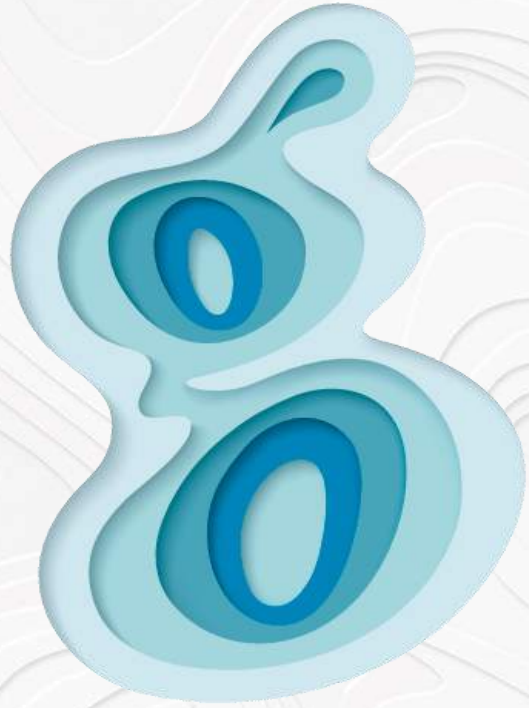




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Invictus Energy –
Zimbabwe

Cabora Bassa Basin
Technical Overview

Getech Group



Potential Fields Data
Globe
Regional Report
Proprietary Analyses



GIS Strategy
GIS Data
Management
Training
Exploration Software



Government
Advisory Services
Exploration
Appraisal
Advisory/Training
License Rounds



UK and USA Based

Products

Data

Internal and external customers

Gravity & Magnetic Data

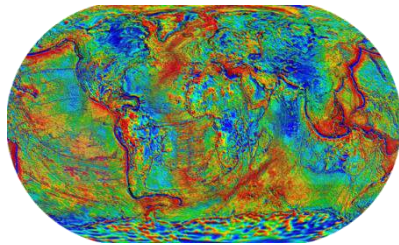
- Largest and most extensive G&M database in the world
- Oil & Gas and Mining applications

Seismic and Well Data

- High-value products accessed through Government Advisory
- Broker data on behalf of data owners

Depth to Basement

- First pass solution using a unique integrated gravity and magnetic inversion methodology



Data Products

Unique geoscience insight, GIS-driven

Globe, Tectonics Online and Regional Reports

- Understand how the Earth's evolution has controlled the location of natural resources
- Better prediction of geological risk and uncertainty
- Reports focus on "hot areas" and Getech's core skills



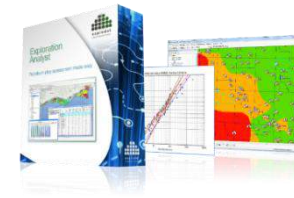
Globe 2018
The most innovative step to date

GIS Software

> 50 companies

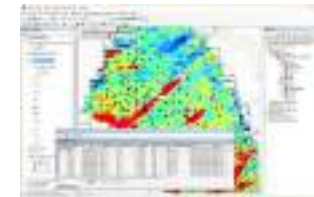
Exploration Analyst

- Make better decisions by assessing basin and play prospectivity.



Data Assistant

- Move data between common E&P interpretation system formats and ArcGIS Desktop



Training

> 2,500 E&P professionals trained in ArcGIS, classroom and remote support for all of our products

Services that leverage our products and core skills

Government Advisory

A strong track-record of delivery

We design, manage and support license and bidding rounds

In 2017 we worked for the governments of Lebanon, Mozambique, Namibia, Ras al Khaimah and Sierra Leone

Sierra Leone

- World Bank funded 2016/2017
- Fourth Licensing Round H1-18
- Getech exclusive brokerage:
 - > 10,000 km² of 3D
 - 8 wells, 4 discoveries



GIS Services

Used by > 60 oil & gas companies

Experts in the management and analysis of complex spatial data

e.g. The Oil & Gas Authority

Responsible for maximizing UK's economic recovery of oil & gas

- Geospatial strategy: review, design and implement an enhanced GIS
- GIS analyst embedded in Aberdeen
- Purchased Exploration Analyst
- Purchased proprietary MultiSat data
- Used our Gravity & Magnetic interpretation services



Geoscience Consulting

Leveraging our products and skills

Complex integrated geoscience and geospatial consultancy projects

Services include:

- Asset-scale prospectivity and risk studies, exploration project management
- Seismic interpretation and integrated Gravity & Magnetic modelling
- Asset due diligence
- Farm-down management
- Basin-scale multiclient studies



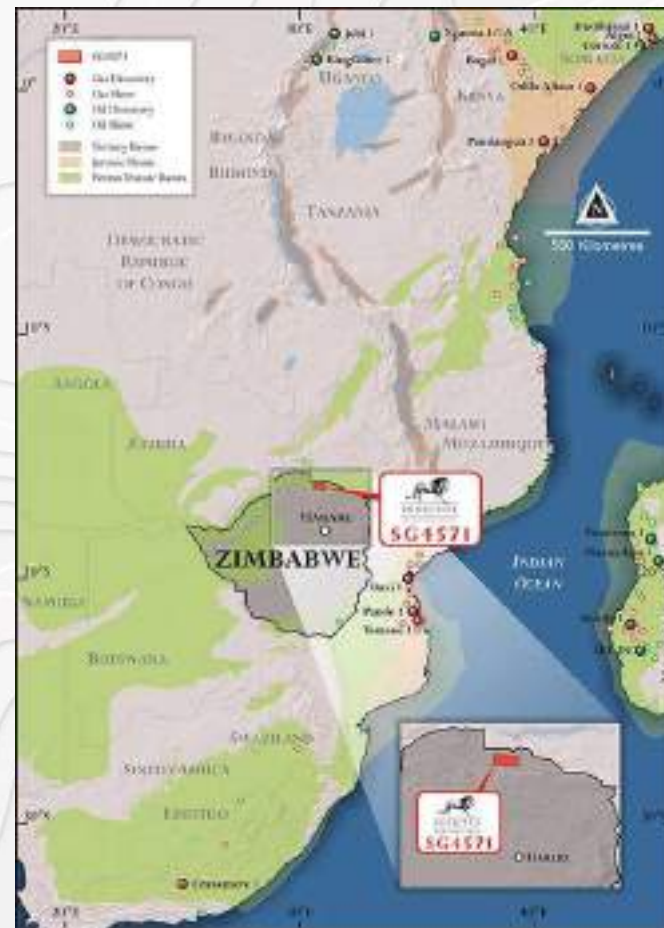
Getech Group Technical Programme for Invictus Energy

- Regional Geological Context utilising Getech Globe
- Creation of a GIS project
- Gravity and Magnetic data reprocessing, interpretation and modelling
- Seismic data transcription, and reprocessing support and Interpretation
- Technical Farm Out Support



Getech Group Technical Programme for Invictus Energy

- Regional Geological Context utilising Getech Globe
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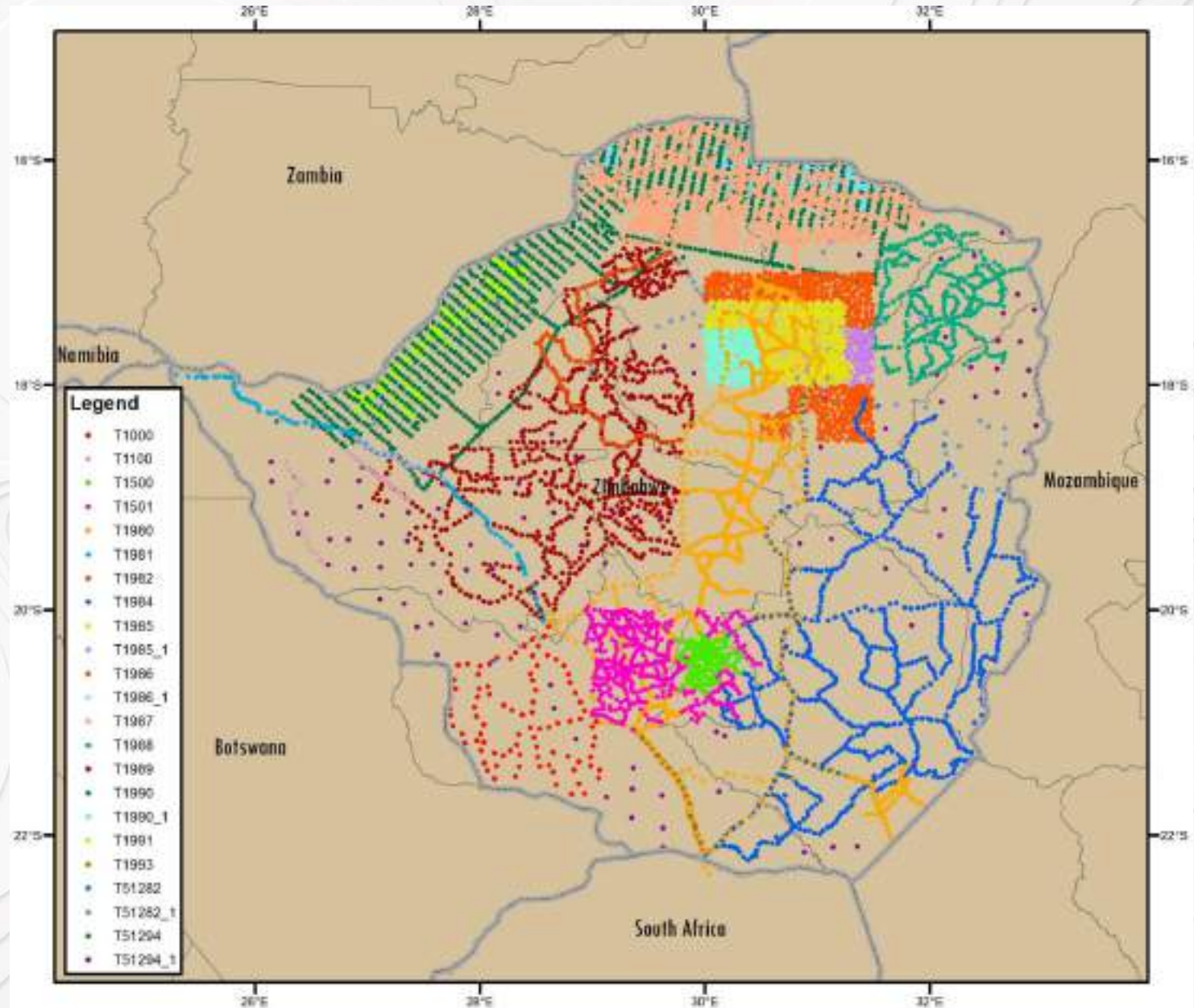




Gravity Data

Gravity Data Supplied to Getech

Gravity database supplied by Invictus Energy has 12,560 gravity data points (64 dummy values for G_{obs} within survey #1100) within Zimbabwe – these contain G_{obs} , elevation and Simple Bouguer Anomaly

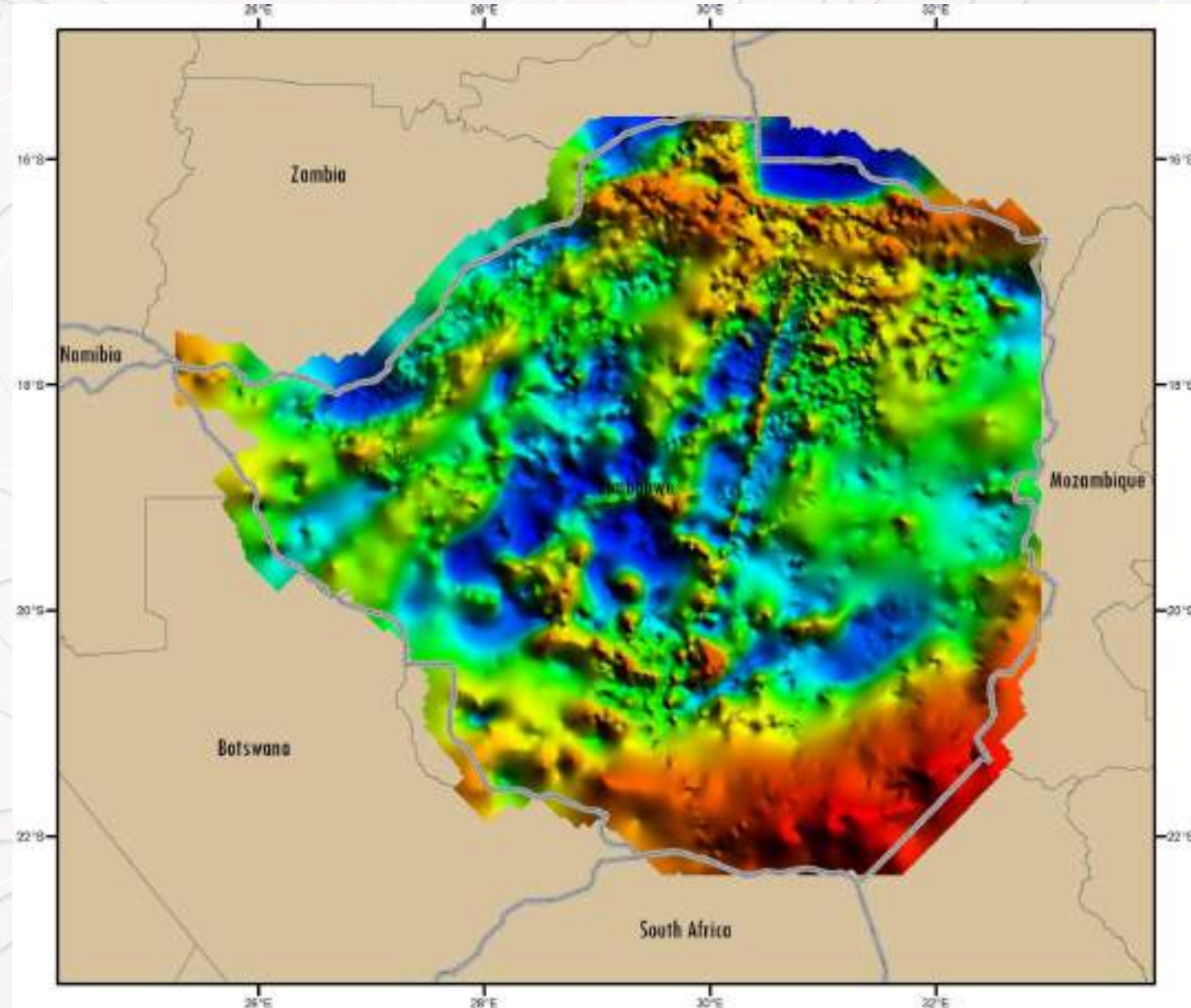


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Gravity Data Supplied to Getech

Simple Bouguer Anomaly (SBA), gridded without any processing.

Grid shows that the data are in a reasonable state but have unknown parameters (specifically the reduction density). Also, SBA does not include a terrain correction.



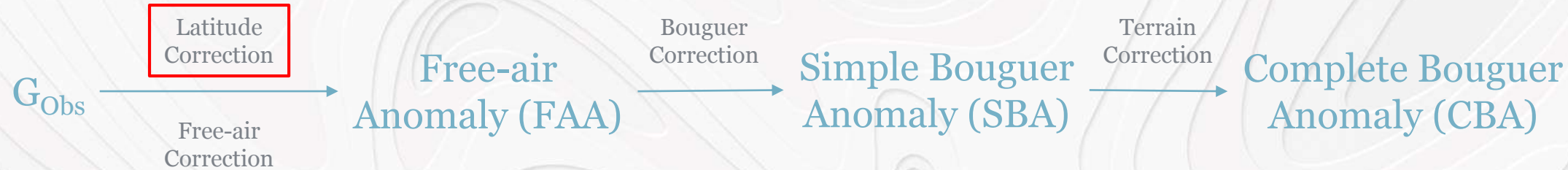
Gravity Point Data

- Channels supplied to Getech:
 - Station Name
 - Longitude
 - Latitude
 - Elevation
 - Observed Gravity (G_{Obs})
 - Terrain Correction (although not fully populated)
 - Simple Bouguer Anomaly

✓ P1991:0	lon	lat	elevation	gobs	SBA	tcor	station
0.0	27.724940	-17.447770	594.90	978256.88	-122.97	0.16	91MZIH-008.241
1.0	27.721740	-17.450450	607.00	978254.83	-122.77	0.22	91MZIH-008.250
2.0	27.718230	-17.453450	609.90	978254.38	-122.81	0.20	91MZIH-008.260
3.0	27.714700	-17.456440	660.90	978243.83	-123.46	0.31	91MZIH-008.270
4.0	27.711170	-17.459410	626.90	978250.40	-123.75	0.34	91MZIH-008.280
5.0	27.708090	-17.462100	532.60	978269.47	-123.39	0.32	91MZIH-008.289
6.0	27.704300	-17.465380	627.40	978250.11	-124.25	0.51	91MZIH-008.300
7.0	27.700800	-17.468390	634.40	978248.93	-124.20	0.57	91MZIH-008.310
8.0	27.697310	-17.471380	582.00	978260.00	-123.61	0.43	91MZIH-008.320
9.0	27.693840	-17.474320	513.20	978274.32	-122.99	0.36	91MZIH-008.330
10.0	27.690360	-17.477340	546.50	978267.72	-123.19	0.18	91MZIH-008.340
11.0	27.687200	-17.480040	531.10	978271.11	-122.97	0.20	91MZIH-008.349
12.0	27.683330	-17.483350	558.30	978265.90	-123.00	0.16	91MZIH-008.360
13.0	27.679800	-17.486340	576.20	978262.66	-122.86	0.16	91MZIH-008.370
14.0	27.676280	-17.489340	583.80	978261.42	-122.76	0.15	91MZIH-008.380
15.0	27.672760	-17.492340	580.80	978262.26	-122.67	0.18	91MZIH-008.390
16.0	27.669230	-17.495350	573.80	978264.22	-122.24	0.13	91MZIH-008.400
17.0	27.665360	-17.498630	571.20	978265.13	-122.02	0.13	91MZIH-008.411
18.0	27.662540	-17.501020	545.30	978270.67	-121.70	0.31	91MZIH-008.419
19.0	27.658340	-17.504610	500.70	978280.21	-121.13	0.31	91MZIH-008.431
20.0	27.655190	-17.507310	524.30	978275.93	-120.90	0.11	91MZIH-008.440
21.0	27.652010	-17.509980	509.10	978279.39	-120.58	0.27	91MZIH-008.449
22.0	27.648150	-17.513250	521.00	978277.53	-120.26	0.11	91MZIH-008.460

To compute the Complete Bouguer Anomaly, a number of processing stages, starting from G_{Obs} , were undertaken.

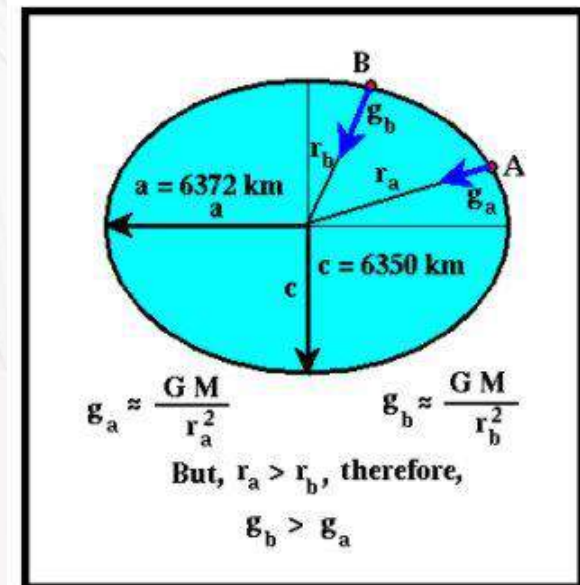
From Observed Gravity -> Complete Bouguer Anomaly



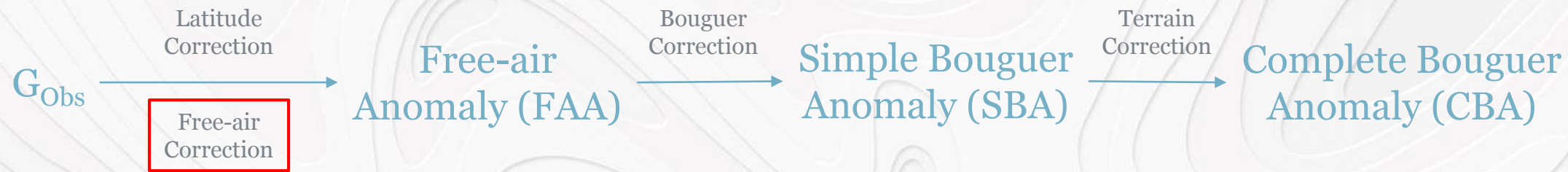
Due to the non-spherical nature of Earth (radius greater at the equator than at the poles), a correction needs to be applied based on the latitude of the gravity station

$$\text{Latitude Correction} = 978032.67714 \frac{(1 + 0.00193185138639 \sin^2 \varphi)}{\sqrt{(1 - 0.00669437999013 \sin^2 \varphi)}}$$

φ = latitude (degrees)



From Observed Gravity -> Complete Bouguer Anomaly



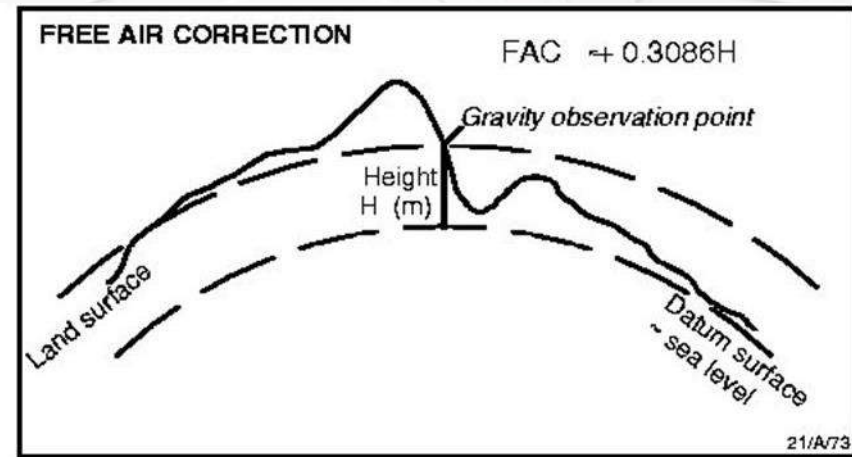
The Free-air Correction (FAC) accounts for the height of the gravity station above a common reference datum (e.g. mean sea level)

$$FAC = 0.3086h$$

h = gravity station elevation (in metres)

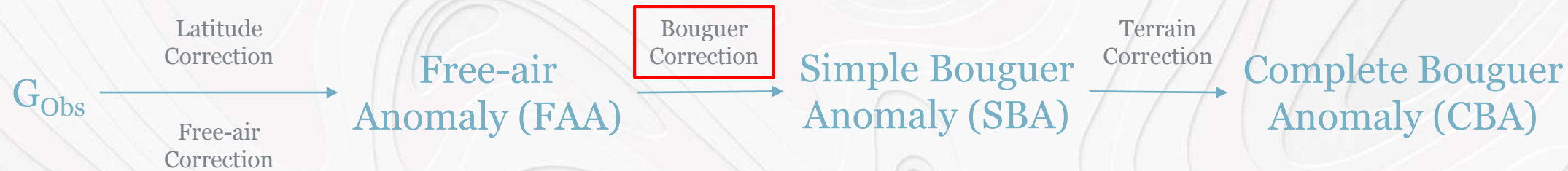


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This correction accounts for the fact that the point of measurement is at elevation H , rather than at the sea level on the reference spheroid.

From Observed Gravity -> Complete Bouguer Anomaly



The Bouguer Correction (BC) accounts for the rock mass between the gravity station and the reference datum, assuming a flat slab of infinite thickness (h) and constant density (ρ)

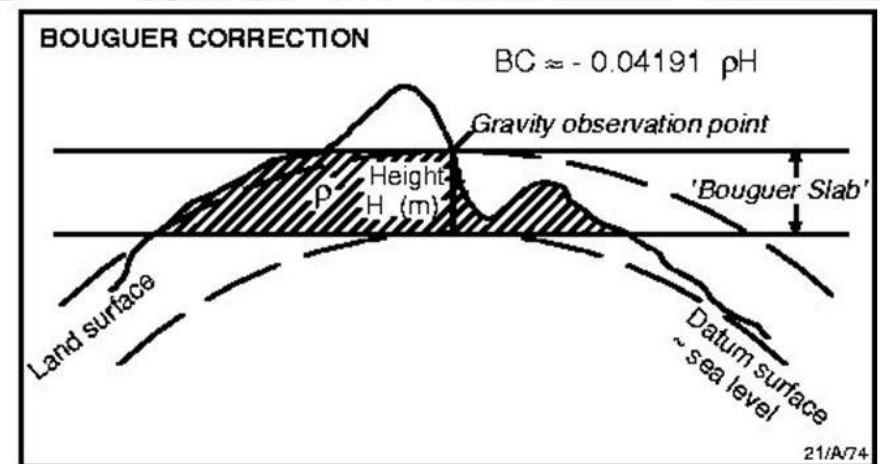
$$BC = 0.04191\rho h$$

ρ = rock density (g/cm^3);

h = gravity station elevation (in metres)

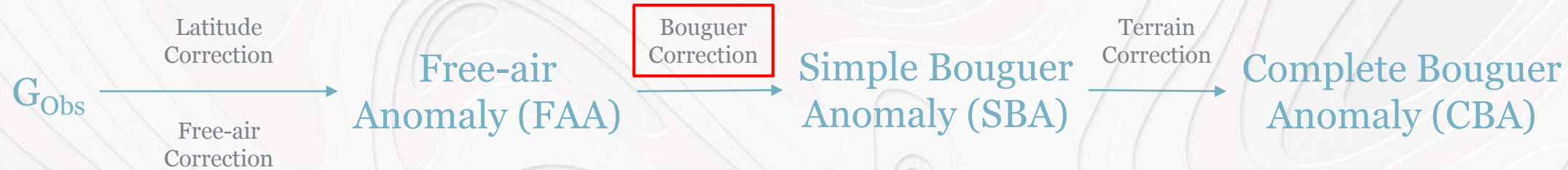


getech



This correction accounts for the gravitational attraction of the rocks between the point of measurement and the sea level.

From Observed Gravity -> Complete Bouguer Anomaly



The Bouguer Correction (BC) accounts for the rock mass between the gravity station and the reference datum, assuming a flat slab of infinite thickness (h) and constant density (ρ)

$$BC = 0.04191\rho h$$

ρ = rock density (g/cm^3);

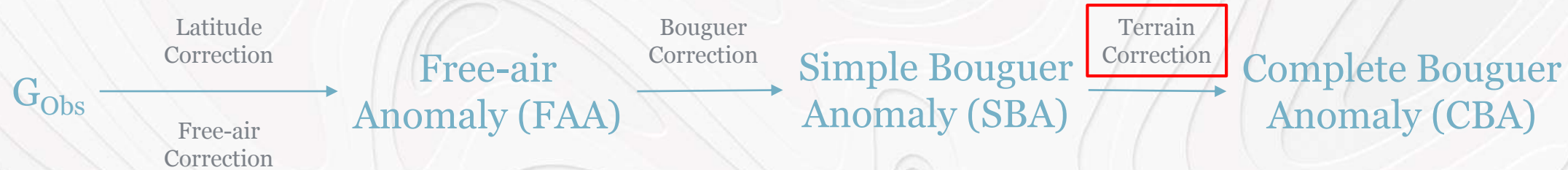
h = gravity station elevation (in metres)

Based on previous gravity work conducted by Mobil (1991) regarding an average sub-surface density, a Bouguer density of 2.5 g/cm^3 has been used as the reduction density in this project.

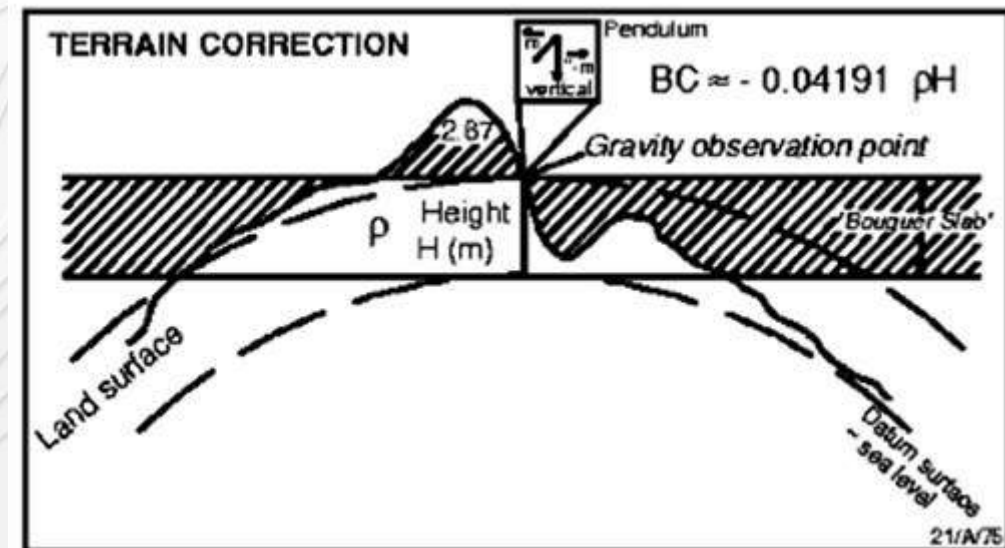
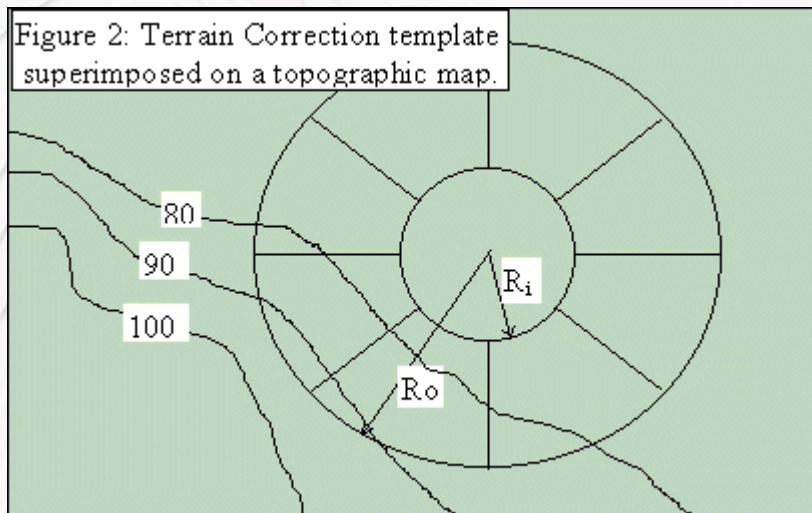


getech

From Observed Gravity -> Complete Bouguer Anomaly



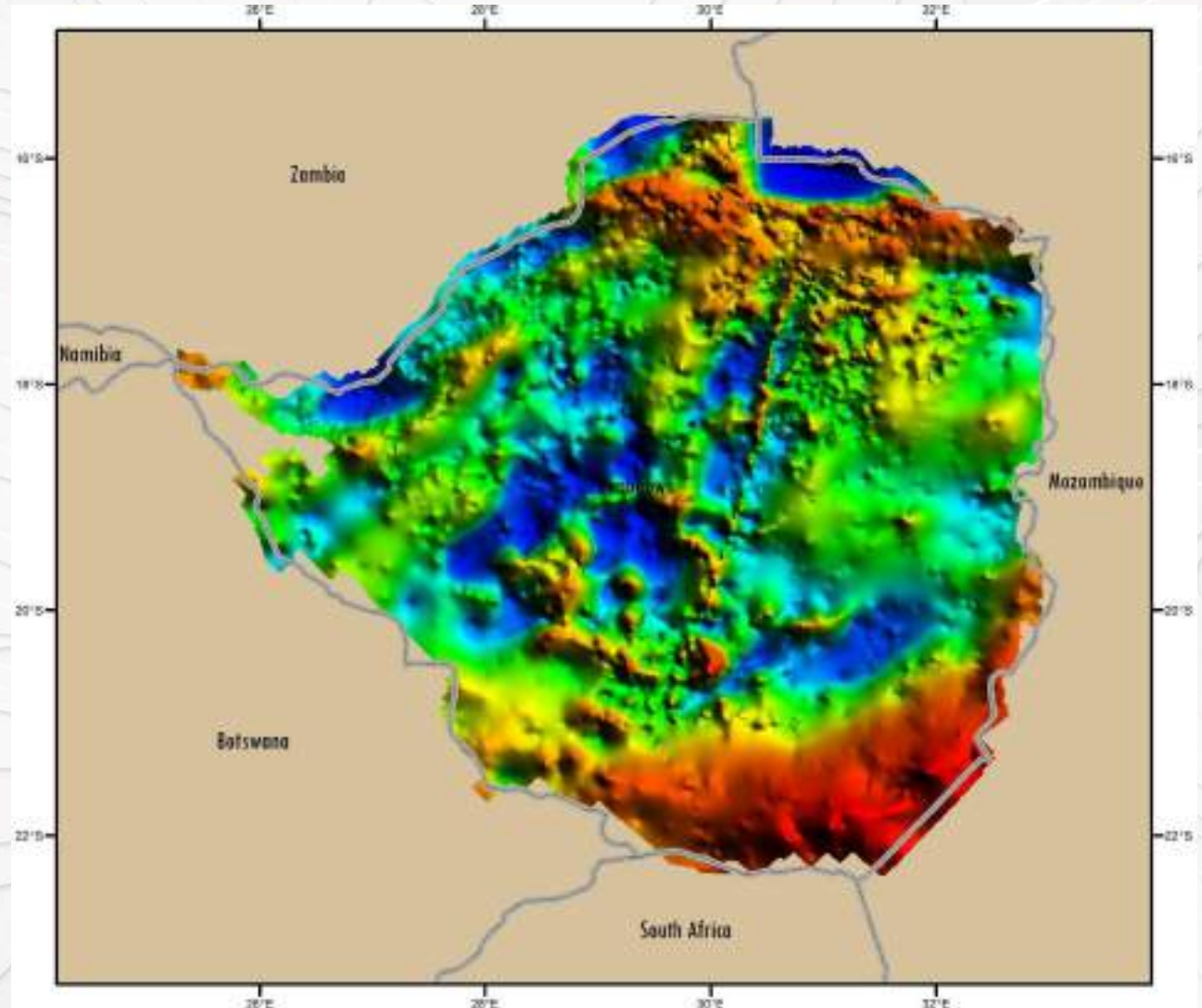
The Terrain Correction accounts for the topography which is present on the top surface of the “flat” slab of infinite thickness used in the Bouguer Correction. This is composed of calculations within inner (R_i) and outer (R_o) zones.



