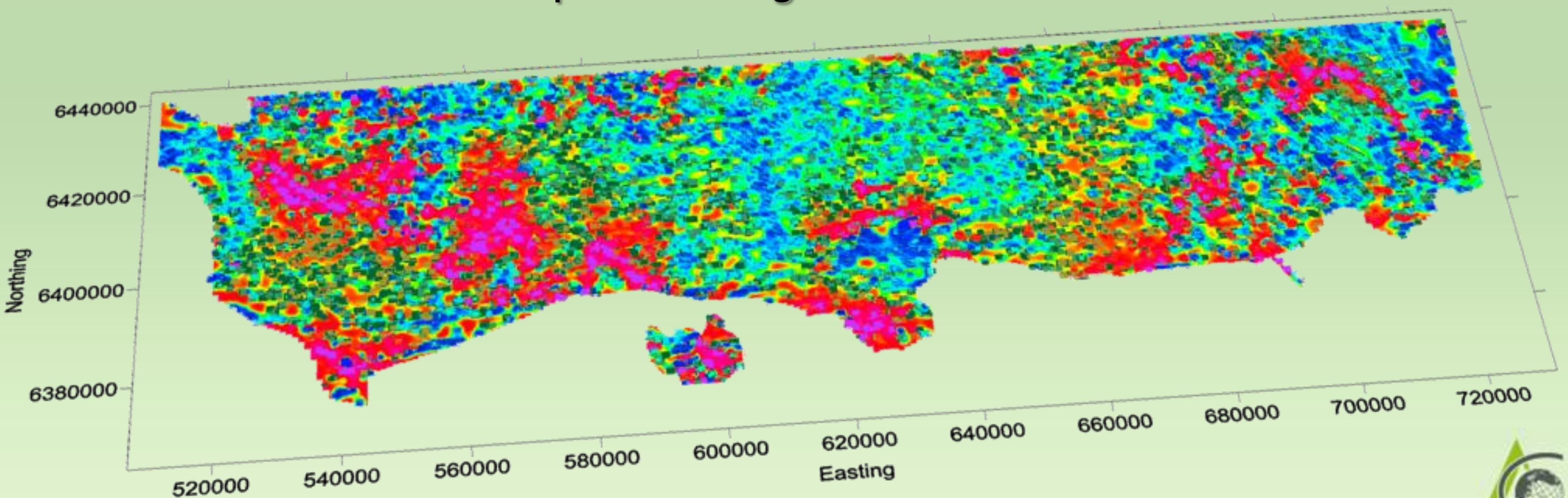
Magnetic Field of Volcanics

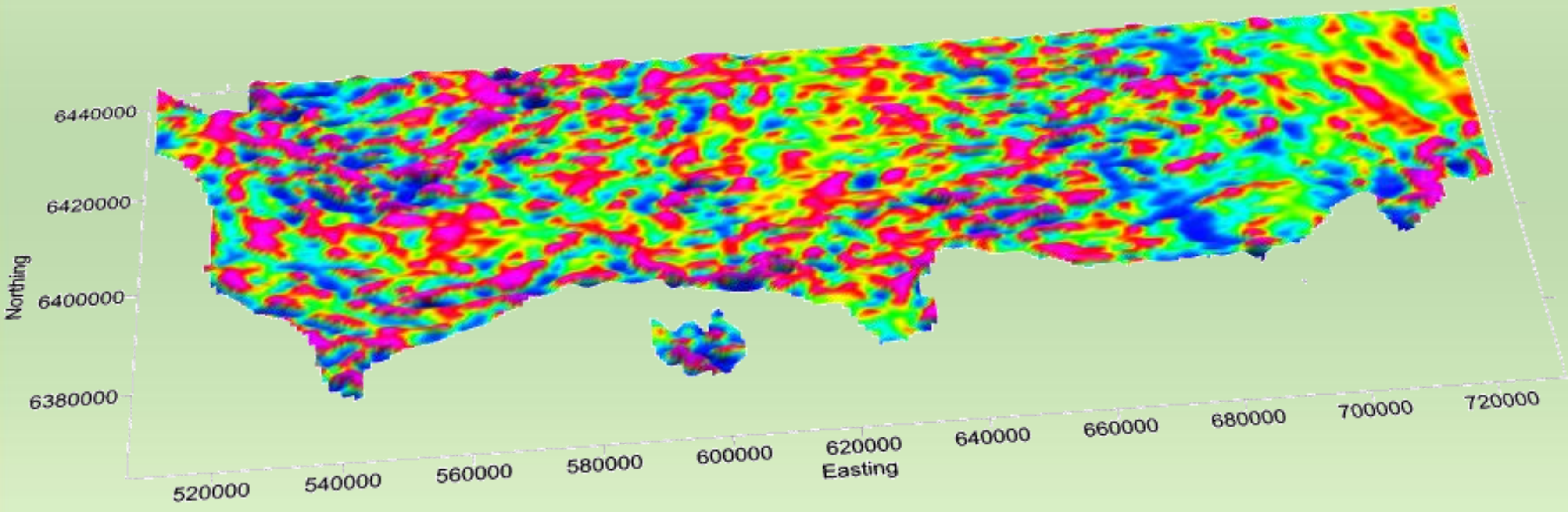
'Volcanics MAG'

