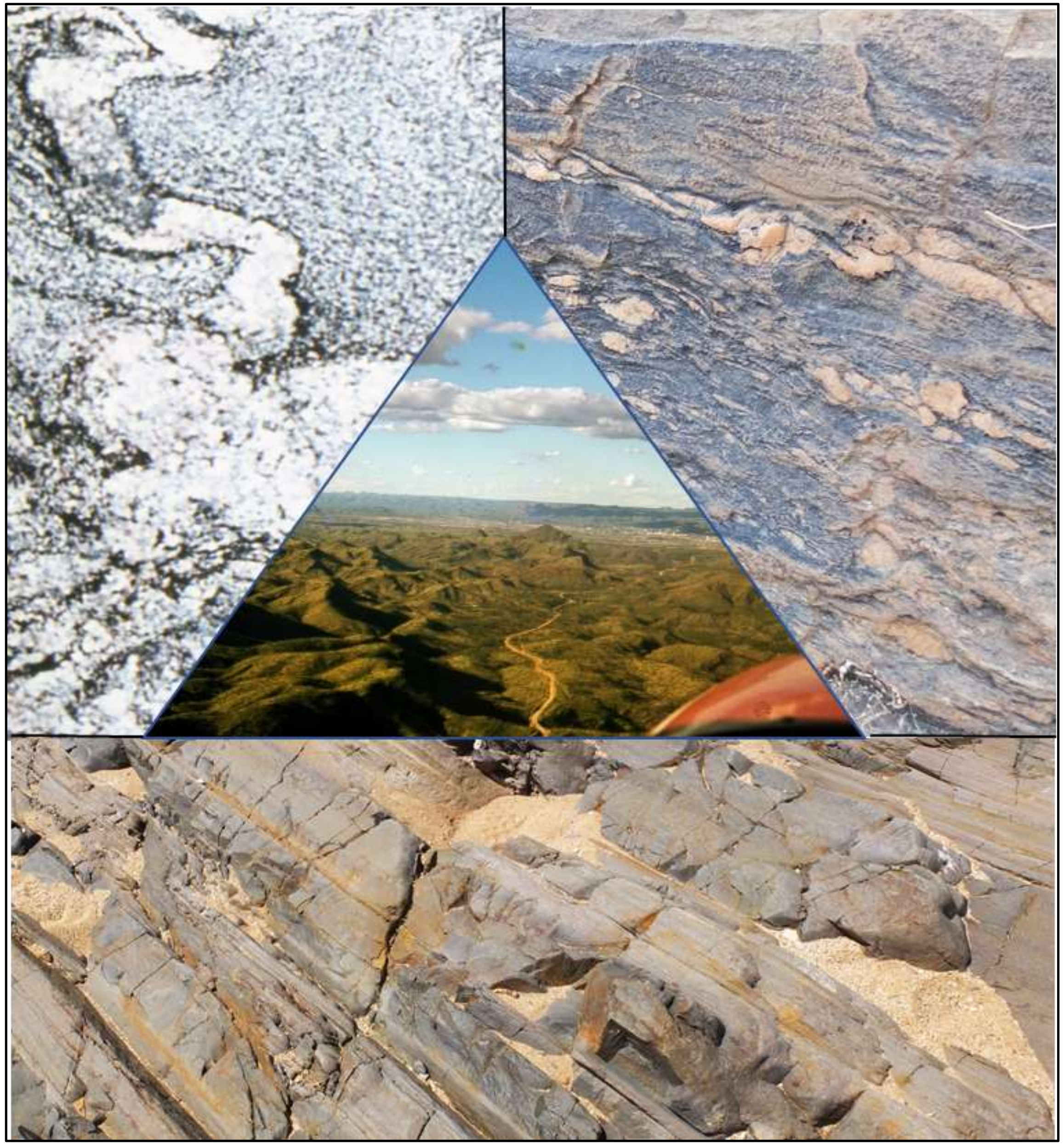


Damara geology, from geosyncline to plate tectonics

A talk given by Nick Watson

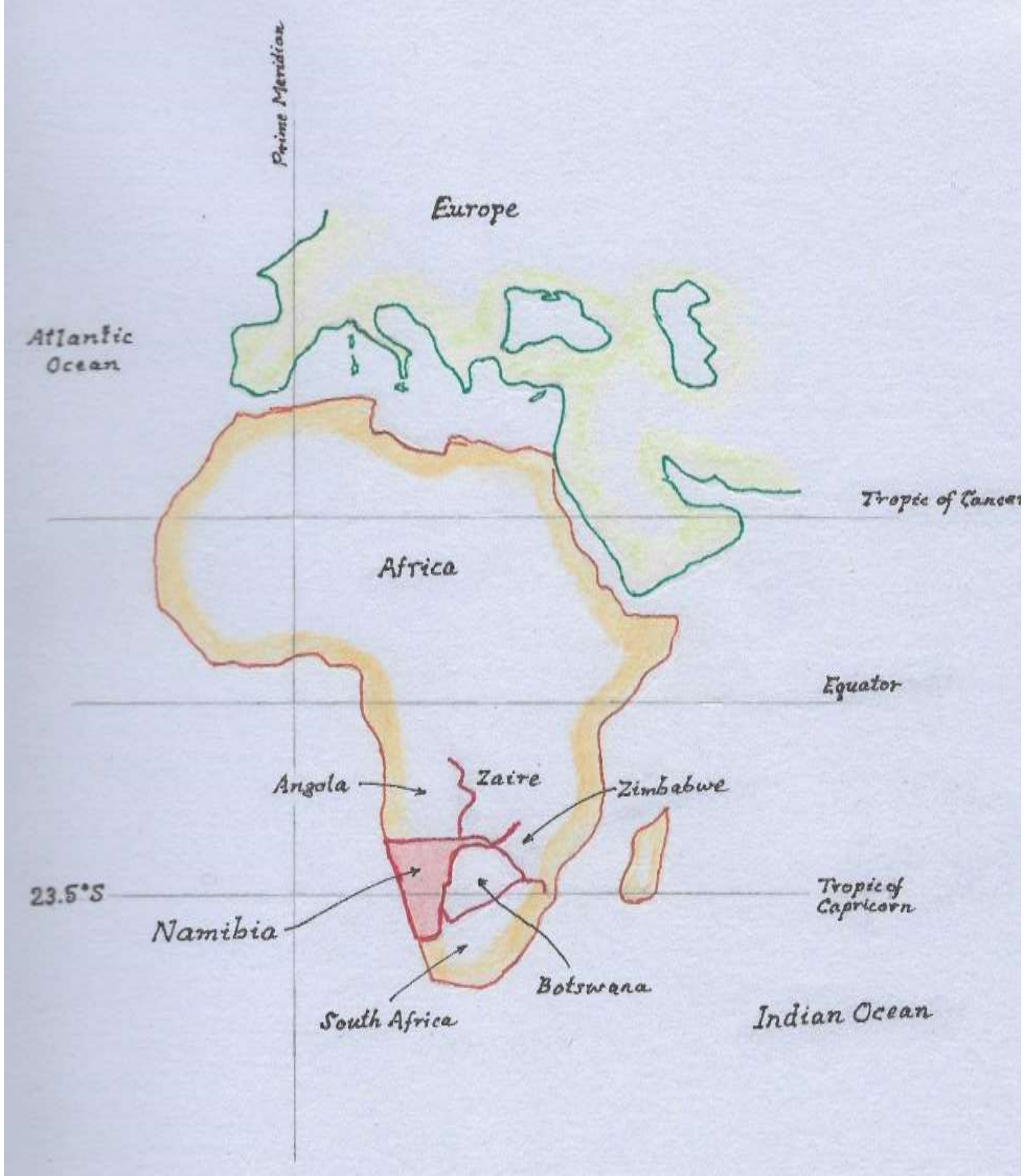
to the West Midlands Regional Group of the Geological Society of London

9th April 2019

Talk Contents

- Introduction
- Namibia, research projects, and geology
- The conundrums
- Geology at two sites
  - Structure and stratigraphy
  - Ophiolites, volcanics, mélange deposits, suture zone
  - Batholiths

Namibia



Prime Meridian
Europe
Atlantic Ocean
Tropic of Cancer
Africa
Equator
Angola
Zaire
Zimbabwe
23.5°S
Tropic of Capricorn
Namibia
Botswana
South Africa
Indian Ocean

Damara reference documents

Publications on Geodynamic origin of Damara

- ‘Intracontinental Fold Belts: Case Studies in the Variscan Belt of Europe and the Damara Belt of Namibia’, 1983, ed. Martin H. and Eder F.W., Springer Verlag, Berlin
- ‘Evolution of the Damara Orogen of South West Africa / Namibia’, 1983, ed. Miller R. McG., Spec. Publ. geol. Soc. S. Afr., **11**

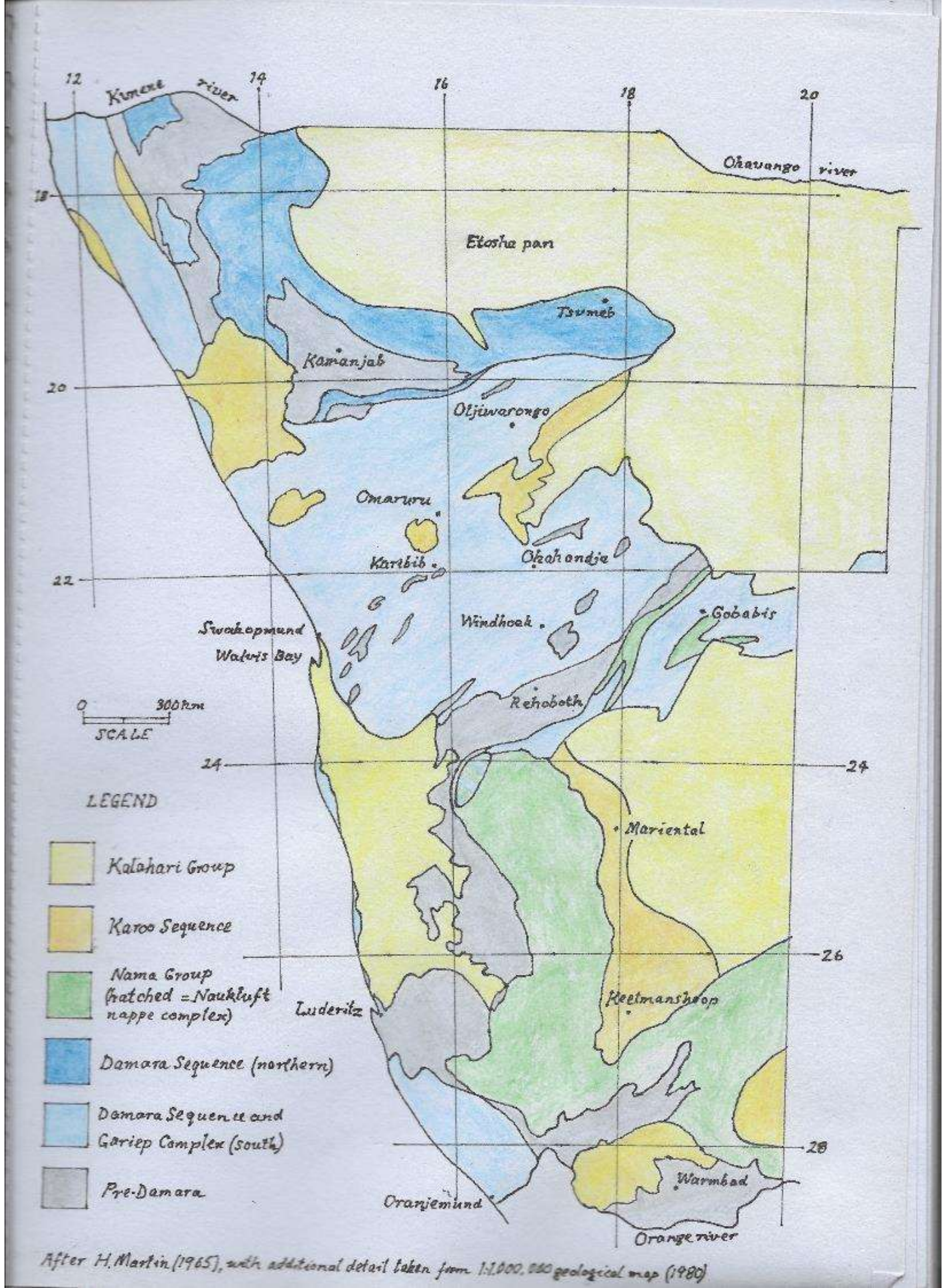
Selected individual publications

- Martin, H, 1965, ‘Precambrian Geology of South West Africa and Namaqualand’, Precambrian Res. Unit, Univ. Cape Town, 159pp
- Barnes, S-J, and Sawyer, E.W, 1980, ‘An alternative model for the Damara Mobile Belt. Ocean crust subduction and continental collision’, Precambrian Res., **13**, 297-336
- Barnes, S-J, 1982, ‘Serpentinites in central South West Africa / Namibia – a reconnaissance study’, Mem. Geol. Surv. S.W.Afr/Namibia, **8**, 90pp
- Miller, R. McG, 2014, ‘Guide to the excursion through the Damara orogen’, The Geological Society of Namibia, 101pp