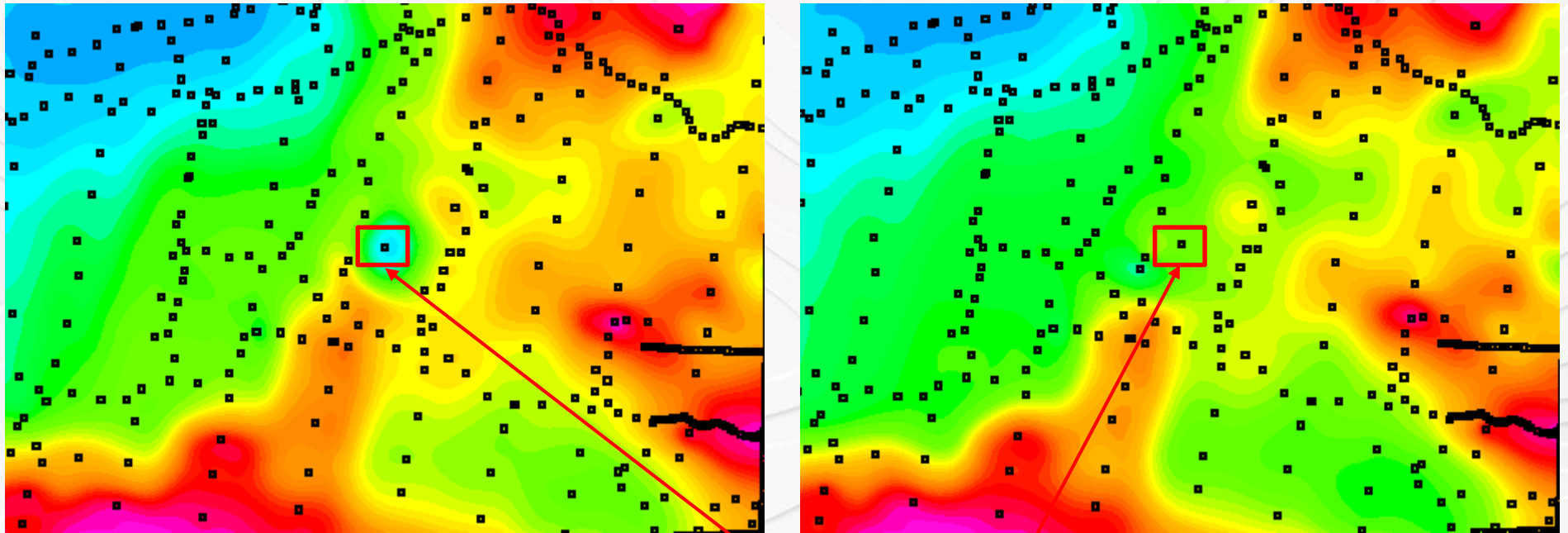
Gridding Gravity Data

- Gridding the full database within Zimbabwe has been performed using a 1 km cell size and UTM 36S projection

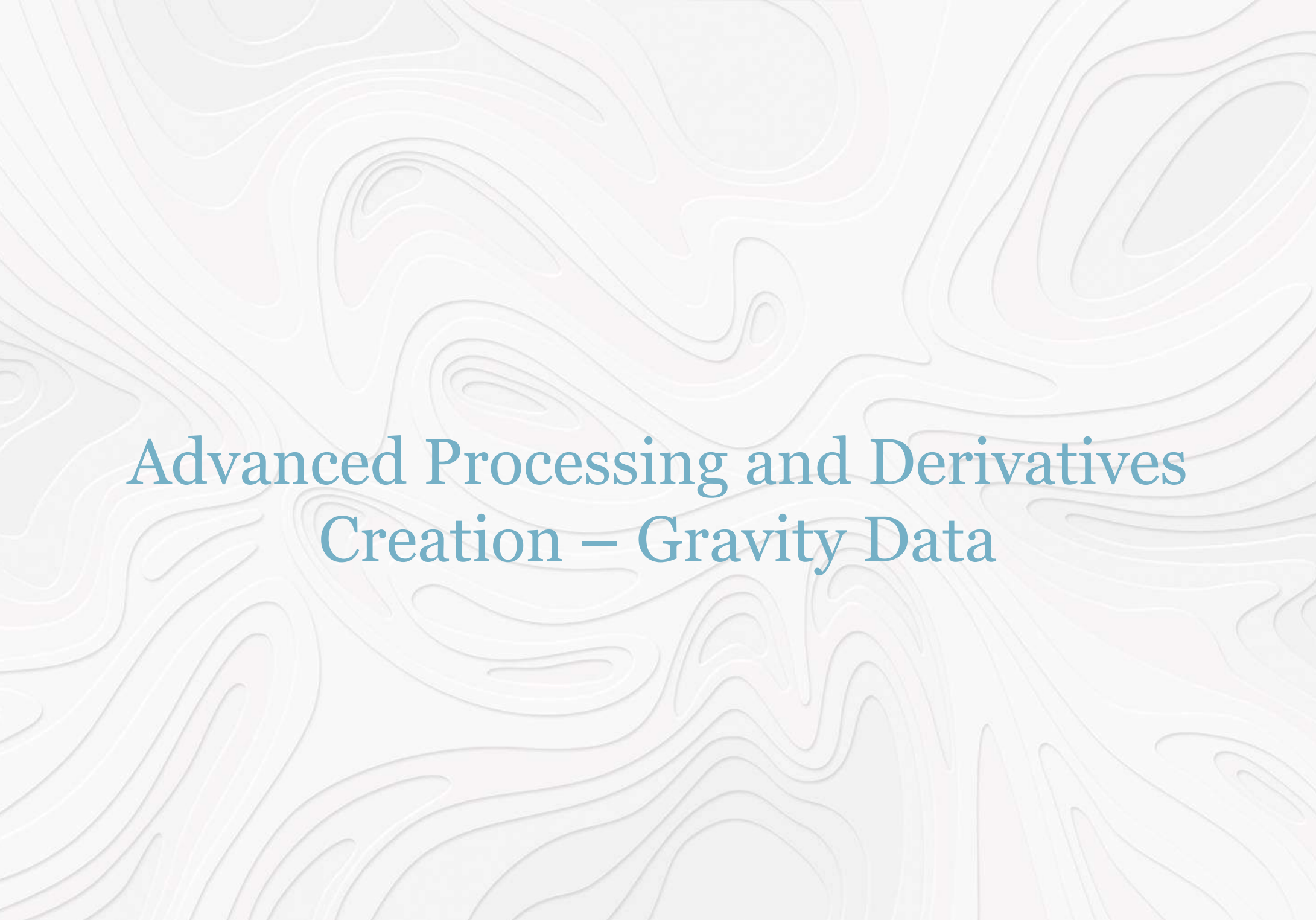
Bouguer Anomaly



Point editing

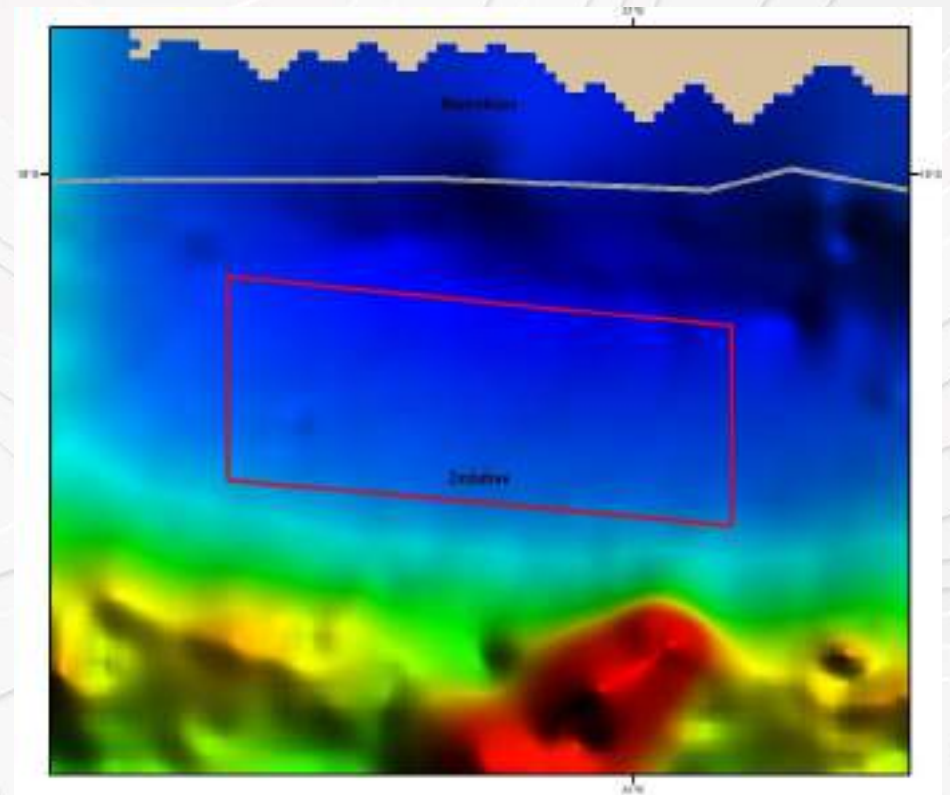
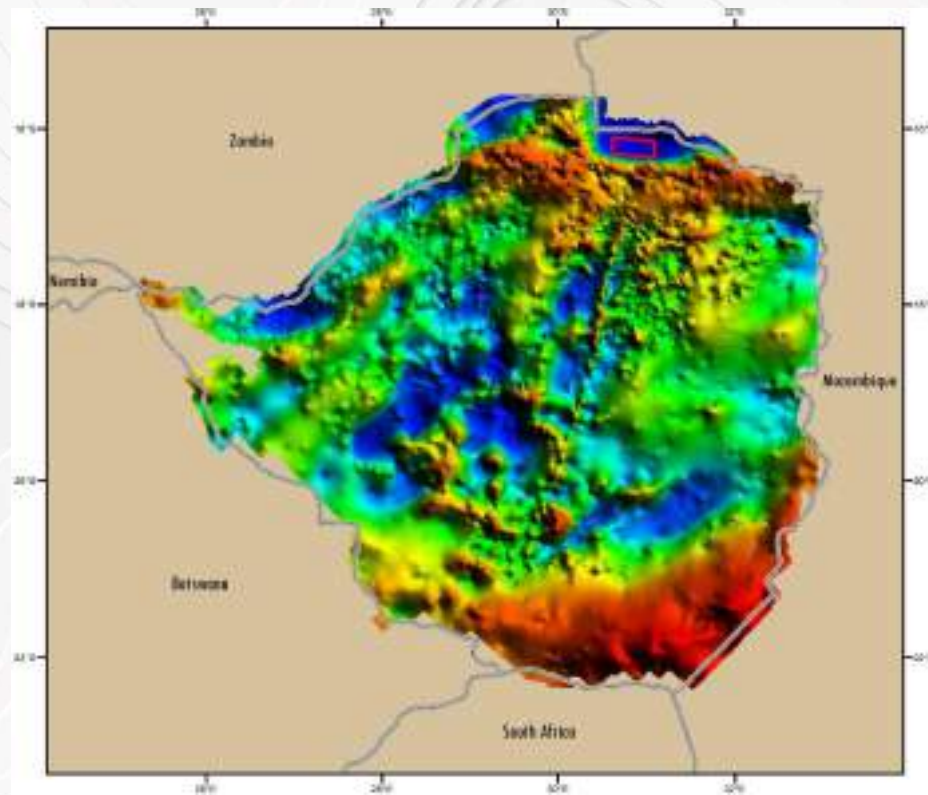


Inspection of the gridded data alongside the station locations allows for suspected erroneous data points to be identified and removed from the gridding process

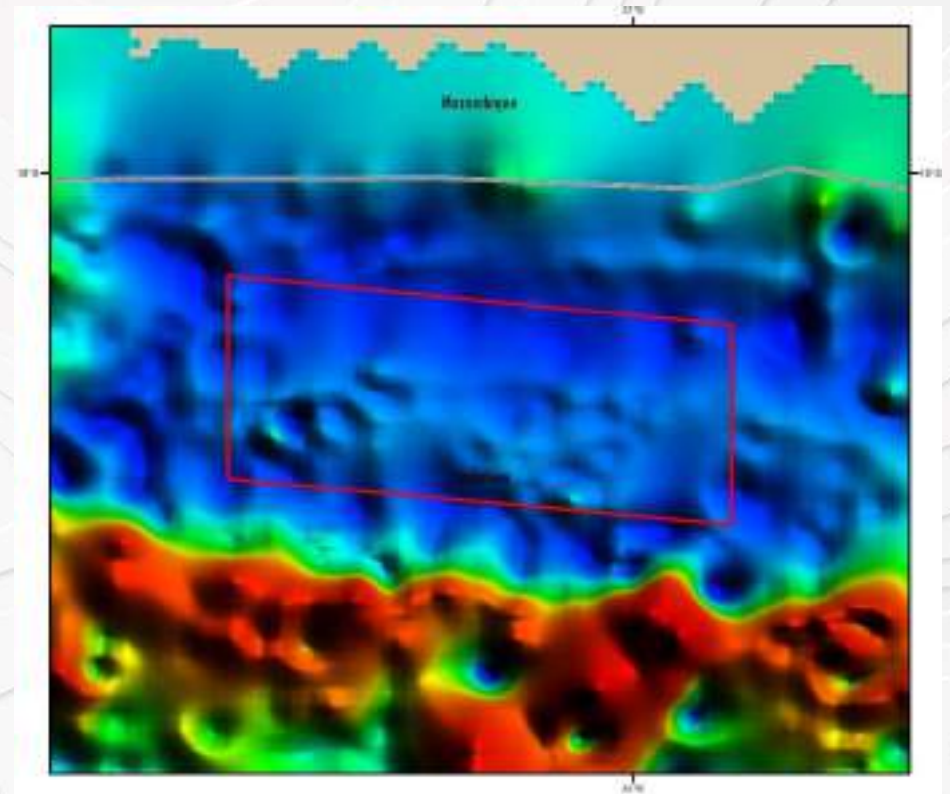
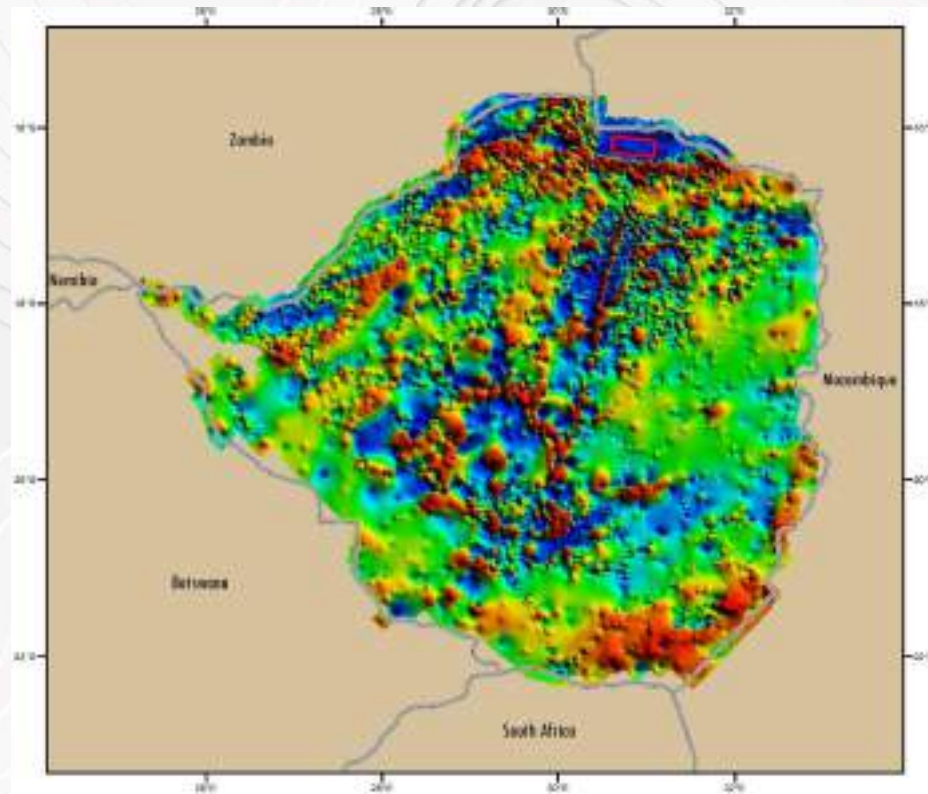
The background of the slide is a topographic map with contour lines in shades of gray and pink, creating a wavy, abstract pattern.

Advanced Processing and Derivatives Creation – Gravity Data

Final Reprocessed Bouguer Grid (2.5 g/cm³)

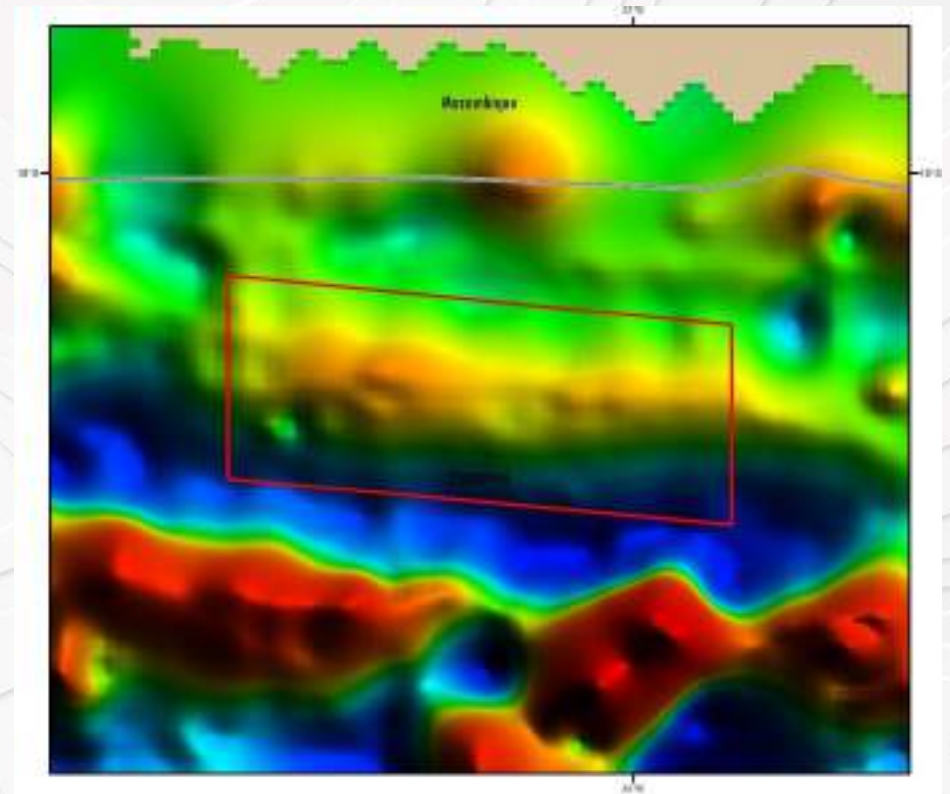
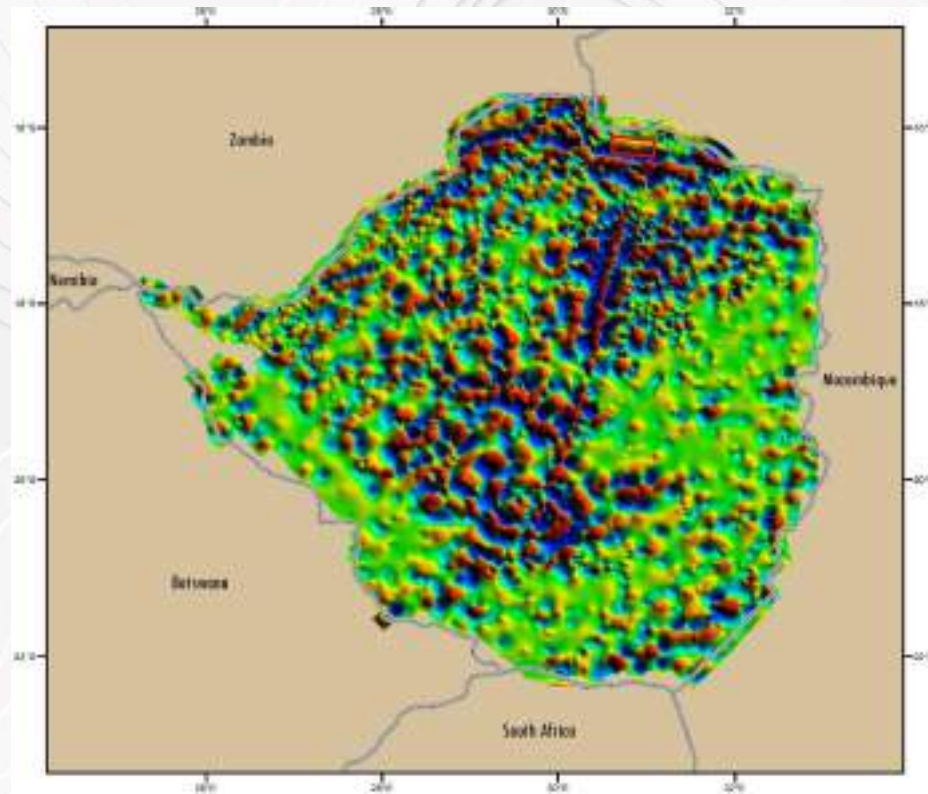


Final Bouguer Grid – First vertical derivative



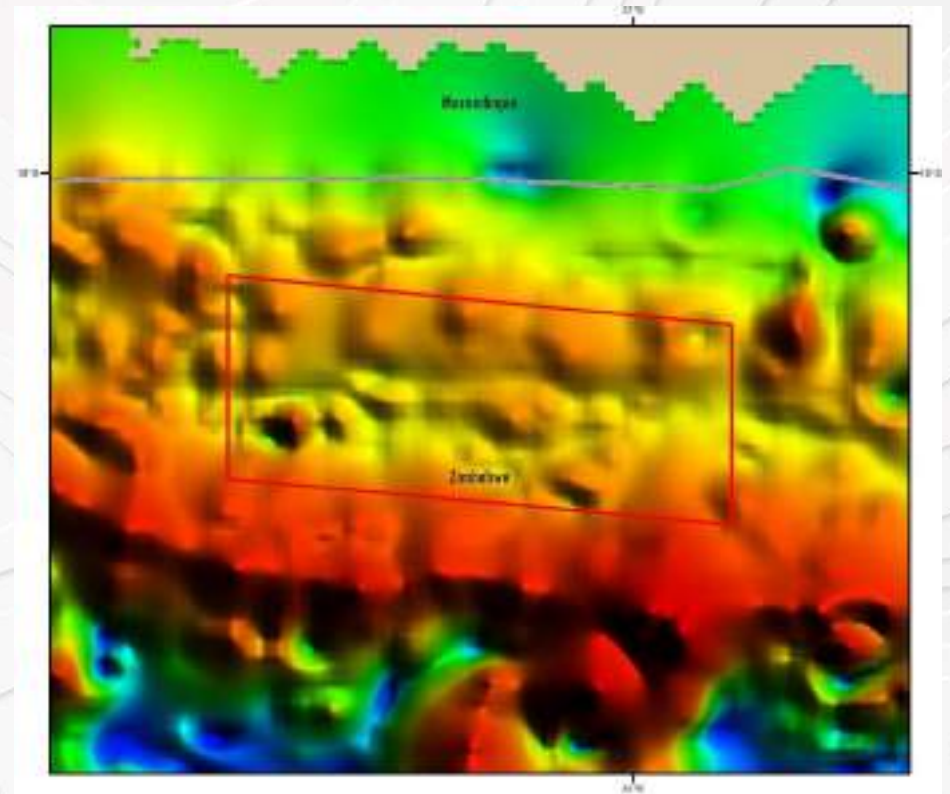
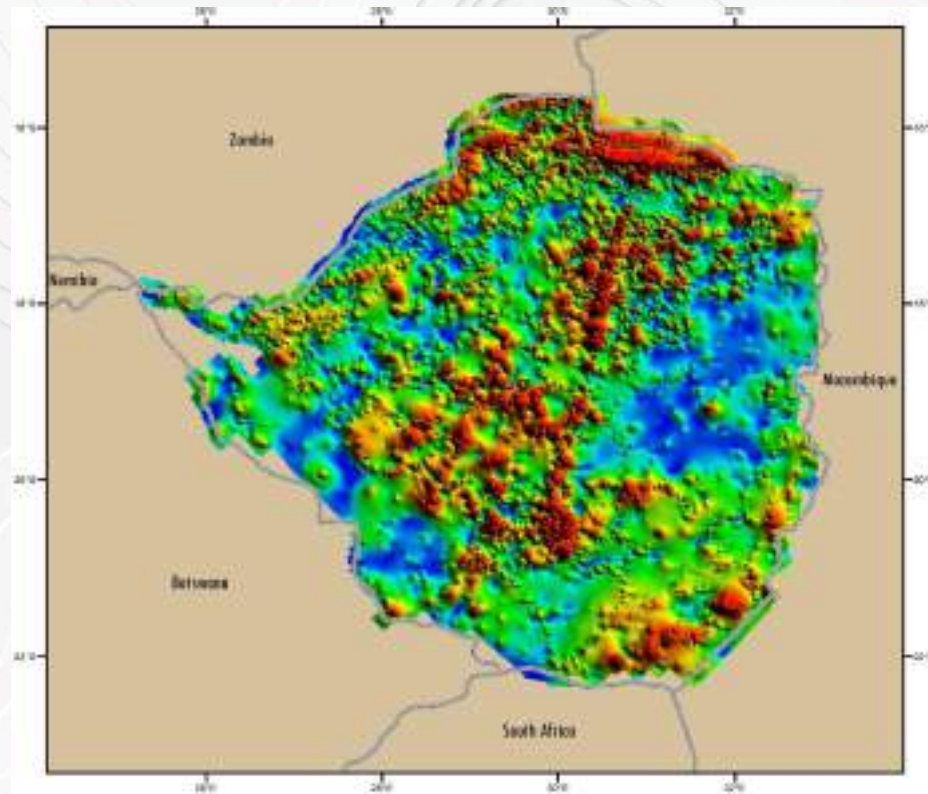
A measure of the downward vertical gradient of the potential field. This enhancement sharpens up anomalies over bodies, allowing clearer imaging of the causative structures. Short wavelength anomalies are amplified.

