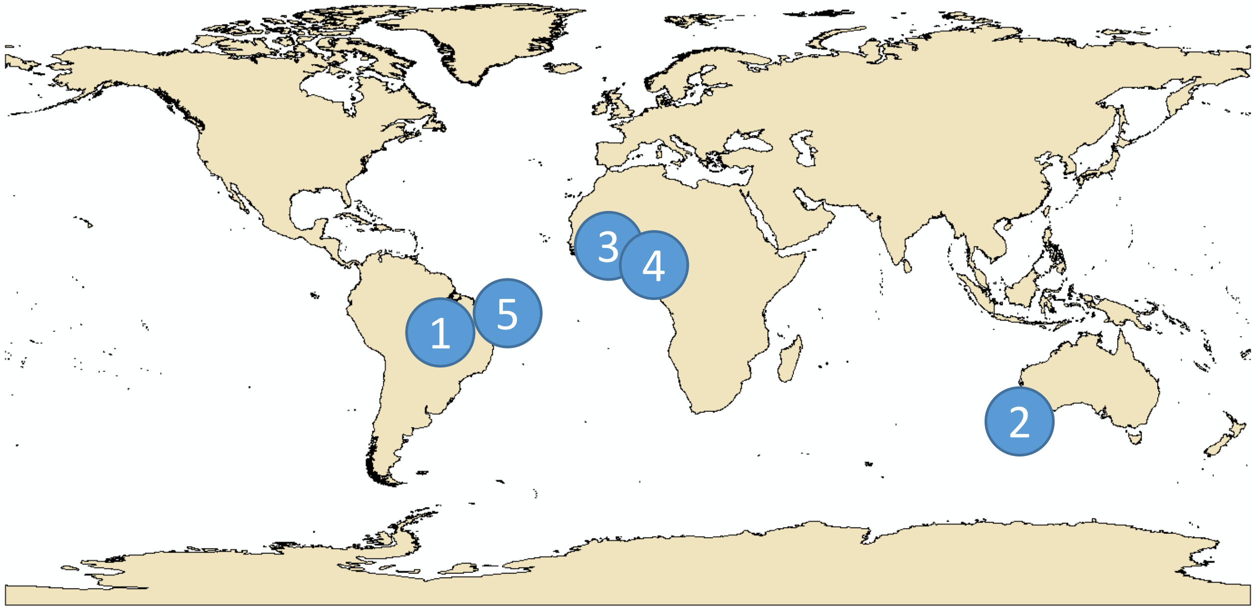
Structural Geophysics

1. Chapadas das Mesas, Brazil- gets people talking in an area where there are no right answers!
2. Noddy Modelling- Intro to 3D structures and geophysical responses
3. Regolith/Geology Study from Burkina Faso-good use of mag, radiometrics and dtm
4. A geology interp of NW Ghana using Mag, Radiometrics and FDEM
5. Borborema Province, Brazil-best geophysics on the planet!



IGGC12

Georgetown

12th Inter Guiana
Geological Conference

12th & 13th December 2022,
in Georgetown, Guyana

saxiproject.org

IGCP638 **Paleoproterozoic Birimian Geology for Sustainable Development**

United Nations
Educational, Scientific and
Cultural Organization

International
Geoscience
Programme

2022 Conference
4th - 9th of December 2022
Accra, Ghana

igcp638.univ-rennes1.fr

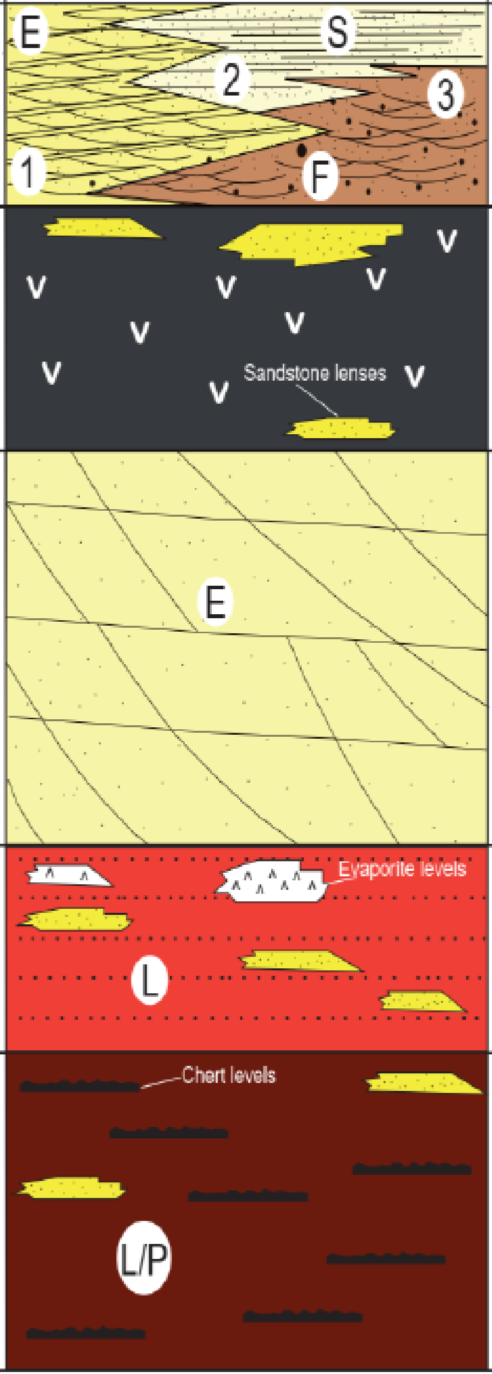
1: Chapada das Mesas National Park

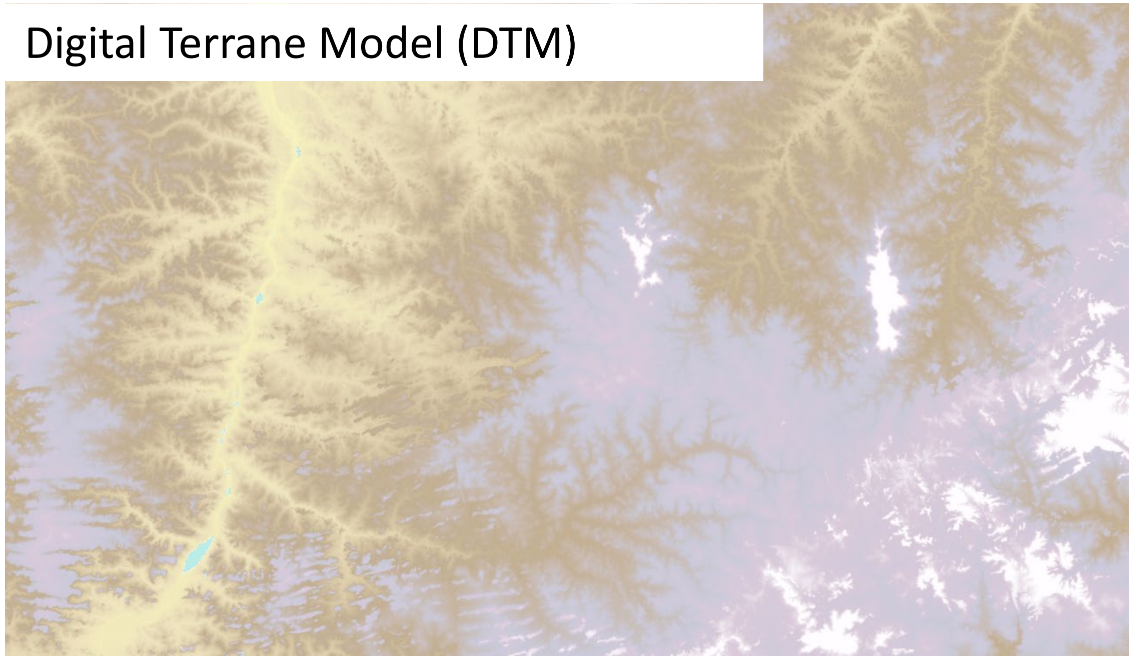
https://earth.google.com/web/search/Parque+Nacional+da+Chapada+das+Mesas+-+Pra%c3%a7a+Al%c3%adpio+Carvalho,+Carolina+-+State+of+Maranh%c3%a3o,+Brazil/@-7.1178698,-47.20315555,318.20877496a,73817.14302608d,35y,0h,0.00127382t,0r/data=CigiJgokCVBl7nXzawdAEX7MIvxpIg_AGdfelH2H1E3AIYwhn57O_FDA

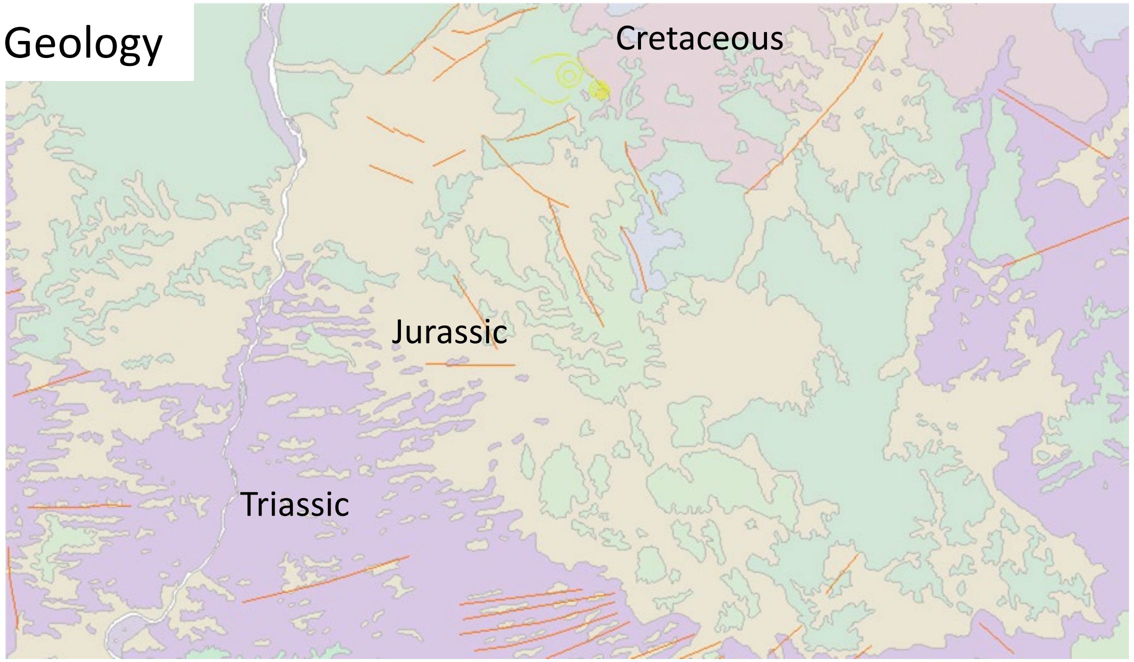
ArcGis/WaxiExplorer

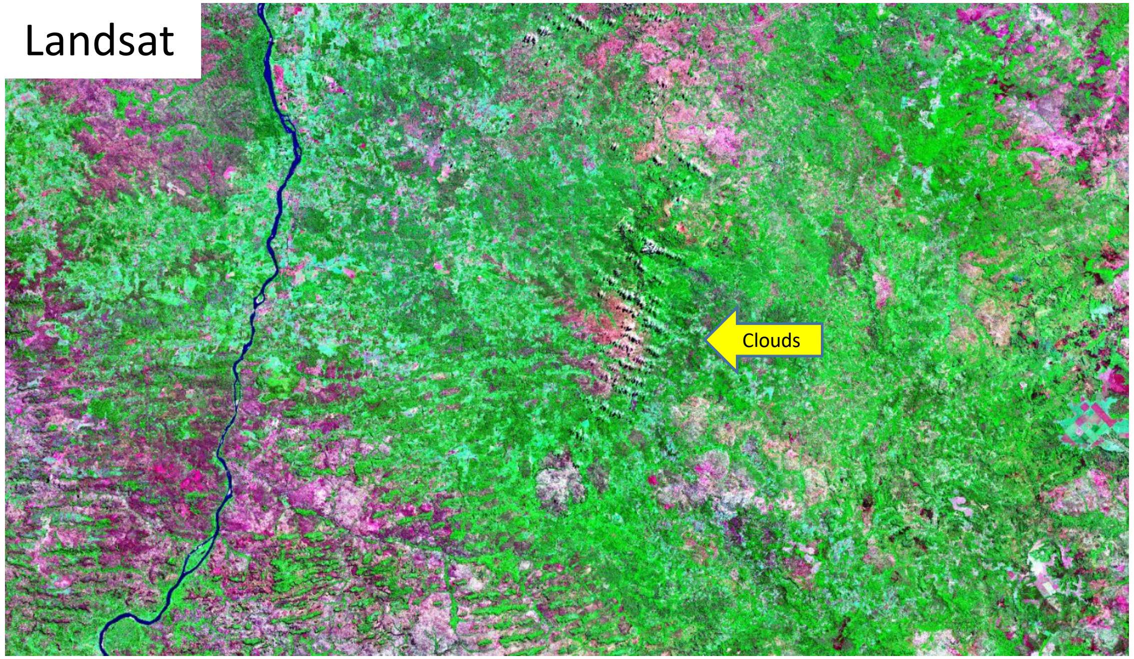
Regional Stratigraphy

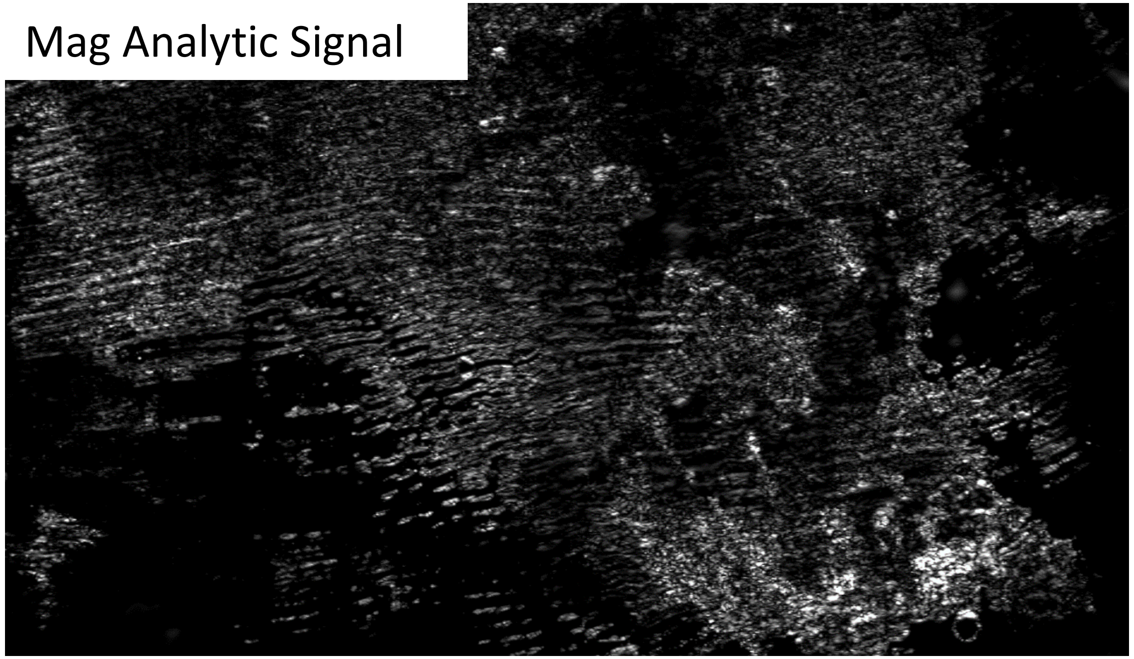
PERIOD	FORMATION	DESCRIPTION	NNW DISTRIBUTION SSE	T[m]
LOWER CRETACEOUS	CORDA	Fine-grained sandstone with medium-scale cross-bedding (1), fine-grained sandstone with parallel bedding (2), and medium- to coarse-grained sandstone with medium-scale trough cross-bedding (3).		30
LOWER JURASSIC	MOSQUITO	Basalt with intercalations (intertrap) of poorly-sorted sandstone lenses.		190
TRIASSIC	SAMBAÍBA	Fine- to medium-grained sandstone with large-scale cross-bedding.		440
TRIASSIC	MOTUCA	Red laminated mudstone interbedded with fine-grained sandstone and evaporite lenses.		140
PERMIAN	PEDRA DE FOGO	Reddish brown mudstone with frequent intercalations of chert and sandstone levels.		240




Digital Terrane Model (DTM)


Geology
Cretaceous
Jurassic
Triassic


Landsat
Clouds


Mag Analytic Signal

Main Question:

What causes observed linear magnetic anomalies?

Sub Questions, based on dtm/landsat/geology/mag :

How high are the mesas?

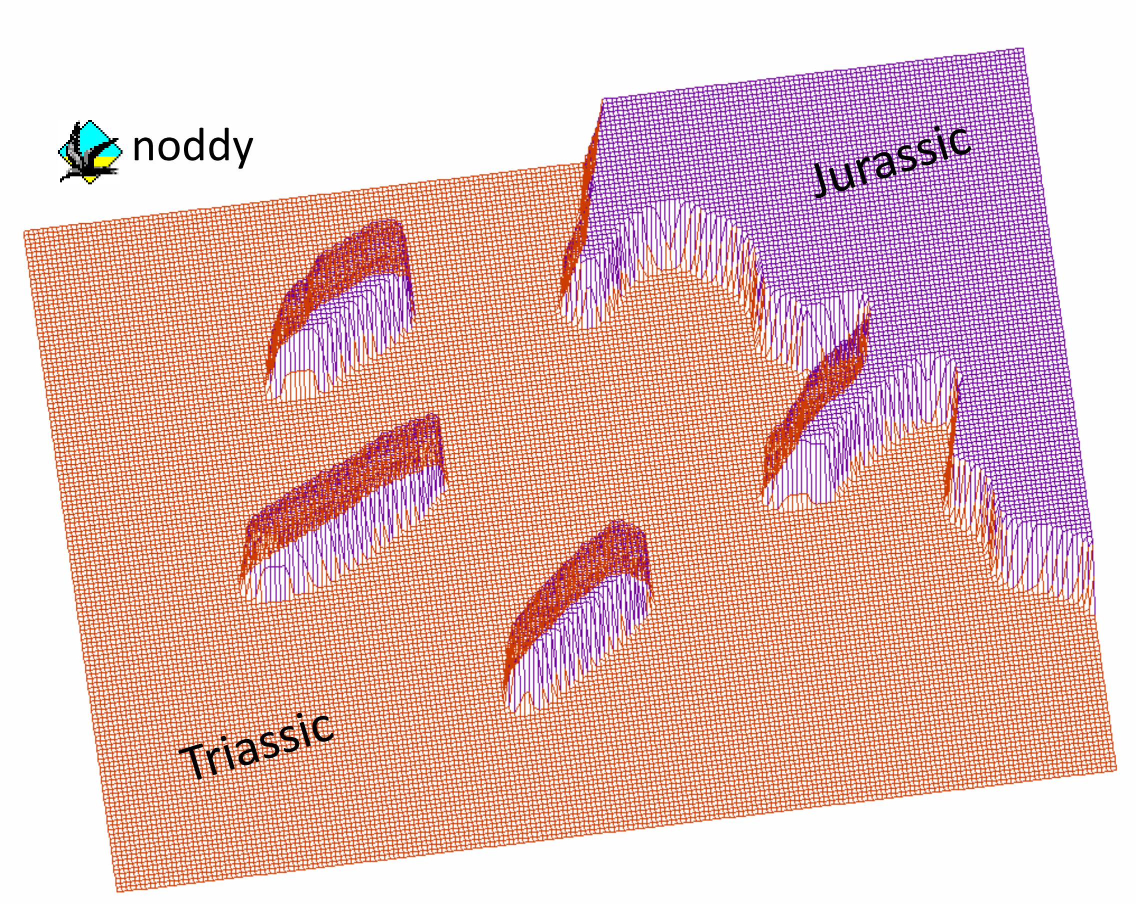
What are the average dimensions of a mesa (long vs short axis)?

Which units define the tops of the mesas?

Which units define the base of the mesas?

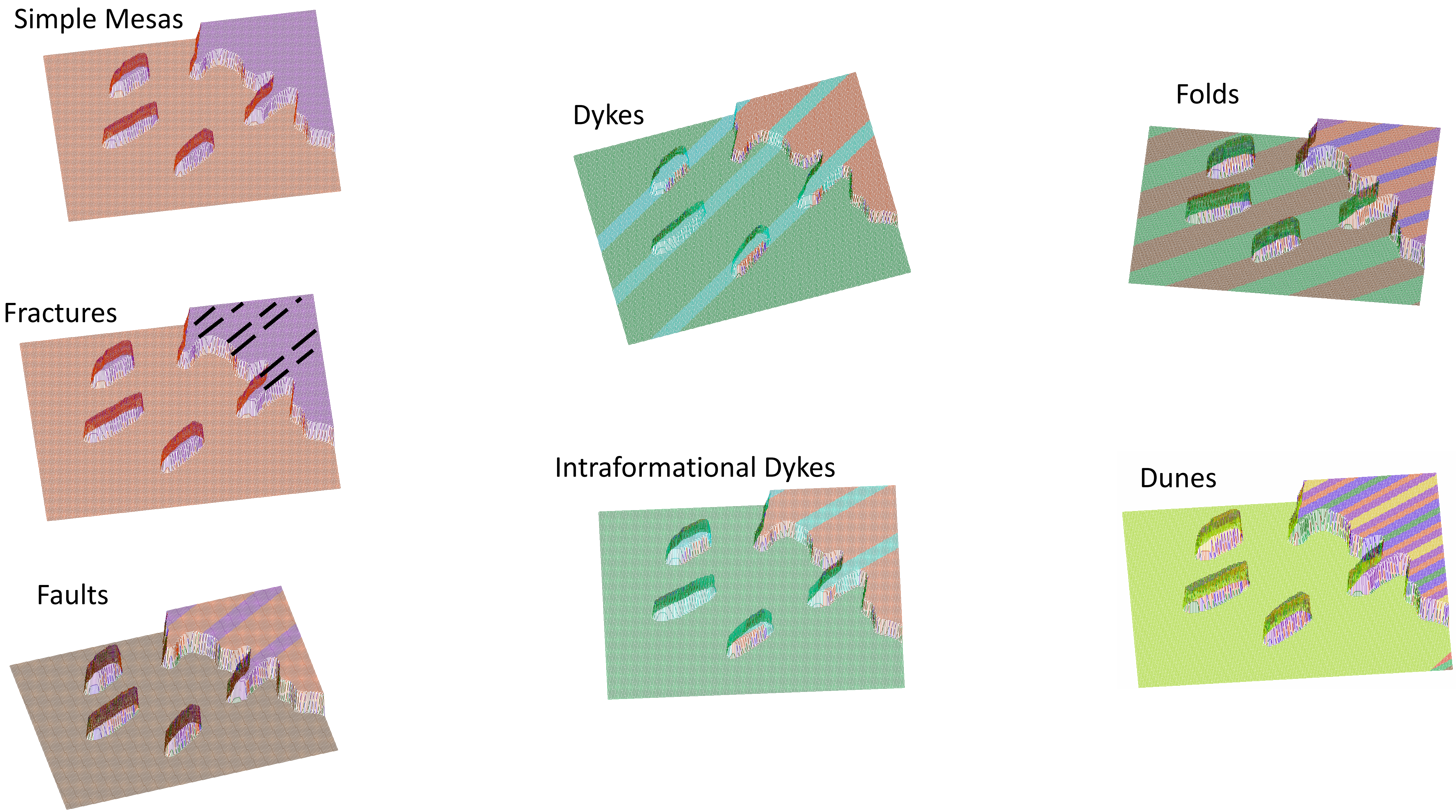
Which units correlate spatially with the magnetic features?

What is possible origin and timing of linear mesas?


noddy
Jurassic
Triassic

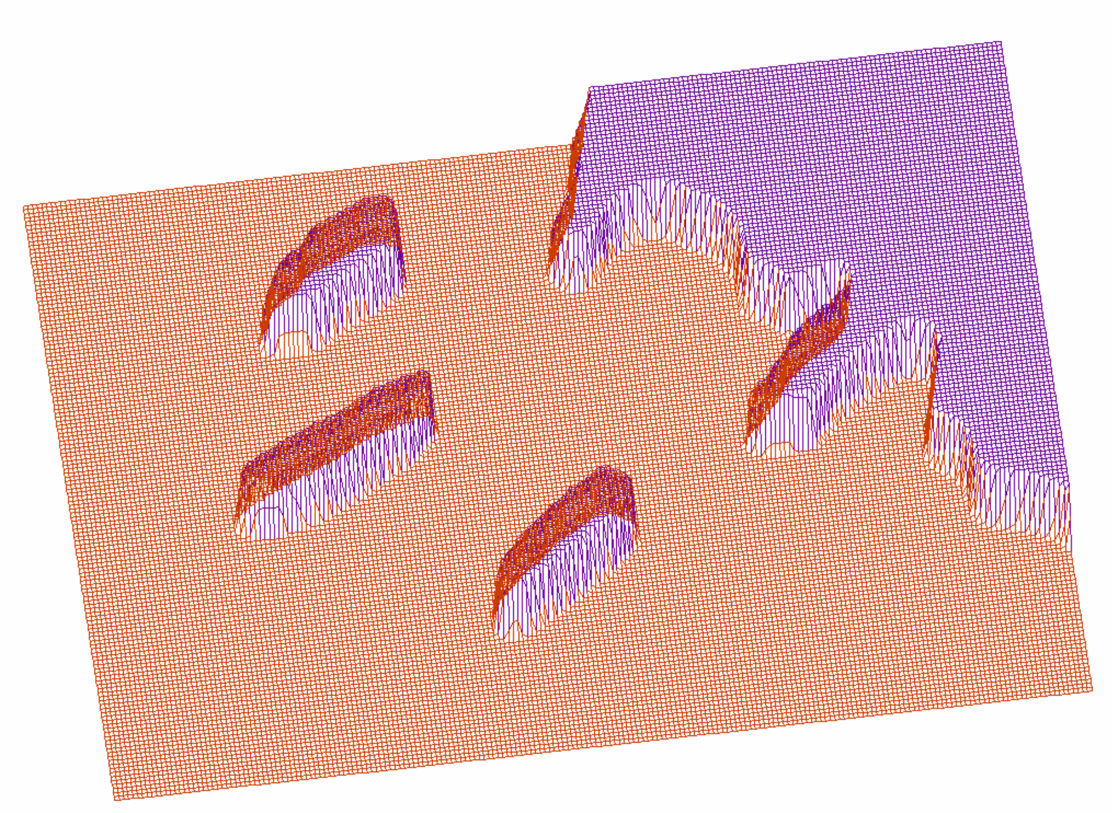

Jurassic
Triassic
Image © 2022 Maxar Technologies
Image © 2022 CNES / Airbus
Google Earth


