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Namibia onshore Hydrocarbon Prospectivity

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Purpose of Talk

1. Overview of Namibian Onshore Basins
2. New encouraging insights
3. How and why to Explore

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Namibia

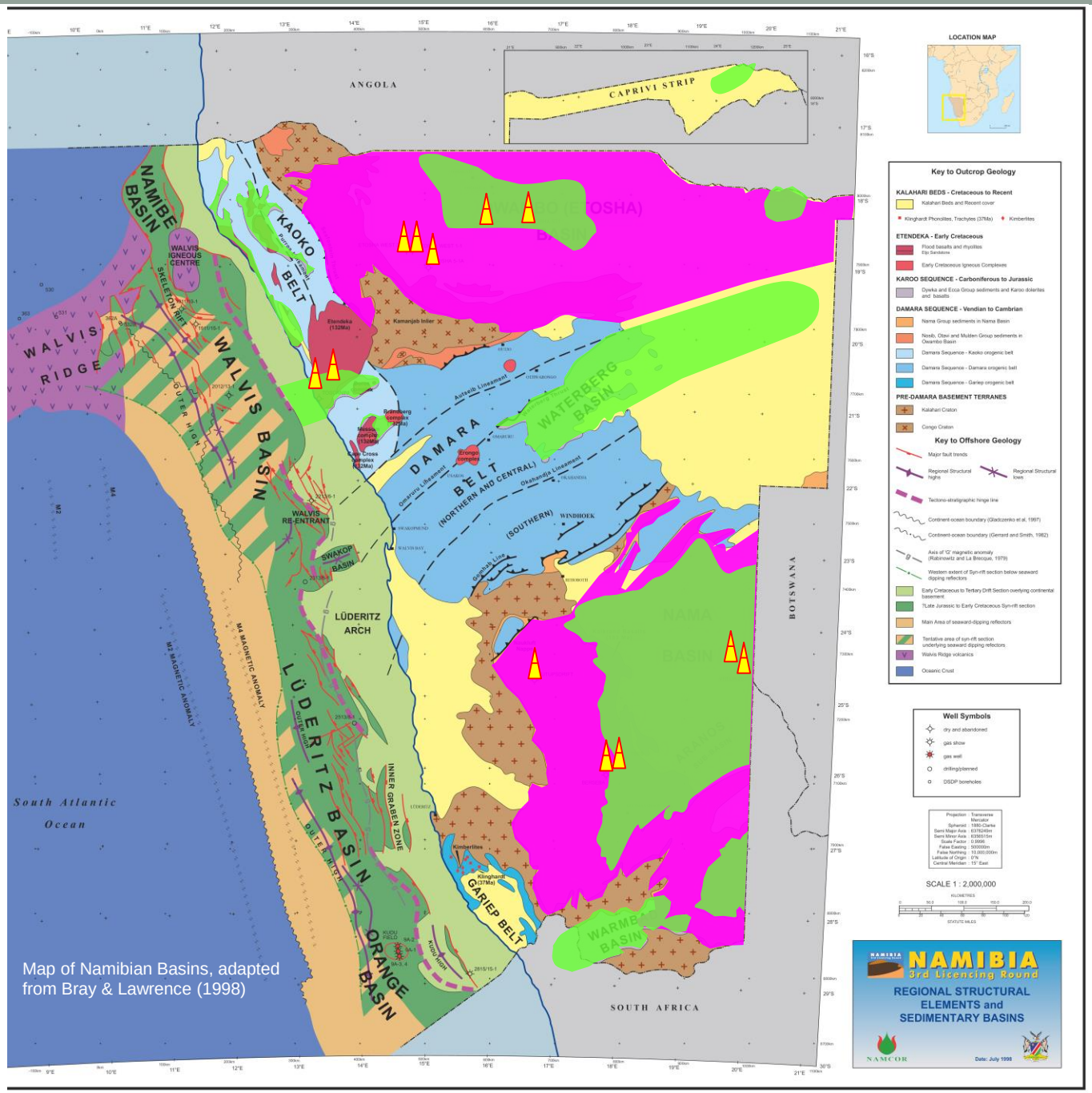
825 419 km^2

Two groups of onshore basins:

1. Neoproterozoic-Early Cambrian rift-foreland basins
2. Karoo (rift) basins (Upper Carboniferous – Jurassic)

Onshore basins cover some 350 000km^2 > 40% of the country

12 onshore wells with TD between 600-2500m

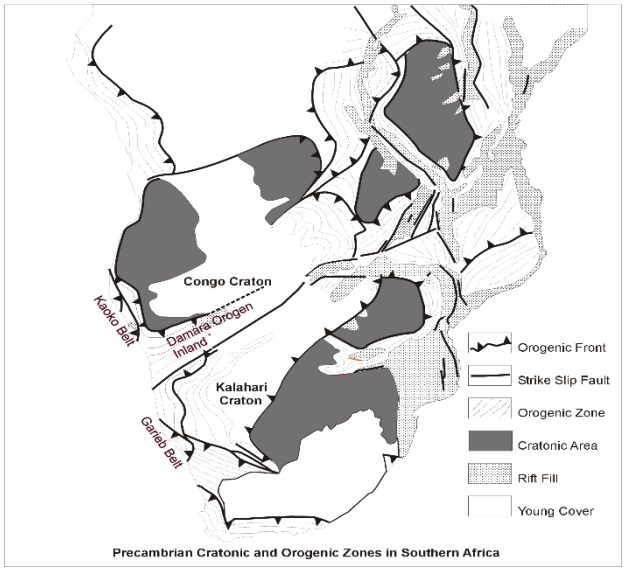


Map of Namibian Basins, adapted from Bray & Lawrence (1998)