Published geological maps (1:250,000 scale, Geological Survey of Namibia)

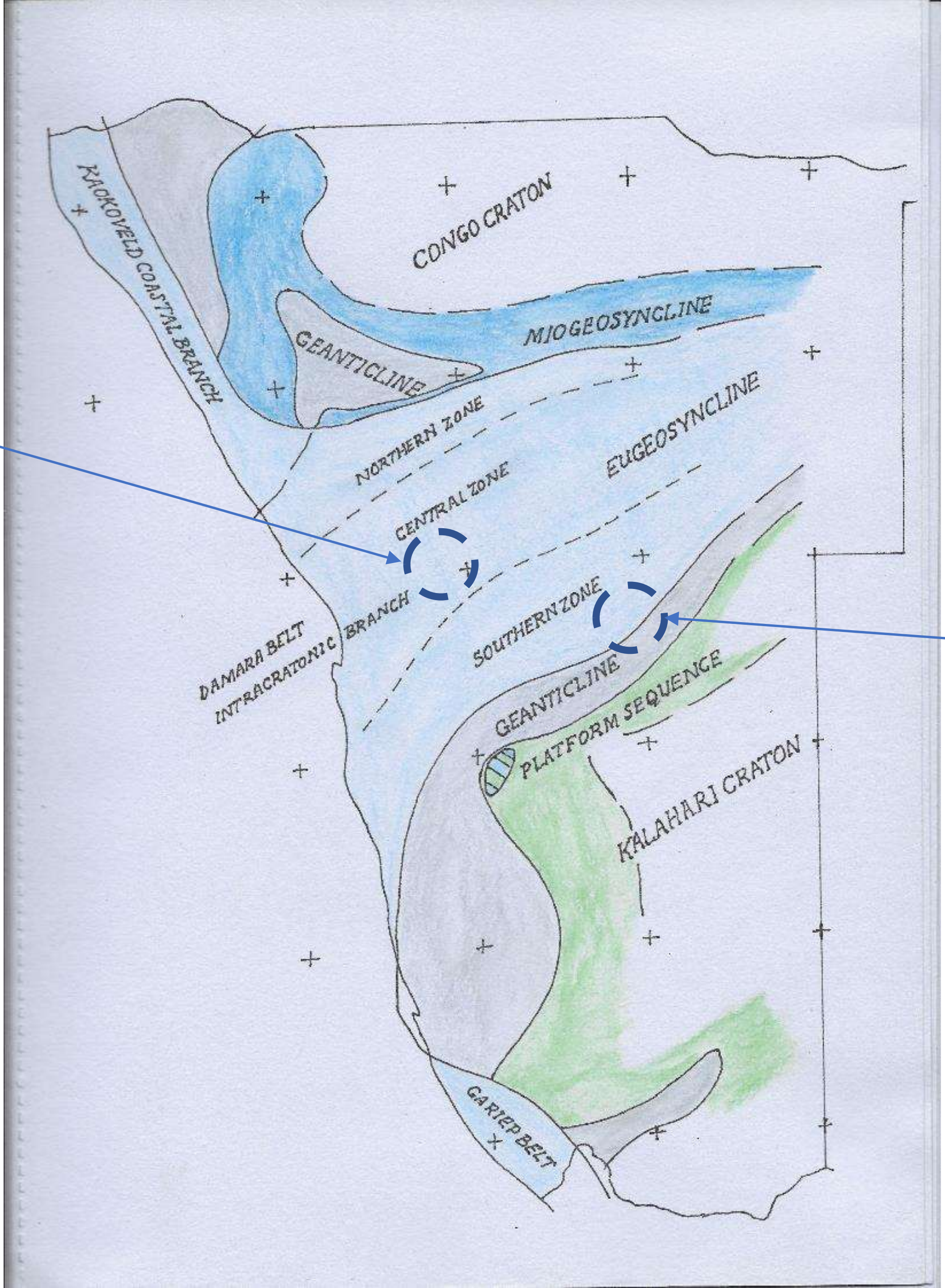
- Sheet 2214 ‘Walvis Bay’, 1995
- Sheet 2114 ‘Omaruru’, 1997
- Sheet 2216 ‘Windhoek’, provisional, 1998

Geology of Namibia



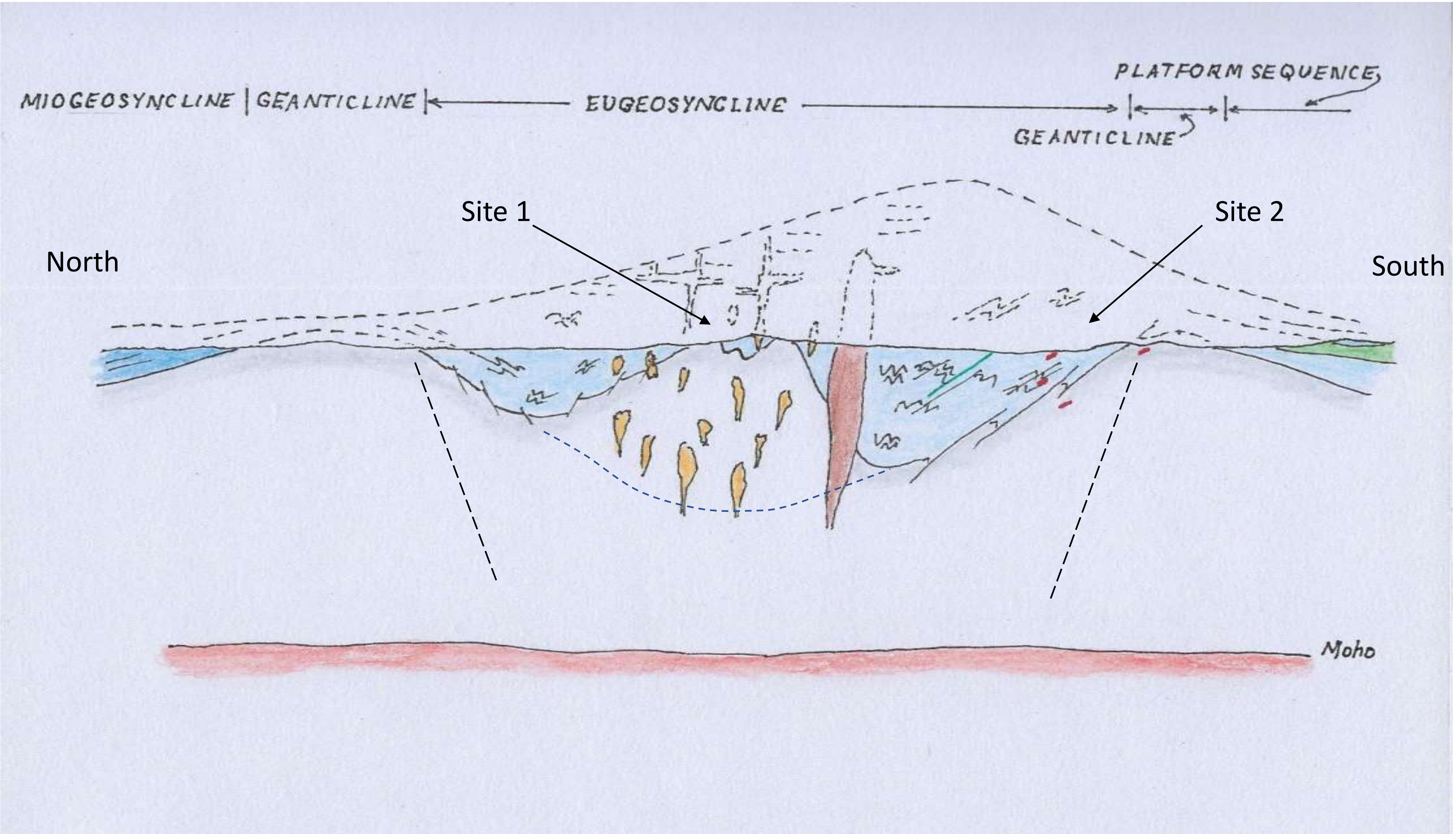
Geosynclinal theory

Site 1
Central zone
Structure and stratigraphy
Batholiths



Site 2
Southern zone
Ophiolites, mélange deposits,
the suture zone, volcanics

Section through the Damara according to geosynclinal theory

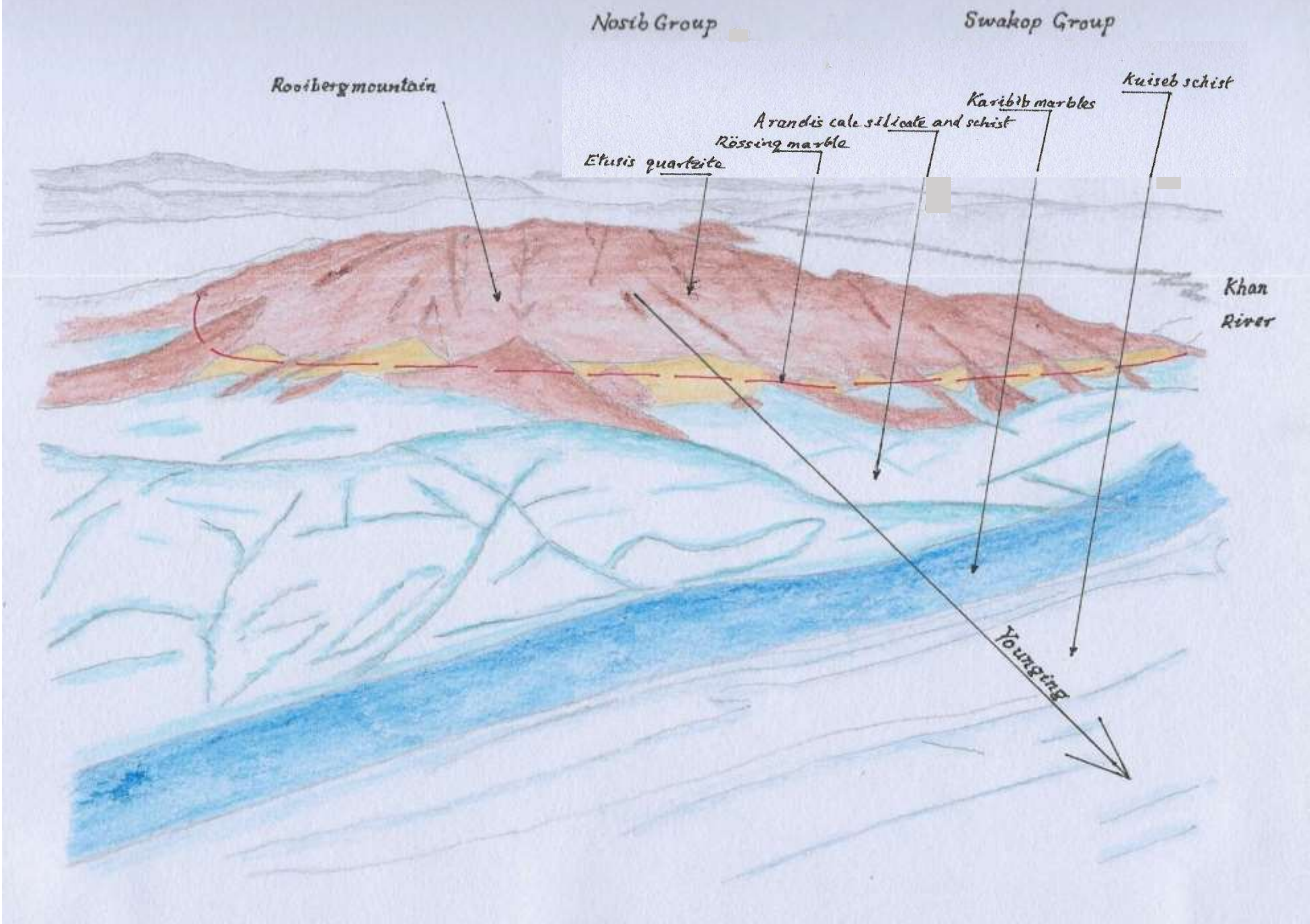


Geodynamic models (up to 1983)