Terra Preta
350
400
450

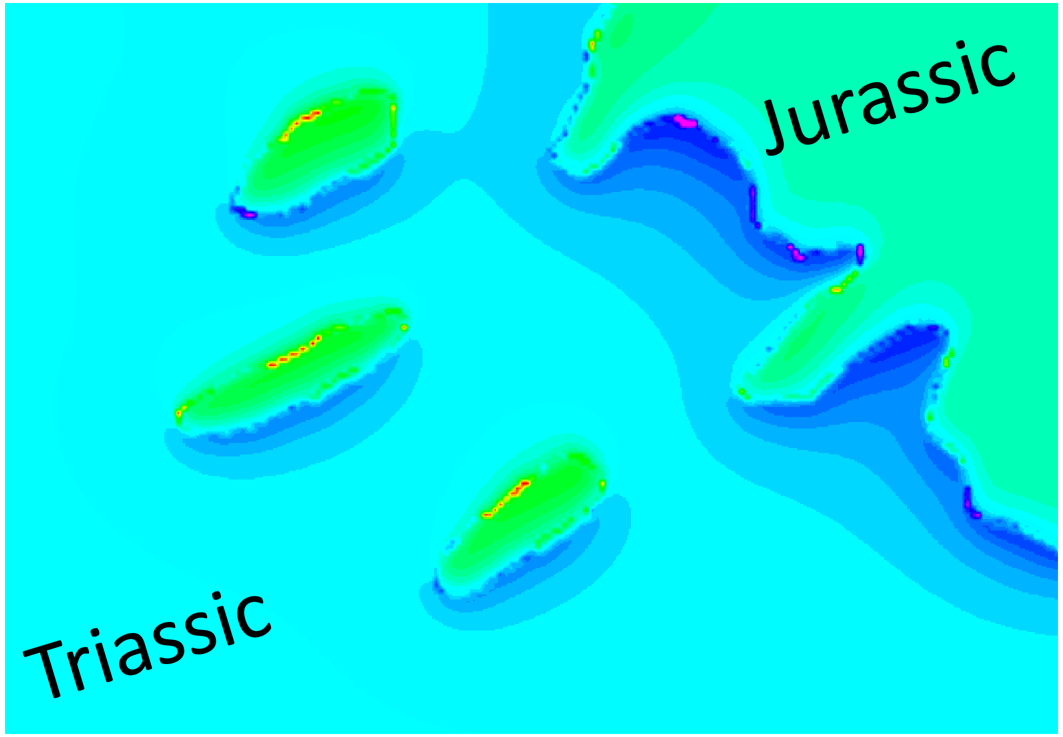

Simple Mesas
Fractures
Faults
Dykes
Intraformational Dykes
Folds
Dunes

Simple Mesas

Model

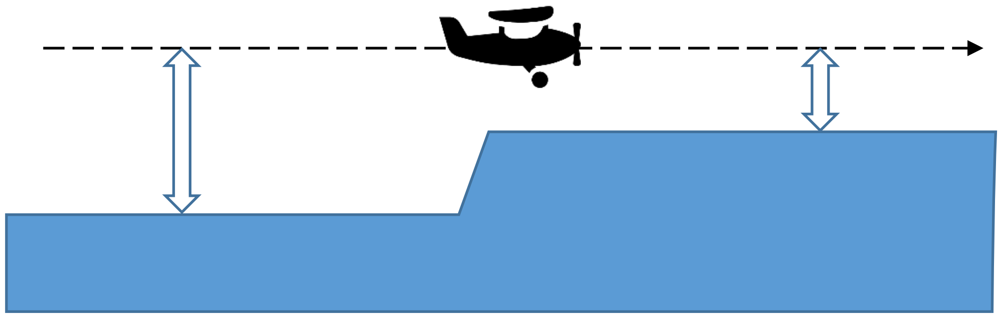


Mag

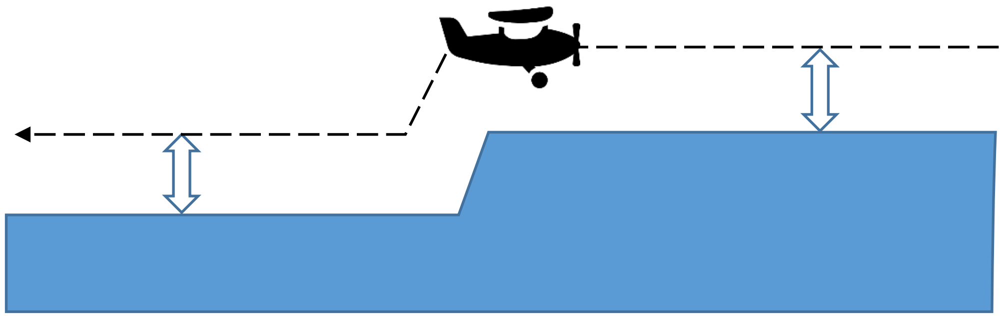


Test: No mag linear features in undissected Jurassic

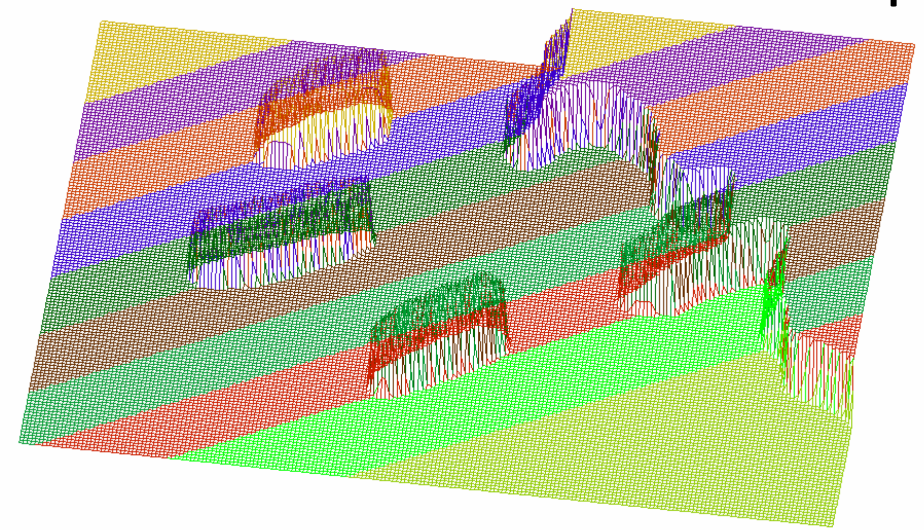
Barometric Survey



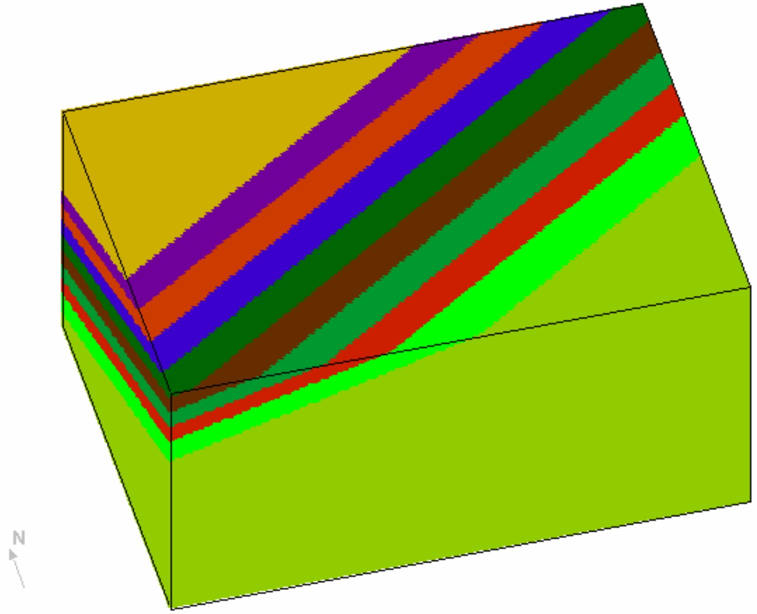
Draped Survey



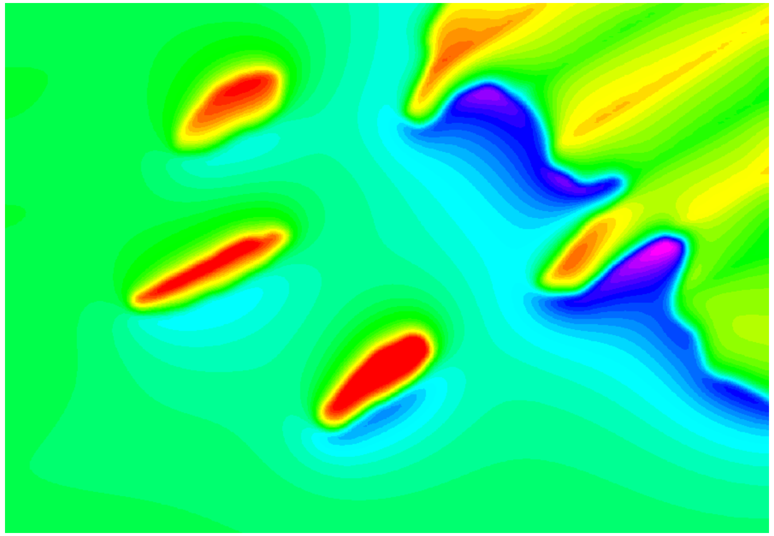
Dipping Stratigraphy



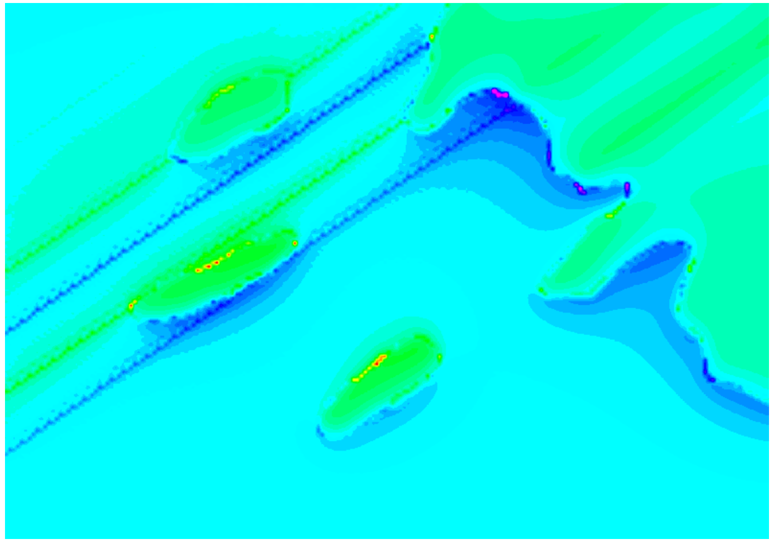
Shallowly dipping strata of different erodability



Barometric

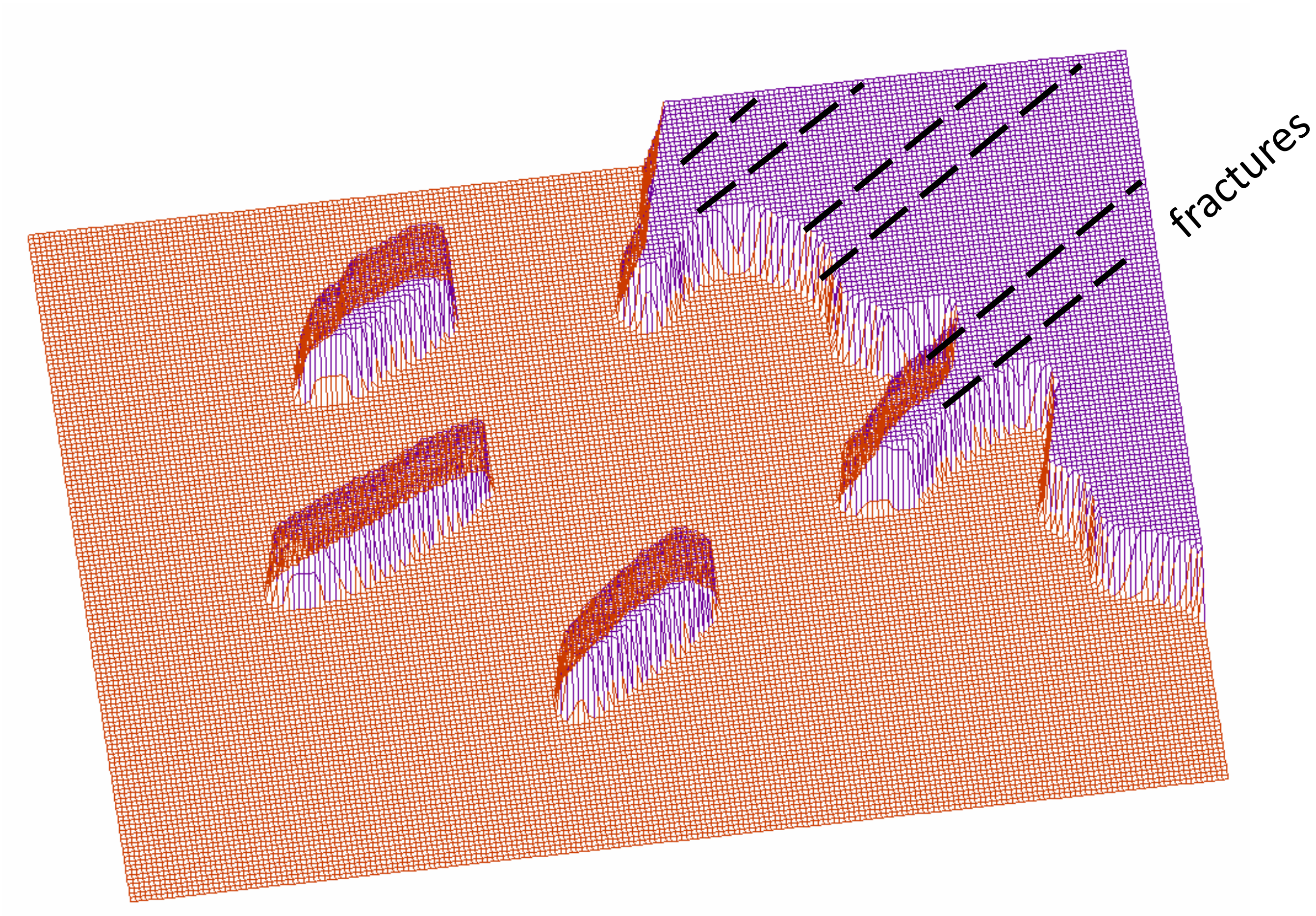


Draped

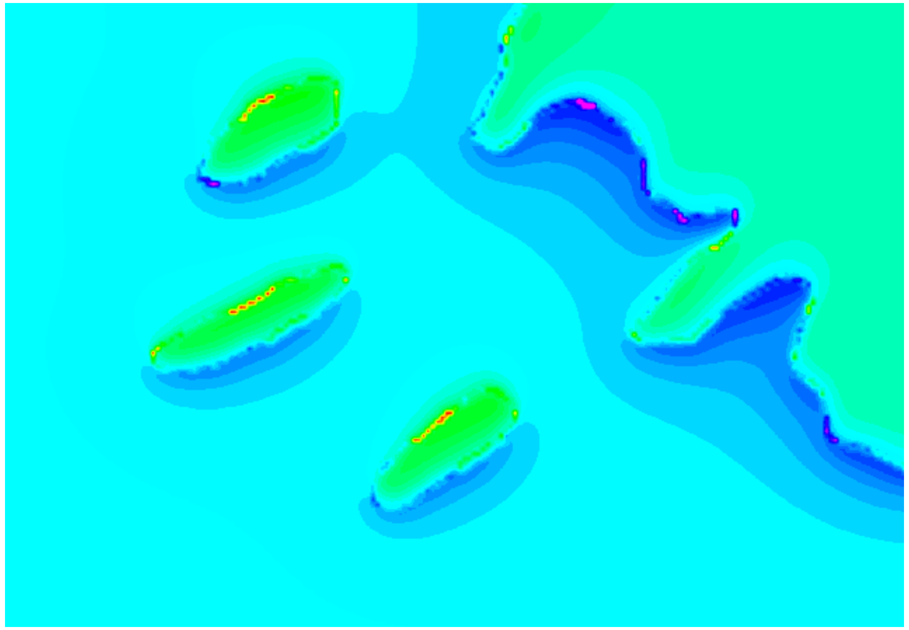


Test: Map pattern suggest sub-horizontal bedding

Fracture Control



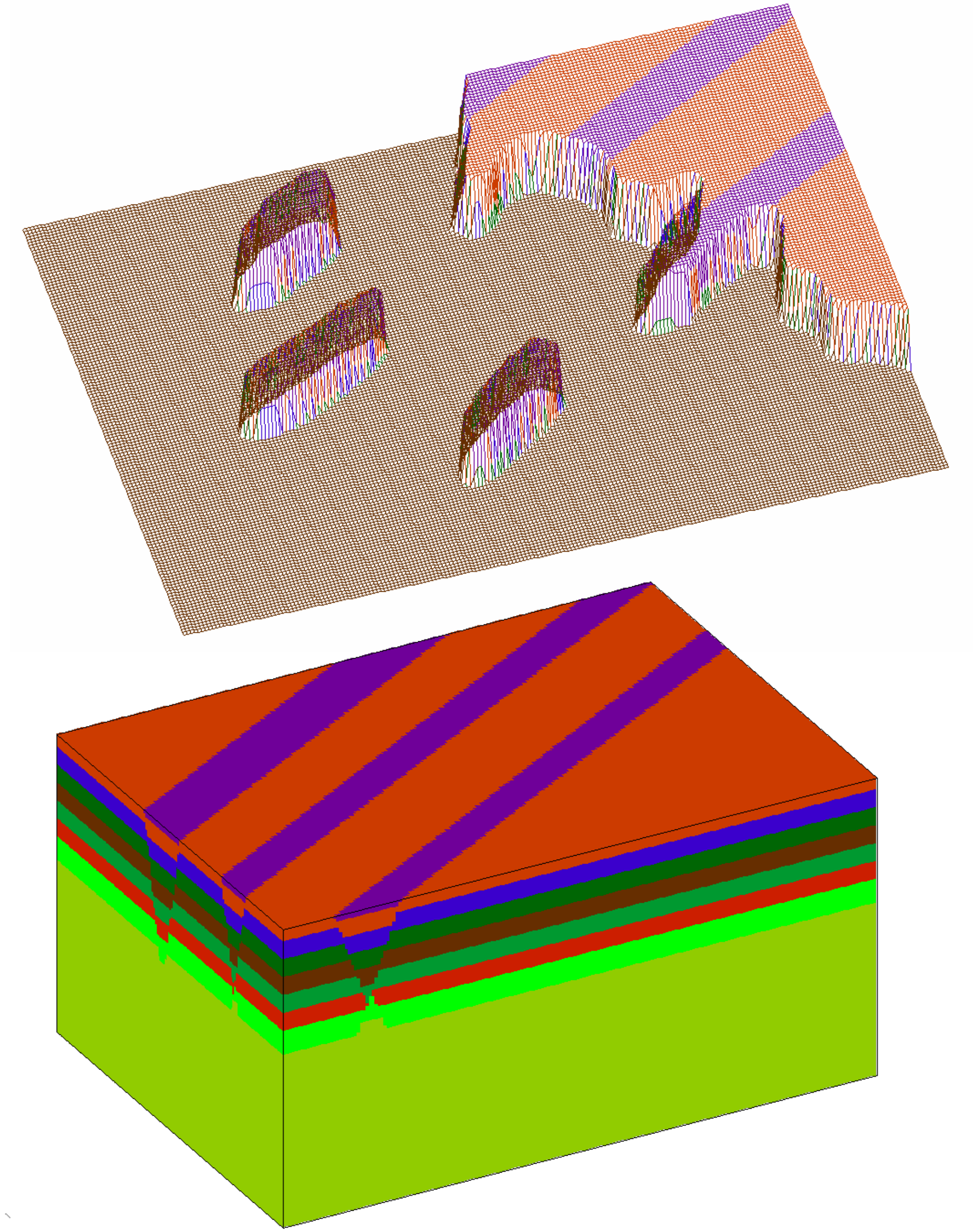
Draped



Test: No mag linear features in undissected Jurassic

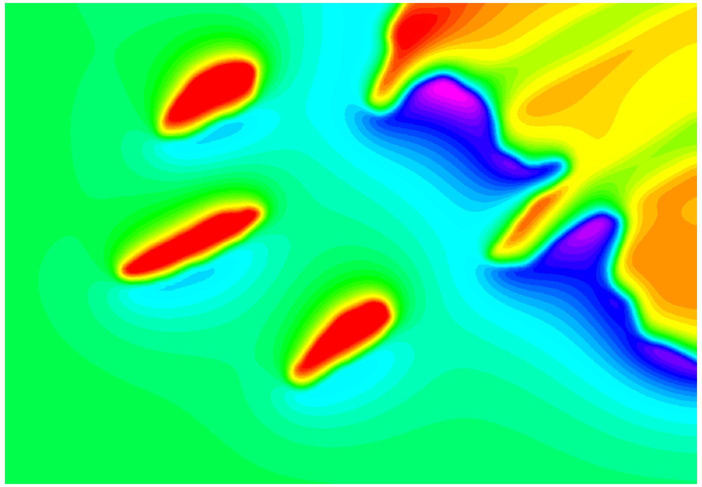
Mesa geometry controlled by pre-existing post-depositional fractures

Faults

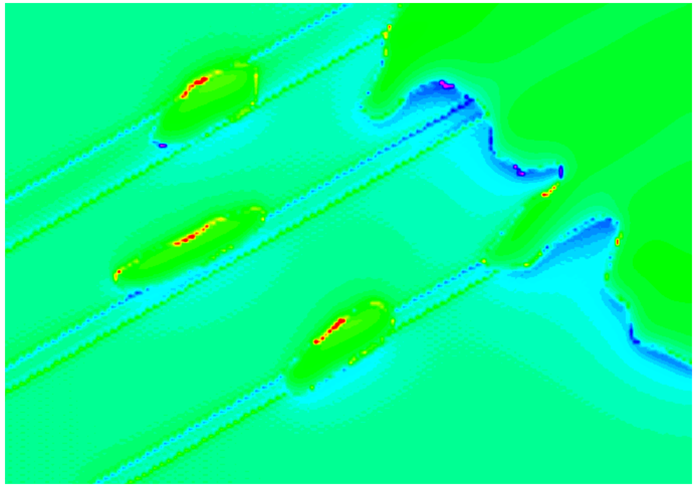


Mesa geometry controlled by pre-existing post-depositional faults

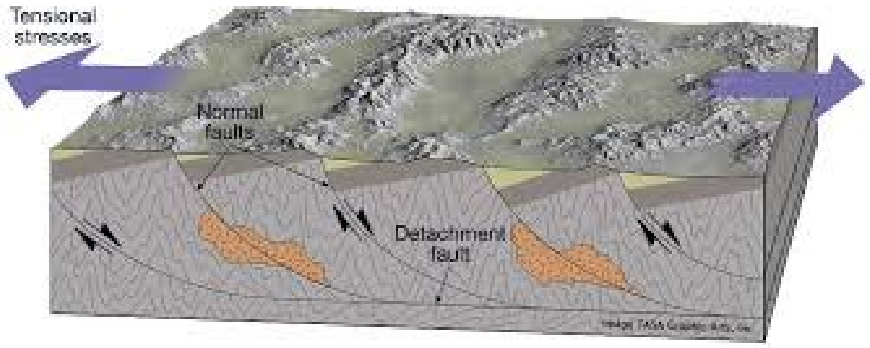
Barometric



Draped



Test: Map doesn’t show only shows faults where there are mesas, not in main Jurassic region



Basin & Range
Nevada, USA

Area > 200 x 200 km

~30,000 m fault spacing

https://earth.google.com/web/@39.37149556,-114.42927751,2087.95626023a,862830.5882071d,35y,0h,0t,0r

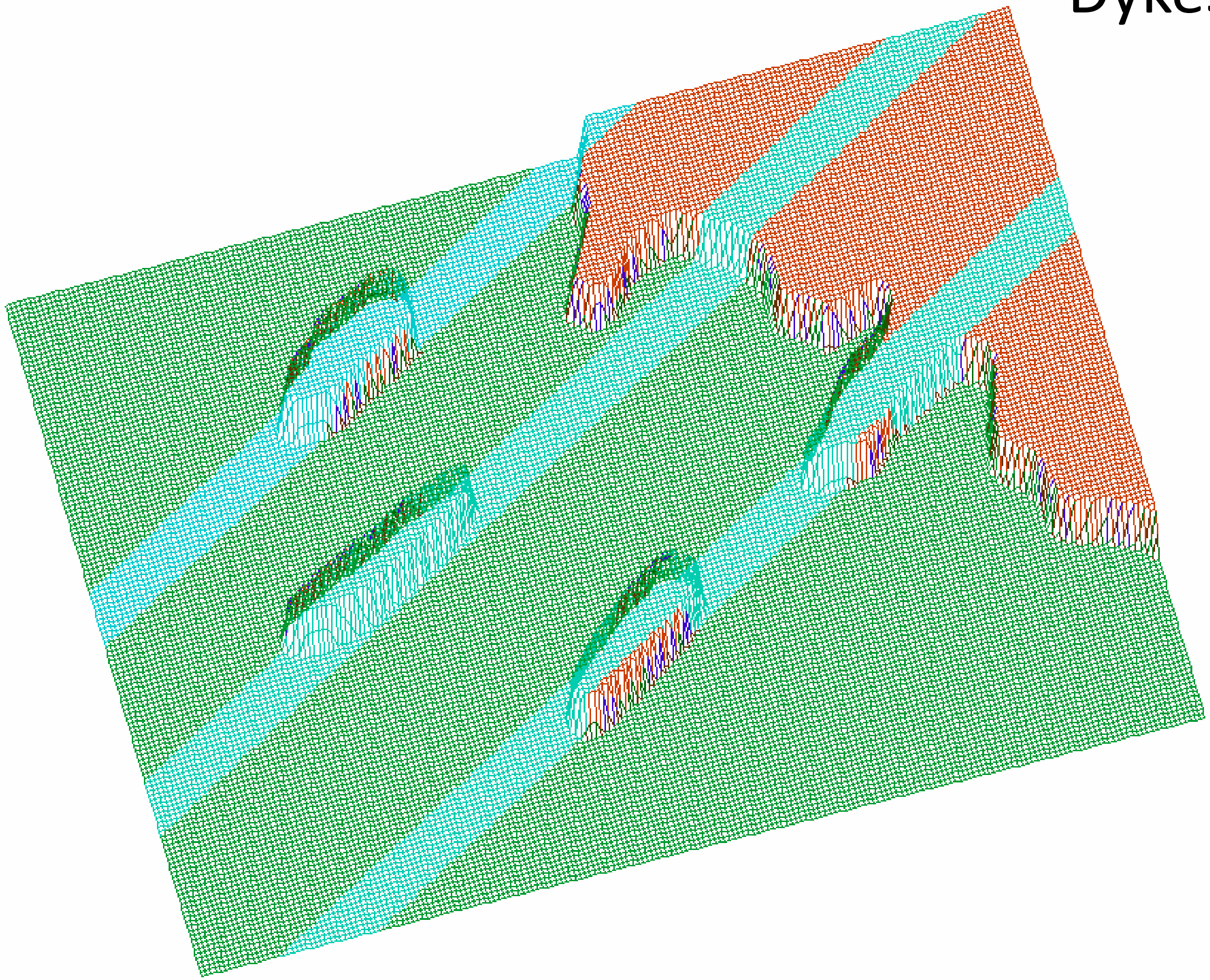
Figure 12. The complex geology within Segment 1 is the result of repeated periods of mountain building alternating with periods of erosion. Most of the basins in the segment are bounded by faults and contain rocks of Cenozoic age. The mountains that separate the basins are formed on rocks of various ages.

EXPLANATION

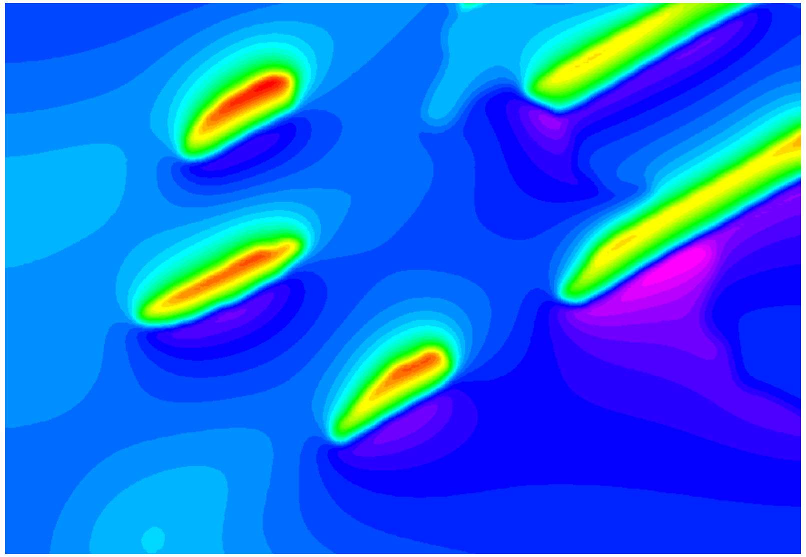
Czc	Cenozoic continental deposits
Czm	Cenozoic marine sedimentary rocks
Mzm	Mesozoic marine sedimentary rocks
Mz	Mesozoic marine sedimentary rocks and continental deposits
MzPz	Mesozoic and Paleozoic marine sedimentary and volcanic rocks
MzPzc	Mesozoic and Paleozoic carbonate rocks
Pz	Paleozoic marine sedimentary rocks and continental deposits
Pzp€	Lower Paleozoic and Precambrian clastic sedimentary rocks
Qv	Late Cenozoic volcanic rocks
Tv	Early Cenozoic volcanic rocks
Mzg	Mesozoic granitic rocks
Mzu	Mesozoic ultramafic rocks
p€	Precambrian igneous and metamorphic rocks
	Fault
	Thrust fault—Sawteeth on upper plate

King, P.B., and Beikman, H.M., 1974, Geologic map of the United States: U.S. Geological Survey, scale 1:2,500,00, 3 sheets.

