Geofísica de alta resolución y su aporte a la cartografía geofísica y geológica nacional y mundial

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Contenidos

- Motivación / Introducción
- Algunas definiciones
- Caso 1: Chile Central
- Caso 2: Norte de Chile, adición de radiometría aérea
- Caso 3: Nigeria
- Conclusiones / Resumen Final

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Introducción

Misión del Servicio Geológico

Generar y proveer el conocimiento geológico-económico del país, maximizando su valor, enfocado al fomento de la inversión y aprovechamiento sustentable de los recursos naturales no renovables.

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Introducción

Cartografia

SHARE

Este programa es el elemento medular de las actividades del SGM porque las cartas geológicas son la base para interpretar y entender la dinámica de la corteza terrestre. Con tecnología de vanguardia, la cartografía geológica permite generar información y con ello analizar a nivel regional los datos geológicos levantados en campo los cuales, una vez geo-referenciados, se presentan en forma de cartas especializadas tanto impresas como en forma digitalizada, accesibles al público interesado.

- Geología
- Geofísica
- Geoquímica
- Ambiental
- Minería, Yacimientos Minerales

SGM
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Introducción

- Queremos generar cartografía geológica…
- Cómo hacemos de éste un proceso más eficiente?

- *Analicemos esta pregunta desde un punto de vista geofísico…*

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Introducción

- El uso de métodos de sensores remotos permite cubrir zonas de gran extensión areal en tiempo reducido
- Los principales servicios geológicos mundiales cuentan con programas continuos de cubrimiento geofísico

(No porque funcione en Australia va a funcionar en Sudamérica…así que veamos ésto en detalle)

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Sensores Remotos?

- Imágenes satelitales
  - Ópticas: Landsat, Aster
  - Radar: RADARSAT
  - Alta resolución: Quickbird, Worldview

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Sensores Remotos?

Comparación de los distintos sistemas de alta resolución

	QuickBird	IKONOS	GeoEye-1	WorldView-1	WorldView-2	Pleiades-1
Resolution	0.6m	0.8m	0.5m	0.5m	0.5m	0.5m
Swath Width	16.5 km	11 km	15 km	15 km	16.4 km	20 km
Multi-Spectral	yes	yes	yes	no	yes 8 bands	yes 4 band
DEM Accuracy	20 meter	20 meter	3 meter	3 meter	3 meter	tba
Average Revisit Time	3-4 days	2-3 days	2-3 days	3-4 days	2- 3 days	1 day*
Mapping Accuracy (w/out GCPs)	20-meter	10-meter	2-meter	3-meter	6.5 meter	4.5 meter
Agility	Limited Single Scan	Very/Stereo Multi-scan	Very/Stereo Multi-scan	Very/Stereo Multi-scan	Very/Stereo Multi-scan	Very/Stereo Multi-scan
Days to Collect 1° x 1°	25	8	5	8	1.1	*1 with Pleiades-2 launched Nov 2012

http://www.spatialenergy.com/products_imagery.html

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Sensores Remotos?

- Imágenes satelitales
  - Ópticas: Landsat, Aster
  - Radar: RADARSAT
  - Alta resolución: Quickbird, Worldview
- Geofísica aérea
  - Magnetometría
  - Gamma-espectrometría (radiometría)
  - EM
  - Gravimetría aérea

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Geofísica aérea

- Magnetometría
  - Mapeo estructural, litológico
  - Método penetrativo (superficie hasta isoterma de Curie)
- Gamma-espectrometría (radiometría)
  - Mapeo de alteración y litológico
  - No penetrativo (~50 cm)
- EM
  - Detección de sulfuros masivos
  - Penetración variable (depende del sistema, conductividad de las rocas, y contratista al cual se le pregunte…)
- Gravimetría aérea

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Geofísica aérea

- Gravimetría aérea
  - Mapeo estructural y litológico
  - Debido al menor rango dinámico de la densidad de las rocas vs susceptibilidad magnética, requiere de instrumentación costosa y de precisión
  - Amplio uso en exploración petrolera, aunque en los últimos 10 años ha ganado popularidad en exploración minera

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Geofísica aérea

- Independiente del método:
  - La resolución depende de la tasa de muestreo (espaciamiento entre líneas) y la altura de vuelo
  - El costo del levantamiento depende de la cantidad de km…Muestreo más fino➔costo más alto!!

(No hace falta un PhD para esta última afirmación…)

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Alta resolución?

- Espaciamiento de líneas y altura de vuelo van de la mano…

Table 2. Maximum flight line spacings.

Survey type	Intended use	Δx
Total field	Contour map	$2\bar{h}$
Total field	Computation of gradient, etc., maps	$\bar{h}$
Vertical gradient	Gradient contour map	$\bar{h}$
Total field	Modeling of single anomalies	$\bar{h}/2$

Δx = maximum flight line or sample spacing.
$\bar{h}$ = mean height of sensor above magnetic sources.

Short Note

Aeromagnetic survey design

A. B. Reid*

GEOPHYSICS, VOL. 45, NO. 5 (MAY 1980); P. 973–976,

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En general, en base a espaciamiento entre líneas:

- 2000–4000m: exploración petrolera (mapeo de estructuras con z>2km)
- 1000-2000m: mapeo regional
- 500 m: regional→mediano detalle
- 50-250m: alta resolución (prospección minera)

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En general, en base a espaciamiento entre líneas:

Espaciamiento entre líneas	Altura de vuelo
2000-4000 m	Antiguos levantamientos “barométricos” con h>600-800m
1000-2000 m	Usualmente barometrico con h~500 m
500 m	Drape, h<250m
50-250 m	Drape, h<100m

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Efecto de altura de vuelo y espaciamiento de líneas

Drape-related problems in aeromagnetic surveys: the need for tight-drape surveys

Duncan Cowan[1] **Gordon Cooper**[2]

Key Words: Depth extent, Drape corrections, Loose-drape, Kimberlites, Source resolution

Exploration Geophysics (2003) 34, 87–92

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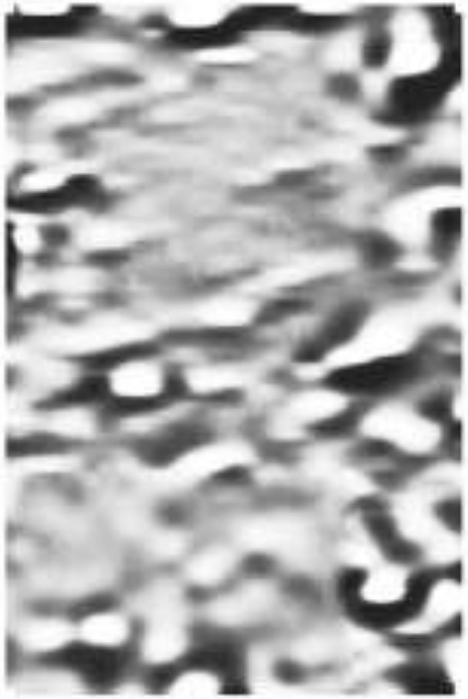
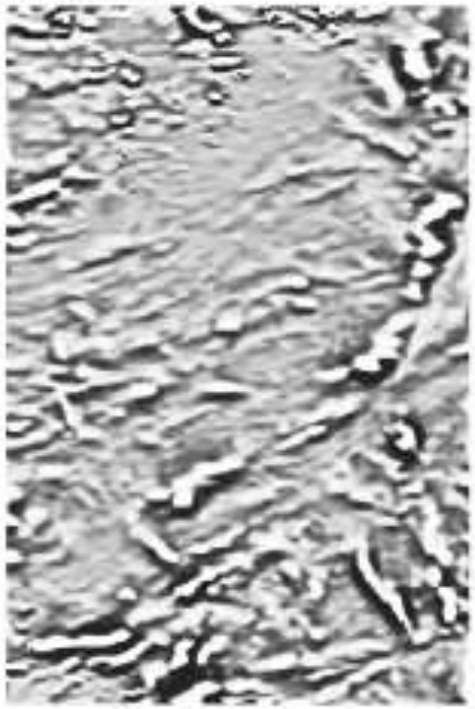
Efecto de altura de vuelo y espaciamiento de líneas

Accord Standard Survey
400 m line spacing
80 m flight height
100 m grid mesh



5 km

Ultra-detail Survey
30 m line spacing
20 m flight height
8 m grid mesh



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Efecto de altura de vuelo y espaciamiento de líneas

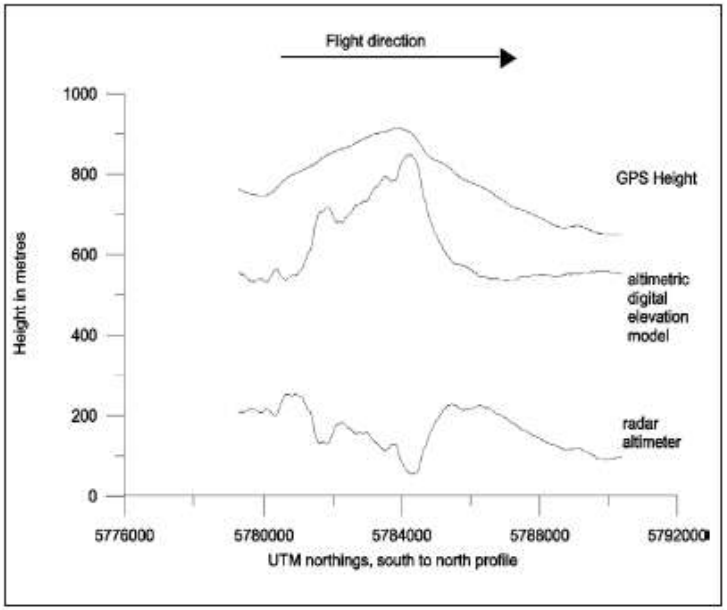

Fig. 2. Example of very loose-drape flying using Piper Navajo. The nominal terrain clearance is 100 m but the average terrain clearance is 170 m. The line spacing was 75 m and the data are virtually useless for detecting small pipes.

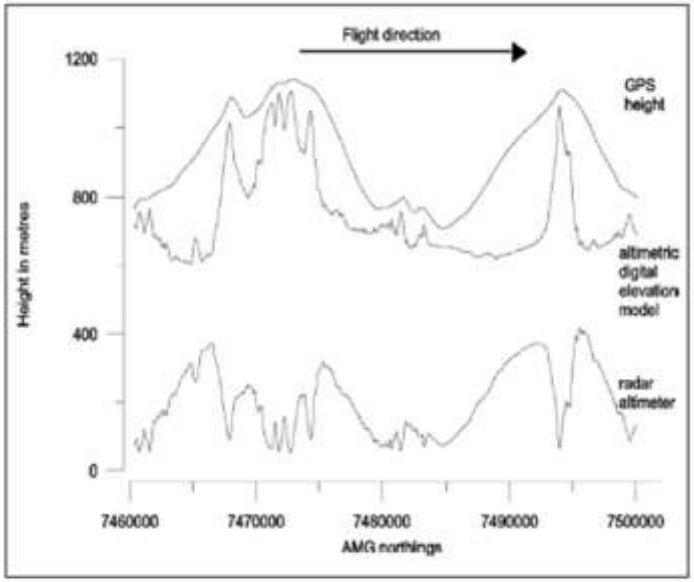

Fig. 3. Example of loose-drape flying using Shrike Aerocommander 500S. The nominal terrain clearance is 100 m but is as low as 50 m over ridges and around 400 m over valleys.

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Efecto de altura de vuelo y espaciamiento de líneas

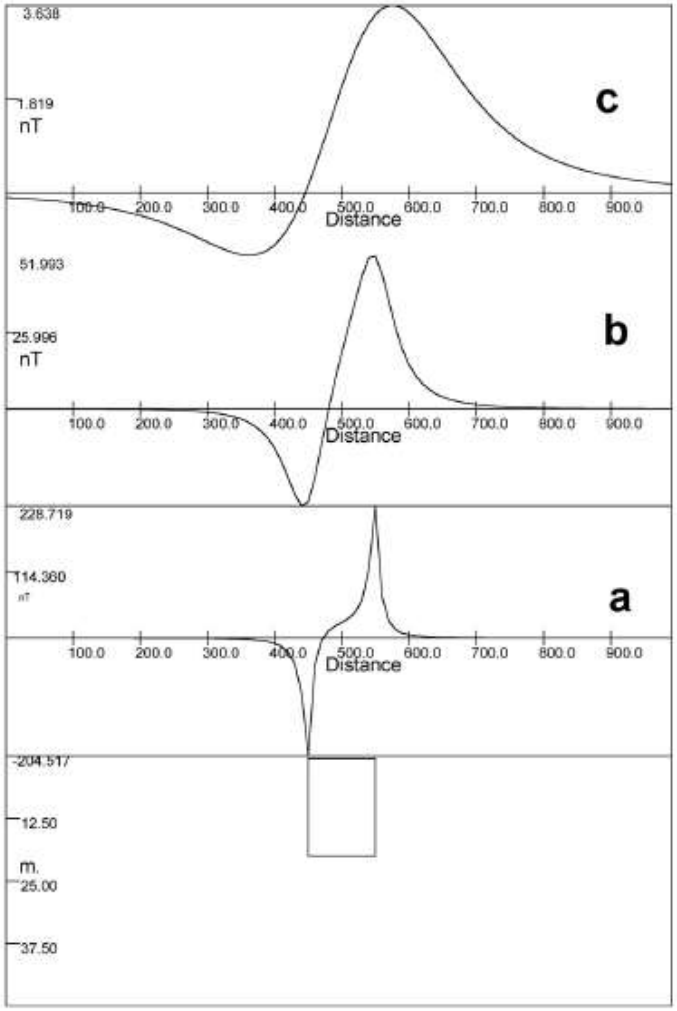

Fig. 12. Magnetic models of vertical sheets at different heights above surface. (a) ground magnetic response (b) 60-m flight height response (c) 150-m flight height response.

H=150 m

H=60 m

H=0 m

Geometría de las anomalías es similar…amplitud??

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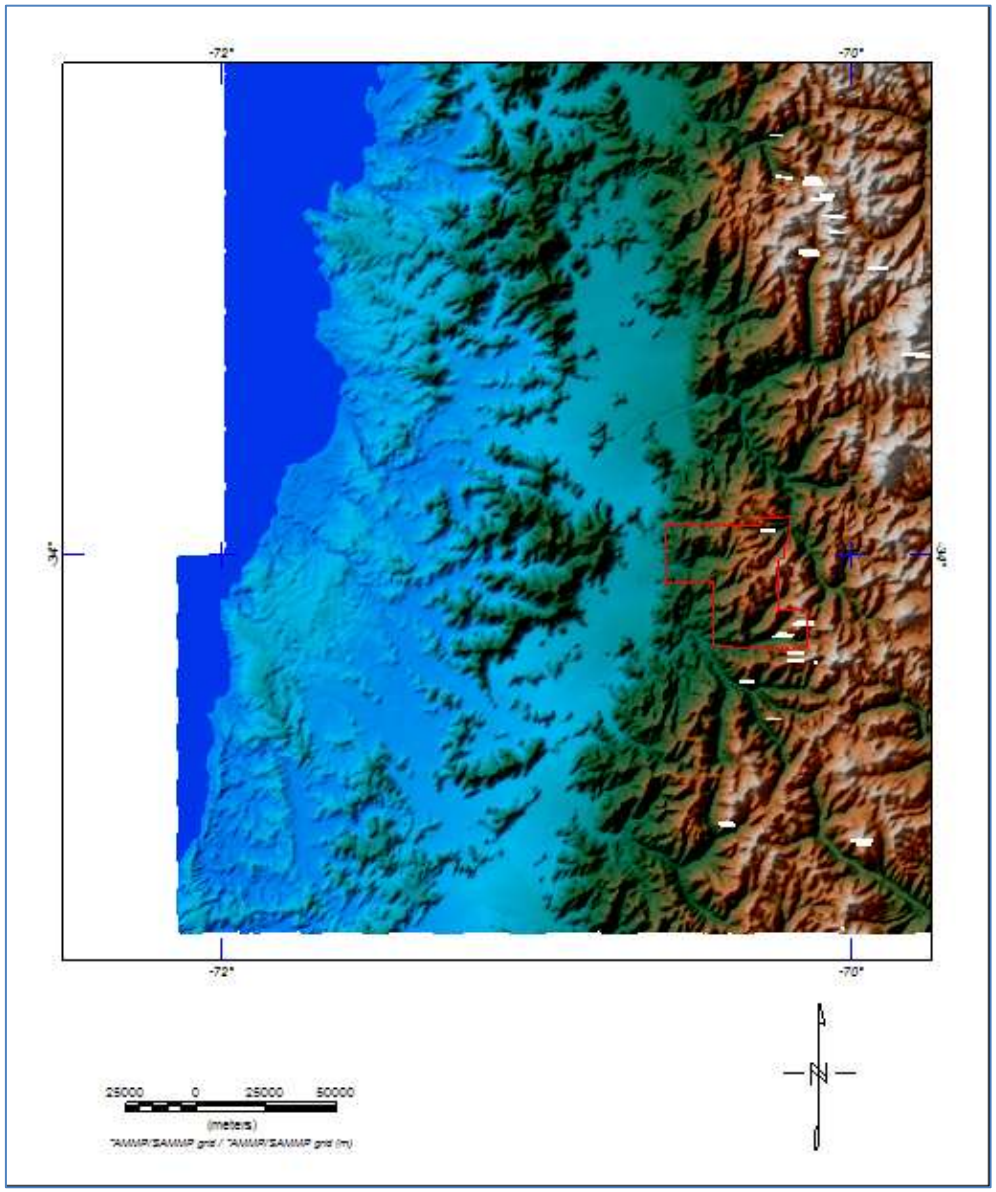

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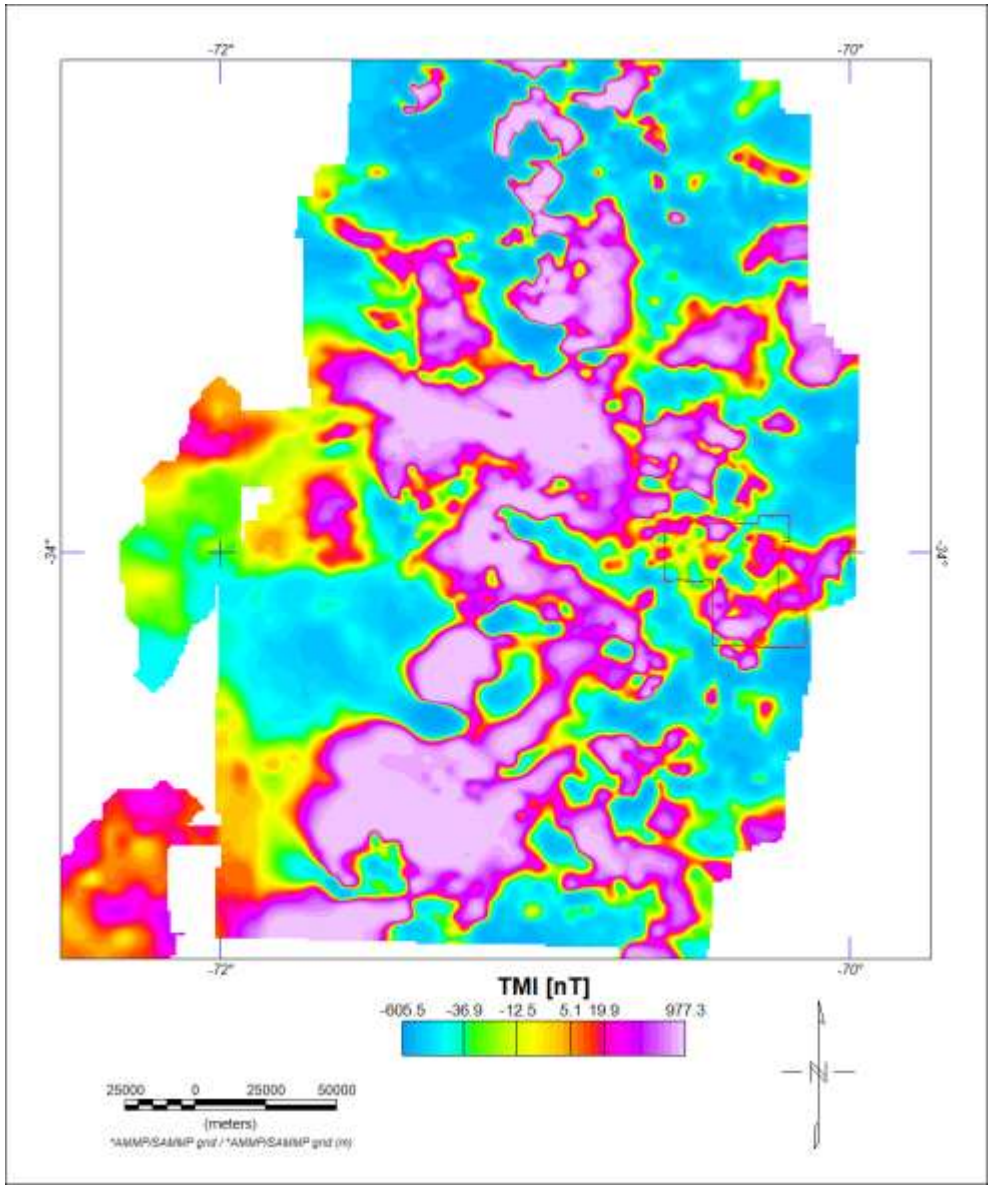
Caso 1: Chile Central



TMI Data
Altura: 900 m (nominal)

Espaciamiento de lineas: 4 km

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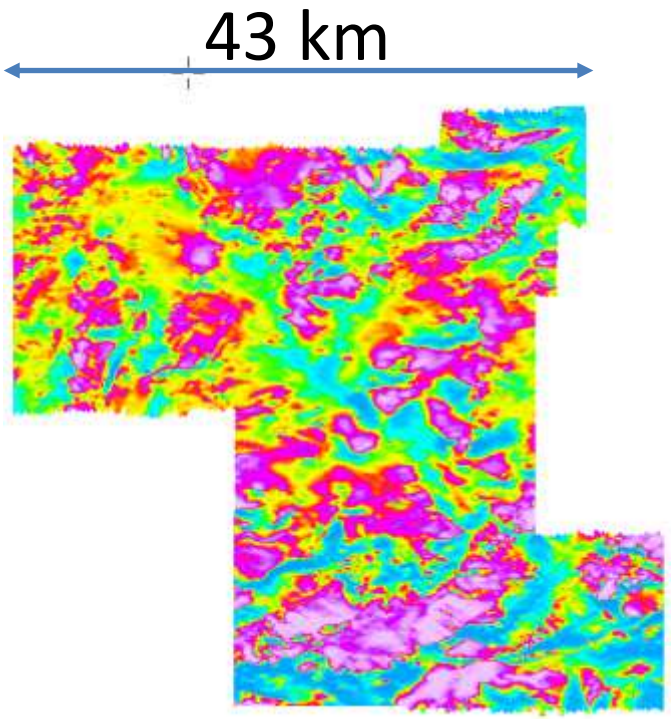
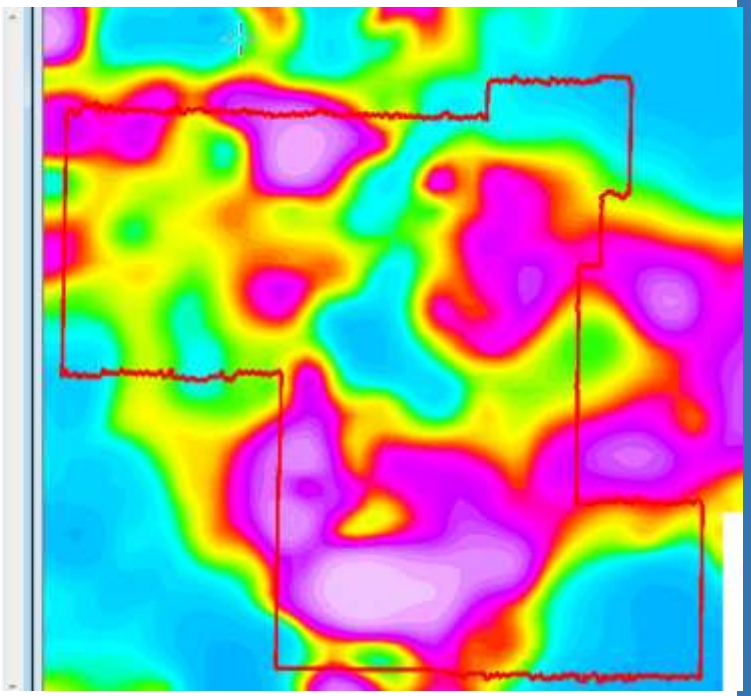
Caso 1: Chile Central