Final Bouguer Grid – 40 km high pass filter



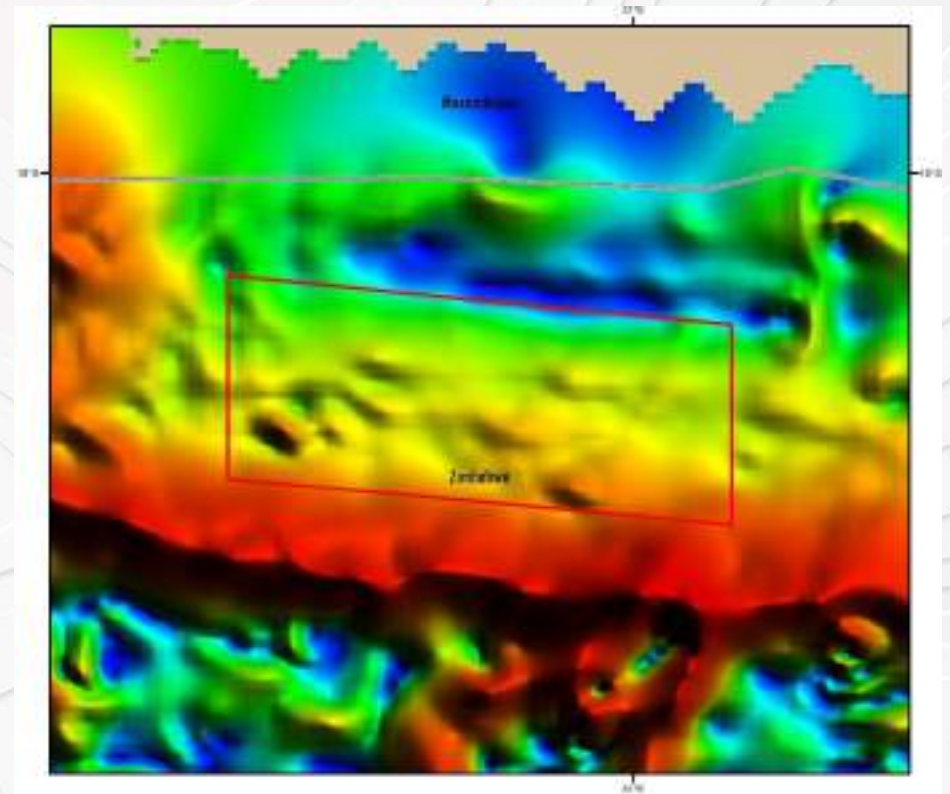
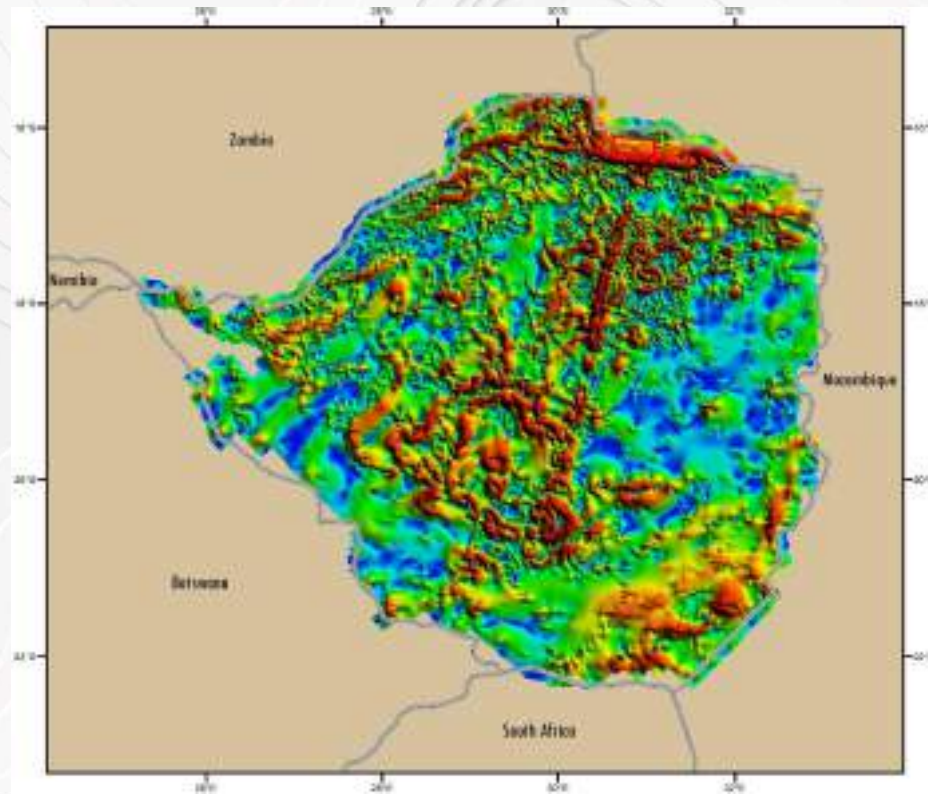
The 40 km high pass filter is calculated using a Butterworth filter (order 4). This removes a long-wavelength regional field, allowing more detailed interpretation of shallow structures.

Final Bouguer Grid – Analytic Signal



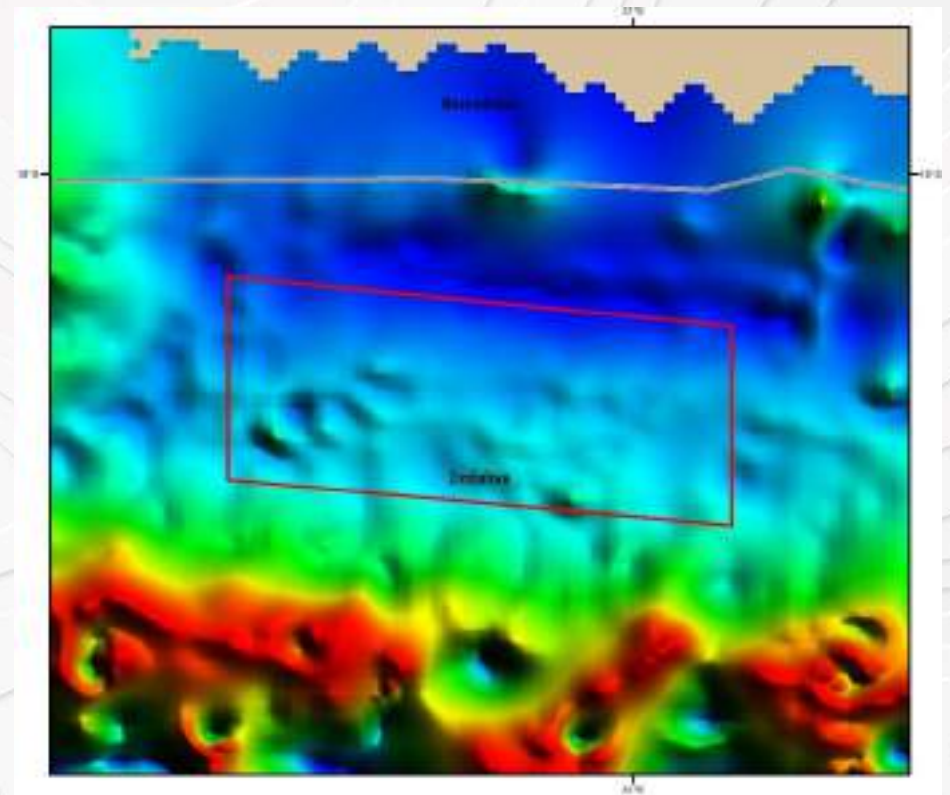
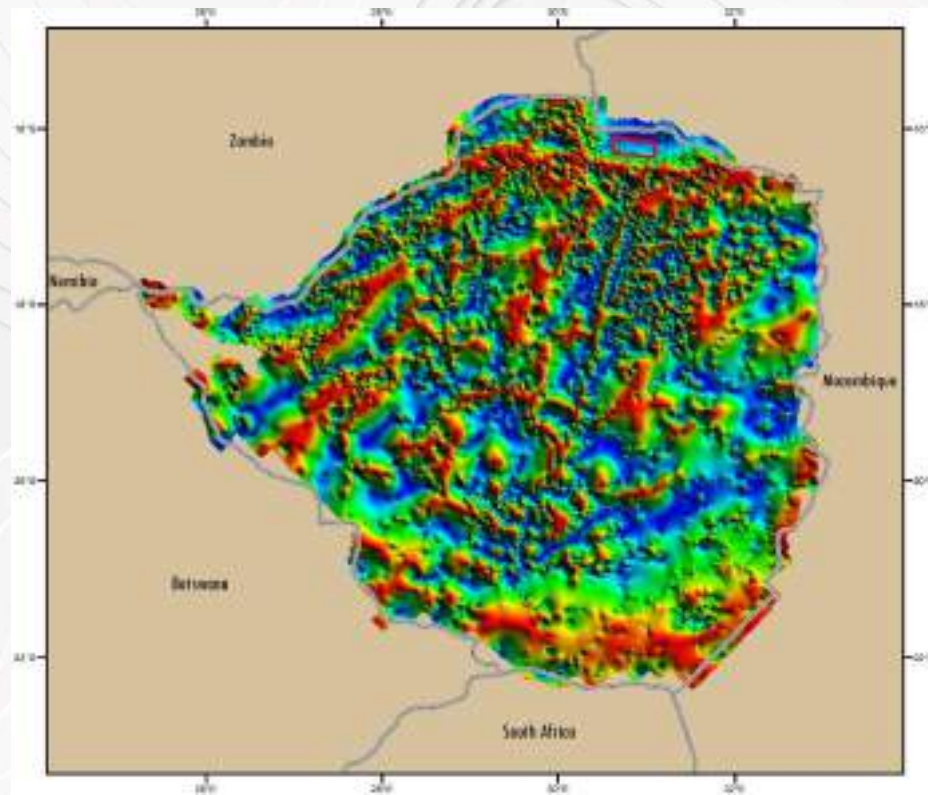
The Analytical Signal has maxima over the top of contacts but contains more noise than the first vertical derivative. Consisting of only positive values, it can be used to give depth estimates to causal bodies using the Half Width at Half Maximum estimation method.

Final Bouguer Grid – Total horizontal derivative



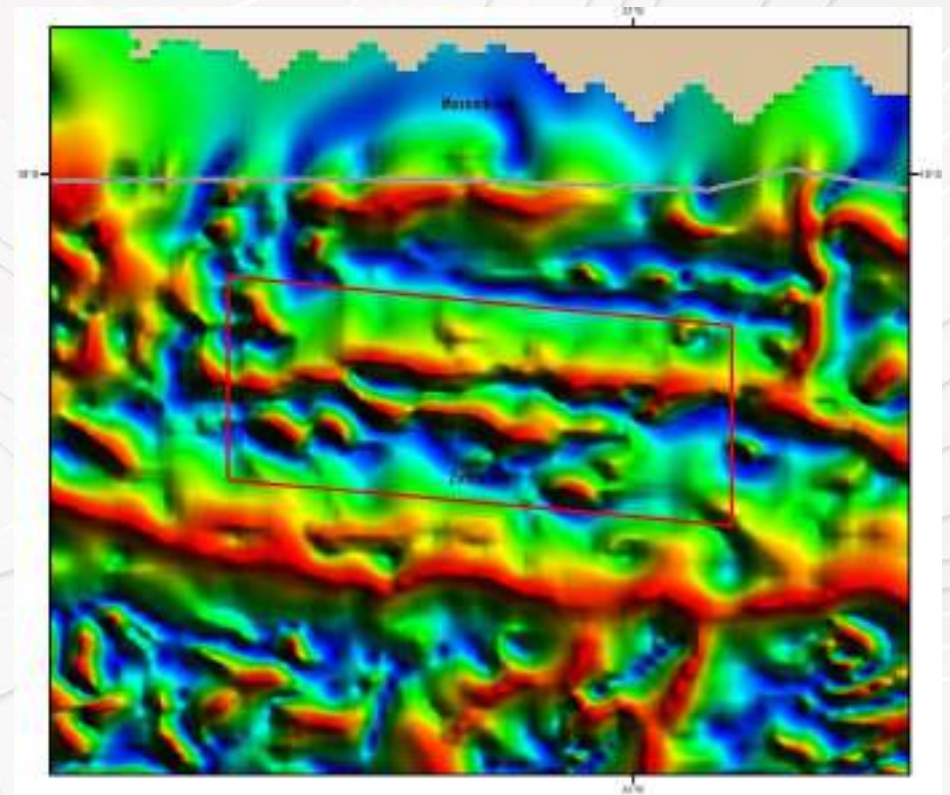
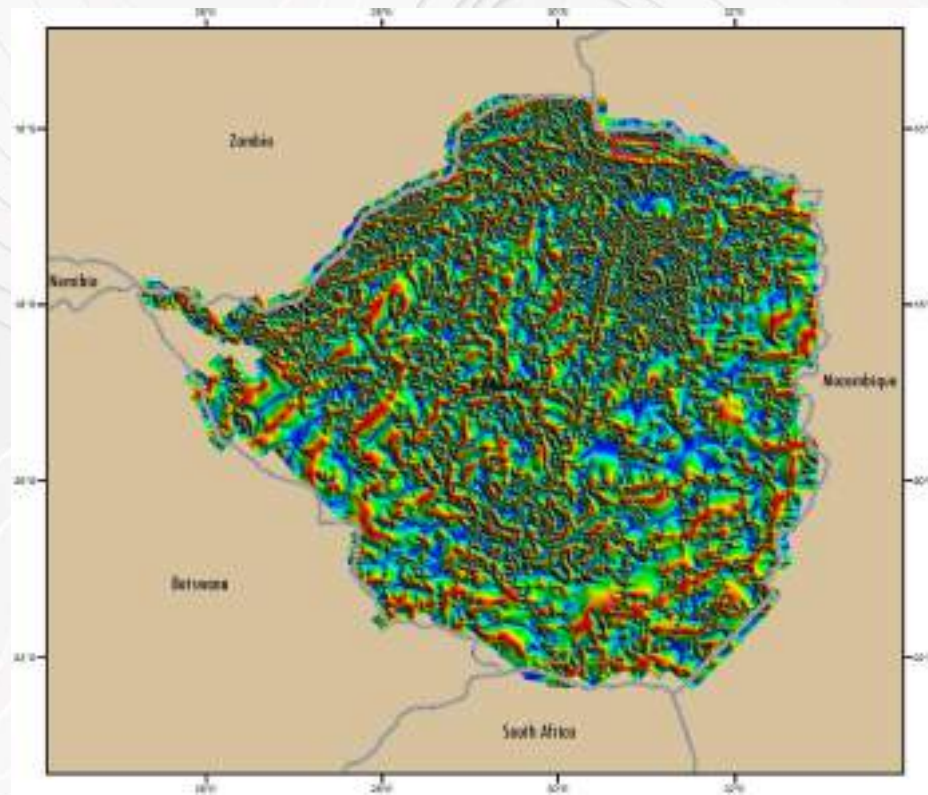
This is a measure of the lateral change in the gravity; it represents the maximum horizontal change in the gravity at a point on the grid. The method is typically used to identify the location of faults or significant lateral compositional boundaries.

Final Bouguer Grid – Tilt derivative



The Tilt derivative (Tilt) is a combination of the first vertical derivative and the total horizontal derivative. It is the arctangent of the vertical derivative divided by the total horizontal derivative. The result is similar to the vertical derivative but tends to equalise the amplitude output and hence highlight more subtle anomalies.

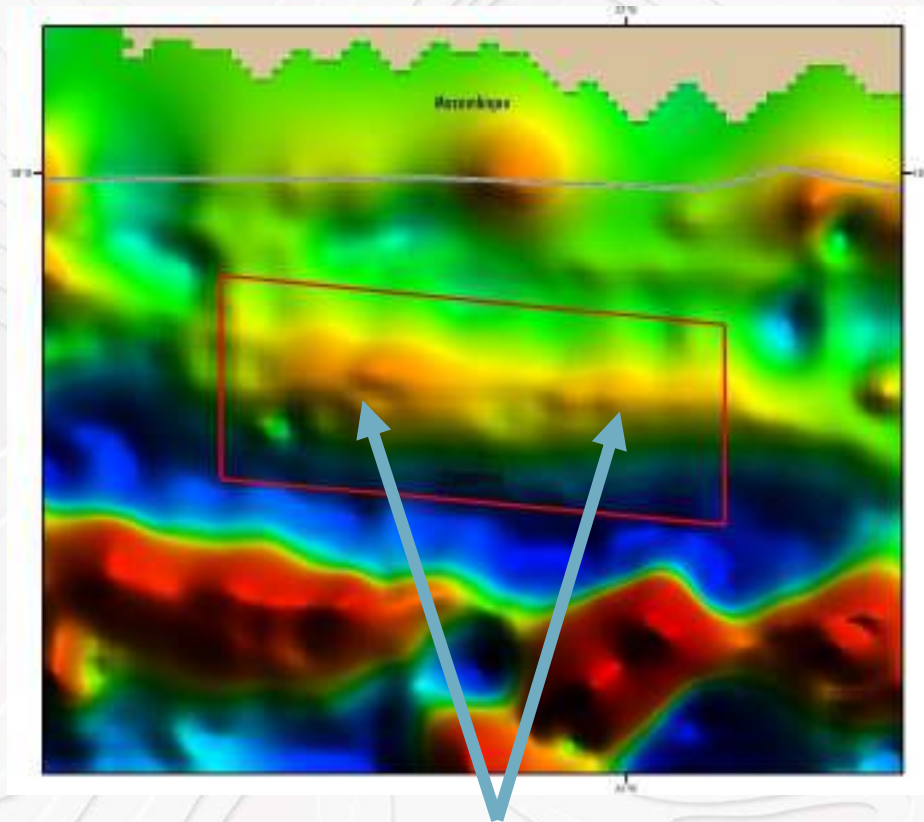
Final Bouguer Grid – Tilt derivative of the THD



The Tilt derivative of the THD is a useful way of highlighting the subtle features in the total horizontal gradient, effectively acting as an image processing tool. The tilt derivative operates in a similar way to an automatic gain control (AGC). The result of applying this to the THD, is to highlight more subtle lineaments that may otherwise be obscured by larger features and therefore not visible in the final map of THD alone.

Early observations of subtle features appearing

40 km high pass filter

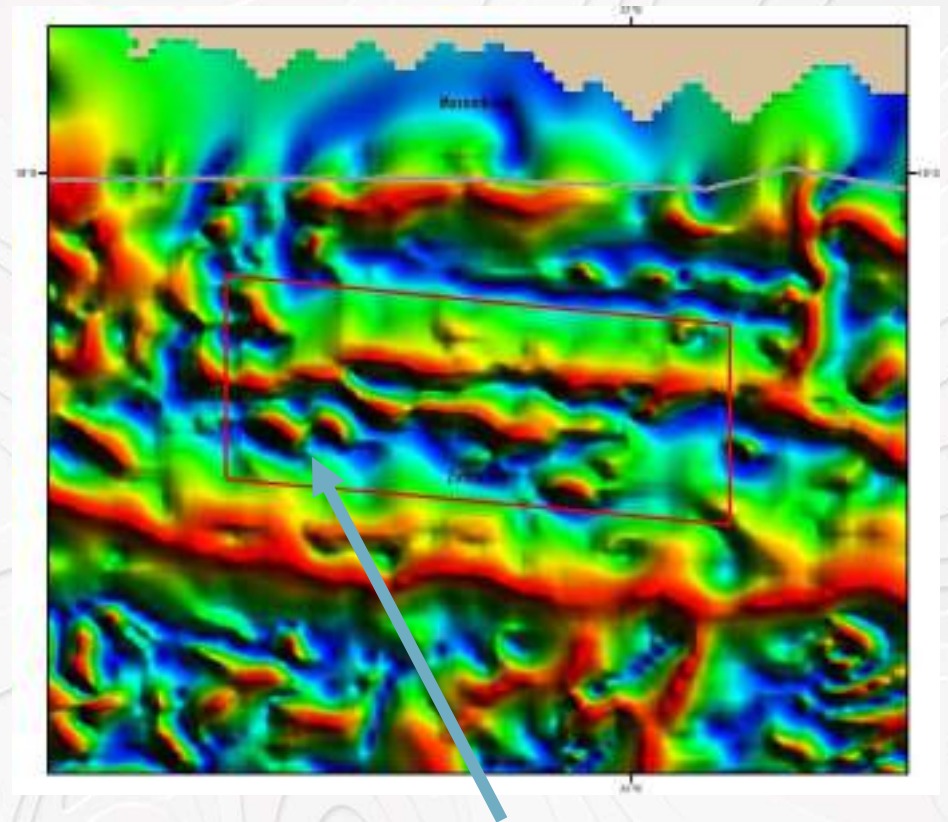


Definitely 1 (but likely 2)
instance(s) of shallow basement
(ESE-WNW trend) through the
block



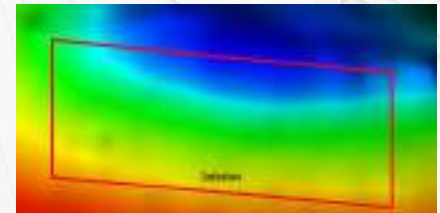
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Tilt of the THD



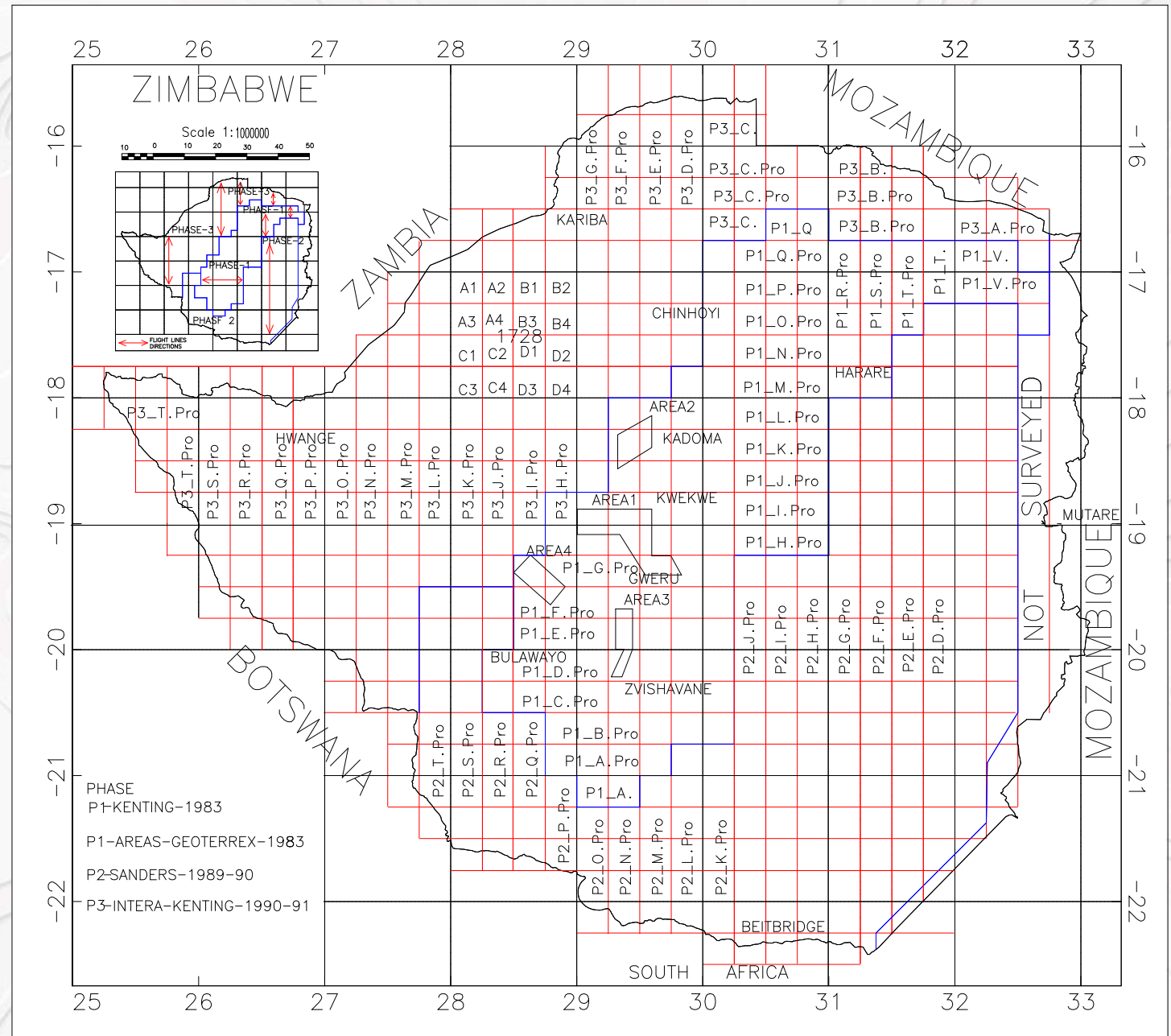
Subtle NW-SE features enhanced
within the southwest of the block

Neither of these are easily
visible in the full data:

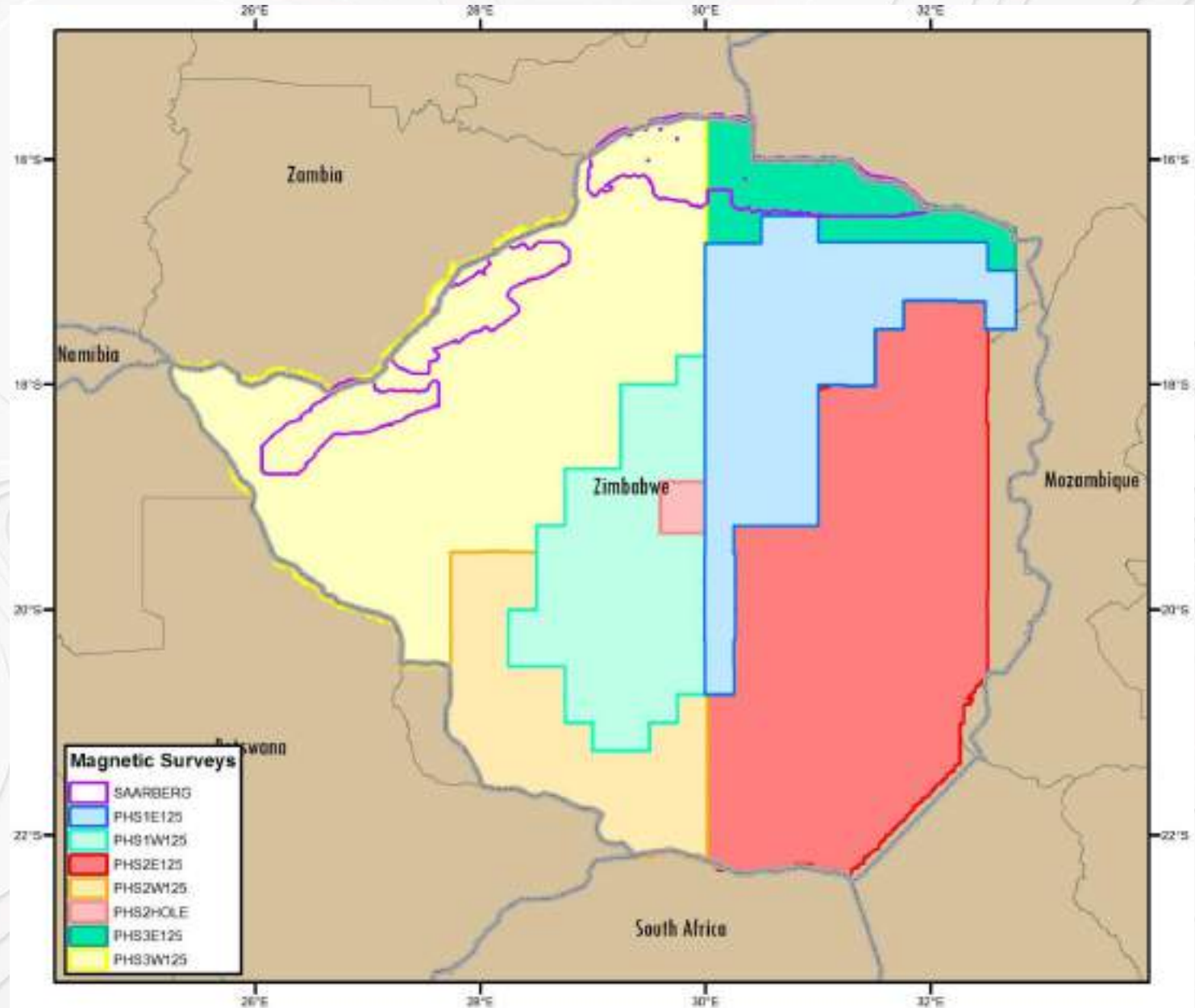


The background of the slide is a topographic map with contour lines in shades of gray and pink, creating a wavy, abstract pattern. The text "Gravity Data" is centered in a blue serif font.

Gravity Data

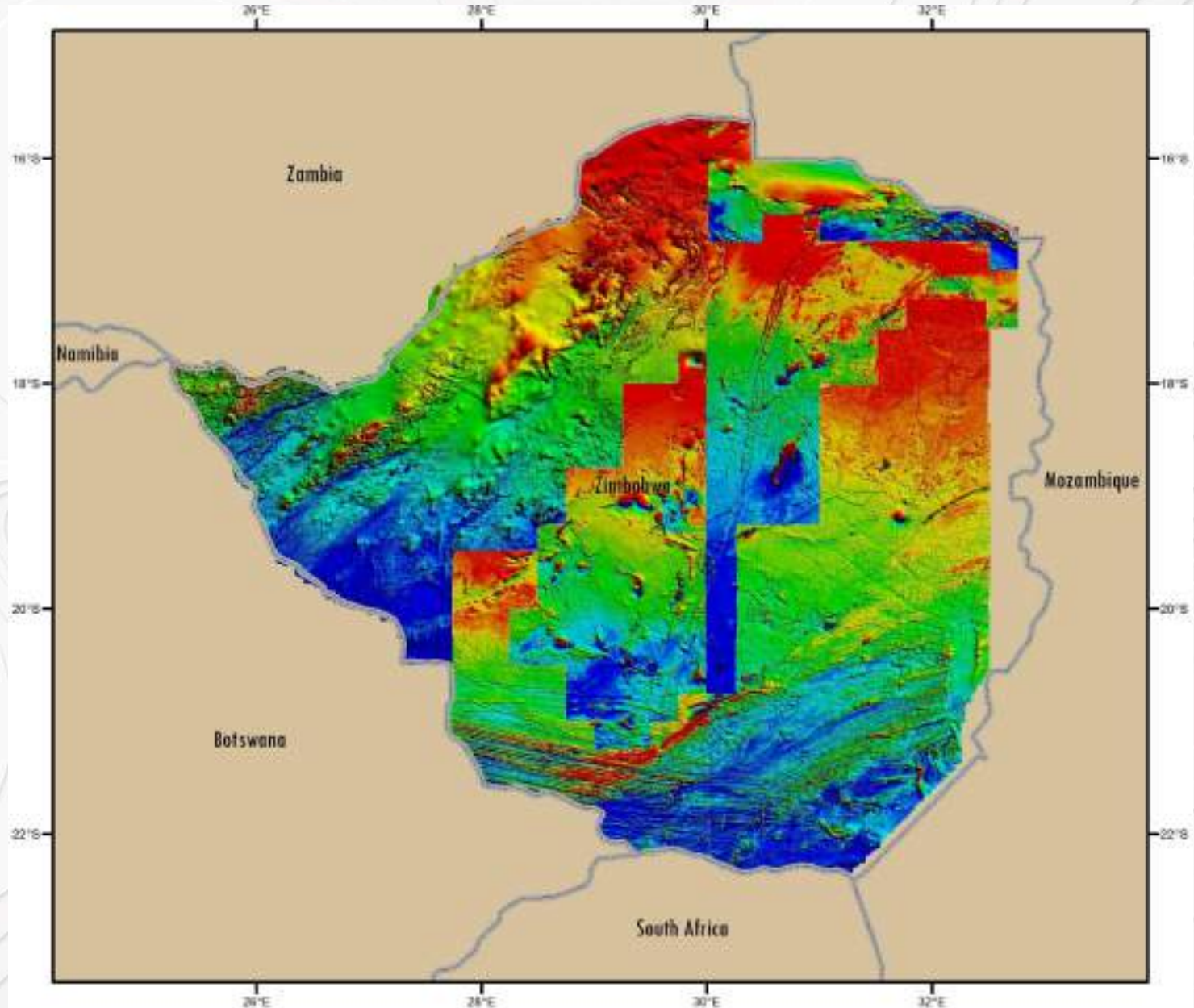


Magnetic Data Supplied to Getech (Overview)

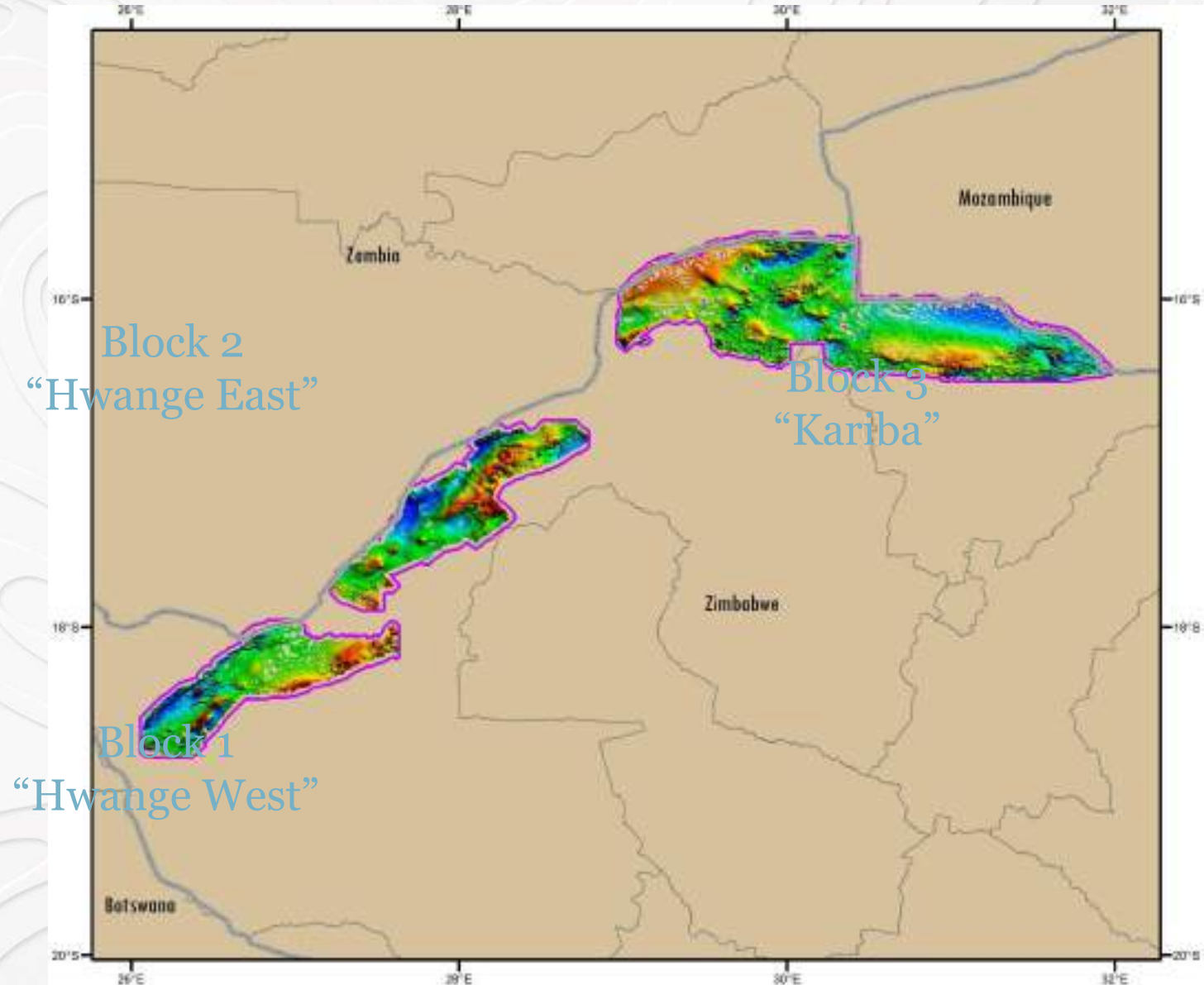


Magnetic Data Supplied to Getech (Phases 1 to 3)

Unlinked surveys which appear to each contain a regional N-S trend (IGRF?) which may need removing.