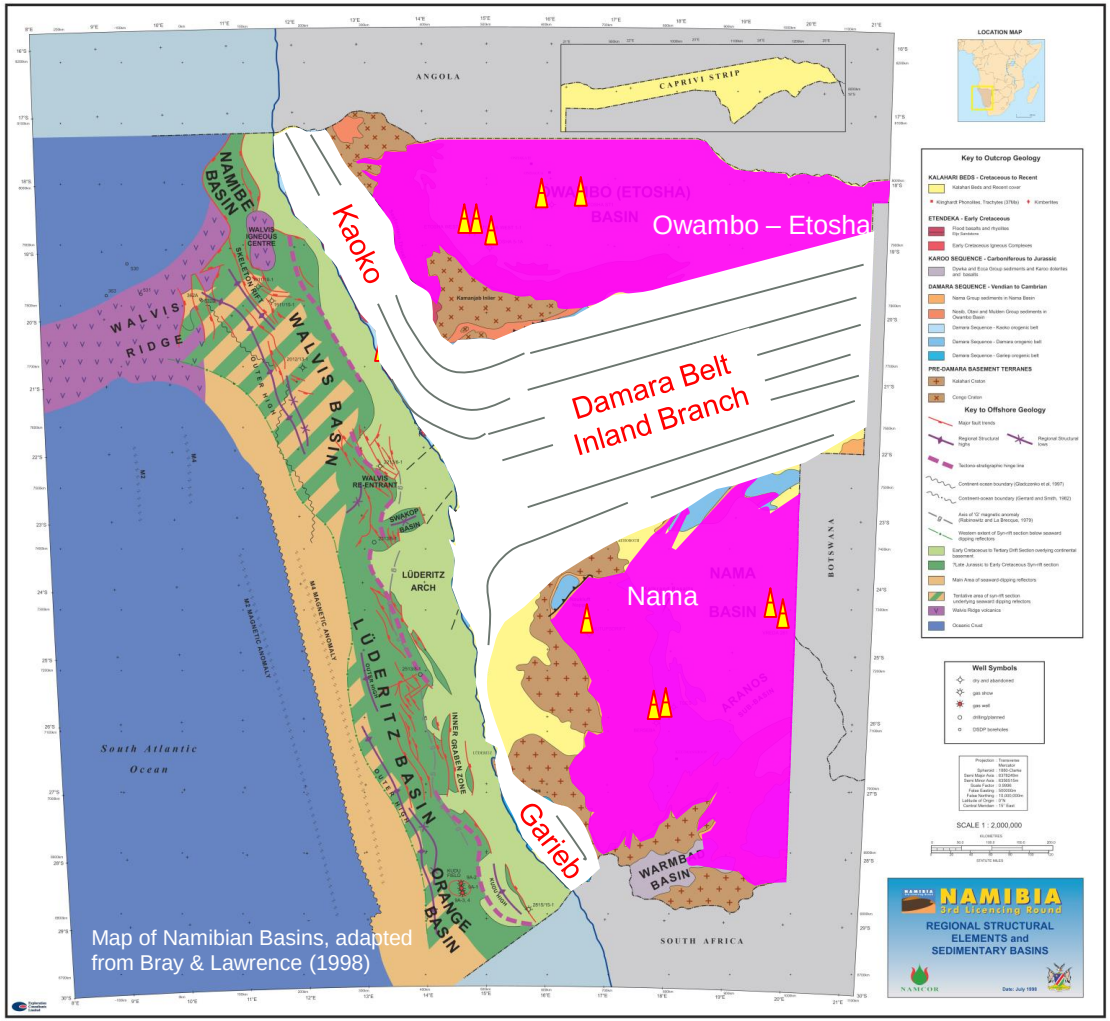
Neoproterozoic / Early Cambrian Basins

1: Owambo-Etosha Basin
2: Nama Basin

- Basins are bordered by early Cambrian Orogenic Belts
- Rift, Platform and Molasse deposits
- Foreland Basin architecture
- Partly covered by Karoo succession
- Largely covered by a veneer of Cainozoic sediments

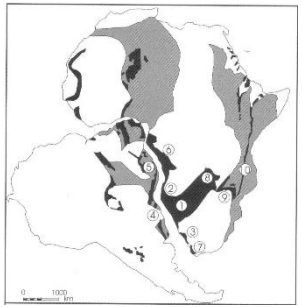


Precambrian Cratonic and Orogenic Zones in Southern Africa



Map of Namibian Basins, adapted from Bray & Lawrence (1998)

Distribution of Pan-African Belts in Africa and adjoining parts of South America
Cahen & Snelling (1966)
Martin & Porada (1977)
Norton & Sclater (1979)



Extent of Cainozoic Kalahari Cover excluding the Namib
Haddon & McCarthy (2005)

Owambo Basin

Vintage Exploration

- Seismic campaigns 1969-1995
- 12 wells of which 5 HC exploration wells (1964-1986)