Alta Resolución
Altura: 70 m
Espaciamiento: 200 m

Levantamiento Regional
Altura: 900 m
Espaciamiento: 4000 m

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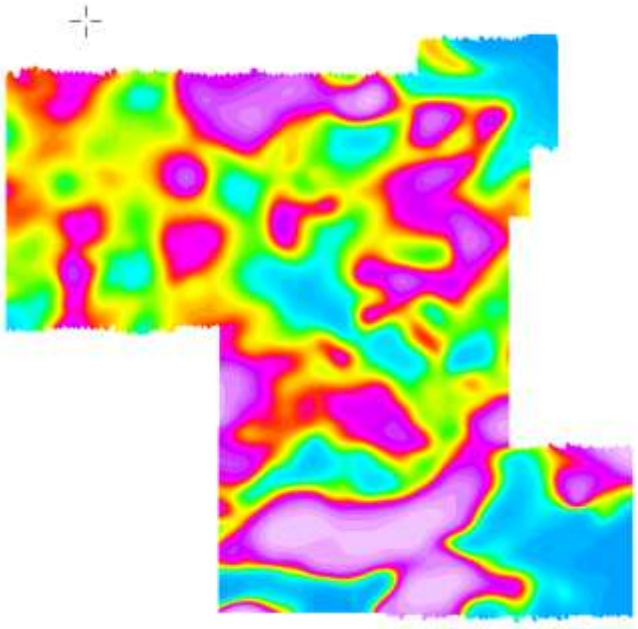
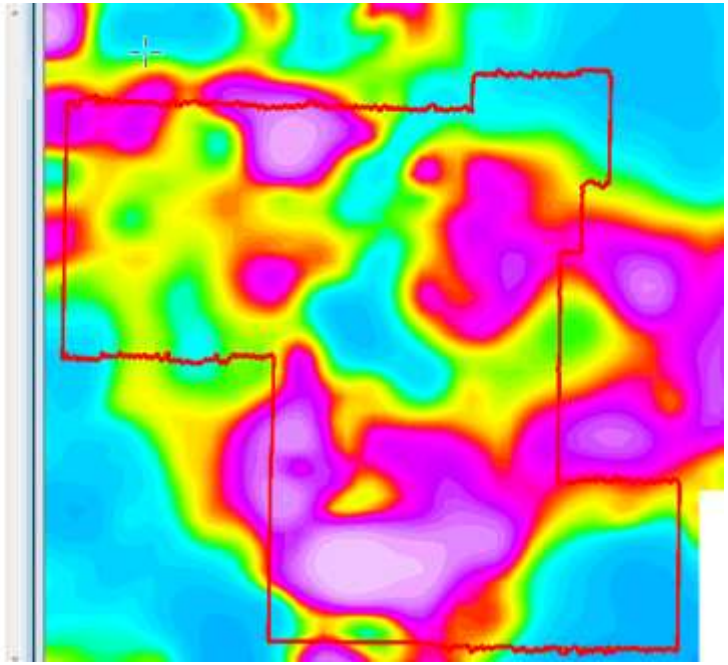
Caso 1: Chile Central

43 km





Alta Resolución
Altura: 70 m
Espaciamiento: 200 m

Continuado 1 km hacia arriba

Levantamiento Regional
Altura: 900 m
Espaciamiento: 4000 m

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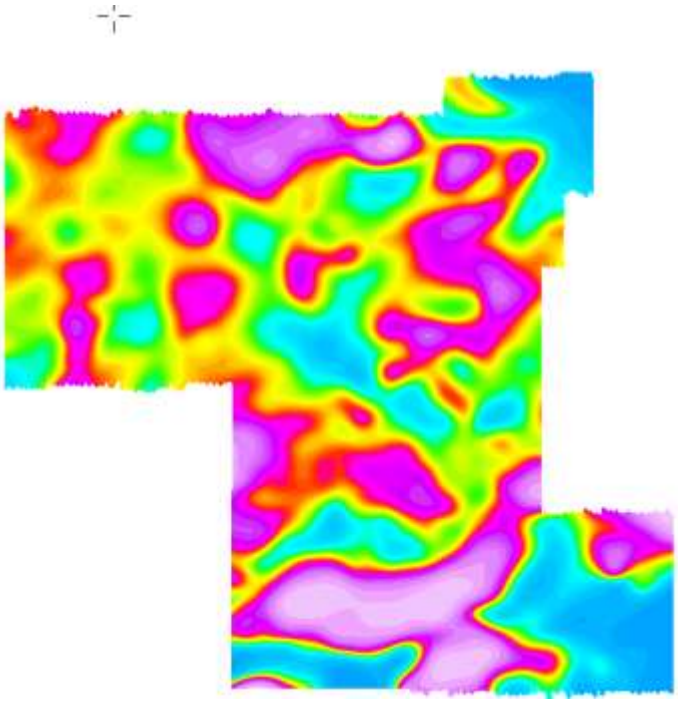
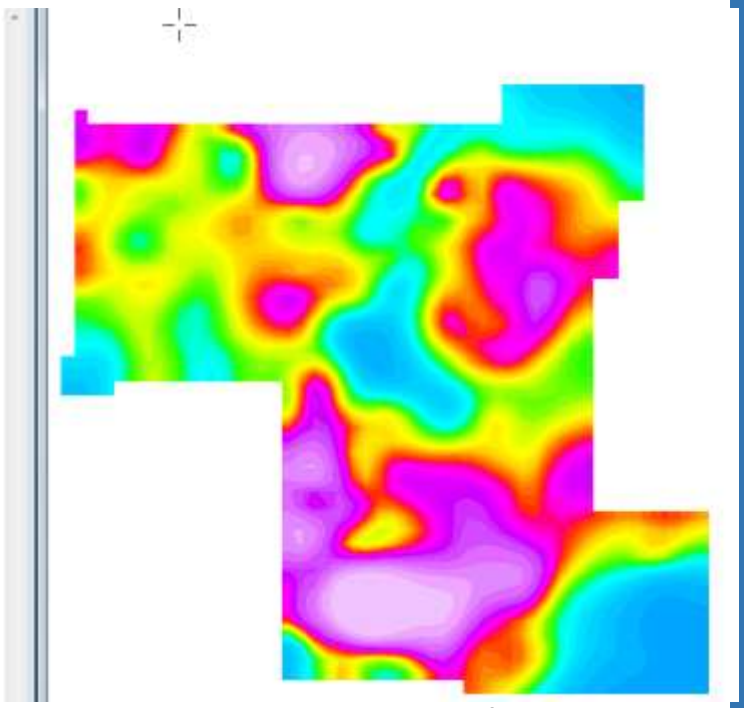
Caso 1: Chile Central

43 km





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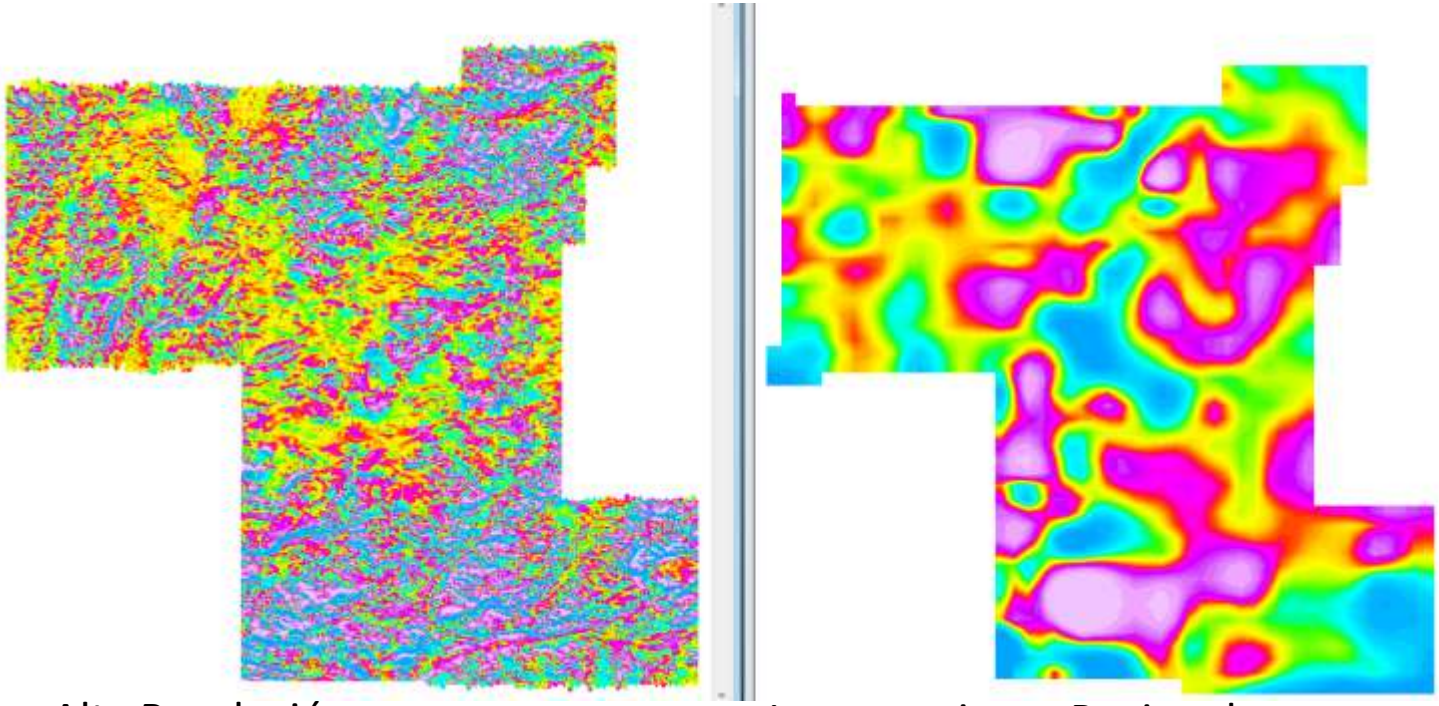
Caso 1: Chile Central

43 km



Alta Resolución
Altura: 70 m
Espaciamiento: 200 m

Levantamiento Regional
Altura: 900 m
Espaciamiento: 4000 m

Primera derivada vertical del campo, para mapeo estructural

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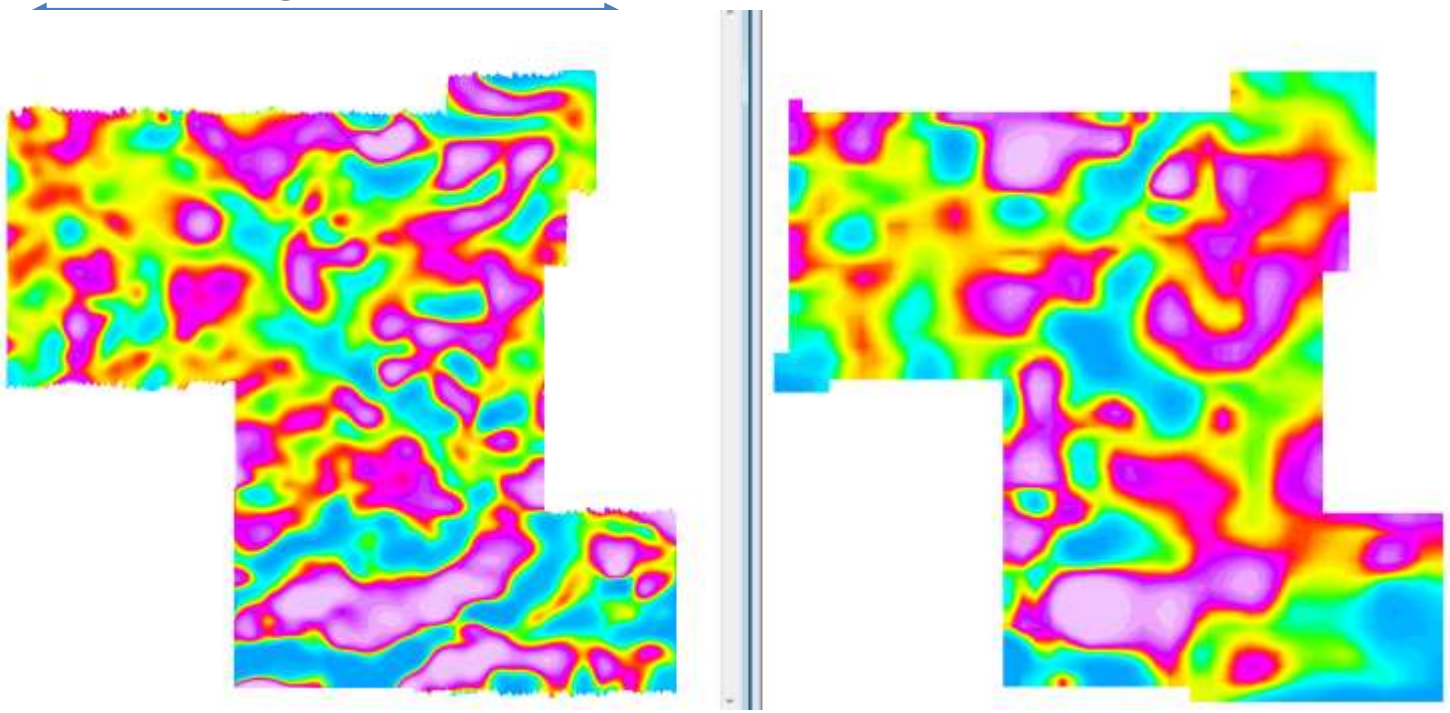
Caso 1: Chile Central

43 km



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Continuado 1 km hacia arriba

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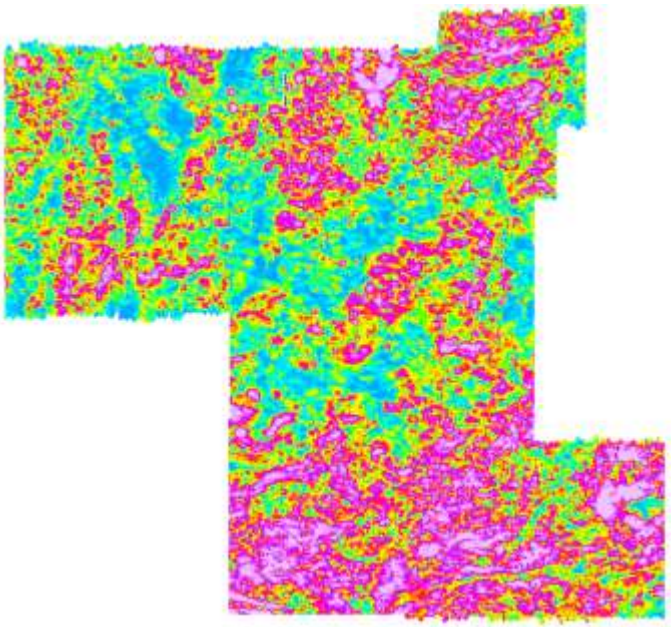
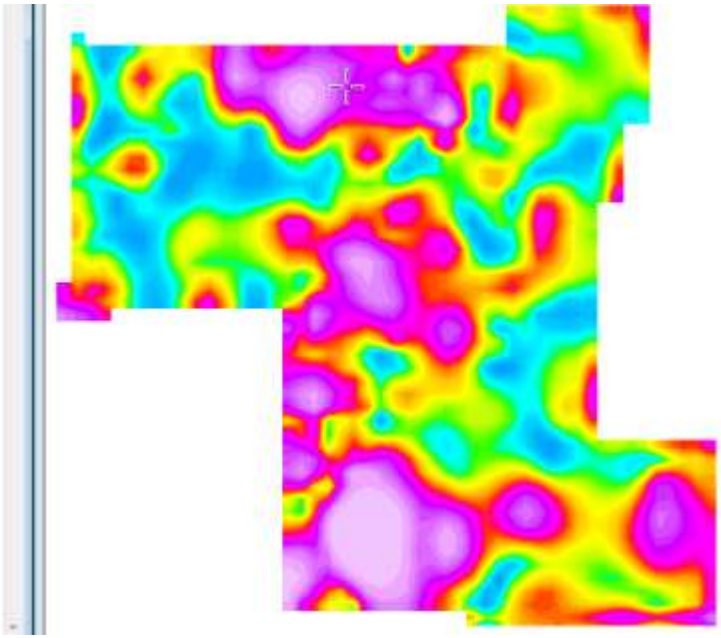
43 km





Alta Resolución
Altura: 70 m
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Levantamiento Regional
Altura: 900 m
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Amplitud de la señal analítica, para mapeo litológico

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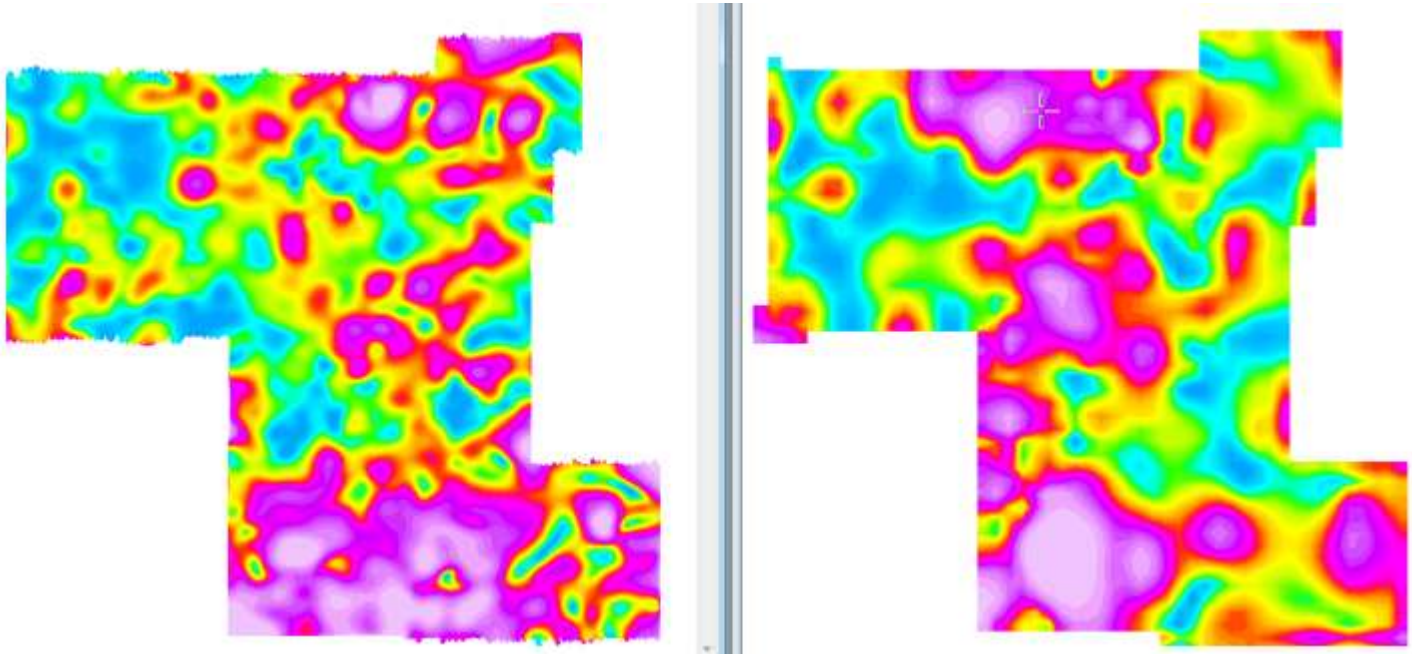
Caso 1: Chile Central

43 km



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Continuado 1 km hacia arriba

Amplitud de la señal analítica, para mapeo litológico

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Caso 1: Chile Central Conclusiones

- El levantamiento “nuevo” muestra mejor resolución incluso cuando los datos se continúan 1 km hacia arriba
- La definición de estructuras y litologías es altamente superior en un levantamiento con espaciamiento <500m

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Caso 2: Norte de Chile

- Zona de Calama, incluyendo franja Oligoceno con numerosos pórfidos-Cu
- Espaciamiento: 500 m
- Altura: ~ 120 m
- Incluye datos radiométricos (en zona árida!)