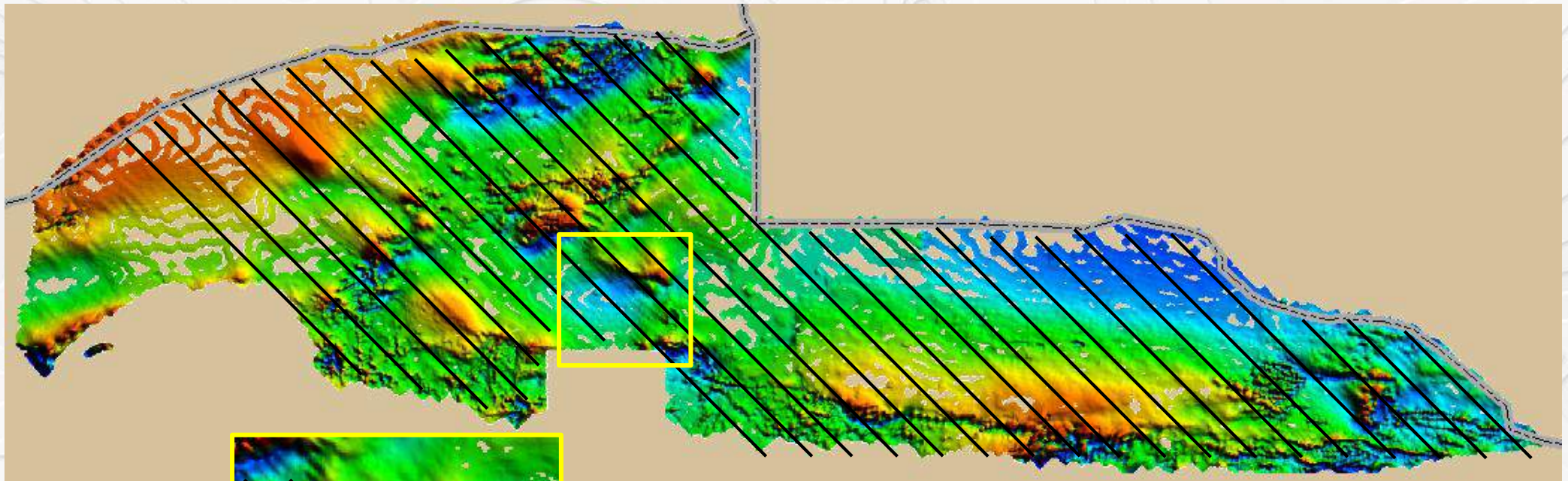


Magnetic Data Supplied to Getech ("SAARBERG")

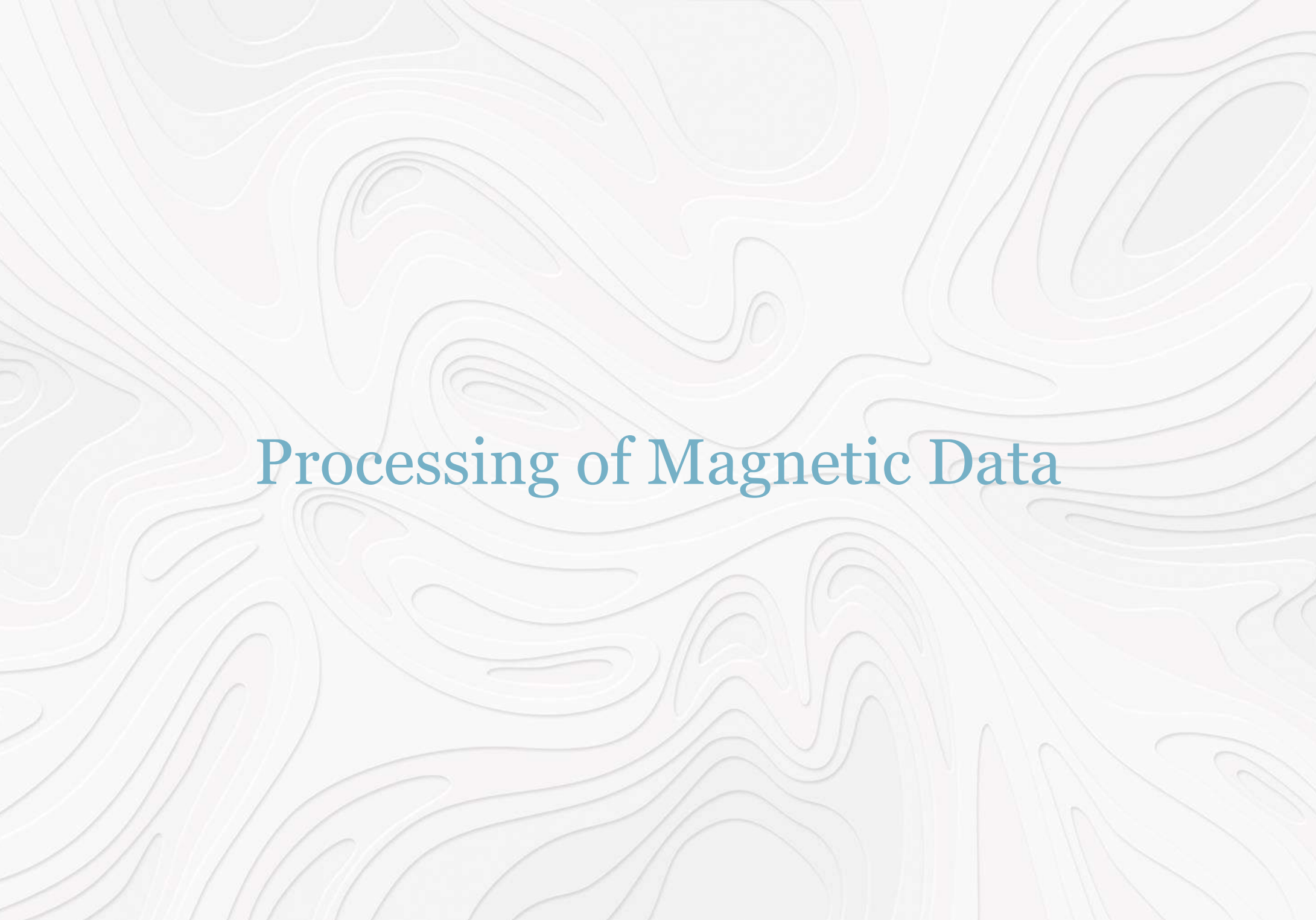


“SAARBERG” Data Comments

- Each of the 3 surveys exhibit NW-SE line-noise within the gridded data as well as map-sheet ‘busts’



Unfortunately, the original flight line locations are unavailable. Line-levelling is thus problematic.

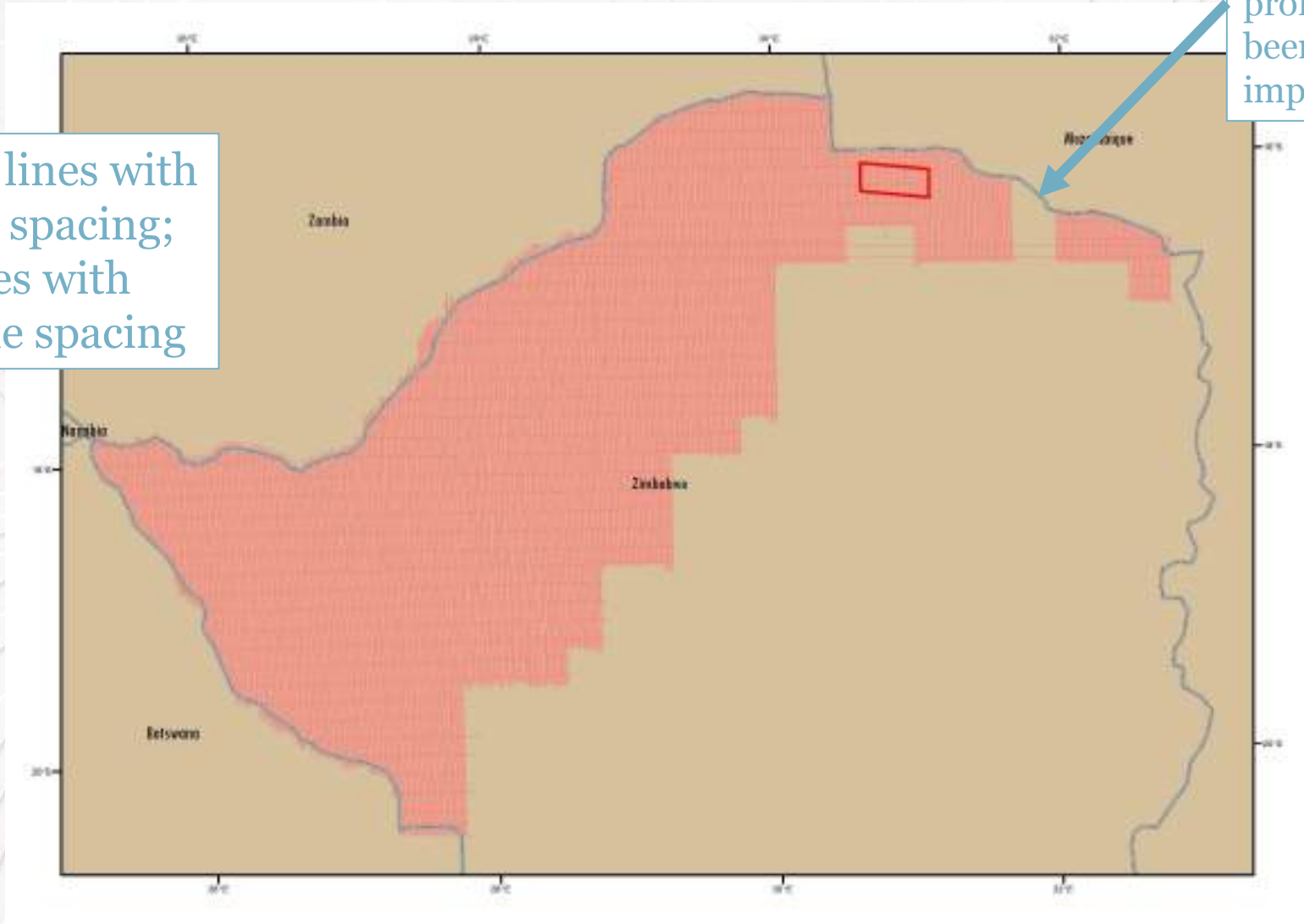
The background of the slide is a topographic map with contour lines in shades of gray and pink, creating a wavy, abstract pattern.

Processing of Magnetic Data

Processing Magnetic Data

N-S profile lines with
c. 1 km line spacing;
E-W tie lines with
c. 14 km line spacing

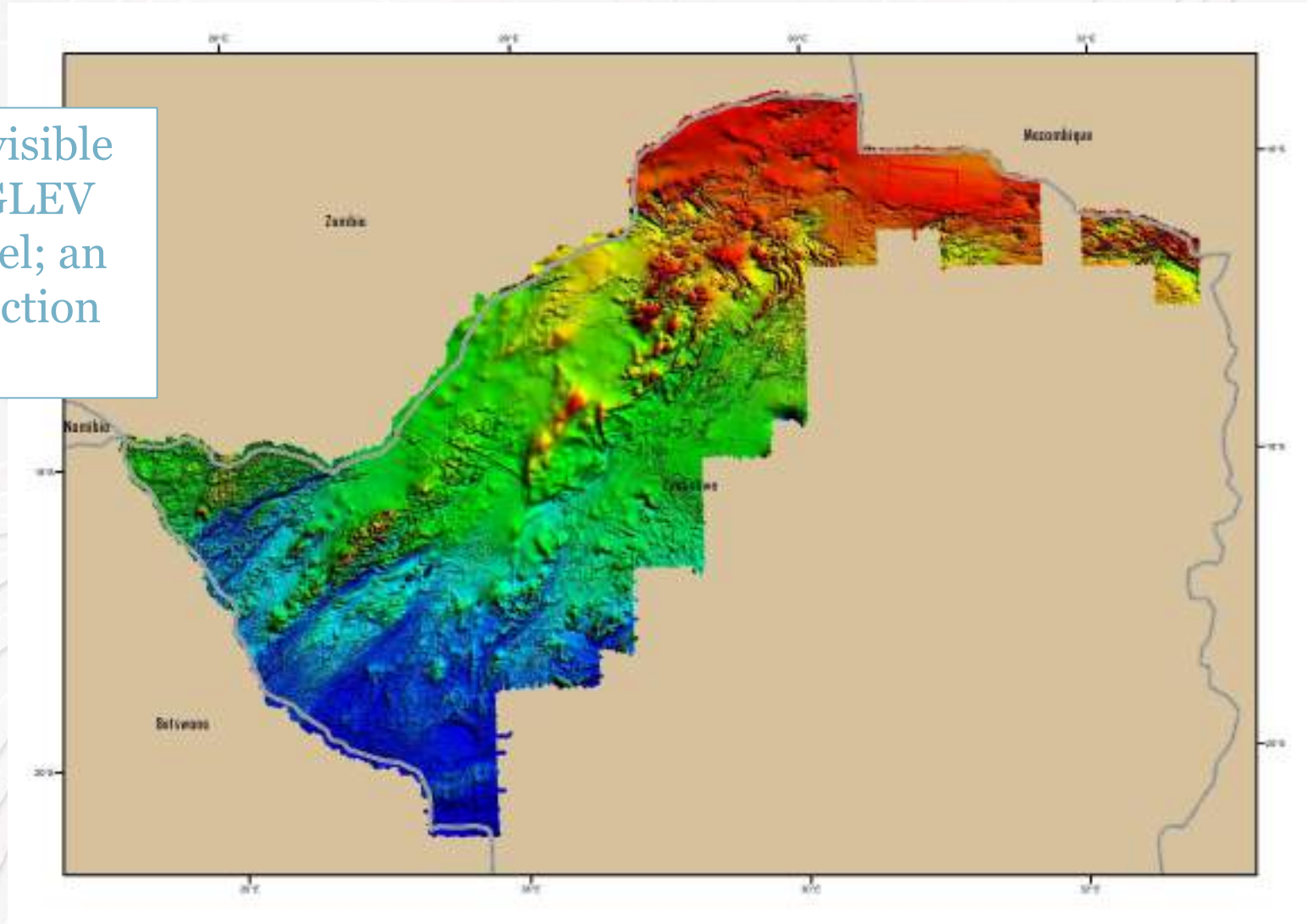
Some line data
missing after the
profile data has
been read and
imported



Due to the time needed to process the SAARBERG survey(s), it was decided to process the regional magnetic data – specifically the Phase 3 data which covered the area of interest (SG4571)

Processing Magnetic Data

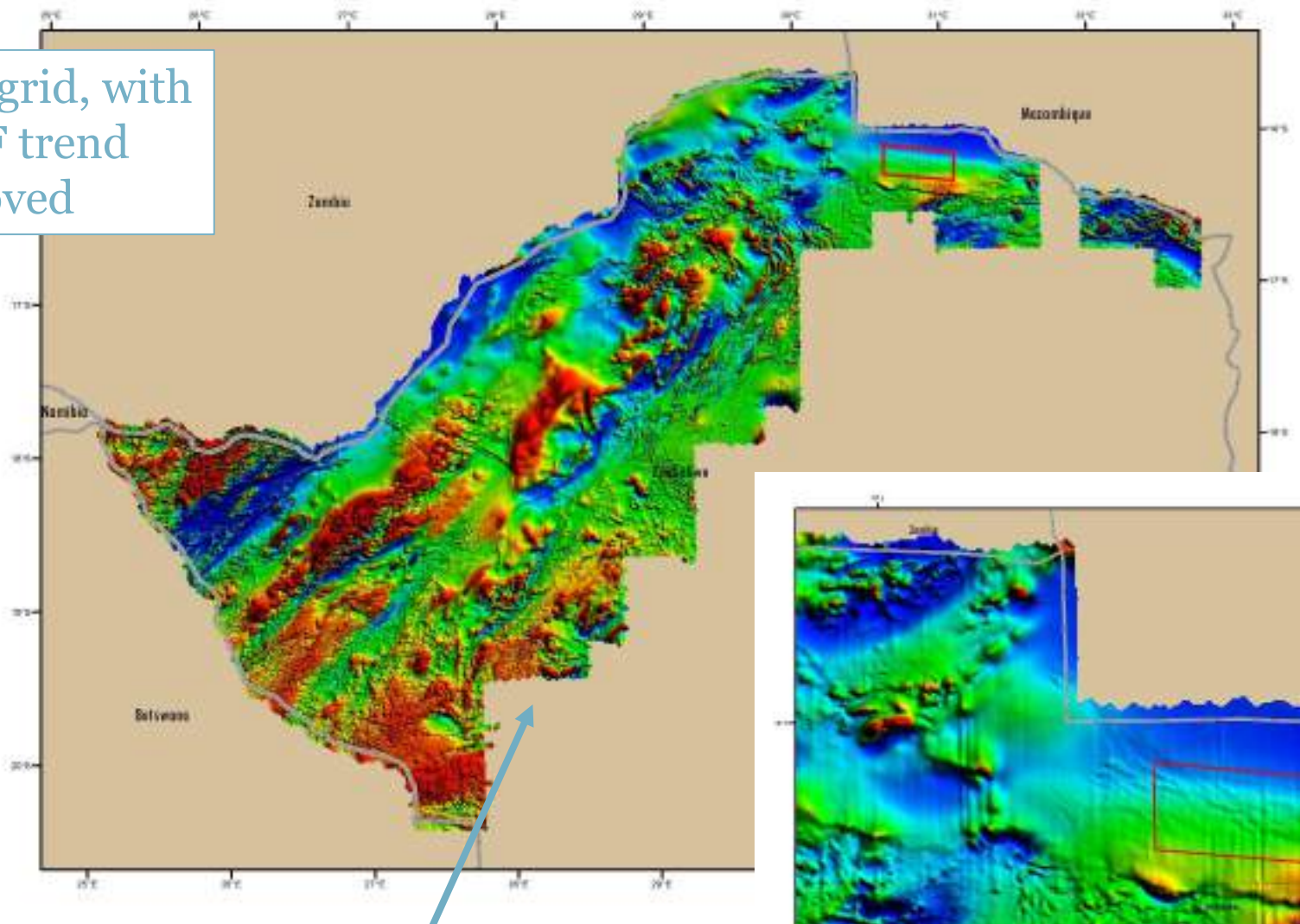
N-S trend visible in the MAGLEV data channel; an IGRF correction is required



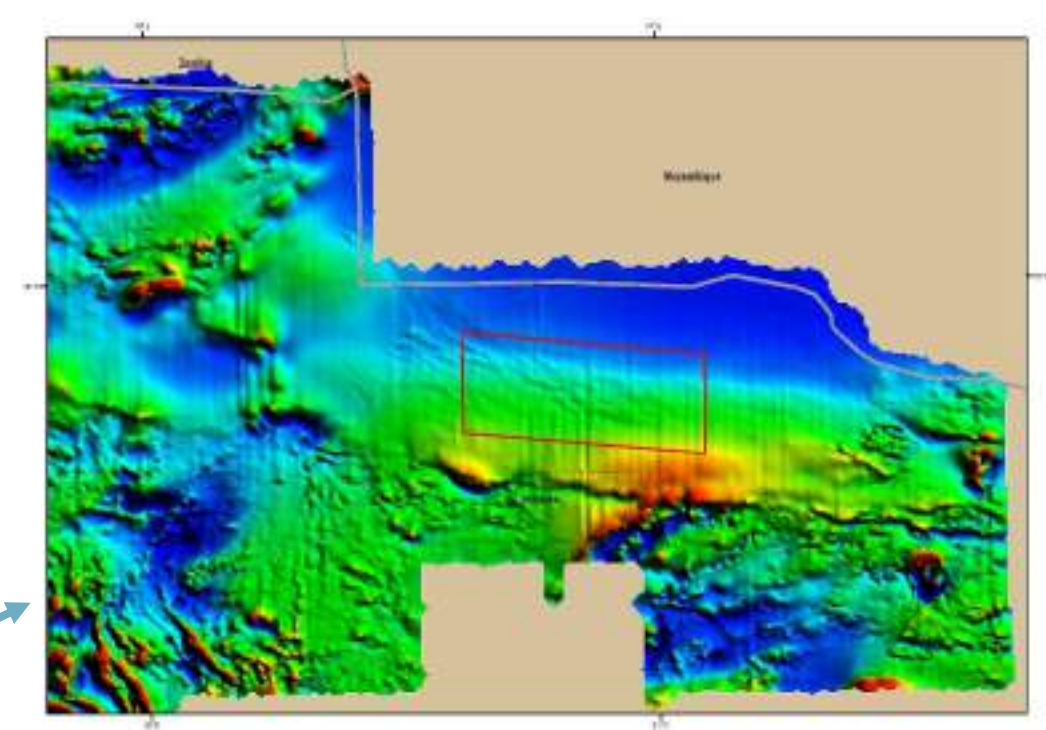
getech

Processing Magnetic Data

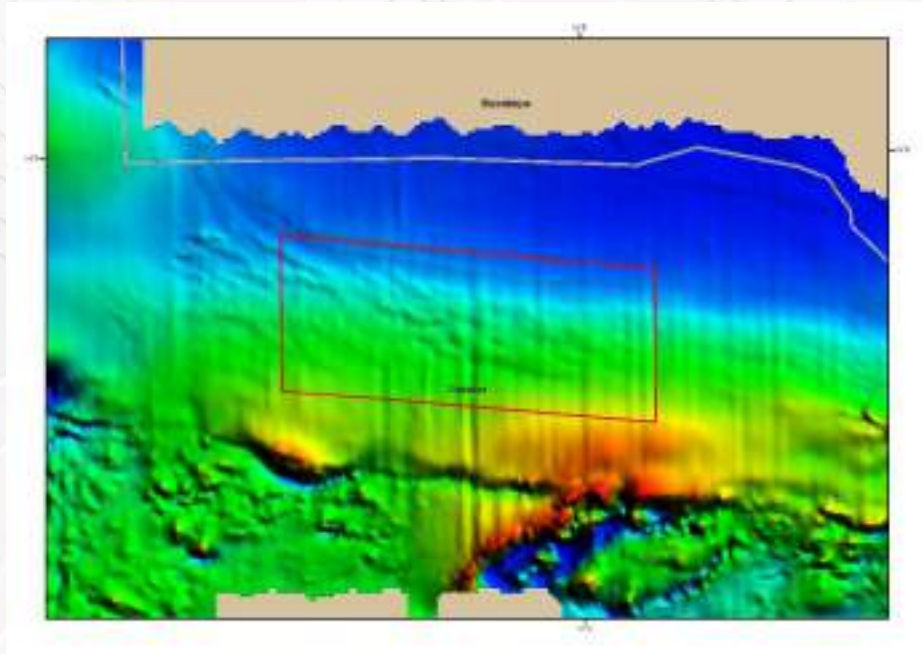
TMI grid, with
IGRF trend
removed



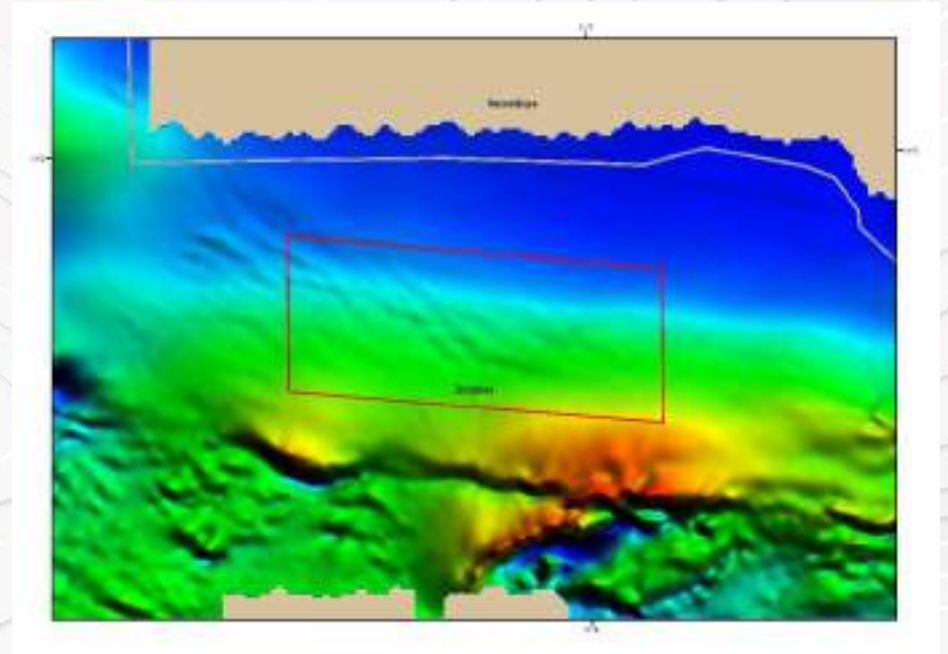
Line noise (N-S and E-W)
still observed within the
gridded data



Processing Magnetic Data



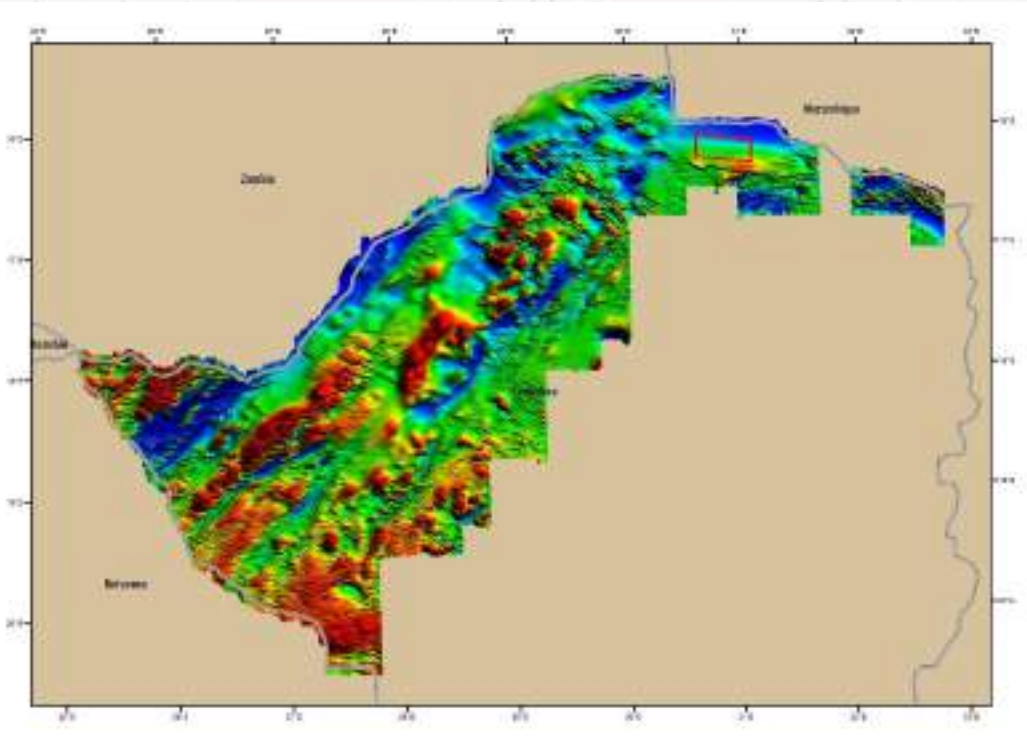
TMI grid



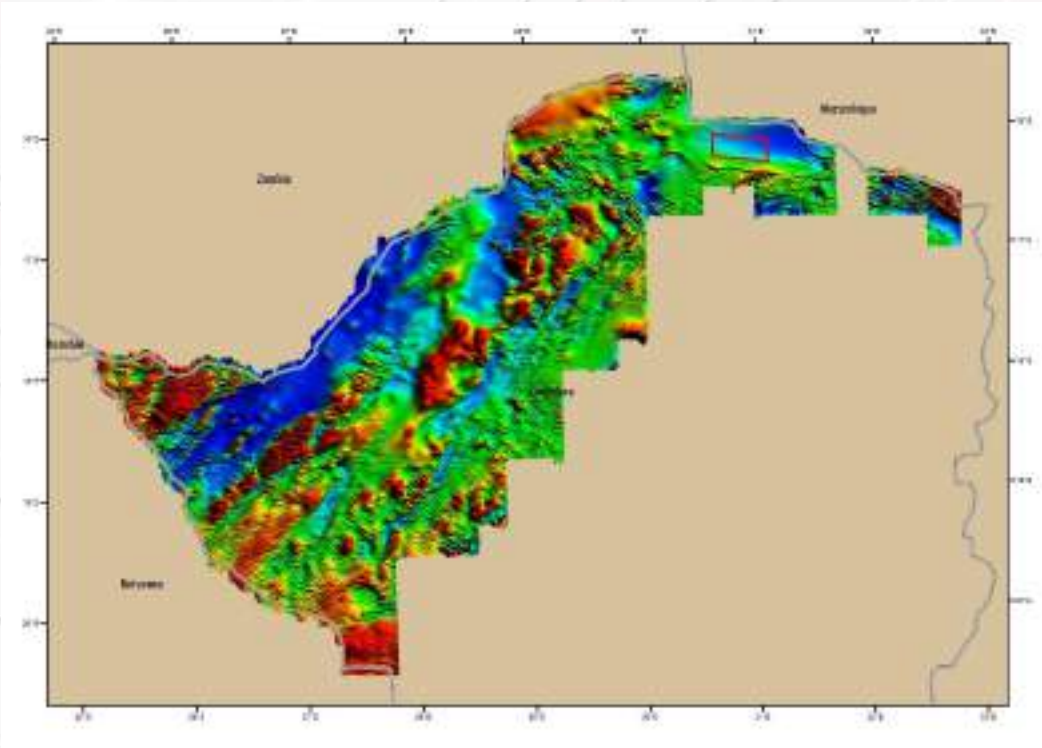
TMI grid, after 3 passes
of micro-levelling

Processing Magnetic Data

Inc. = -57.7
Dec. = -8.1



TMI grid

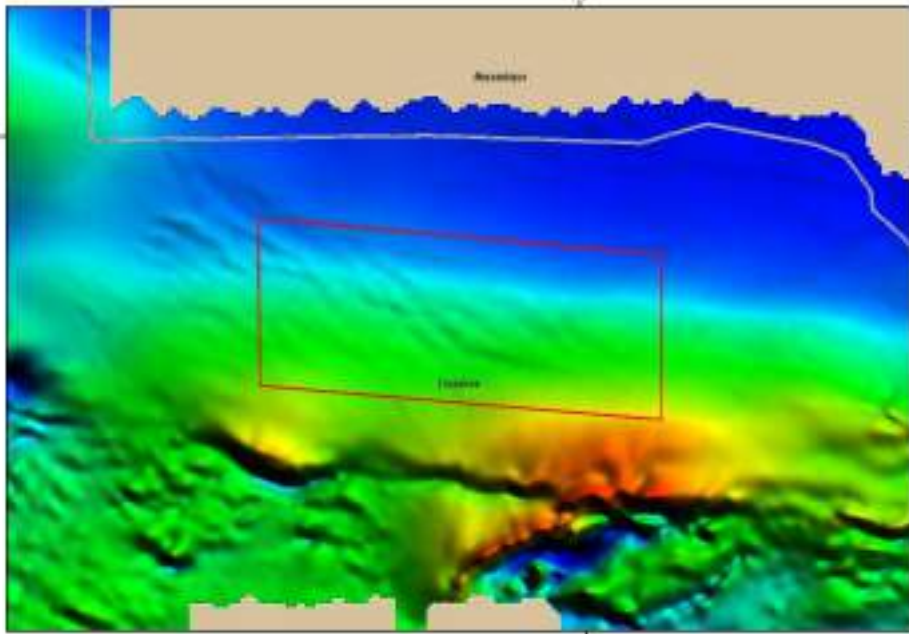


RTP grid

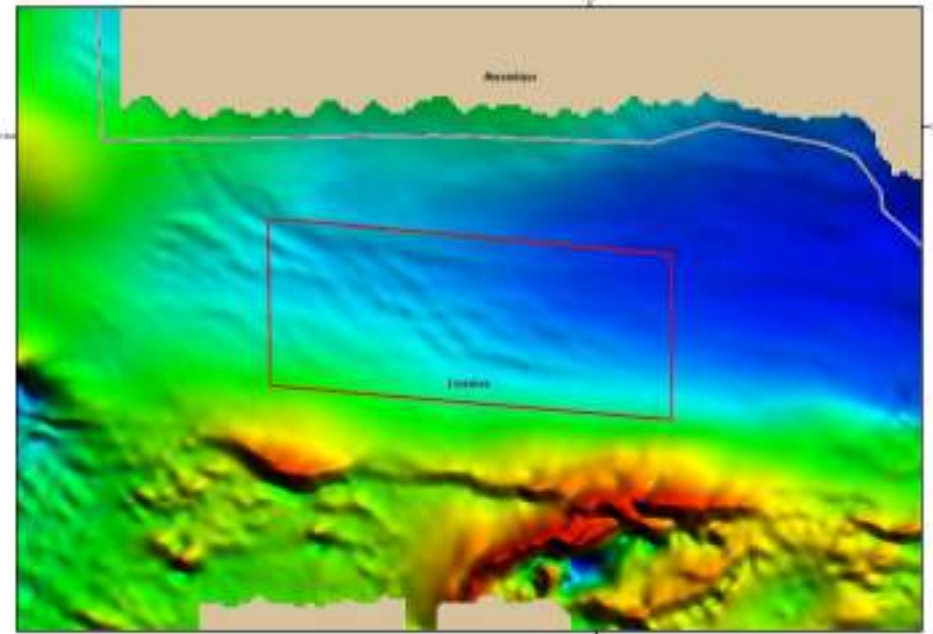
RTP transformation applied to the data, in order to locate the anomalies centrally over the causative bodies. From this point, derivatives and filters can be applied.