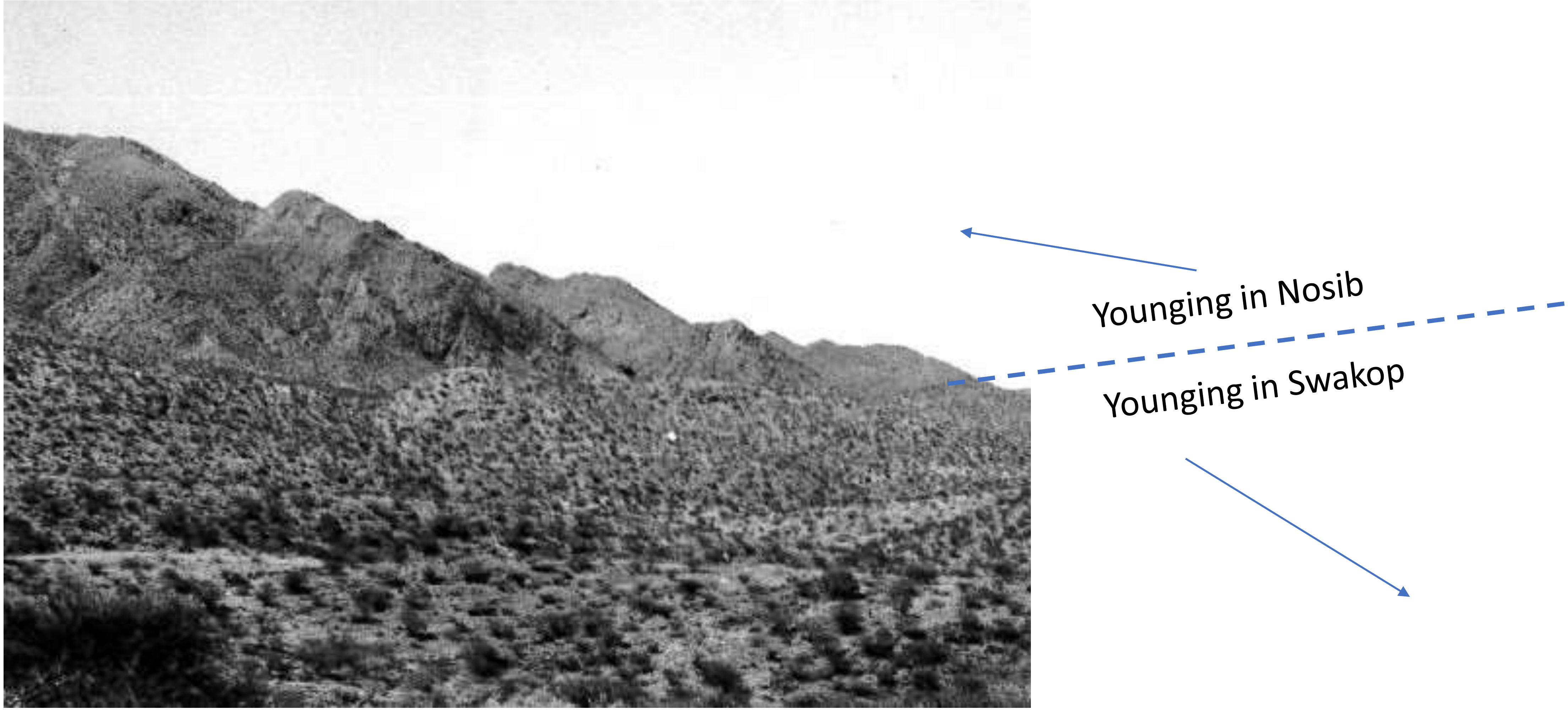
MODEL	DESCRIPTION
PRE PLATE TECTONICS	
Geosyncline	Large linear sedimentary basin founded on continental crust, regarded as a weak crustal zone bounded by stable cratons
PLATE TECTONICS – FAILED ARM OF A TRIPLE JUNCTION	
Aulacogen/modified aulacogen	Intracratonic fold belt, mantle plume leads to rift tectonics and diapirism, folding linked to gravitational instability in the lower lithosphere
PLATE TECTONICS – WILSON CYCLE	
Plate tectonics – wide / narrow ocean	Wilson cycle of sea floor spreading, generation of oceanic crust, followed by creation of a forearc / passive margin basin with MORB volcanics, subduction and continental collision
Possible sinistral movement, transform faults and transpression applicable to all plate tectonic models?	

Conundrums
Road Testing Plate Tectonics

- Continuous stratigraphy traceable over the whole orogenic belt, with continental crust in basement exposures
- The lack of a suture line between the two continents, marked by ophiolites and mélange deposits, and separating zones with different pre-collision sedimentation and deformation history
- Paucity of volcanics in the forearc trench deposits
- There is large volume of granite, but where are the tonalites (andesite volcanics source magma)?


Nosib Group
Swakop Group
Rooibergmountain
Kuiseb schist
Karibib marbles
Arandis calc silicate and schist
Rössing marble
Etusis quartzite
Khan
River
Younging

Inverted bedding in Nosib quartzite at the Rooiberg



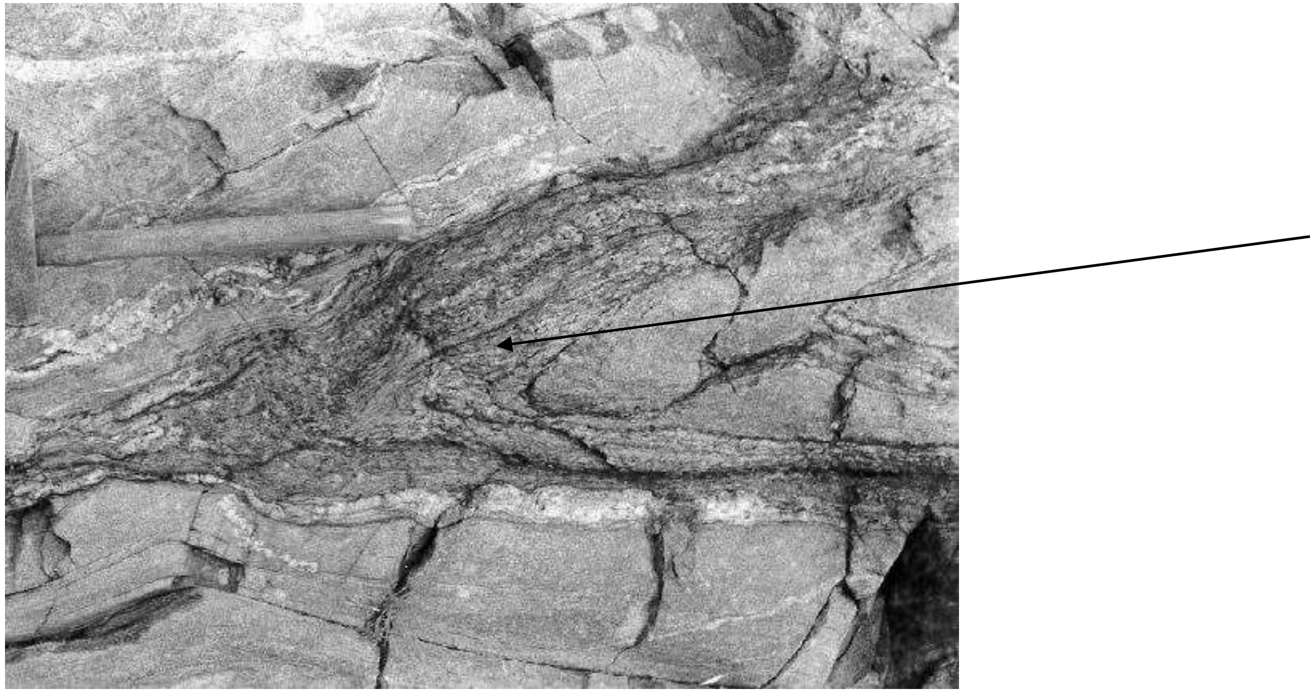
Etusis quartzite

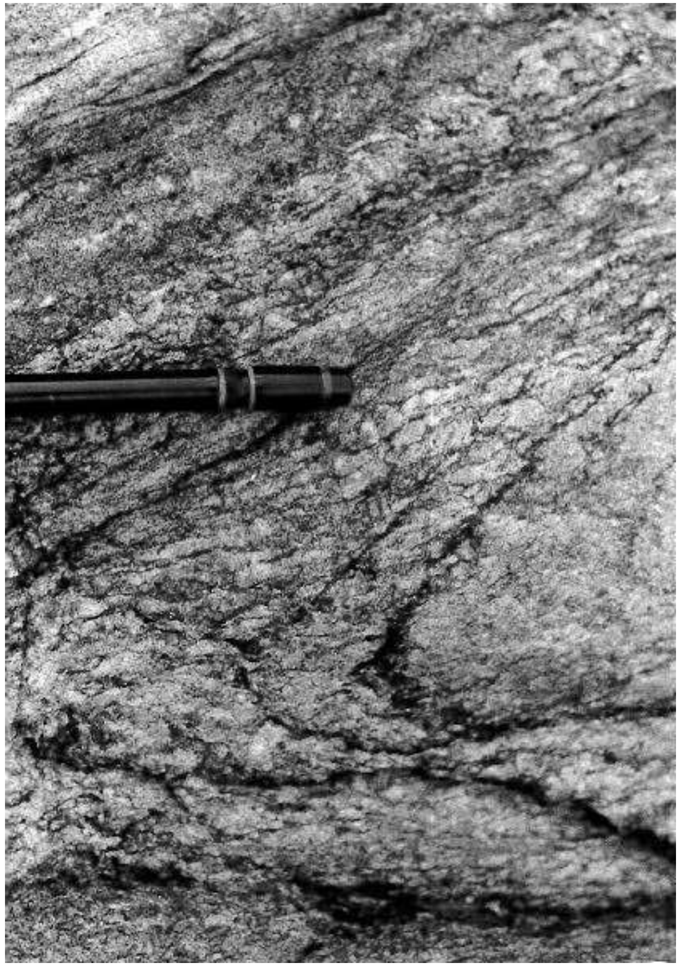
Cross bedded arkosic quartzite

Rossing marble

Dolomitic fosterite marble with skarn lenses

Kuiseb schist folding and schistosity development

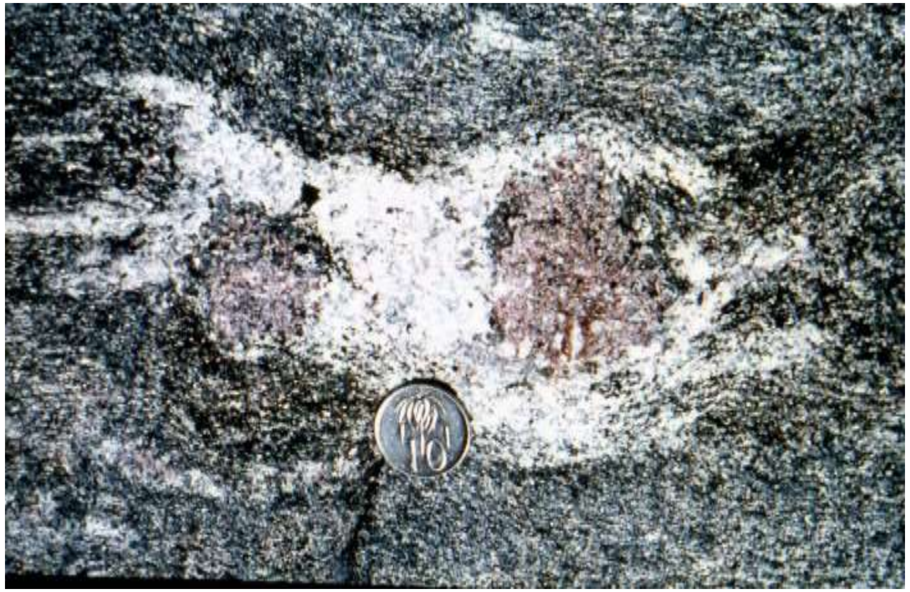




Structure

- Isoclinal f_2 fold core with cordierite porphyroblasts
- Sinous S_1 inclusion trails
- Coarse S_2 axial planar cleavage

Kuiseb schist metamorphic grade



Metamorphism in the Kuiseb schist[1]

- Biotite + sillimanite + quartz $\rightleftharpoons$ cordierite + K-spar + H_2O + garnet
- Local partial melting
- T = 650^{o}C, P = 4.25kbar, X_{H_20} = 0.125 (425MPa = c15km cover)