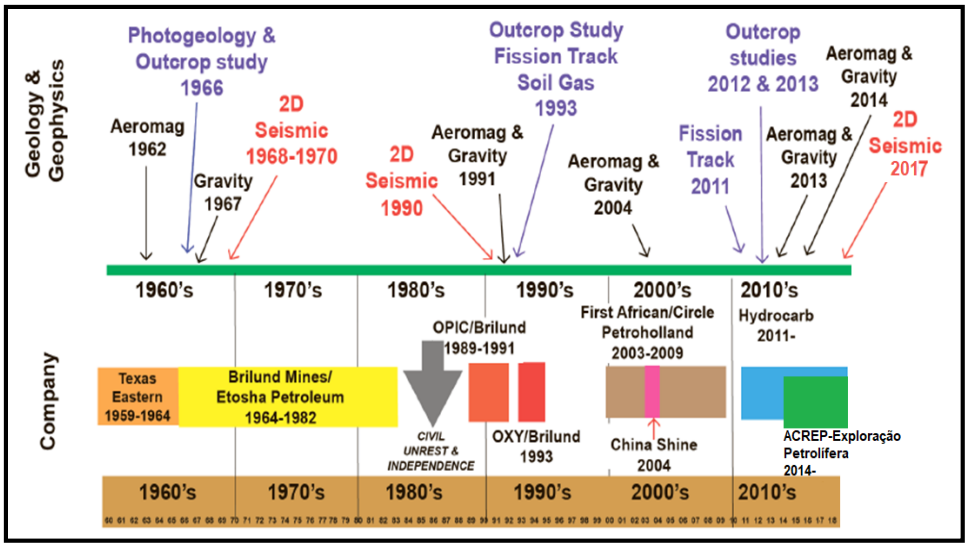
Exploration from 2000

- Four aerial surveys (mag/gravity) (2004, 11, 13, 14)
- Soil gas sampling north and east of Etosha (2012)
- 120km 2D test lines (2017)
- Airbus remote sensing study (2018)
- Passive seismic (2018)

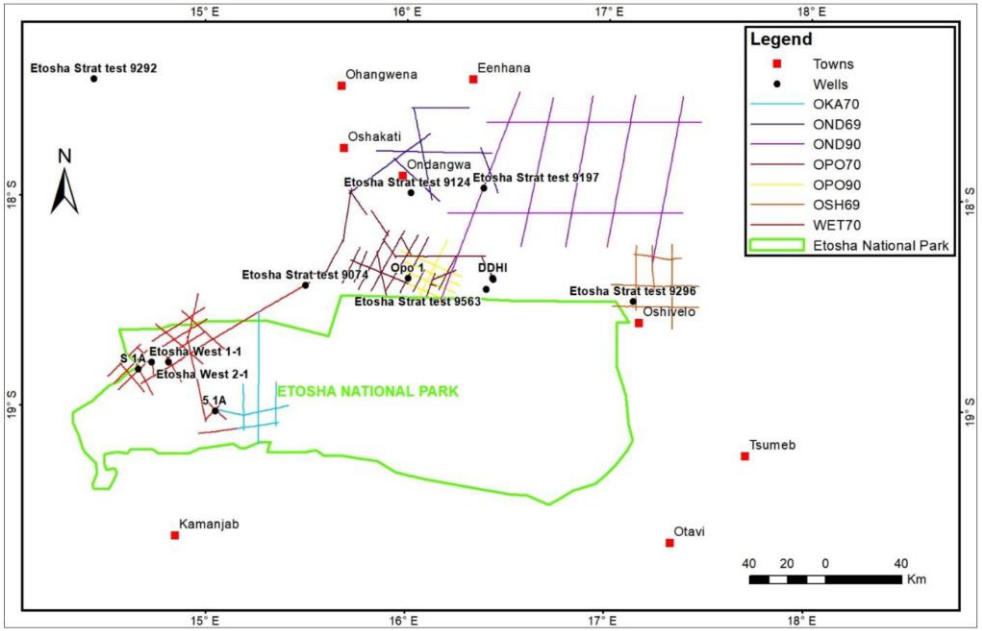
Findings

- Delineation of depocenters mature fairways
- Anticlinal and roll over traps towards basin margin
- Carbonate built-ups as potential reservoirs
- MOST RECENT: Intriguing correlation of aeromagnetic defined anticline structures, soil gas HCs, and passive seismic for DHSs

Well	Year	Operator	TD (m)	Well Result
ST-1	1964	Texas Eastern	1875	Dry Hole
Etosha 1-1	1970	Brilund	1584	Dry Hole
Etosha 2-1	1970	Brilund	1228	Dry Hole
Etosha 5-1A	1970	Brilund	2509	Oil shows
OPO-1	1986	OPIC	700	Dry Hole



Summary of exploration history in the Owambo Basin until 2017. Modified from Hoak et al. (2014)