Processing Magnetic Data

Inc. = -57.7
Dec. = -8.1

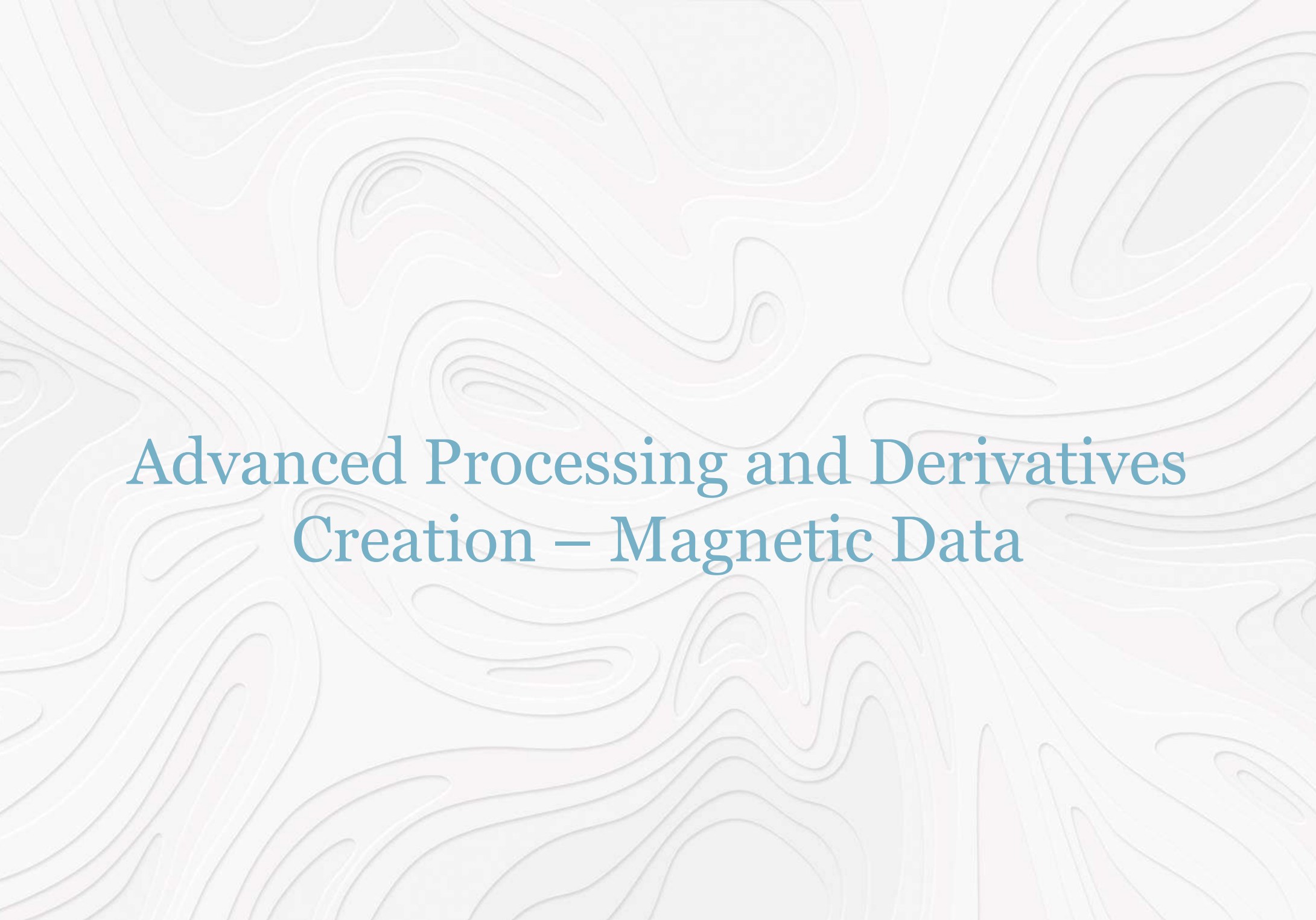


TMI grid



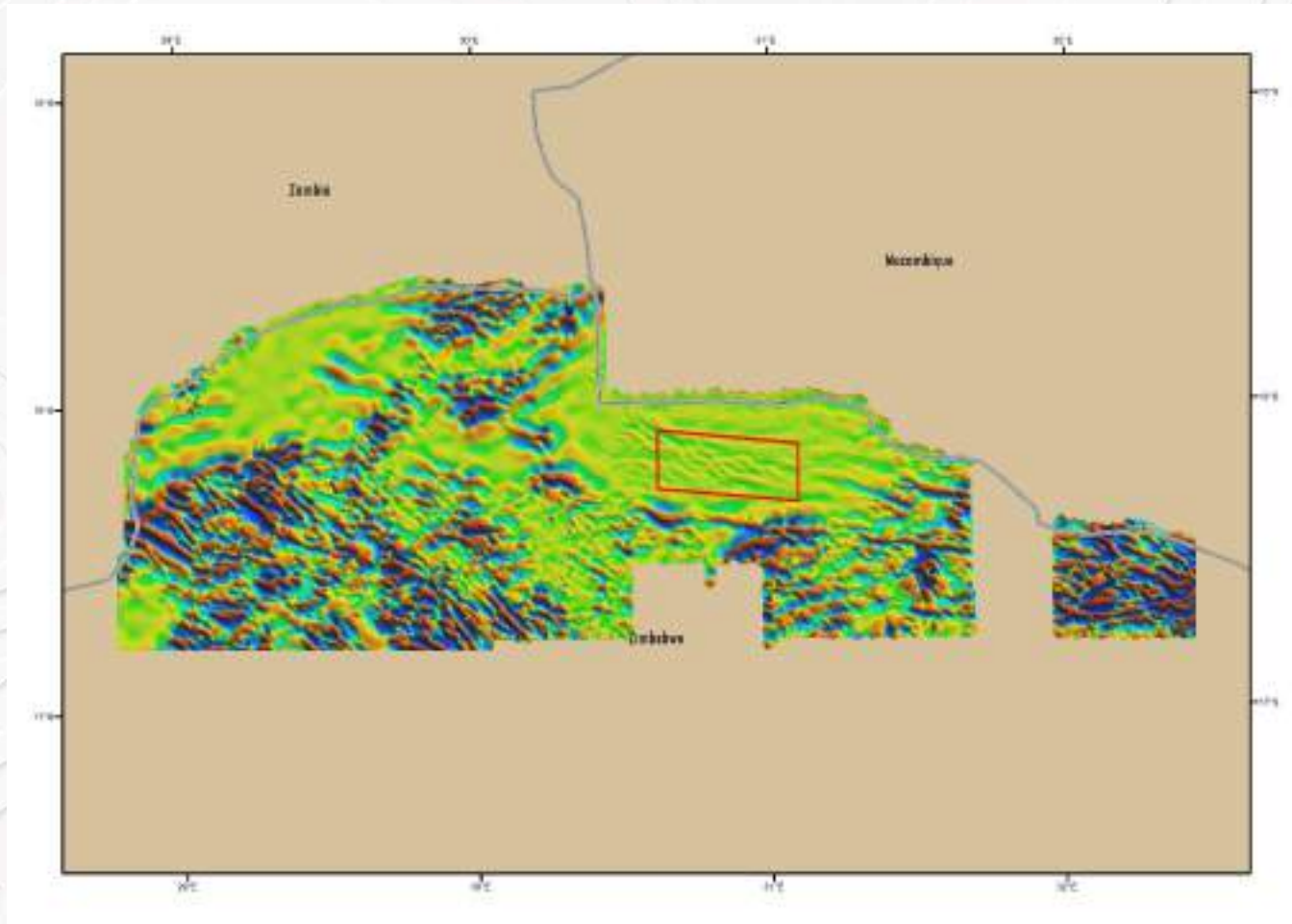
RTP grid

RTP transformation applied to the data, in order to locate the anomalies centrally over the causative bodies. From this point, derivatives and filters can be applied.



Advanced Processing and Derivatives Creation – Magnetic Data

Final RTP Grid – 10 km high pass filter

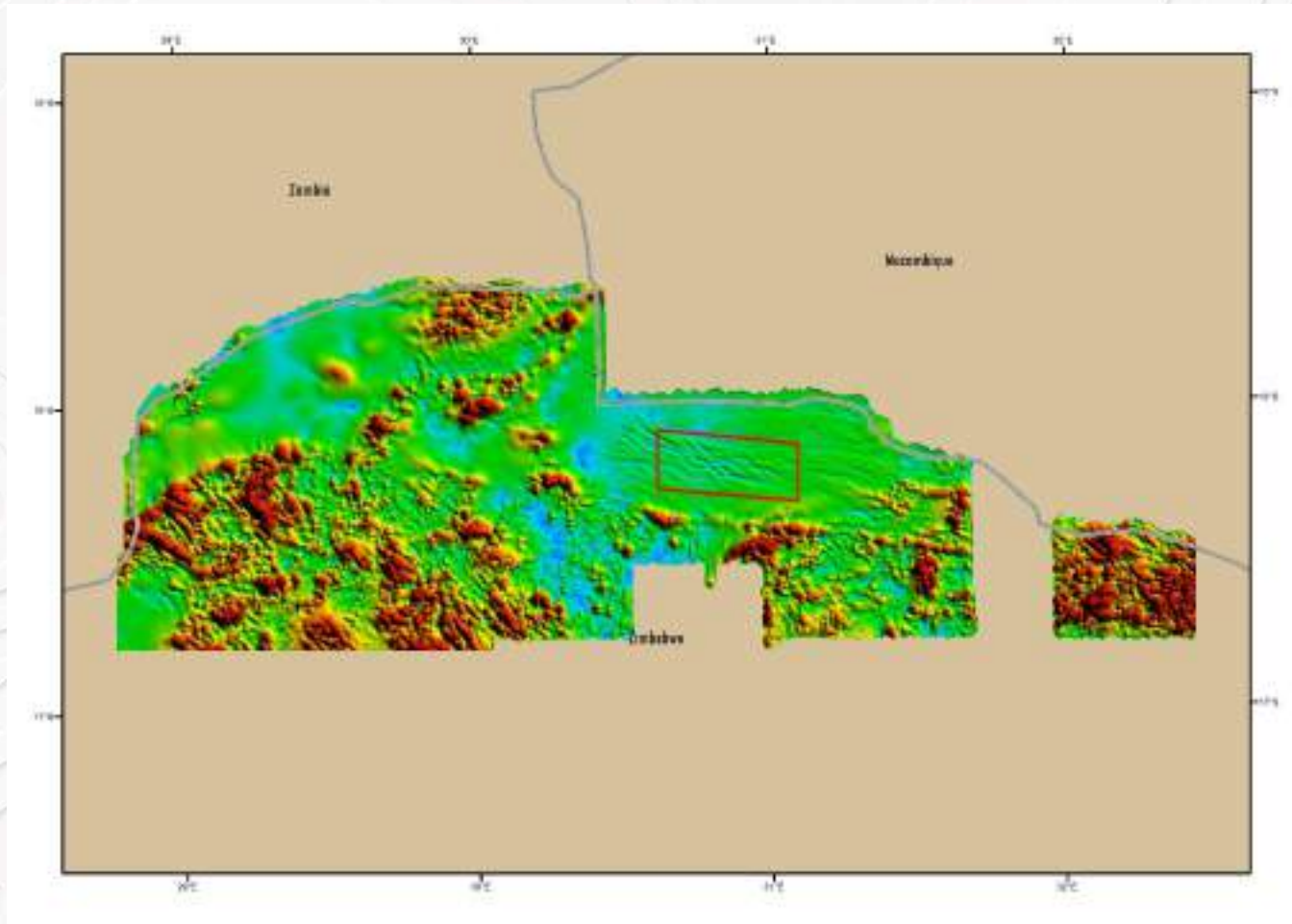


The 10 km high pass filter is calculated using a Butterworth filter (order 4). This removes a long-wavelength regional field, allowing more detailed interpretation of shallow structures.



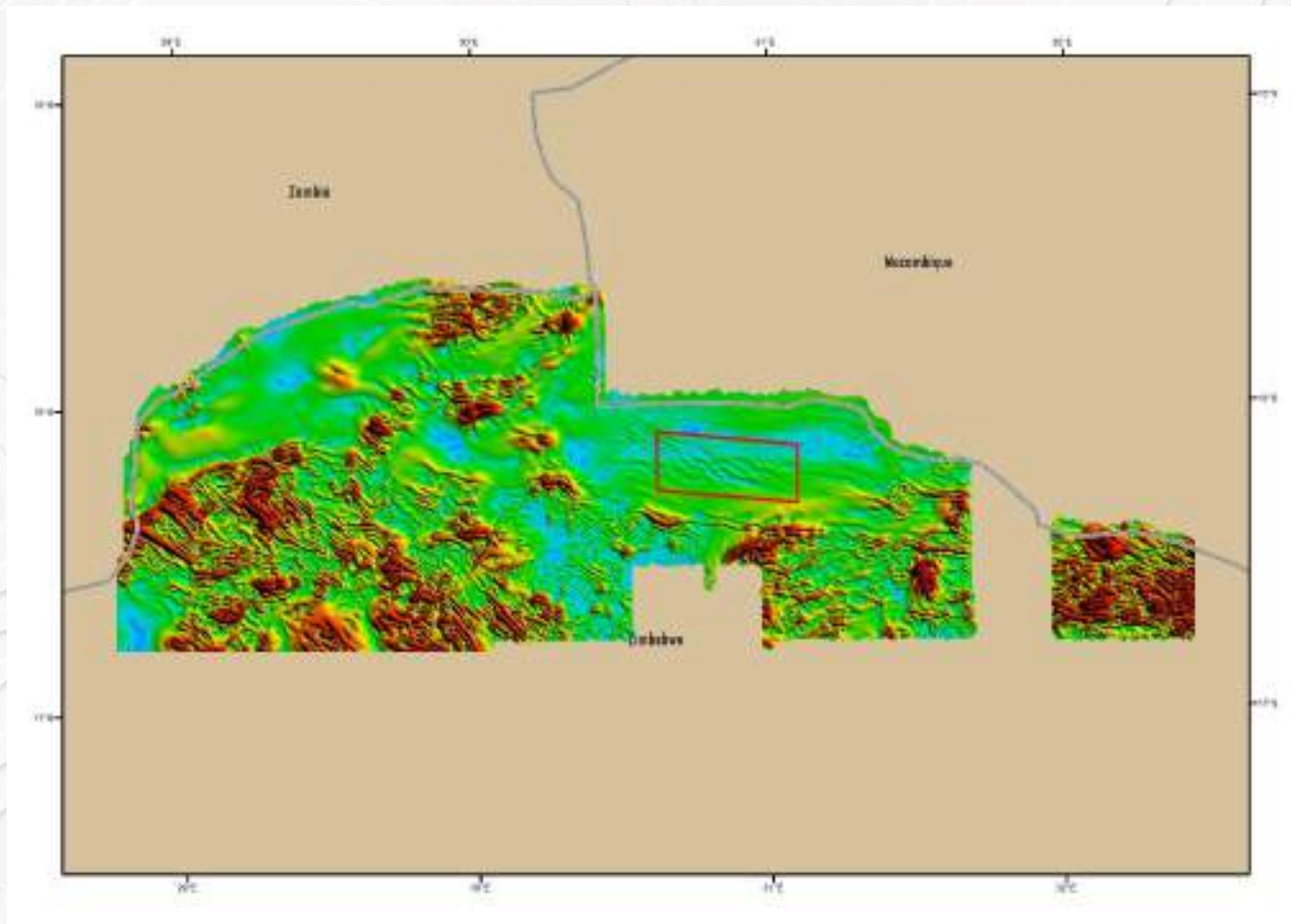
getech

Final RTP Grid – Analytic Signal



The Analytical Signal has maxima over the top of contacts but contains more noise than the first vertical derivative. Consisting of only positive values, it can be used to give depth estimates to causal bodies using the Half Width at Half Maximum estimation method.

Final RTP Grid – Total horizontal derivative

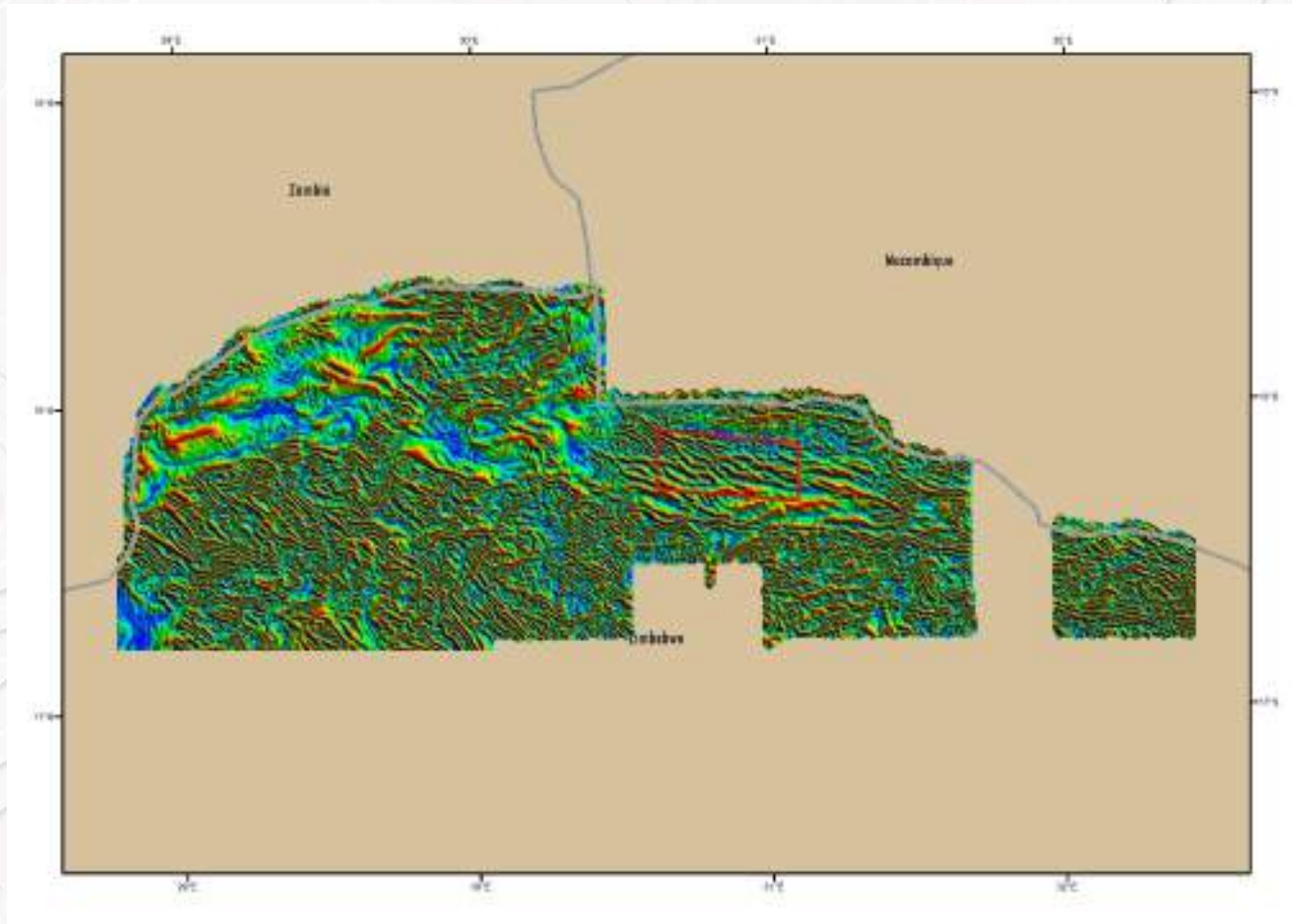


This is a measure of the lateral change in the gravity; it represents the maximum horizontal change in the gravity at a point on the grid. The method is typically used to identify the location of faults or significant lateral compositional boundaries.



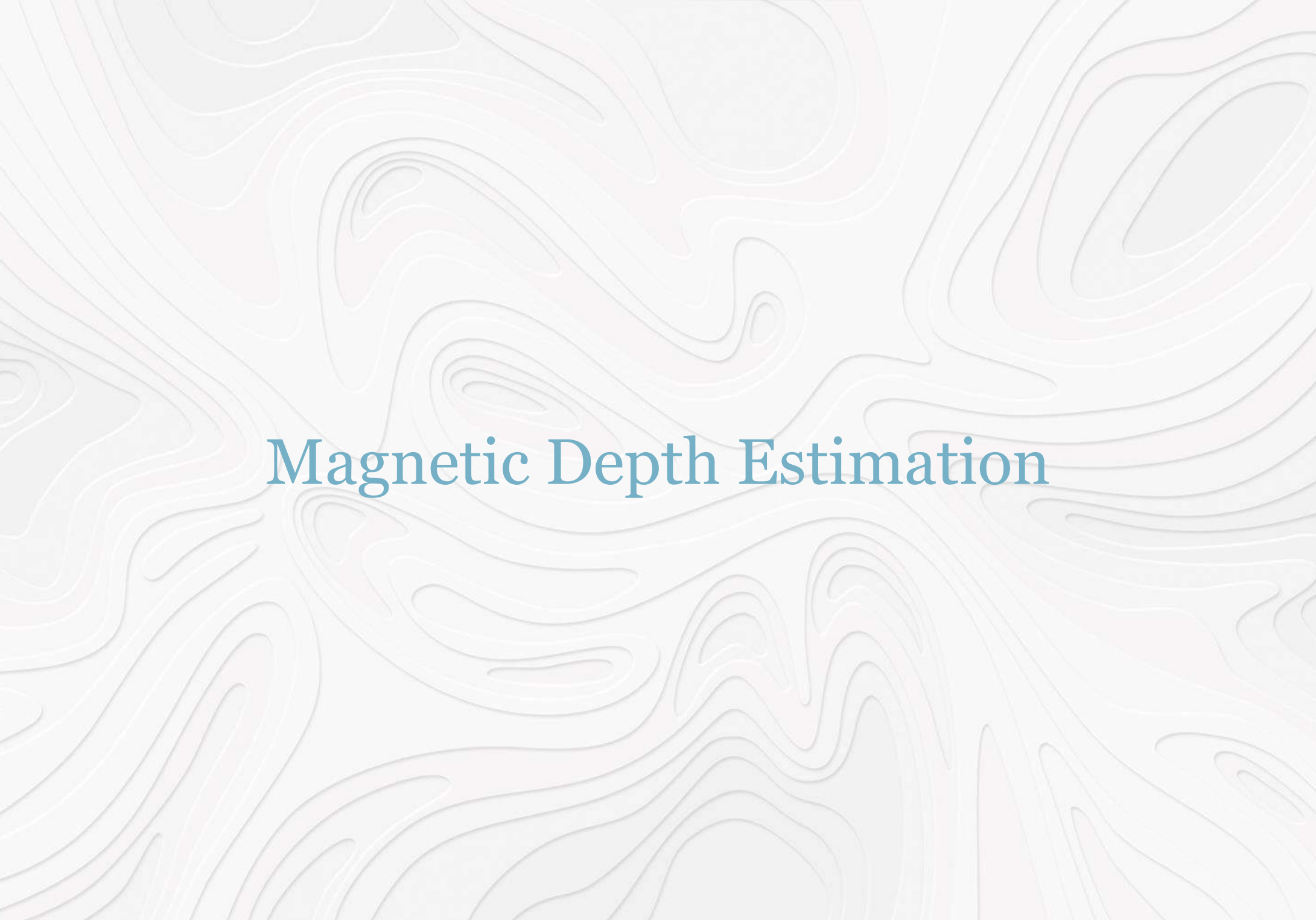
getech

Final RTP Grid – Tilt derivative of the THD



The Tilt derivative of the THD is a useful way of highlighting the subtle features in the total horizontal gradient, effectively acting as an image processing tool. The tilt derivative operates in a similar way to an automatic gain control (AGC). The result of applying this to the THD, is to highlight more subtle lineaments that may otherwise be obscured by larger features and therefore not visible in the final map of THD alone.



The background of the slide is a topographic map with contour lines. The lines are thin and light gray, forming a complex, wavy pattern across the entire surface. The colors are muted, with shades of light gray, off-white, and very pale pink or rose gold, giving it a subtle, textured appearance.