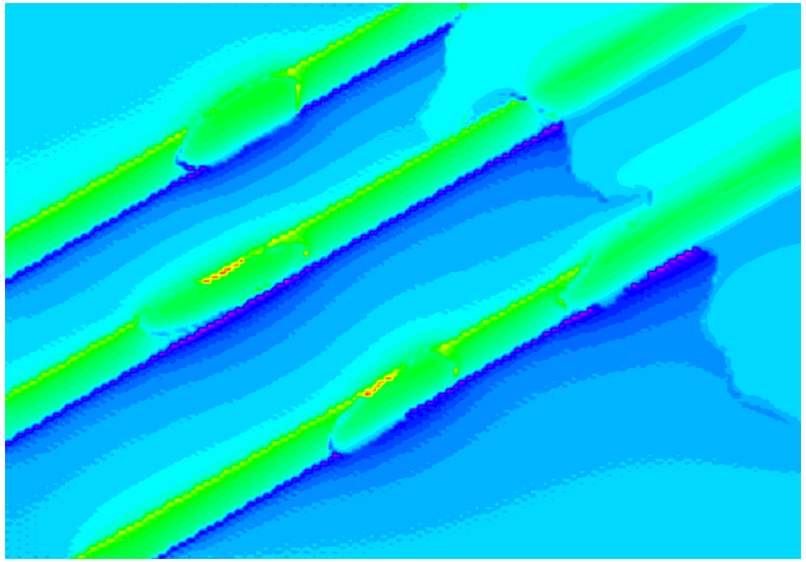
Dykes



Barometric

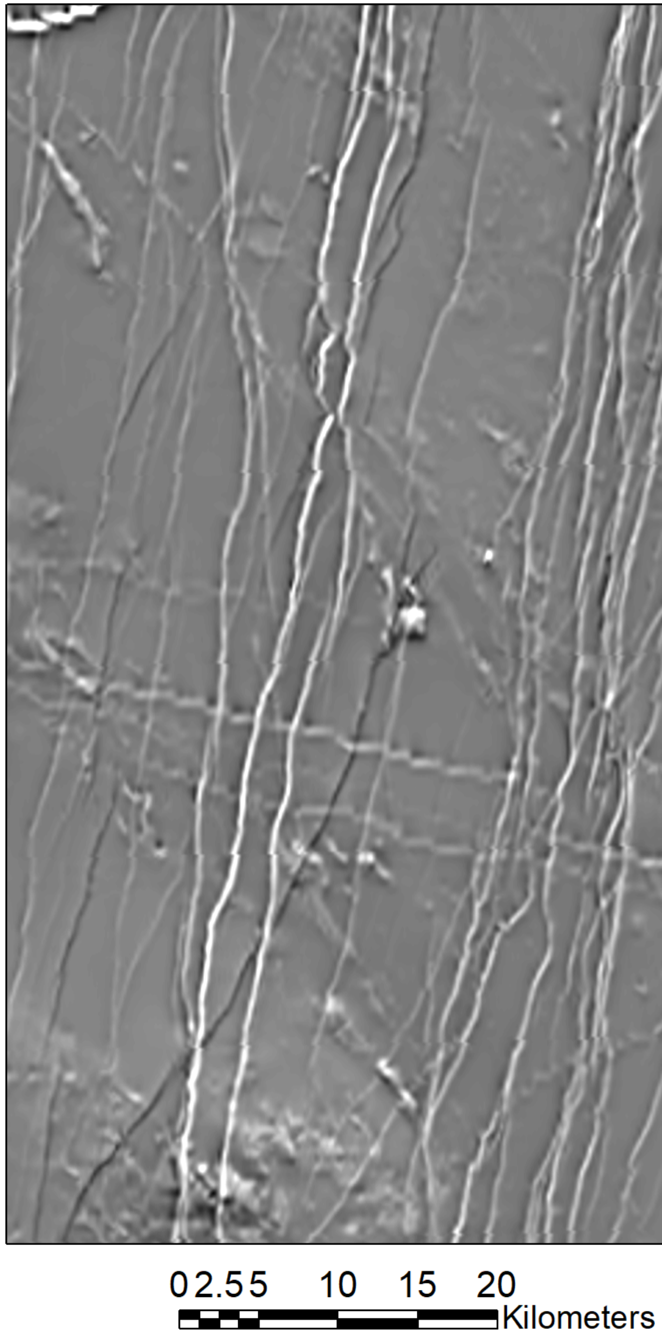


Draped



Test: Dykes also intruded Triassic units

Mesa geometry controlled by pre-existing post-depositional dykes

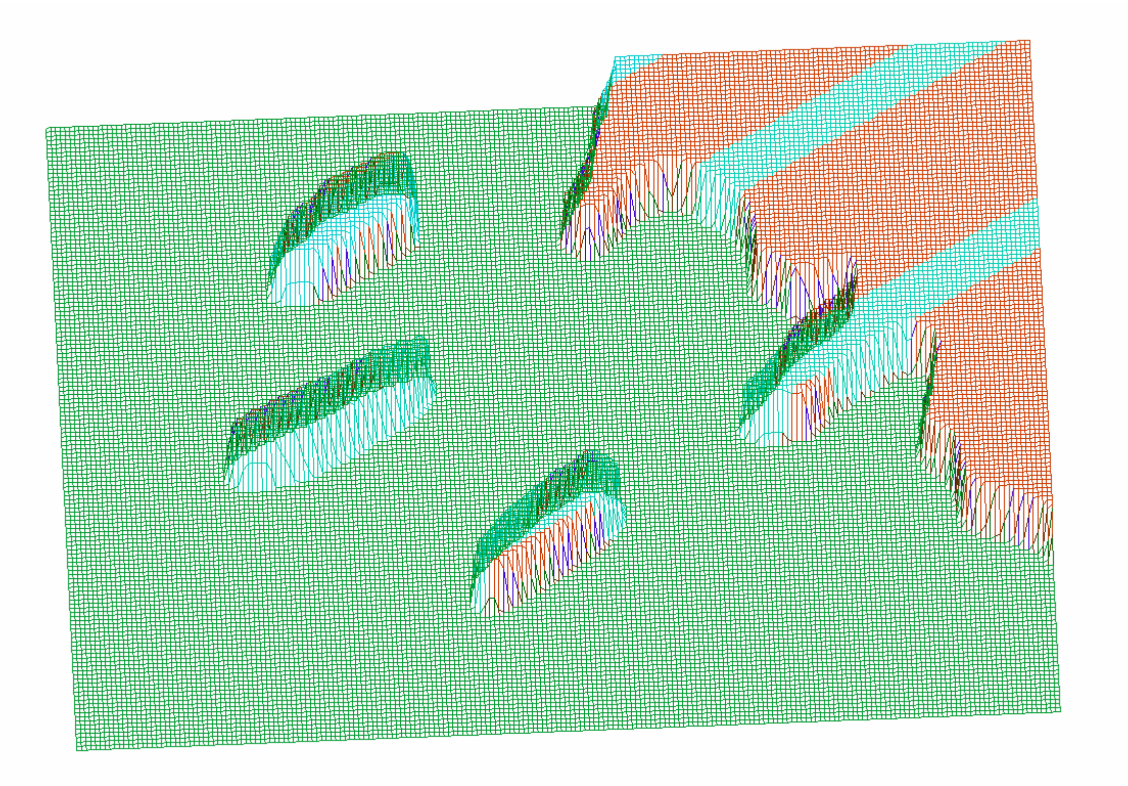


Reguibat Inlier, Mauritania

Area > 100 x 100 km

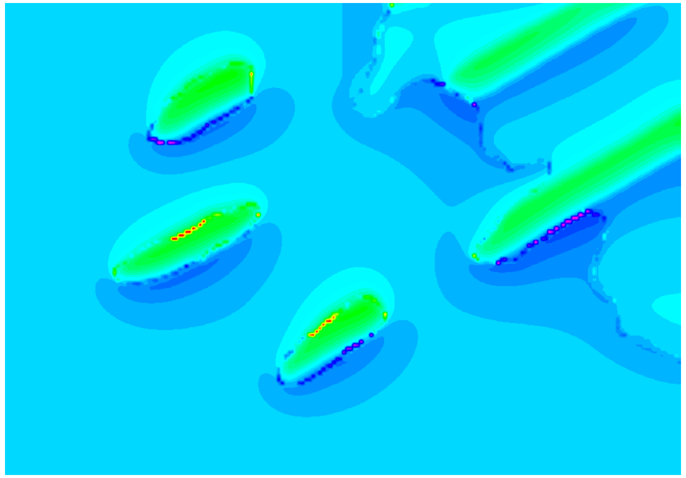
~2,000 m dyke spacing

Intra-formational dykes

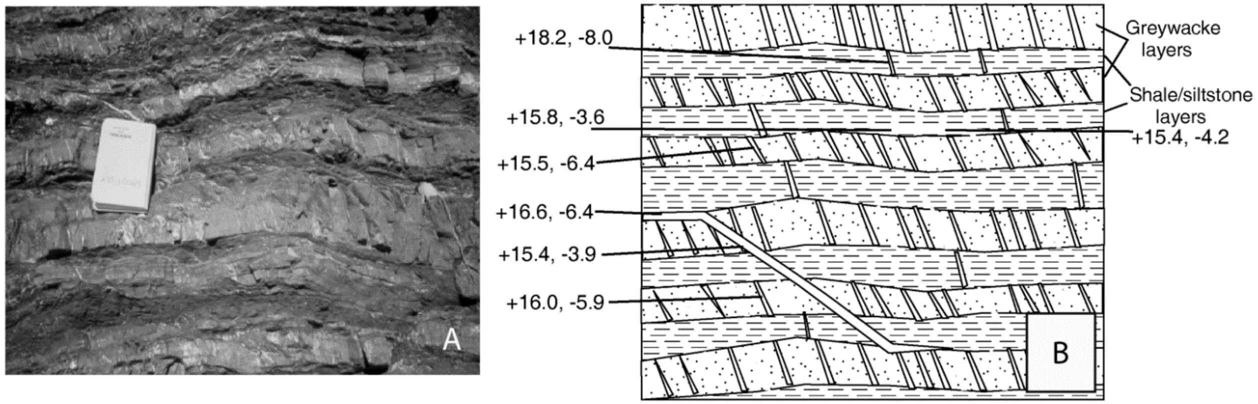


Dykes that only get filled within a specific horizon

Draped

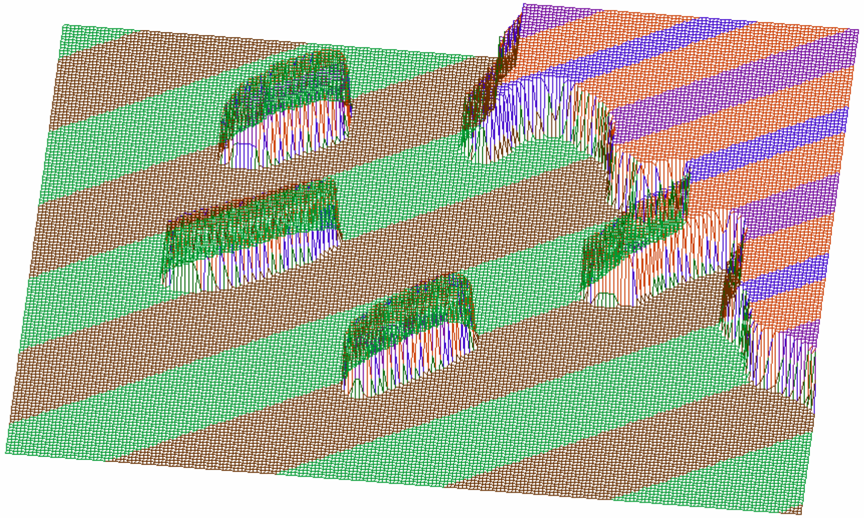


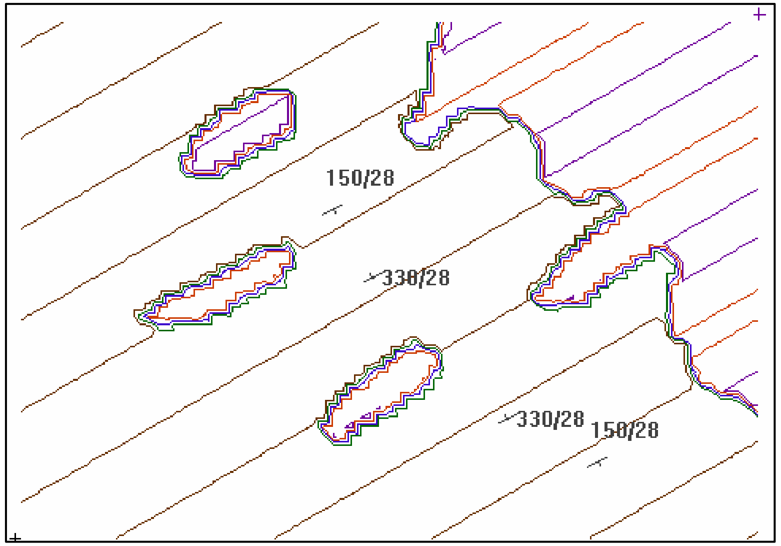
Test: Can this happen? Where does magma come from?

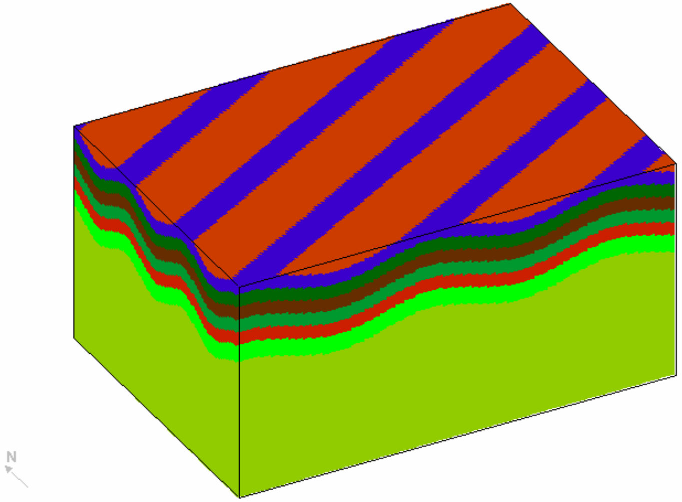


Seth J. Sadofsky & Gray E. Bebout (2004) Field and Isotopic Evidence for Fluid Mobility in the Franciscan Complex: Forearc Paleohydrogeology to Depths of 30 Kilometers, International Geology Review, 46:12, 1053-1088

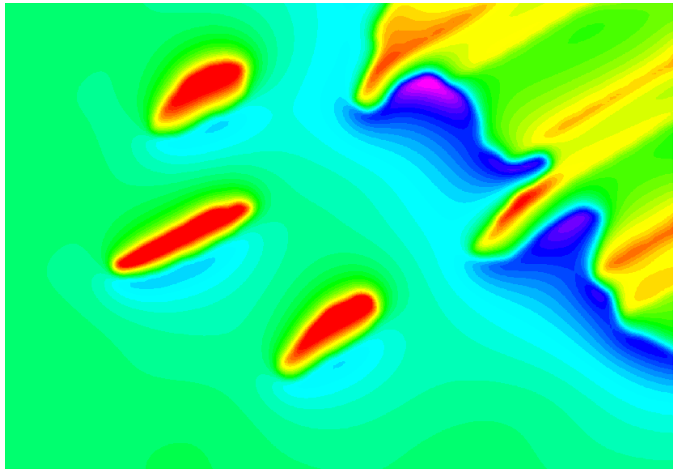
Folds



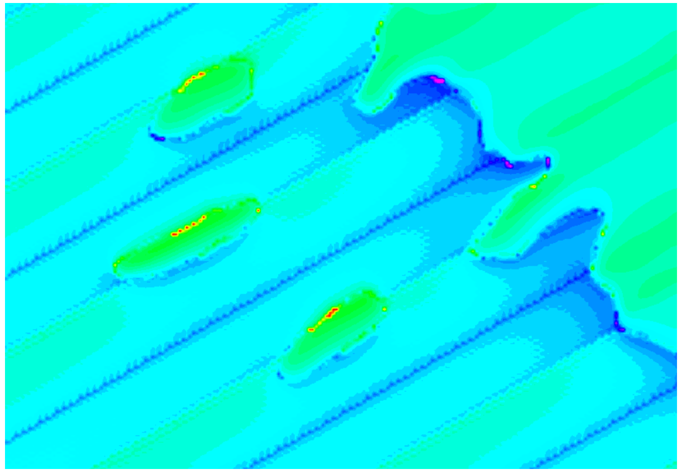




Barometric



Draped



Test: Folds Triassic as well, no evidence of folds on map?

Mesa geometry controlled by pre-existing post-depositional folds

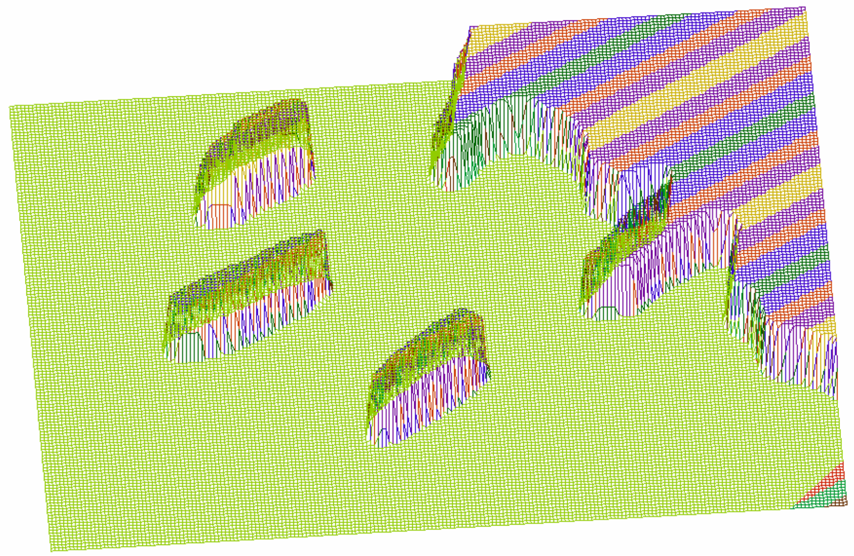
South of Damera, Namibia

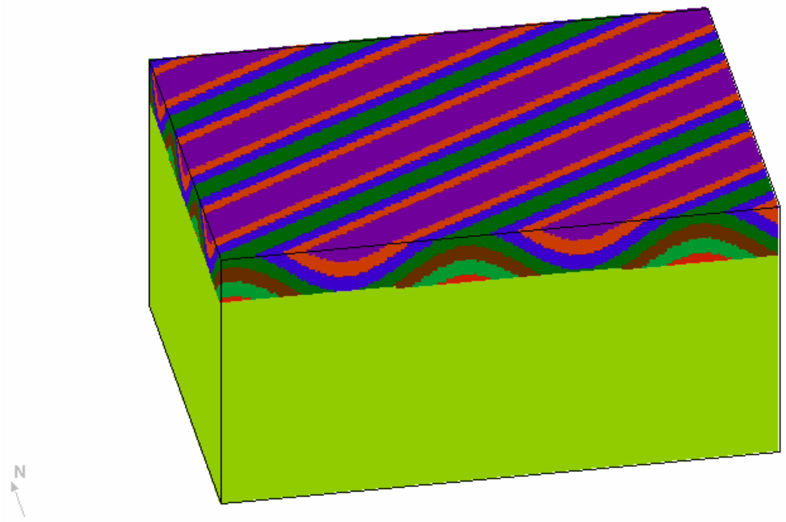
~80 x 30 km fold sequence

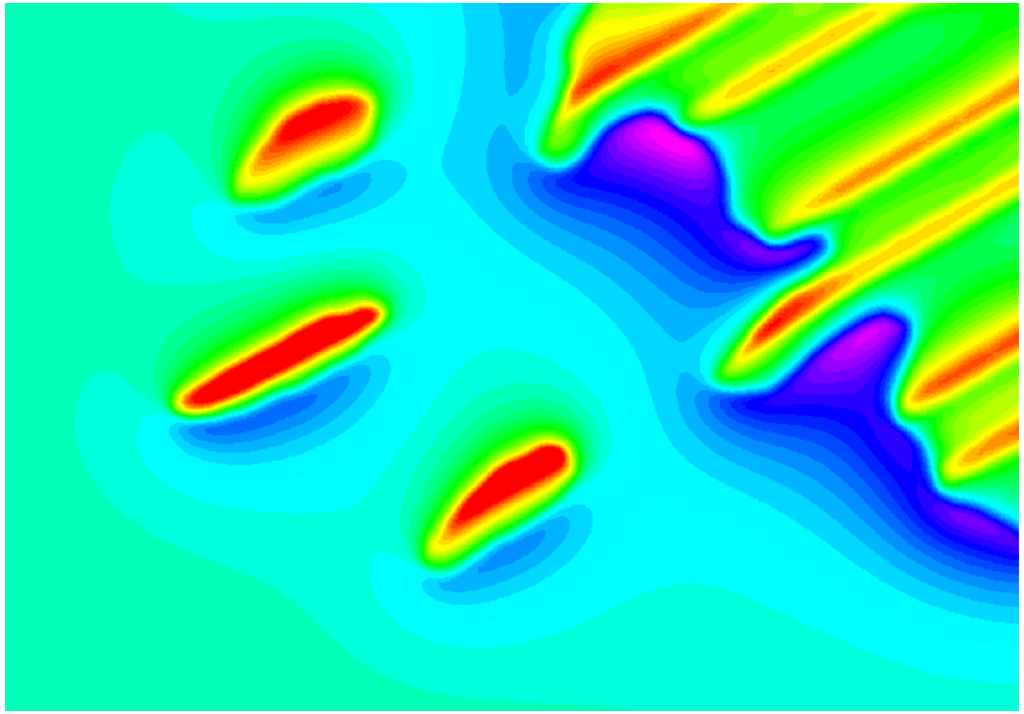
~350 m between limbs

https://earth.google.com/web/search/-24.8,14/@-21.05441513,14.01247905,436.60072107a,11651.12554251d,35y,0.00000012h,1.16549356t,0r/data=CigiJgokCZDlrDC7_zfAEcWZEwQ5lTjAGVY9c5G4Ey9AIbtwwtmihi1A

Jurassic Dunes



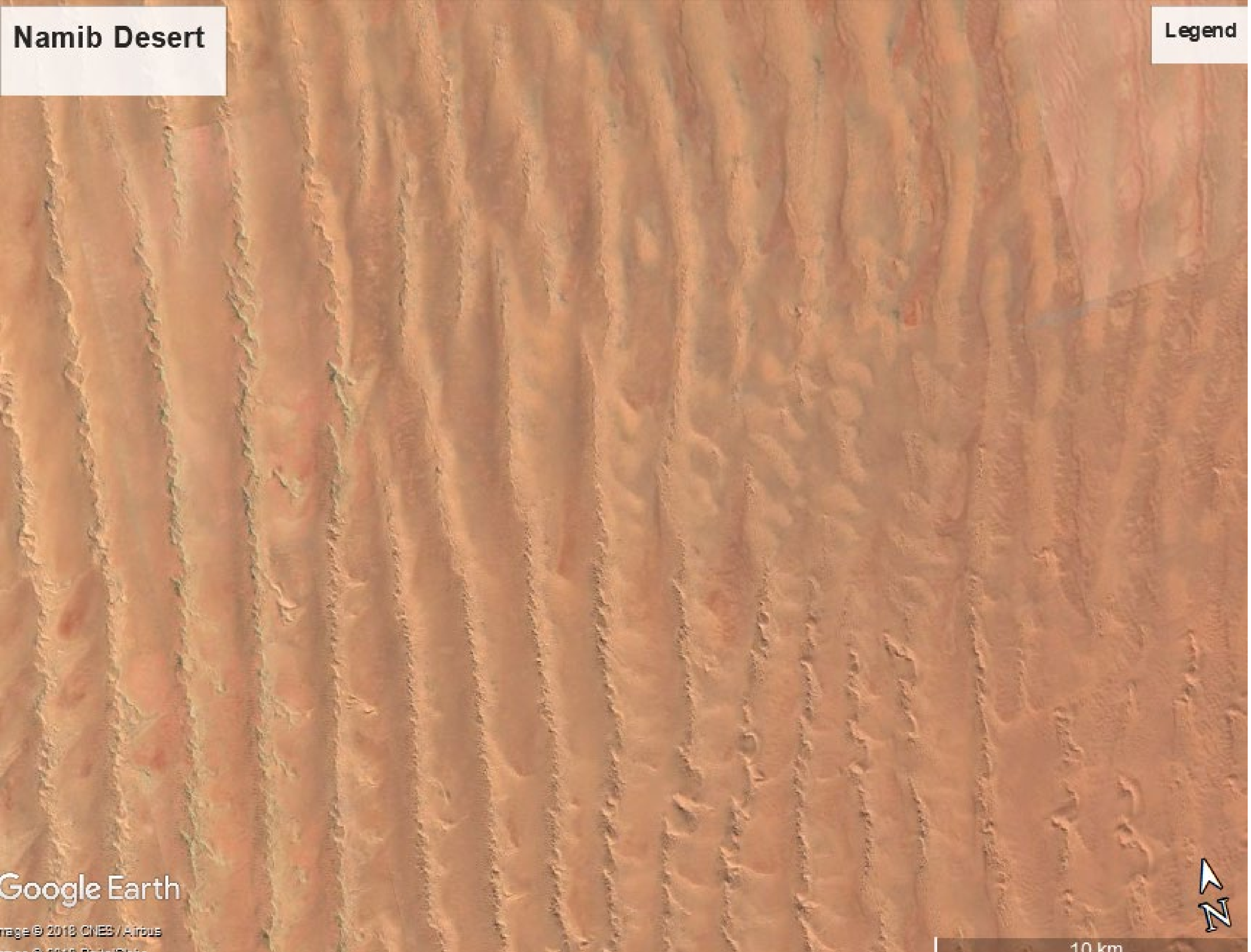




Test: Can this happen? What is the magnetic unit (volcanic infill?)

Mesa geometry controlled by pre-existing syn-depositional Triassic-era dunes

Namib Desert,
Namibia

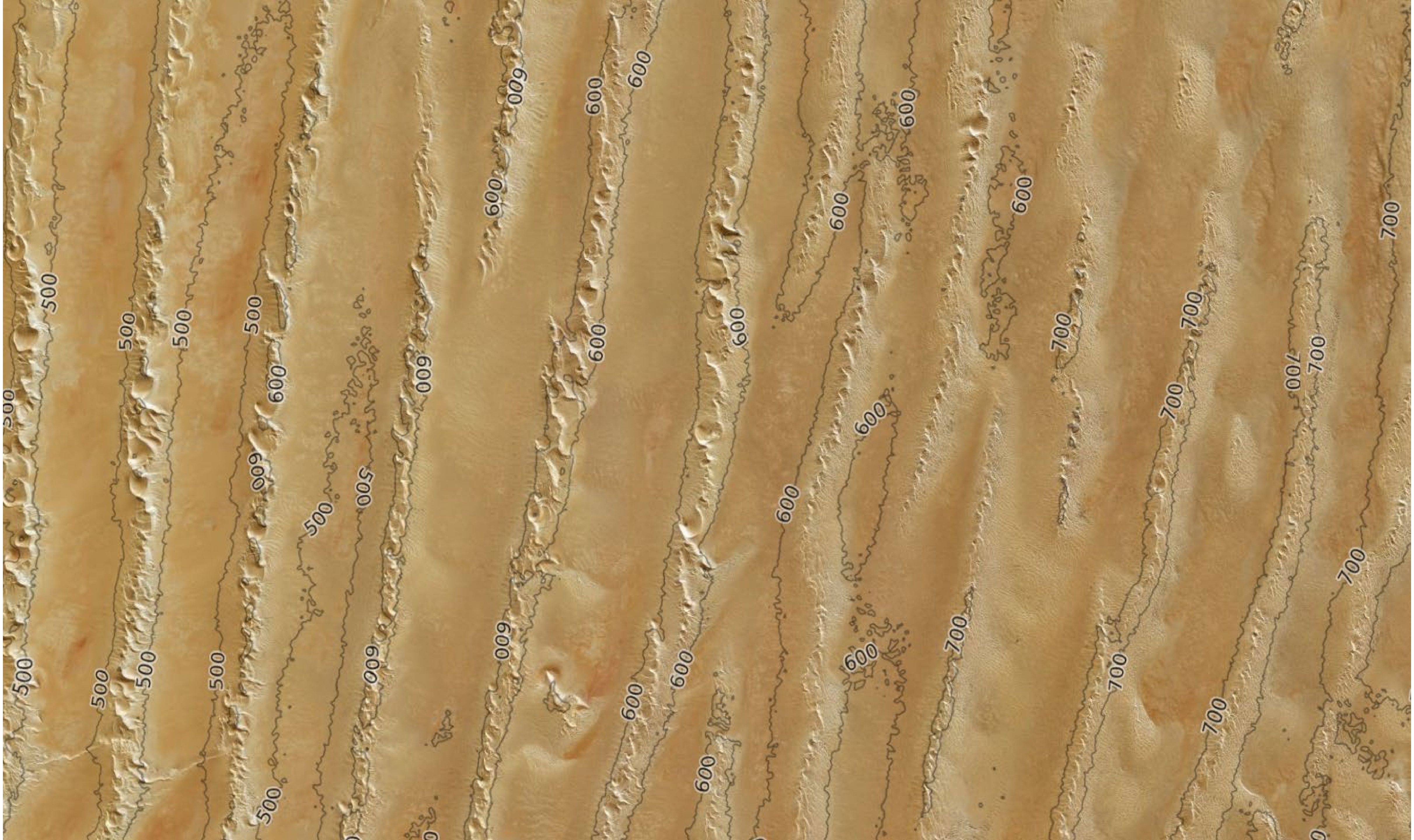


Namib Desert > 200 x 200 km

~2000 m Dune spacing

dunes up to 1200 m high

https://earth.google.com/web/@-24.29141542,15.15073936,624.95953978a,102141.41527807d,35y,-0h,0t,0r


500
600
700

Preservation of ancient eolian landscapes beneath flood basalt: an example from the Officer Basin, Western Australia

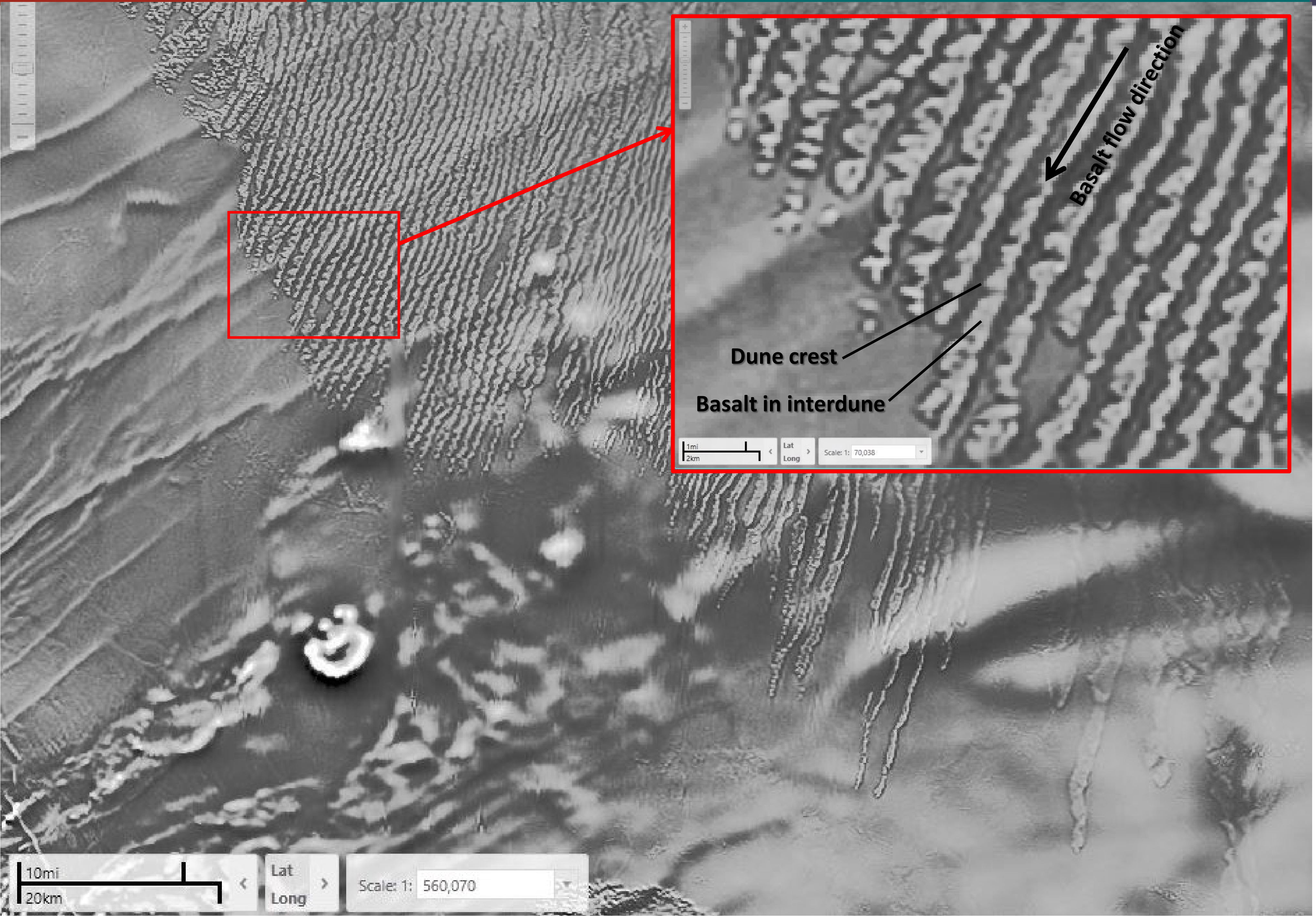
Peter Haines

GSWA

Officer Basin

- 525 000 km^2 in WA and SA
- Up to 10 km thickness
- Early Neoproterozoic to Paleozoic
- Marine and non-marine

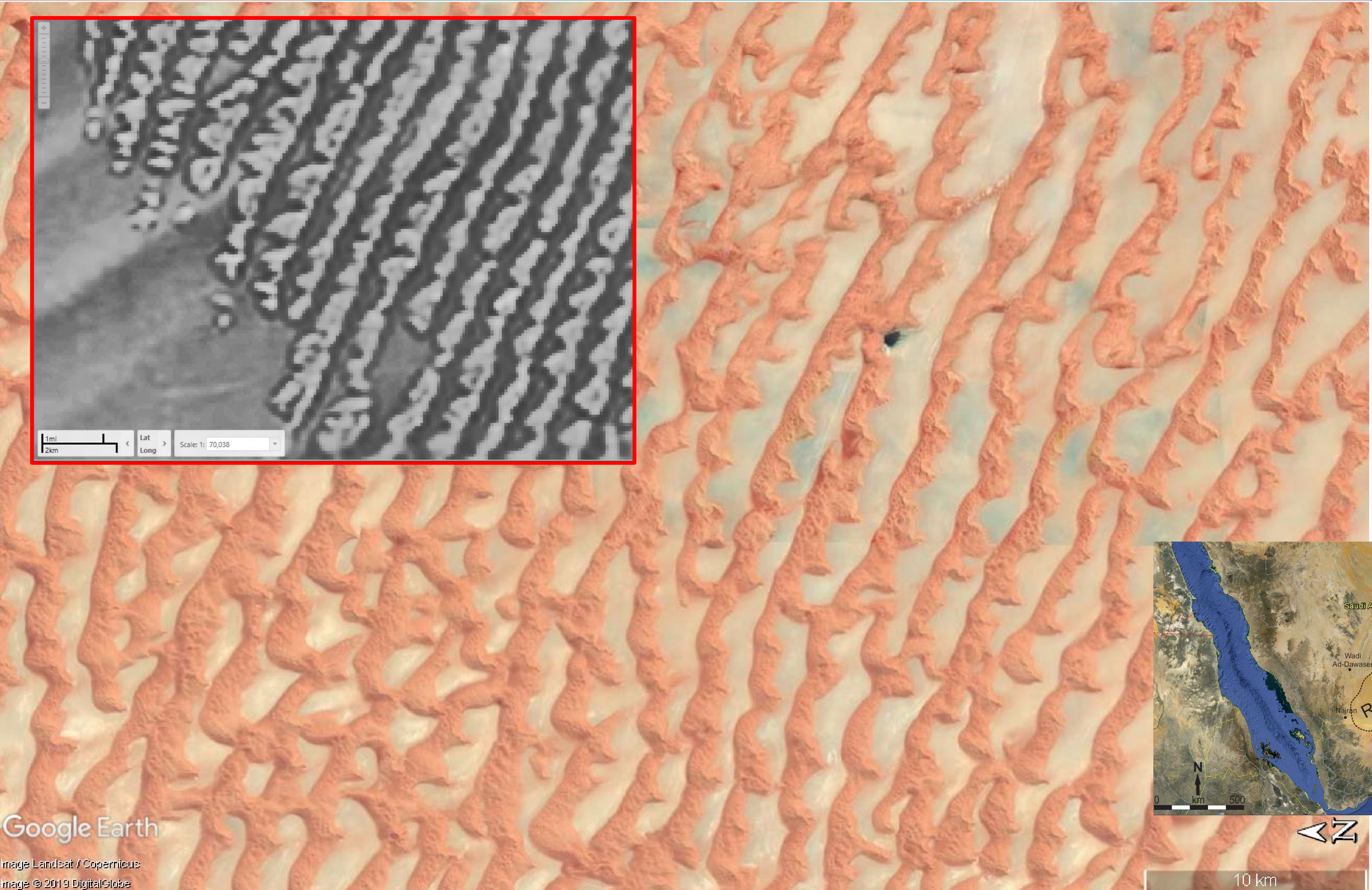

Durba
Sandstone
McFadden
Formation

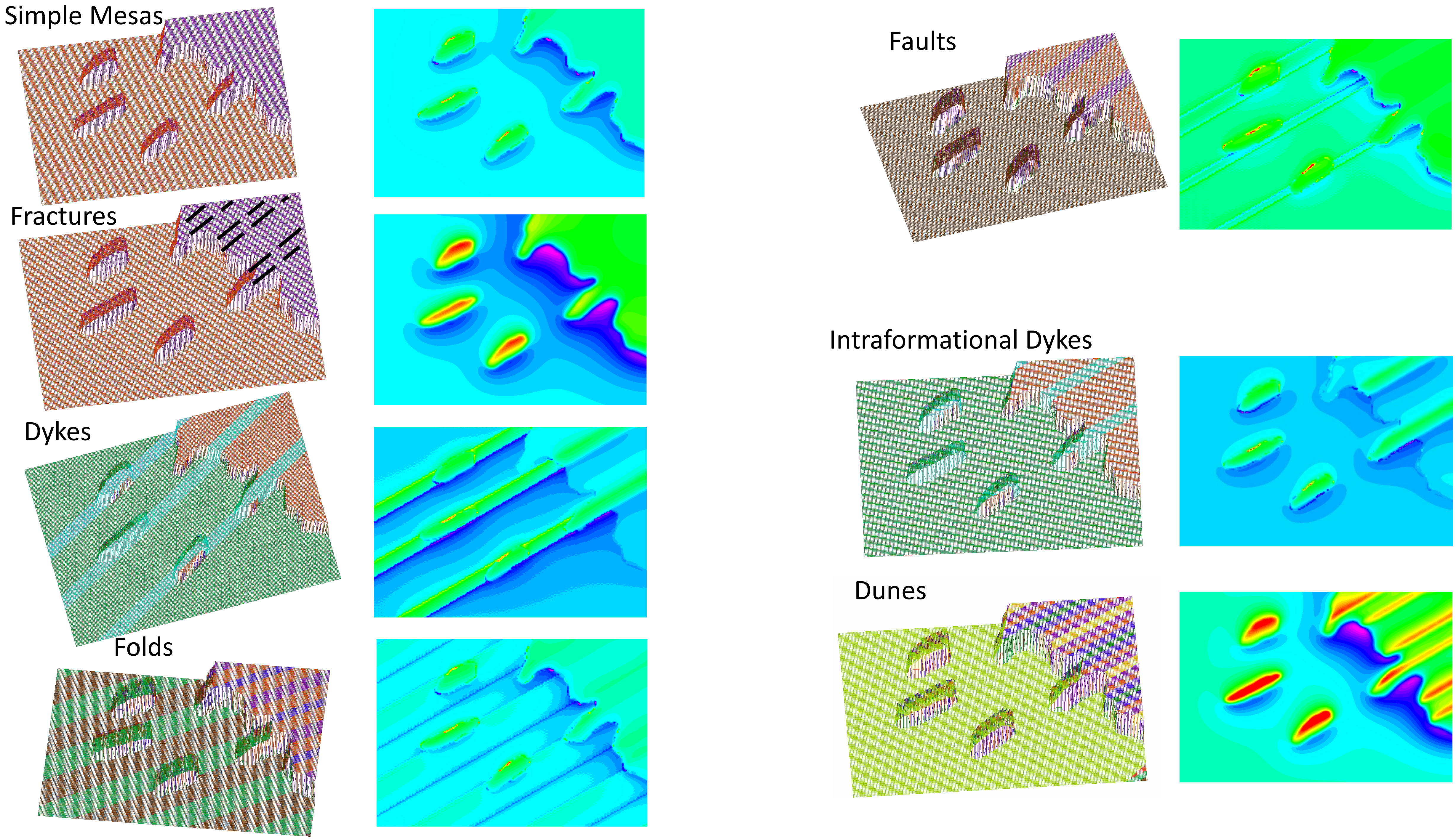


1st vertical derivative aeromagnetic image

Generated in GeoVIEW (GSWA)