- 'Volcanics MAG' is computed from 3D-voxel synthetic model of Volcanics using Magnetic Susceptibilities computed by ACM
  - Layer-1: Lower GRV; av. 0.01 – 0.05 SI units
  - Layer-2: Upper GRV; av. 0.001 – 0.01 SI units
- 'Volcanics MAG' is computed using in-house software



Magnetic Field of Volcanics

Magnetic Field computed from
3D-Voxel Synthetic Model of GRV



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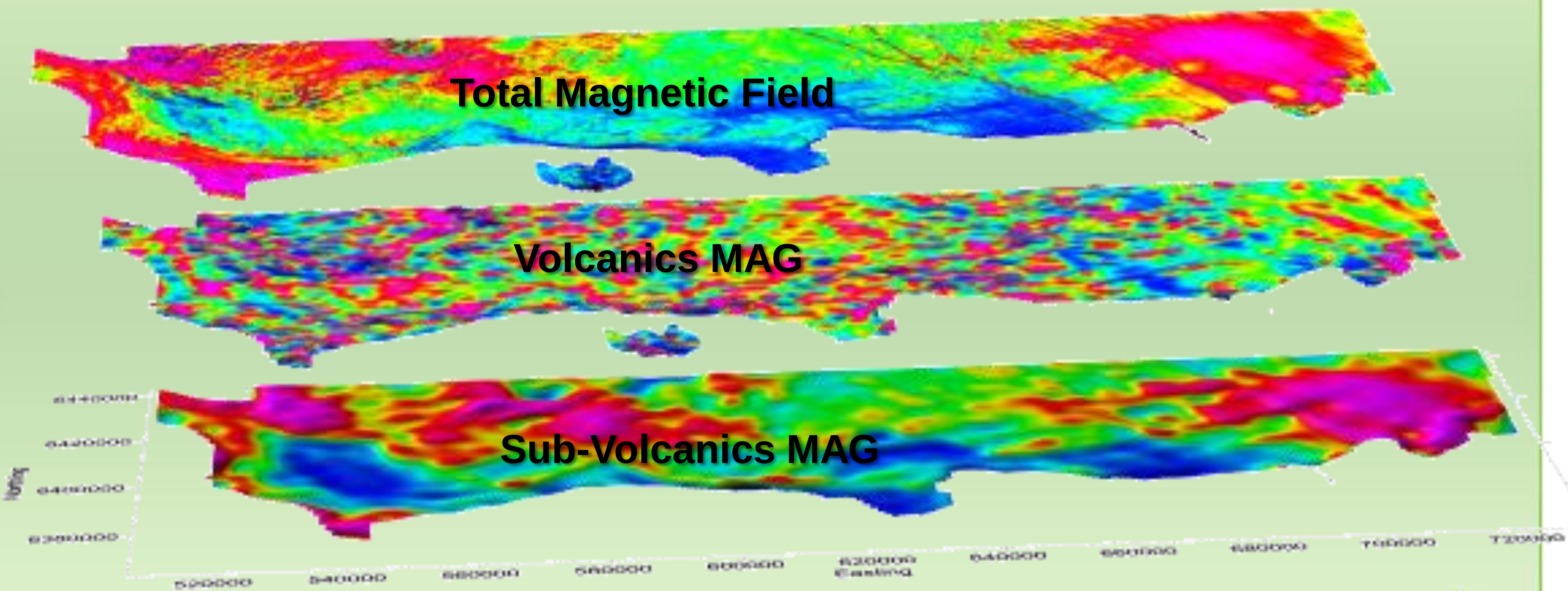
Archimedes