Seismic 2D Surveys from 1969-1995 and exploration wells 1964-1986)

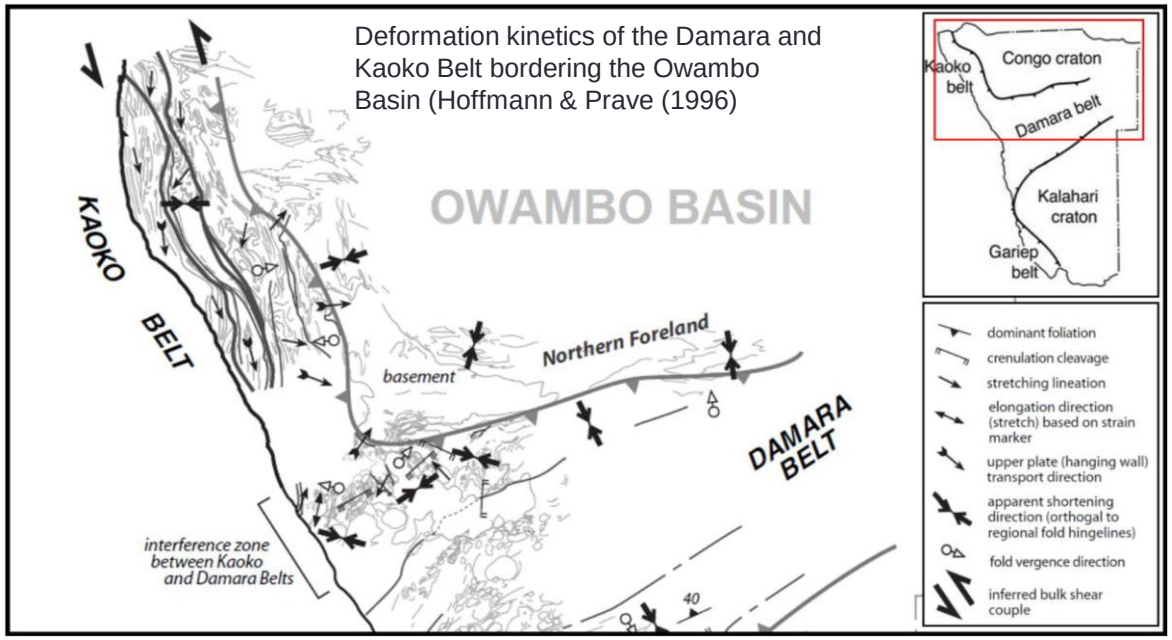
Owambo Basin Geology

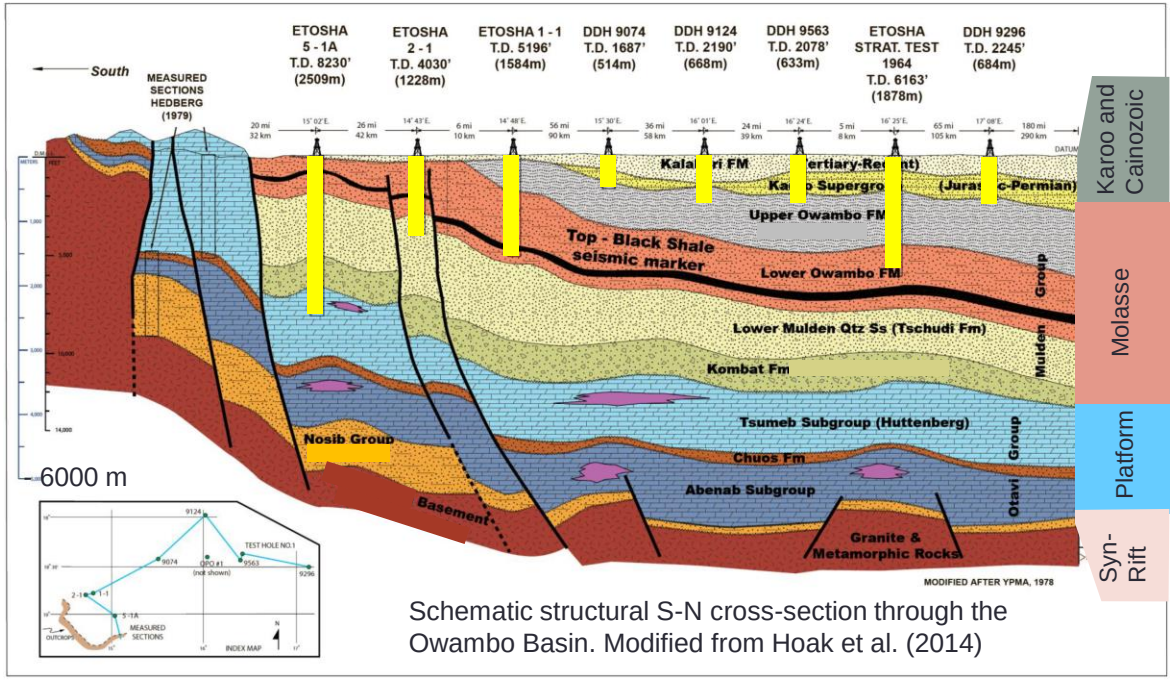
Tectonostratigraphy

- Syn-rift followed by passive margin platform deposition, followed by retroarc foreland basin formation with molasse deposition during Damara (pan-African) orogeny
- Neoproterozoic to early Cambrian deposition
- Compression during Cambrian with minor Phanerozoic reactivation events

Wells

- Three wells pass through Black Shale marker (2.8% TOC)
- Only one exploration well reaches top of platform sequence at TD 2509m
  - Two deeper source rock levels expected, better chance of maturity
- Sandstones of good RQ and fractured carbonates intersected (<15% porosity)
- HC show in one well



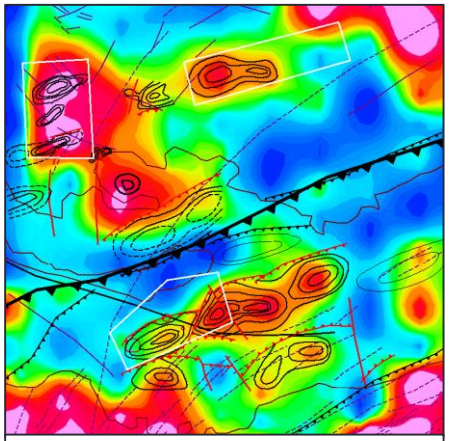


Schematic structural S-N cross-section through the Owambo Basin. Modified from Hoak et al. (2014)