Rub’ Al-Khali sand sea southeastern Saudi Arabia

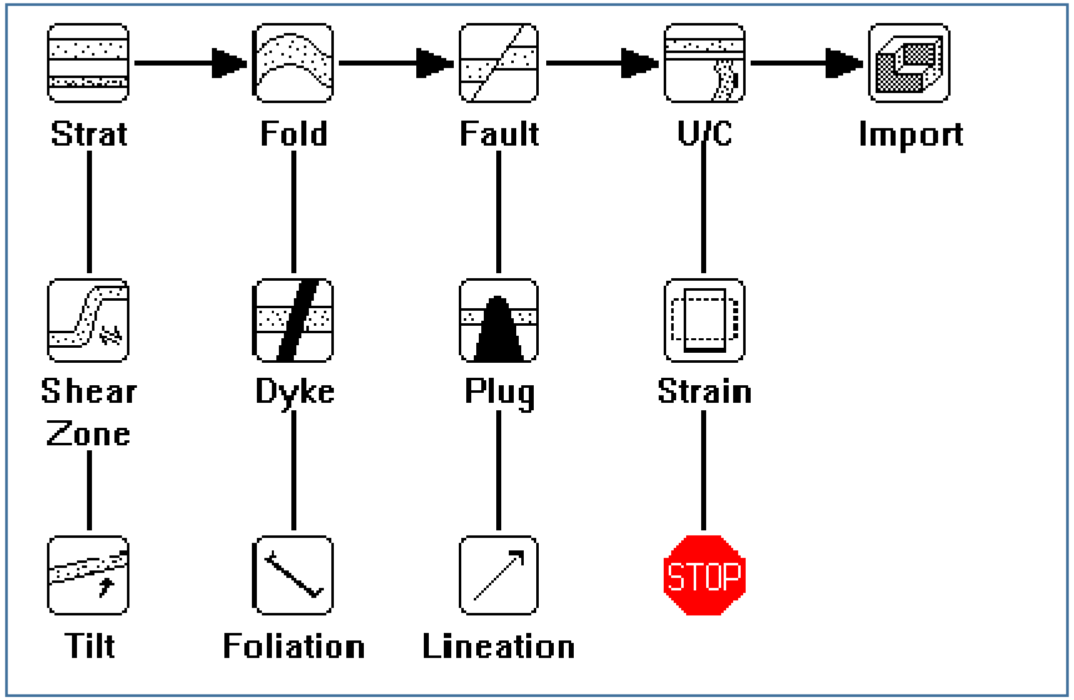



Simple Mesas
Fractures
Dykes
Folds
Faults
Intraformational Dykes
Dunes

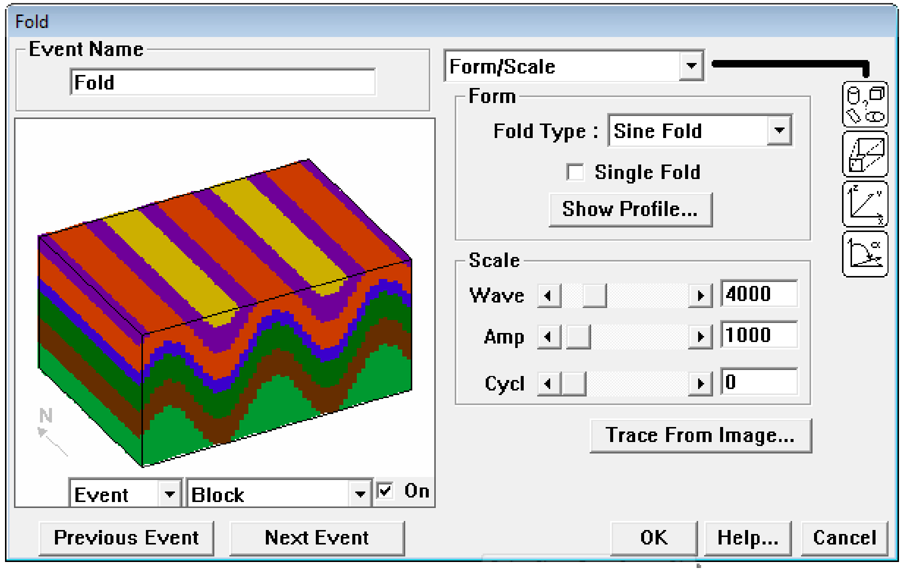
Prac 2 Forward 3D geological and geophysical modelling

Integrated geological and geophysical modelling

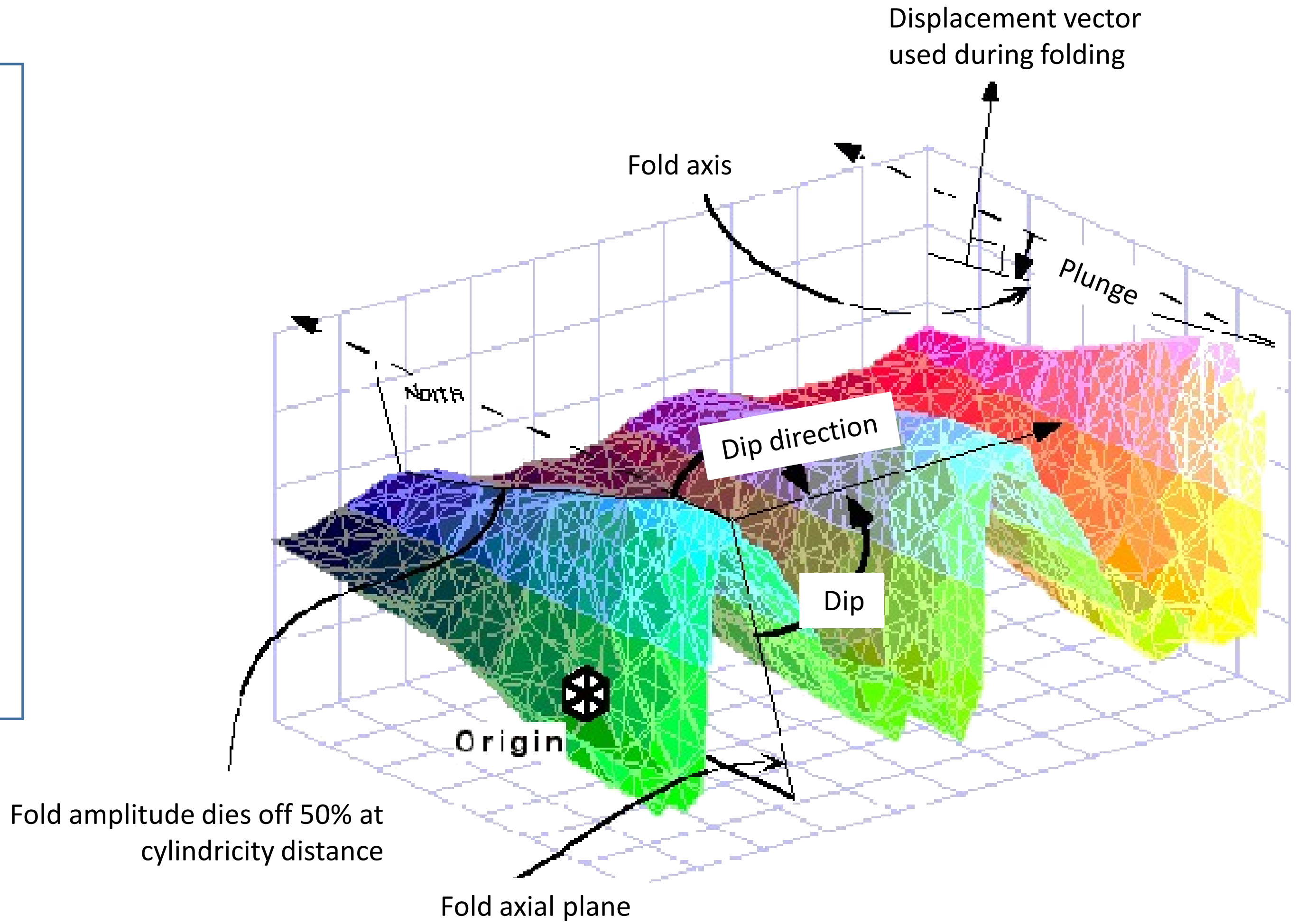
Prac 2 3D



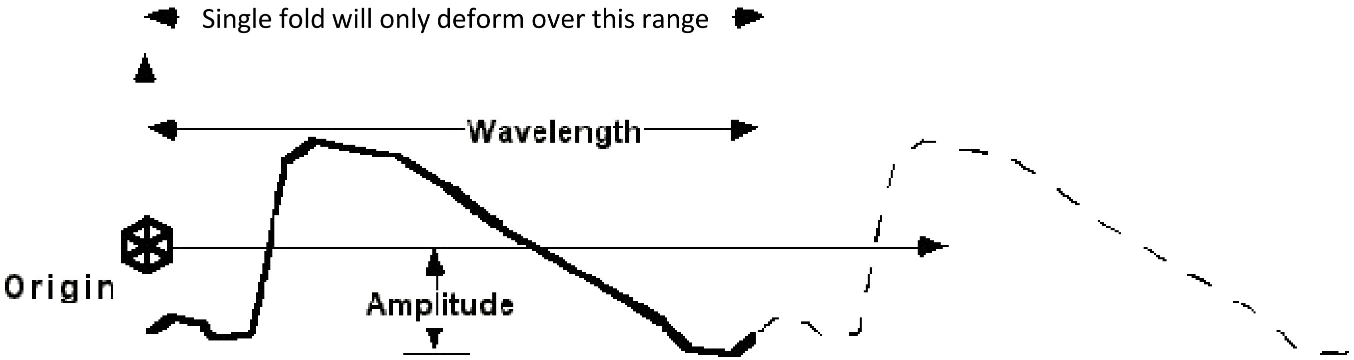
Strat
Fold
Fault
U/C
Import
Shear Zone
Dyke
Plug
Strain
Tilt
Foliation
Lineation
STOP



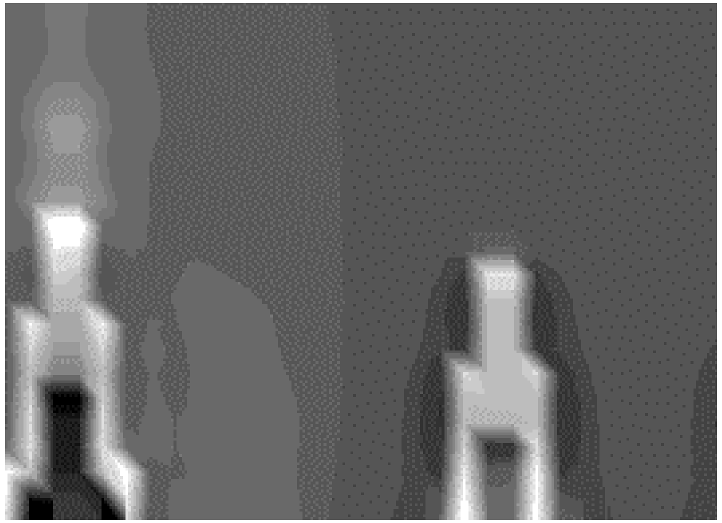
Fold
Event Name
Fold
Form/Scale
Form
Fold Type : Sine Fold
Single Fold
Show Profile...
Scale
Wave 4000
Amp 1000
Cycl 0
Trace From Image...
N
Event
Block
On
Previous Event
Next Event
OK
Help...
Cancel



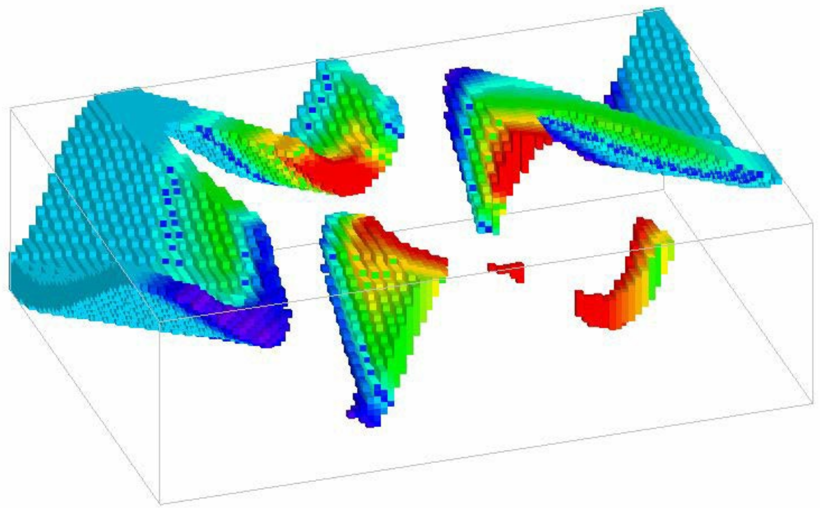
Displacement vector used during folding
Fold axis
Plunge
North
Dip direction
Dip
Origin
Fold amplitude dies off 50% at cylindricity distance
Fold axial plane



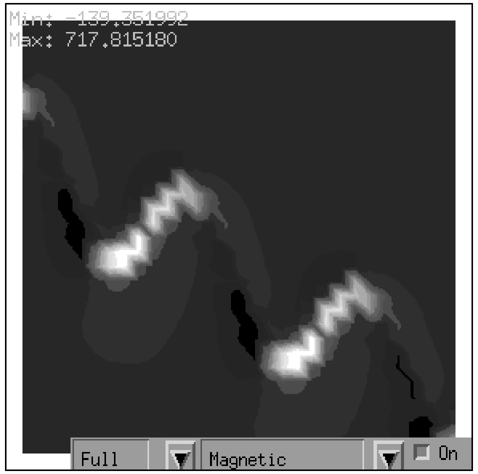
Single fold will only deform over this range
Wavelength
Origin
Amplitude



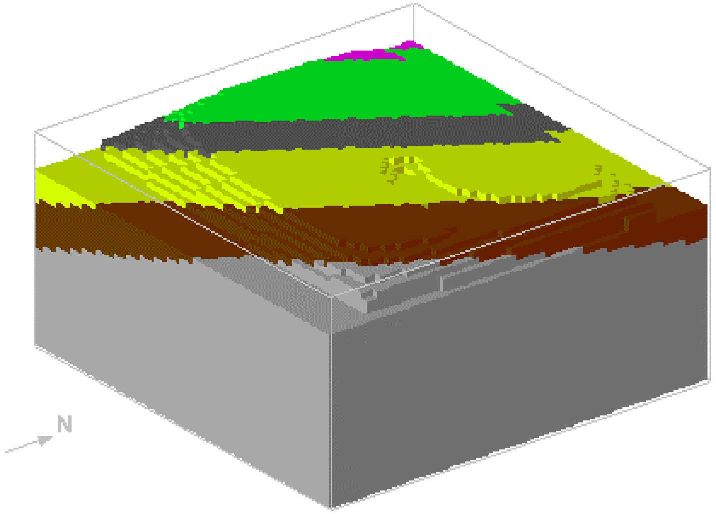
Plunging folds



Alteration effects



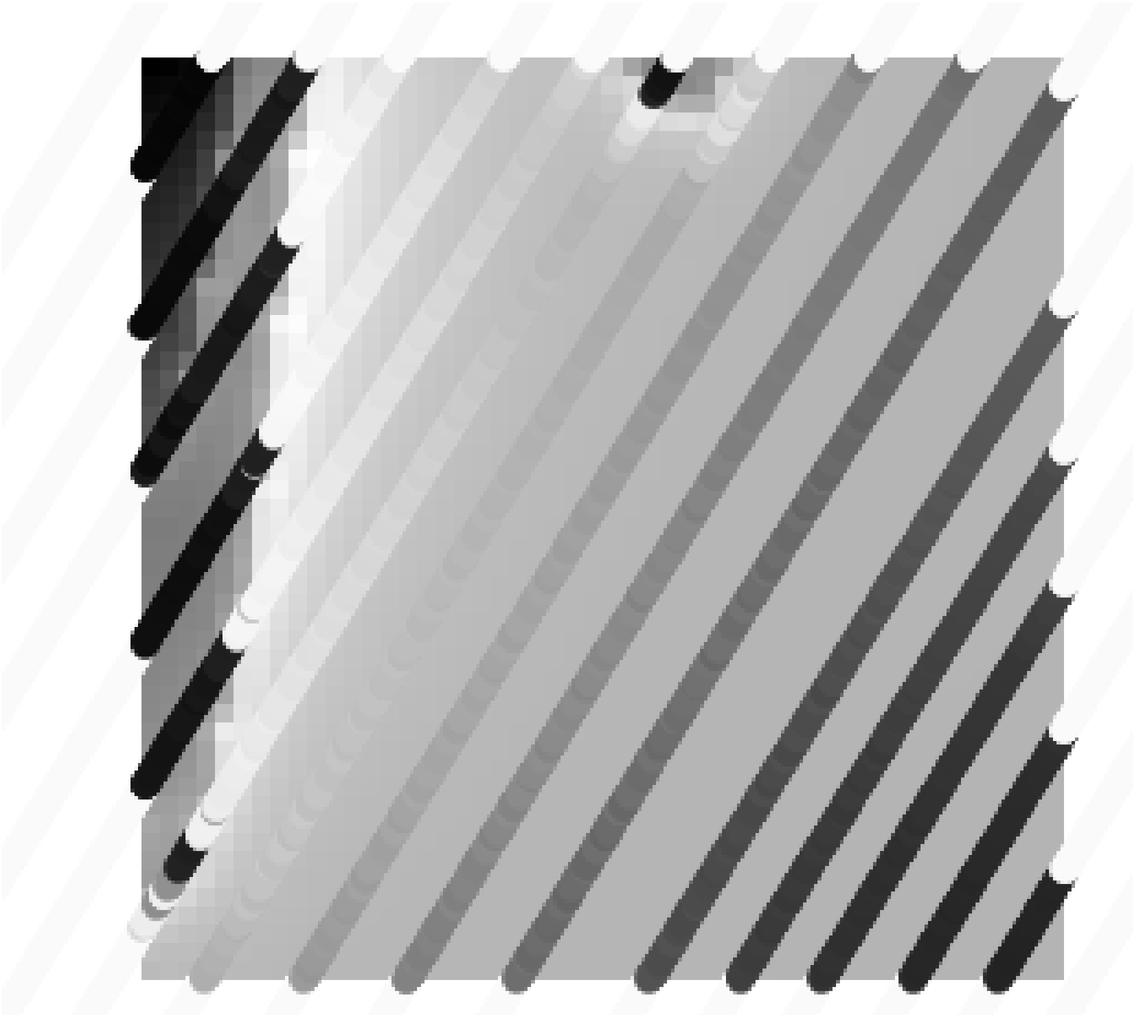
Deformed remanence field



Variable Cover effects

Flight line simulations

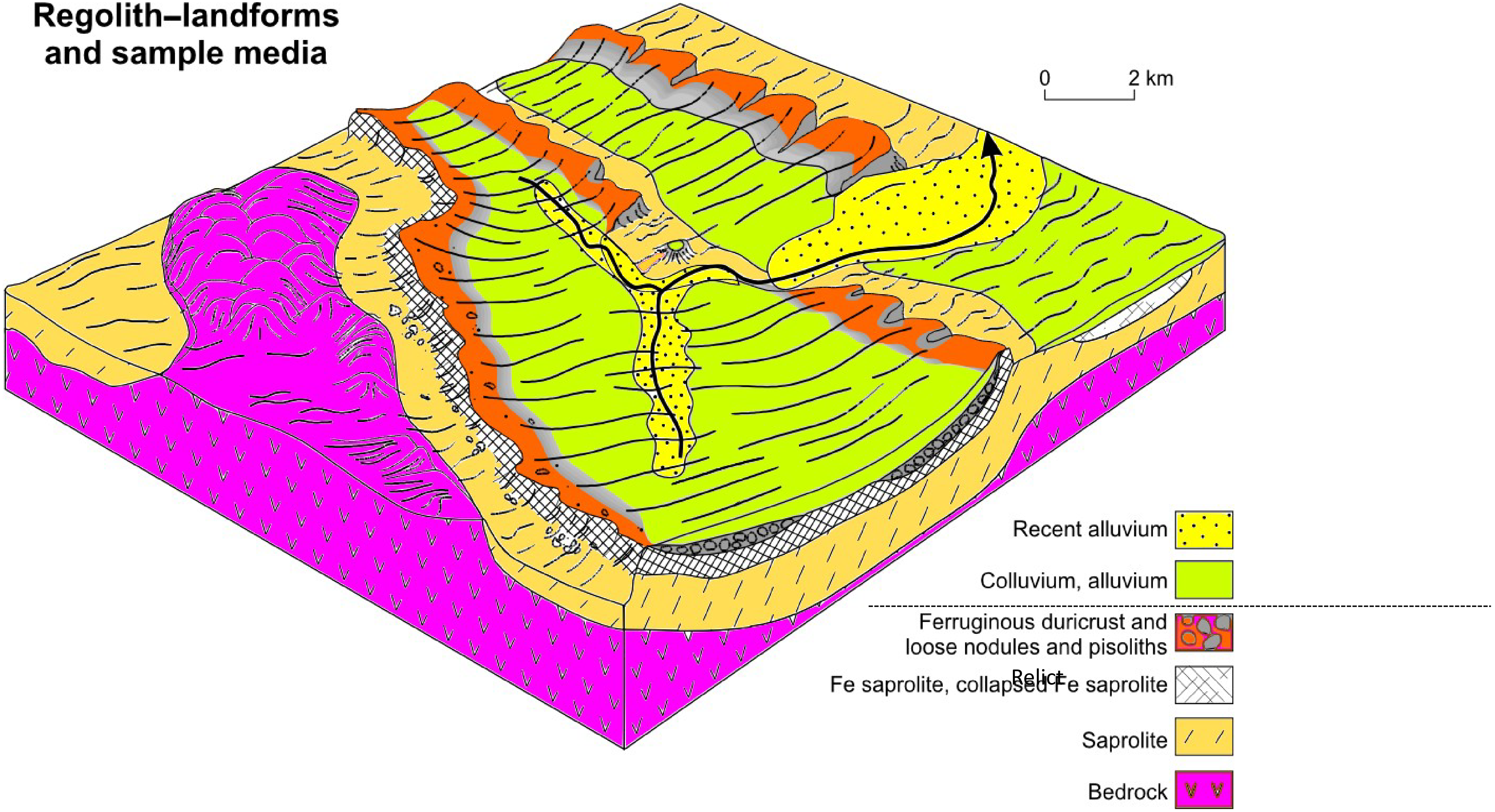
1. Convert geophysics to ermapper format
2. Load into GISfile
3. Make new polyline layer
4. Draw lines, giving each line a unique ID
5. Densify lines by distance
6. Extract vertices
7. Sample raster values

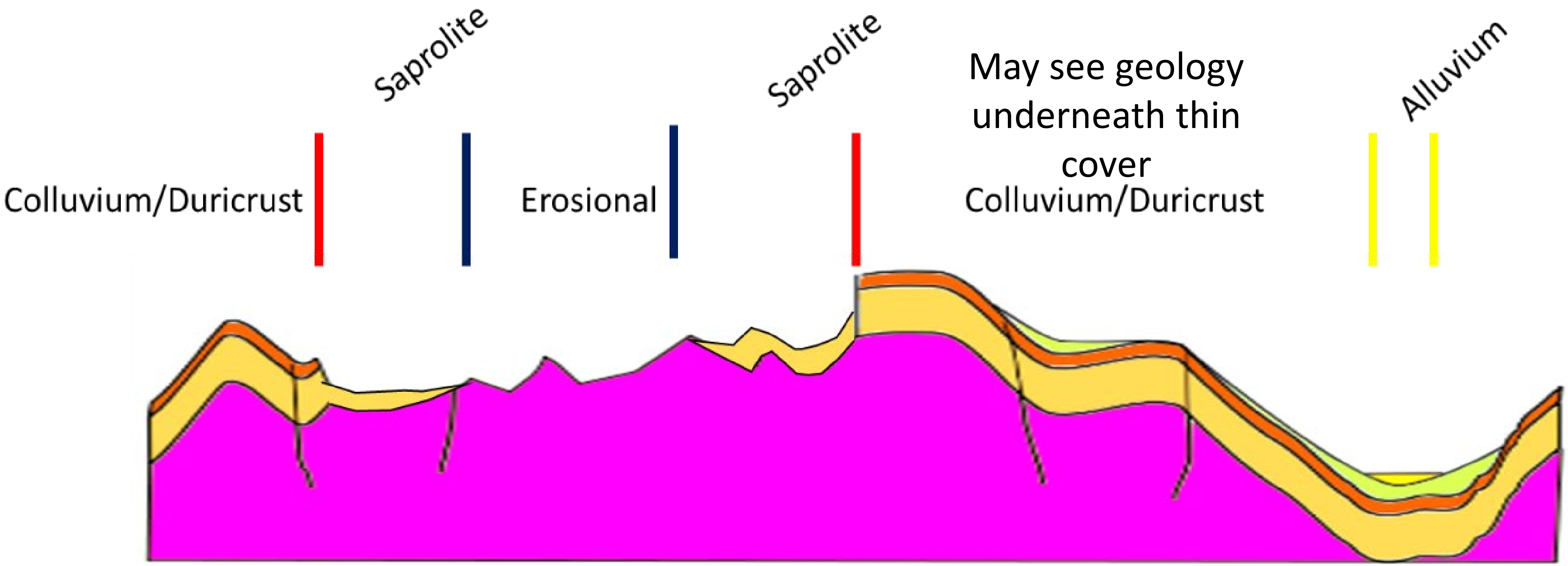


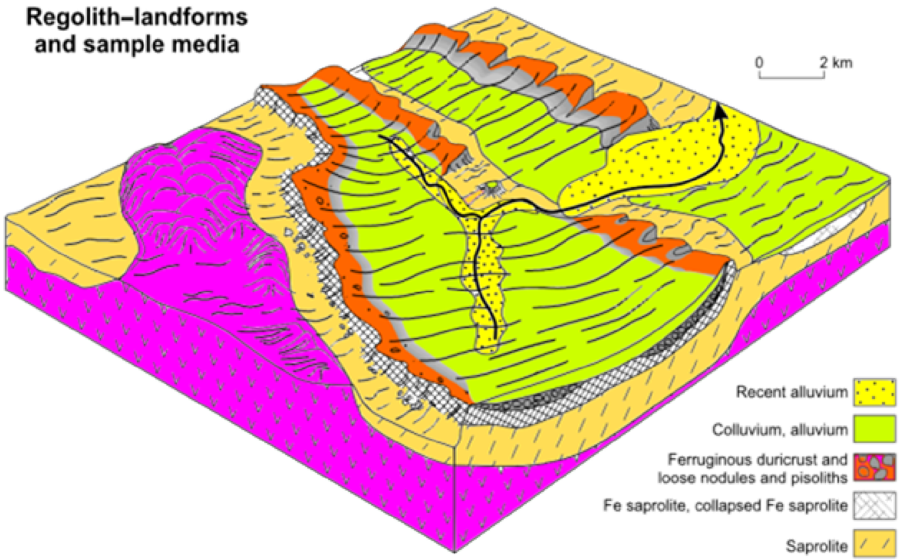
3. Regolith/Geology in Burkina Faso

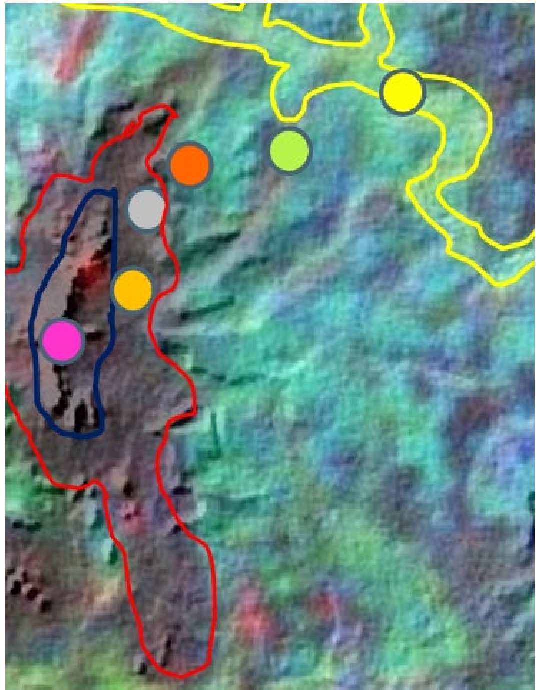

HIGH QUALITY
MOTOR OIL
SAE 60

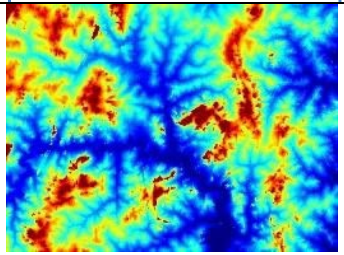
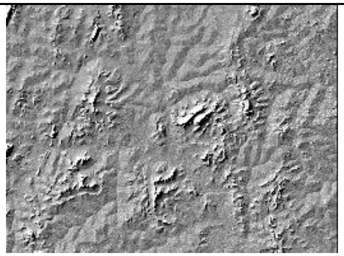
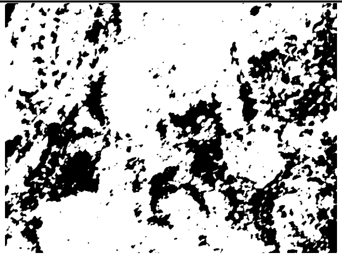
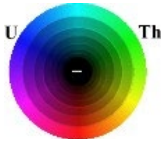
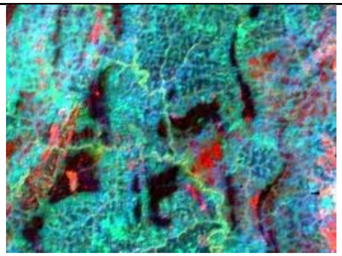
Regolith–landforms and sample media




Saprolite
Saprolite
May see geology underneath thin cover
Alluvium
Colluvium/Duricrust
Erosional
Colluvium/Duricrust


Regolith–landforms and sample media
0
2 km
Recent alluvium
Colluvium, alluvium
Ferruginous duricrust and loose nodules and pisoliths
Fe saprolite, collapsed Fe saprolite
Saprolite
Bedrock



Regolith_interp	Your interpretation	
B1_DEM.jpg	Digital Terrain Model (DTM)	
B1_DEM_sh.jpg	DTM shaded from NW	
B1_KTh_threshold.png	Thresholded K/Th ratio	
B1_KThU.jpg	KThU ternary image 	

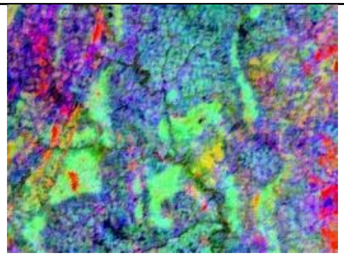
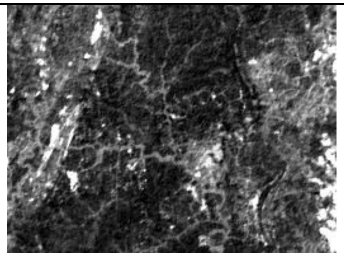
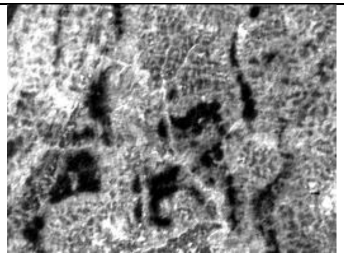
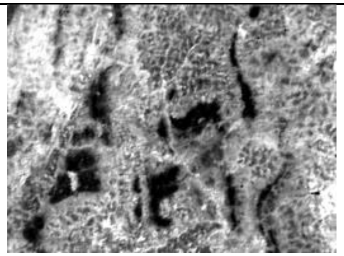
B1_PCA324.jpg	Principal Component Image	
B1_K.jpg	K band	
B1_Th.jpg	Th Band	
B1_U.jpg	U band	
B1_TC.jpg	Total Count band	

Table 3

Summary table of the lithologies; their mineralogical, petrophysical characteristics, and expression in the airborne geophysical data. DTM – digital terrain model, andes. – andesite, volc.-sedim. – volcano-sediment, qtz – quartz, pl – plagioclase, cpx – clinopyroxene, hbl – hornblende, act – actinolite, chl – chlorite, ep – epidote, bt – biotite, kfs – K-feldspar, kln – kaolinite, czo – clinozoisite, carb – carbonate, hem – hematite, gt – goethite. Folds/Faults – red line – interpreted fault/shear zone, yellow line – lithological contact, turquoise line – interpreted fold hinge.