Sub-Volcanic Magnetic Field

Sub-Volcanic Magnetic Field

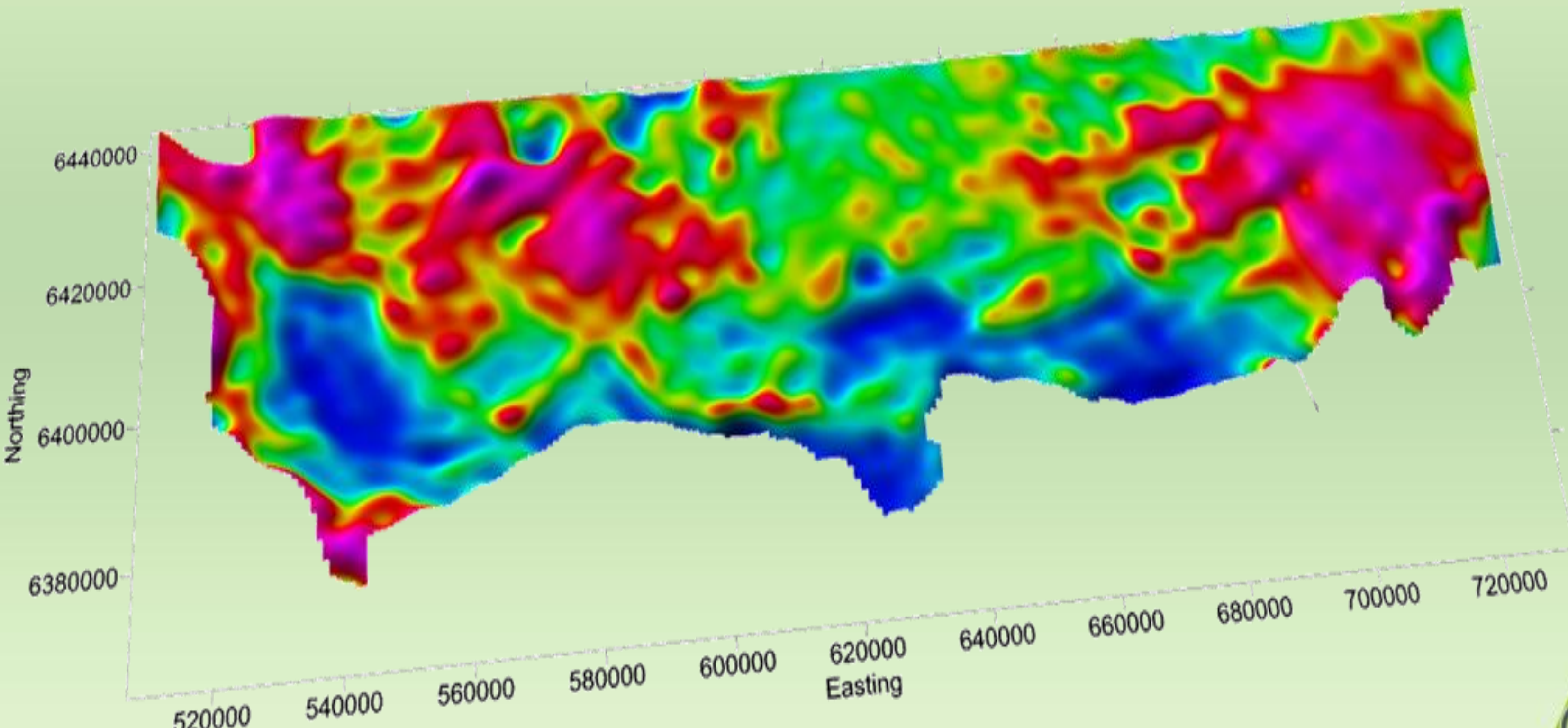
TMI –'Volcanics MAG' = 'Sub-Volcanic MAG'