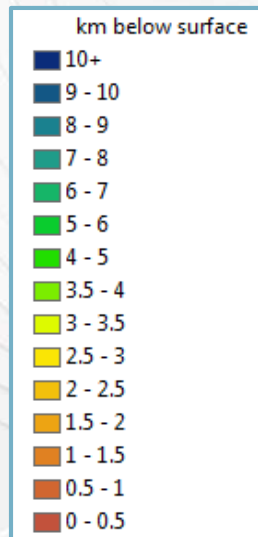
Magnetic Depth Estimation

Magnetic Depth Estimation

Two magnetic depth estimation procedures were employed

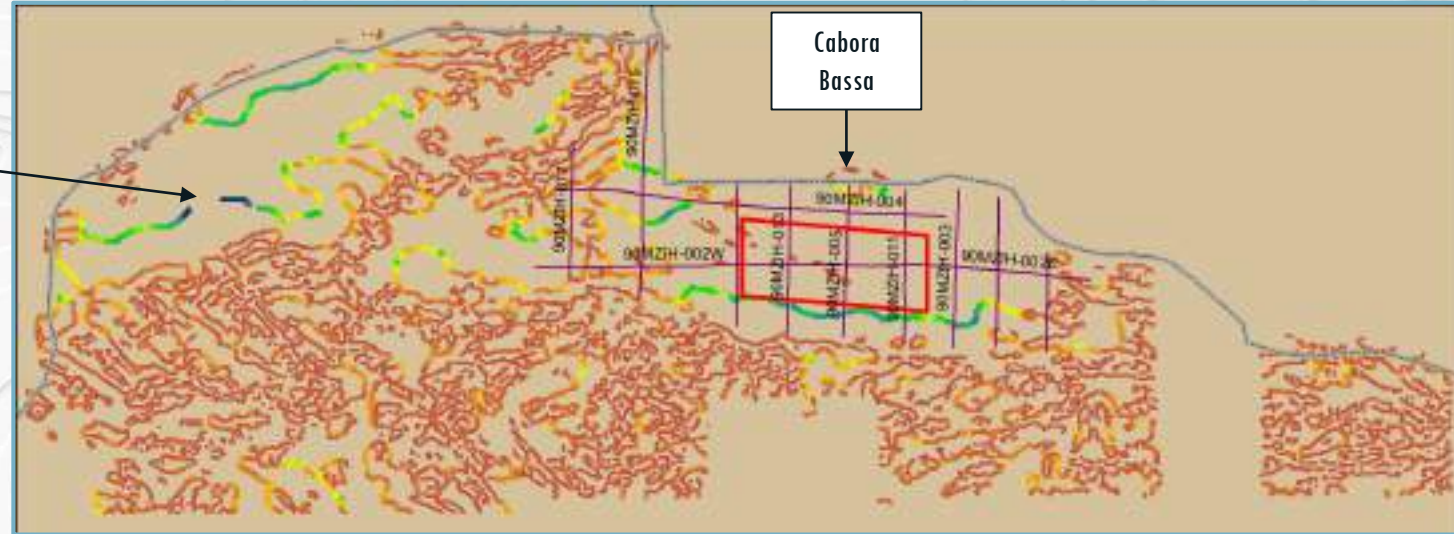
- Tilt Depth
 - Lower resolution, less noisy
- SPI
 - Higher resolution, can be noisier

Tilt Depth

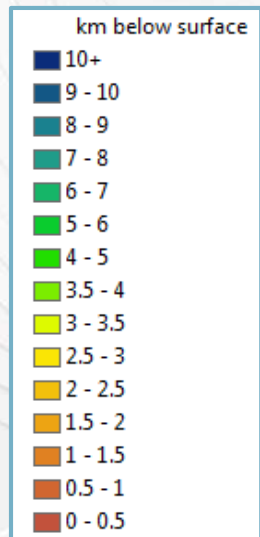


Mana Pools

Cabora
Bassa

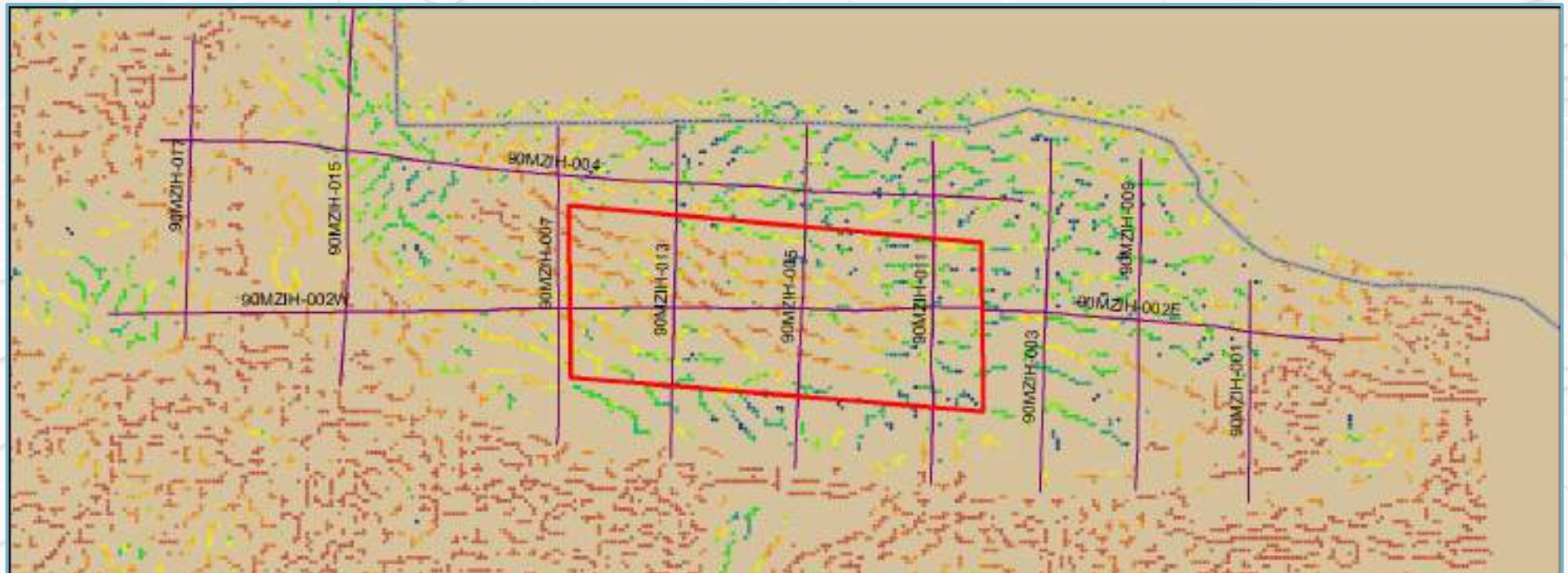


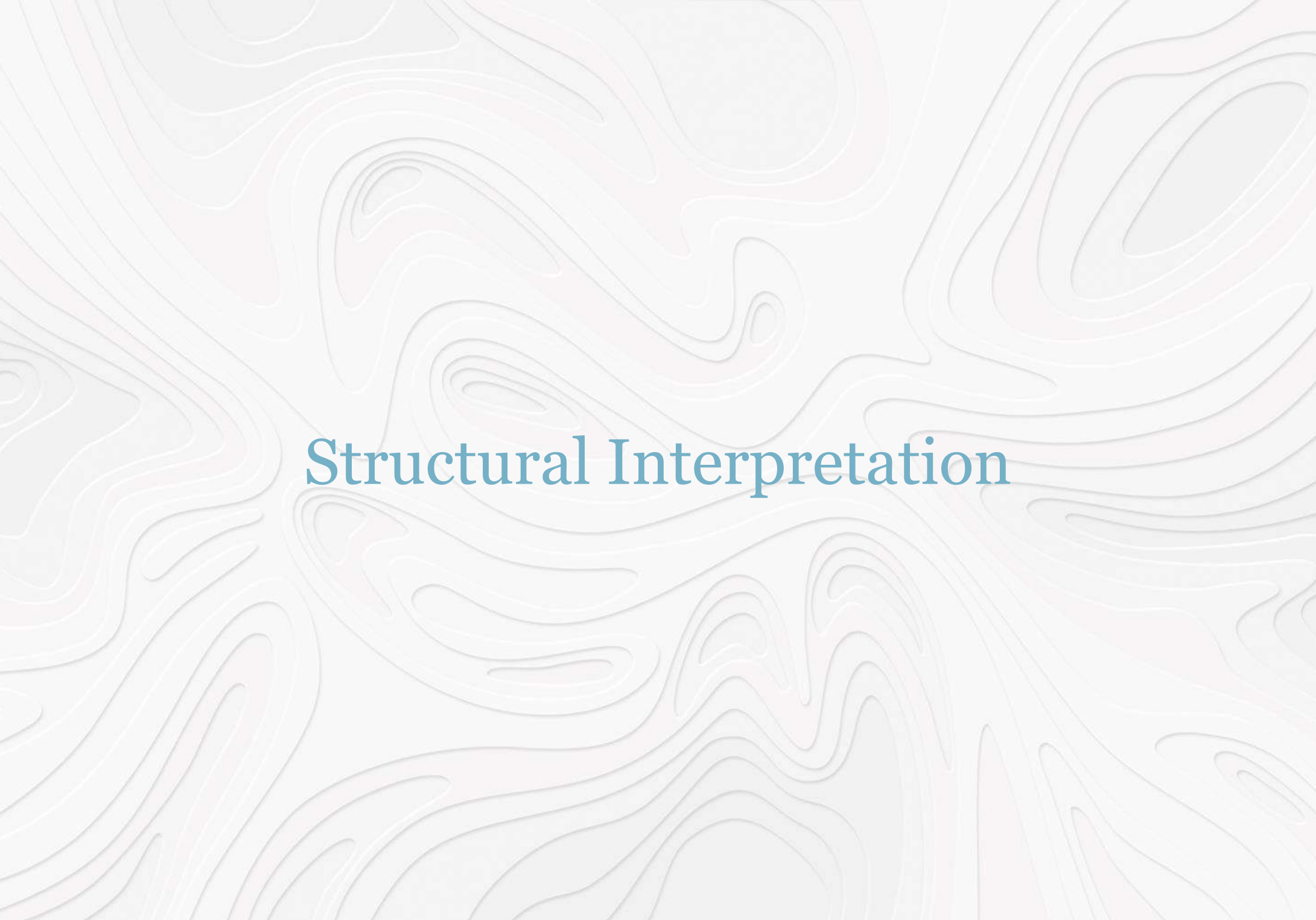
SPI



Mana Pools

Cabora
Bassa



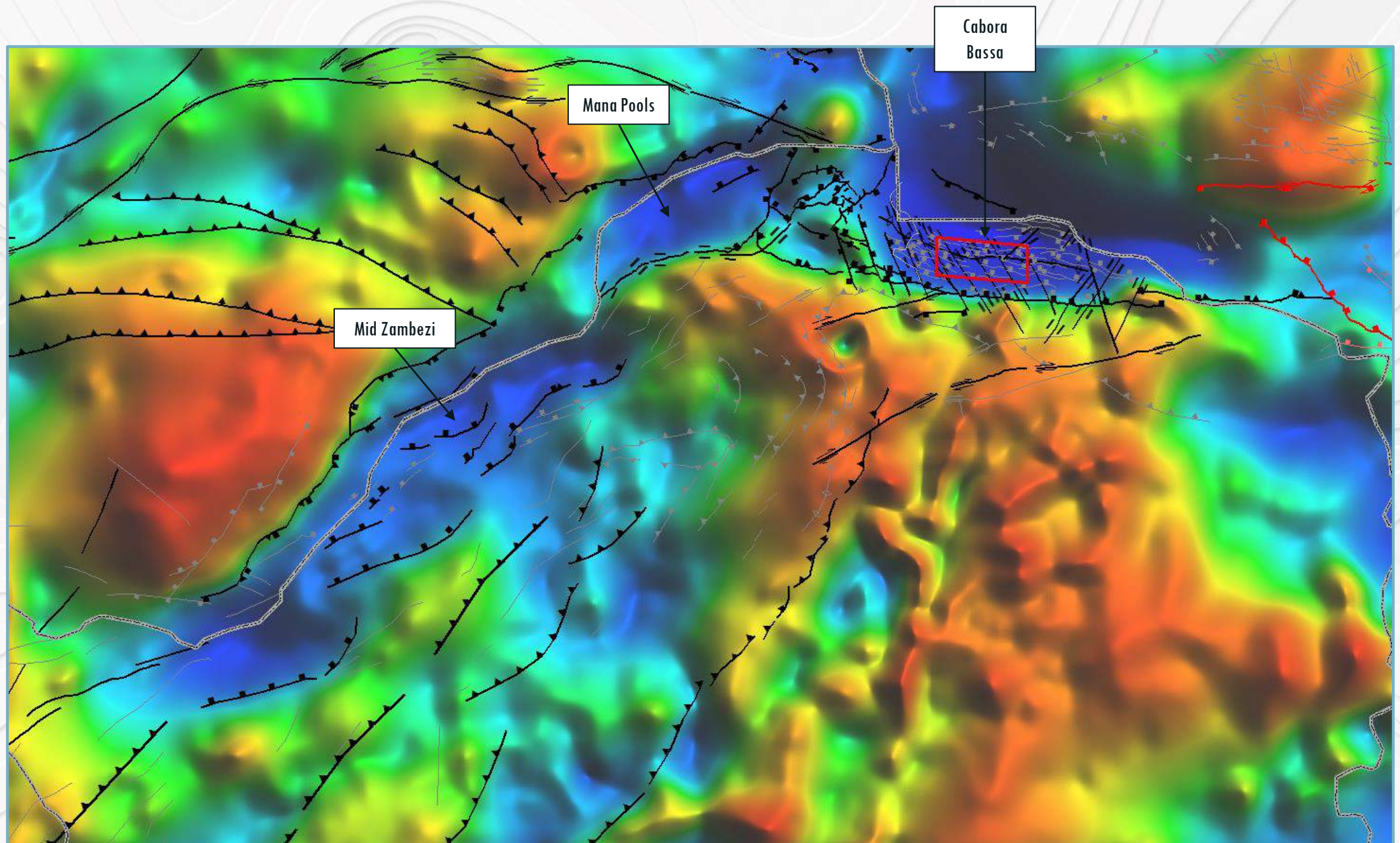


Structural Interpretation

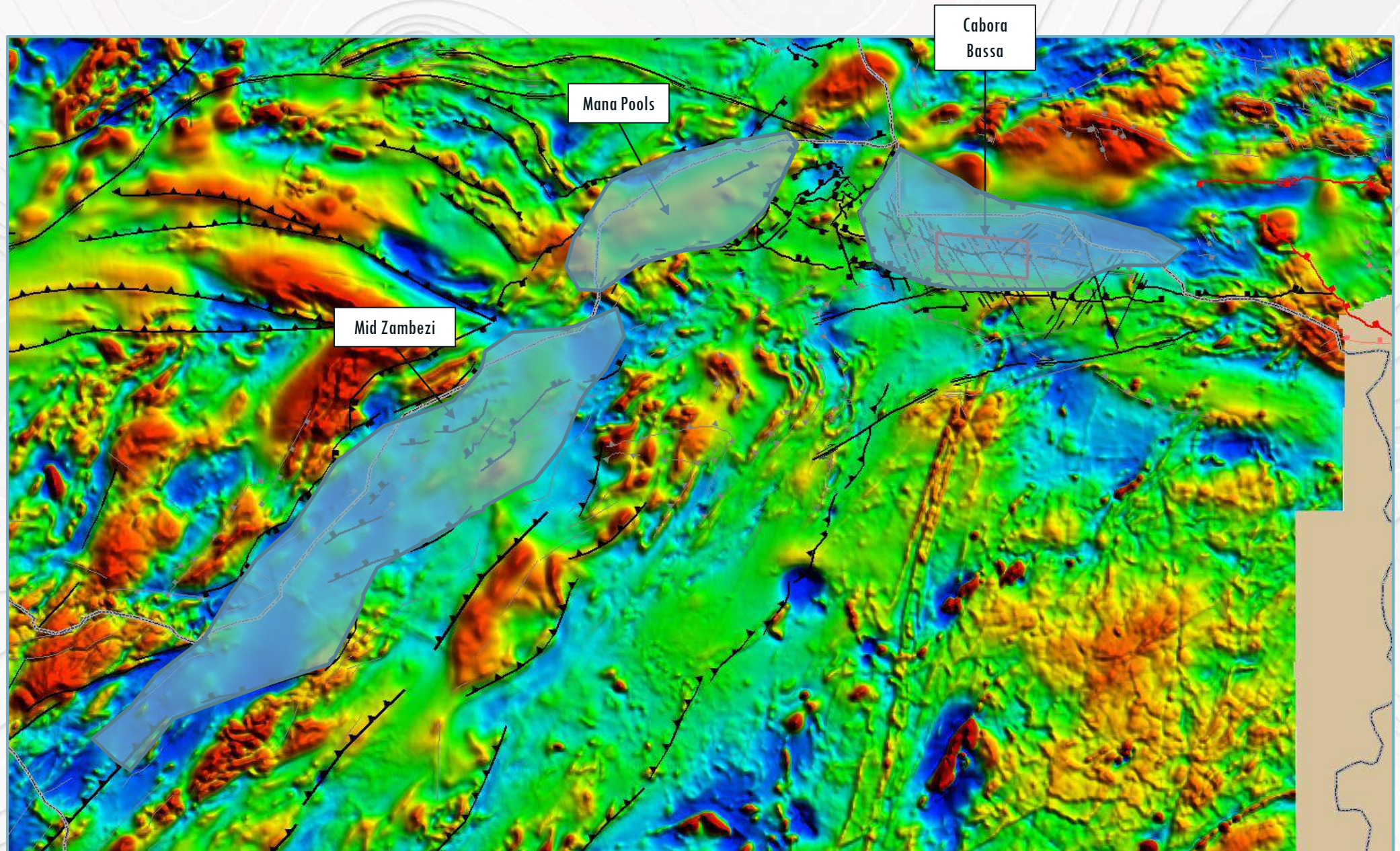
Structural Interpretation Methodology

- Extract structural interpretation from Globe
- Refine interpretation regionally based upon Getech G&M data
- Zoom in on Cabora Bassa Basin and add further level of detail using Invictus supplied data

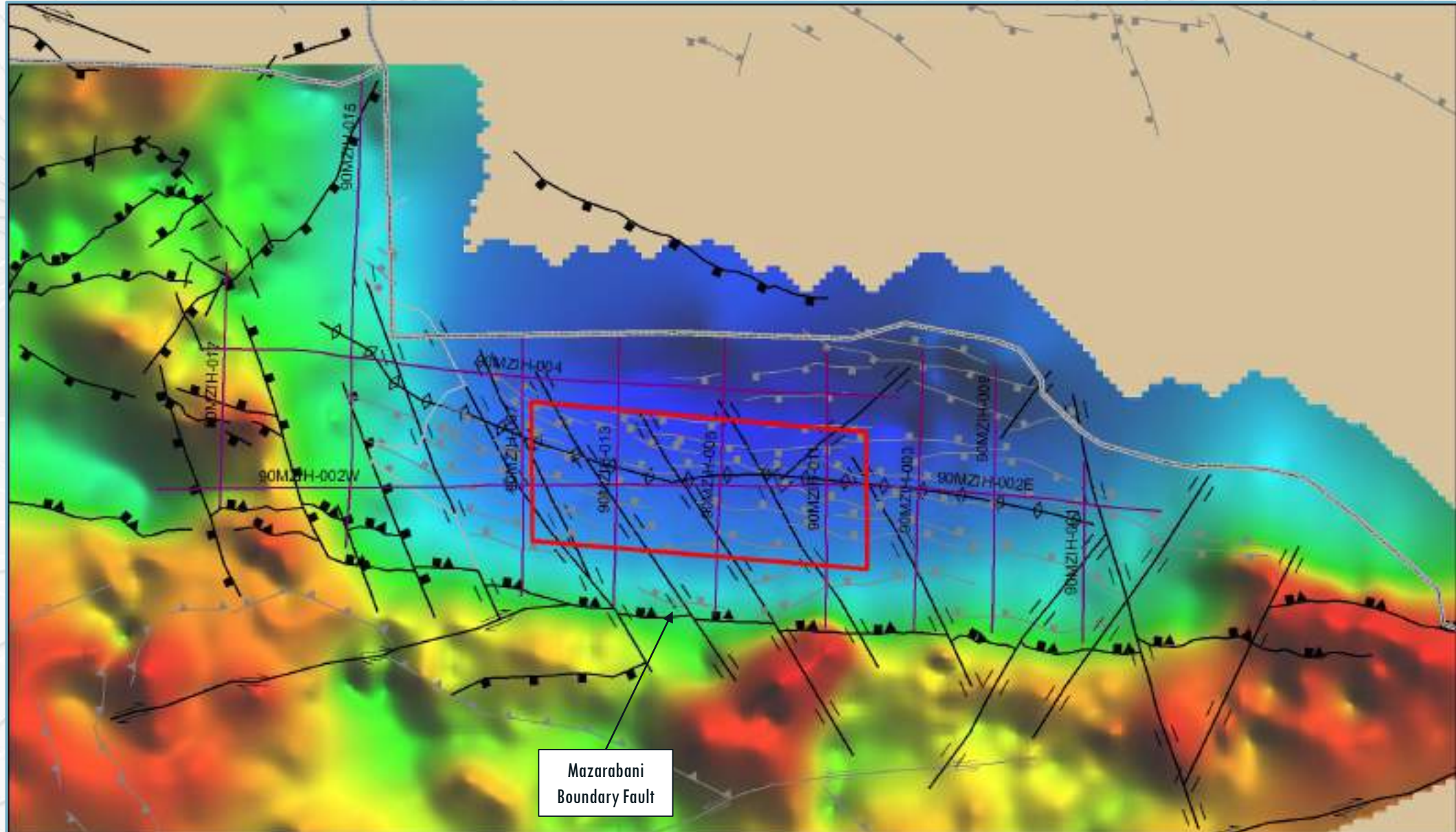
Regional Picture – Getech Isostatic Gravity



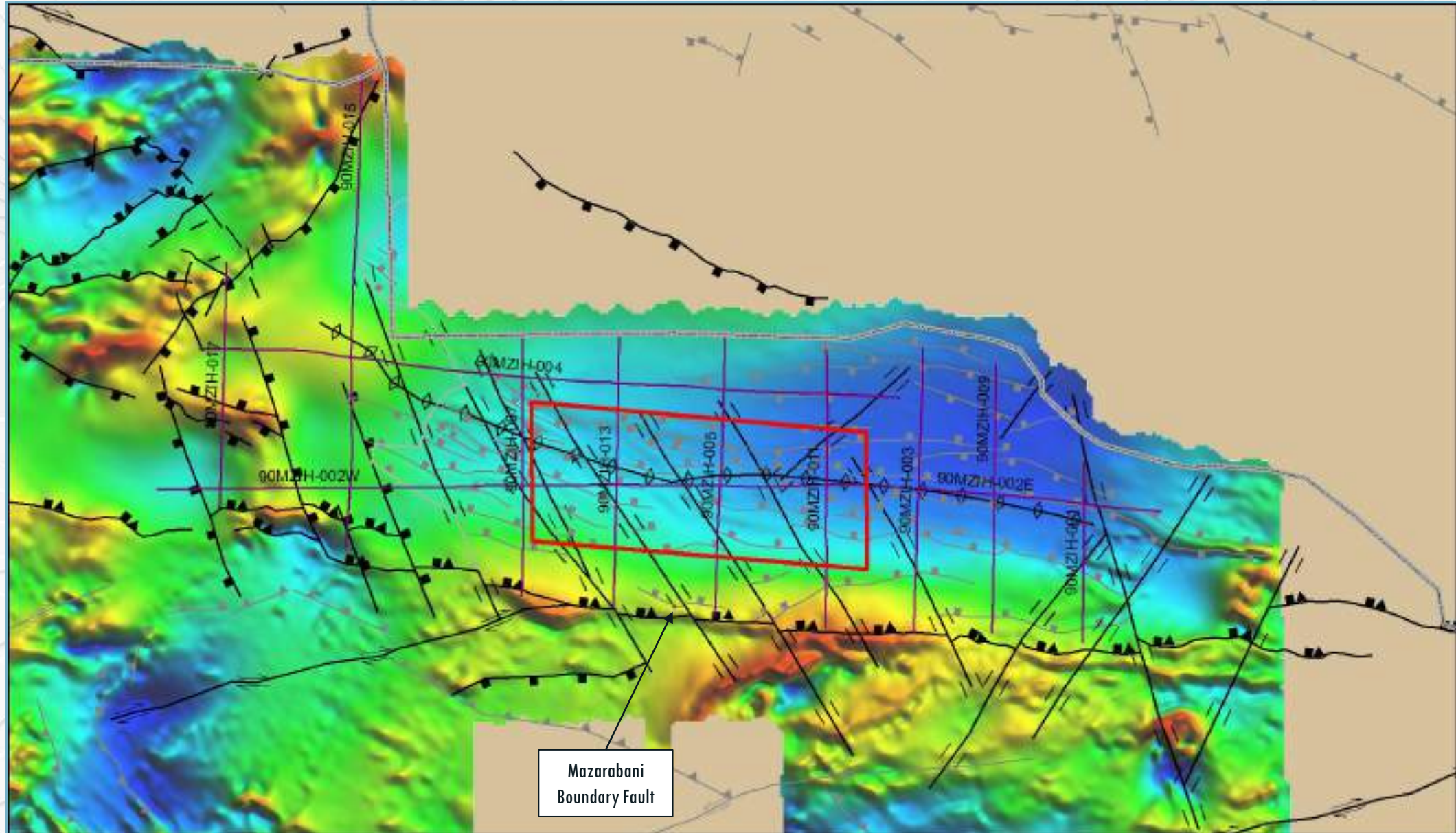
Regional Picture – Getech DRTP Magnetics



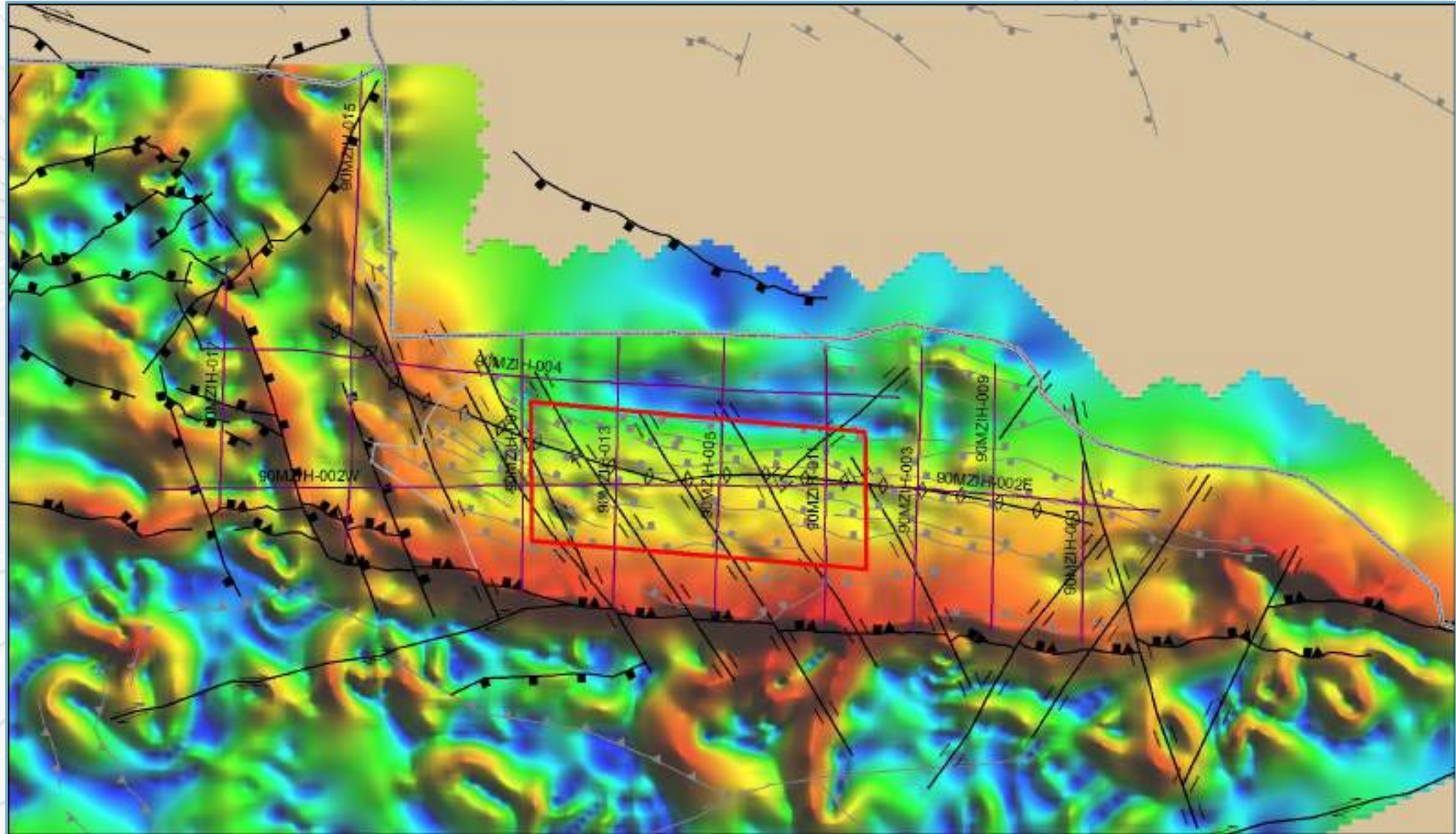
Cabora Bassa– Invictus Bouguer Gravity



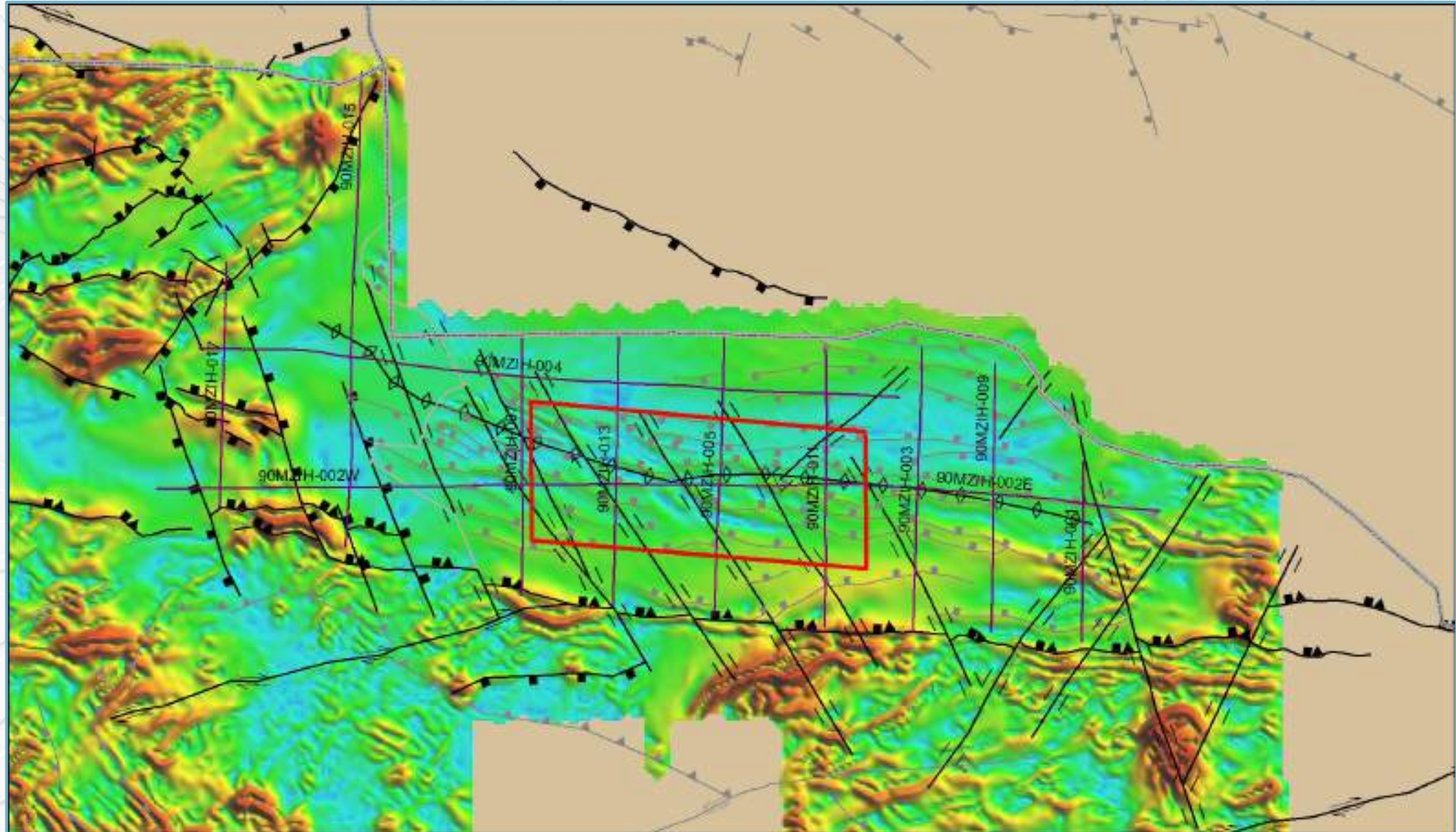
Cabora Bassa– Intera-Kenting DRTP Magnetics