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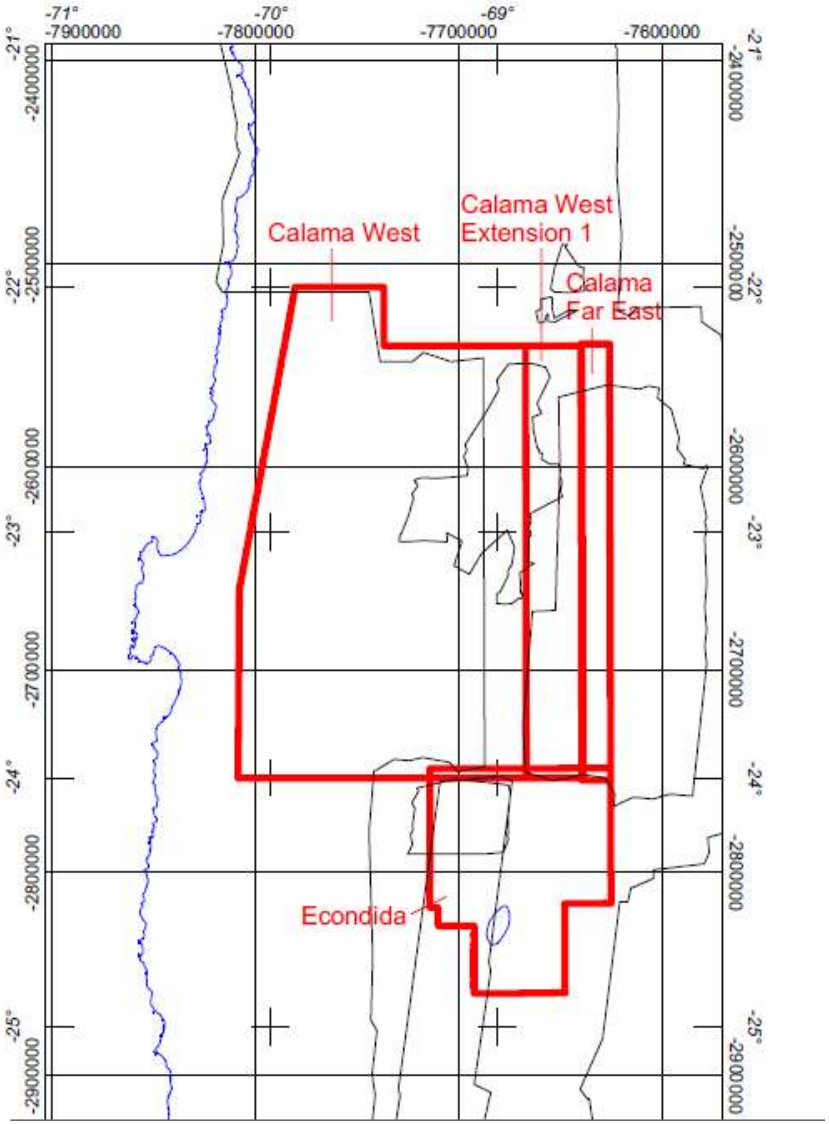
Caso 2: Norte de Chile

Calama West
500 m line spacing
56,123 line km

Calama West Extension 1
500 m line spacing
10,985 lin km

Calama Far East
500 m line spacing
5,618 line km

Escondida
250 m line spacing
29,424 line km



Levantamientos multicliente (PGW/Scintrex-Fugro), financiados por 3 compañias mineras

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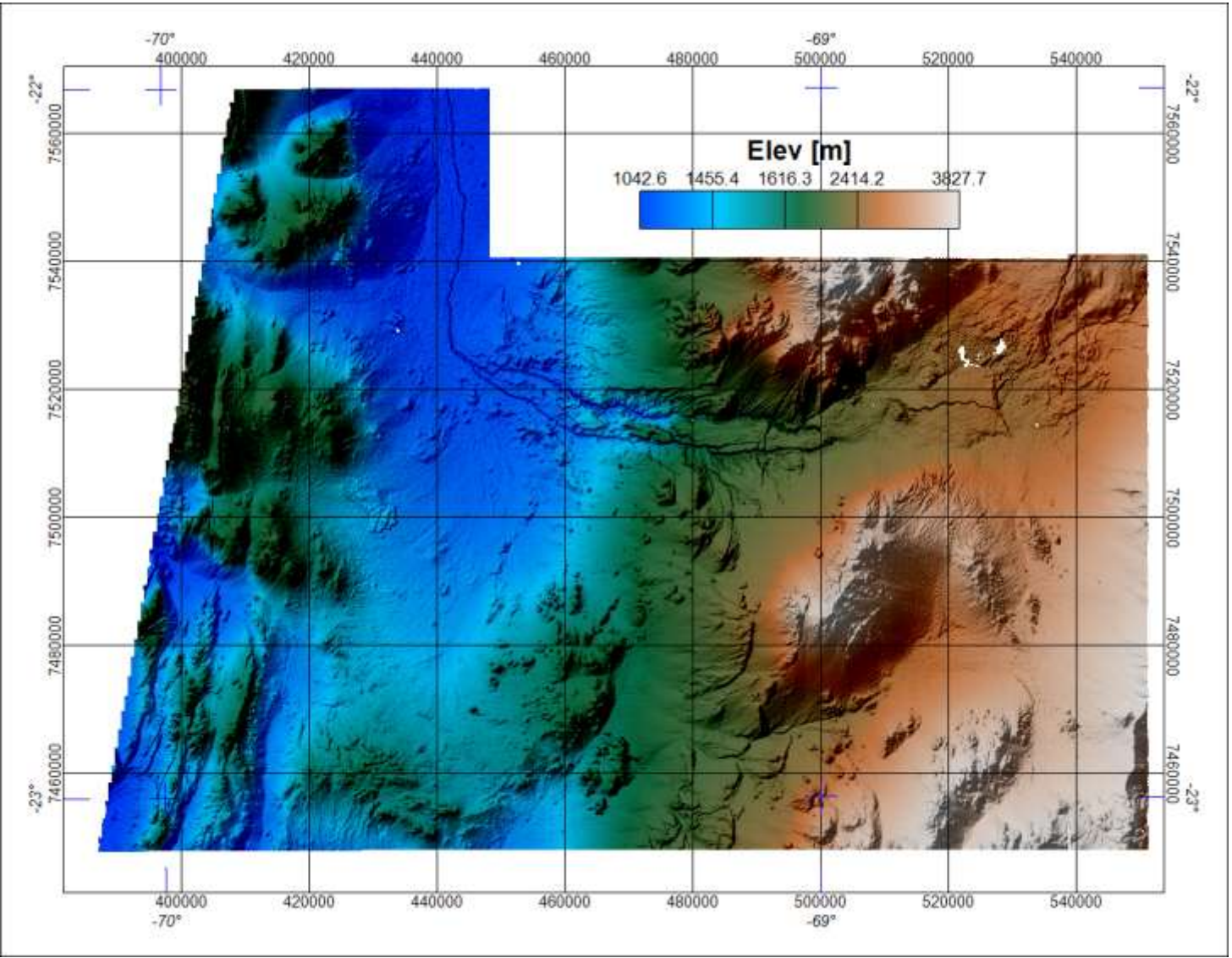
Caso 2: Norte de Chile



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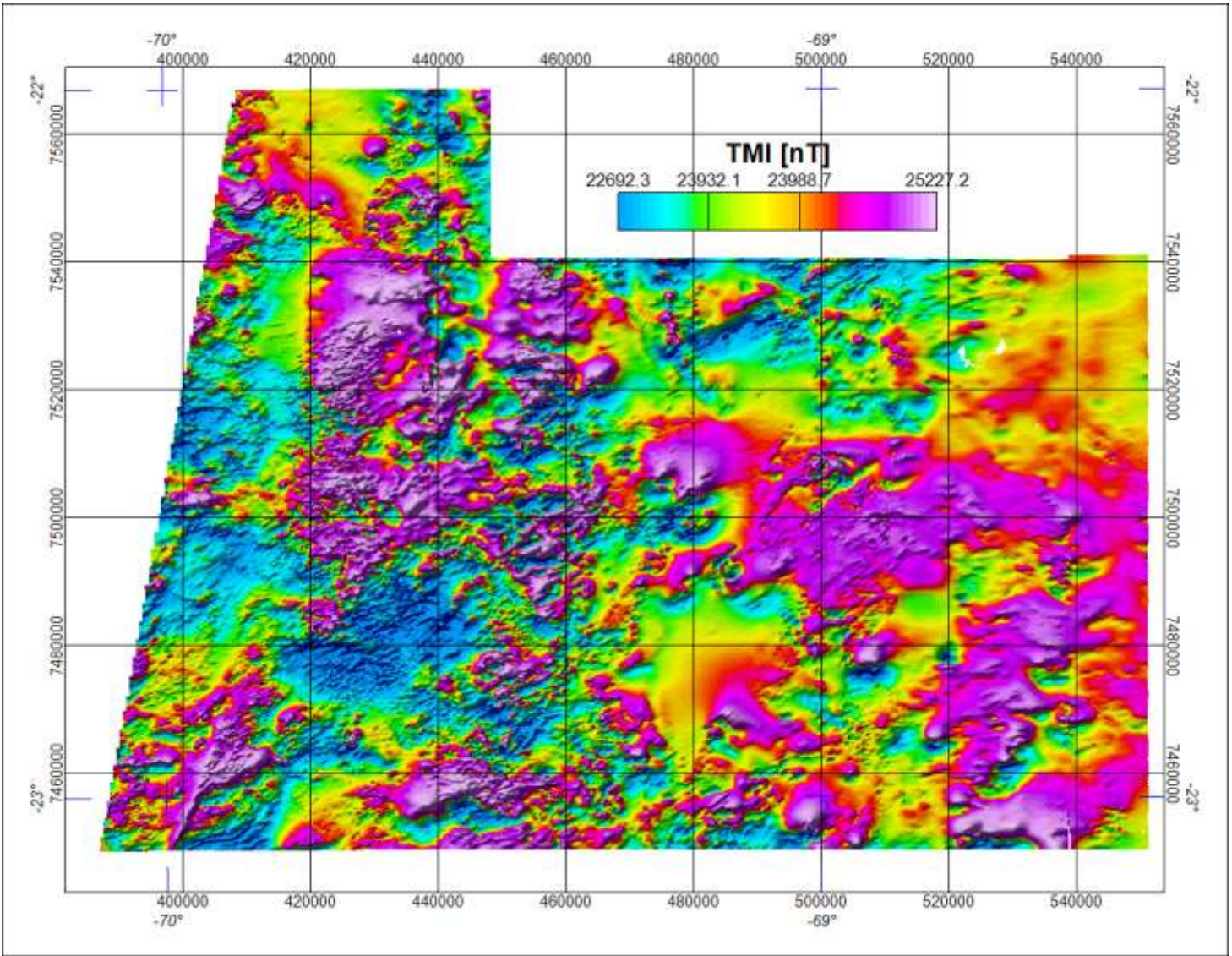
Caso 2: Norte de Chile



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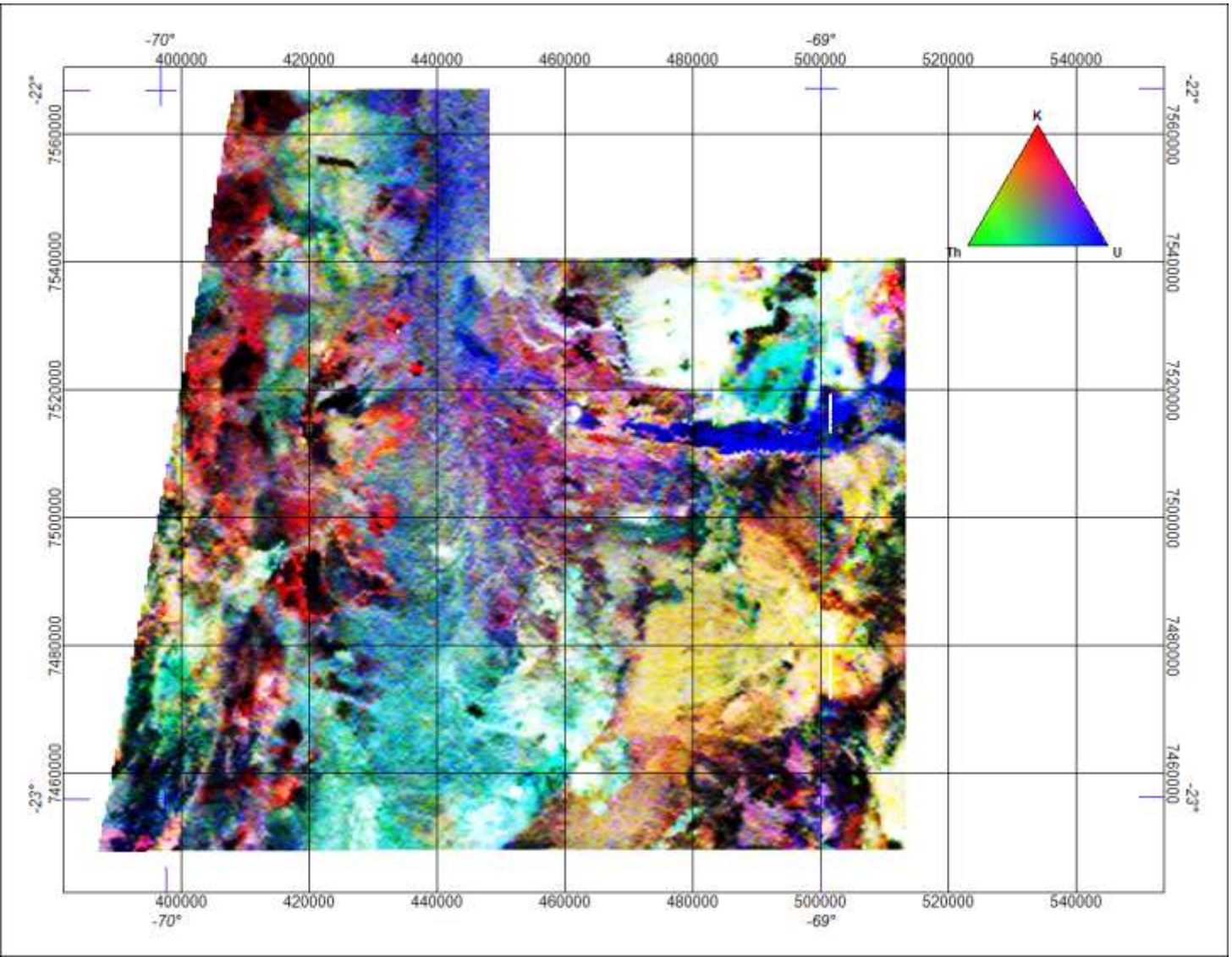
Caso 2: Norte de Chile



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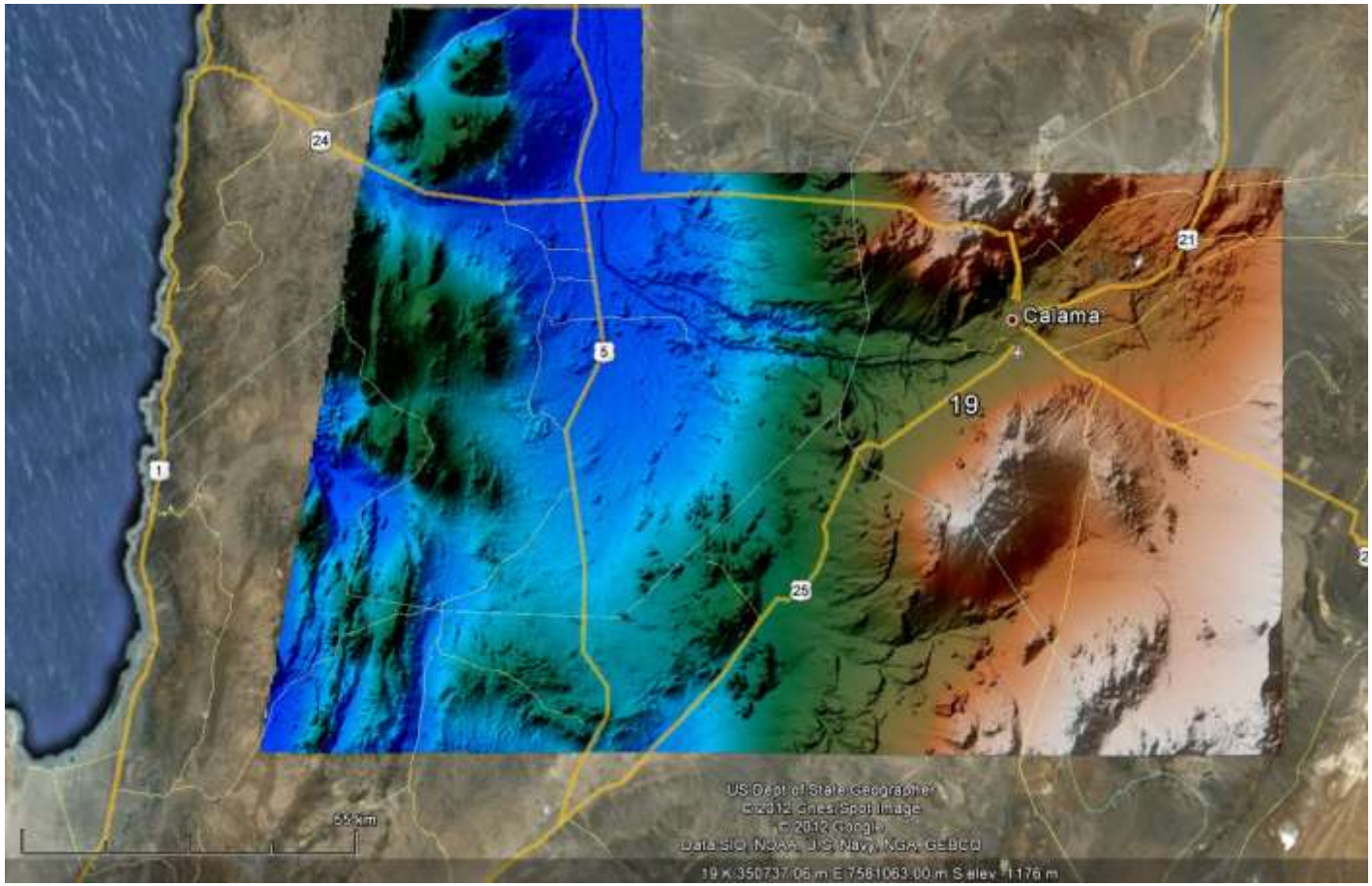

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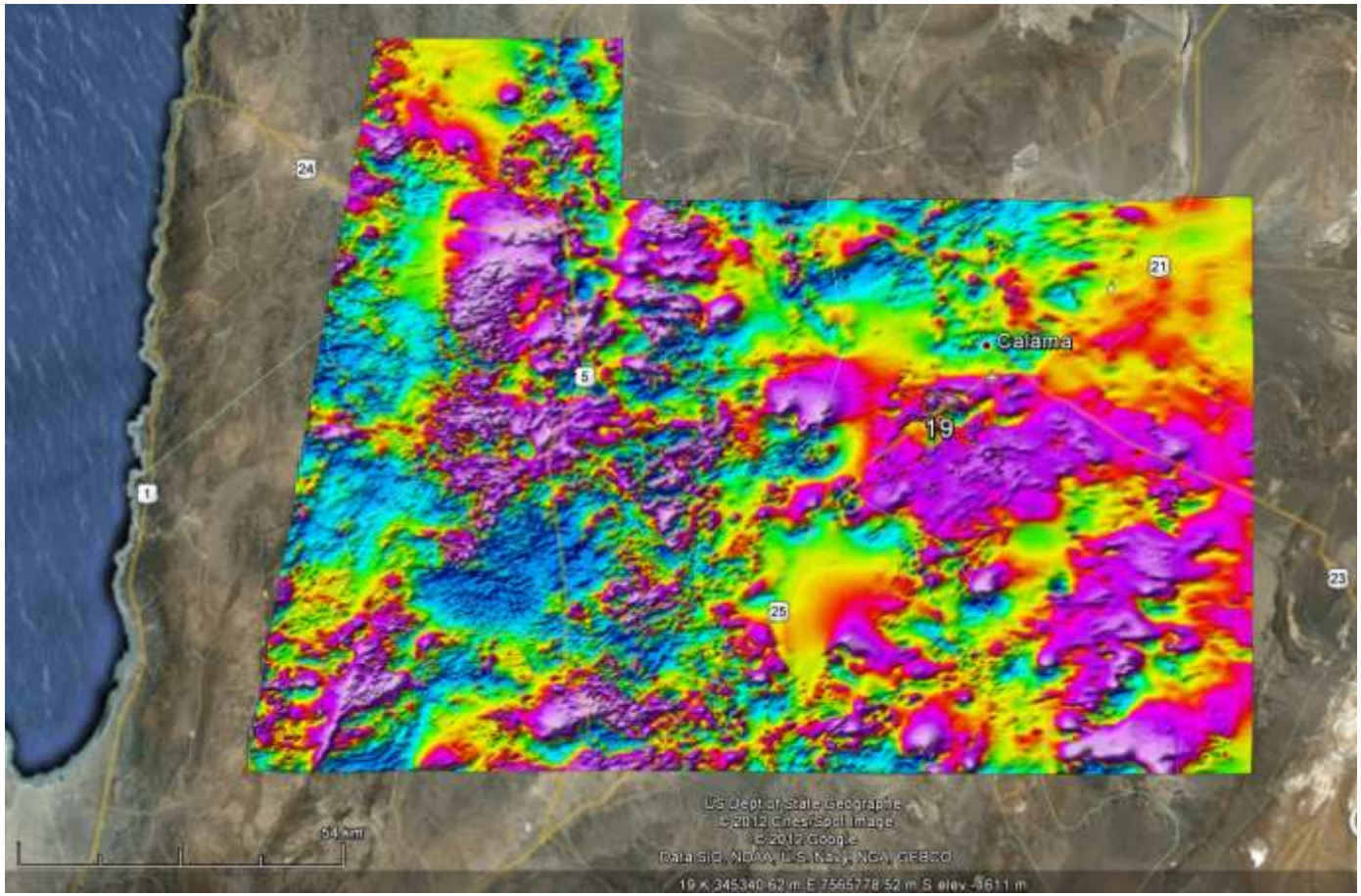

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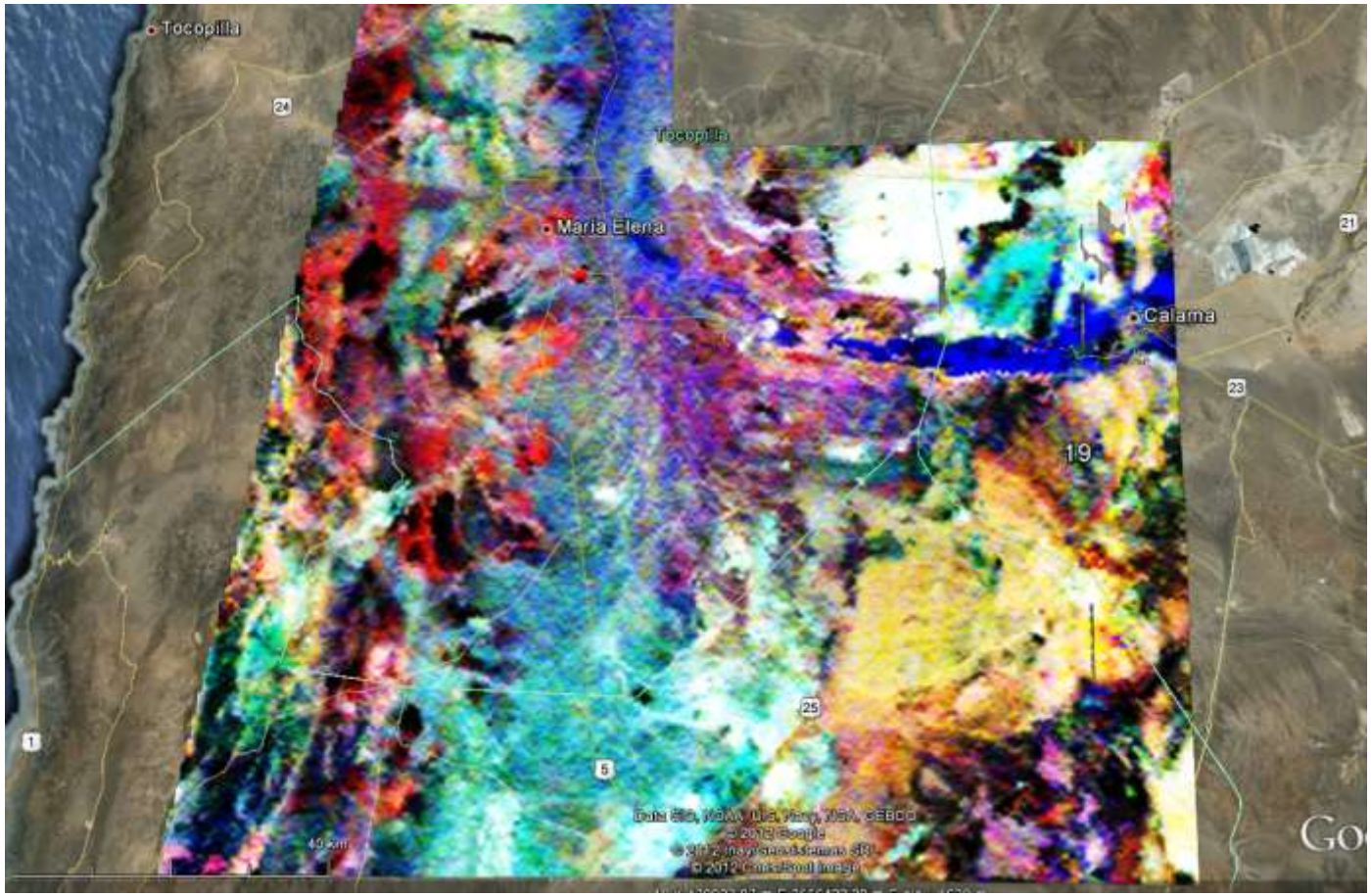

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Caso 2: Norte de Chile
Conclusiones

- La resolución de 500 m es suficiente para entregar invaluable información estructural y litológica;
- Los datos radiométricos muestran gran definición de unidades, a pesar de la cobertura sedimentaria
- El costo de volar Mag+Spec es ~30%-50% más que volar sólo Mag, pero el valor de la información lo justifica

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Nigeria's Nationwide High Resolution Airborne Geophysical Surveys