3D-Voxel Synthetic Model

TMI –'Volcanics MAG' = 'Sub-Volcanics MAG'

Magnetic Field of Sub-Volcanic Crust



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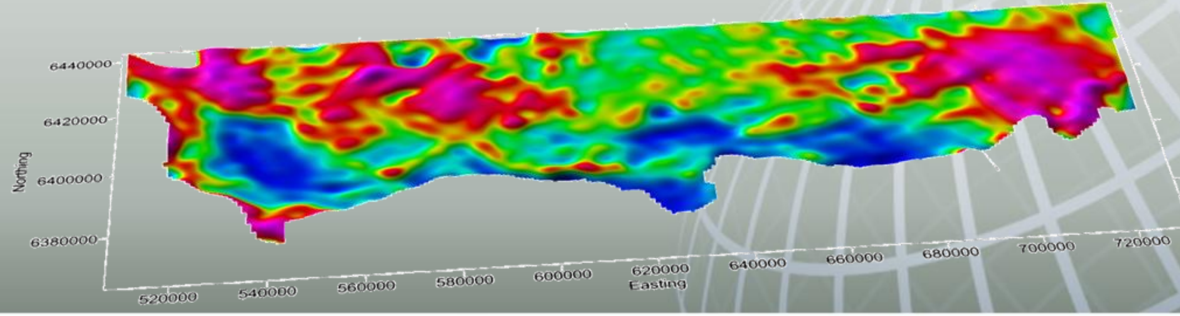
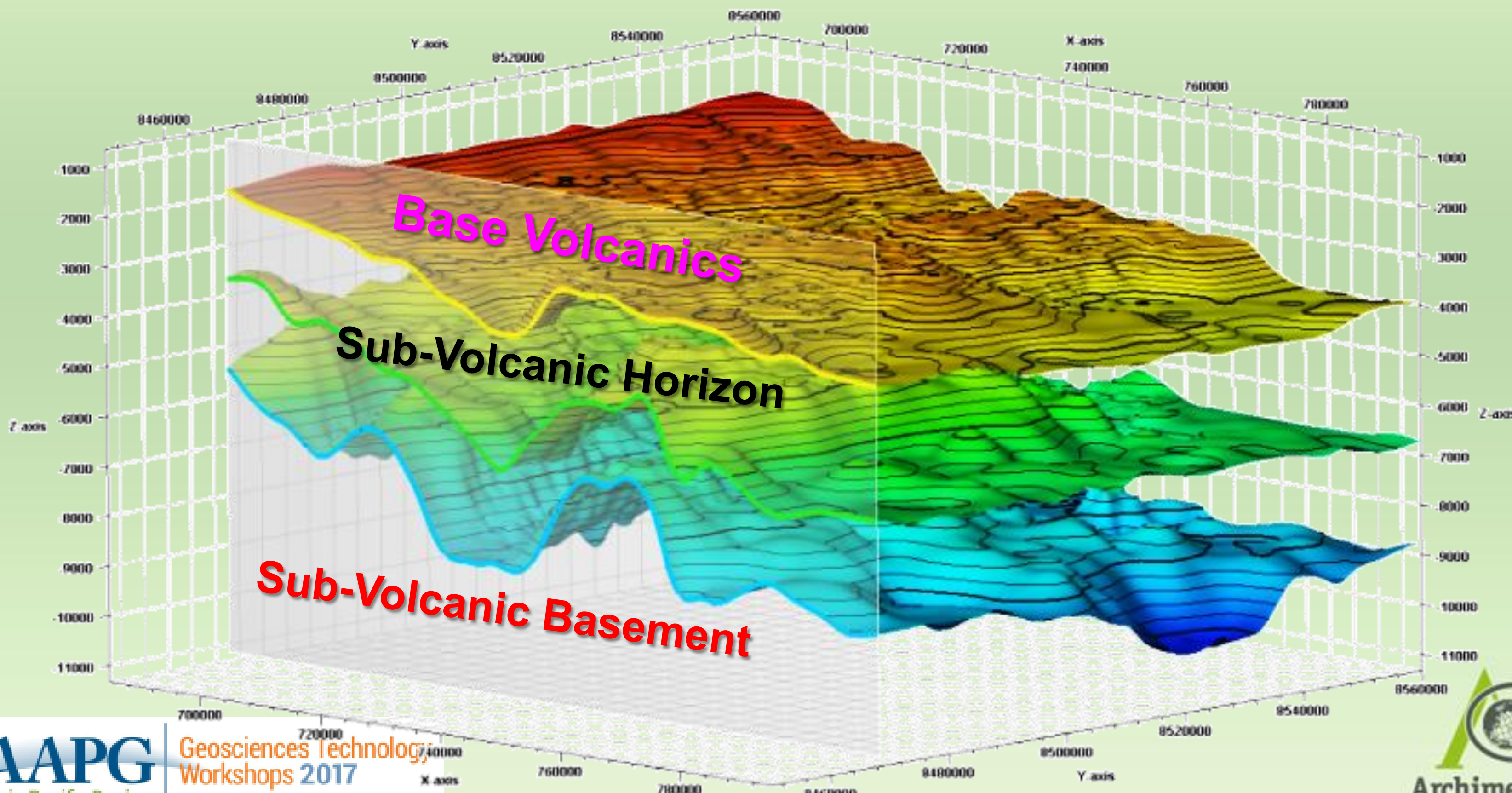
Interpretation