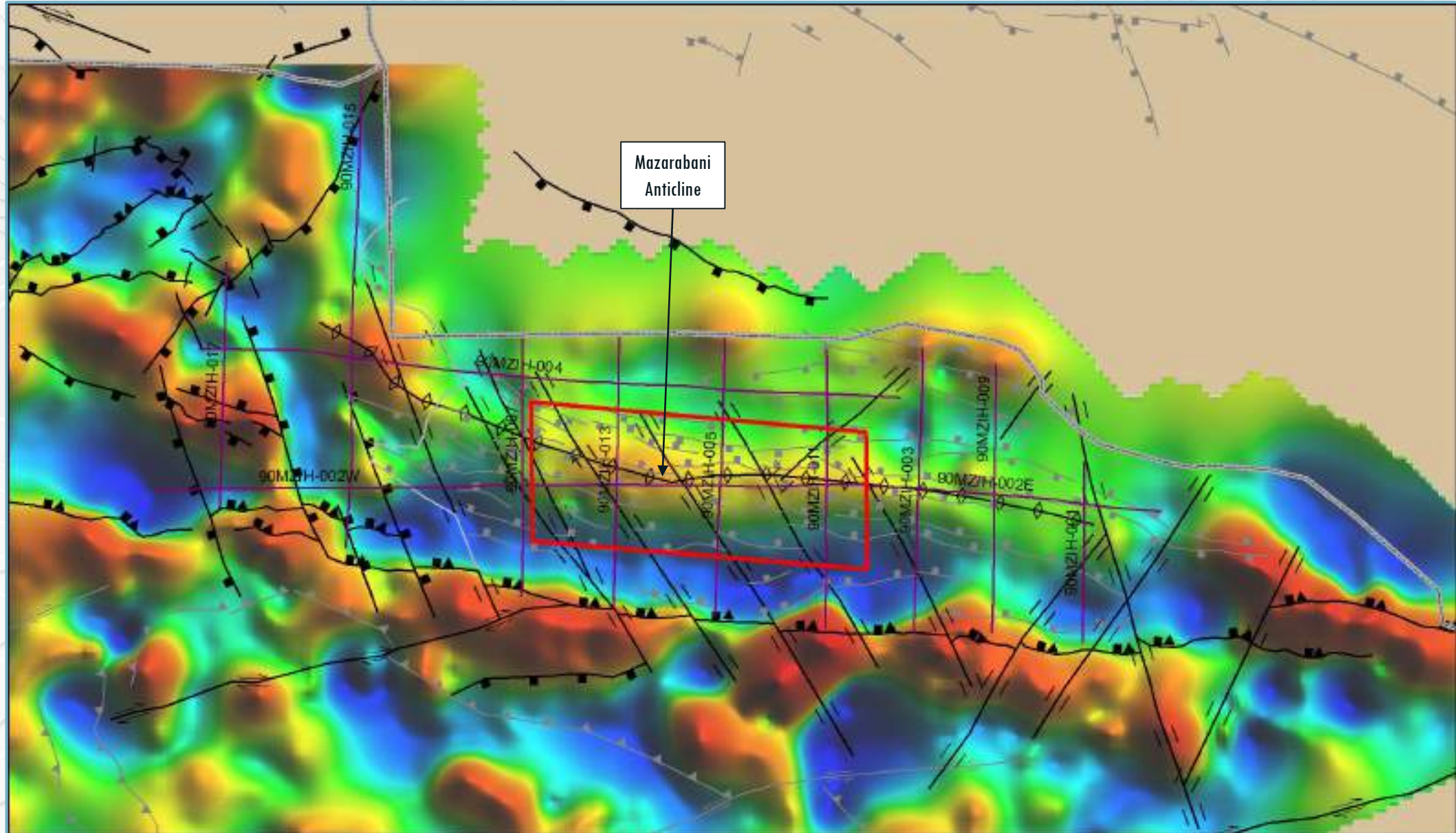
Cabora Bassa– Invictus Bouguer Gravity THD



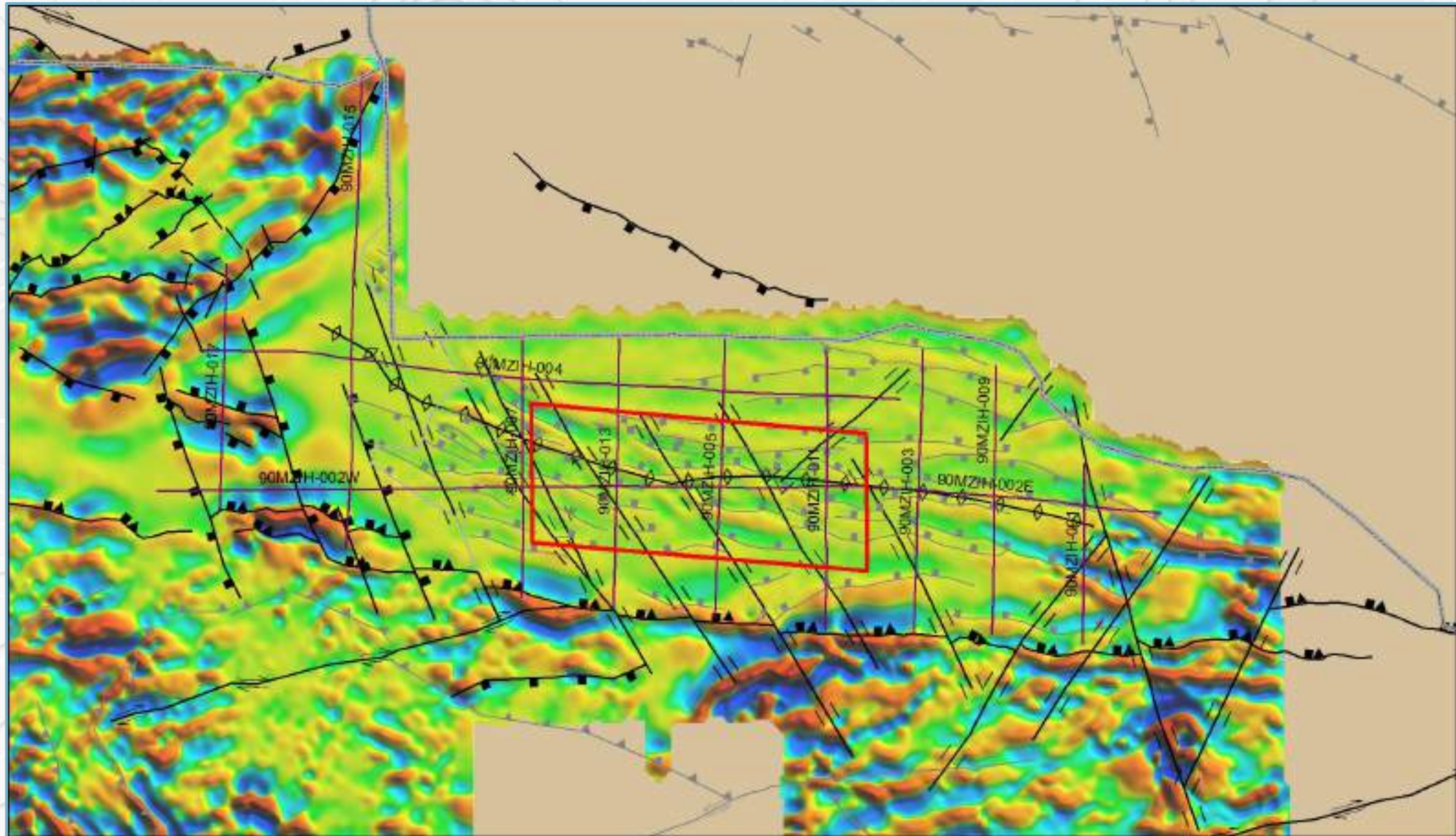
Cabora Bassa– Intera-Kenting DRTP Magnetics THD



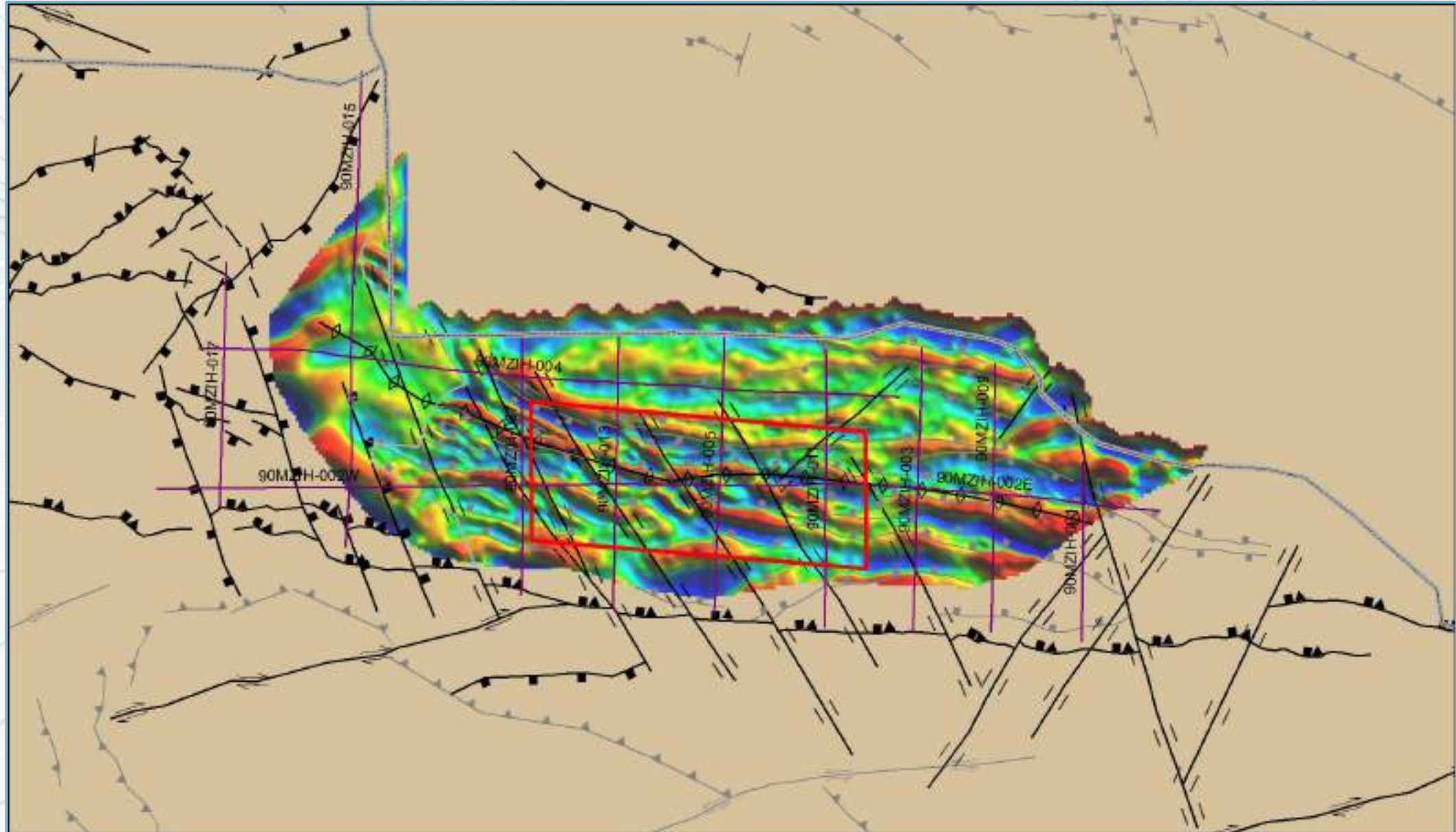
Cabora Bassa– Invictus Bouguer Gravity HP 40km



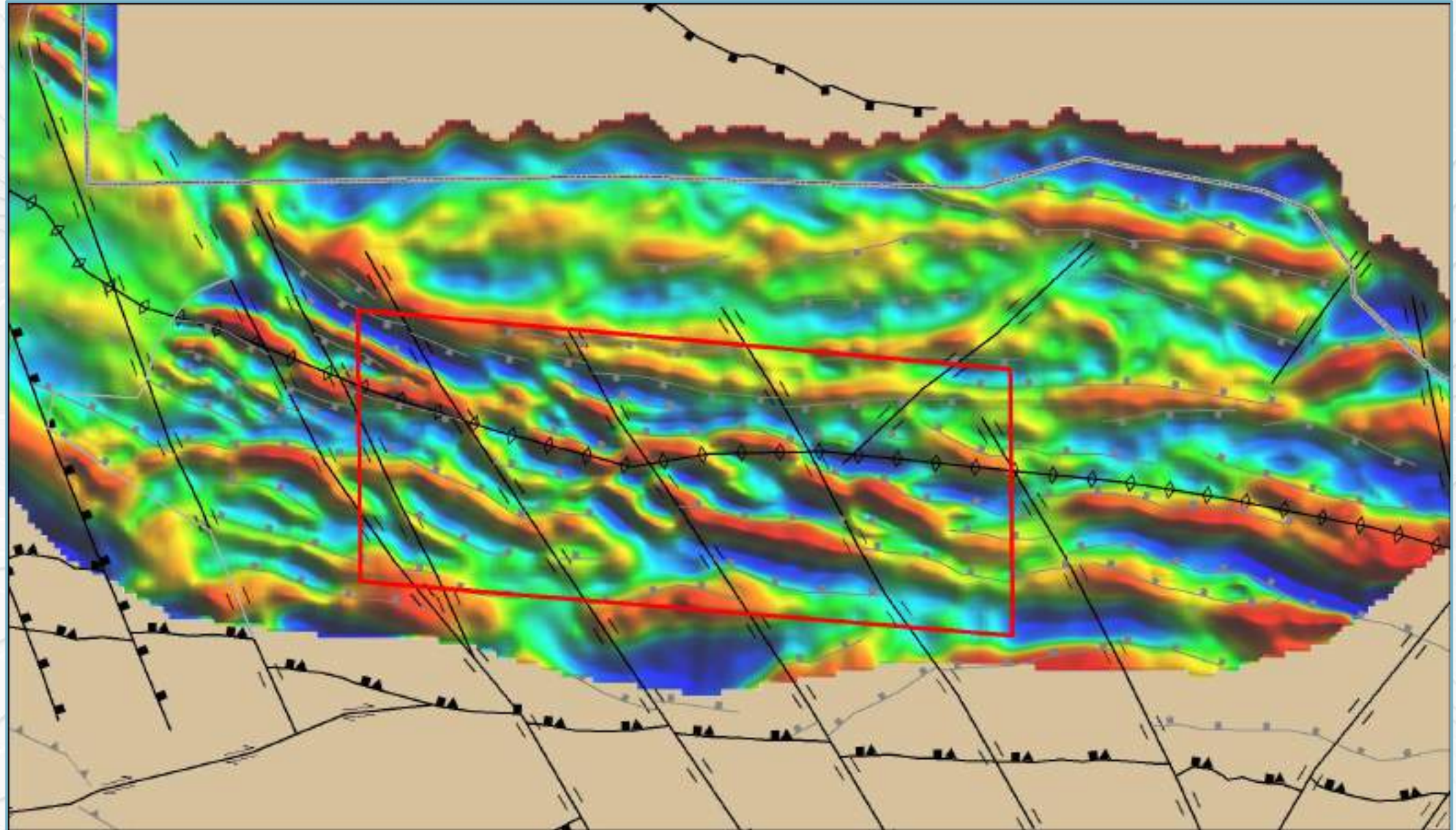
Cabora Bassa– Intera-Kenting DRTP Magnetics HP 10km



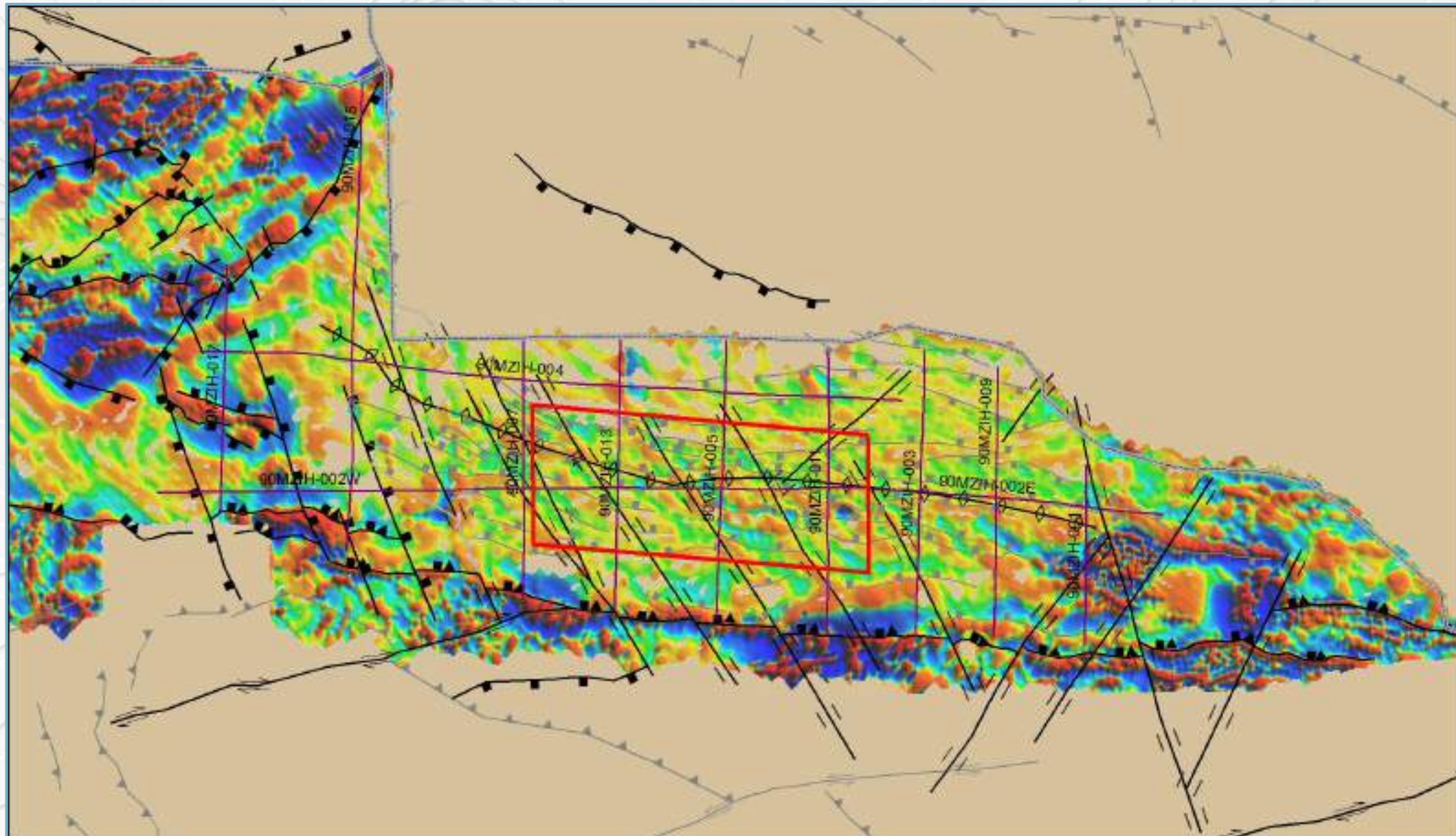
Cabora Bassa– Intera-Kenting DRTP Magnetics HP 10km



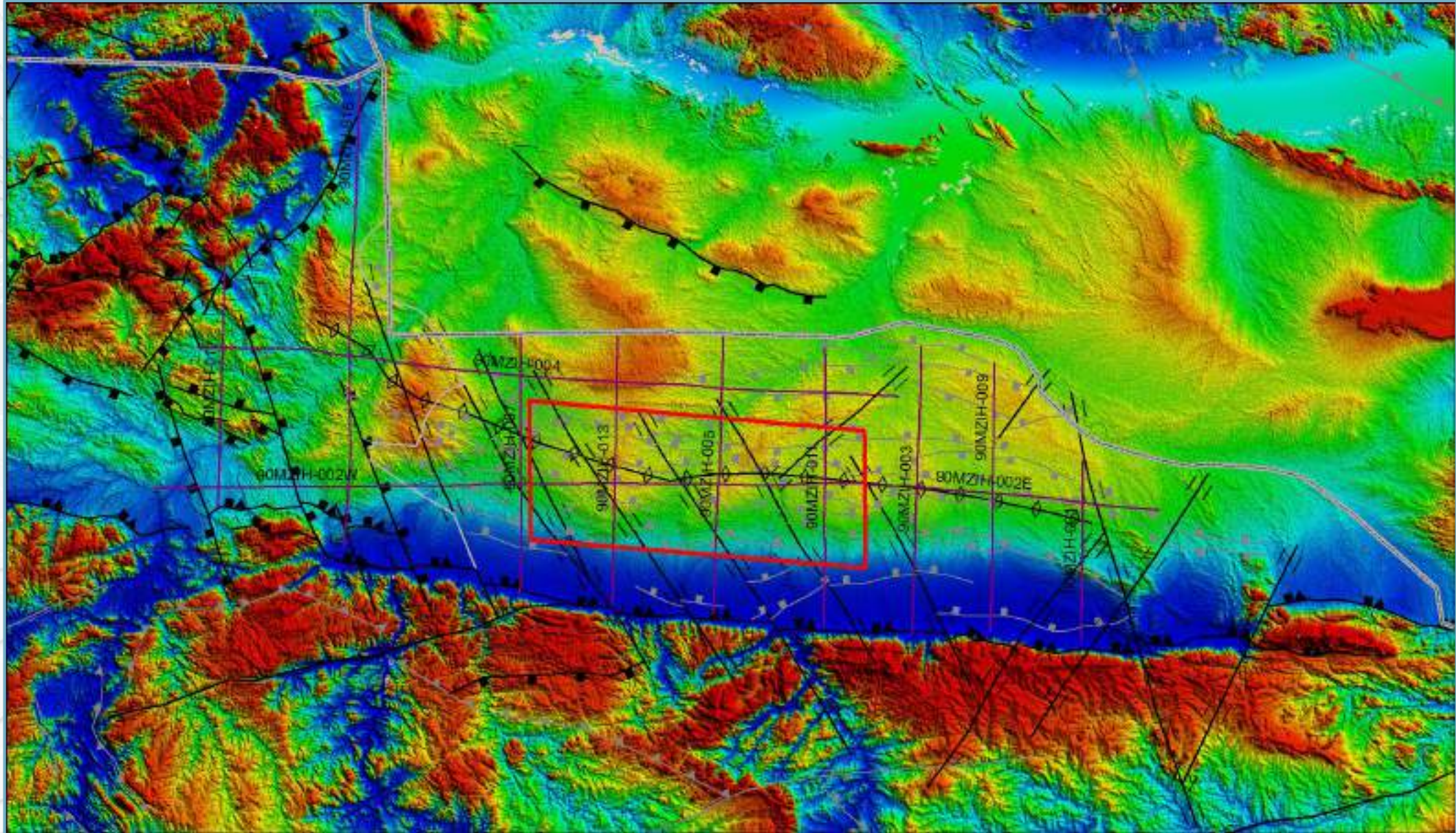
Cabora Bassa– Intera-Kenting DRTP Magnetics HP 10km



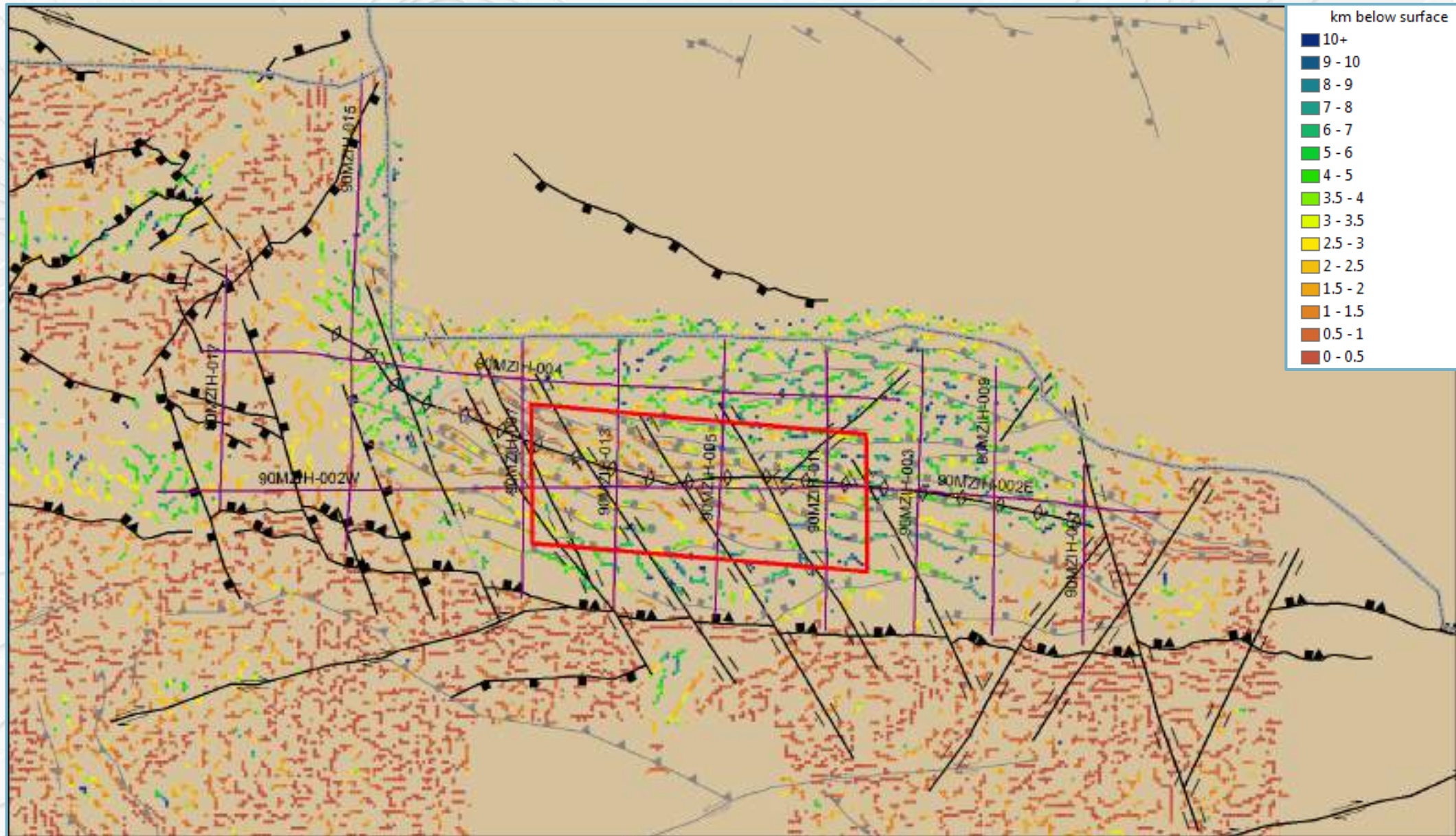
Cabora Bassa– Saarberg DRTP Magnetics HP 10km