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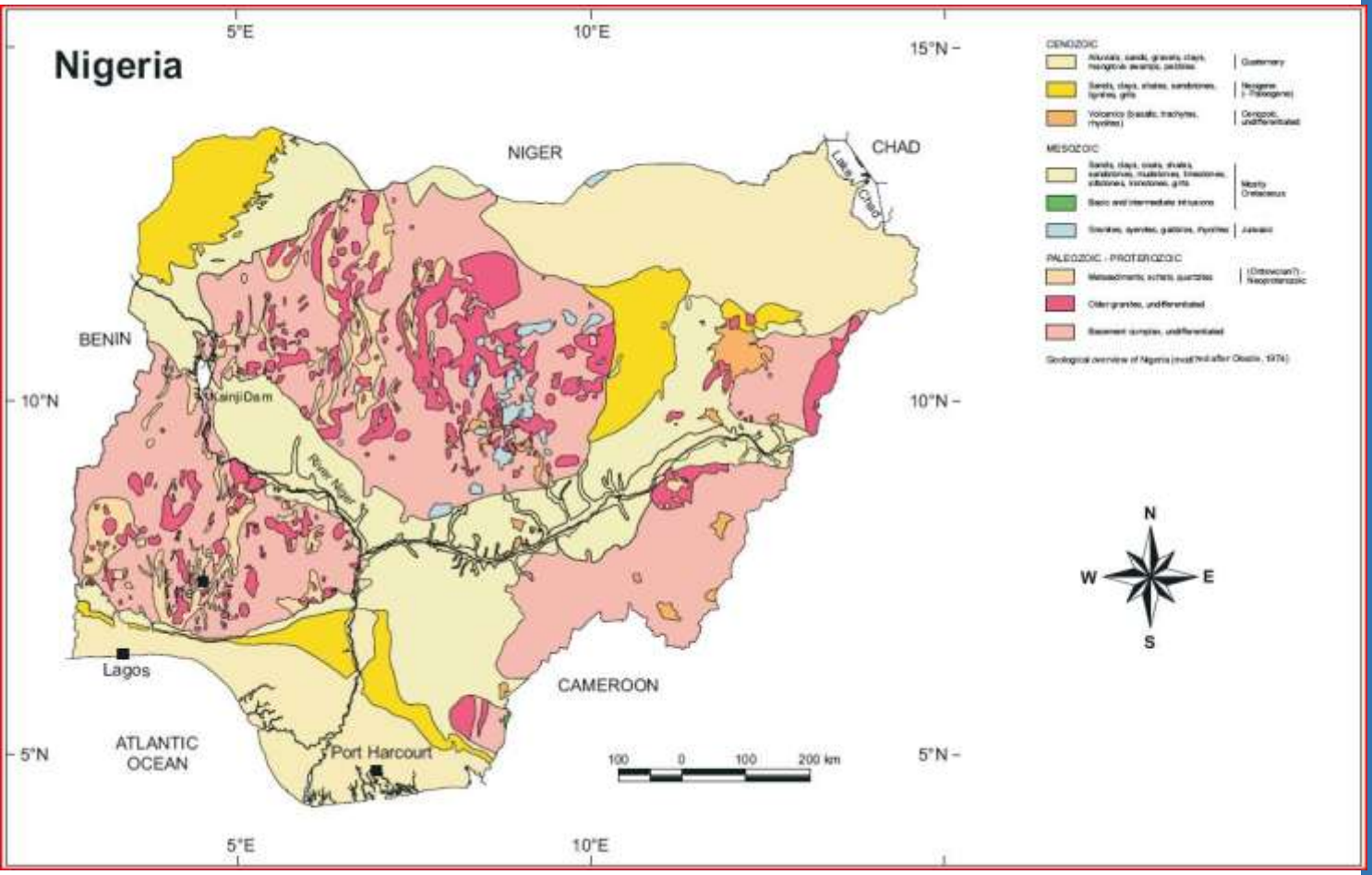
Nigerian Geology



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Survey Index

All flown by Fugro Airborne Surveys

>2 million line-km

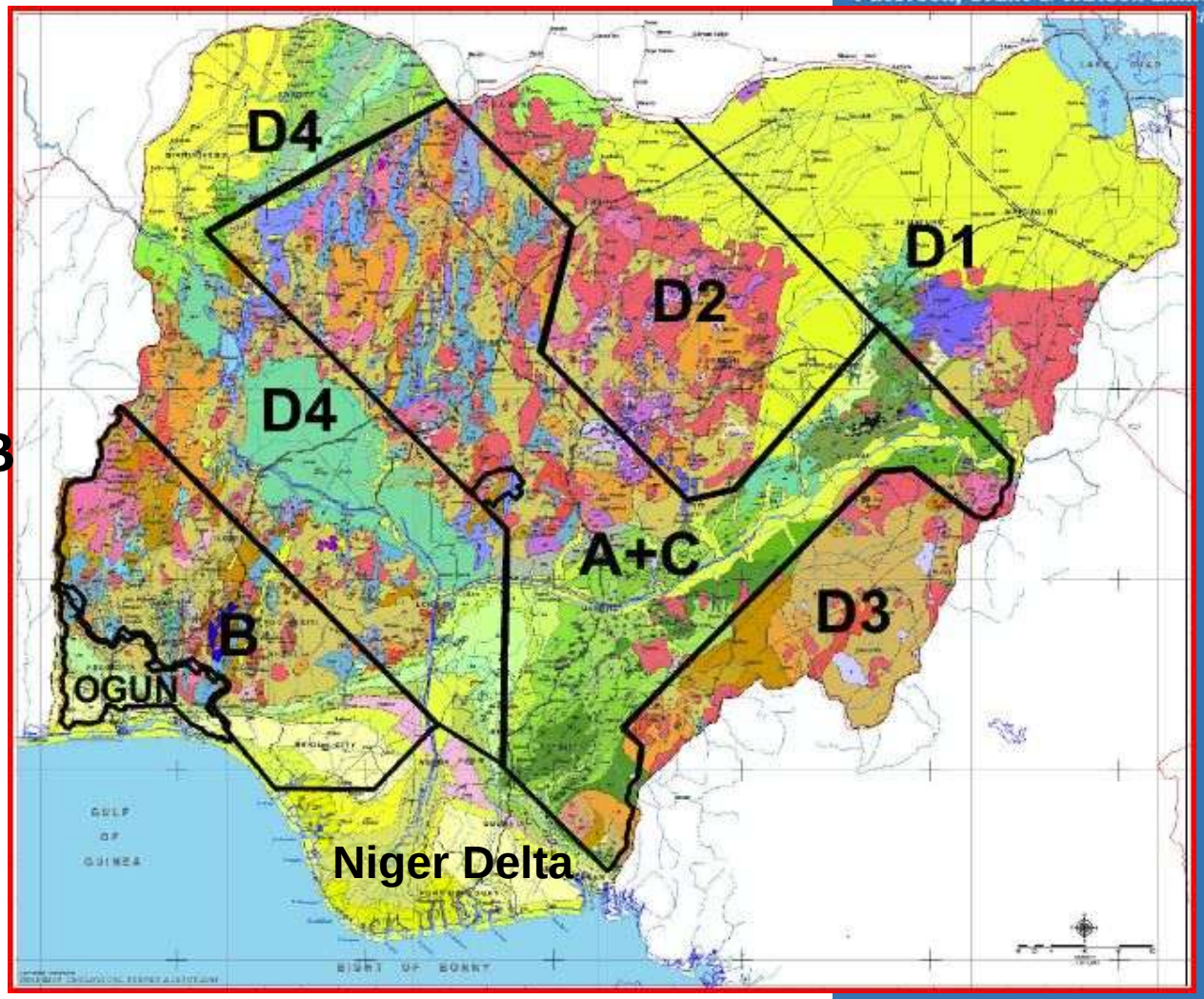
2003 – Ogun State

2005-07 – A+C and B

2007-09 – D1, D2, D3 and D4

2010 – Niger Delta

EM blocks in selected areas



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Survey Specifications

- **Triaxial magnetic gradiometer – two wingtip and single tail sensors – 10 Hz sampling (~7.5 m)**
- **Gamma-ray spectrometer – 1 Hz sampling (~75 m)**
- **500 m line spacing – NW-SE orientation**
- **5 km control line spacing – NE-SW orientation**
- **Nominal 80 m terrain clearance on pre-planned drape surface**
- **Measured horizontal gradients and gradient-enhanced gridding**
- **Radiometric NASVD noise reduction**

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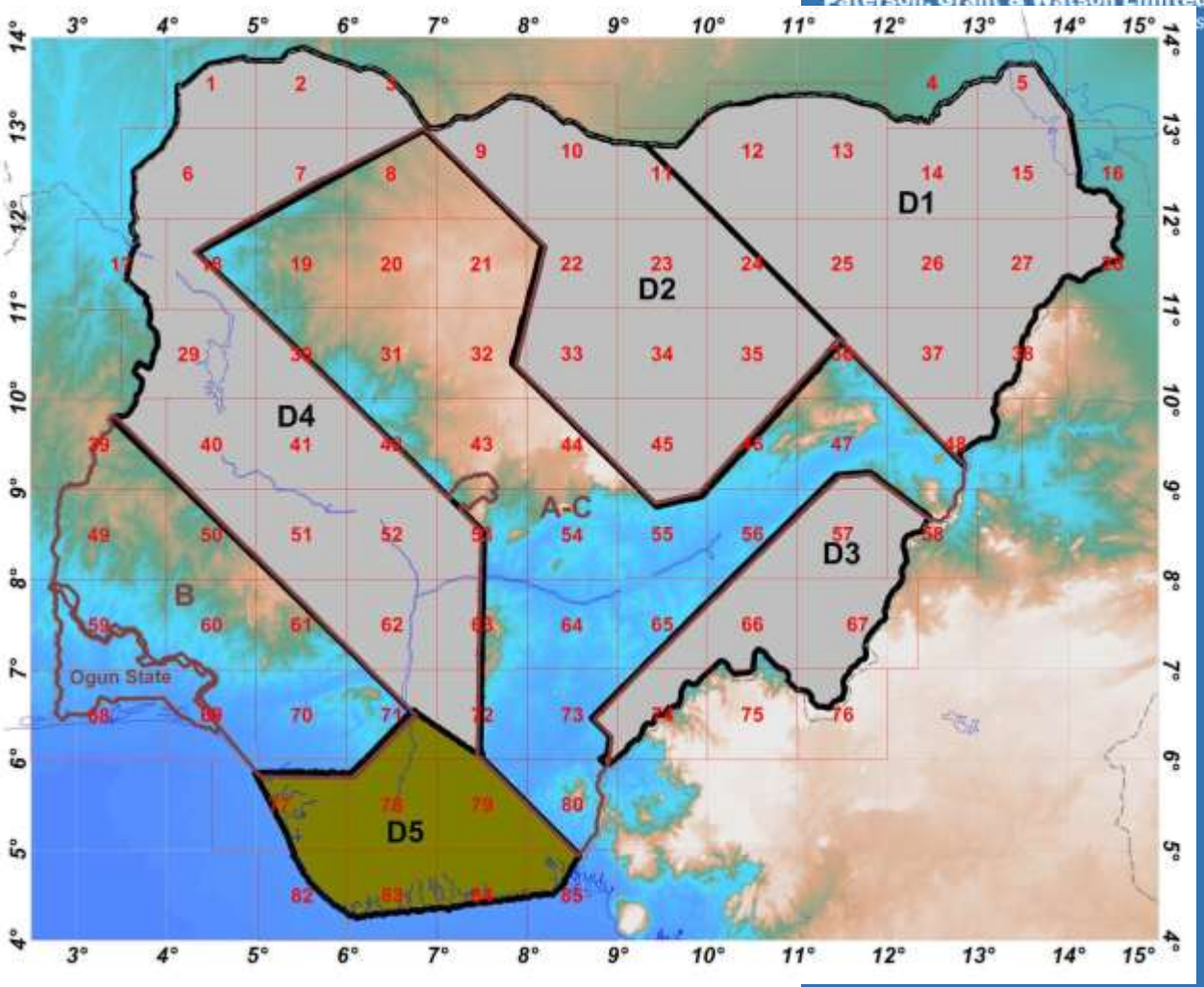
Interpretation Index

Phase I – Fugro
A+C and B

Phase II – PGW
D1, D2, D3 and D4

D5 – PGW

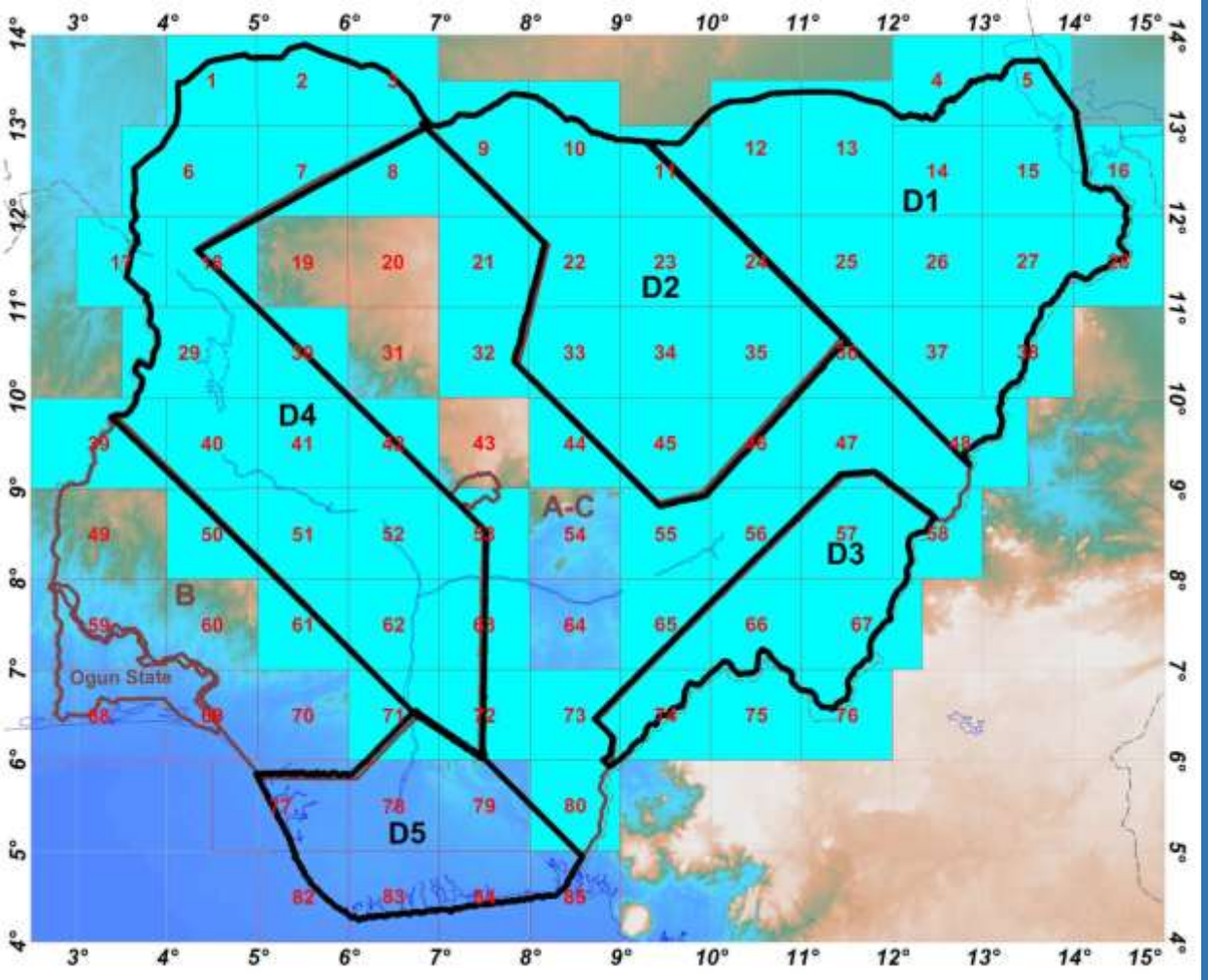
Integration – PGW
Phase 1, Phase 2
and Ogun State



Geophysical Map Index

1:250,000

- **5 magnetic products**
- **Ternary radiometric image**
- **Litho-structural interpretation**
- **Regolith interpretation**
- **Report for each sheet**
- **Niger Delta treated separately**



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Interpretation Index

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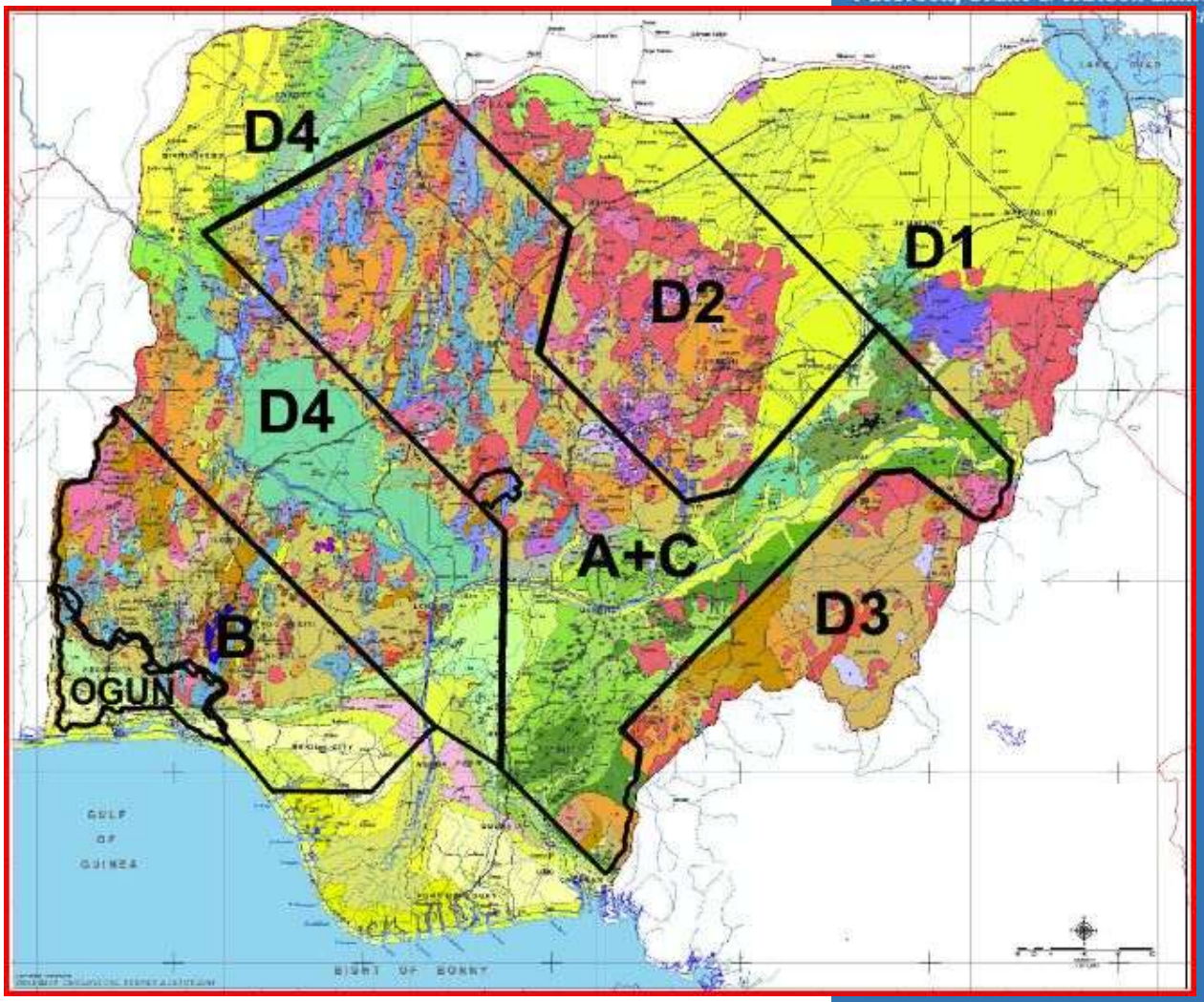
Phase I – Fugro
A+C and B

Phase 2 – PGW
D1, D2, D3 and D4

Integration – PGW
Phase 1, Phase 2
and Ogun State



PGW Interpretation Project

- **Process magnetic data to assist interpretation**
- **Prepare derived products from magnetic, radiometric, terrain and Landsat data**
- **Grid and profile-based magnetic modeling**
- **Phase II blocks interpreted at 1:250,000 scale**
- **Nationwide merging of geophysical grids**
- **Synoptic nationwide interpretation at 1:1 million scale**

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PGW Training

- **Processing and modeling of geophysical data**
- **Interpretation of geophysical data**
- **Hands-on (Abuja, Kaduna, Toronto)**
- **GIS and cartography related to geophysical interpretation**

- **Ground truth of selected geophysical anomalies and geological features**

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PGW Training

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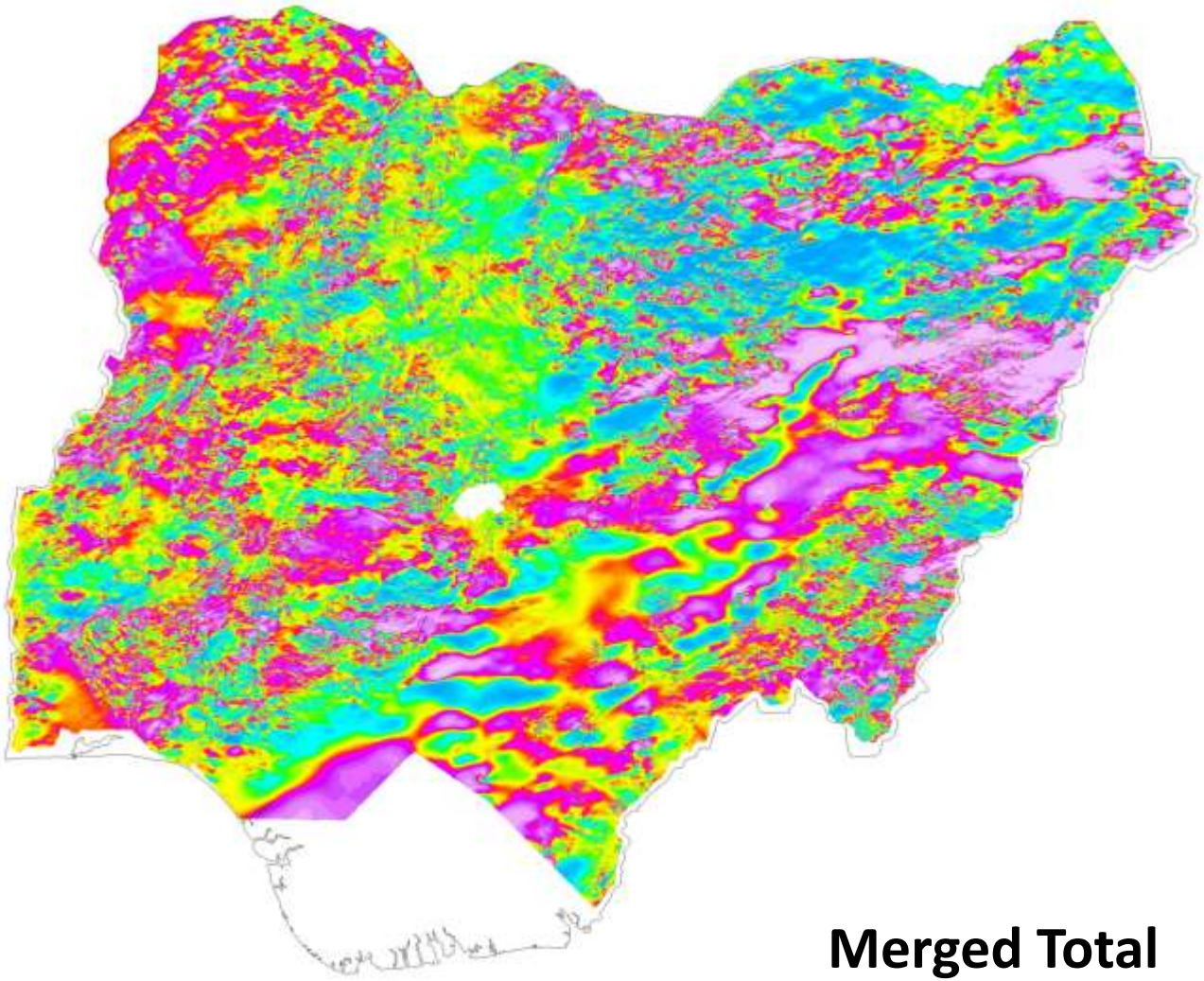
Magnetic Data Processing