[1]Barnes and Sawyer, 1980

Complex interference fold patterns in the Karibib marbles

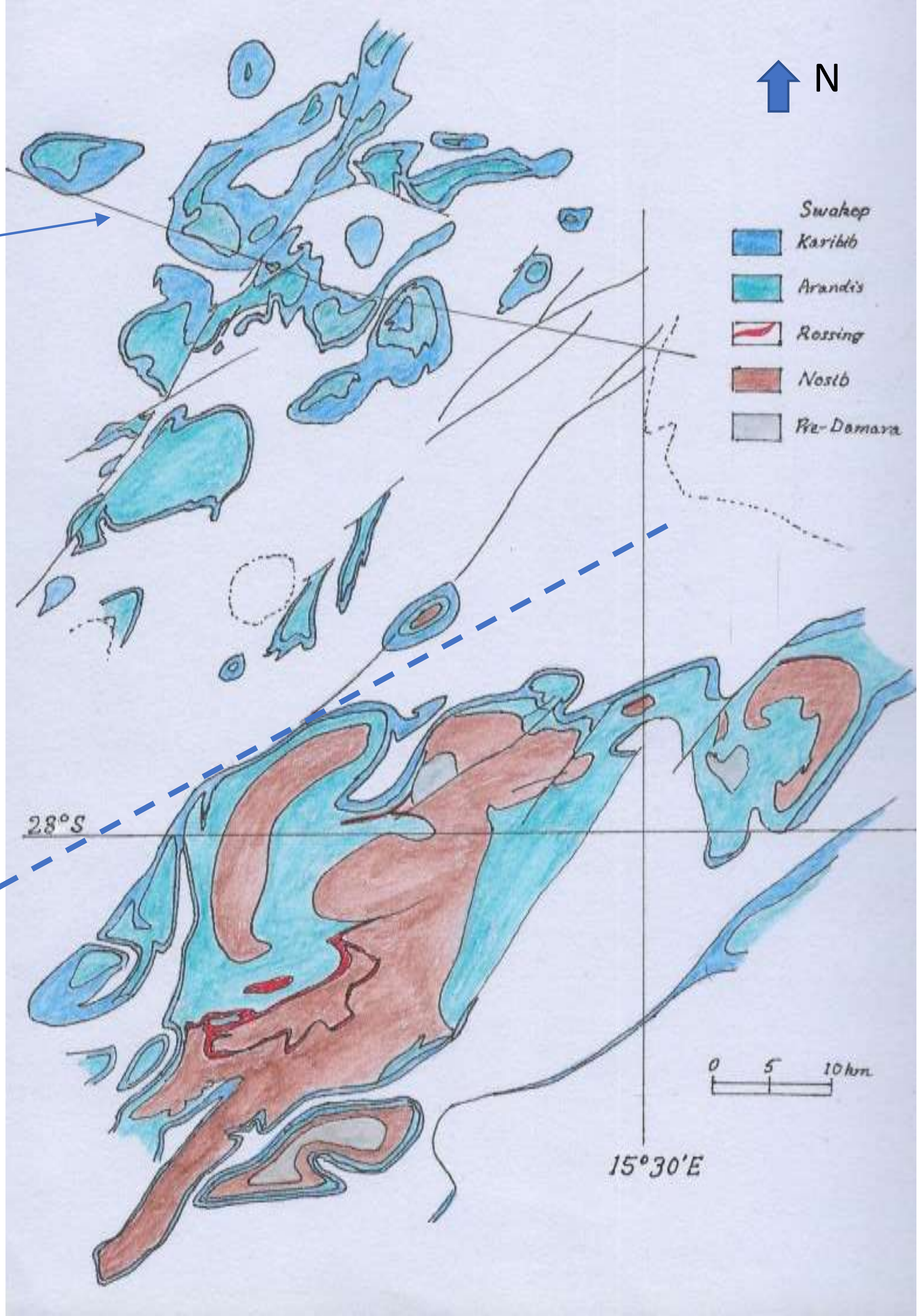
Central zone structure and stratigraphy

Line of section

Multiple dome and basin features defined by Karibib marble

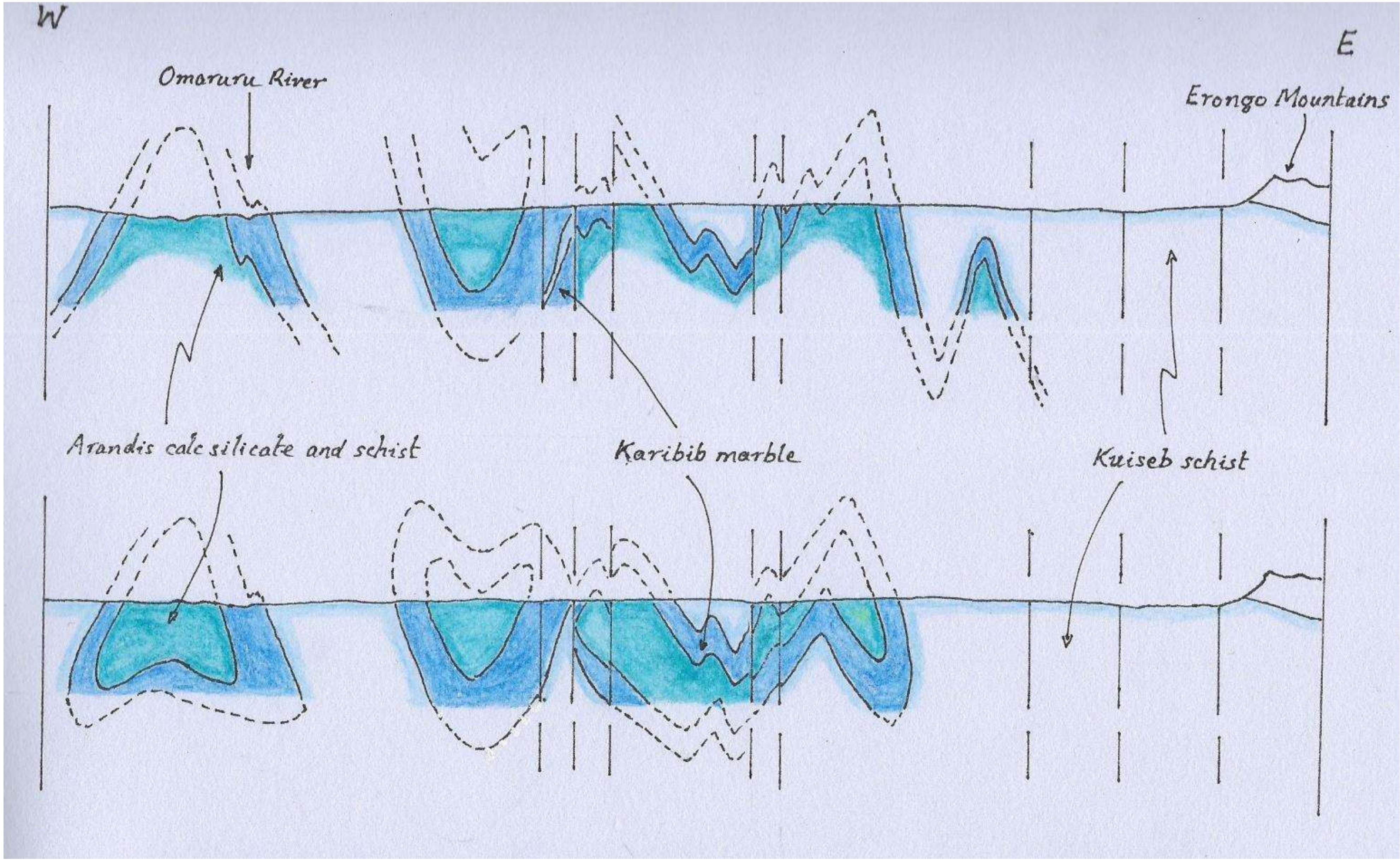
Omaruru Lineament separates tectonic domains

Single large dome defined by Karibib marble

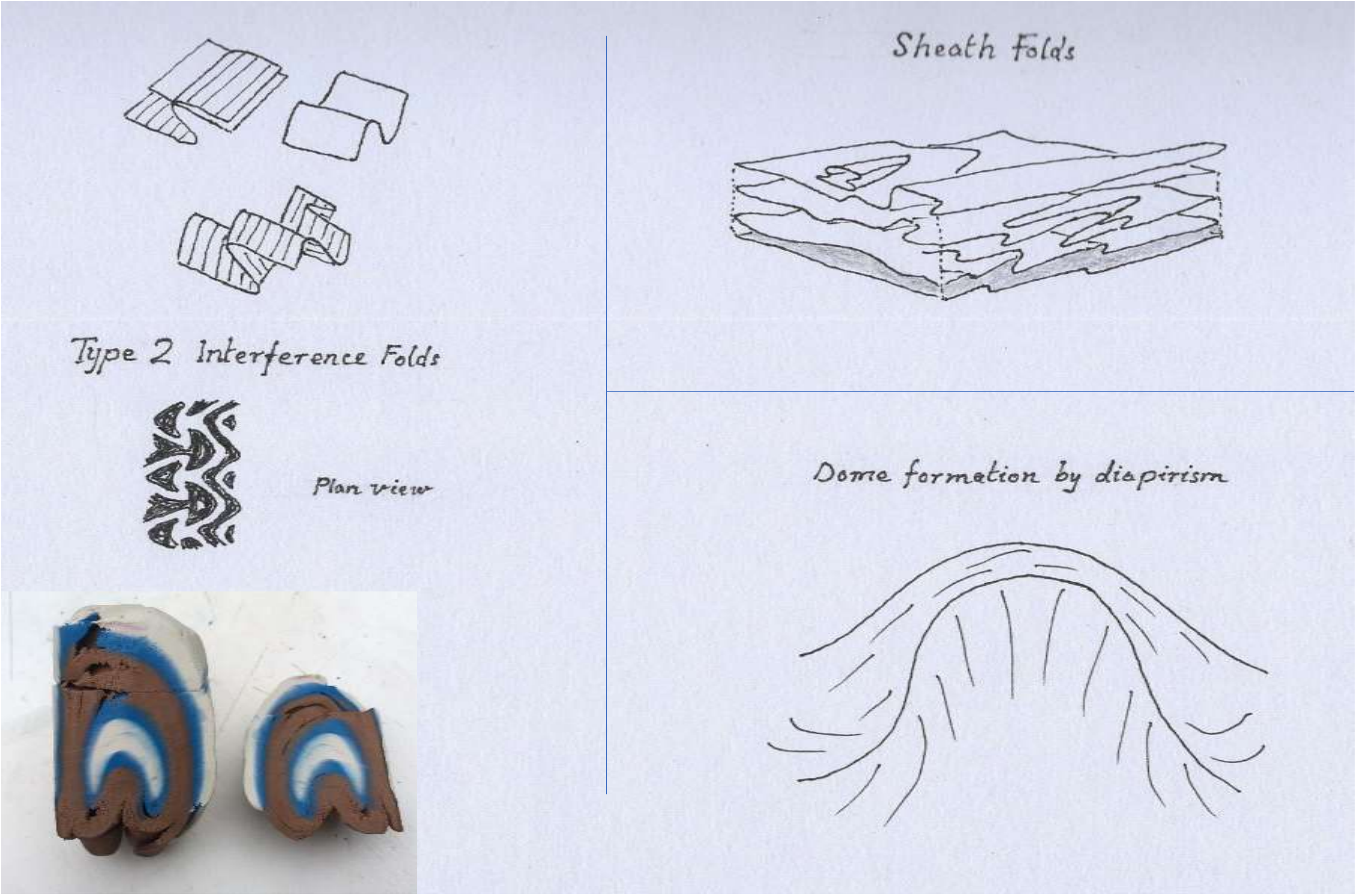


Aerial view

Horizontal sections based on different interpretations



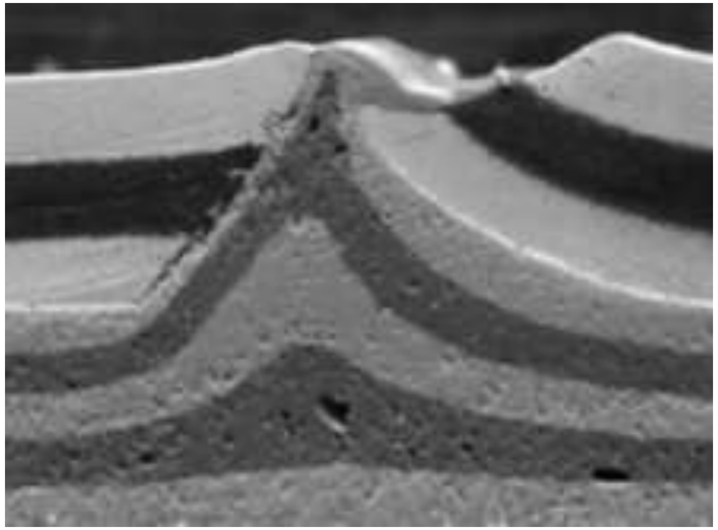
Horizontal compressive or vertical stress regime