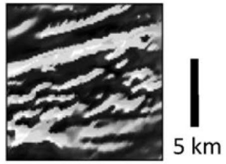
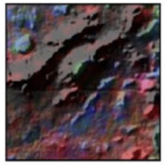
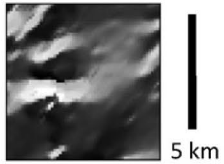
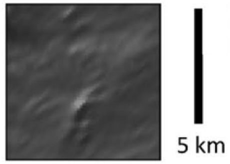
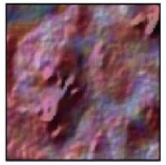
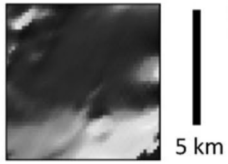
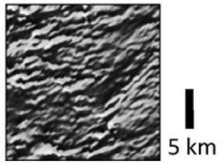
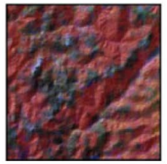
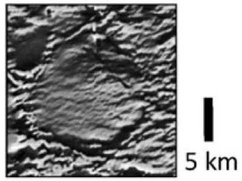
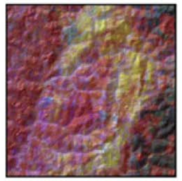
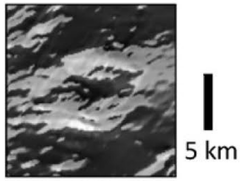
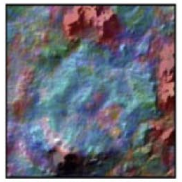
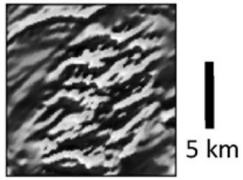
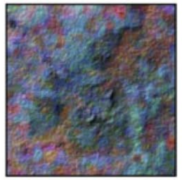
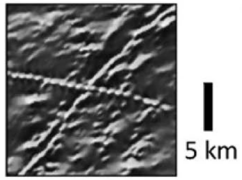
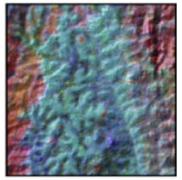
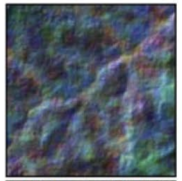
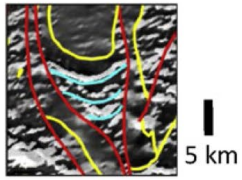
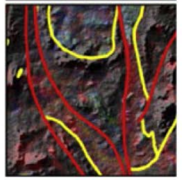
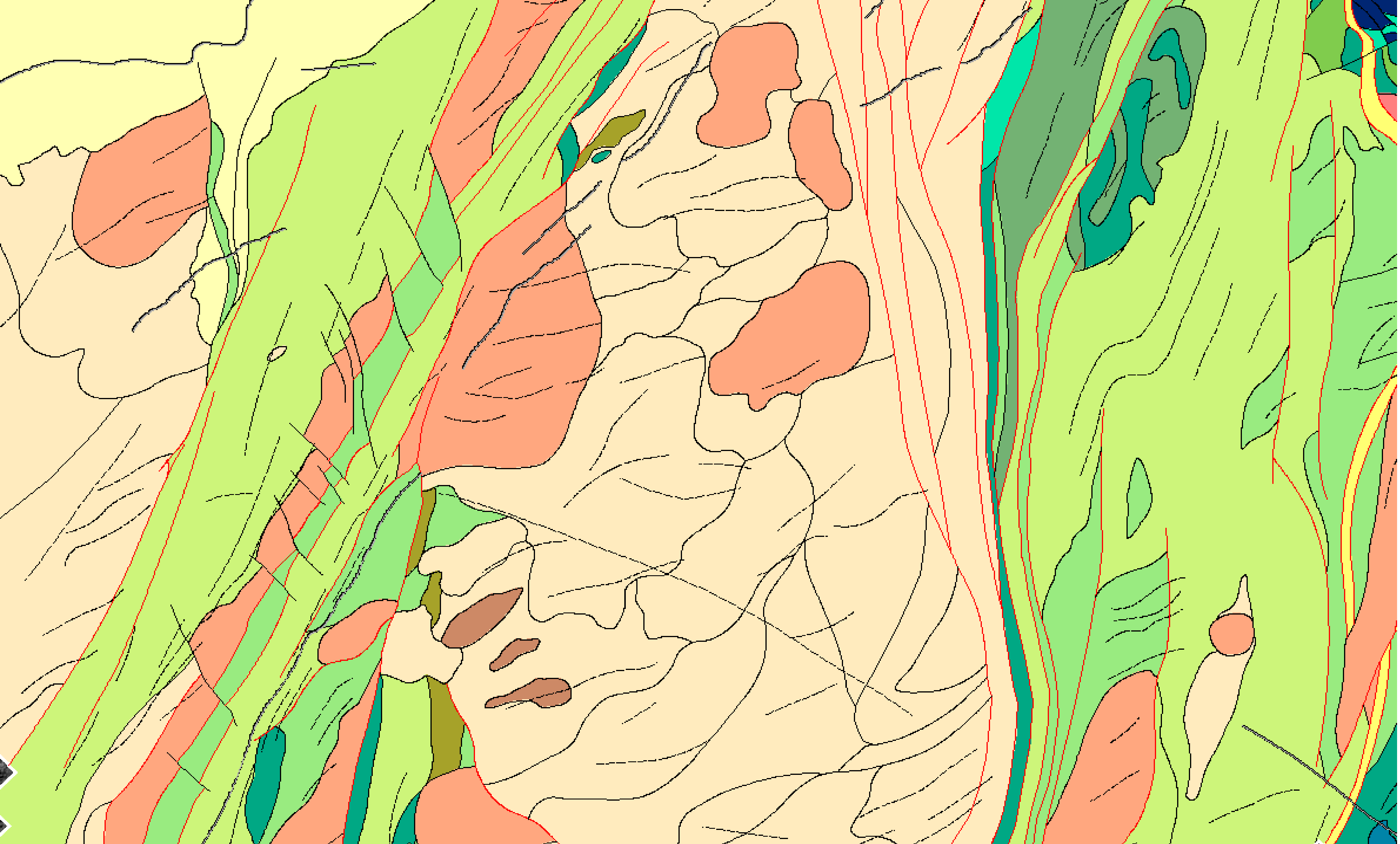
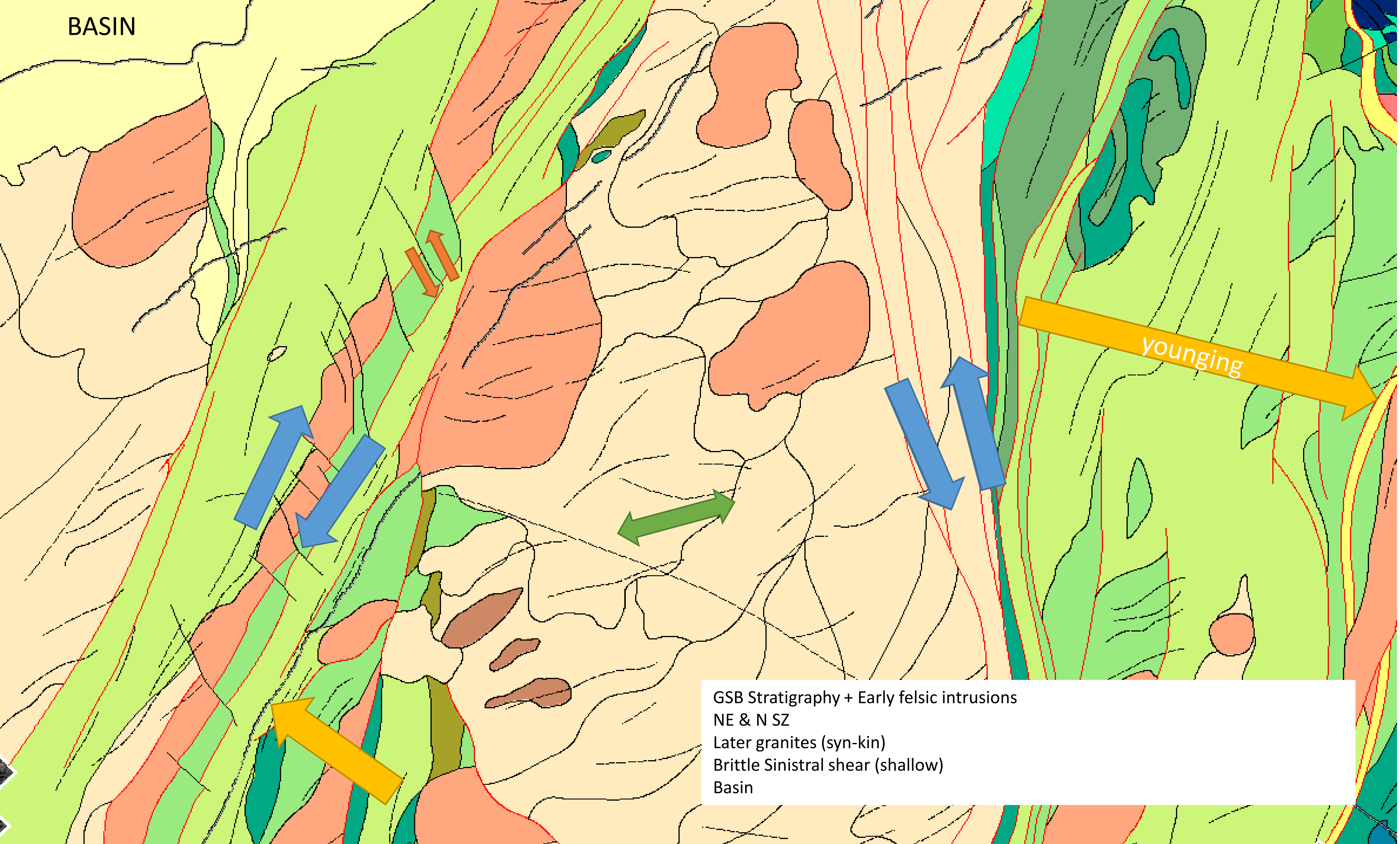
Legend	Lithology and structures	Mineralogy	Density and mag. susceptibility	Airborne Magnetic response	Magnetic image	Airborne radiometric response	Radiometric + shaded DTM image
Ultrabasic rock	Dunite; massive Pyroxenite; mass.	ab, ol, serp, ep, chl pl, cpx/hbl	NA NA	Not distinguishable from basalts and gabbros		K, eTh, eU poor	
Basalt, gabbro; Basalt	(Micro)grabbro, dolerite; massive, localized SZ Basalt; massive, localized SZ	pl, cpx, hbl/act, chl, ep/czo, qtz pl, hbl/act, chl, ep/czo, qtz	High 2.90 – 3.11g/cm^3 0.1 – 150x10^{-3} SI bimodal	Moderate to high intensity, variable N-S to NE-SW oriented magnetic fabric		K, eTh, eU poor	
Basaltic andes.; andesite, pyroclastic flow	Andesite, massive; localized SZ Pyroclastic flow; massive, local. SZ	pl, ep/czo, chl, act, qtz	Medium to high 2.73 – 3.07 g/cm^3 0.01 – 30x10^{-3} SI unimodal	Moderate to low intensity andesitic -> basaltic increasingly magnetic		Medium to high K, moderate eTh and eU	
Pyroclastics, volc.-sedim.	Tuffs, foliated; localized SZ	pl, ep/czo, chl, act, qtz		Moderate to low intensity , smooth texture, andesitic layers add magnetic fabric			
Rhyolite, dacite	Felsic - dacites, rhyolites; massive	qtz, ab, ep, chl, ms	NA 0.01-0.12x10^{-3} SI	Not recognizable, small bodies usually		Medium to high K, moderate eTh and eU (usually small bodies)	
Birimian sediments, volc.-sedim.	Wackestones and argillites; foliated, locallized SZ	qtz, ab, chl, ms, carb, ep	Medium to low 2.60 – 2.90 g/cm^3 0.01 – 0.4x10^{-3} SI unimodal	Low intensity uniform, andesitic layers add fabric		Low to moderate K, eU, eTh, affected by regolith	
Tarkwaian-type sedim.	Conglomerate; mass., localized SZ Sandstone, gritstone; massive, localized SZ Arkose, pelite; foliated	qtz, ab, ms, carb, ep	Medium to low 2.71 – 2.76 g/cm^3 0.1 – 0.12x10-3 SI unimodal	Low intensity, uniform		Moderate K, moderate to low eTh, eU	
Tonalite, trodhjemite, granodiorite (ME1)	Granodiorite, tonalite and diorite; HT banding, mylonitic foliation, locally mylonitic	pl, qtz, bt, hbl	Medium to low 2.64 – 2.80g/cm^3 0.1 – 34x10^{-3} SI bimodal/ multimodal	Low to moderate intensity, variable NNE-SSW oriented magnetic fabric, complex interlocked bodies		Moderate to low K, moderate eTh and eU, affected by regolith	

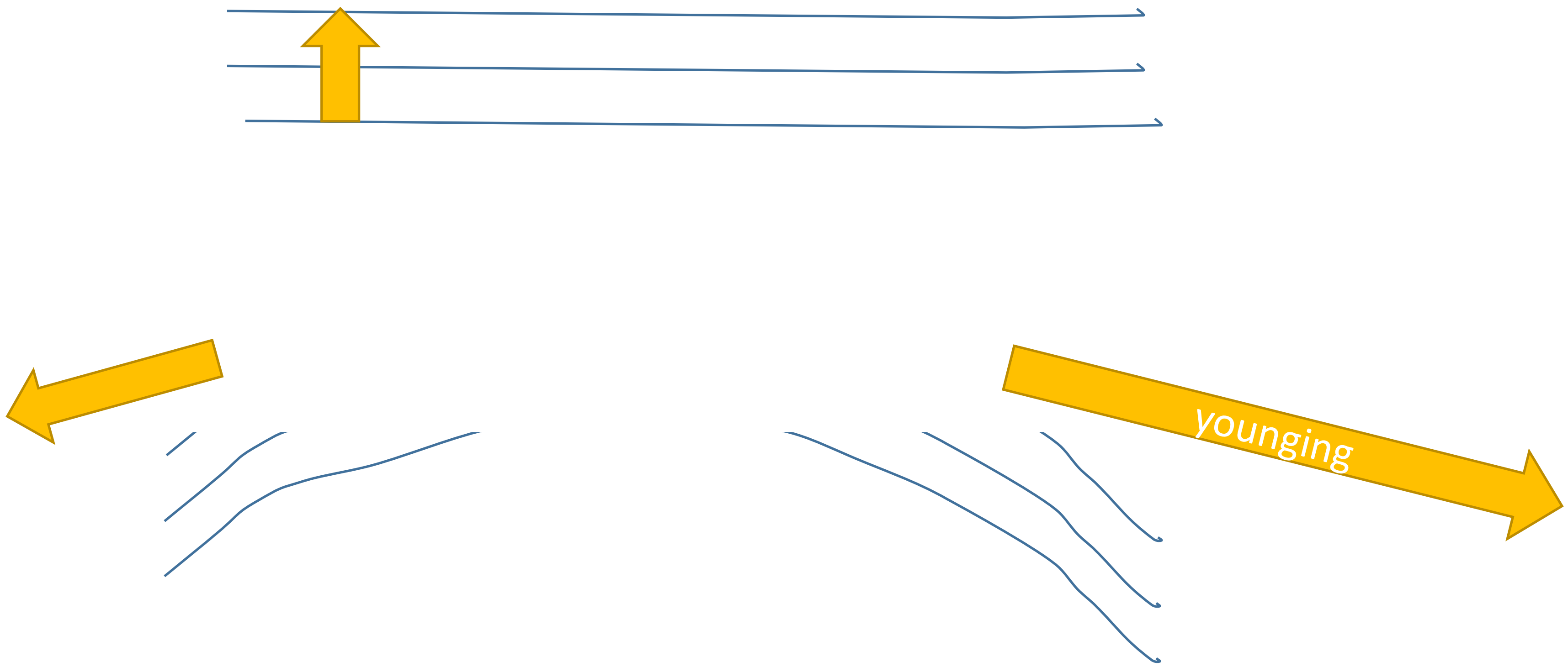
Table 3 (*Continued*)

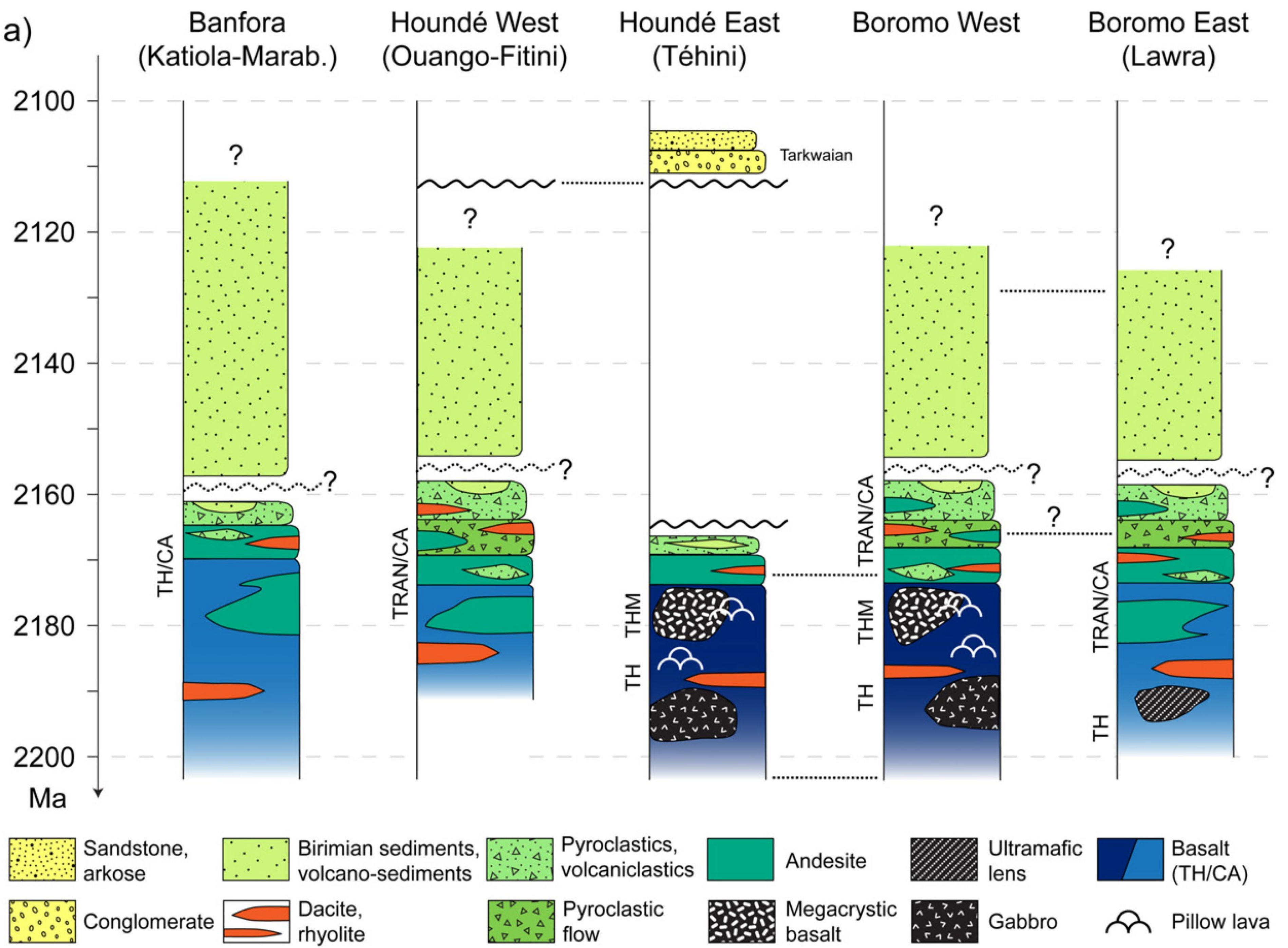
Granodiorite, granite (ME2)	Granite and granodiorite; mylonitic foliation, localized SZ, massive	pl, qtz, kfs, bt, (hbl)	Medium to low 2.63 – 2.73 g/cm^3 0.1 – 37x10^{-3} SI bimodal/ multimodal	Moderate to high intensity Sub-elliptical bodies		Moderate to high K, eTh and eU, affected by regolith	
Granite (ME3)	Granite, leucogranite; locally mylonitic, massive, mylonitic foliation	pl, kfs, qtz, ms, bt,	Medium to low 2.63 – 2.73 g/cm^3 > 0.4x10^{-3} SI	High intensity sub-elliptical bodies, magnetic zoning		High K, eTh, eU, affected by regolith	
Gabbro, diorite (ME4)	Gabbro; massive	cpx, hbl, pl, qtz	NA 0.18 – 0.39x10^{-3} SI	Moderate to high intensity		Low	
Dolerite dyke	Dolerite dyke, massive	ol, opx, cpx, hbl, bt, pl	NA 15 – 76.8x10^{-3} SI unimodal	Highly magnetic, linear features		Not recognizable	
Not on map	Fe-rich duricrust	hem, gt, kln, qtz	NA NA		5 km	Low K, high eTh and eU	
Not on map	Soft pediment	hem, gt, kln, sme, qtz	NA NA		5 km	Low K, high eTh and eU	
Folds/Faults	Folding geometries or changes in lithology and structural patterns	NA	NA NA	Folds - curved magnetic patterns Faults - abrupt changes in magnetic patterns, truncation, displacement		Folds - curved patterns Faults - Changes in the content of radioelements when contrasting lithologies are present	

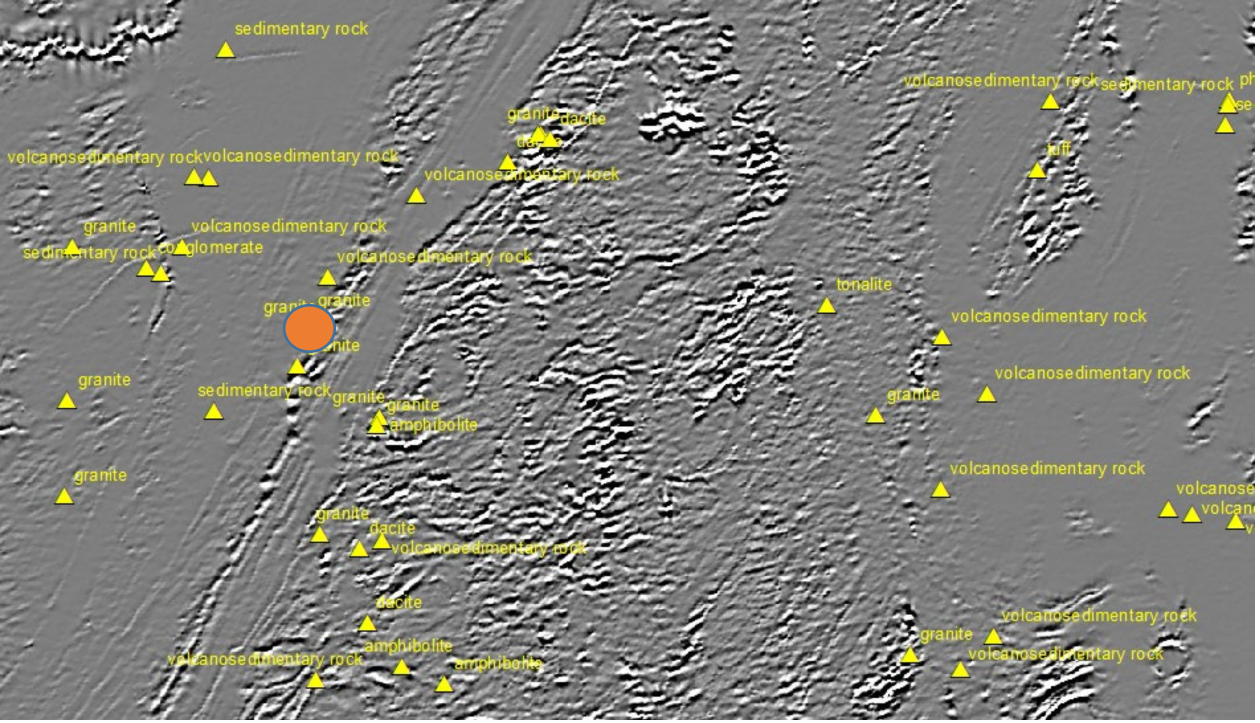


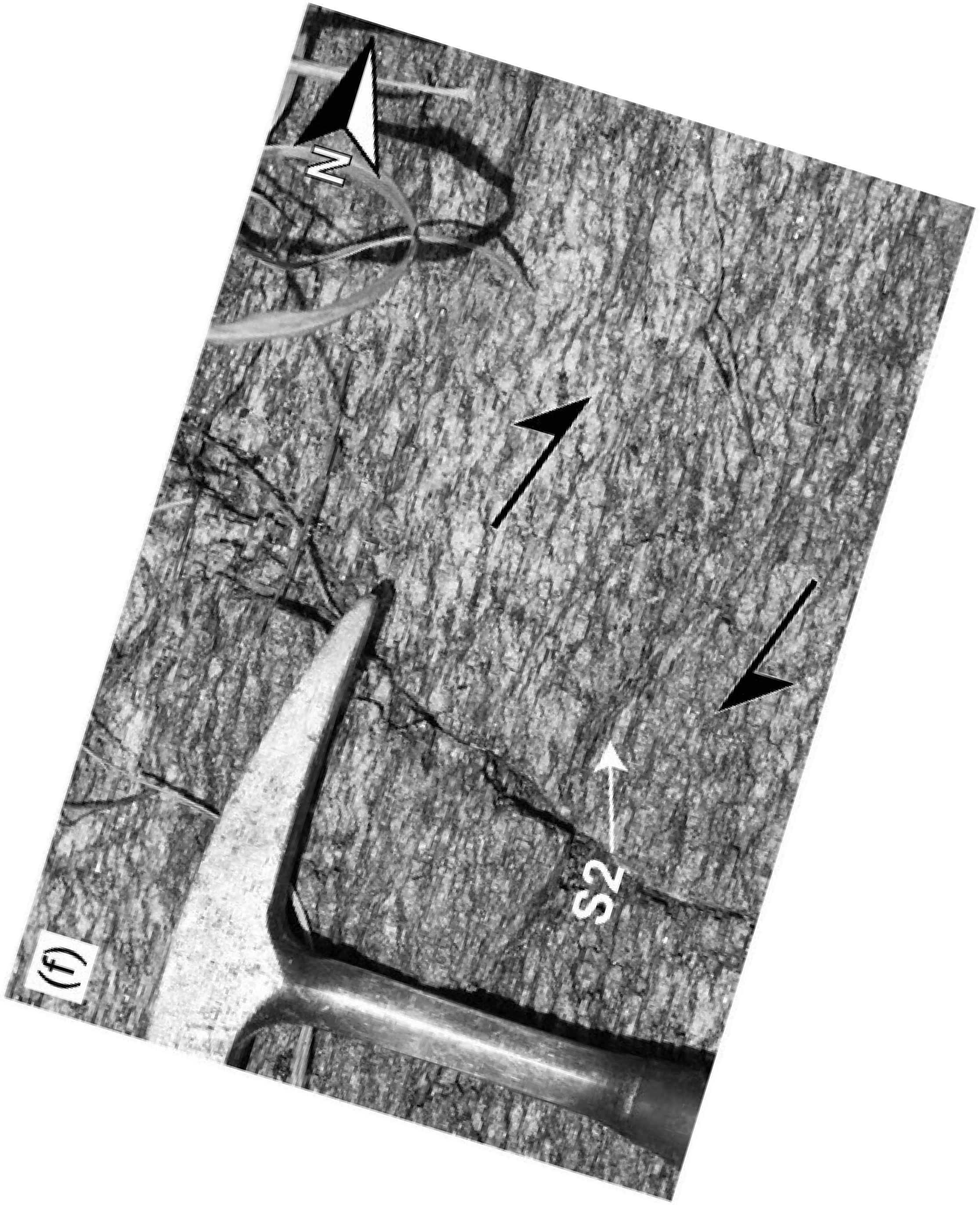


GSB Stratigraphy + Early felsic intrusions
NE & N SZ
Later granites (syn-kin)
Brittle Sinistral shear (shallow)
Basin


younging


a)
Banfora
(Katiola-Marab.)
Houndé West
(Ouango-Fitini)
Houndé East
(Téhini)
Boromo West
Boromo East
(Lawra)
2100
2120
2140
2160
2180
2200
Ma
Tarkwaian
TH/CA
TRAN/CA
THM
TH
Sandstone, arkose
Conglomerate
Birimian sediments, volcano-sediments
Dacite, rhyolite
Pyroclastics, volcaniclastics
Pyroclastic flow
Andesite
Megacrystic basalt
Ultramafic lens
Gabbro
Basalt (TH/CA)
Pillow lava


sedimentary rock
volcanosedimentary rock
sedimentary rock
granite
dacite
volcanosedimentary rock
volcanosedimentary rock
tuff
volcanosedimentary rock
granite
volcanosedimentary rock
sedimentary rock
conglomerate
volcanosedimentary rock
granite
tonalite
volcanosedimentary rock
granite
volcanosedimentary rock
sedimentary rock
granite
granite
granite
amphibolite
granite
volcanosedimentary rock
granite
granite
dacite
volcanosedimentary rock
volcanosedimentary rock
dacite
granite
volcanosedimentary rock
volcanosedimentary rock
amphibolite
amphibolite
volcanosedimentary rock