Merged Total Magnetic Intensity

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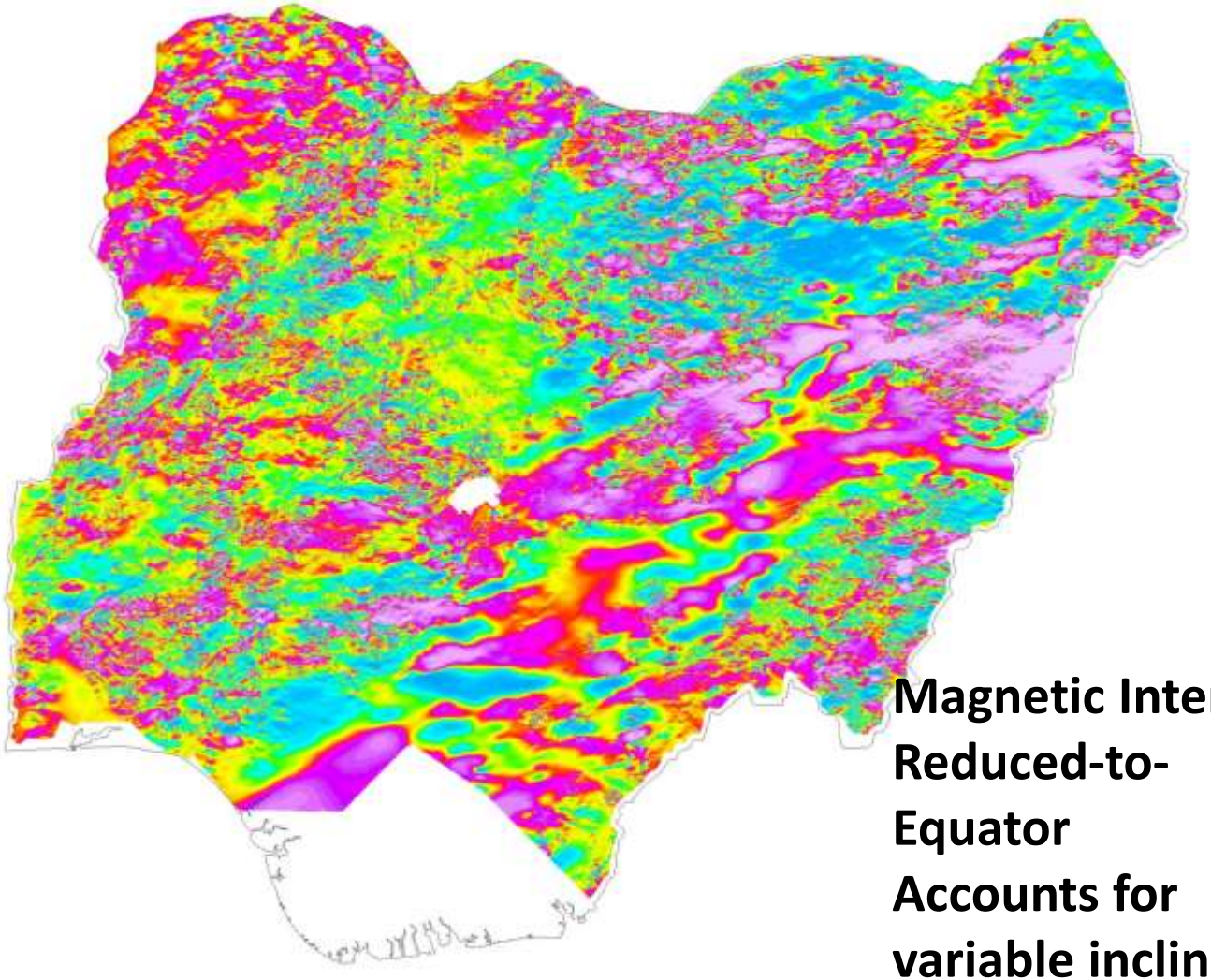
Magnetic Data Processing



Magnetic Intensity Reduced-to-Equator Accounts for variable inclination and declination

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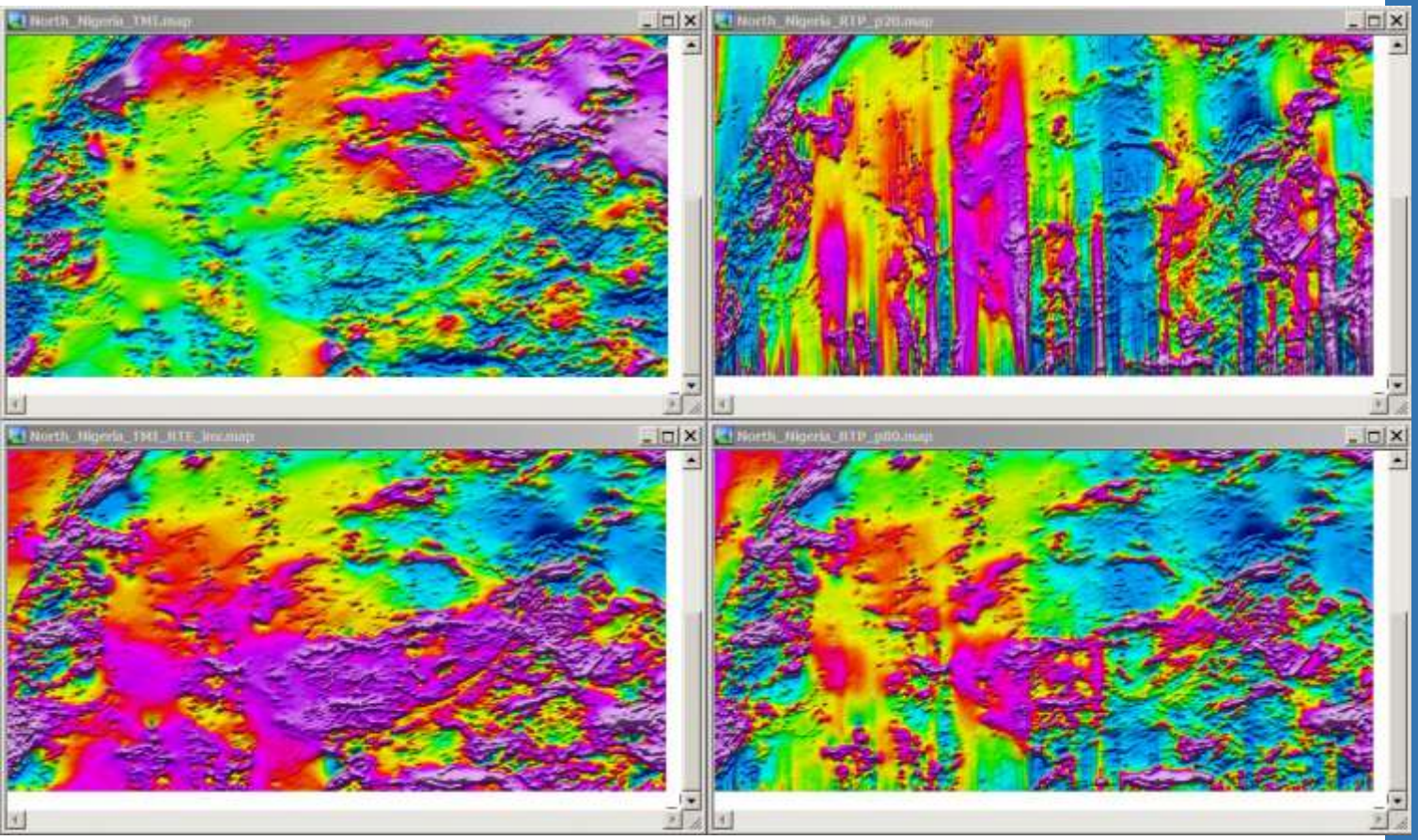
Magnetic Data Processing

RTP vs RTE



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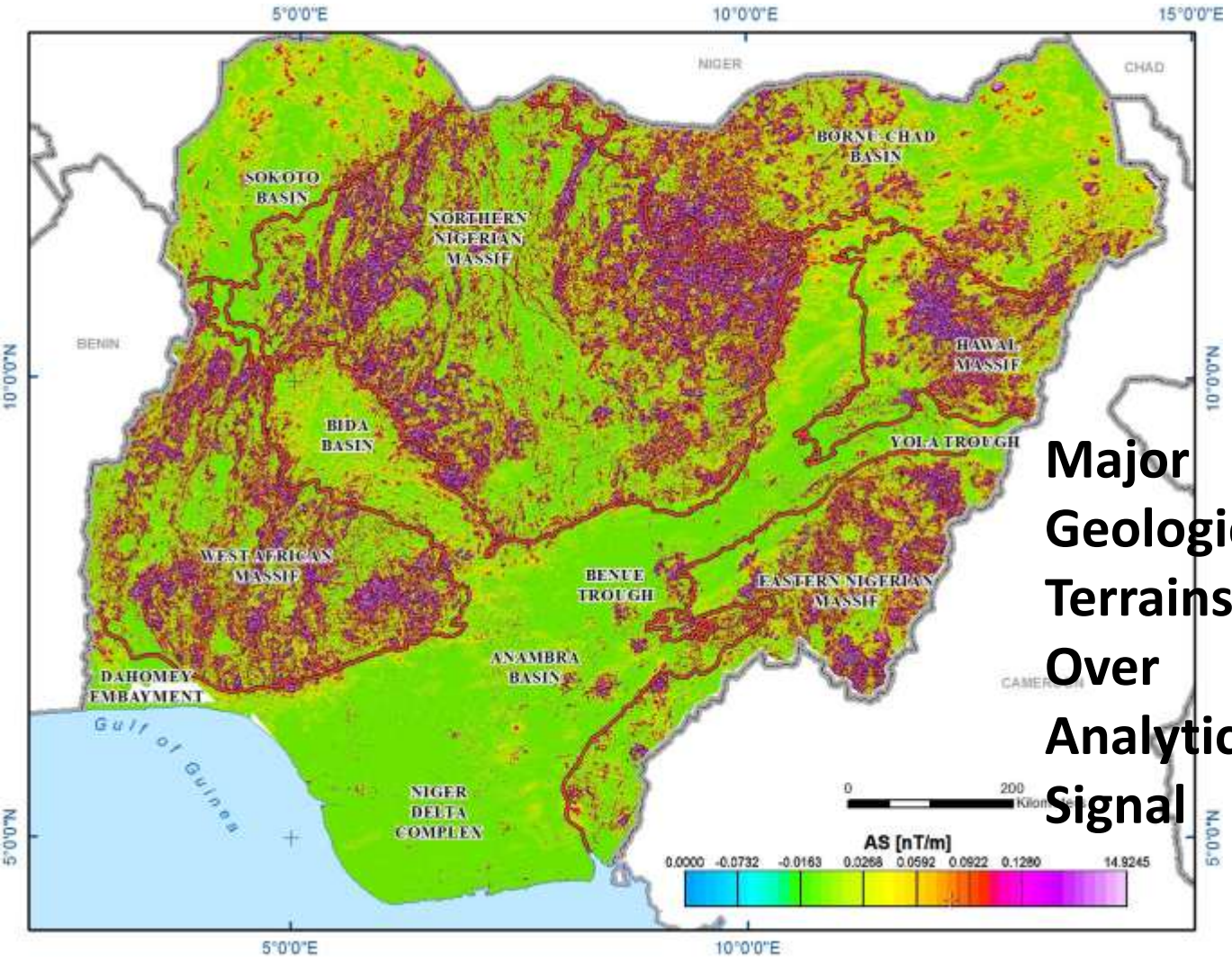
Magnetic Data Processing



Major Geological Terrains Over Analytic Signal

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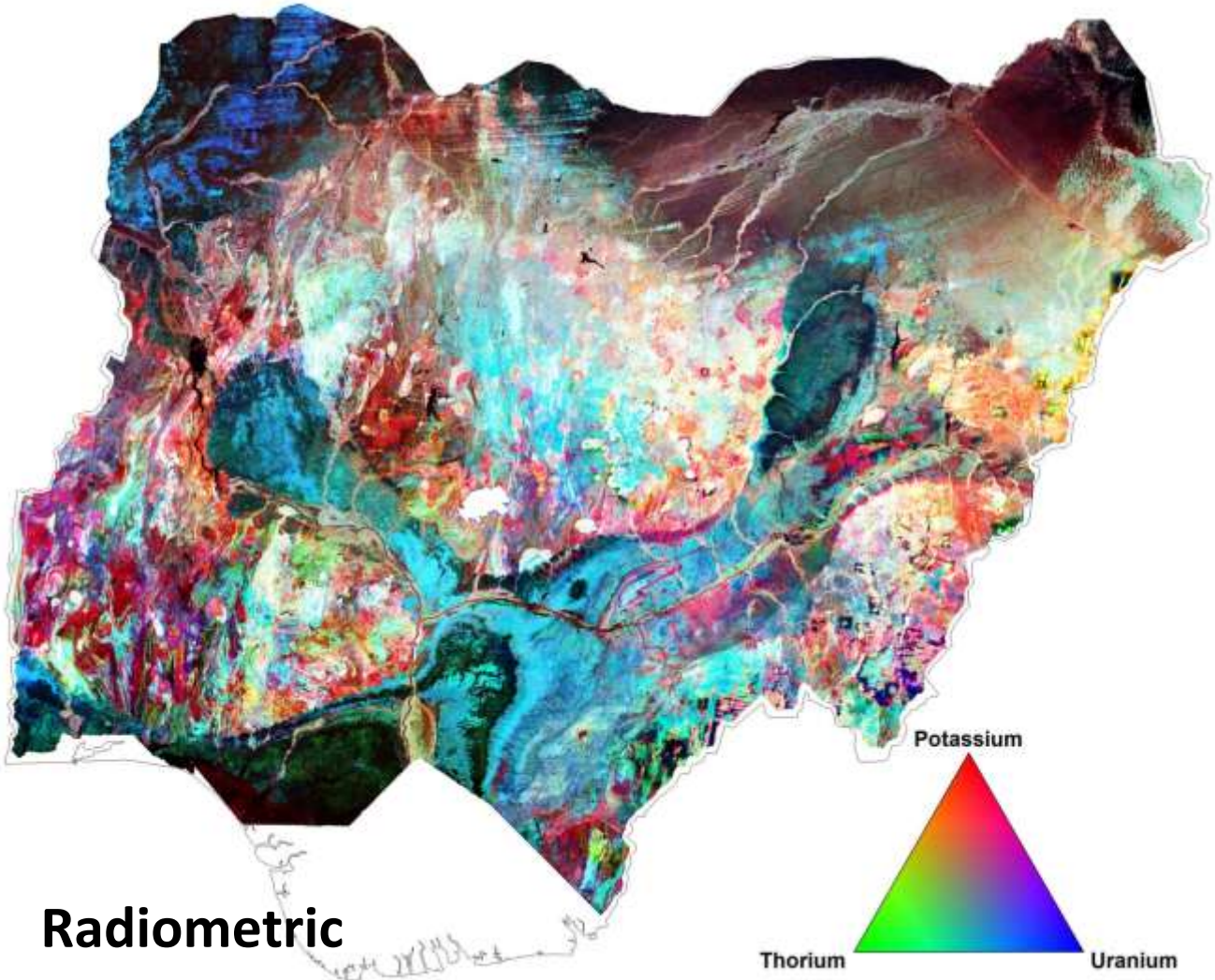
Radiometric Data Processing



Radiometric Ternary Image

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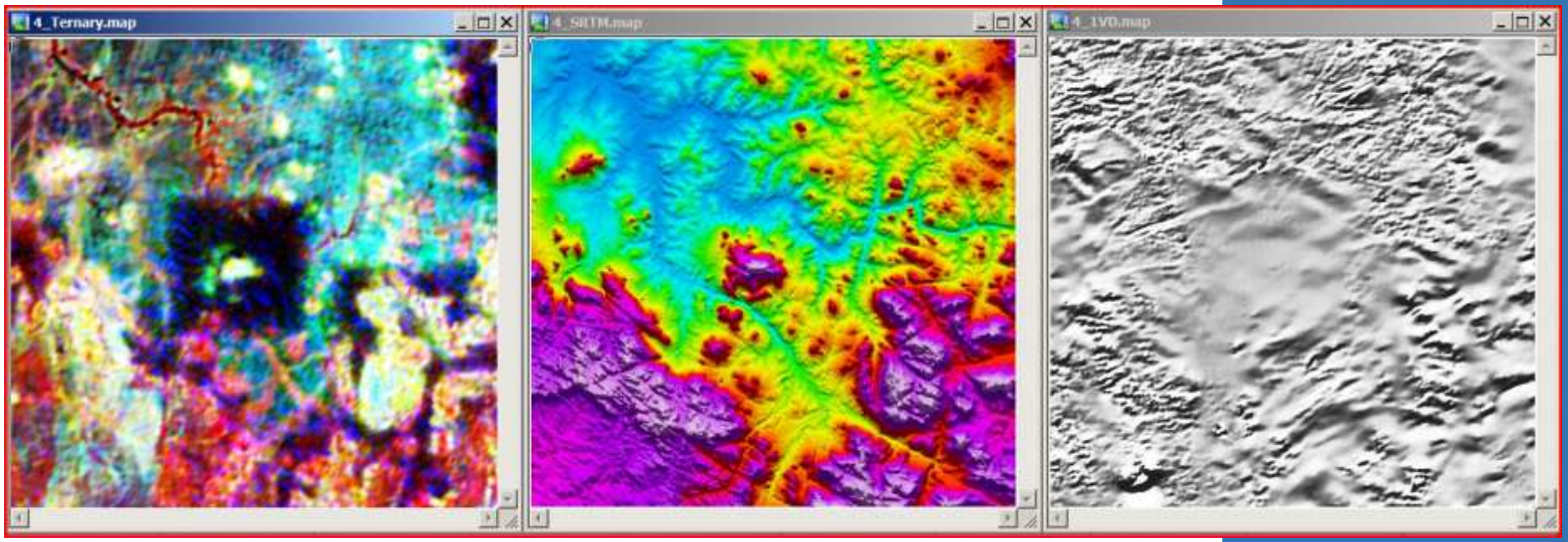
Radiometric Data Processing



Effect of drape surface in rough terrain:
Halo of null response over steep slopes

Radiometric Data Processing

Radiometric Ternary Image

Useful within the sedimentary basins in addition to hard rock

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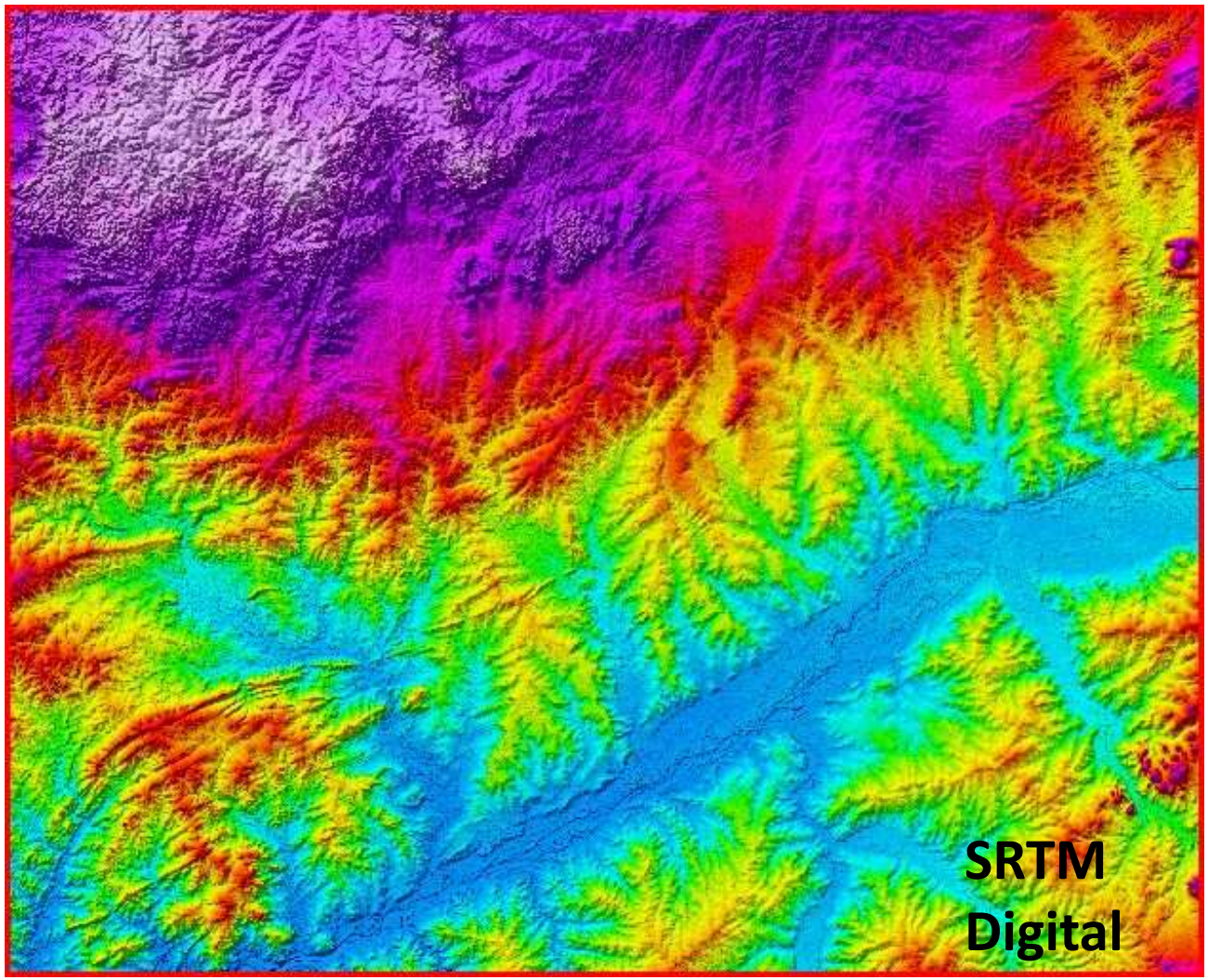
Radiometric Data Processing



SRTM Digital Topography

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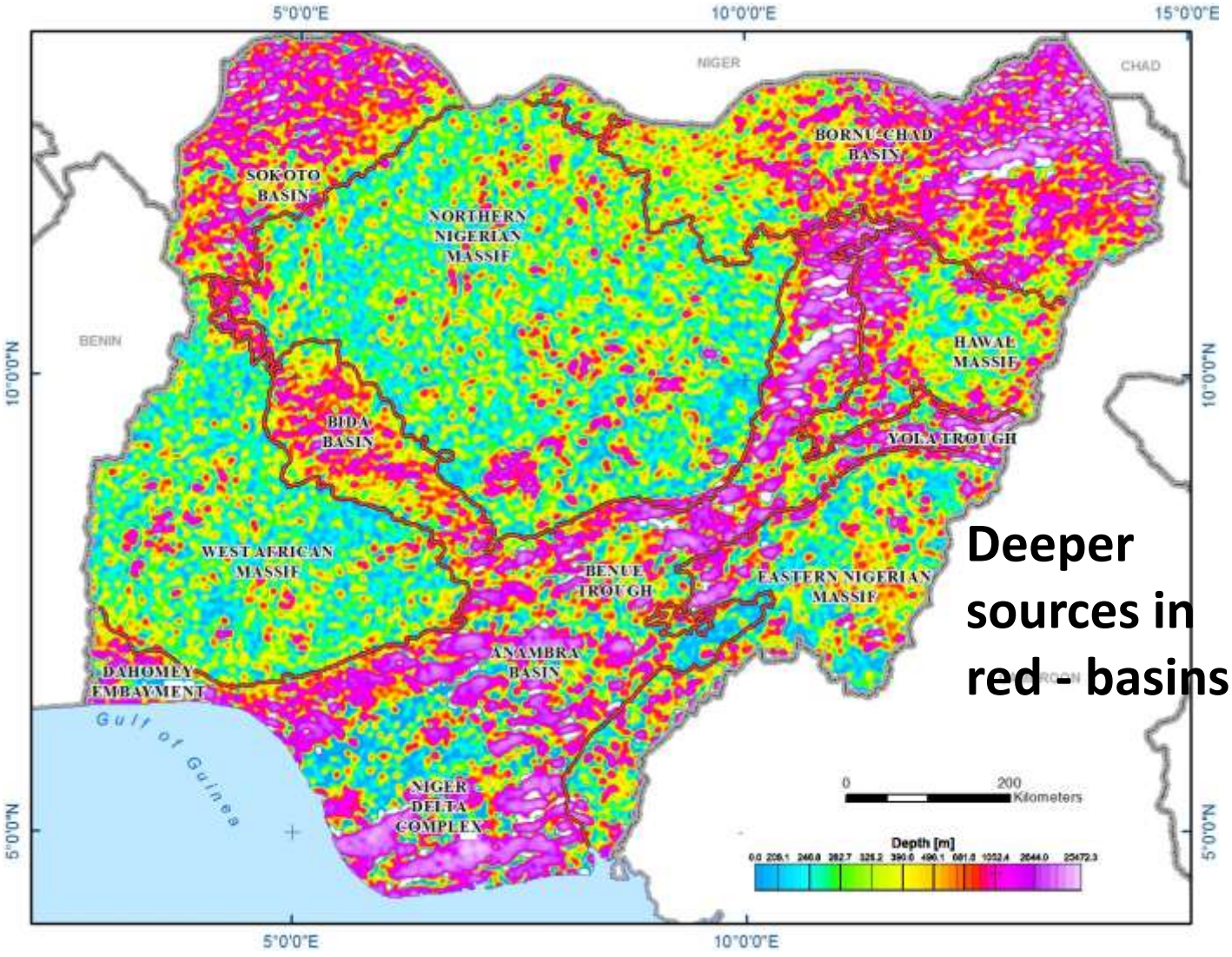
Depth to Magnetic Sources