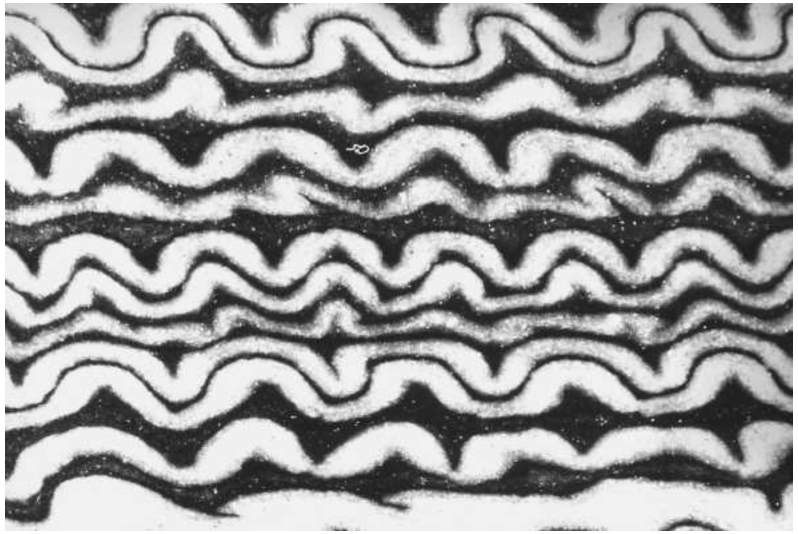


Structure and stratigraphy

- Different theories for the origin of dome and basin structures
- Geosynclinal and intracratonic theories are supported by vertical tectonic interpretations – diapirs and high heat flow
- Horizontal movement – shear zones and interference folding – favours continental collision and plate tectonics

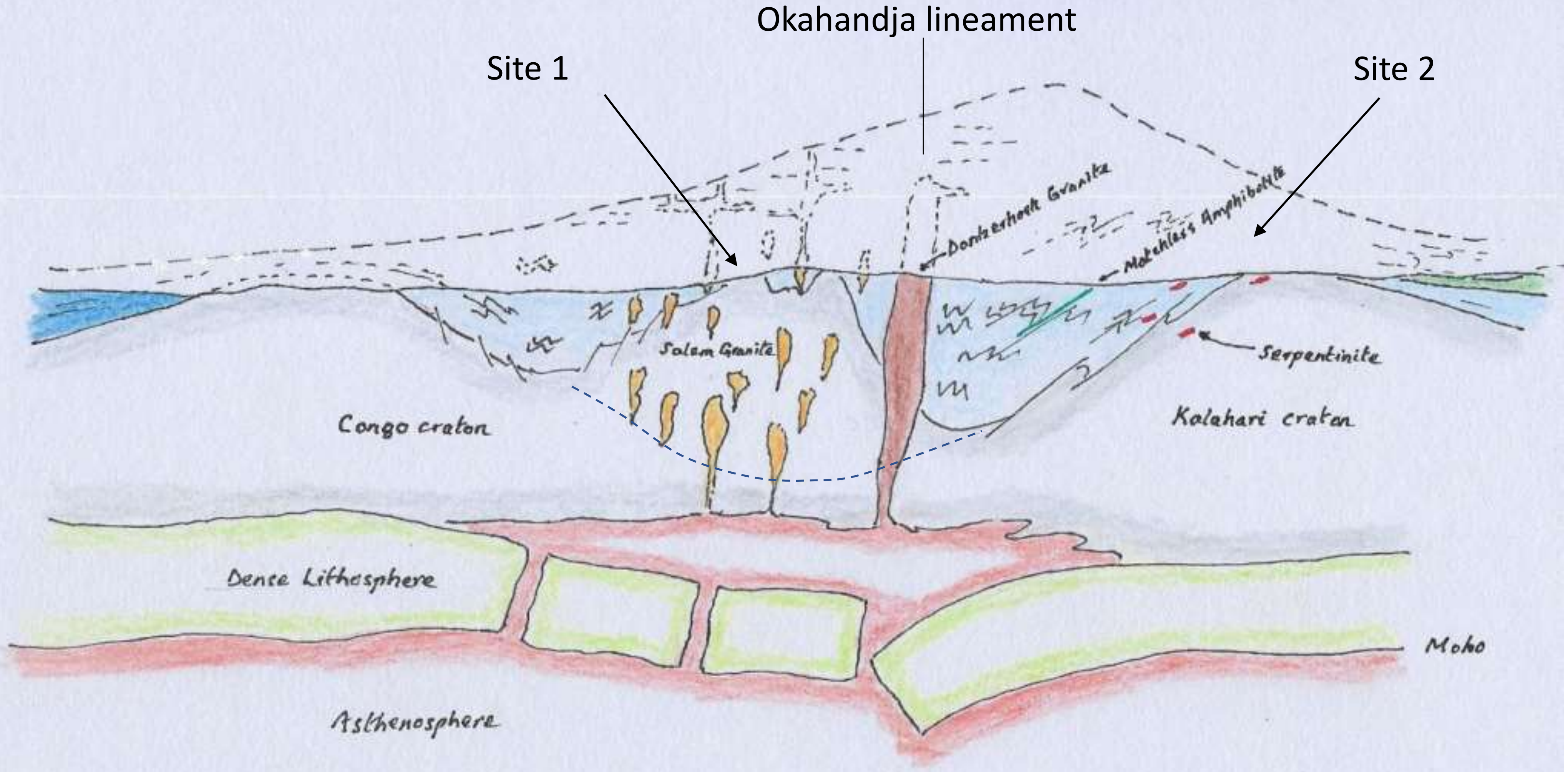
(are the interference folds the higher crustal expression of shear zones at depth?)

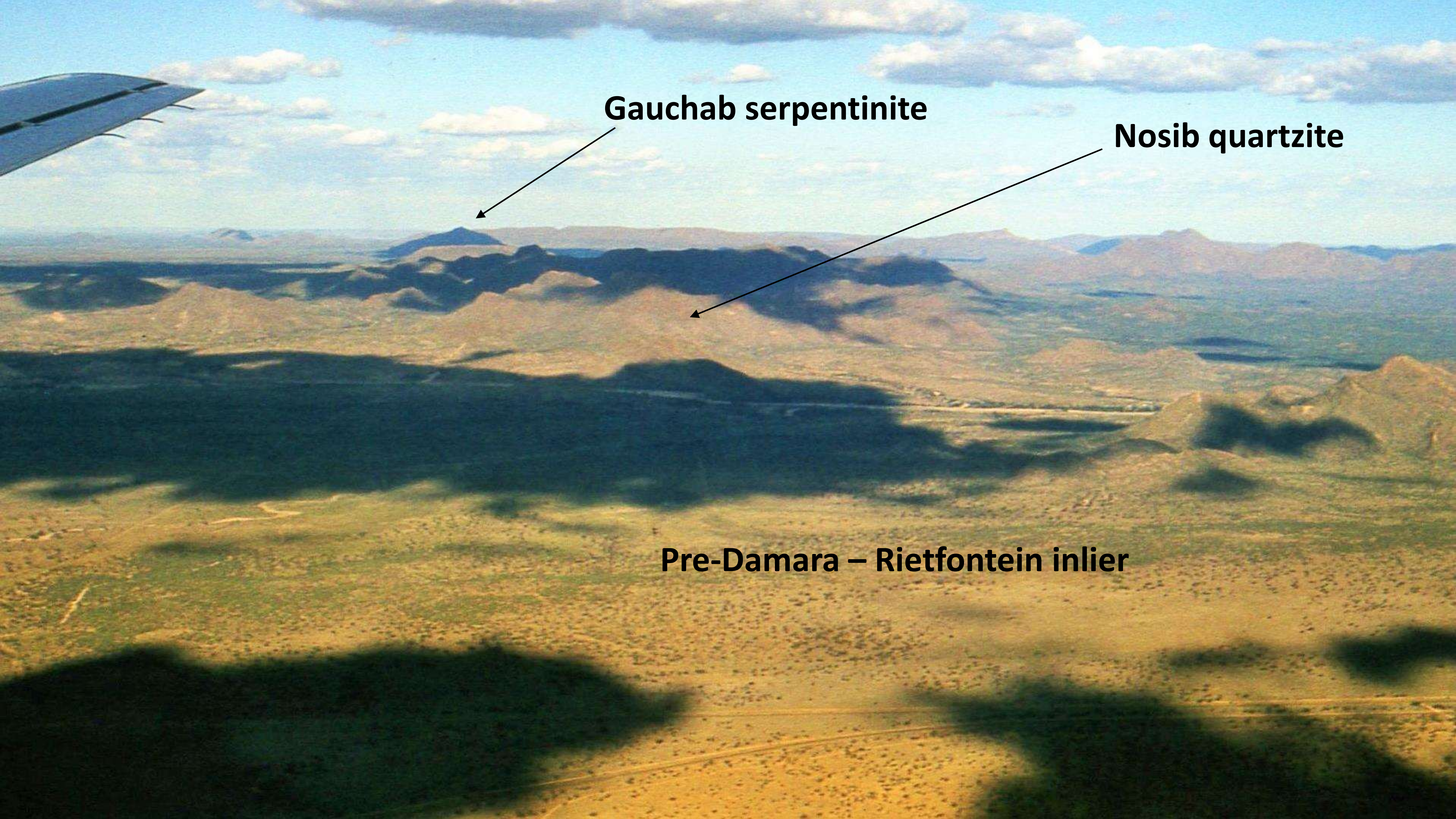




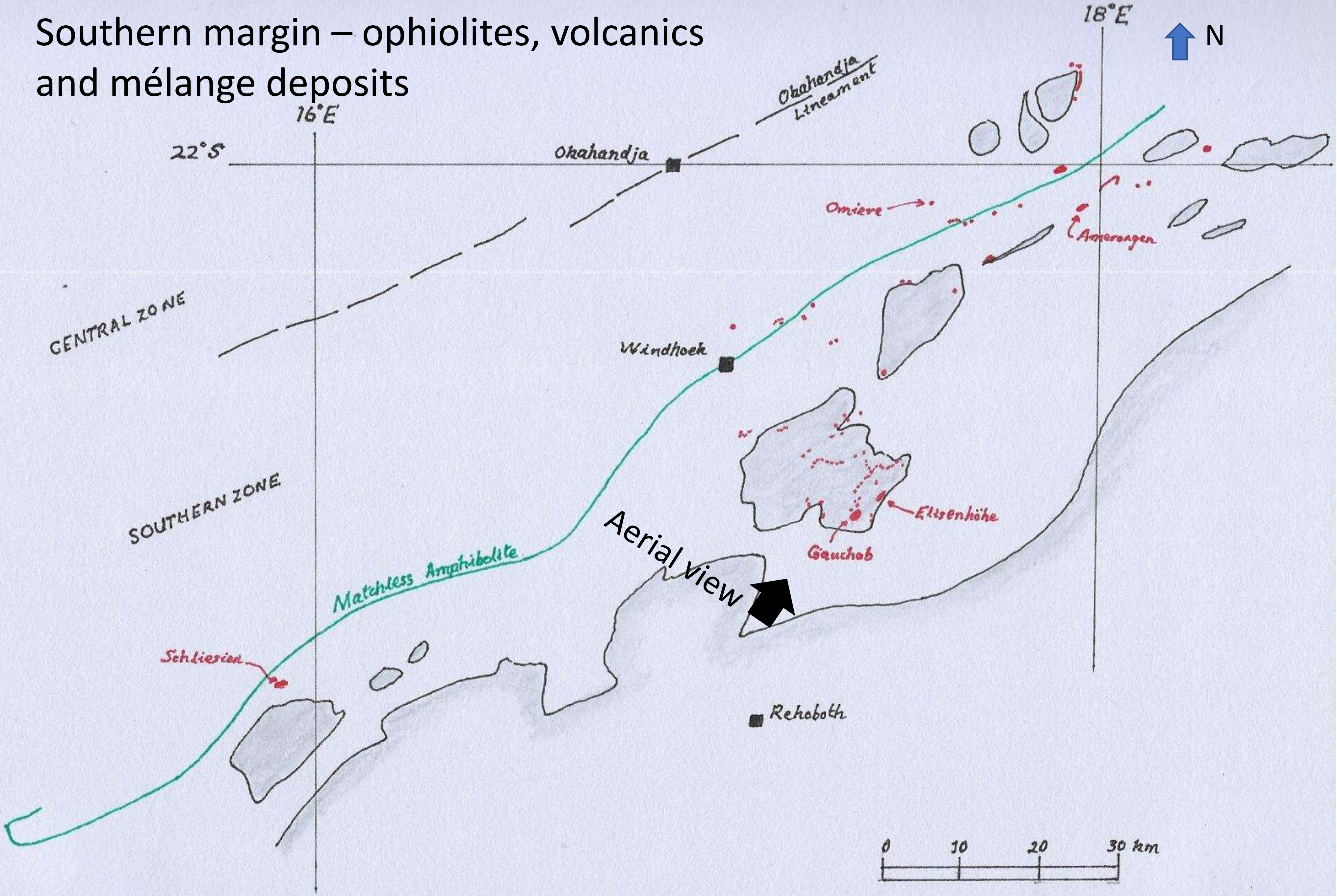
- But reversal of vertical movement needed to explain graben to horst transition

Section through the Damara according to intracratonic aulacogen theory




Gauchab serpentinite
Nosib quartzite
Pre-Damara – Rietfontein inlier

Southern margin – ophiolites, volcanics and mélange deposits



Process of interpretation[1]

Data collation
Field mapping, sampling

Analysis
Mineralogy and petrography, XRF

Classification
T-tests, principal component analysis, cluster analysis, multiple discriminant analysis, variance

Mineral reactions

- Harzburgite + H_2O = hobnail serpentinite + magnetite
- Hobnail serpentinite + quartz = talc schist + H_2O
- Spinel harzburgite + H_2O = chlorite schist
- Lherzolite + H_2O = CPX bearing serpentinite = amphibole fels

PCA

- The parent rock of serpentinite can be determined from the chemistry.
- Samples are largely Alpine (93 per cent) and usually depleted (83 per cent).
- Bodies in pre-Damara rock have a wider spread than those in Damara rock.