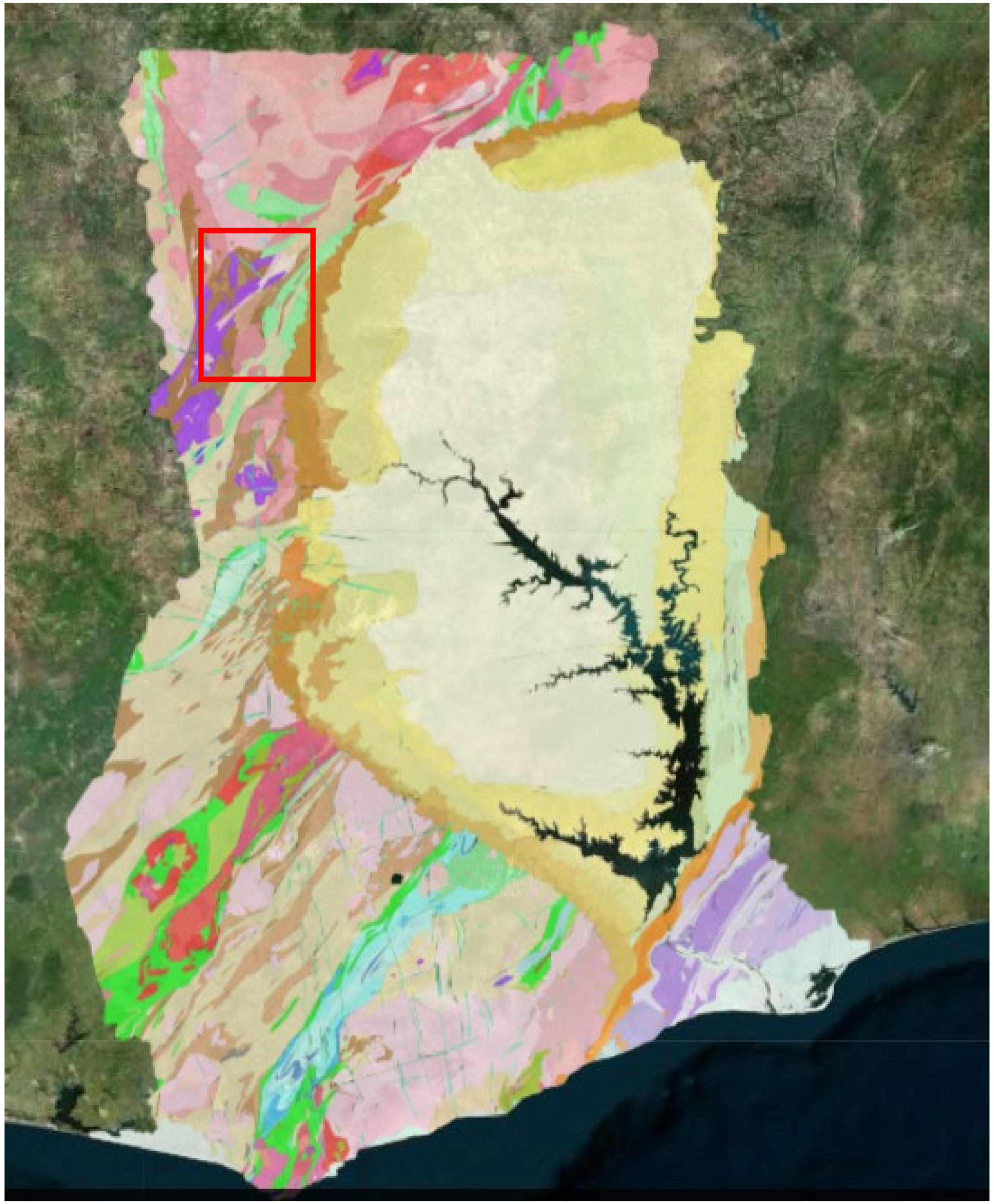

N
S2
(f)

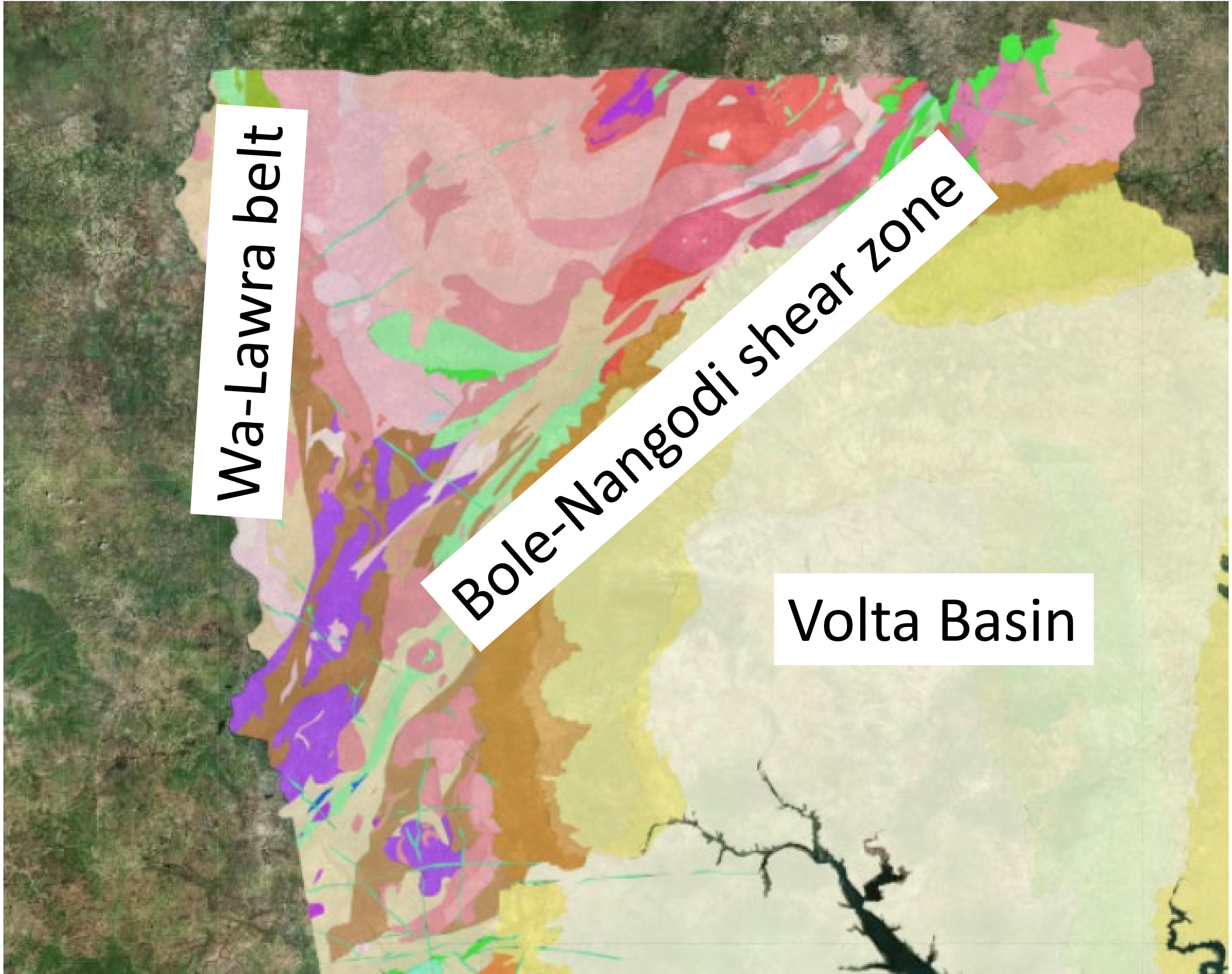
Participant datasets:

1. If you are allowed, send me the data today so I can see what I can make of it

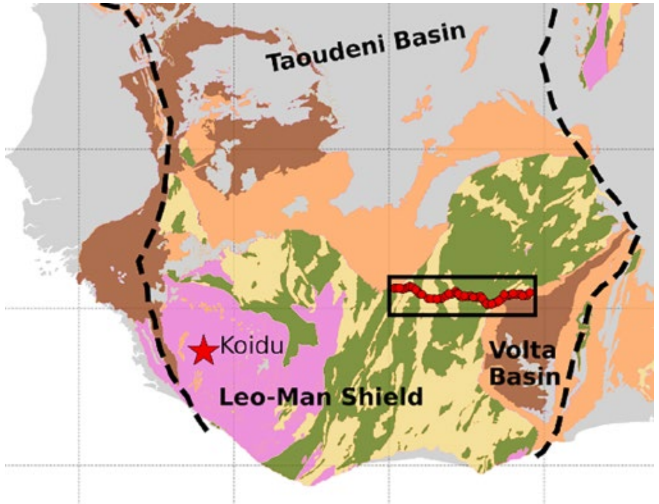
2. If it is confidential data, at least send me the coordinates or shapefile of the region of interest- in lat longs or provide project system, but not mine grid!

4. NW Ghana



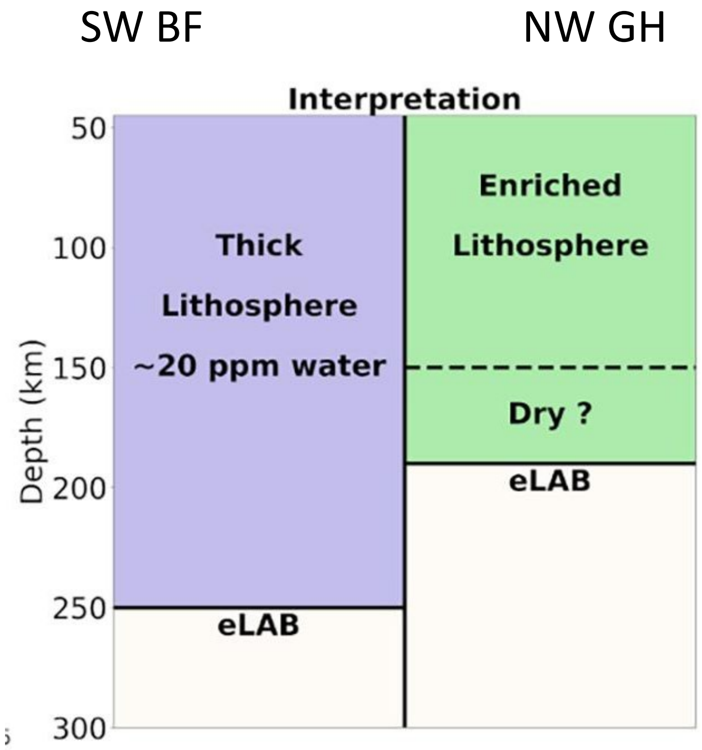

Wa-Lawra belt
Bole-Nangodi shear zone
Volta Basin

Magnetotelluric experiment



- Confirmed important crustal and lithospheric extent of major structures mapped at surface

- Fundamental crustal boundary parallel to SWBF/NWGH border in Wa-Lawra area



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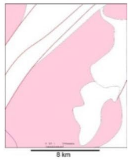
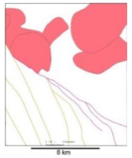
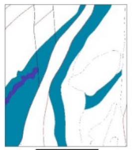
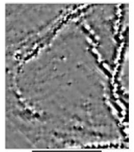
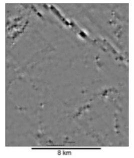
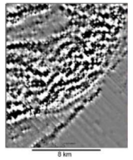
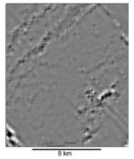
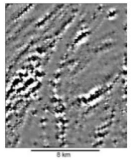
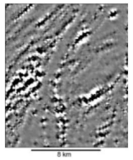
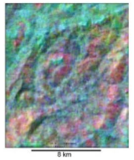
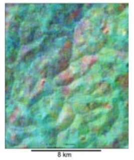
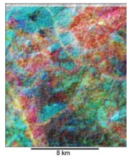
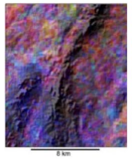
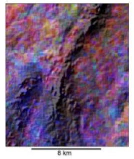
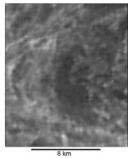
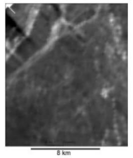
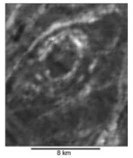
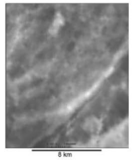
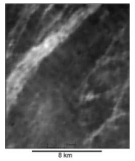
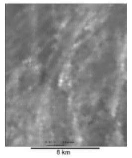
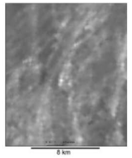
Scientific questions

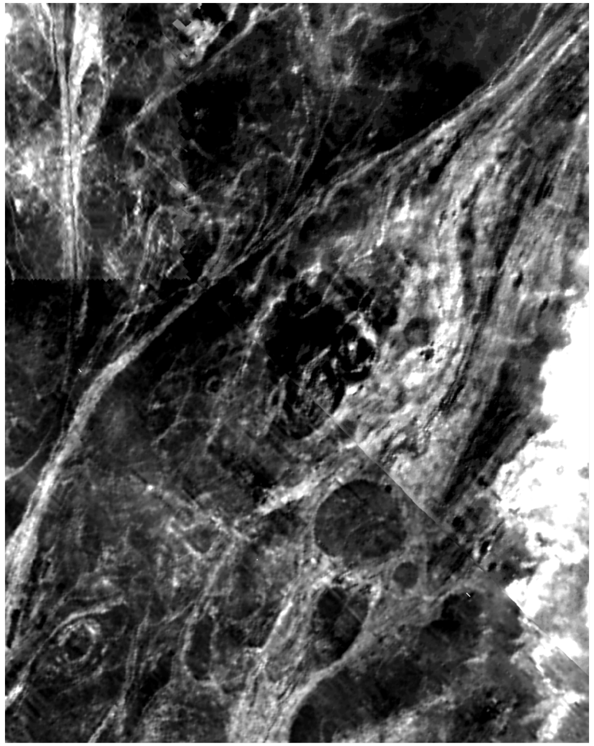
Relationship between domains of contrasting metamorphic conditions

- « Antebirimian » basement and Birimian volcano-sédimentary belts ?

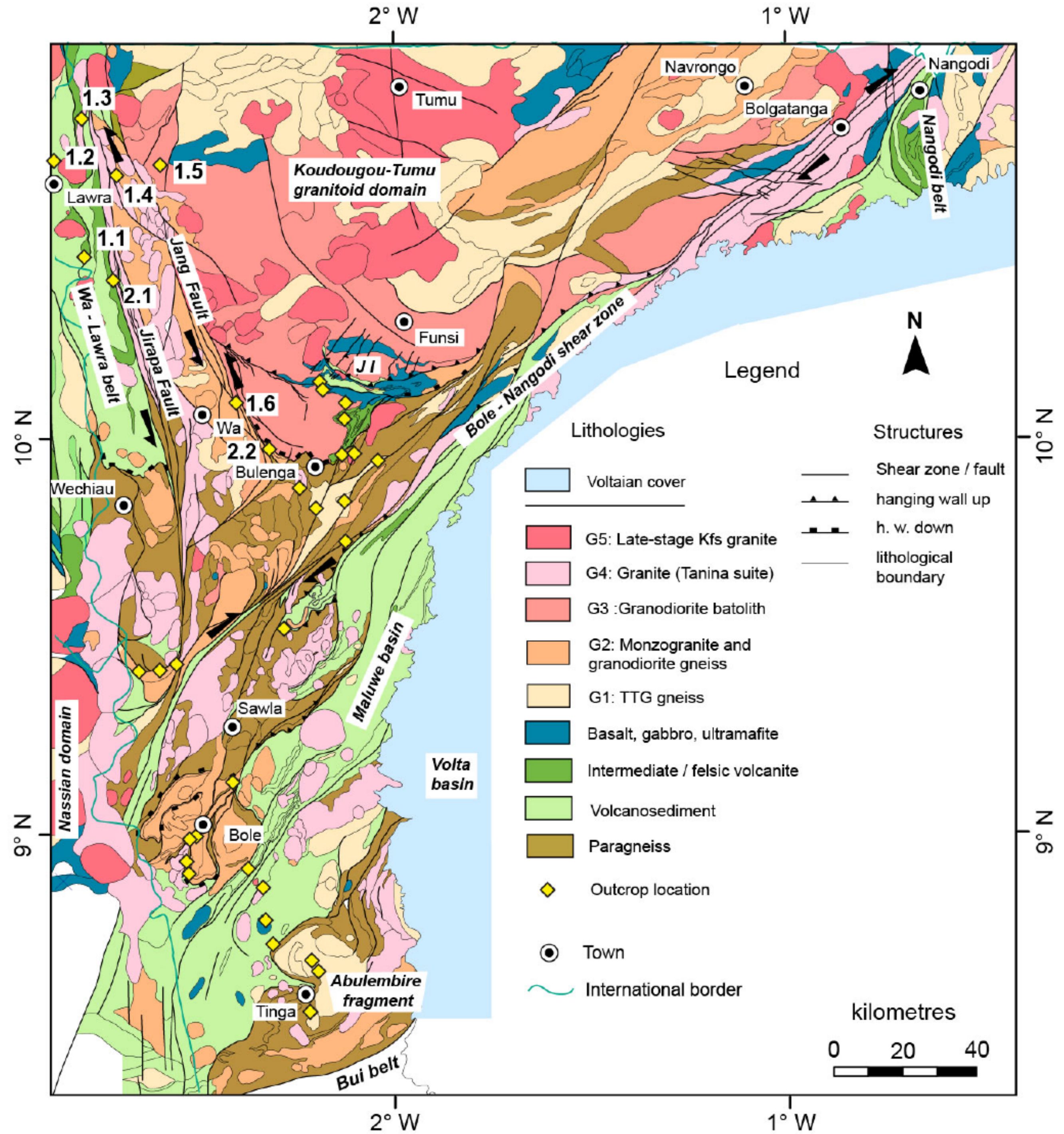
- Distinct crustal-scale slices of the Eburnean orogen ?

Geology-Petrophysics-Geophysics Correlation tables

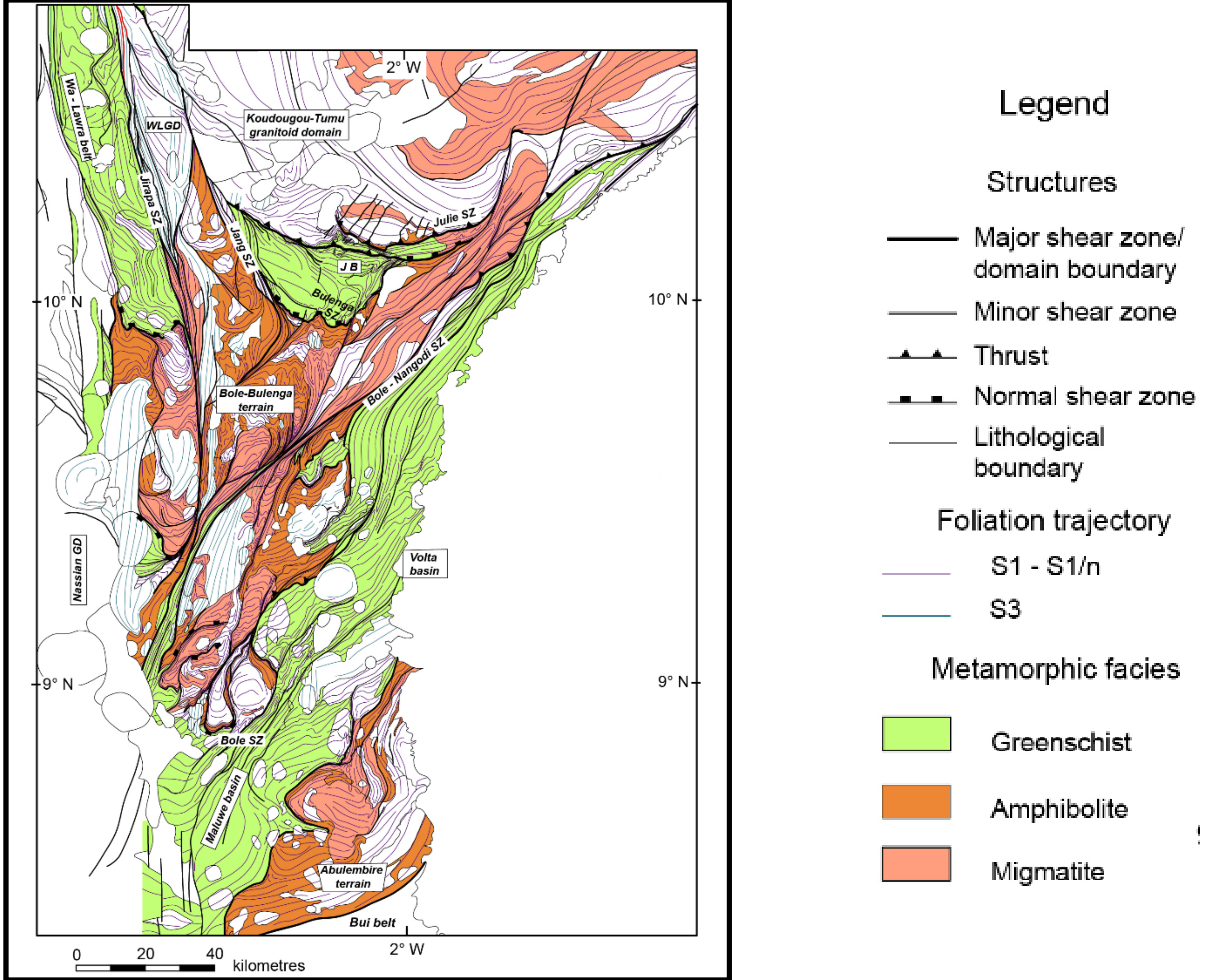
Lithology	G1: TTG gneiss	G2: TTG	Mafic orthogneiss	G3 : granodiorite	G4: Biotite granite & granodiorite	G5: Potassic granite	Andesite/dacite	Basalt/metabasalt
Mineralogy	qz, pl, hbl, bt	qz, pl, kf, hbl (±ep)	qz, pl, hbl, ilm (± gt)	qz, pl, hbl, bt	qz, pl, kf, bt	qz, kf, pl, bt (±ep)	qz, pl, hbl, sph,	act, chl, qz, ep, cal
Magnetic susceptibility (10-3 SI)	0.05, 0.30-0.40, 4-10, multimodal	0.10-0.30	0.10-0.5, 1.0-10 (bimodal)	1.0-55	0.005-0.15	0.10-8.0, bimodal	0.30-0.40	*no data*
Sample	BN261	BN092	BN506	BN380	BN112	BN083	BN02	BN101
U (ppm)	0.29	2.15	0.81	0.46	1.55	4.45	0.810	0.075
Th (ppm)	3.79	3.49	2.26	1.16	12.85	13.9	2.2	0.2
K2O (%)	0.92	3.07	0.56	1.48	2.03	5.16	0.51	0.14
Map								
Airborne magnetic response	Moderate to high intensity, marked magnetic fabric	Low to moderate, homogeneous.	Low to high , heterogeneous, strong magnetic fabric	Very high, heterogeneous, strong magnetic fabric	Low intensity, homogeneous interlocked bodies	Low to high intensity.	Low to moderate intensity, variable	High intensity layers
Magnetic image								
Airborne radiometric response	K, Th, U poor (dark)	Moderate to high K, moderate U, low Th (red)	Moderate K, moderate U, low Th (red to blue) ??	Low to moderate K Th, U poor (dark to red)	Moderate K, high Th, low U (green, yellow, orange)	Very high K, high Th, moderate U (red-yellow)	moderate U (blue), low Th, K.	K, Th, U poor (dark)
Radiometric + shaded DTM								
Airborne electro-magnetic signal	Heterogenous	Low intensity, homogeneous	Heterogeneous	Heterogeneous	Low intensity, homogeneous	*no data*	Low intensity, homogeneous	Moderate to high intensity
Electro-magnetic image						*no data*		



FDEM



Block et al.,
in prep.


2° W
Koudougou-Tumu granitoid domain
WLGD
Wa - Lawra belt
Jirapa SZ
Jang SZ
Julie SZ
J B
Bulenga SZ
10° N
10° N
Bole-Bulenga terrain
Bole - Nangodi SZ
Nassian GD
Volta basin
9° N
9° N
Bole SZ
Maluwe basin
Abulembire terrain
Bui belt
2° W
0
20
40
kilometres
Legend
Structures
Major shear zone/ domain boundary
Minor shear zone
Thrust
Normal shear zone
Lithological boundary
Foliation trajectory
S1 - S1/n
S3
Metamorphic facies
Greenschist
Amphibolite
Migmatite

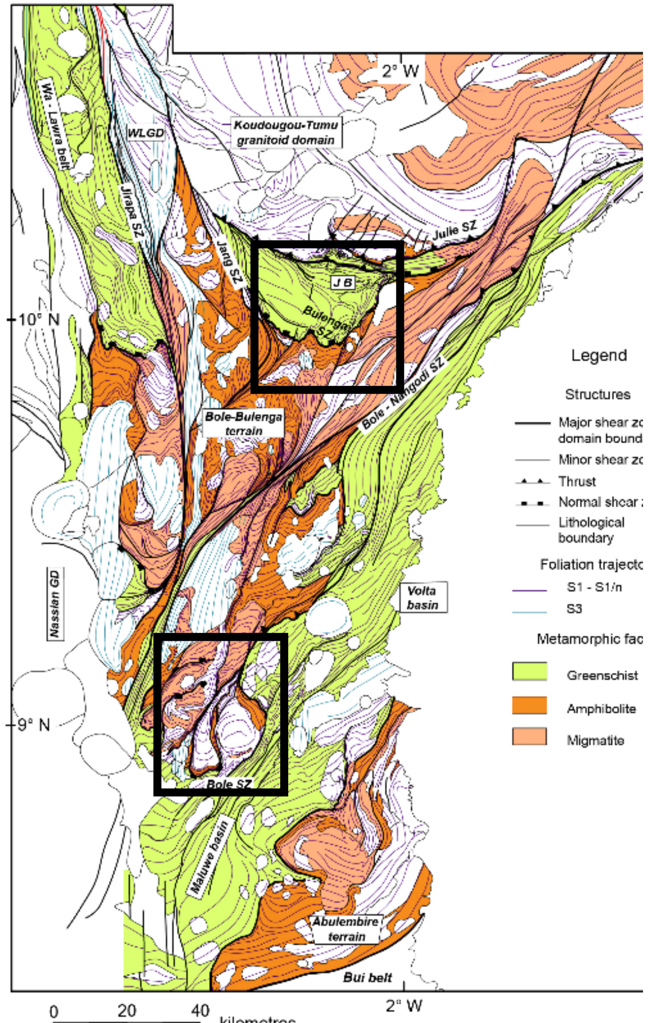
Deformation « D1 »

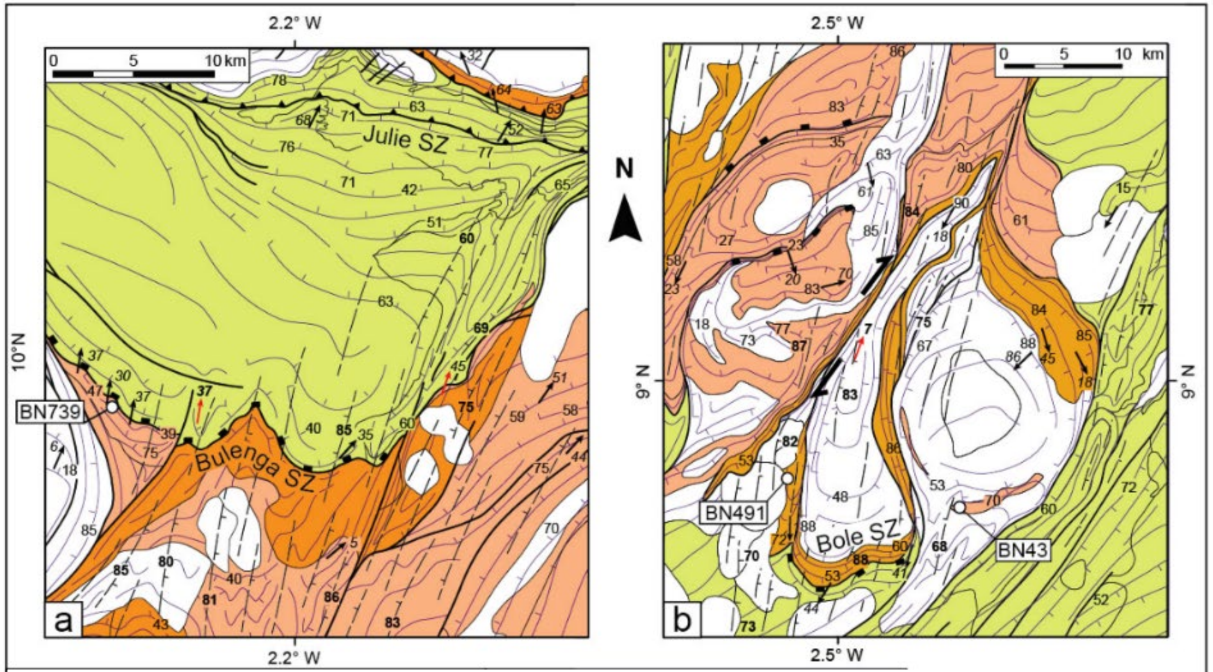
Contraction > N-S shortening

Amphibolite – granulite-facies metamorphism

Deformation « D2 »

Extension > N-S stretching
Normal shear zones / detachments





Interpretation:

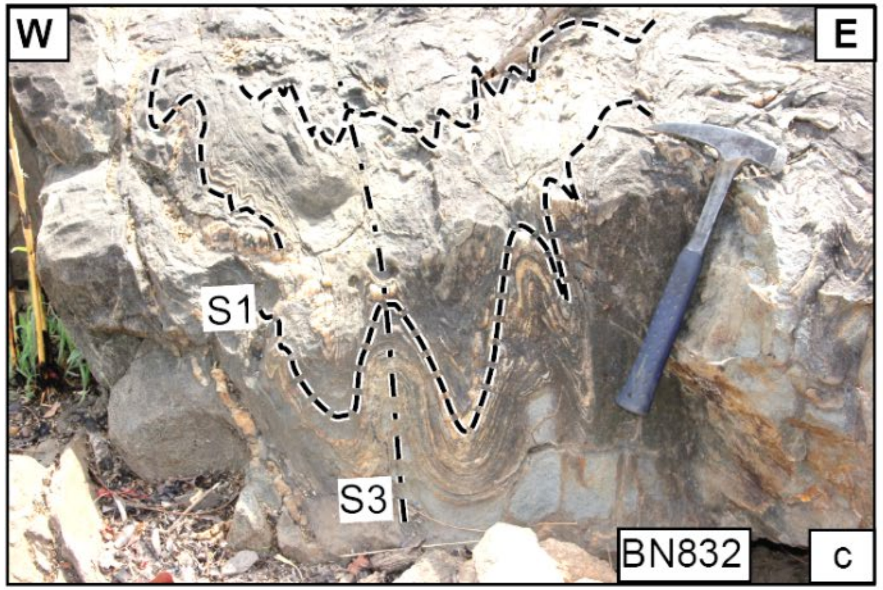
Crustal gravitational flow

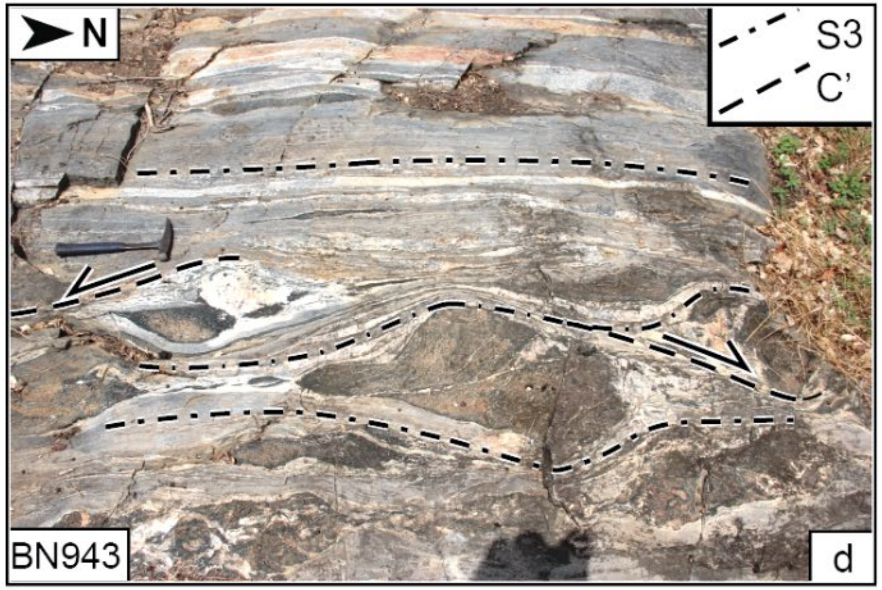
Crustal thinning and decompression

Beginning of lower-crust exhumation in an anatectic dome

Max. age ca. 2130 Ma.