Deeper sources in red - basins

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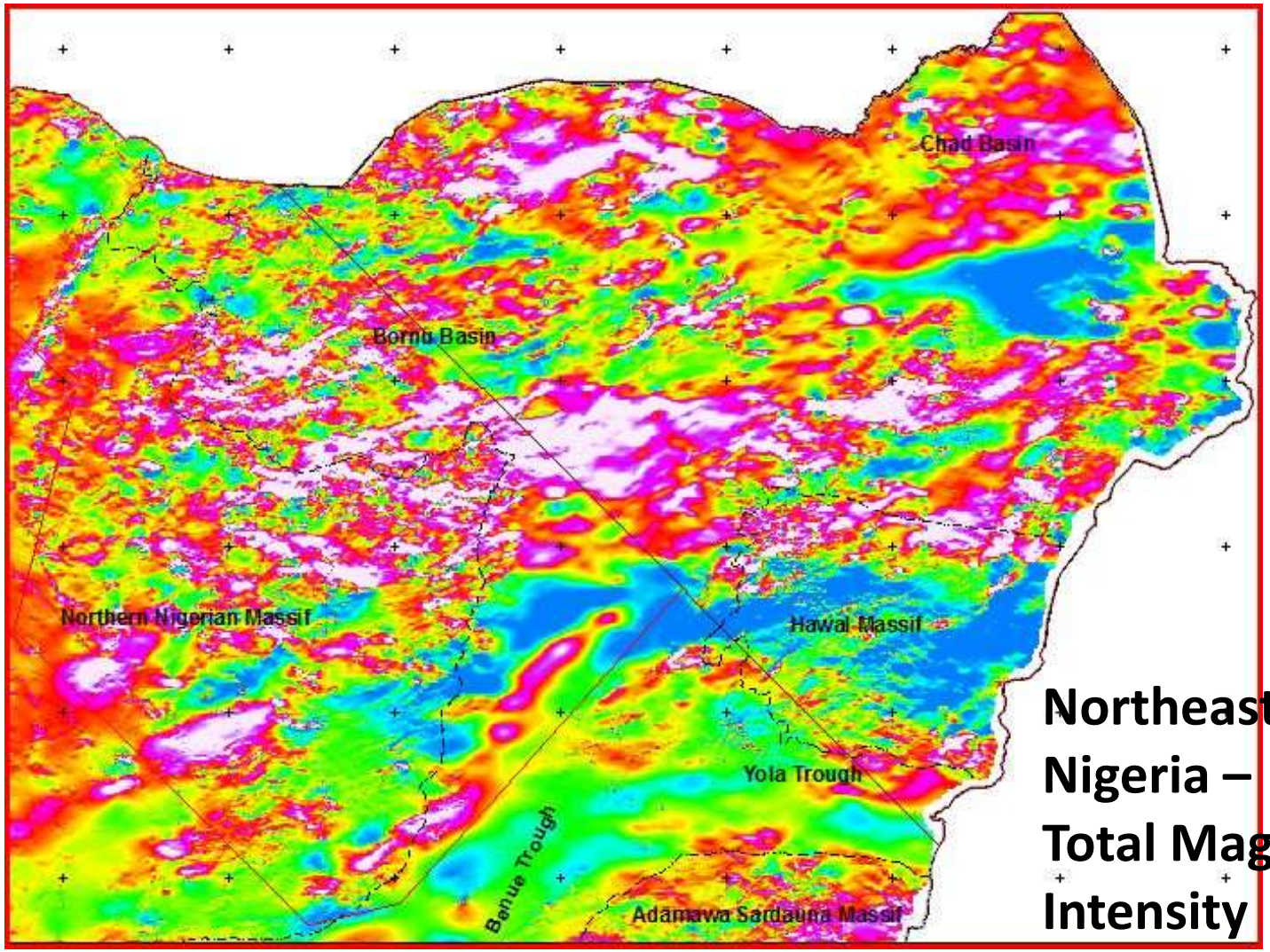
Depth to Magnetic Sources



Northeast Nigeria – Total Magnetic Intensity

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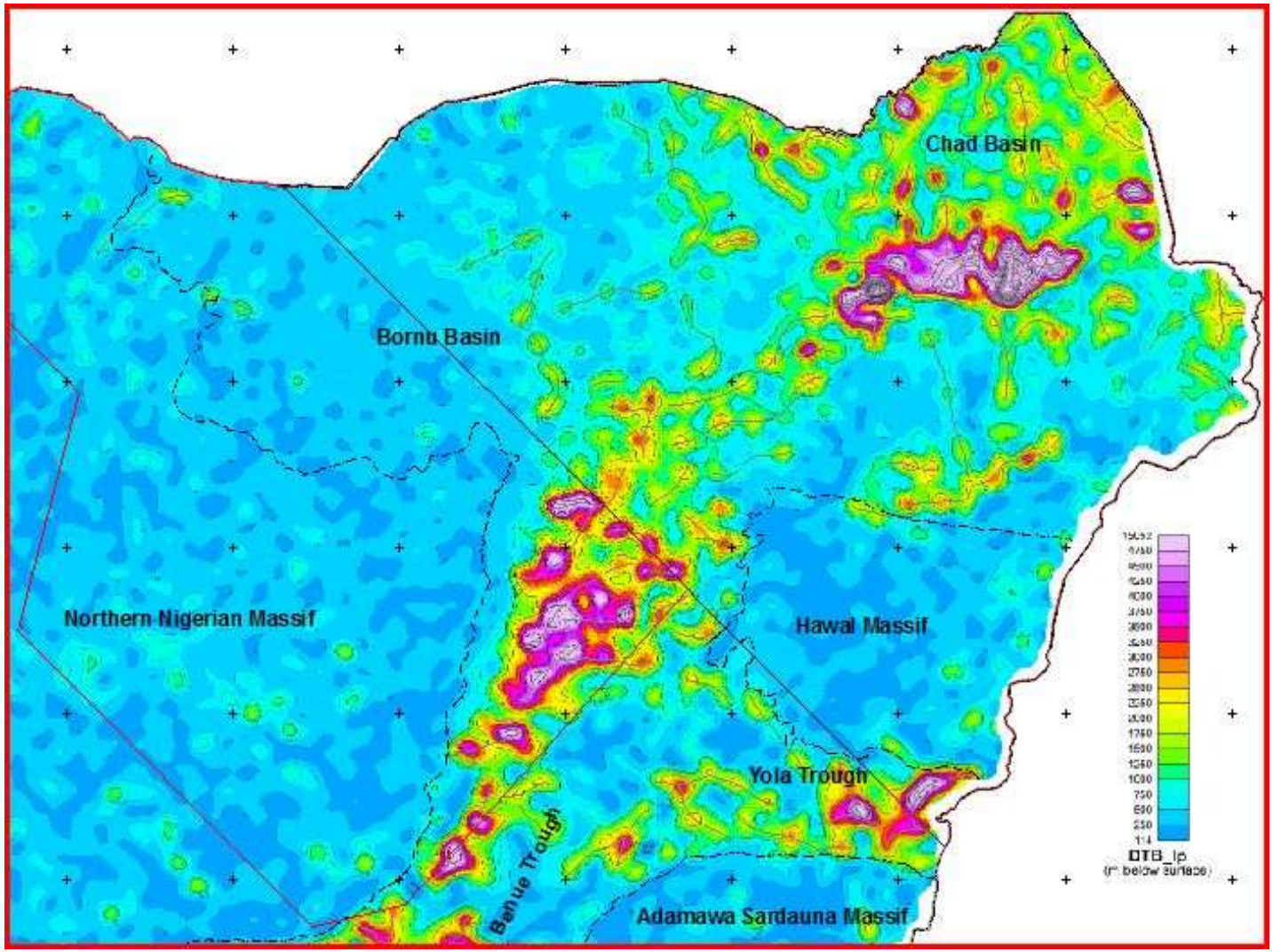
Depth to Magnetic Sources



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Northeast Nigeria – Depth to Magnetic Sources

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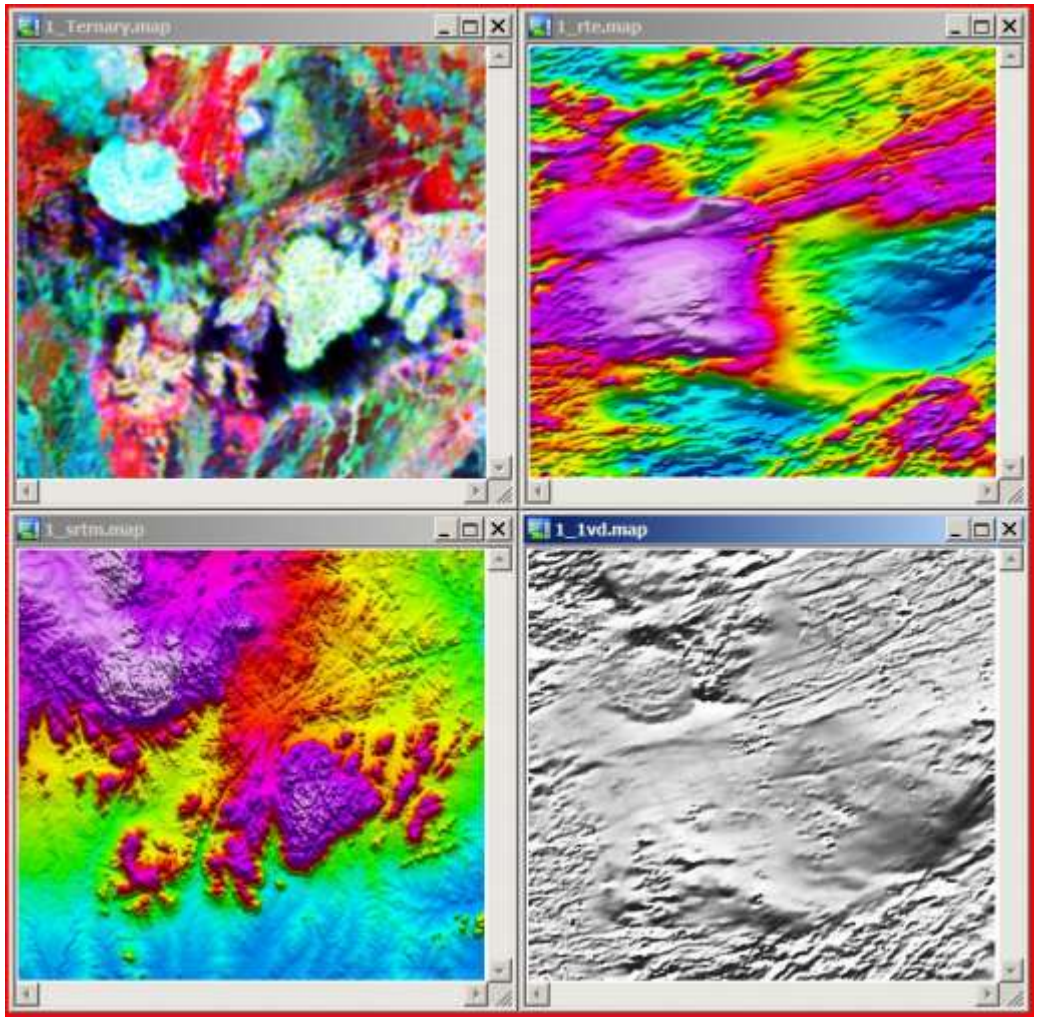
Basement Responses



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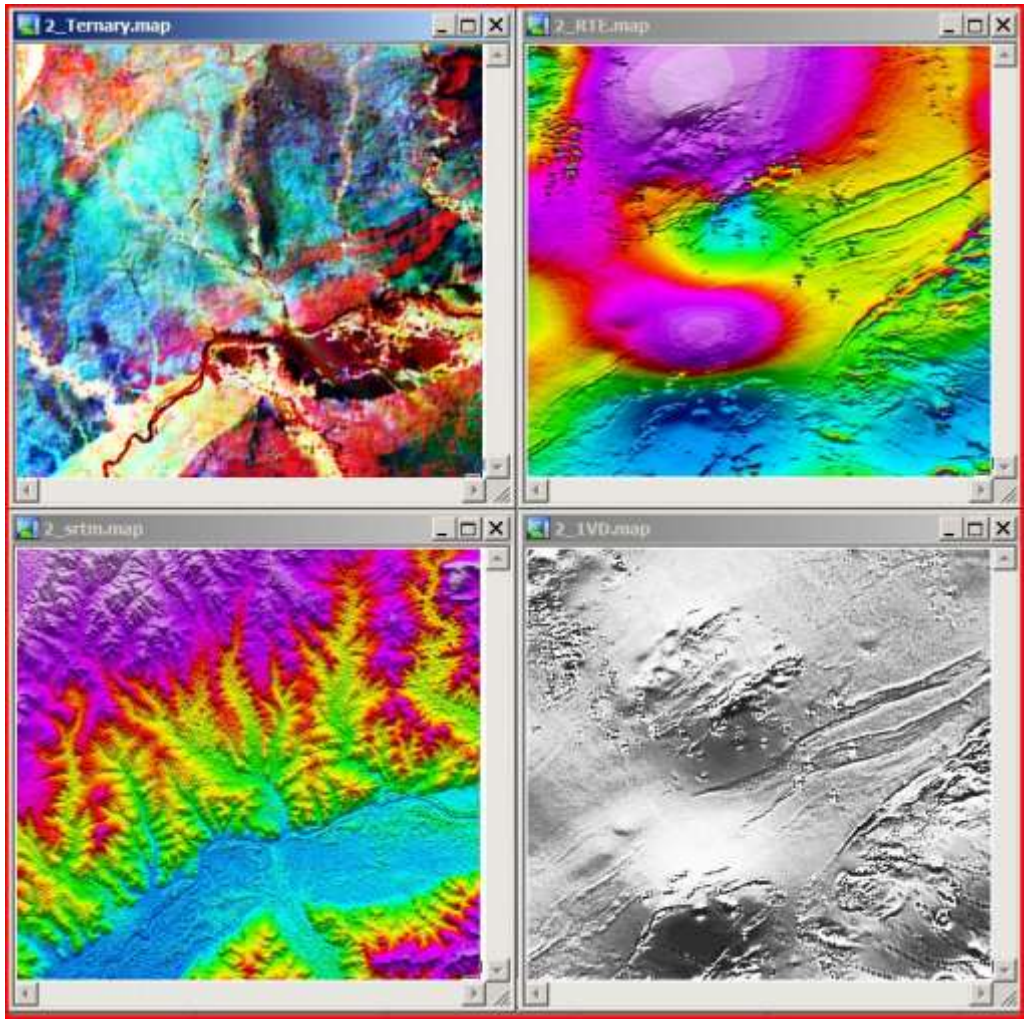
Basin Responses



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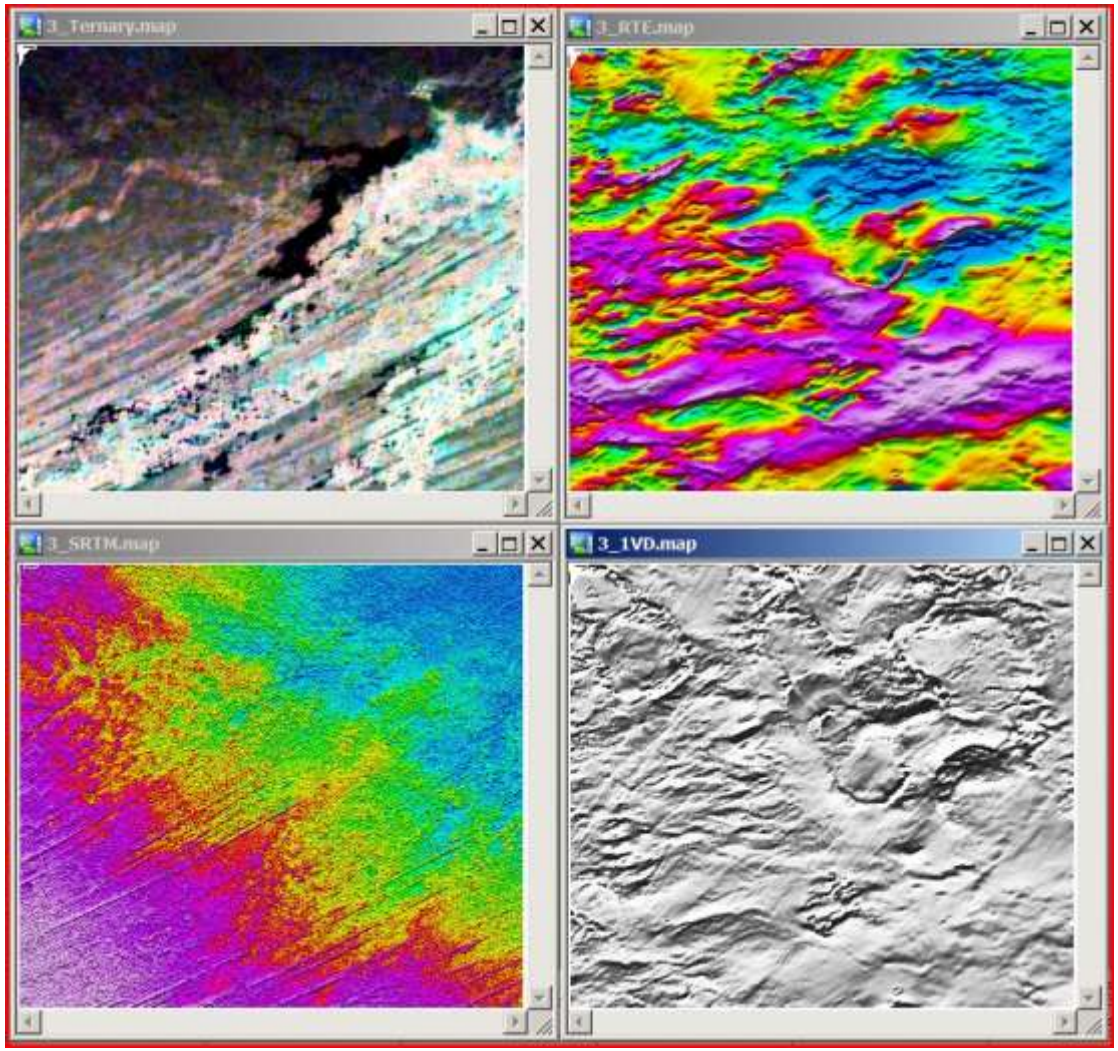
Shallow Basin Responses



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Interpretación Regional

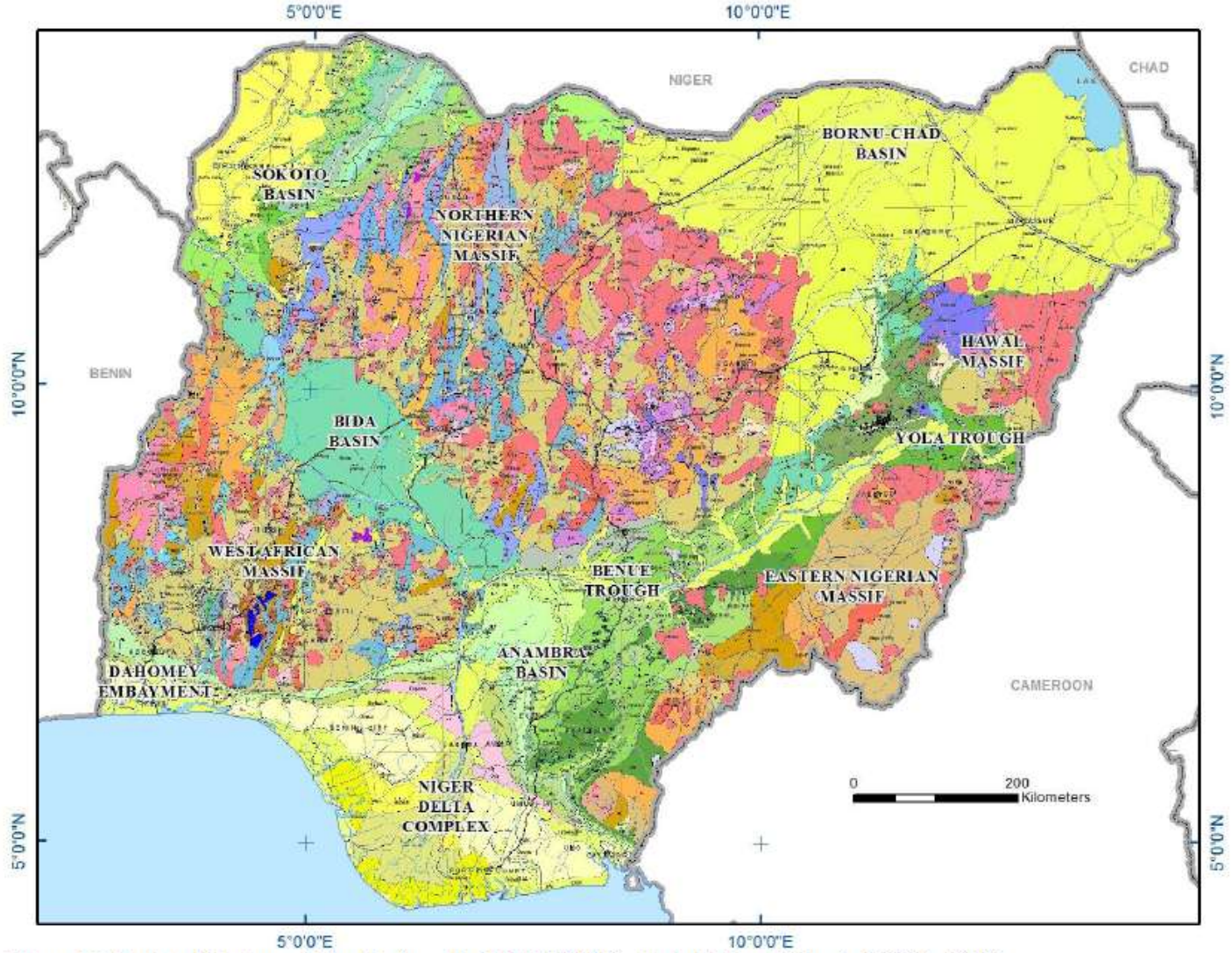

Figure 16. Regional Geology of Nigeria, from the 1:2,000,000 Geological Map of Nigeria (NGSA, 2006).