Origin of serpentinites

- Originally depleted mantle rock
- Low grade metamorphism at spreading stage
- Cold emplacement with thrust tectonics
- Higher temperatures cause further dehydration reactions

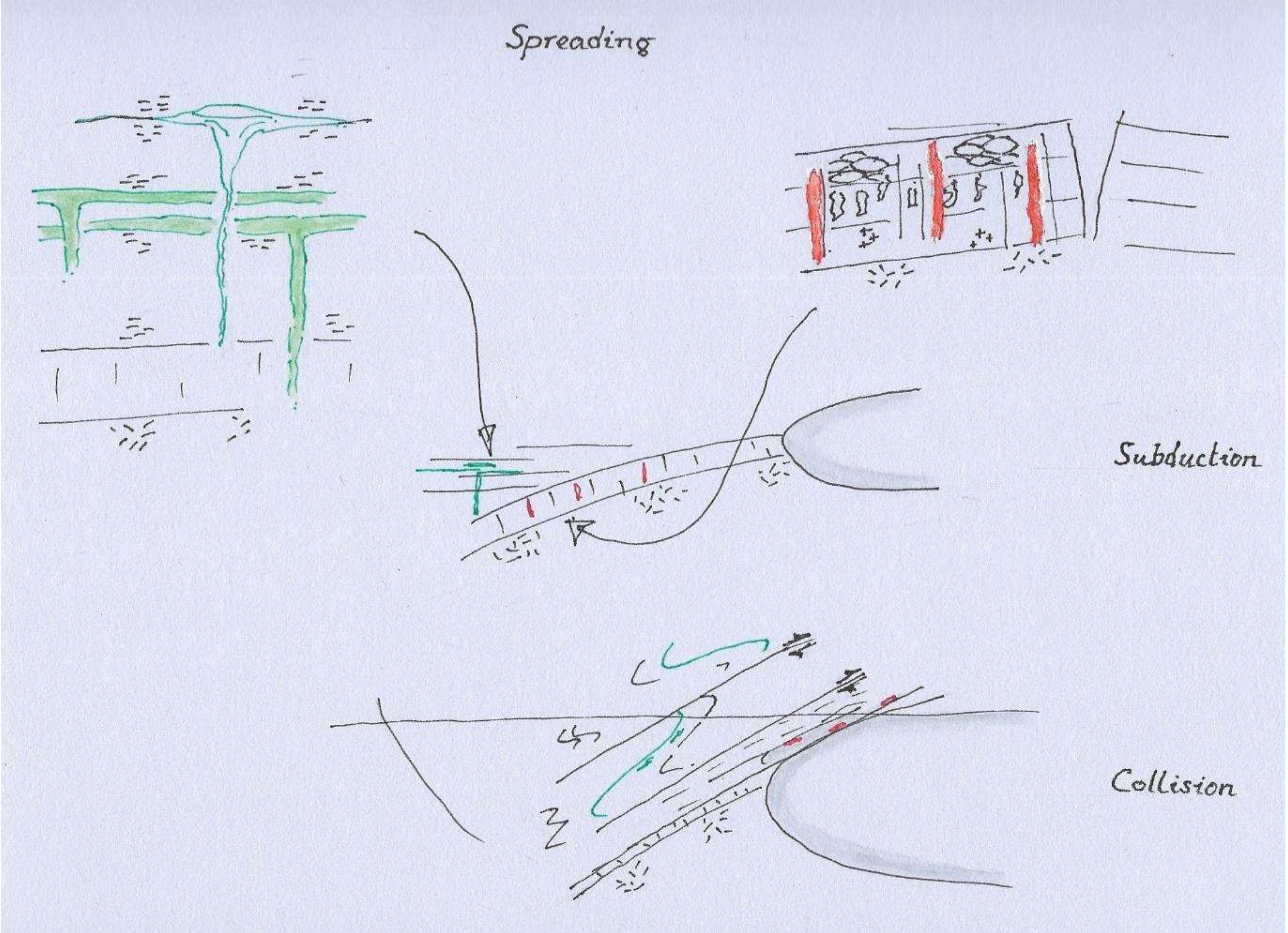
[1]Barnes, 1980

Matchless amphibolite – MORB geochemistry

Schist sequence – turbidites – associated with Matchless amphibolite

Pale hyaloclastic layers in between possible pillow lavas in fine grained amphibolite

Southern zone – an interpretation



Intense shearing in Kuiseb schist

Disrupted quartz veins and fold closures
in strong transposition cleavage

Metamorphism[1]

- Fe-garnet+Mg-biotite = Mg-garnet+Fe-biotite
- Almandine+muscovite = annite+2kyanite+quartz
- T° = 575°C and P=6.3 kbar (630MPa or c22km cover)

[1]Barnes, 1980

Auas quartzite

Thrust contact between Auaus quartzite on the mountain range and underlying Pre-Damara basement in foreground

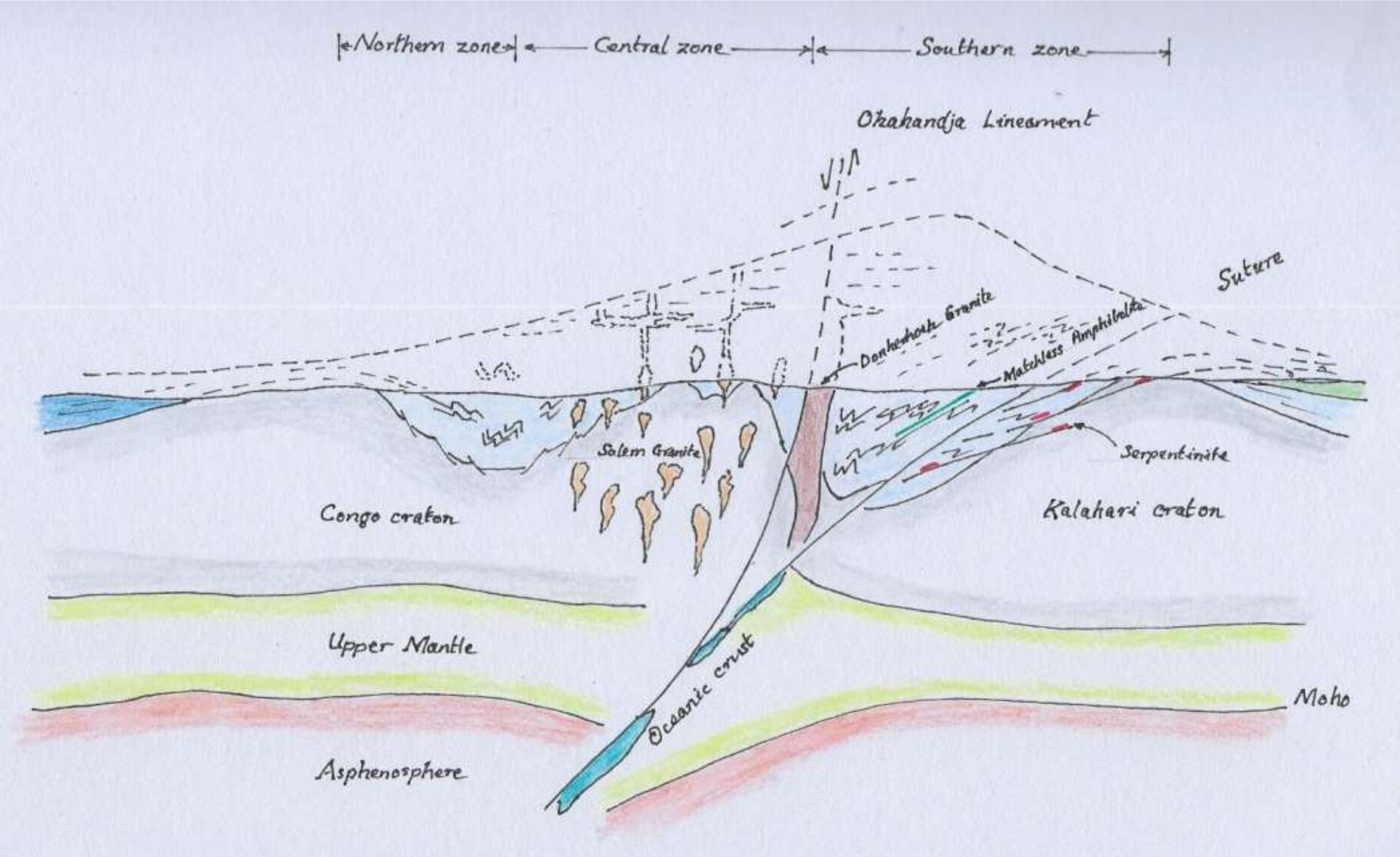
Hakos quartzite

Large scale Type 3 refolded fold closure marks the NE limit of a major quartzite horizon in the lower part of the Damara

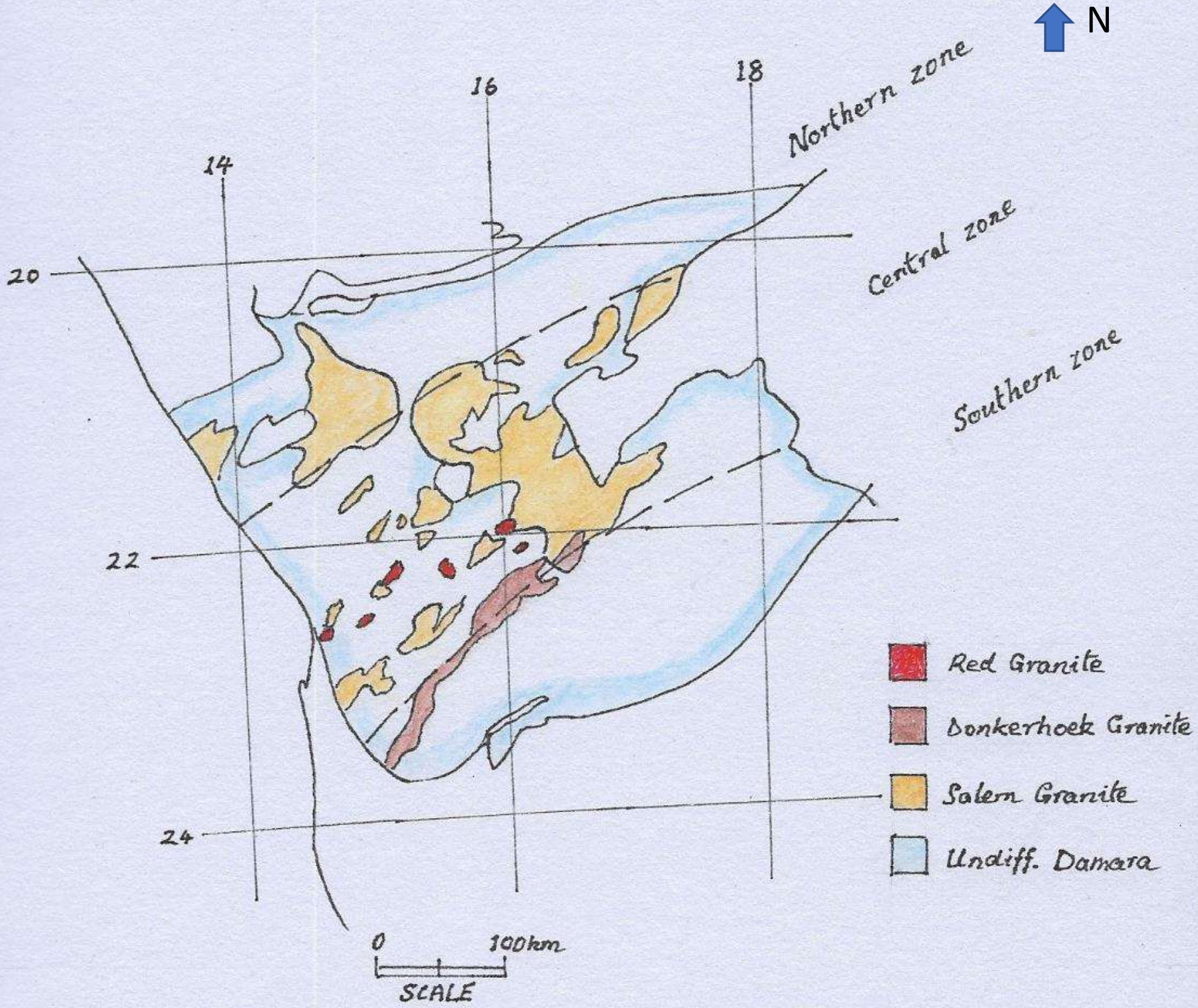
Ophiolites, volcanics, mélange deposits, suture zone