Deformation « D3 »





Contraction > E-W shortening & NW dextral shearing

Progressive strain localisation

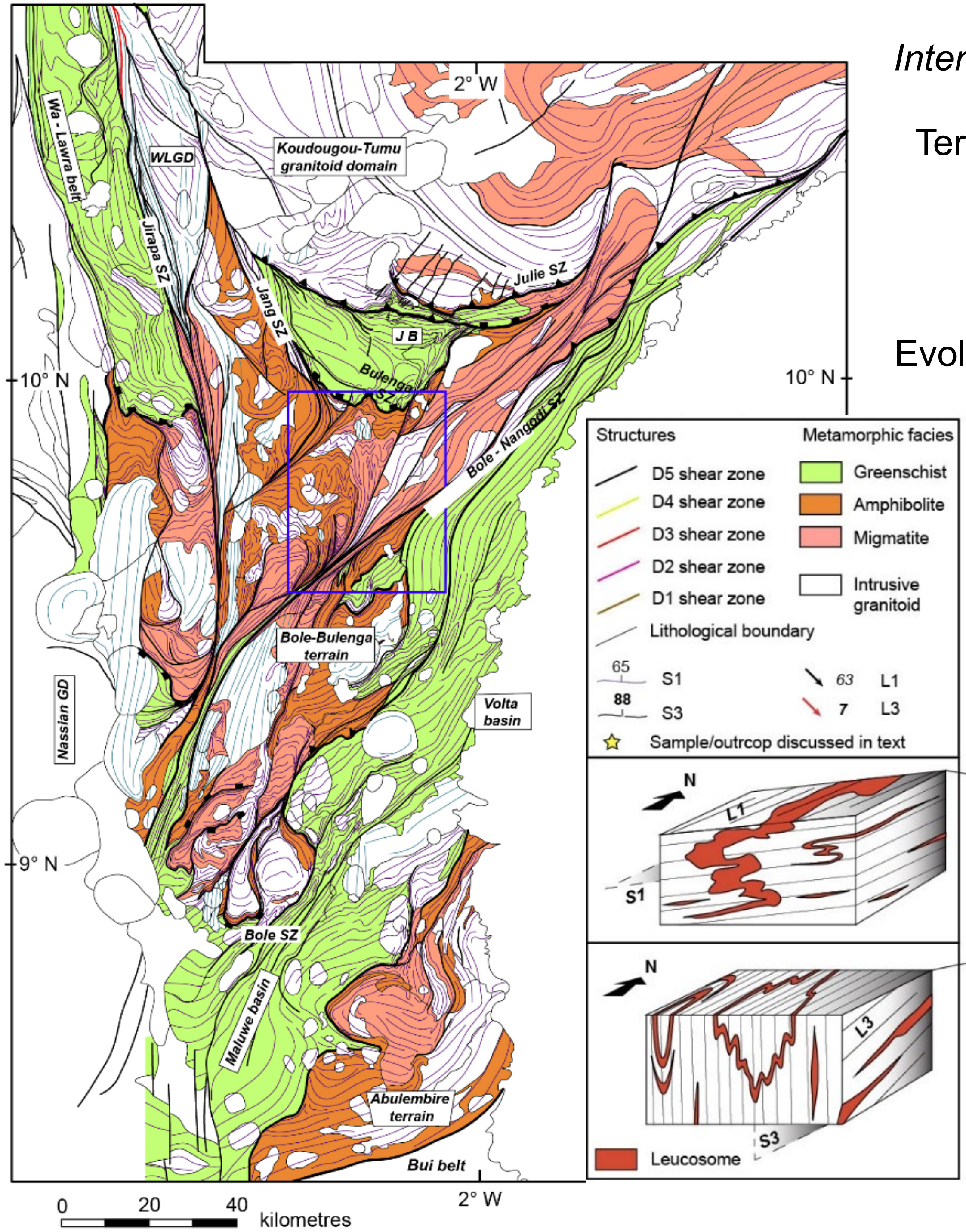
Amphibolite-facies metamorphism

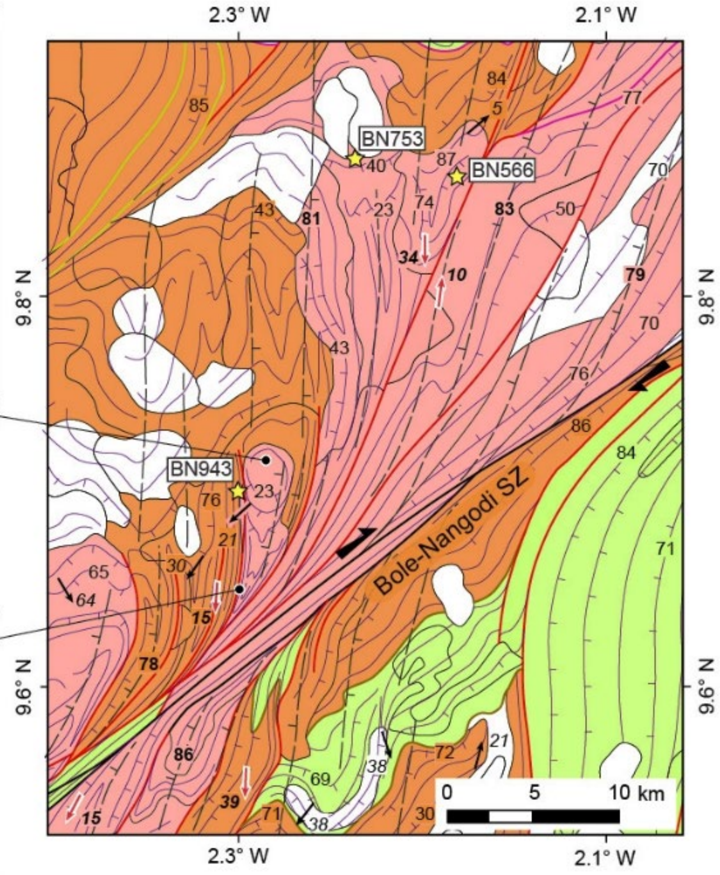
Interpretation:

Termination of lower-crust exhumation

Tectonic juxtaposition of various domains

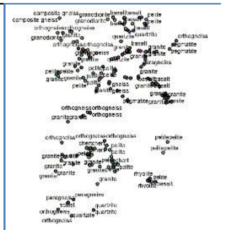
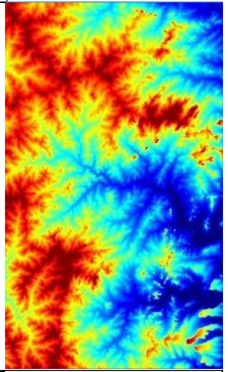
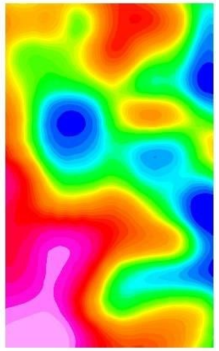
Evolution towards transcurrent tectonics.

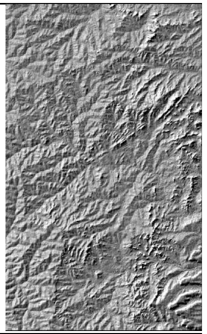
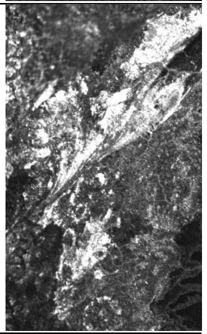
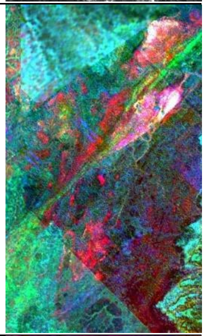
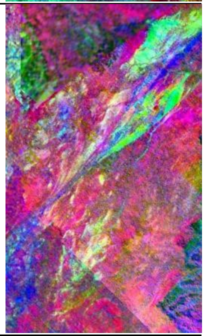


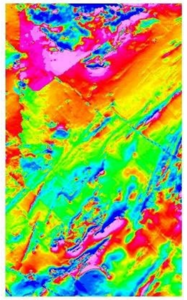
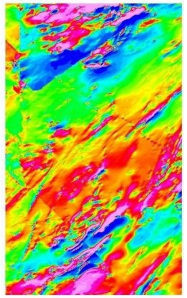
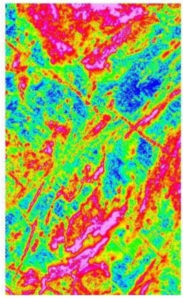
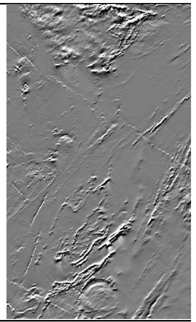


Conclusions (NW Ghana)

- Recognition of regional high-grade metamorphism
- Re-assessment of the belt/basin/basement relationship
- Indications of a rheologically strong lithosphere at ca. 2140 Ma, enabling heterogeneous thickening and exhumation
- Craton architecture: sub-domains of similar ages but stabilised sequentially... ?

NG_interp	Your Interpretation	Us the Id code to distinguish contact types
outcrops	Outcrop database	
NG_DEM.jpg	Digital Terrain Model (DTM)	
NG_FA.jpg	Free Air Gravity	

NG_DEM_sh.jpg	Shaded DTM (from NW)	
NG_KTh1.jpg	K/Th ratio	
NG_KThU1.jpg	KThU ternary Radiometrics	
NG_PCA2341.jpg	Principal Components Radiometrics	

NG_TMI.jpg	Total Magnetic Intensity	
NG_INVRTE.jpg	Negative of Reduced to Equator Image	
NG_TMI_AS.jpg	Analytical Signal	
NG_INVRTE_vd1_grey.jpg	First Vertical Derivative of Neg RTE	

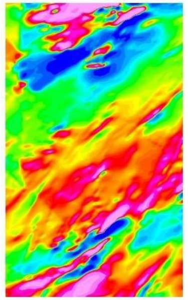
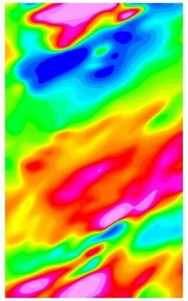
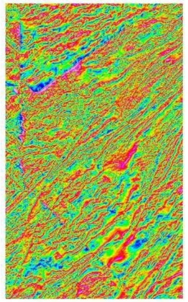
NG_INVRTE_vd1_agc_bw.jpg	Automatic Gain control of 1VD Neg RTE	
NG_INVRTE_up500.jpg	500m upward continued Neg RTE	
NG_INVRTE_up2000.jpg	2000m upward continued Neg RTE	
NG_INVRTE_tilt.jpg	Tilt Derivative	

Table 1

Synthesis of the petrophysical properties and geophysical signatures of the lithologies represented on the geological map (Fig. 3). Thumbnails represent subsets of geophysical datasets of 12 × 18 km processed according to the same method as the images presented in Fig. 2. The geophysical responses of the lithological types served as criteria for mapping. Whole rock geochemical analyses were conducted by A.L.S. Mineral Laboratory, Sevilla, Spain.

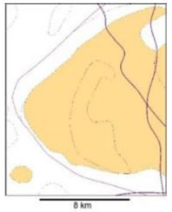
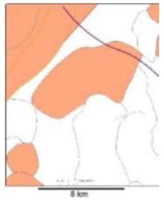
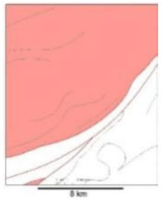
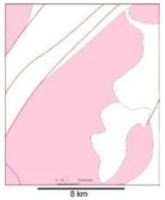
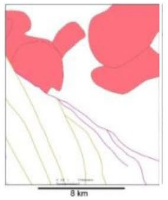
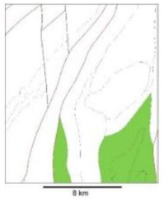
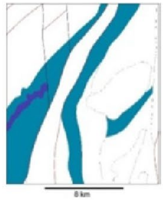
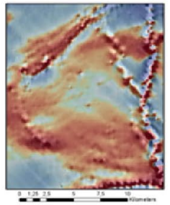
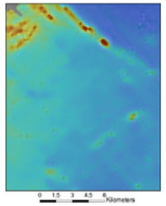
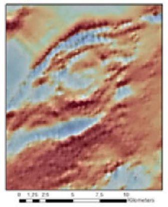
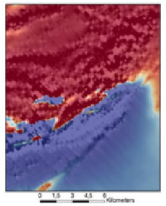
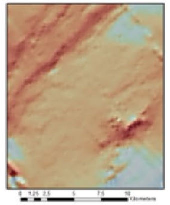
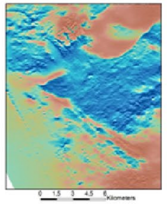
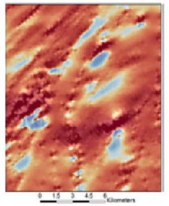
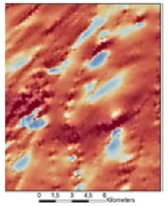
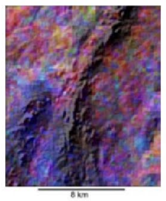
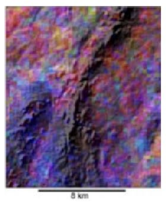
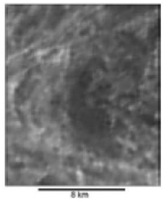
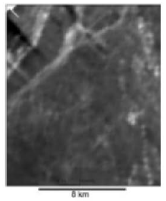
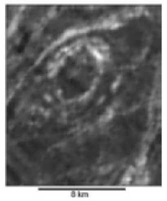
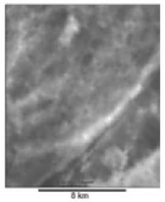
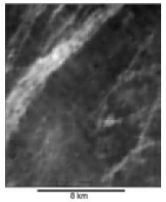
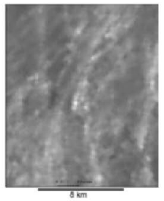
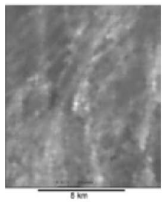
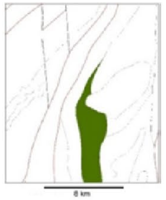
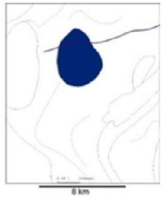
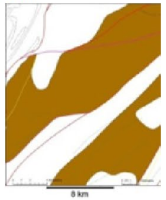
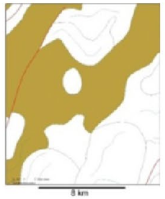
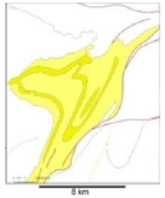
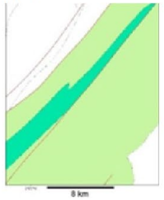
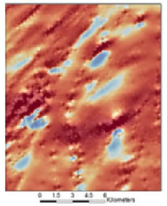
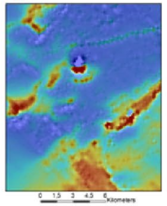
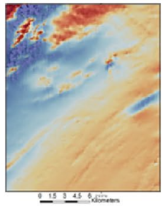
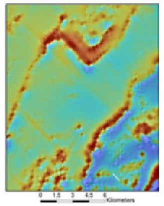
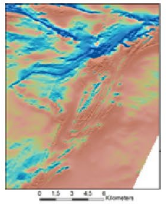
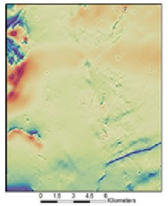
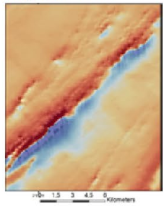
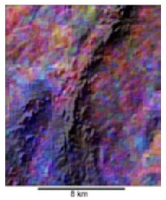
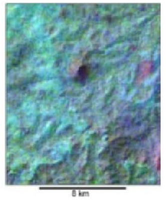
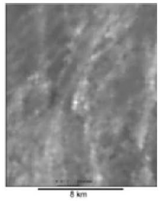
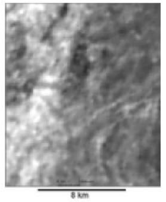
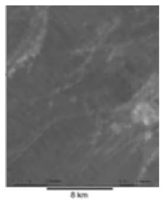
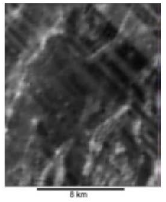
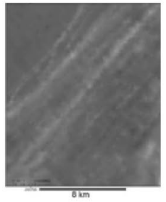
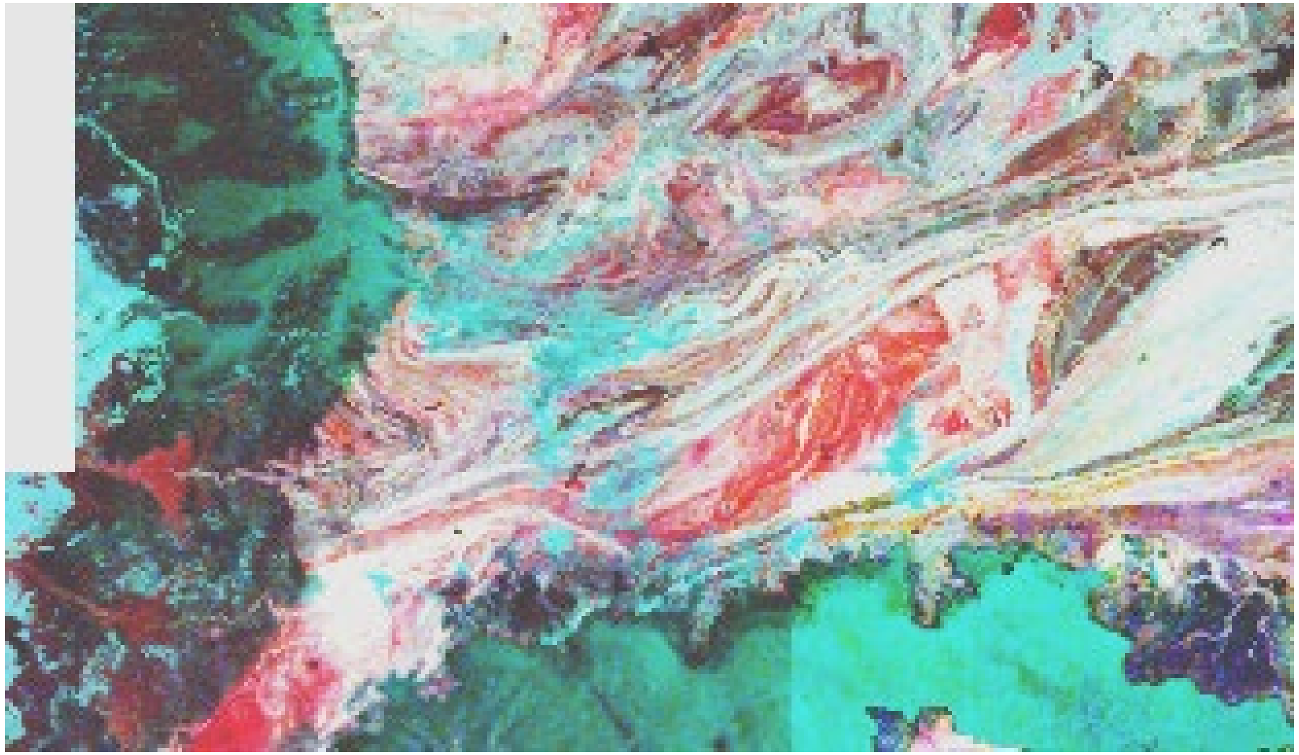
Lithology	G1: TTG & granodiorite gneiss	G2: granodiorite & diorite	Mafic orthogneiss	G3: granodiorite	G4: biotite granite & granodiorite	G5: potassic granite	Andesite/dacite	Basalt/metabasalt
Mineralogy	qz, pl, hbl, bt	qz, pl, kf, hbl (±ep)	qz, pl, hbl, ilm (±gt)	qz, pl, hbl, bt	qz, pl, kf, bt	qz, kf, pl, bt (±ep)	qz, pl, hbl, sph,	act, chl, qz, ep, cal
Magnetic susceptibility (10^{-3} SI)	0.05, 0.30–0.40, 4–10, multimodal	0.10–0.30	0.10–0.5, 1.0–10 (bimodal)	1.0–55	0.005–0.15	0.10–8.0, bimodal	0.30–0.40	No data
Sample	BN261	BN092	BN506	BN380	BN112	BN083	BN02	BN101
U (ppm)	0.29	2.15	0.81	0.46	1.55	4.45	0.810	0.075
Th (ppm)	3.79	3.49	2.26	1.16	12.85	13.9	2.2	0.2
K_2O (%)	0.92	3.07	0.56	1.48	2.03	5.16	0.51	0.14
Map								
Airborne magnetic response	Moderate to high intensity, marked magnetic fabric	Low to moderate, homogeneous.	Low to high, heterogeneous, strong magnetic fabric	Very high, heterogeneous, strong magnetic fabric	Low intensity, homogeneous interlocked bodies	Low to high intensity.	Low to moderate intensity, variable	High intensity layers
Magnetic image								
Airborne radiometric response	K, Th, U poor (dark)	Moderate to high K, moderate U, low Th (red)	Moderate K, moderate U, low Th (red to blue)??	Low to moderate K Th, U poor (dark to red)	Moderate K, high Th, low U (green, yellow, orange)	Very high K, high Th, moderate U (red–yellow)	moderate U (blue), low Th, K.	K, Th, U poor (dark)
Radiometric + shaded DTM								
Airborne electro-magnetic signal	Heterogenous	Low intensity, homogeneous	Heterogeneous	Heterogeneous	Low intensity, homogeneous	No data	Low intensity, homogeneous	Moderate to high intensity
Electro-magnetic image						No data		

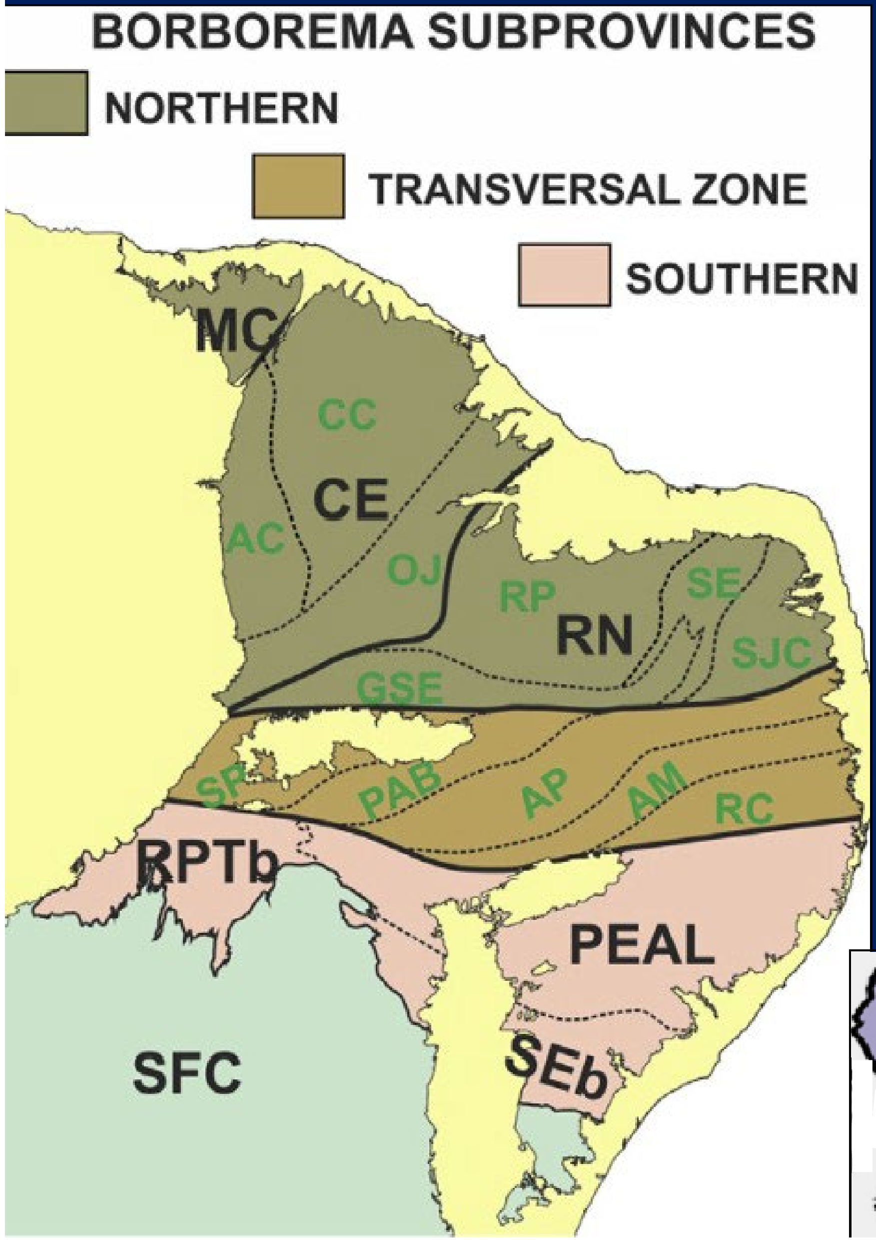
Table 1 (*Continued*)

Lithology	Mn-rich sediment	Gabbro & dolerite dyke	Composite gneiss	Paragneiss	Polymictic sediments & conglomerates	Volcano-sedimentary schist	Rhyolite/felsic volcanoclastite
Mineralogy	No data	act, chl, sph, after cpx, hbl?	qz, bt, pl, wm (±grt, alsi)	qz, bt, pl, wm, gt, alsi/st	qz, pl, kf, wm, chl, ep, py	qz, chl, ms	qz, chl, wm (±grt)
Magnetic susceptibility (10^{-3} SI)	0.05–0.9, unimodal	0.2–2.0	0.01–0.35	0.10–0.35		0.05–0.55	0.04–0.20
Sample	BN006	BN104	BN392	BN047	BN110	BN411	BN400
U (ppm)		0.153	1.68	1.32	1.936	1.5	1.711
Th (ppm)		0.5	6.04	5.53	6.5	5.66	5.7
K_2O (%)		0.50	3.35	2.27	3.40	1.78	0.79
Map							
Airborne magnetic response	Low to high, marked magnetic horizons	High intensity, strong signal	Low intensity, smooth homogeneous surface	Low intensity, smooth homogeneous surface	Contrasted intensity in stratigraphic horizons	Low intensity, smooth homogeneous surface	Occasional highly magnetic lavas
Magnetic image							
Airborne radiometric response	K, Th, U poor (dark)	K, Th, U poor (dark)	High (*K* + *Th*)/(K + Th + U) (red–orange)	Low U, moderate Th, K (green–yellow)	Low U, K, moderate to high Th (green–yellow)	Low U, moderate Th, K (orange–yellow)	Moderate U, Th, K (orange–yellow)
Radiometric + shaded DTM							
Airborne electro-magnetic signal	High intensity, heterogeneous	Low intensity	Low intensity, homogeneous	Low intensity, homogeneous	No data	Very high intensity	Moderate intensity
Electro-magnetic image					No data		

5: Borborema Province



Perspectives - Underexplored Au systems



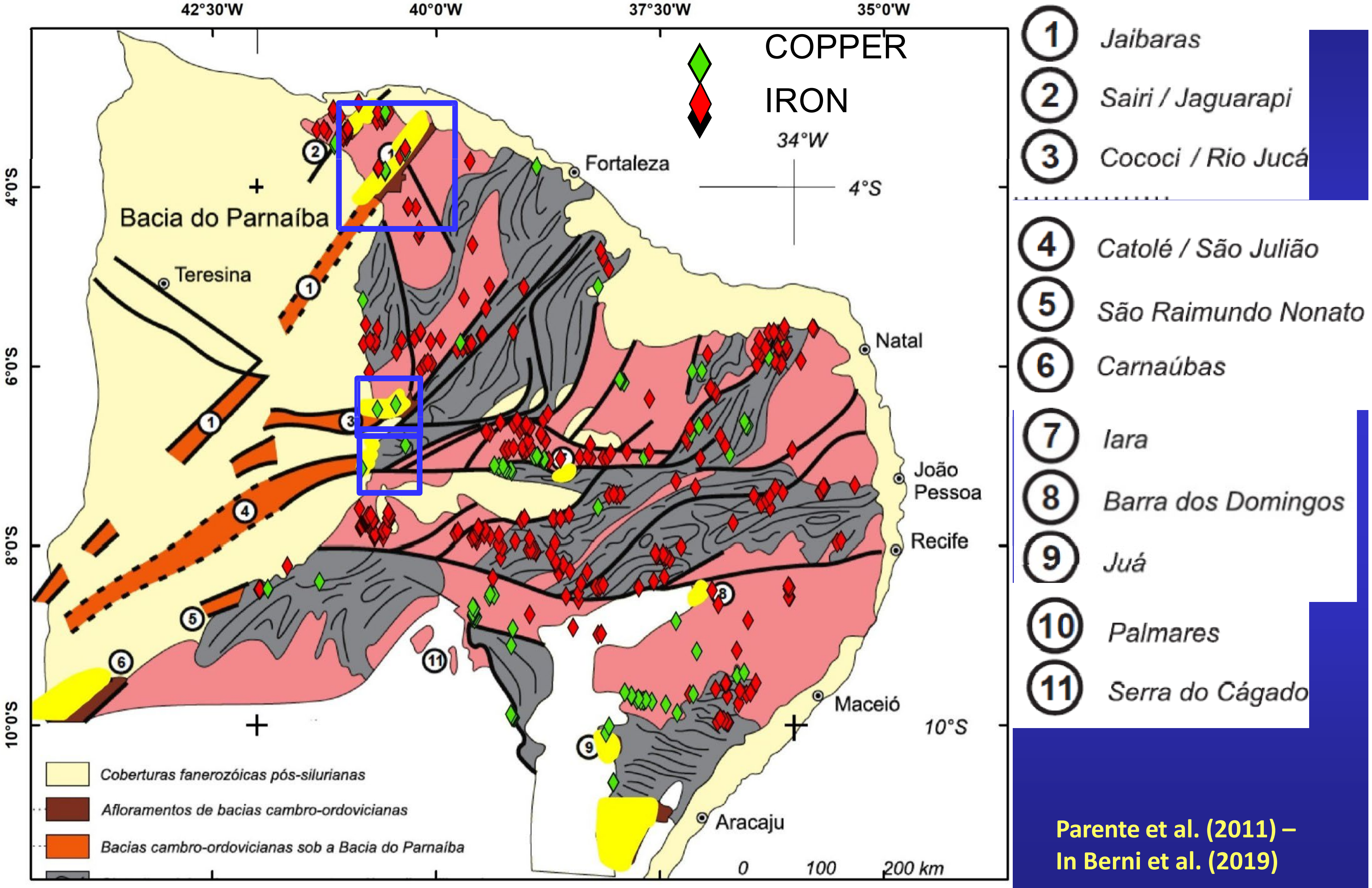
- Vast terrane covering 900 x 900 km
- At least 5 Archaean nuclei
- Numerous Palaeoproterozoic tectonic blocks
- Major Mesoproterozoic metamophic belt
- Welded together by Neoproterozoic mobile belts, shear zones, fossil arcs, magmatic arcs, continental **arc and a** quintuple, ESE-vergent, imbricated thrust system
- **Prolific occurrence record of Au, Cu, Fe, Ni, W, Sn, Mo and Ta, amongst other metallic and non-metallic minerals**

Divided into: Northern, Transversal (or Central), and Southern sectors.