Sub-Volcanic Magnetic Field Examples



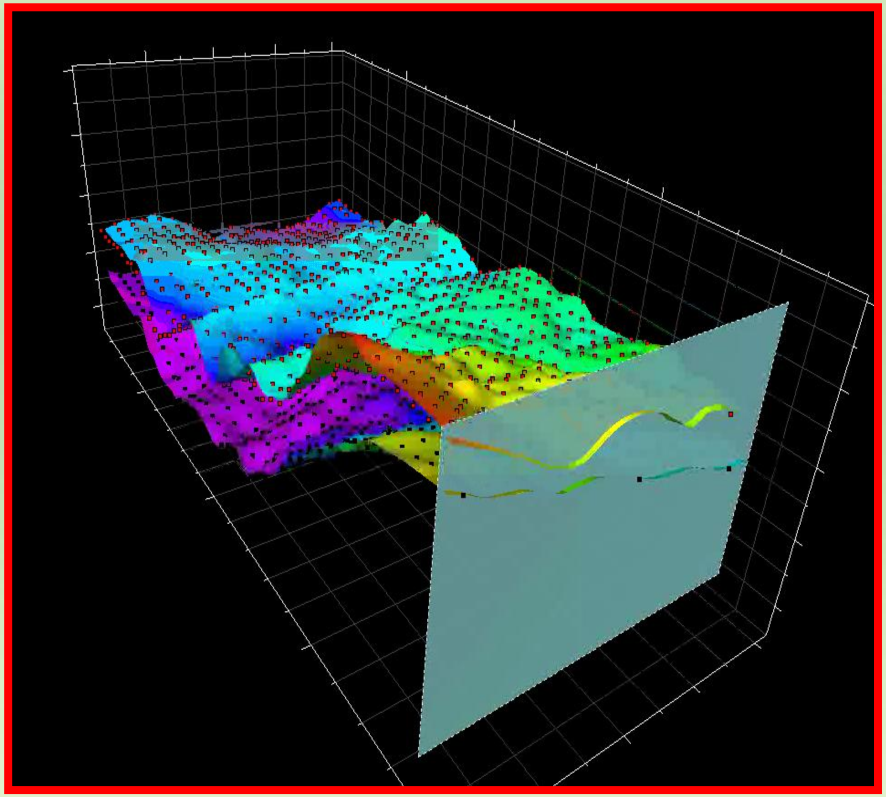
Sub-Volcanic Geology

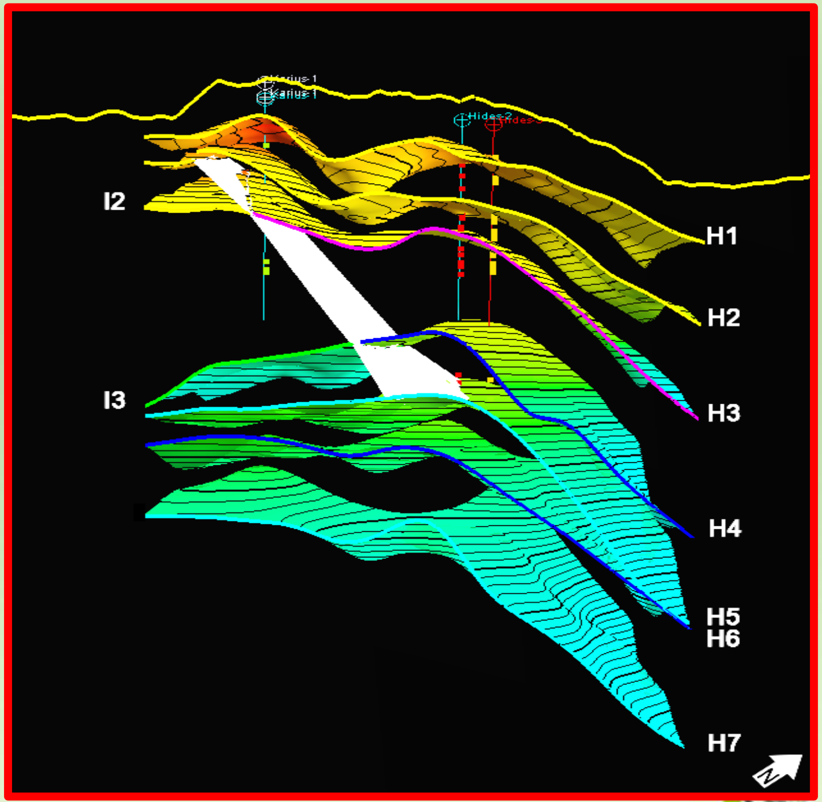
Sub-Volcanic MAG used to map Basement, Sedimentary Horizons & Faults beneath thick Volcanics such as Deccan Traps