- Evidence is strong for oceanic crust but no typical ophiolites or mélange deposits
- Intracratonic theories cannot easily explain serpentinites
- MORB volcanics – the Matchless amphibolite, further evidence for oceanic crust
- Evidence for collision tectonics – shearing, sheath folds and thrusts
- Cryptic suture zone

Section through the Damara according to wide ocean plate tectonic model

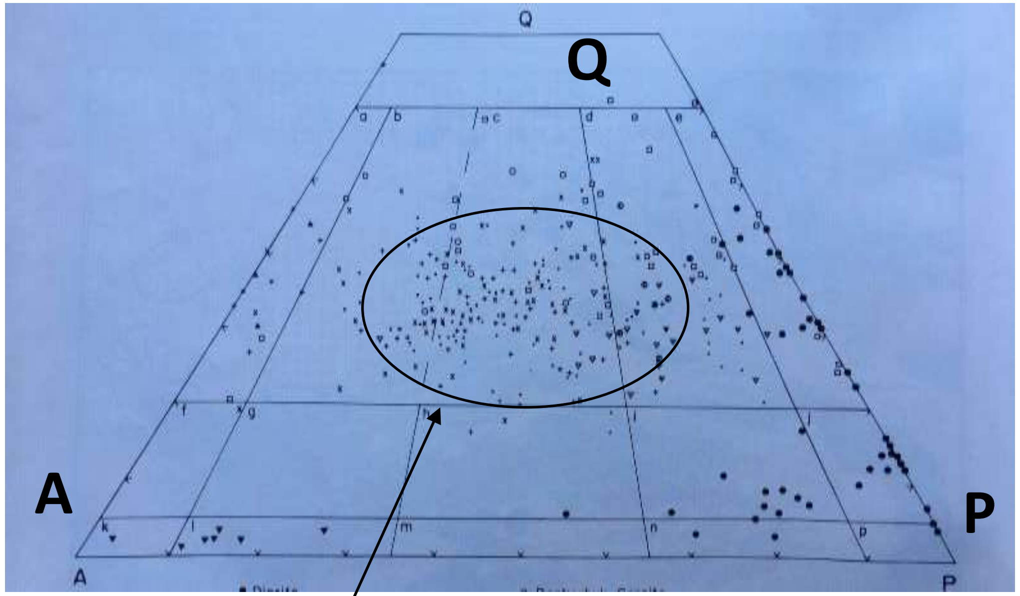


Batholiths



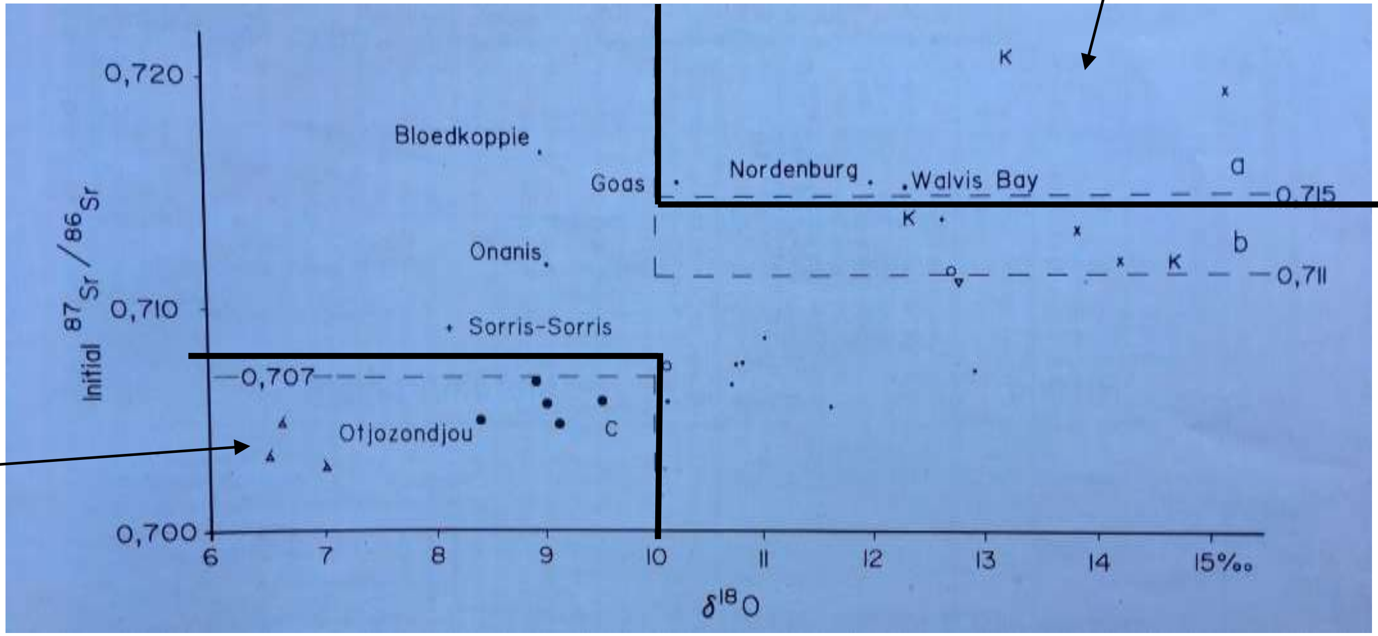
N
Northern zone
Central zone
Southern zone
14
16
18
20
22
24
Red Granite
Donkerhoek Granite
Salem Granite
Undiff. Damara
0
100km
SCALE

Mineralogy and geochemistry of Damara granites[1]



Typical Damara granites fall in 'granite/granodiorite' field of QAP ternary diagram

S-type granites
(Salem, red granite)



I-type granites
(Donkerhoek)

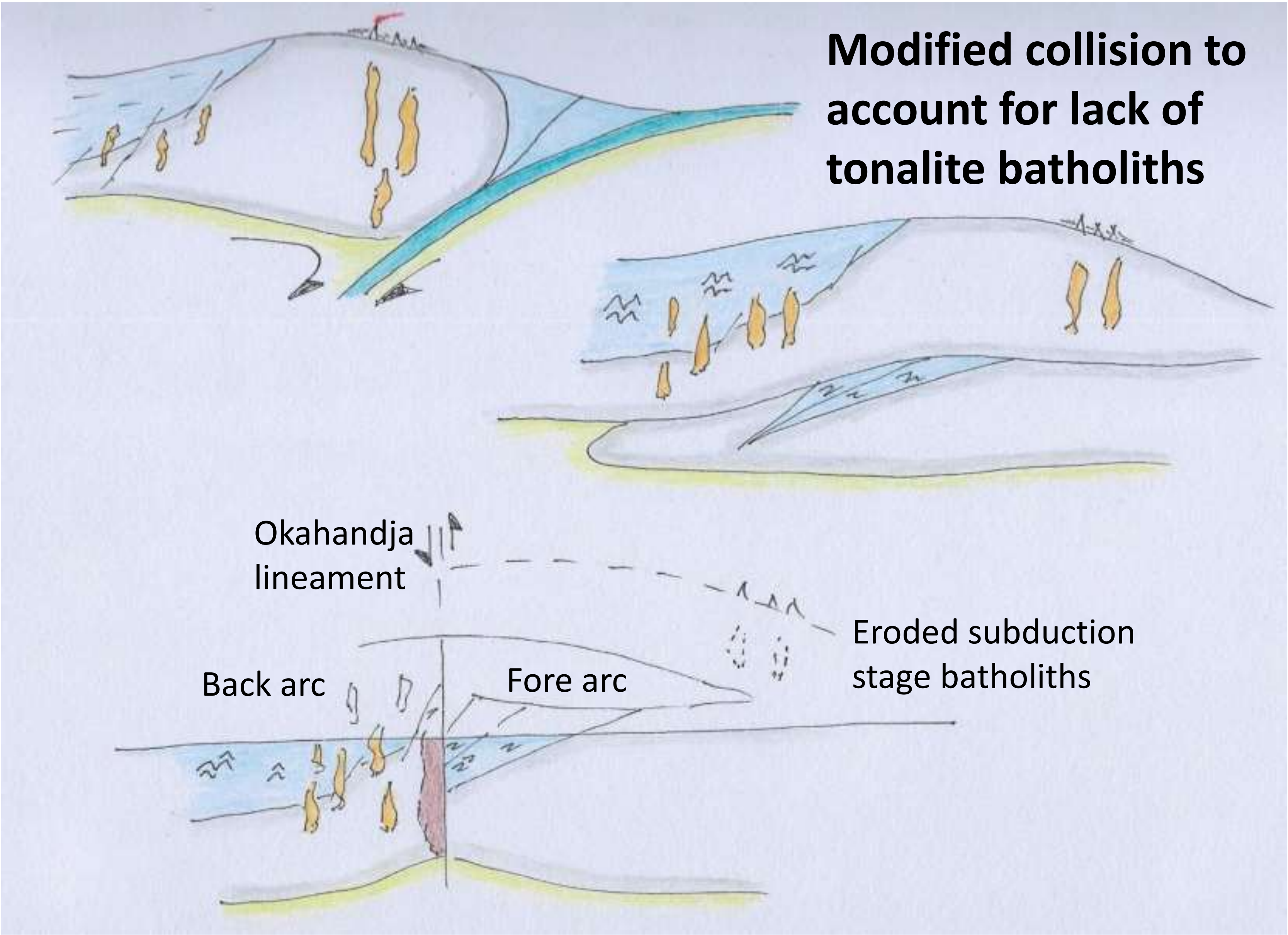
[1]Miller, 1983

Batholiths

- Lack of tonalites (plutonic equivalent of andesite volcanics)
- Crustal signature for Salem suite
- Mantle signature for Donkerhoek granite

Modified collision to account for lack of tonalite batholiths

Barnes-Sawyer model at subduction stage



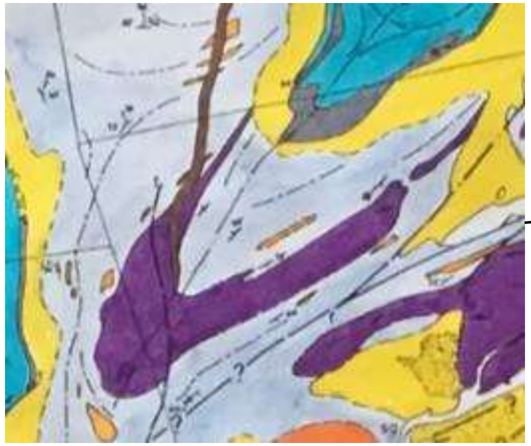
Modified Barnes-Sawyer model at collision stage

Peneplanation stage

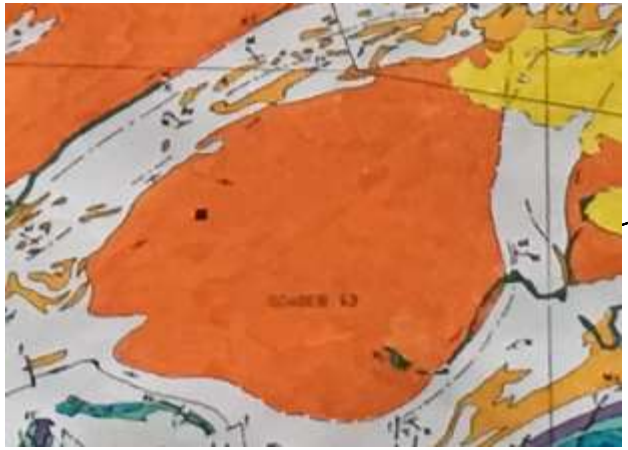
‘The intriguing implication is that the 2.0Ga rocks of the upper Damara basement are underlain by significantly younger continental crust.’
Hawksworth and Marlow, 1983