Major & secondary domains

Lobato et al. (2019) – *Gold in Brazil*

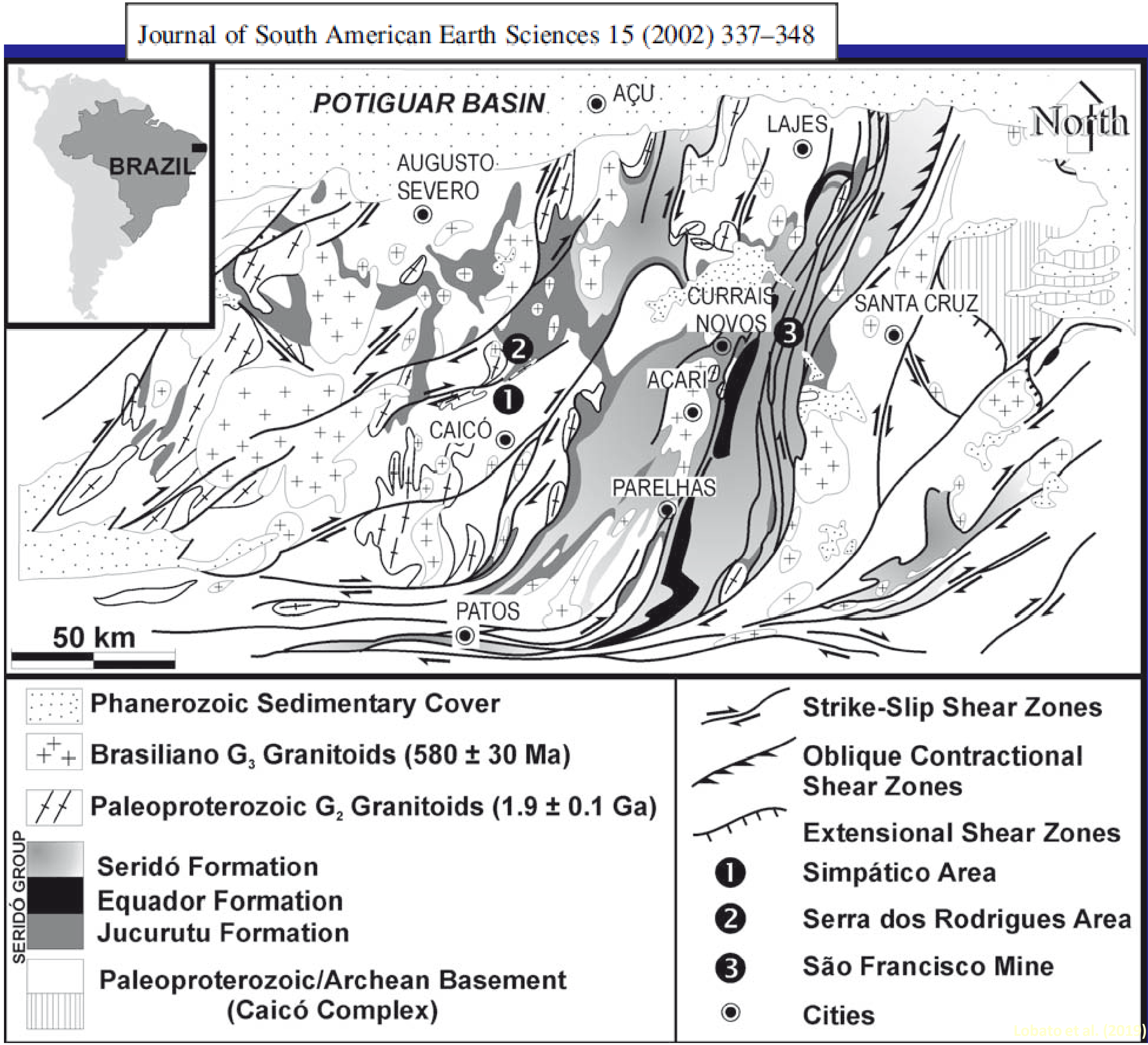
Slide courtesy L Lobato



Parente et al. (2011) – In Berni et al. (2019)

Slide courtesy L Lobato

Lobato et al. (2019) – *Gold in Brazil*



Crusader Borborema gold deposit

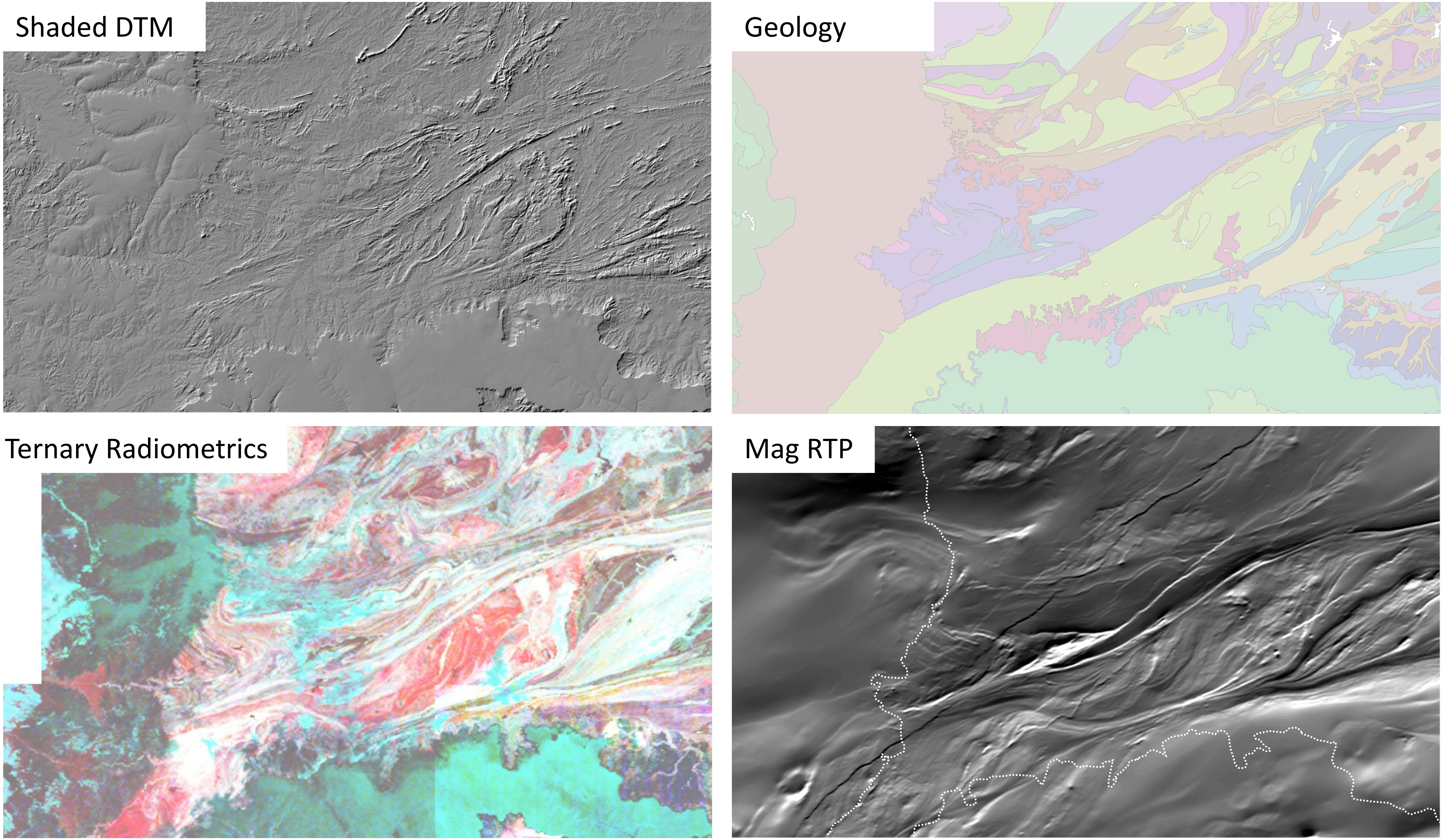
Araújo et al. (2002)

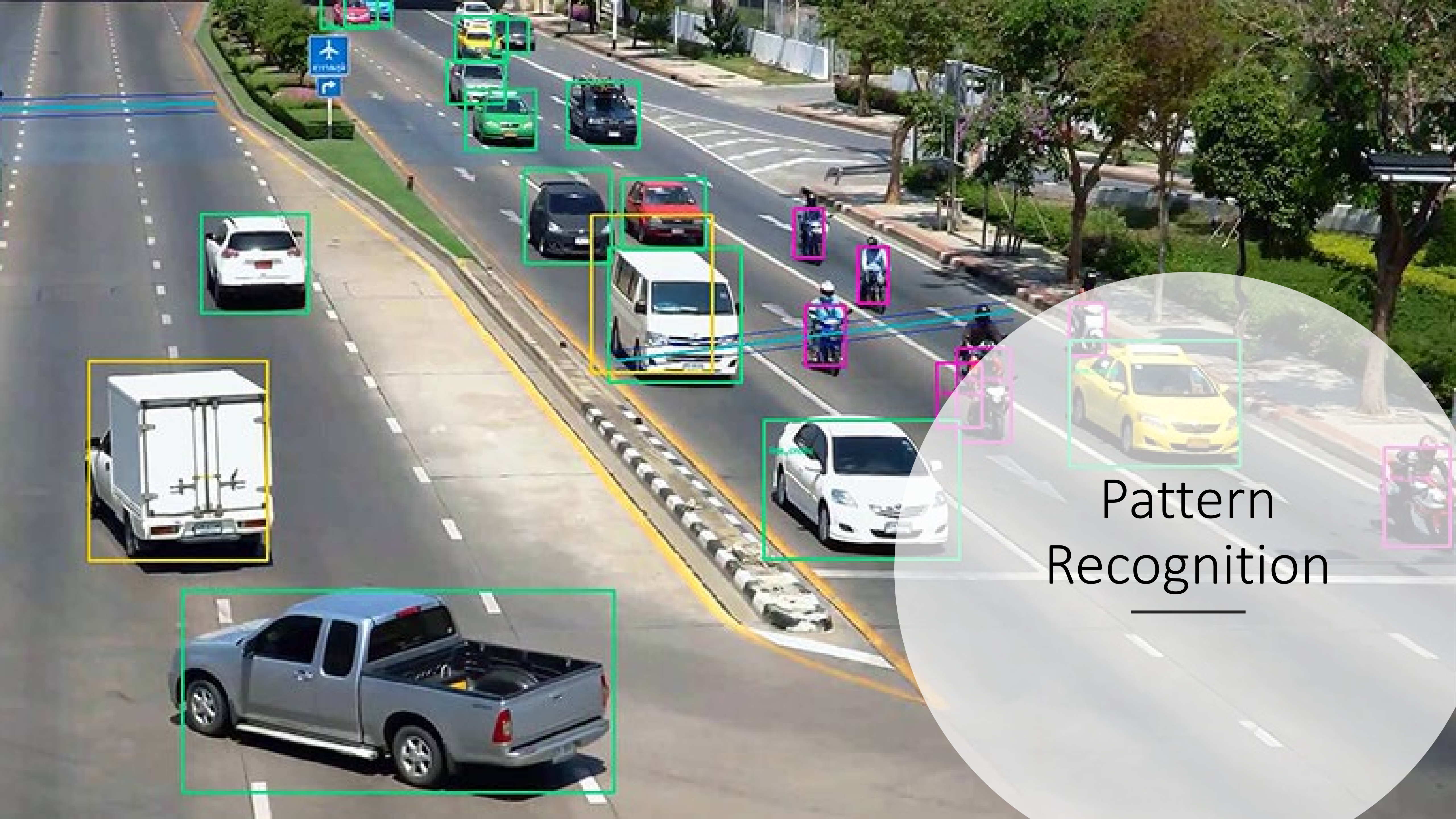
3

Shear-zone related, Neo-**proterozoic** high-meta-**morphic grade orogenic gold?**

(Crusader Resources Borborema **Gold Project**) Faixa Seridó

Slide courtesy L Lobato

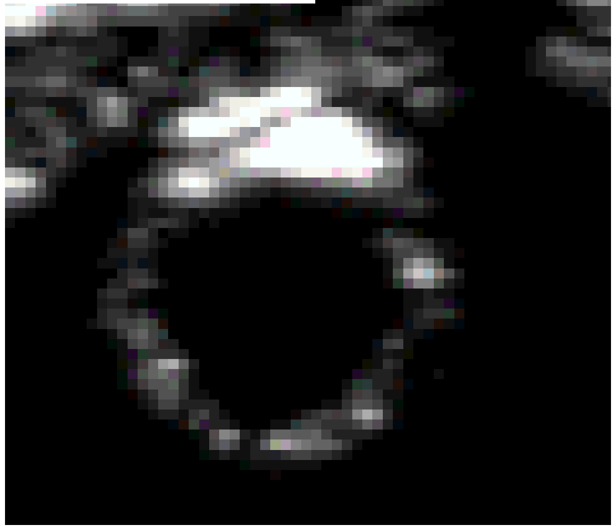

Shaded DTM
Geology
Ternary Radiometrics
Mag RTP

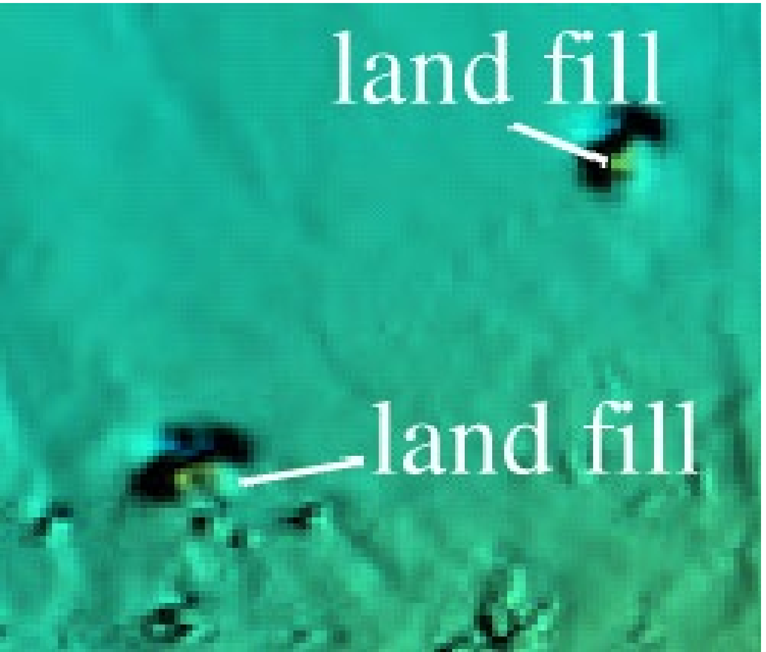


Pattern Recognition

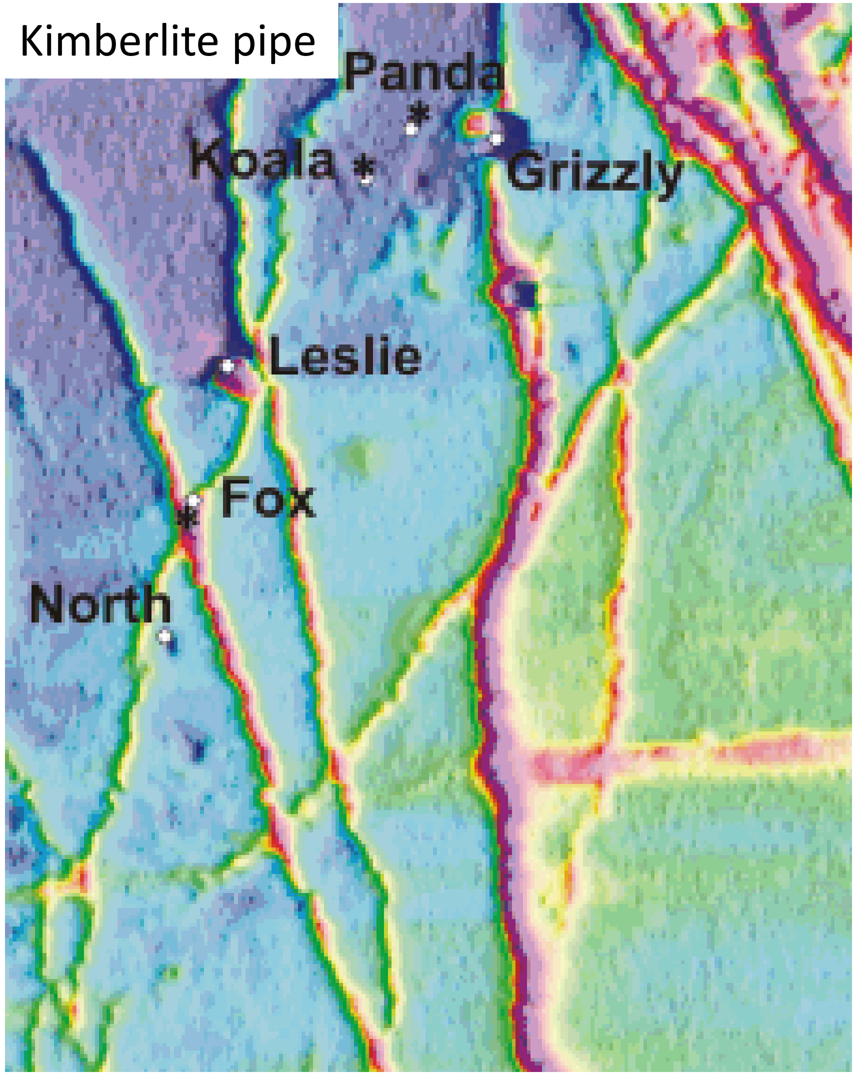
Point features

Impact Crater

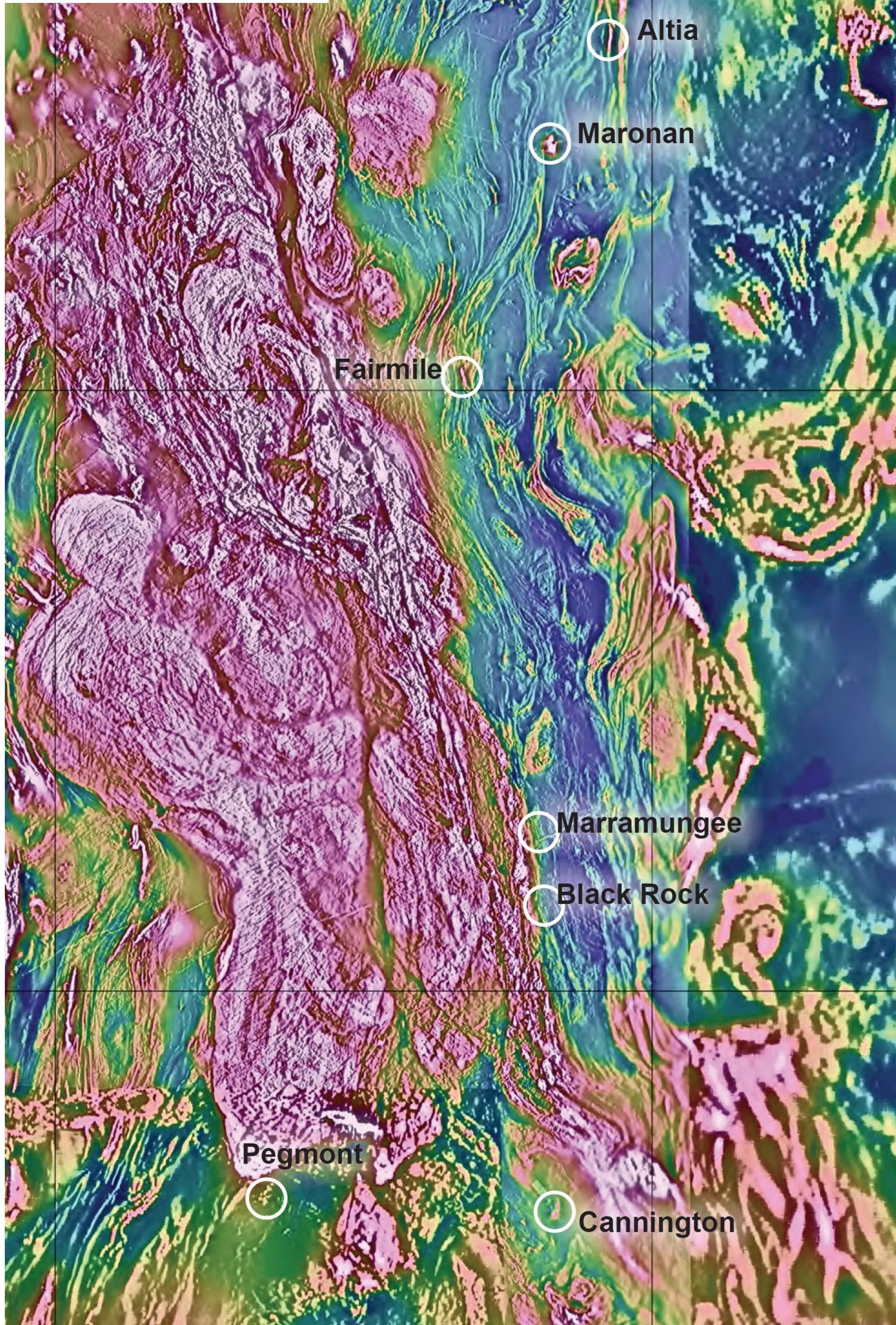


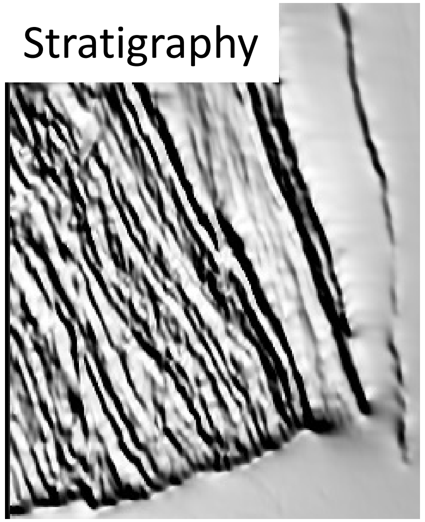


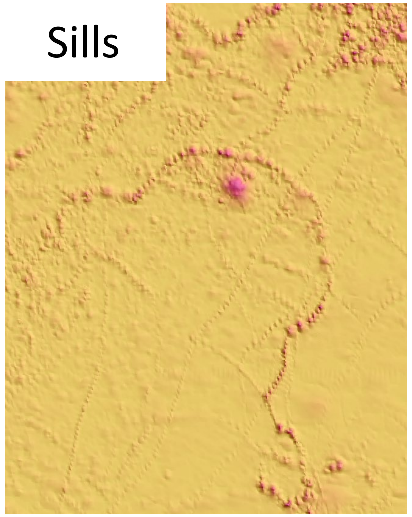
Kimberlite pipe

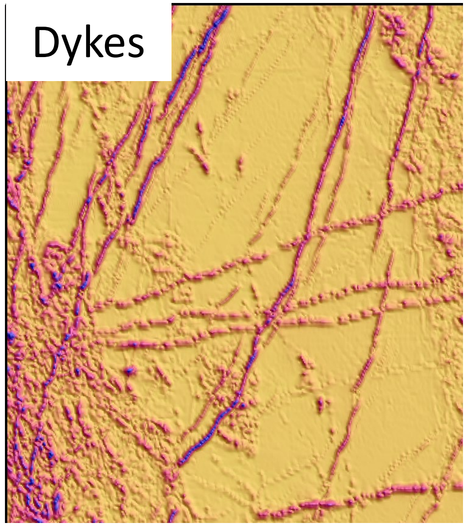


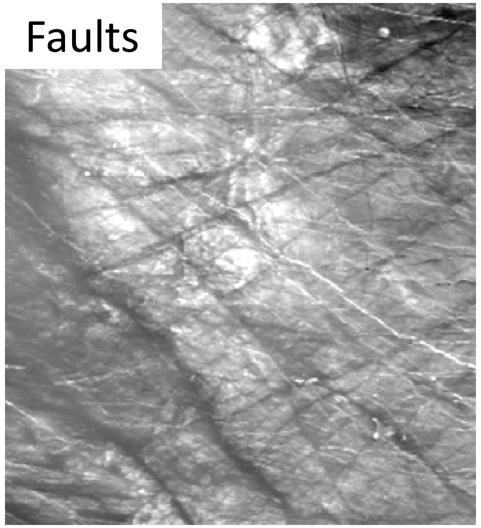
Ore deposits

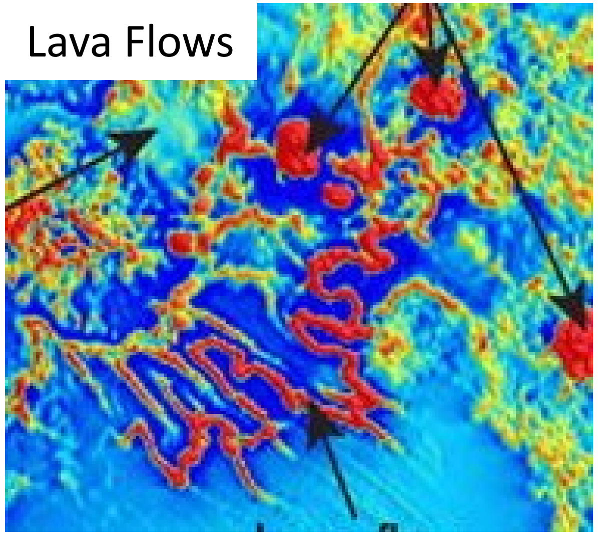



Stratigraphy

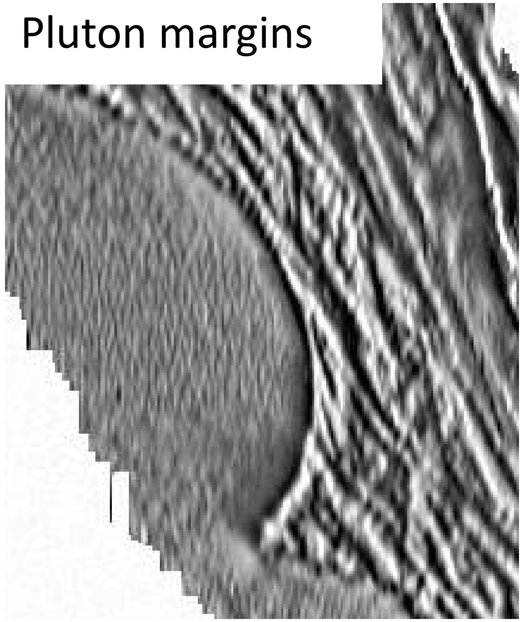

Sills

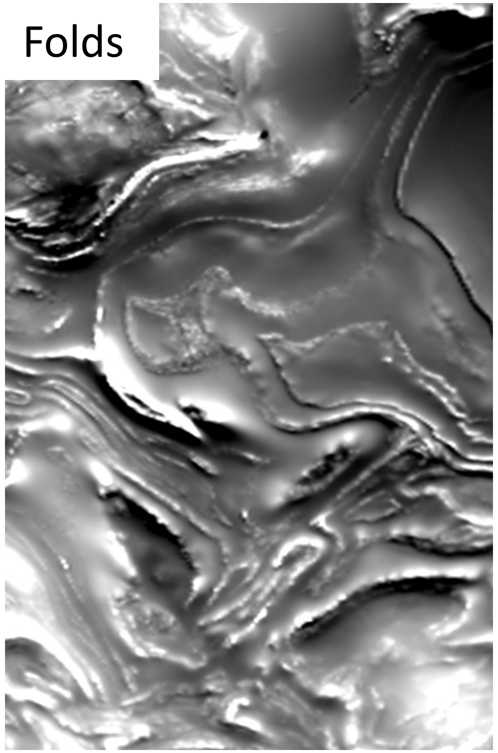

Dykes

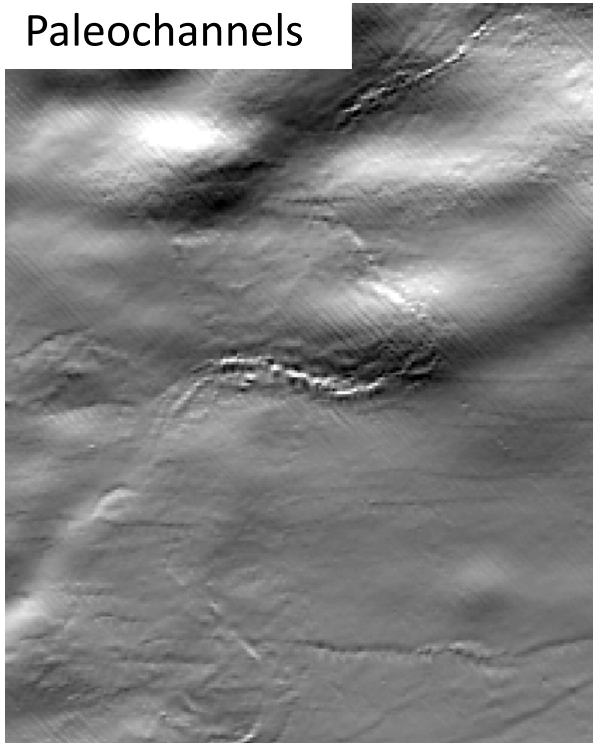

Faults

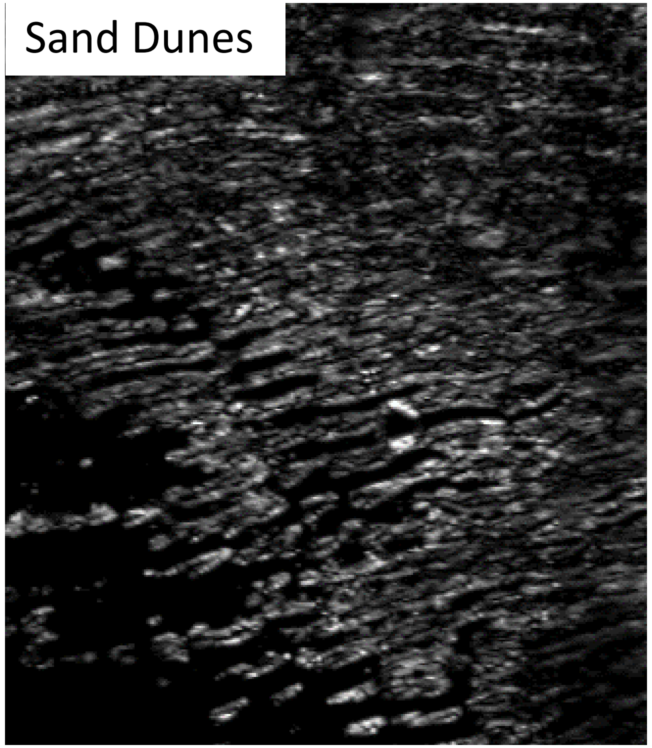

Lava Flows

Single or multiple linear features


Pluton margins


Folds


Paleochannels


Sand Dunes

Area-filling features