Sub-Volcanic Geology

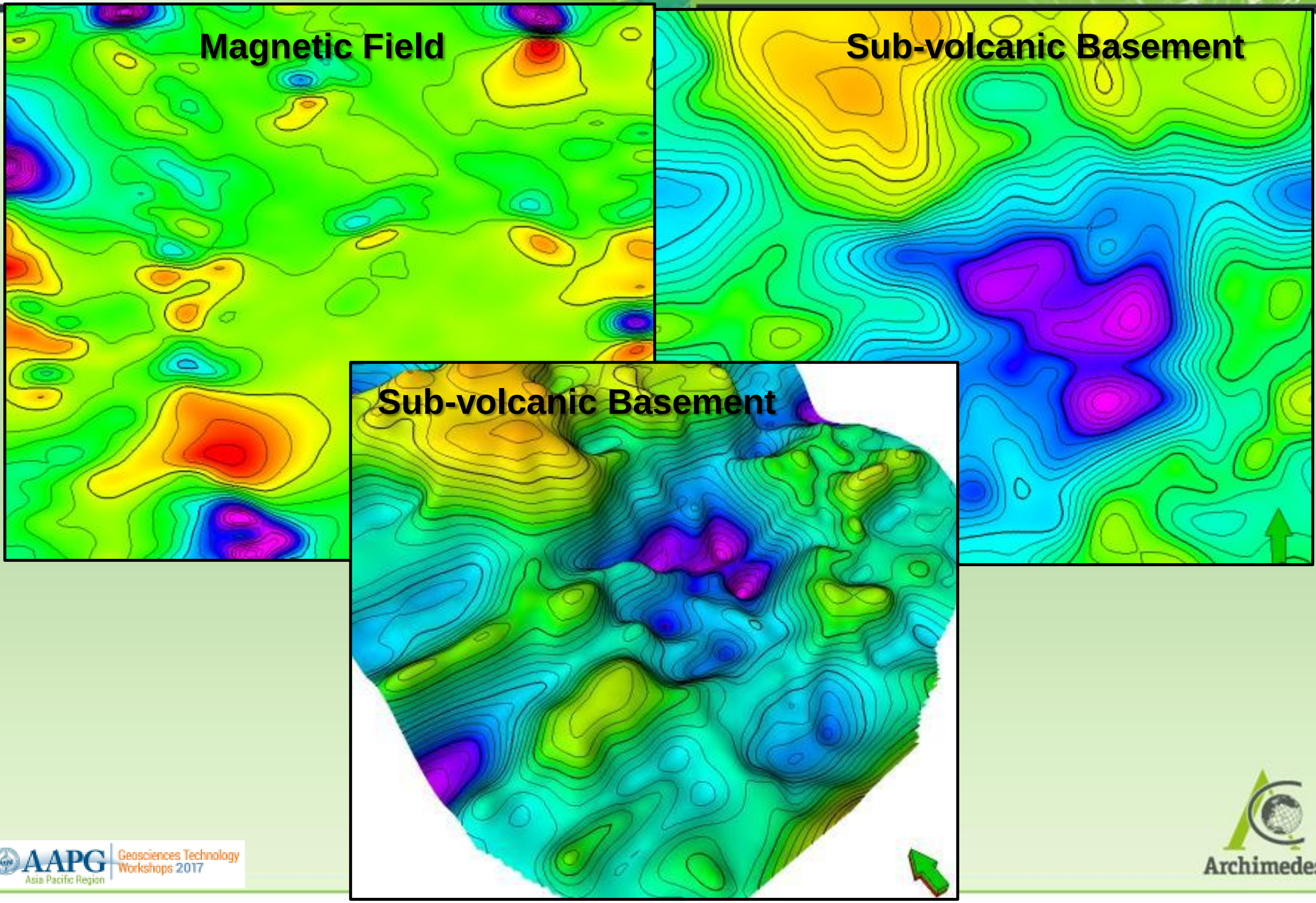
Computed Sub-Volcanic Magnetic Field was analysed to map Sub-Volcanic Basement, Sedimentary Horizons & Faults in PNG & Sirte Basin in Libya





Mapping Sub-Volcanic Basement

Mekong Delta, Vietnam



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Conclusions

- New Method presented allows magnetic anomalies of GRV to be removed from TMI field & Sub-Volcanic Magnetic Field to be computed
- ACM detected Magnetic Sources within GRV & underlying basement
- Magnetic Sources, visualised in 3D, allowed imaging the thickness of the Upper & Lower GRV & also the underlying Basement, for the first time.
- Base Volcanics was successfully mapped along NS profiles using: magnetic susceptibility values, distribution patterns & abundance of Magnetic Sources within GRV. Results were validated by comparison with drillholes & passive seismic.
- Magnetic Field of Volcanics was computed from 3D-Voxel synthetic model of GRV
- This field was subtracted from TMI field to produce Sub-Volcanic Magnetic Field, which can be used to map basement, multiple sedimentary horizons & faults
- Our New Method can assist in solving petroleum exploration challenges in India & other volcanic provinces around the world

Acknowledgements

- Authors would like to acknowledge the contribution to development of this New Method by the late, Emeritus Prof David Boyd from the University of Adelaide
- We would like to thank the DSD of South Australia & exploration companies in the GRV province for sponsorship & support of the Test Project
- Thank you to Geoscience Australia & DSD for providing magnetic data

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Kivior, I., Shi, Z., Boyd, D. And McClay, K.R., 1993, Crustal studies of South Australia based on energy spectral analysis of regional magnetic data. *Exploration Geophysics,* 24, pp 603–608.

Schmidt, P.W. and Clark, D.A., 2011. Magnetic characteristics of the Hiltaba Suite Granitoids and Volcanics: Late Devonian overprinting and related thermal history of the Gawler Craton. *Australian Journal of Earth Sciences,* 58(4), pp.361-374.

Thank You