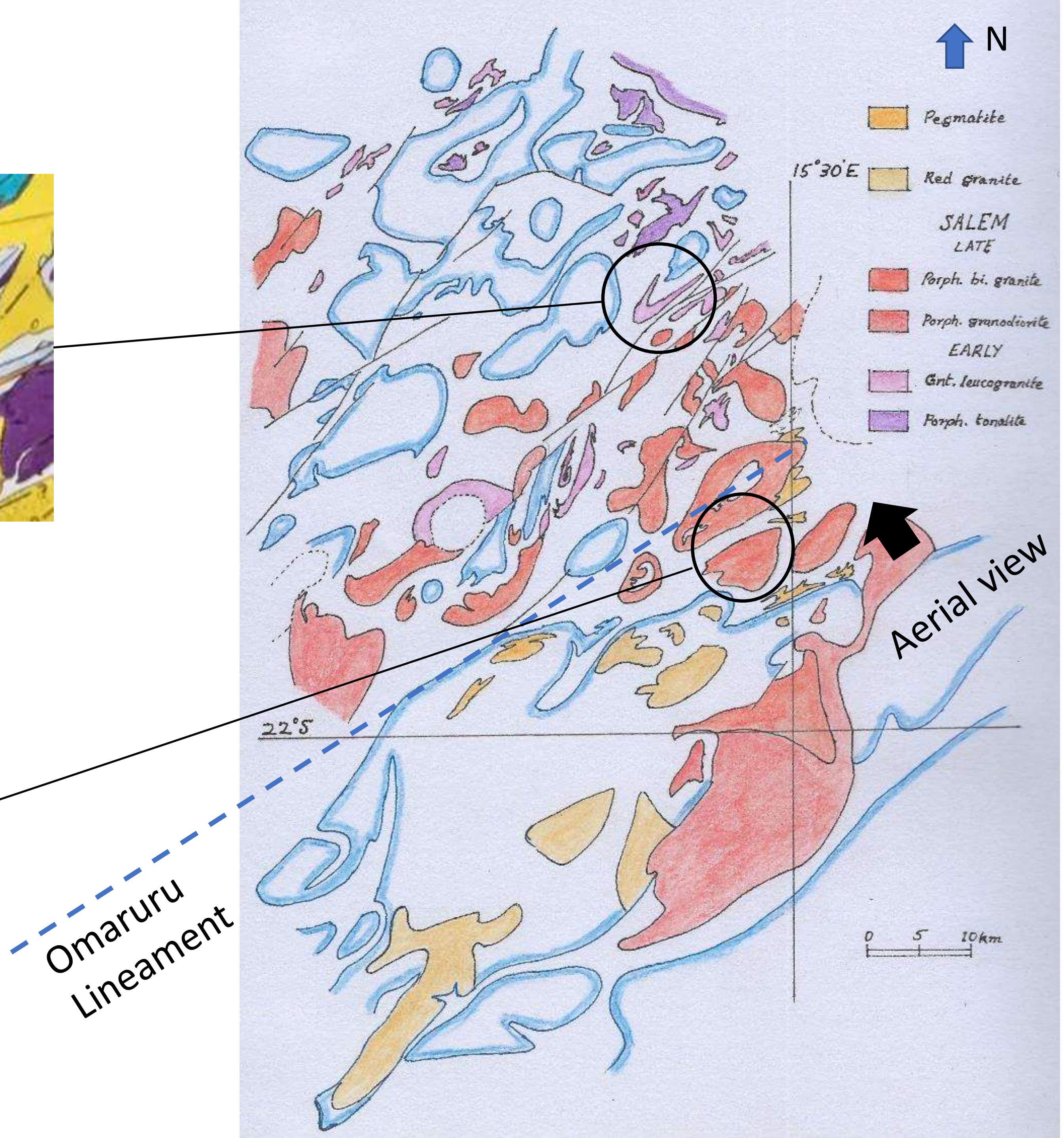
Central zone granites

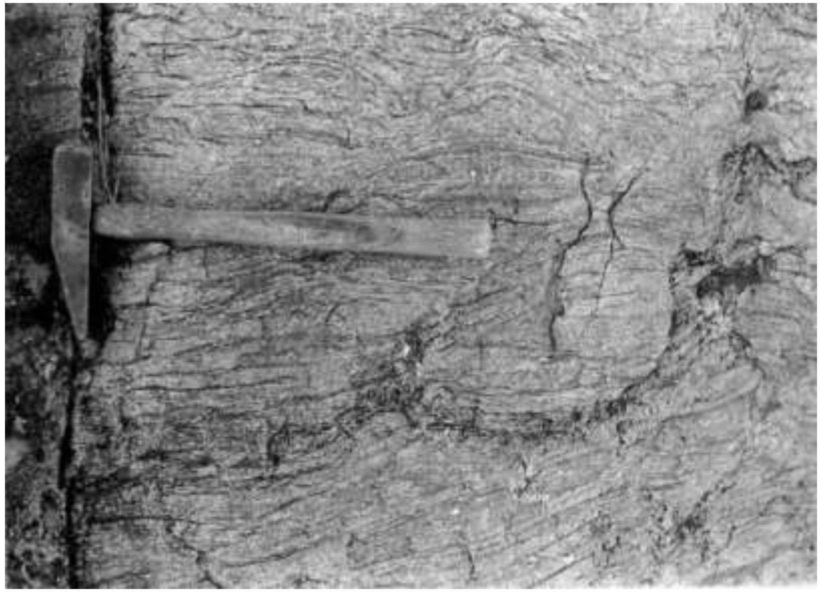
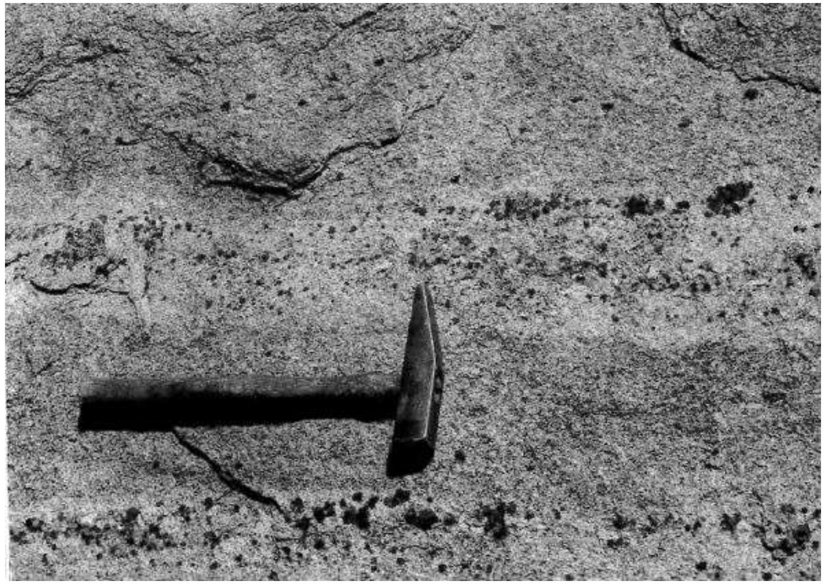
Early granites folded around dome structure



Late granite intrusion in Kuiseb schist

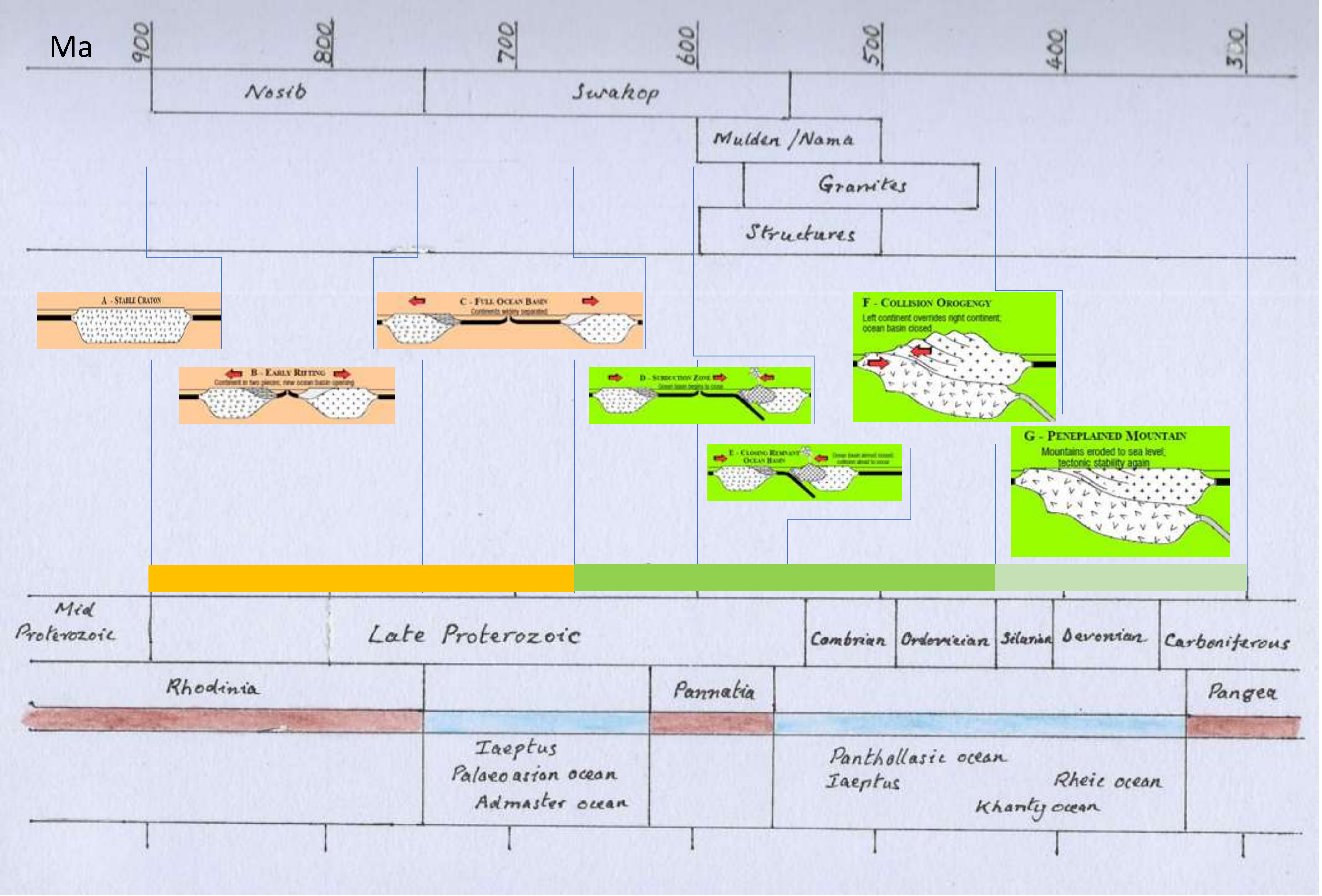




	Leucogranite	Granodiorite – tonalite
Early		
Late		

Summary

- 1970s research programmes – outcomes published in 1983
  - Plate tectonics supersedes geosynclinal theory
  - Different geodynamic models – fixism (vertical) and mobilism (horizontal)
- Law of superposition and the interpretation of structures
- The present is the key to the past – but should we worry if it’s not exactly the same?
- The Wilson Cycle – a useful framework for analysis and interpretation of a complex problem
- Some casual observations
  - Centre zone back arc developed separately from Southern zone forearc / passive margin sediments
  - Sheath folds at depth are separated from interference folds by Rossing marble décollement
  - Additional collision movement accounts for lack of tonalites , youthful isotope signature of granite intrusions, juxtaposition of back arc and forearc, early and late granites



Ma
900
800
700
600
500
400
300
Nosib
Swakop
Mulden /Nama
Granites
Structures
A - STABLE CRATON
B - EARLY RIFTING
C - FULL OCEAN BASIN
D - SUBDUCTION ZONE
E - CLOSING REMNANT OCEAN BASIN
F - COLLISION OROGENY
Left continent overrides right continent; ocean basin closed
G - PENEPLAINED MOUNTAIN
Mountains eroded to sea level; tectonic stability again
Mid Proterozoic
Late Proterozoic
Cambrian
Ordovician
Silurian
Devonian
Carboniferous
Rhodinia
Pannatia
Pangea
Iaeptus
Palaeoasian ocean
Admaster ocean
Panthollasic ocean
Iaeptus
Rheic ocean
Khanty ocean