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Interpretación Regional: Litología

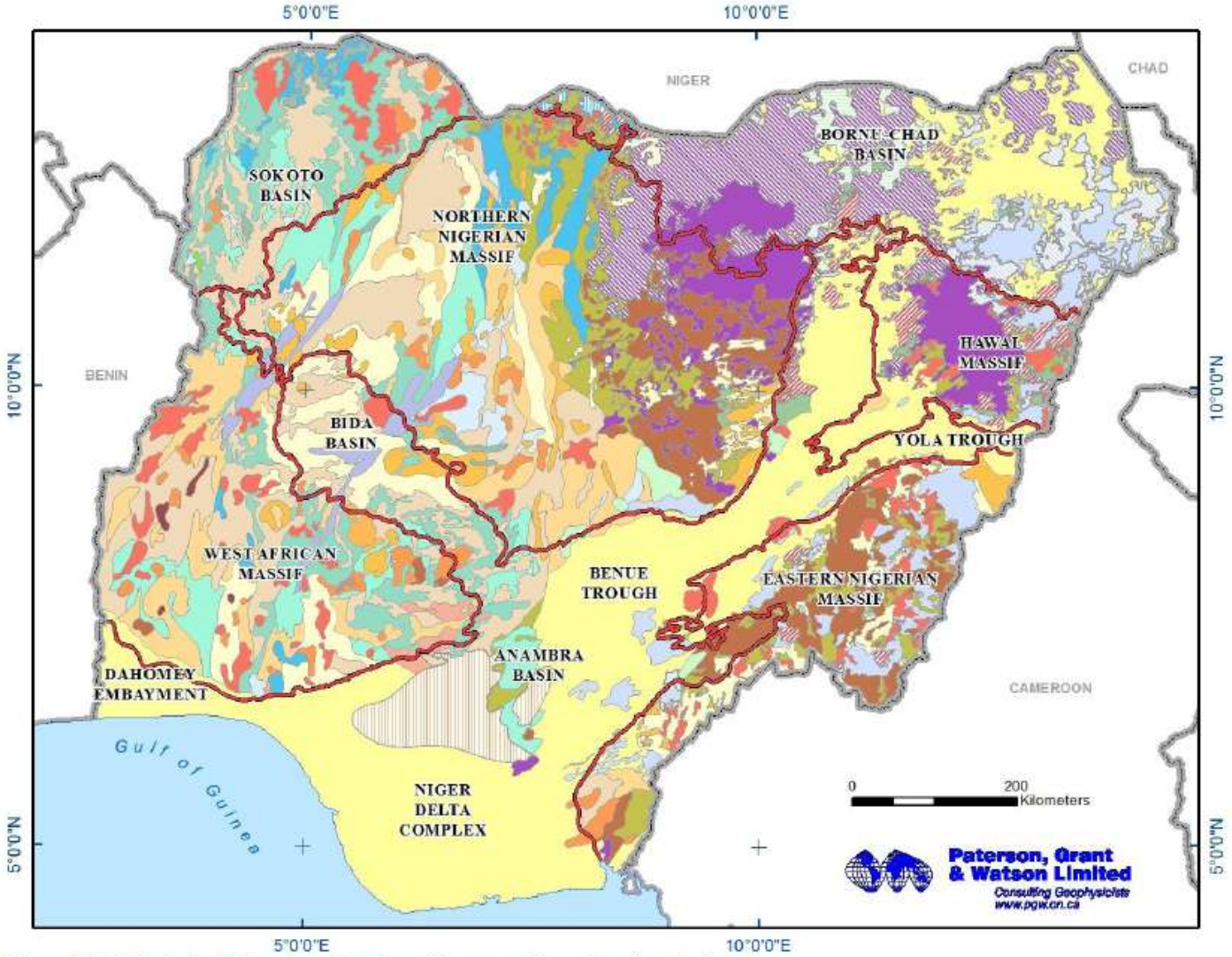

Figure 17. Lithological interpretation from the magnetic and radiometric data.

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Interpretación Regional

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Interpretación Regional: Estructuras

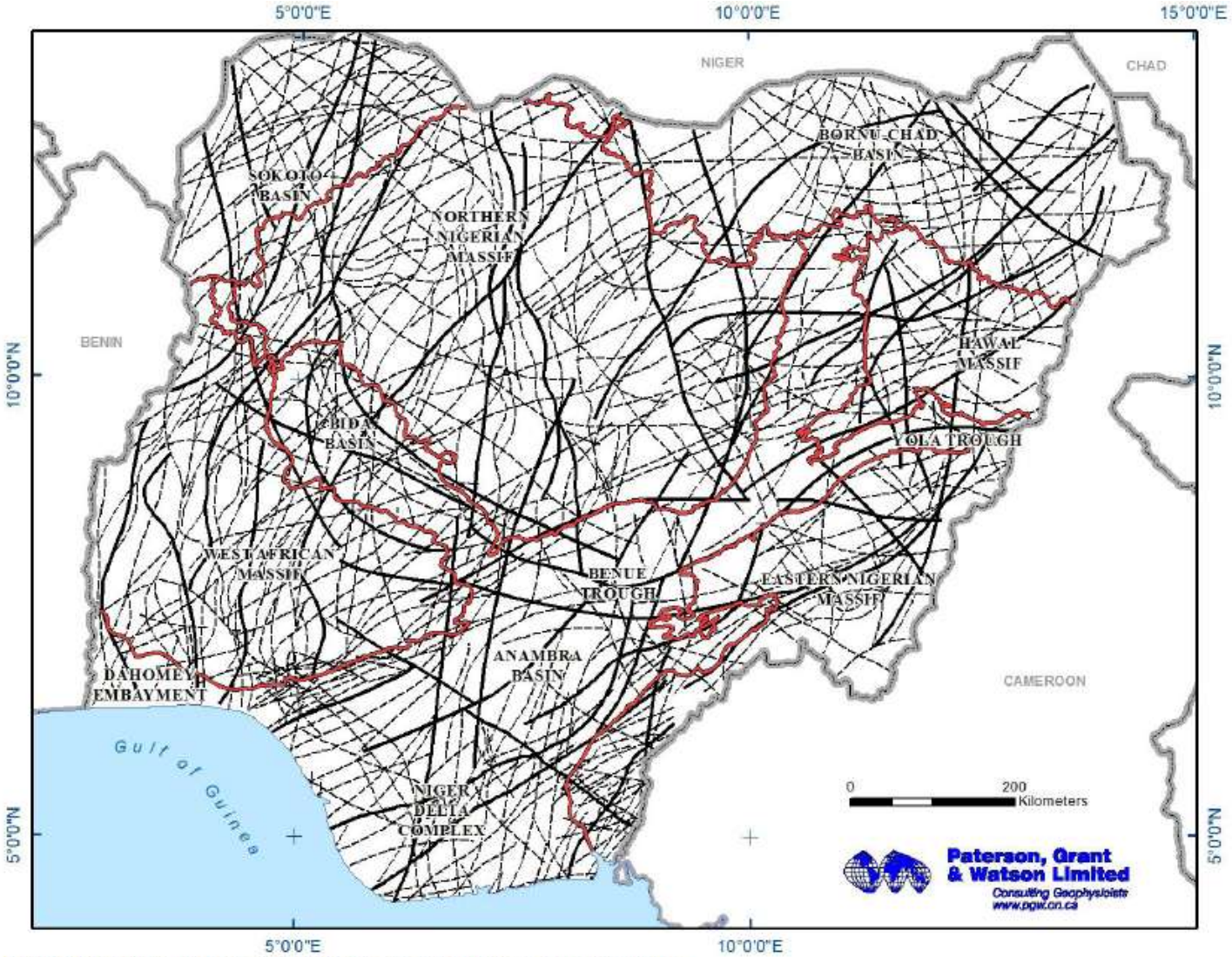

Figure 19. Structural interpretation from the airborne magnetic data.

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Interpretación Regional: 290 Blancos de Exploración

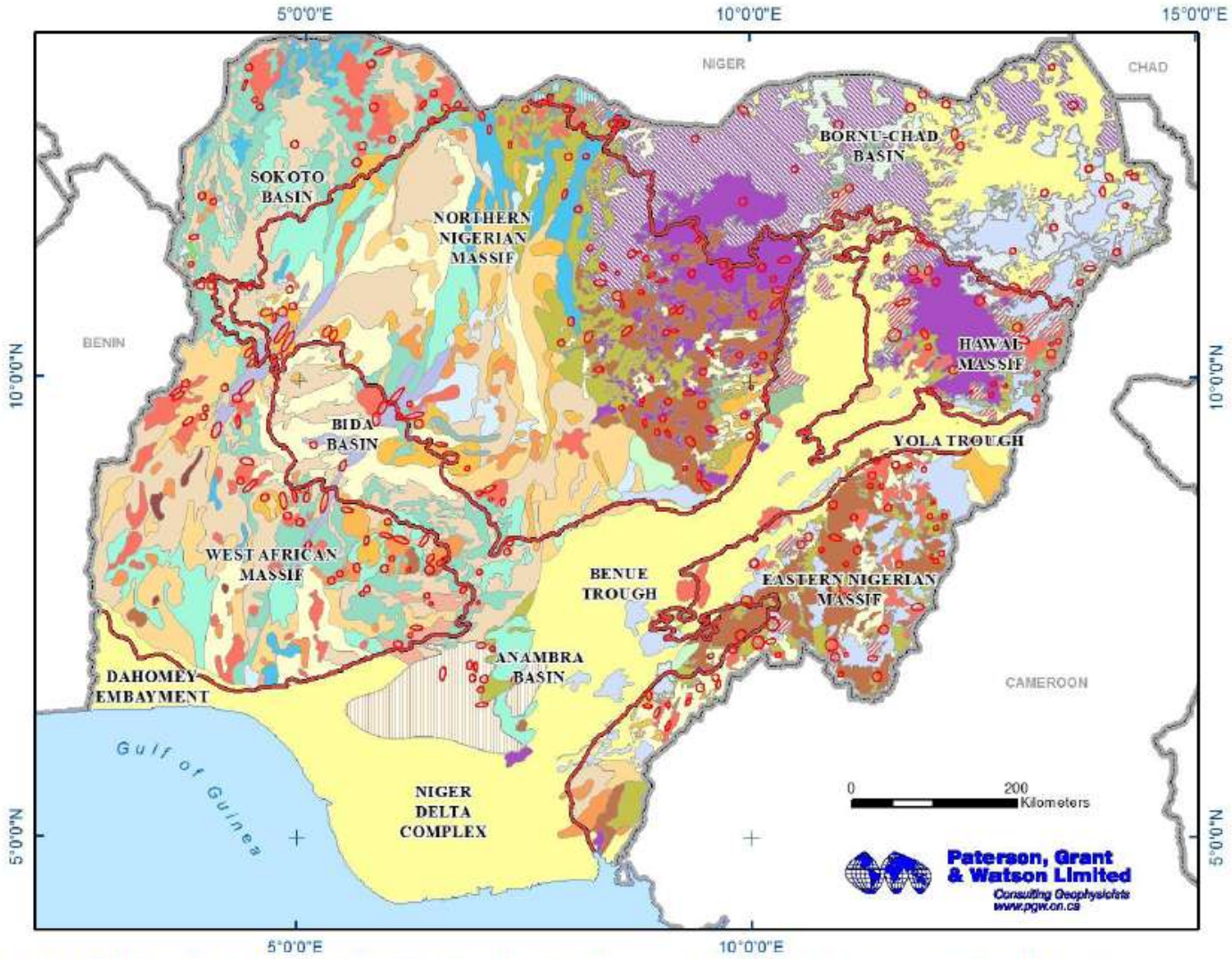

Figure 20. Lithological interpretation with mineral exploration targets for the Phase II coverage (outlined in red).

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Segilola Gold Project

- **CGA Mining Limited announced JORC and 43-101 compliant resource of 620,000 ozs (December 3, 2009)**
- **Gold is hosted in quartz-feldspar veins and altered gneissic host rock within the Ilesha Schist Belt**
- **Schist belts in western Nigeria are domains of Upper Proterozoic metasedimentary, metavolcanic and intrusive sequences that are oriented parallel to the boundary between the West African Craton and the Pan African province (similar to Ghana)**

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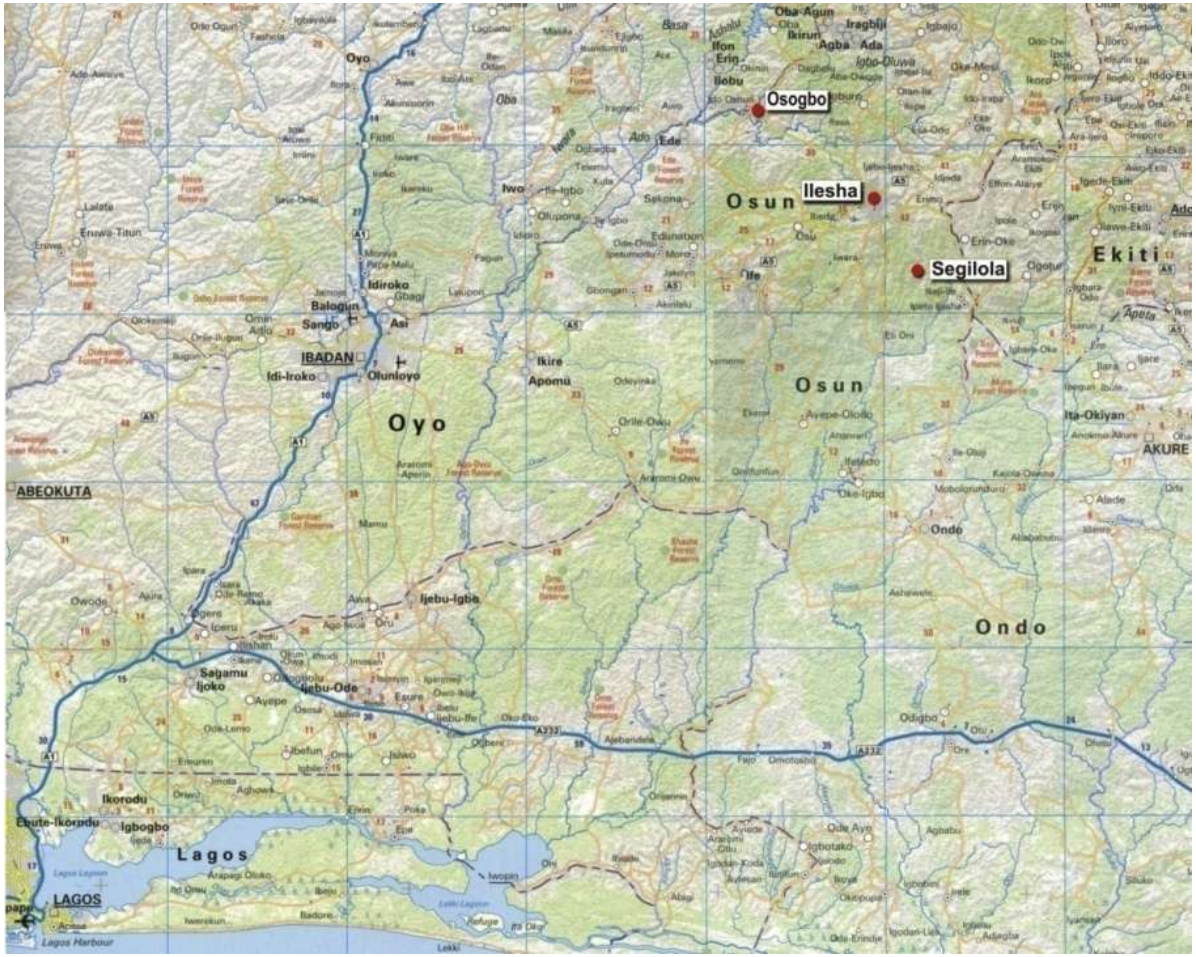
Segilola Gold Project



Located in Osun State, SW Nigeria

Northeast of Lagos

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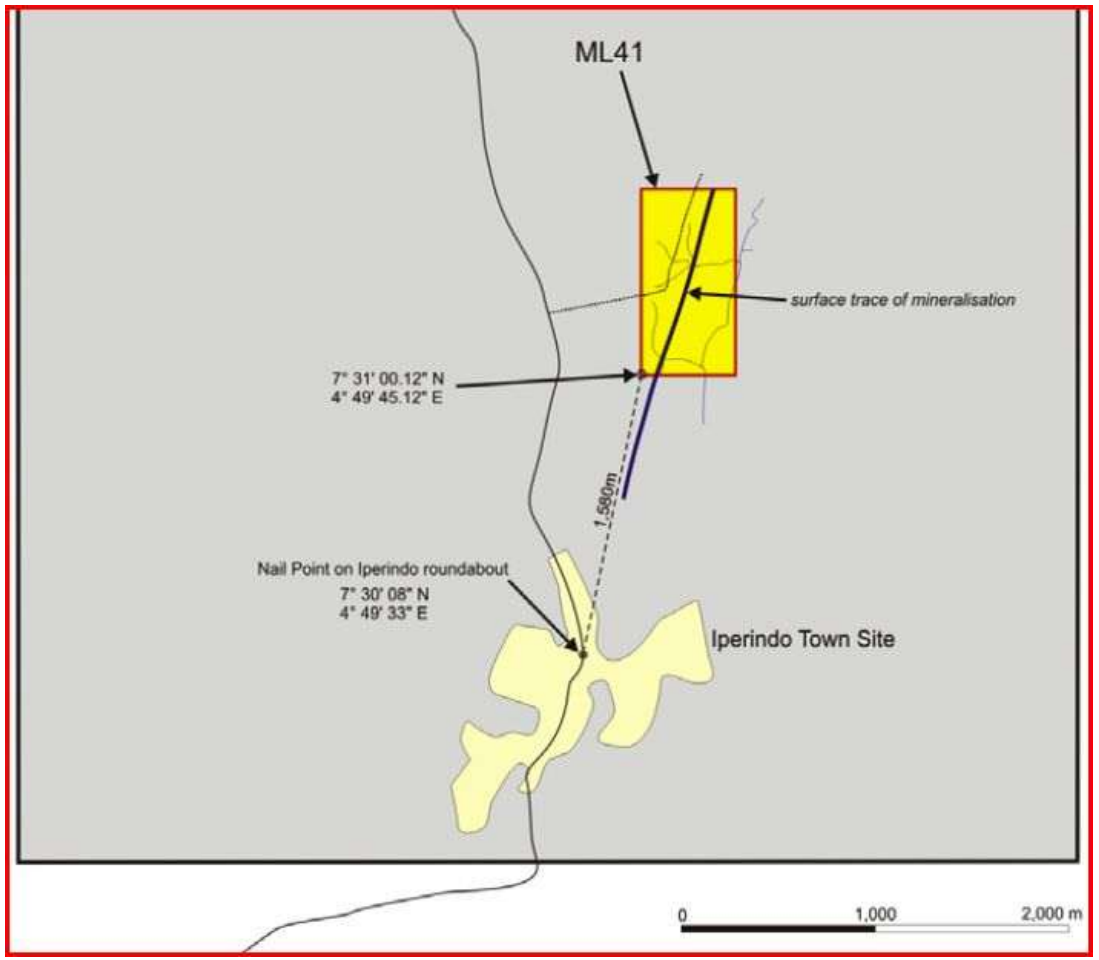
Segilola Gold Project



NNE trace of mineralized zone oriented along the strike of the Ilesha Schist Belt

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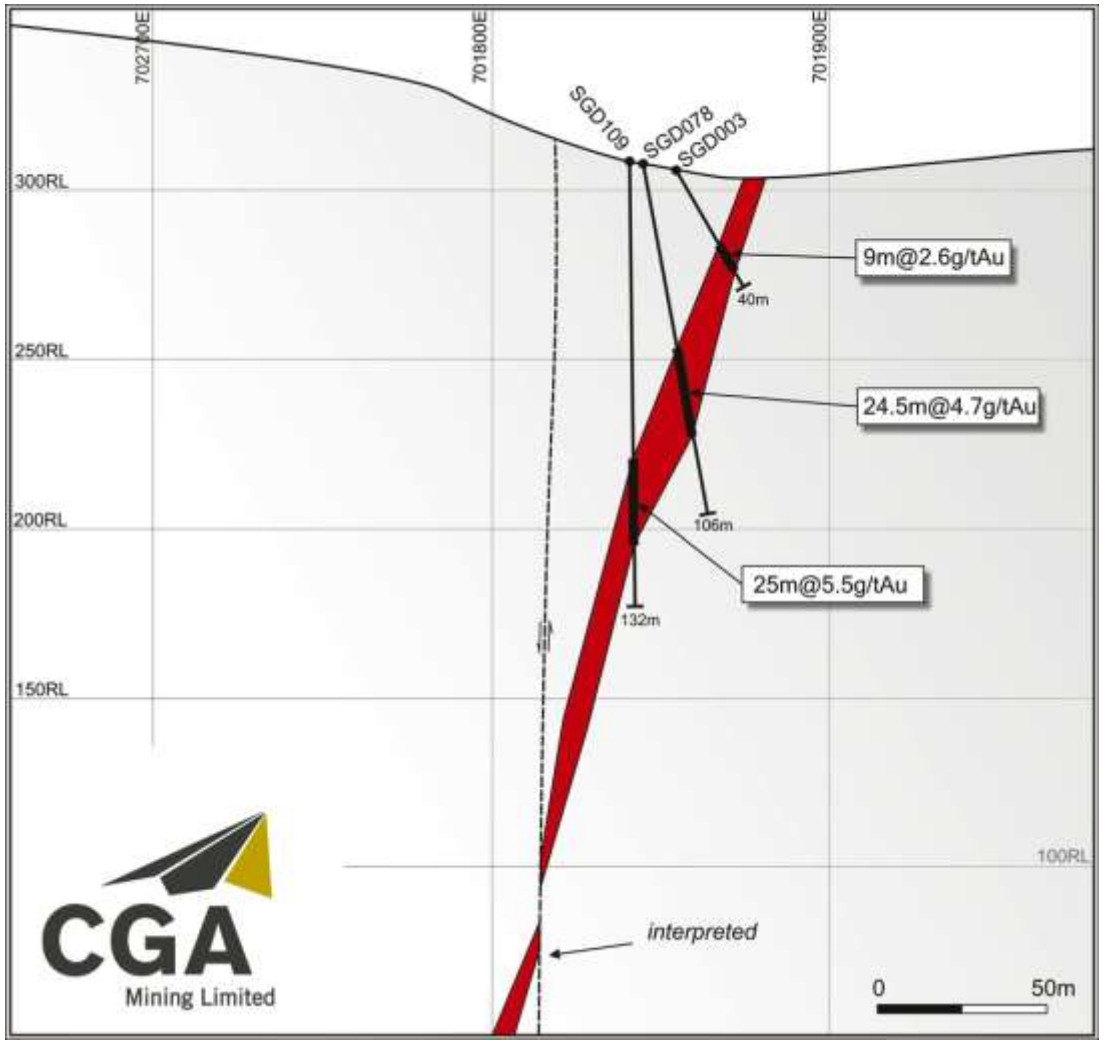
Segilola Gold Project



Mineralization in steeply dipping shear zone showing good continuity along strike and down-dip

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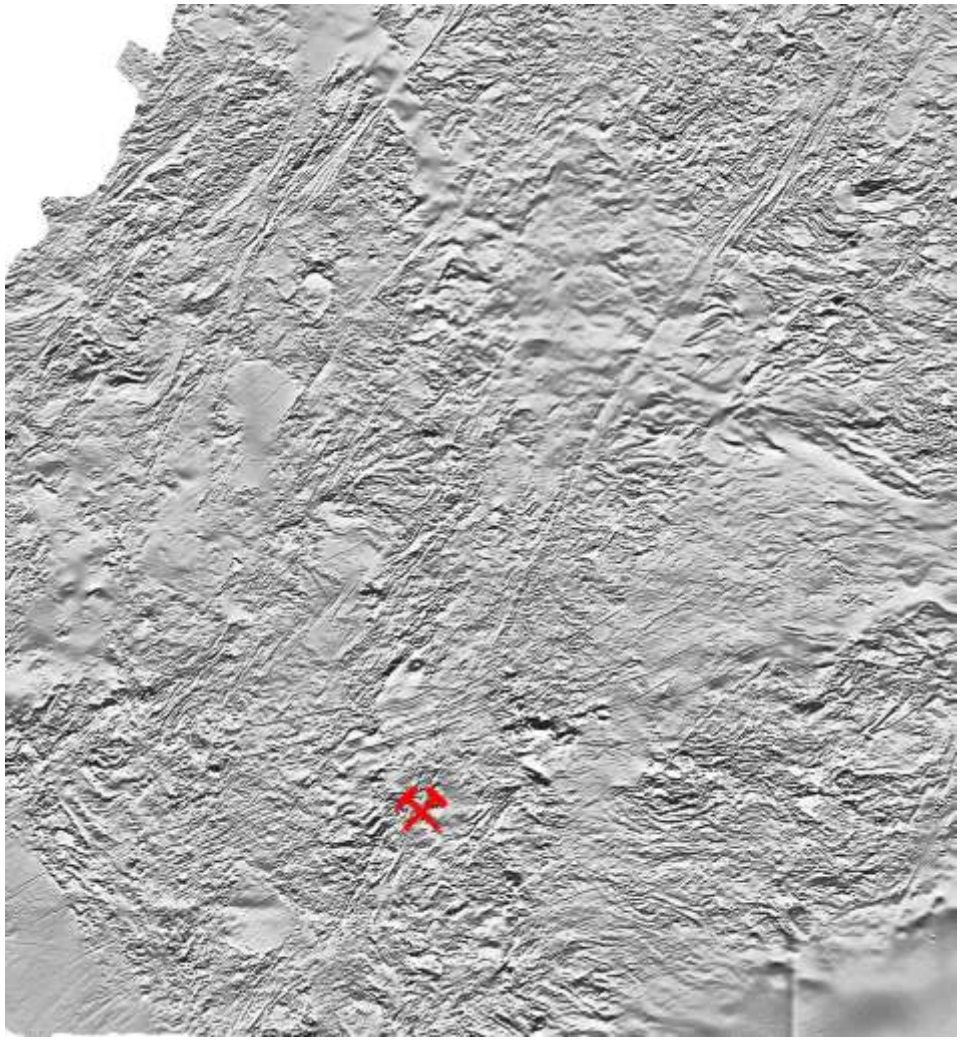
Segilola Gold Project