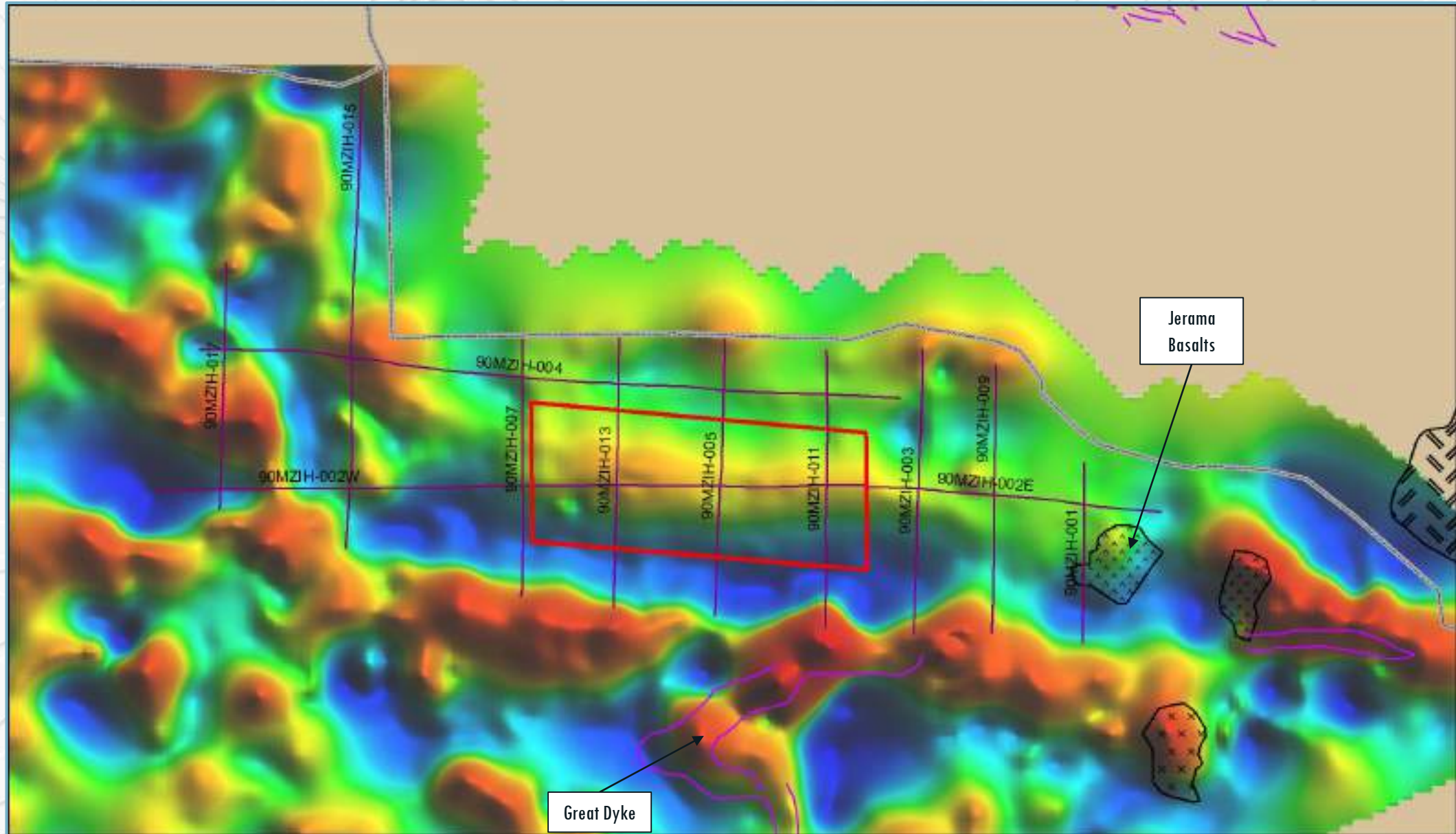
Cabora Bassa– SRTM Topography HP 50km



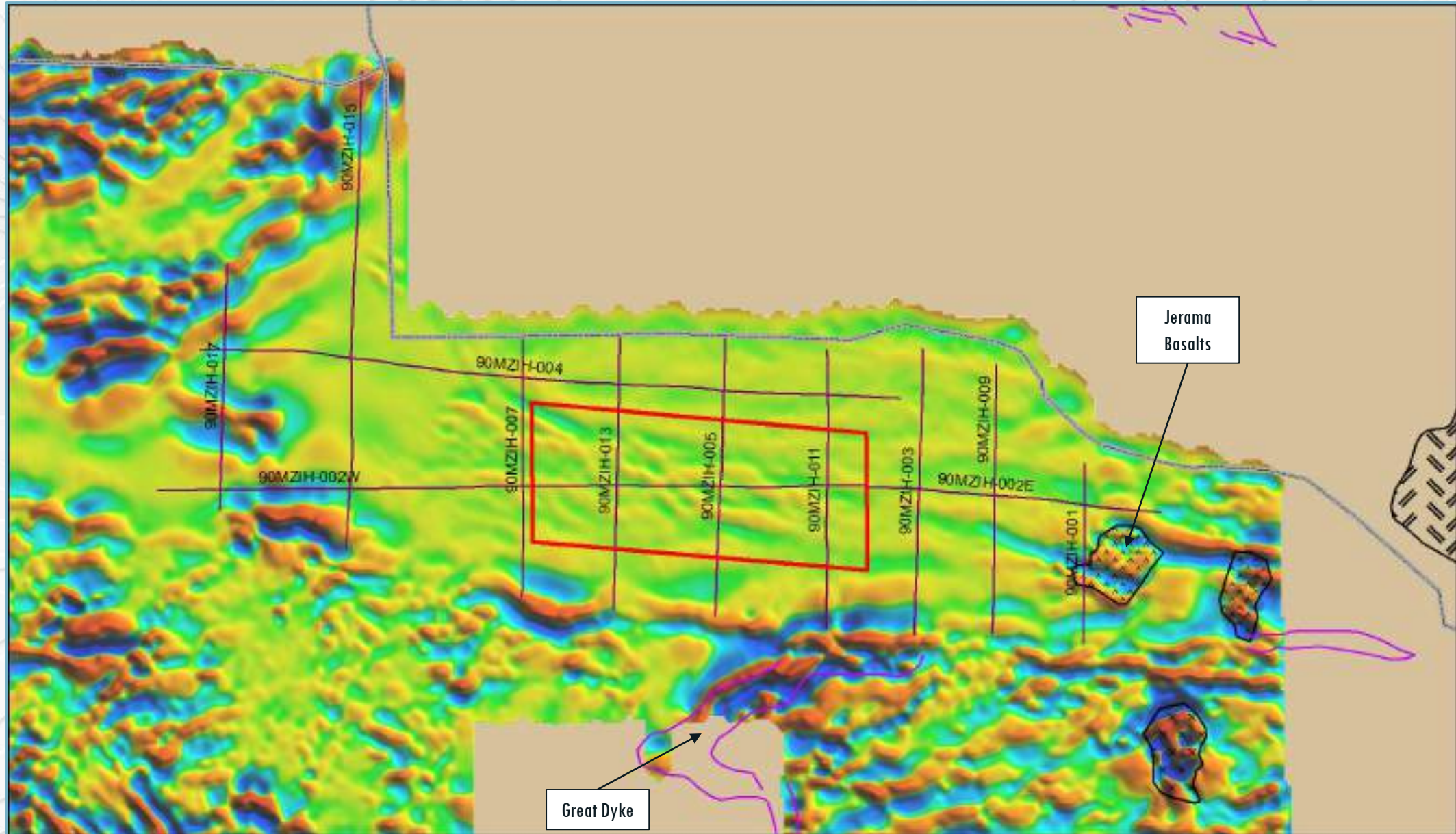
Cabora Bassa– SPI depth results



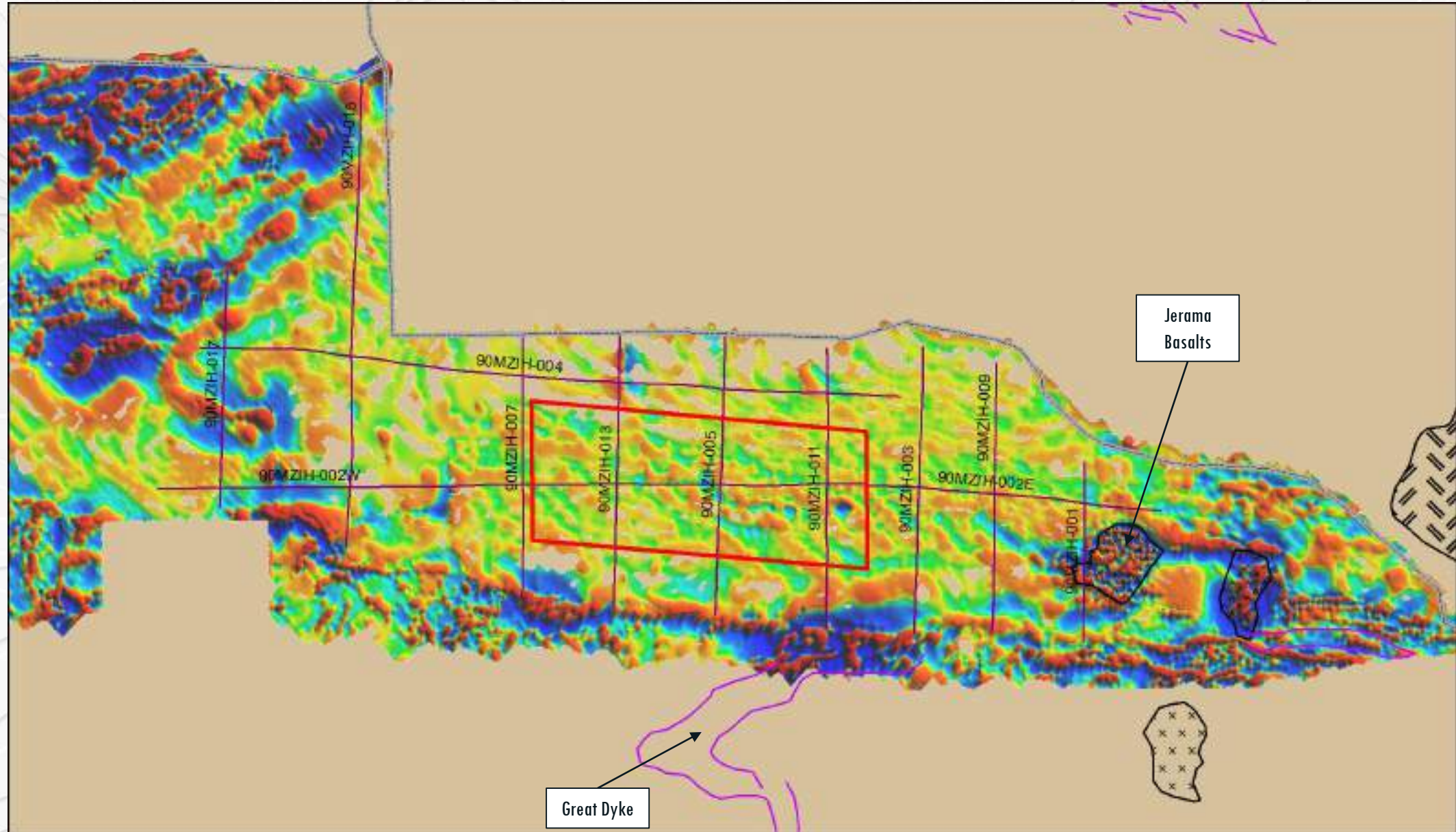
Cabora Bassa volcanics –Invictus Bouguer Gravity HP 40km



Cabora Bassa volcanics –DRTP Magnetics HP 10km



Cabora Bassa volcanics – Saarberg DRTP Magnetics HP 10km



Cabora Bassa– Origin of intra-basin mag anomalies?

Oesterlen & Millsted, 1994

SYSTEM		GROUP	FORMATIONS CABORA BASSA BASIN	
Jurassic	M	Upper Karoo	Cabora Bassa Basalt (kB)	
	L		Forest Sandstone (k9)	
Triassic	U		Pebbly Arkose (k8)	
	M		Angwa	AM (k7)
	L		Sandstone	MSM (k6)
Permian	U	Lower Karoo	Mikanga (k5)	
	L		Kondo Pools (k1)	
	L			
Upper Carbonif.				
REFERENCES			Oesterlen 1990, 1991	

Angwa Fm.

stone which is well sorted, either well bedded or flaggy, and commonly displays flaser bedding (Figure 12) and climbing ripples. The sandstone grades upwards to flaggy siltstone and mudstone which is composed mainly of kaolinite and illite and is seldom more than a few metres thick. Thin beds of massive ironstone and light-grey, micritic limestone occur frequently within the sequence and marcasite concretions, mostly oxidized to limonite, are also common.

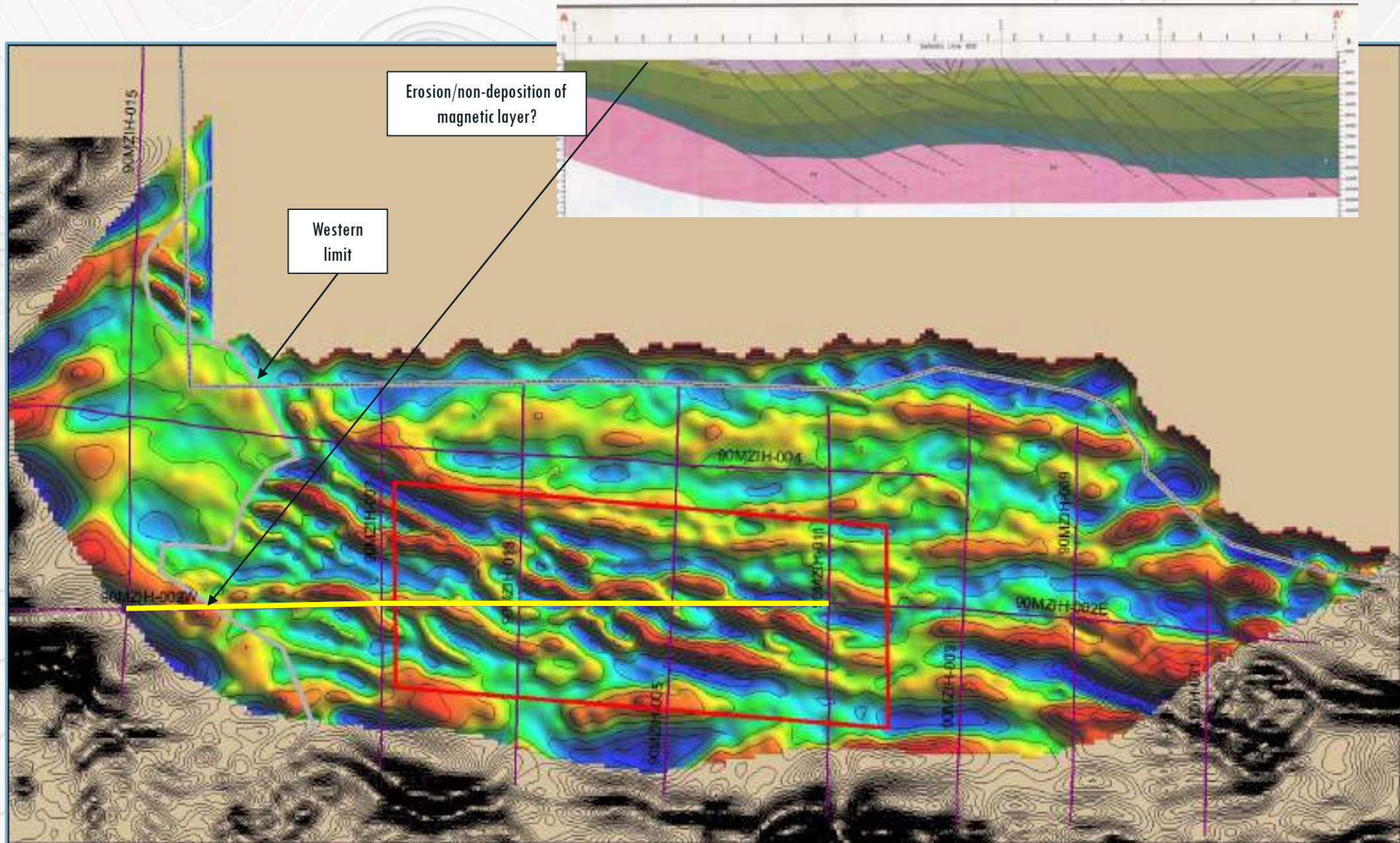
Key, Cotterill & Moore (2015)

However, end-Karoo volcanism in the Cabora Bassa Rift-basin was confined to localised volcanic centres with emanating dykes and sheets (Lächelt 2004; GTK Consortium 2006; Key, 2011b; 2012; Key and Barclay 2013) and may not have had much of a direct effect on magma within the rift.

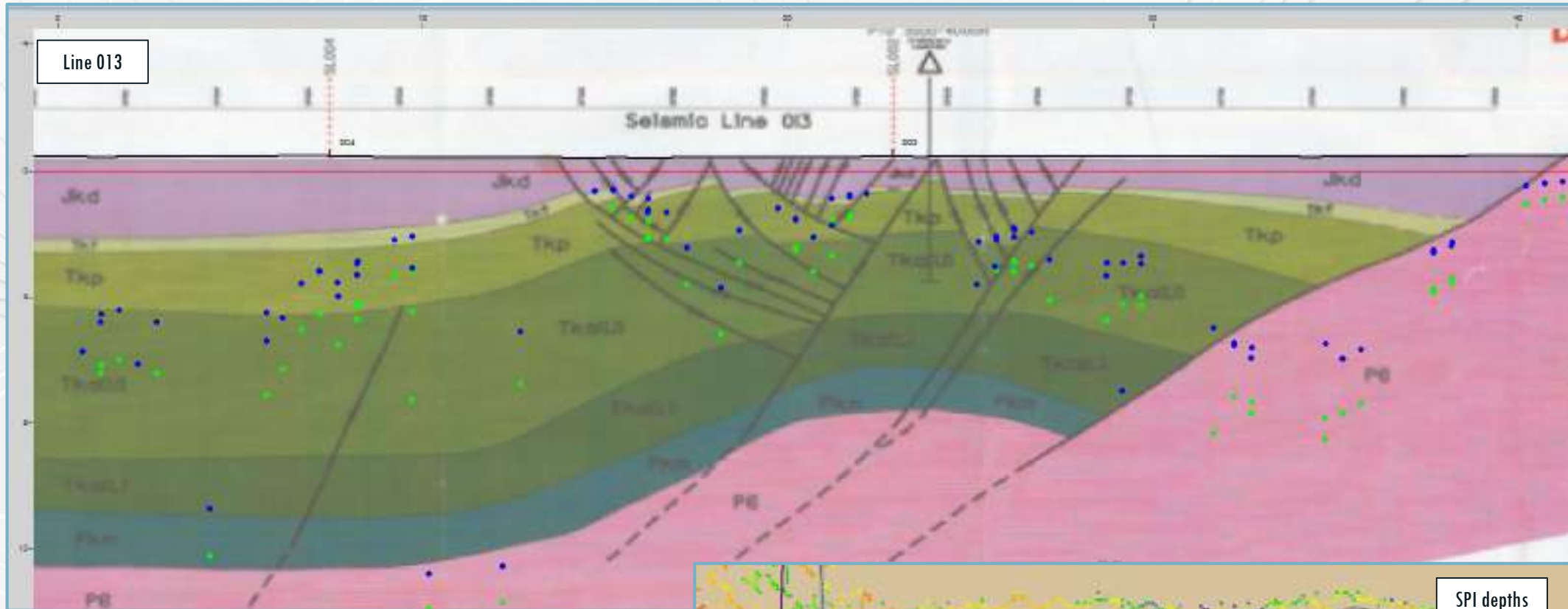
Shoko & Gwavava (1999)

A possible source could be the weathered, transported Great Dyke and Jerama basaltic material,

Cabora Bassa– Origin of intra-basin mag anomalies?



Cabora Bassa– Origin of intra-basin mag anomalies?



Comparison with old seismic interpretation



Remaining G&M work

- Integrating new seismic data is an important part of the G&M work
- 2D G&M modelling
 - Test seismic & structural interpretation
- 3D inversion for depth to basement
 - Produce depth to basement surface from gravity and/or magnetic inversion
- Plan to complete when reprocessed seismic data is available- April- May 2019



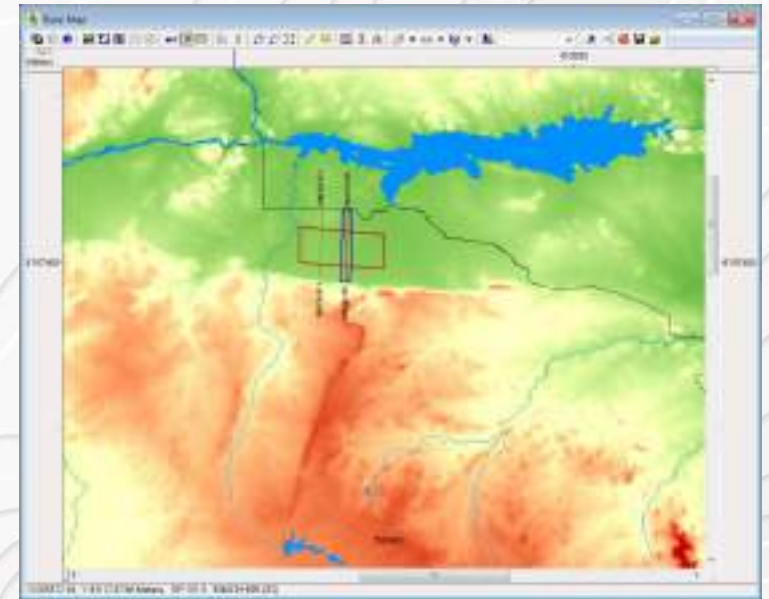


Seismic Data

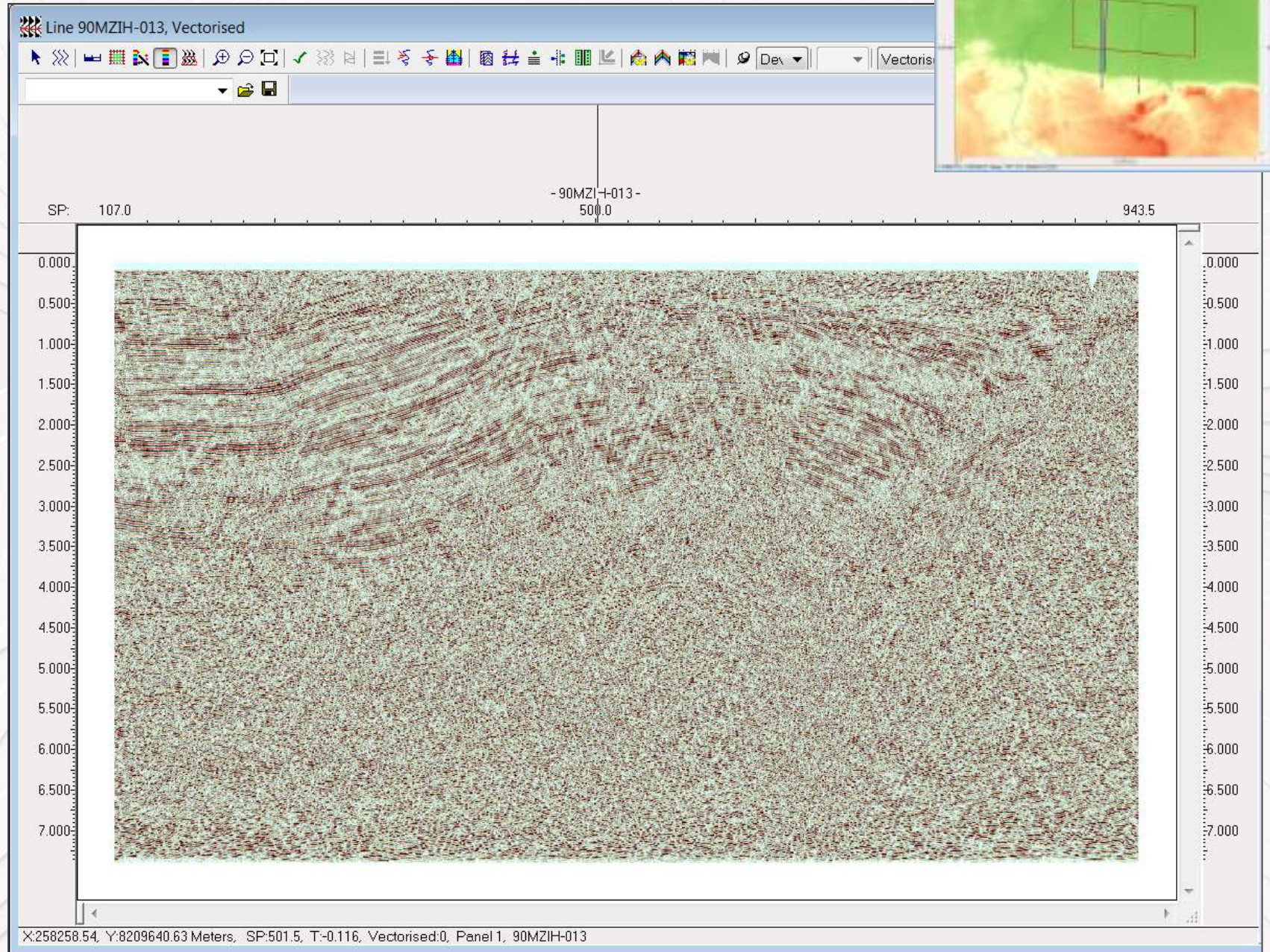
Seismic Data Transcription



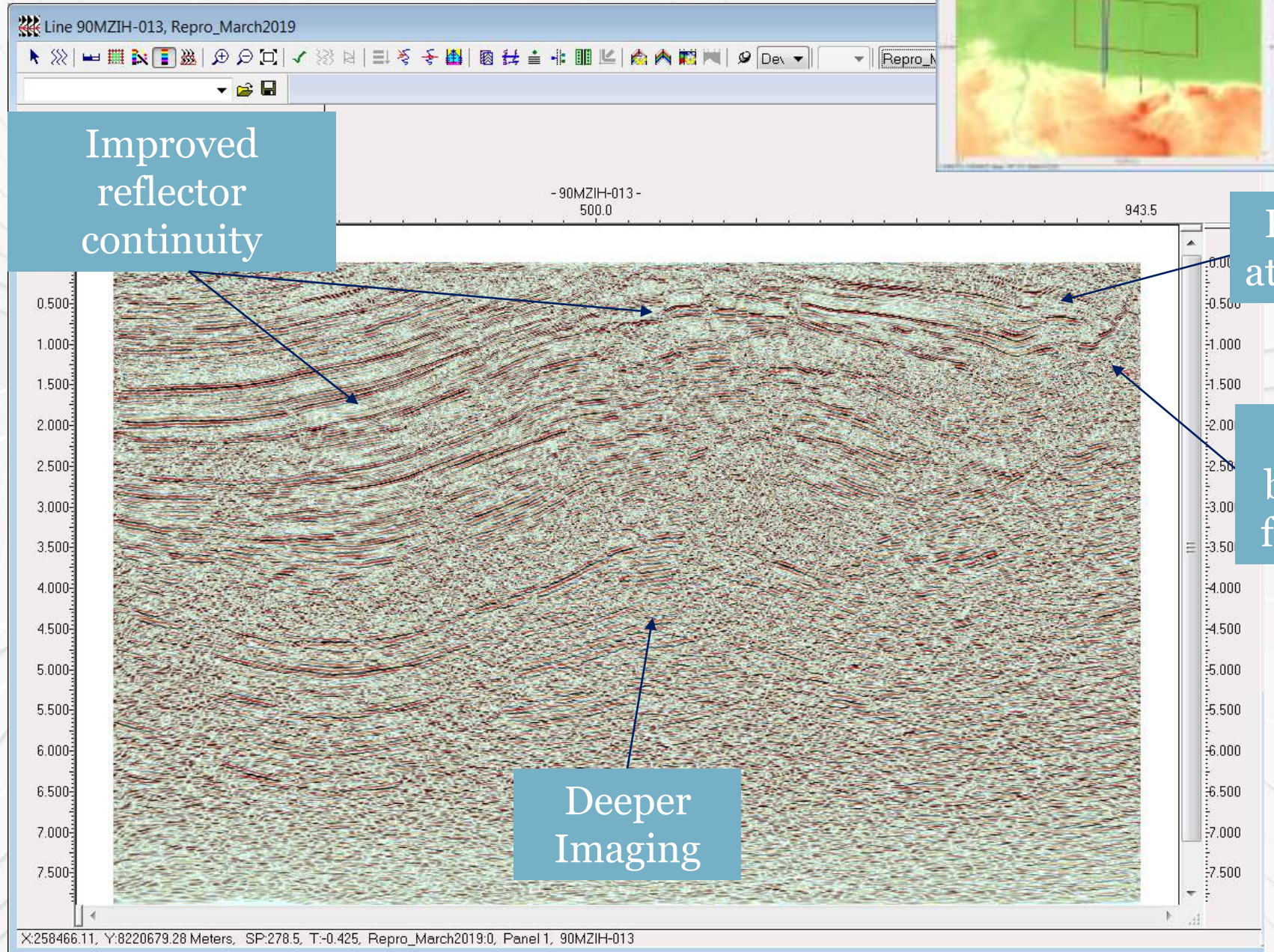
- Seismic data transcription in ZGS concluded during Q4 2018
- Exxon Mobil provided field data in addition to complement the transcribed data base (importantly observer logs)
- Seismic processing due to complete in April 2019 (2 lines provided to date)
- Excellent results seen to data in reprocessed seismic data
- Once reprocessing complete Getech Group will be supporting Invictus by conducting seismic interpretation and prospectivity study incorporating G&M work prior to farm out process



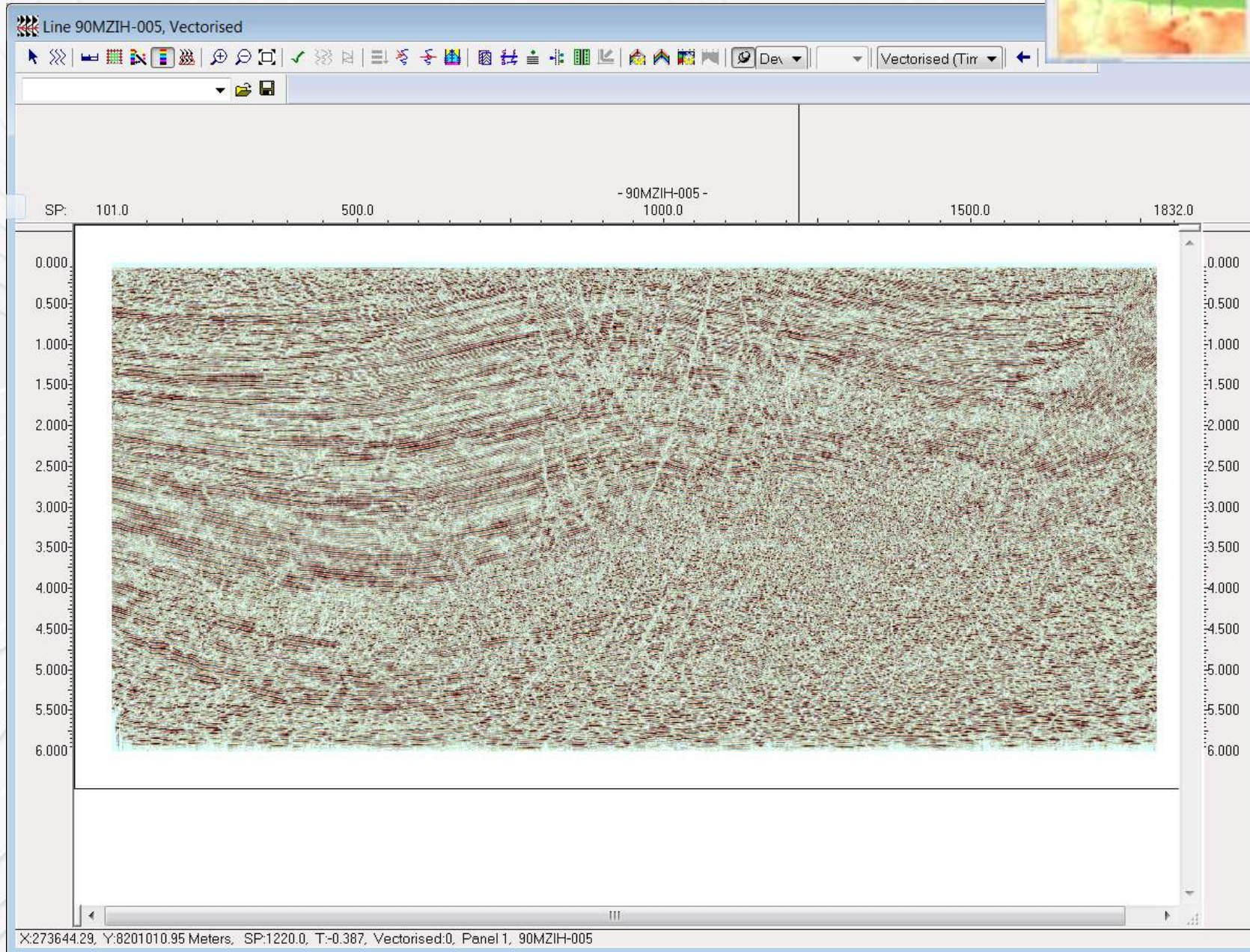
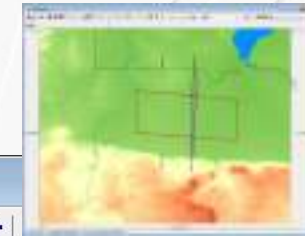
90MZIH-013- Vectorised



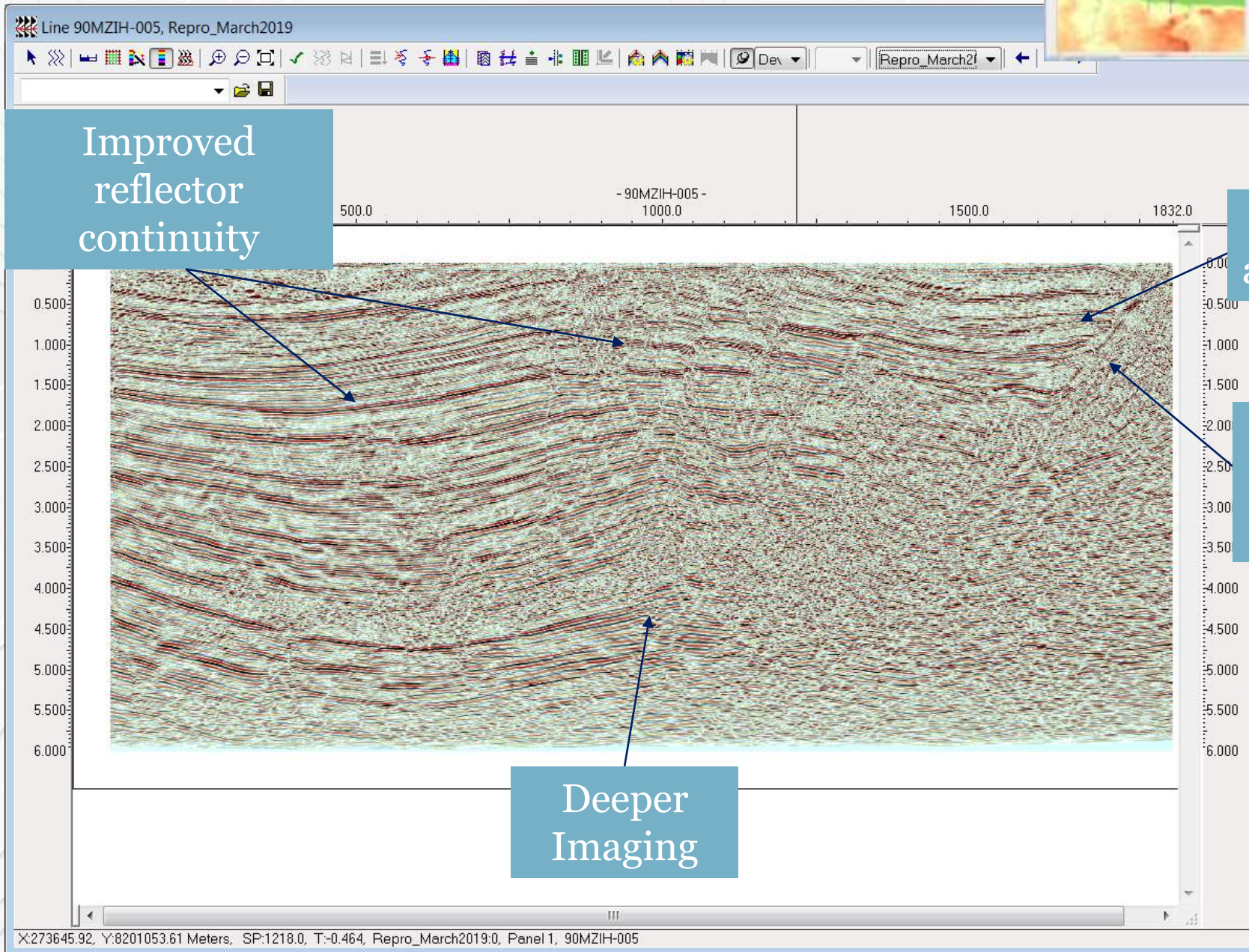
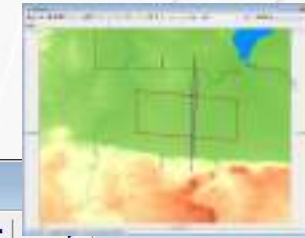
90MZH-013- Reprocessed



90MZH-005- Reprocessed



90MZH-005- Reprocessed



Getech Group Technical Programme for Invictus Energy

- Regional Geological Context utilising Getech Globe
- Creation of a GIS project
- Gravity and Magnetic data reprocessing, interpretation and modelling
- Seismic data transcription, and reprocessing support and Interpretation
- Technical Farm Out Support