Reduced-to-equator magnetic field

Deposit located on NNE-striking magnetic lineament

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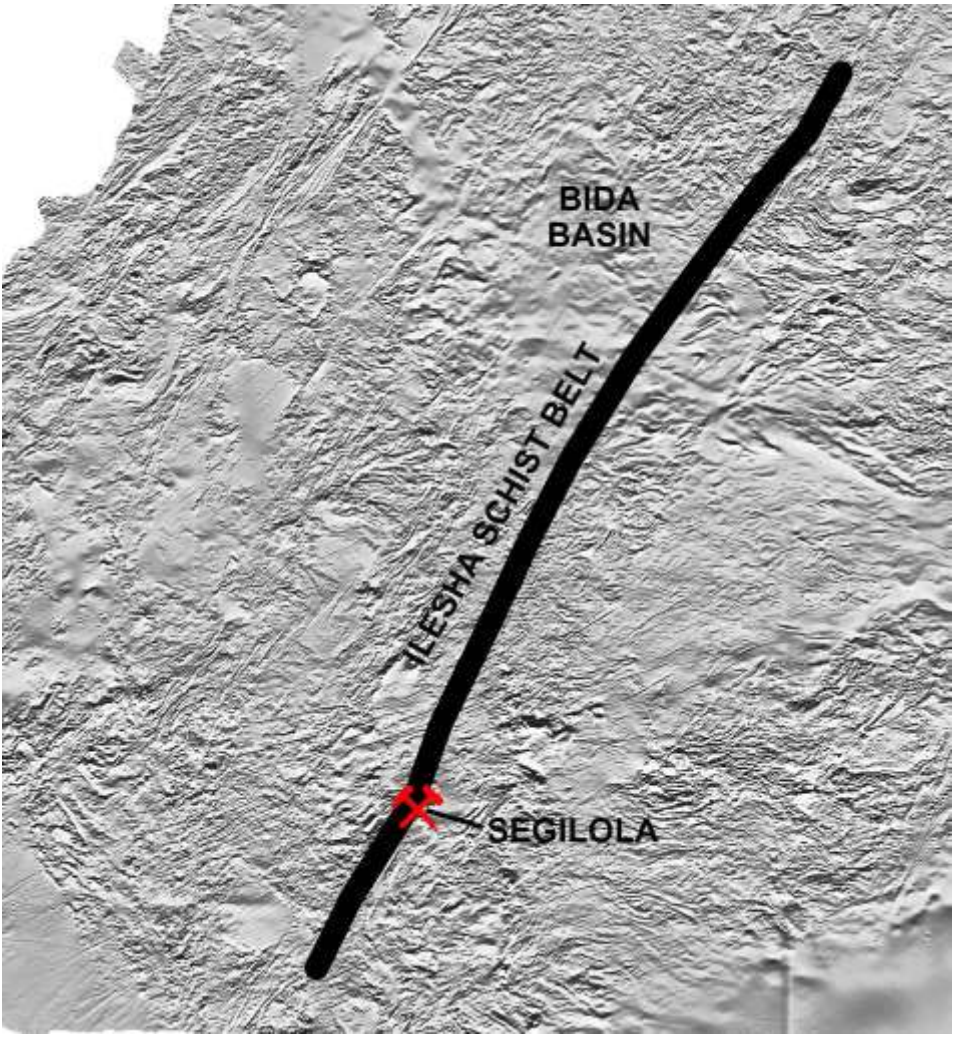

Ilesha Schist Belt continues for more than 400 km

Runs beneath Bida Basin

Several parallel schist belts and shear zones

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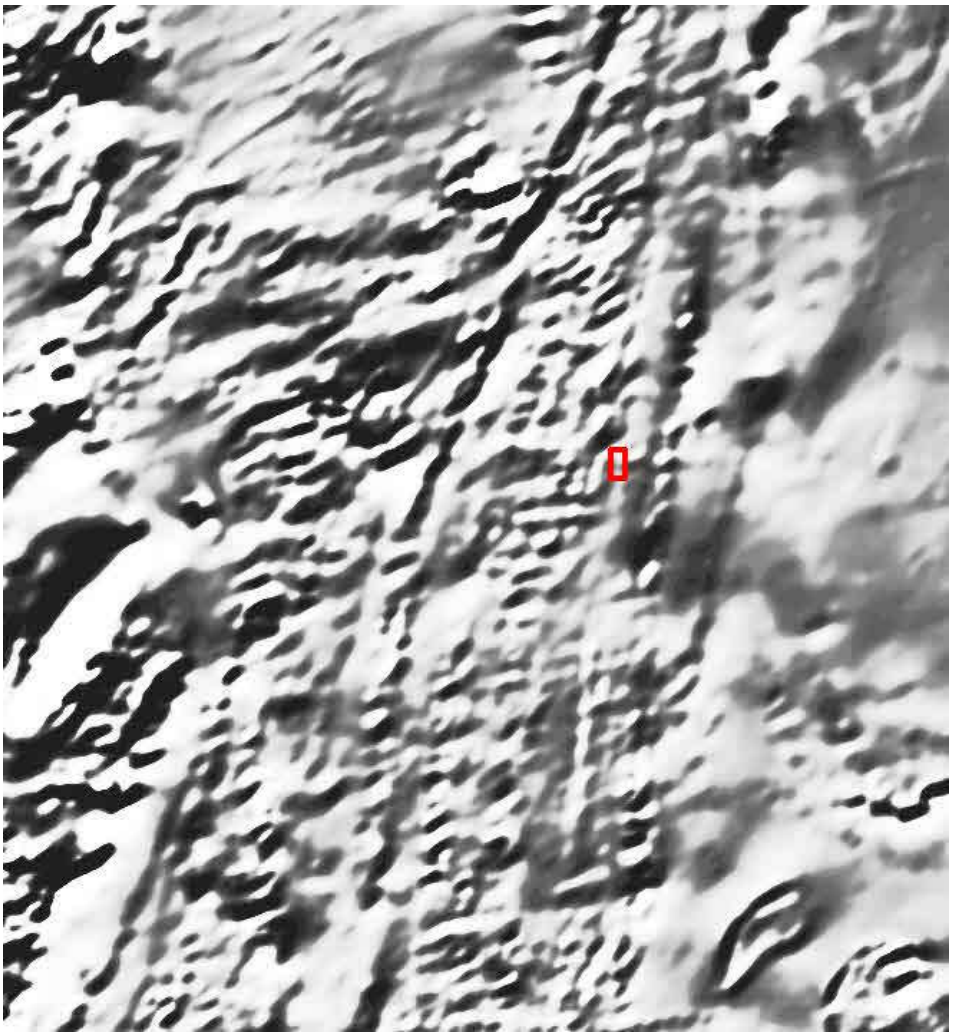

Magnetic first vertical derivative

NNE-striking shear

NE- and E-striking crosscut structures

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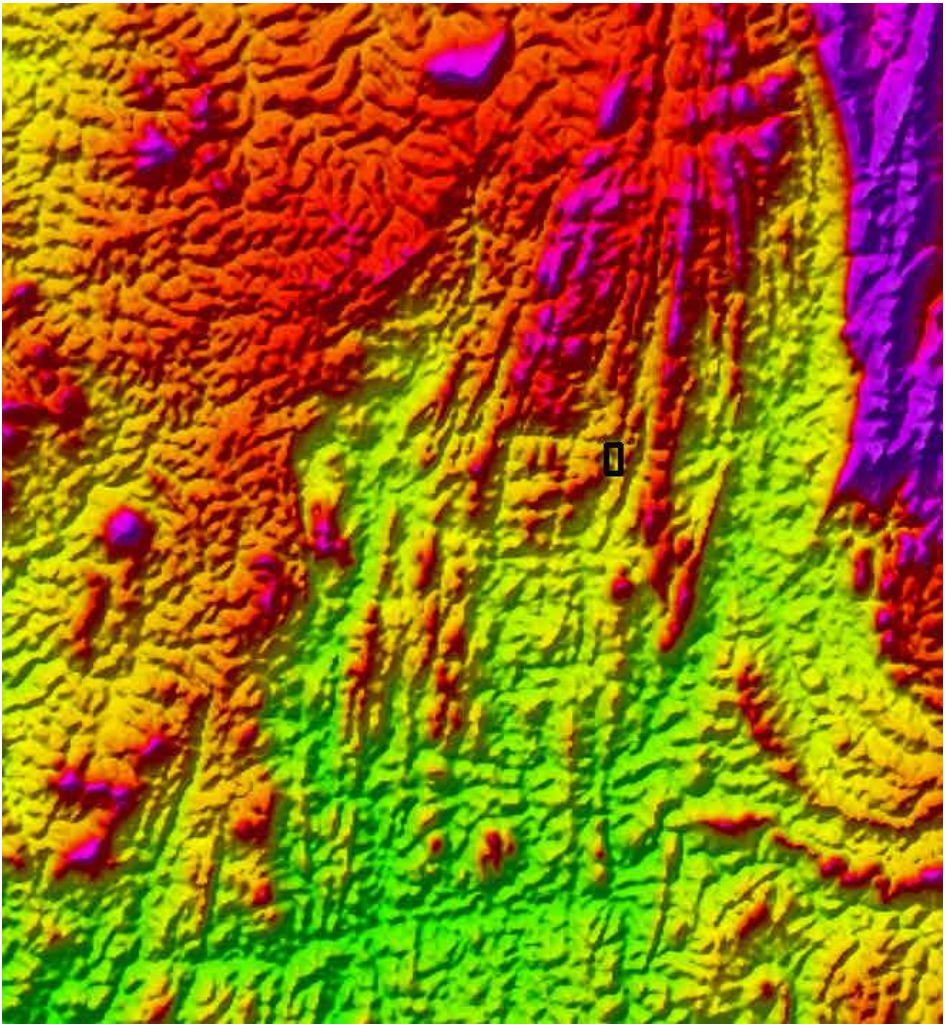

SRTM topography

Horizons and structures quite evident on surface

Good for surface exploration – geochemistry, trenching, etc.

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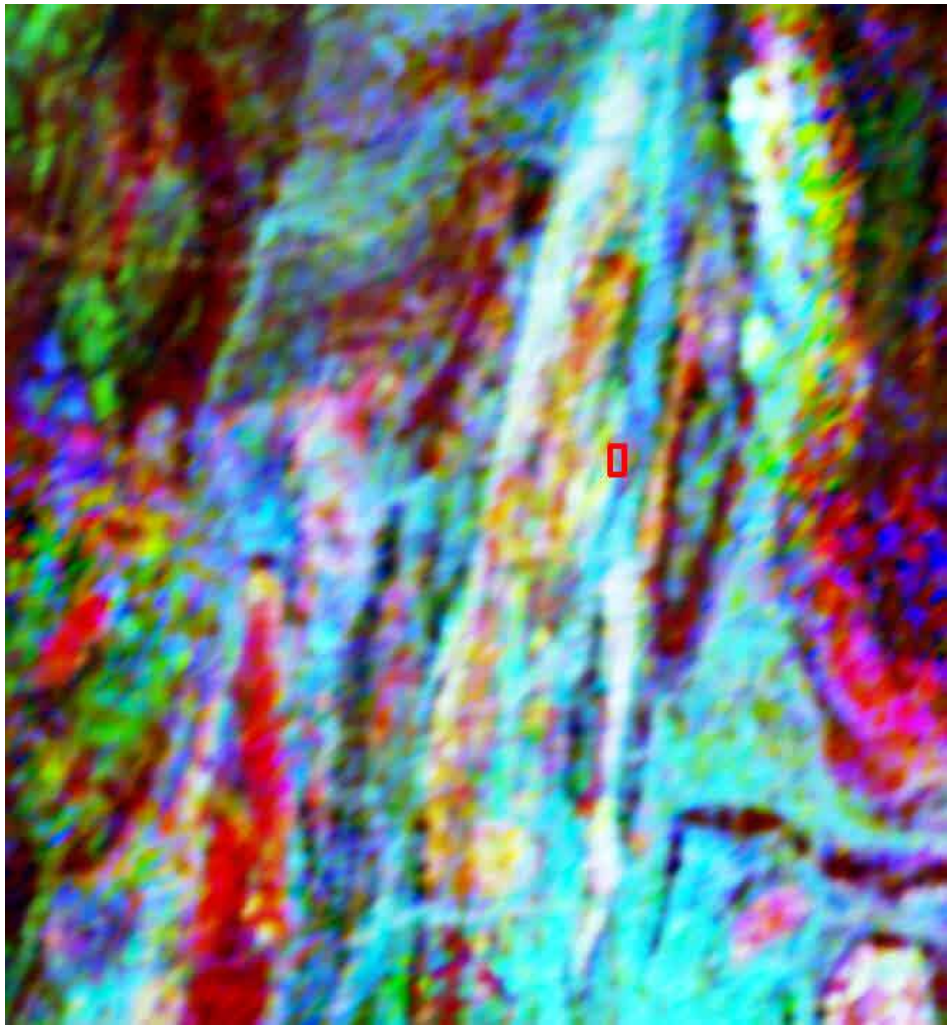
Segilola Gold Project



Radiometric ternary image

Mapping of individual horizons

Possible alteration

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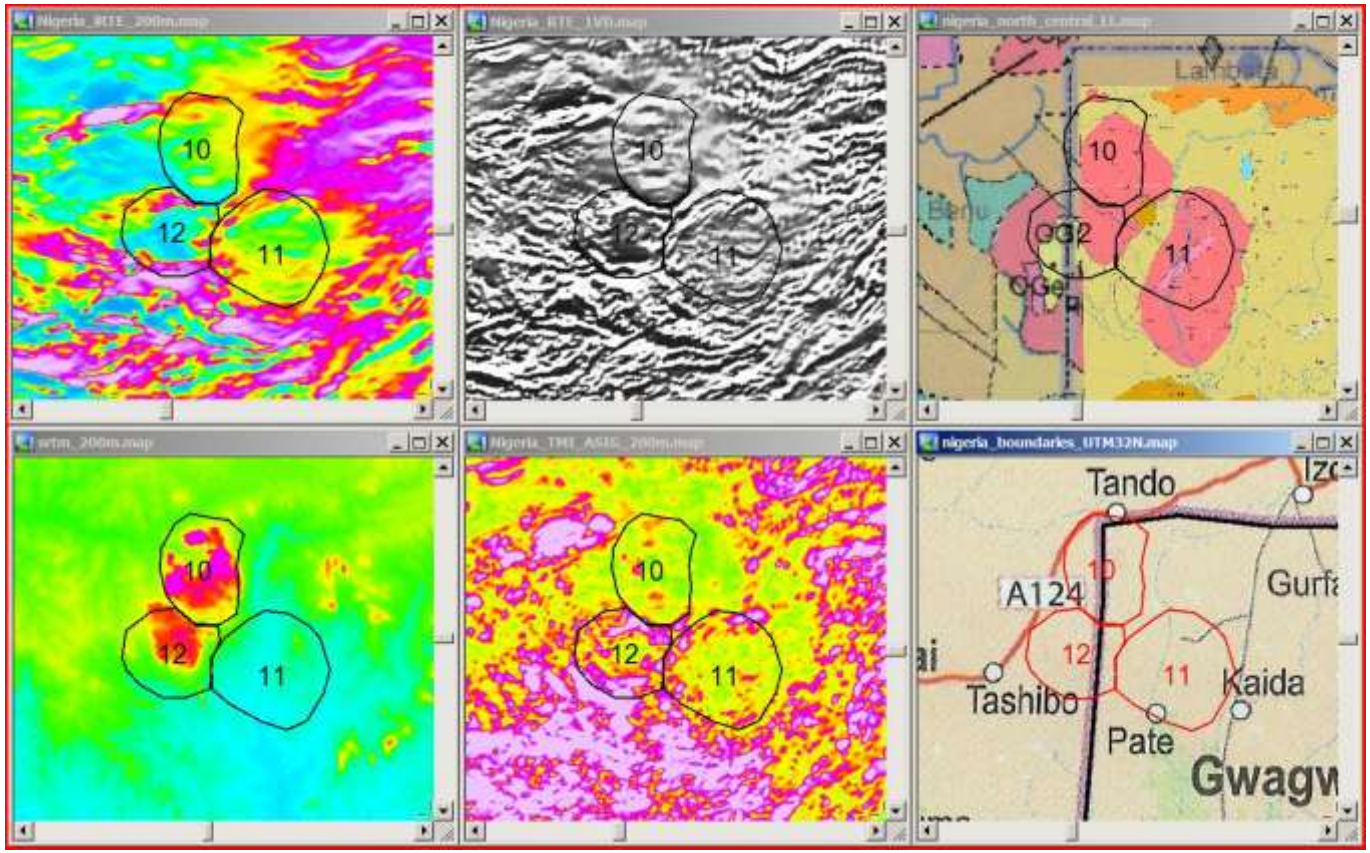
Ground Truth

Red – sites selected on basis of geology, DEM, radiometrics and magnetics

Blue – sites completed in one month

Ground Truth



Geology, DEM and magnetics

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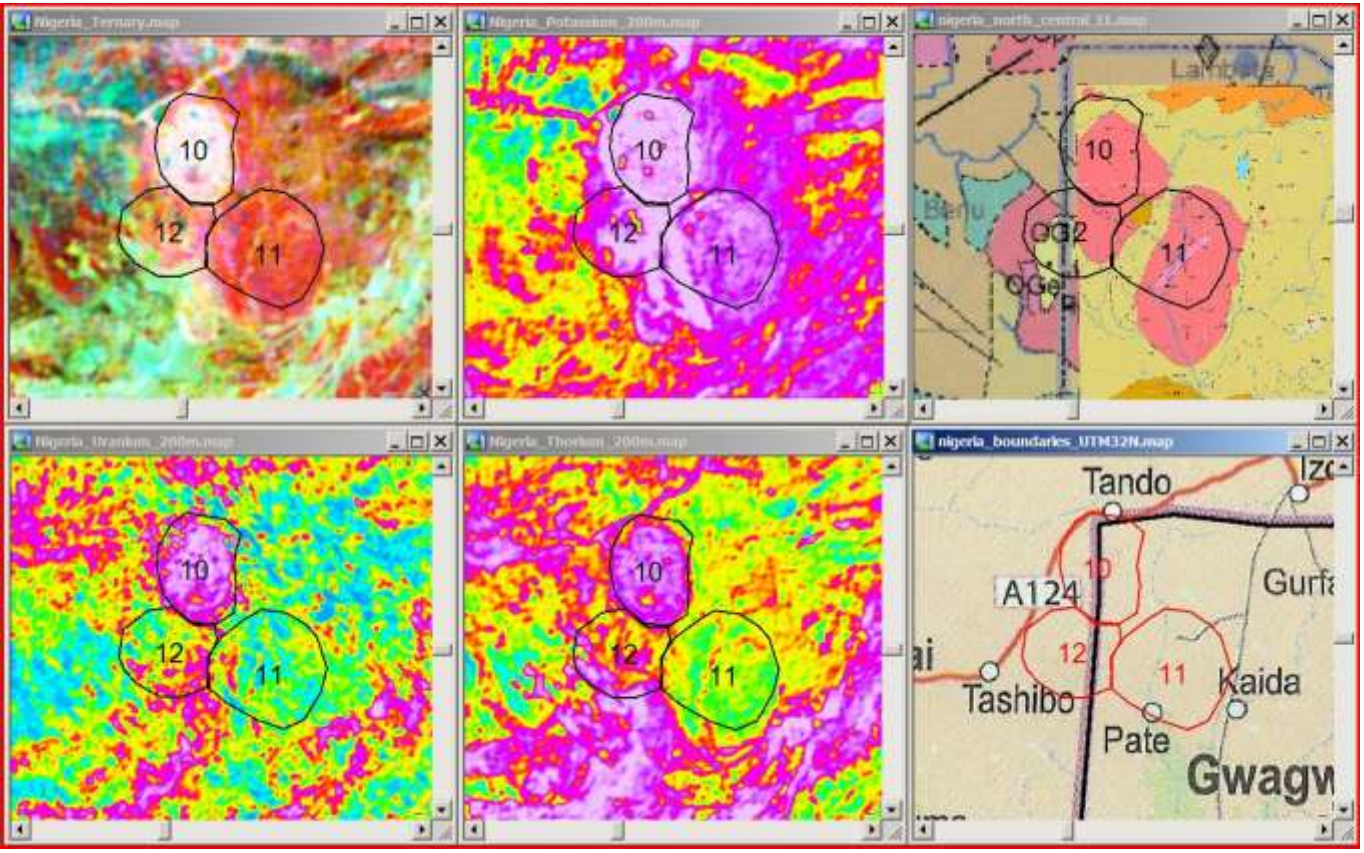
Ground Truth



Geology, DEM and radiometrics

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Ground Truth

Figure: a) Coarse-grained granite with a weak foliation. b) Strongly foliation biotite-gneiss. c) Pyroxene rich, gabbroic-textured rock (at back). d) Fine-grained basalt with sulphide minerals.

Unmapped basalt and sulphides

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Ground Truth

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Nigeria: Resumen

- >2M de km mag & spec
- Cobertura geofísica completa en todo el país
- Interpretación a escala 1:250,000 sobre toda la Fase 2 + Interpretación a 1:1M y 1:2M sobre todo el país
- Geofísica aérea, 500 m espaciamiento entre líneas, útil para mapeo regional y exploración (Segilola)

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Nigeria: Resumen

- Además de toda la cartografía, se generaron 290 blancos de exploración, los cuales son un primer acercamiento a la exploración minera en Nigeria
- El programa de procesamiento e interpretación incluyó ~3 meses de entrenamiento/capacitación para el personal de NGSA (Serv. Geológico de Nigeria) y 1 mes de trabajo de campo para verificación de anomalías

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Contenidos

- Motivación / Introducción
- Algunas definiciones
- Caso 1: Chile Central
- Caso 2: Norte de Chile, adición de radiometría aérea
- Caso 3: Nigeria
- Conclusiones / Resumen Final

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Conclusiones (1)

- La geofísica aérea (magnetometría, radiometría) es de primer orden en un programa de cartografía geológica nacional
- No sólo entrega información en zonas cubiertas o de difícil acceso, sino que también permite dar continuidad al mapeo de campo

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Conclusiones (2)

- En aquellas zonas donde existe cobertura antigua (espaciamiento > 2 km, altura de vuelo >700 m), se recomienda re-volar con un espaciamiento de 500-1000 m y alturas de vuelo menores
- Un programa de 500 m de espaciamiento entre líneas entrega información valida tanto para fines cartográficos (geología regional) como para exploración, por lo que el valor de la información es mucho mas importante

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Gracias!

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