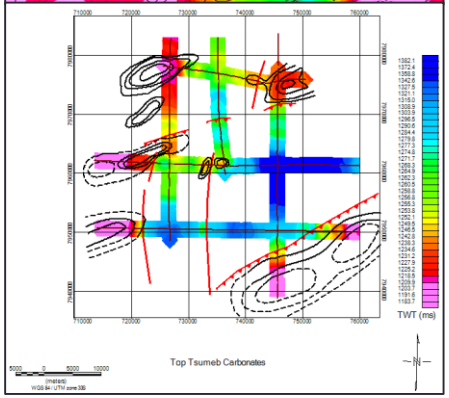
Recent Findings

Structural Modelling

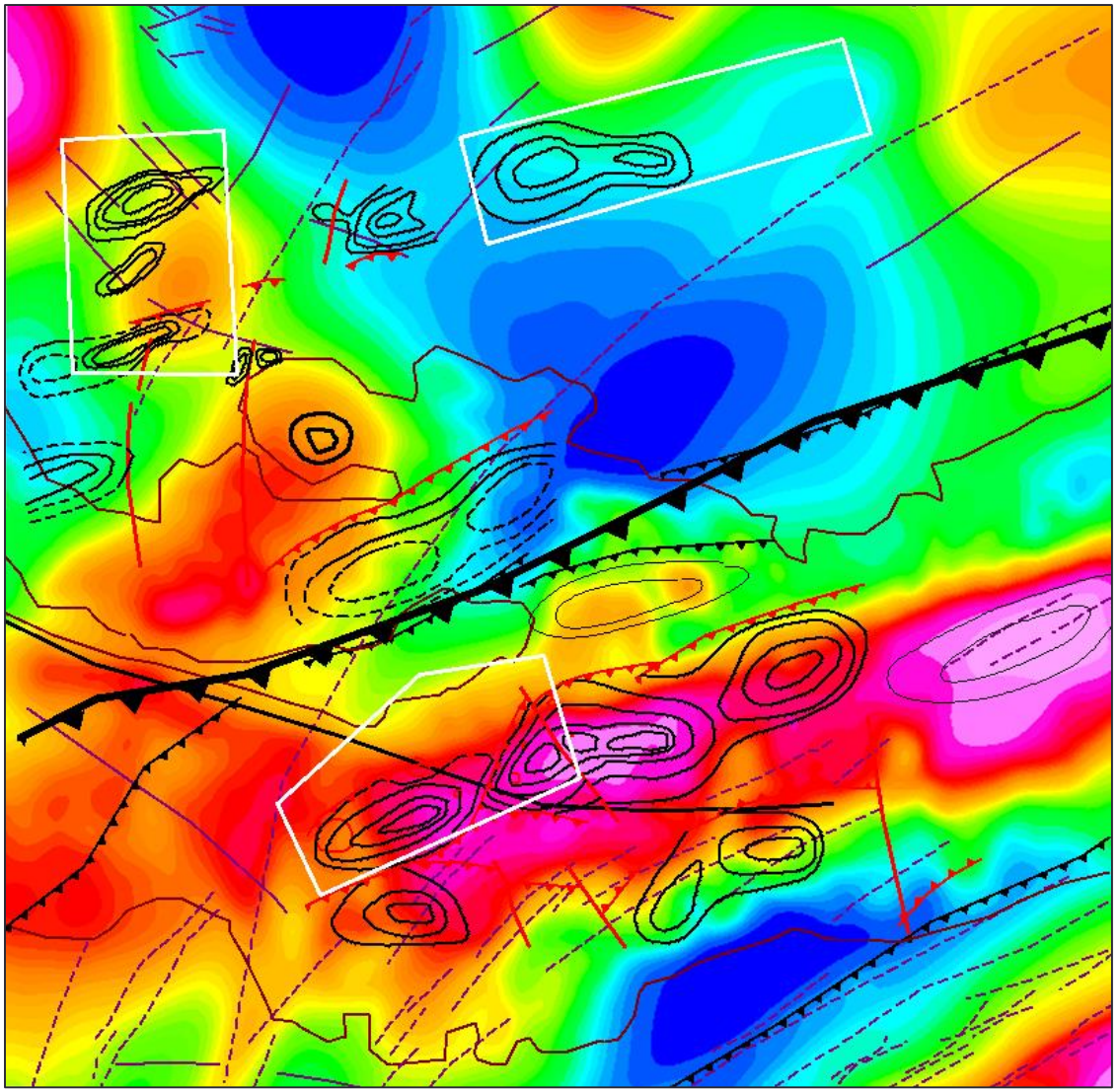
- Structures modelled with magnetic-gravity near basin margin
- Reveals foldbelt with larger anticlines
- Consistent with seismic



Gravimetric structural interpretation coincides largely with magnetic interpretation



Widely spaced 2D seismic showing shallow top platform carbonates (red) coinciding with anticlines deduced from gravity-magnetics



Aeromagnetic structural interpretation of the southern Owambo Basin. High frequency have been filtered using upward continuation from 2000m, reduced to pole. White frames show passive seismic surveys

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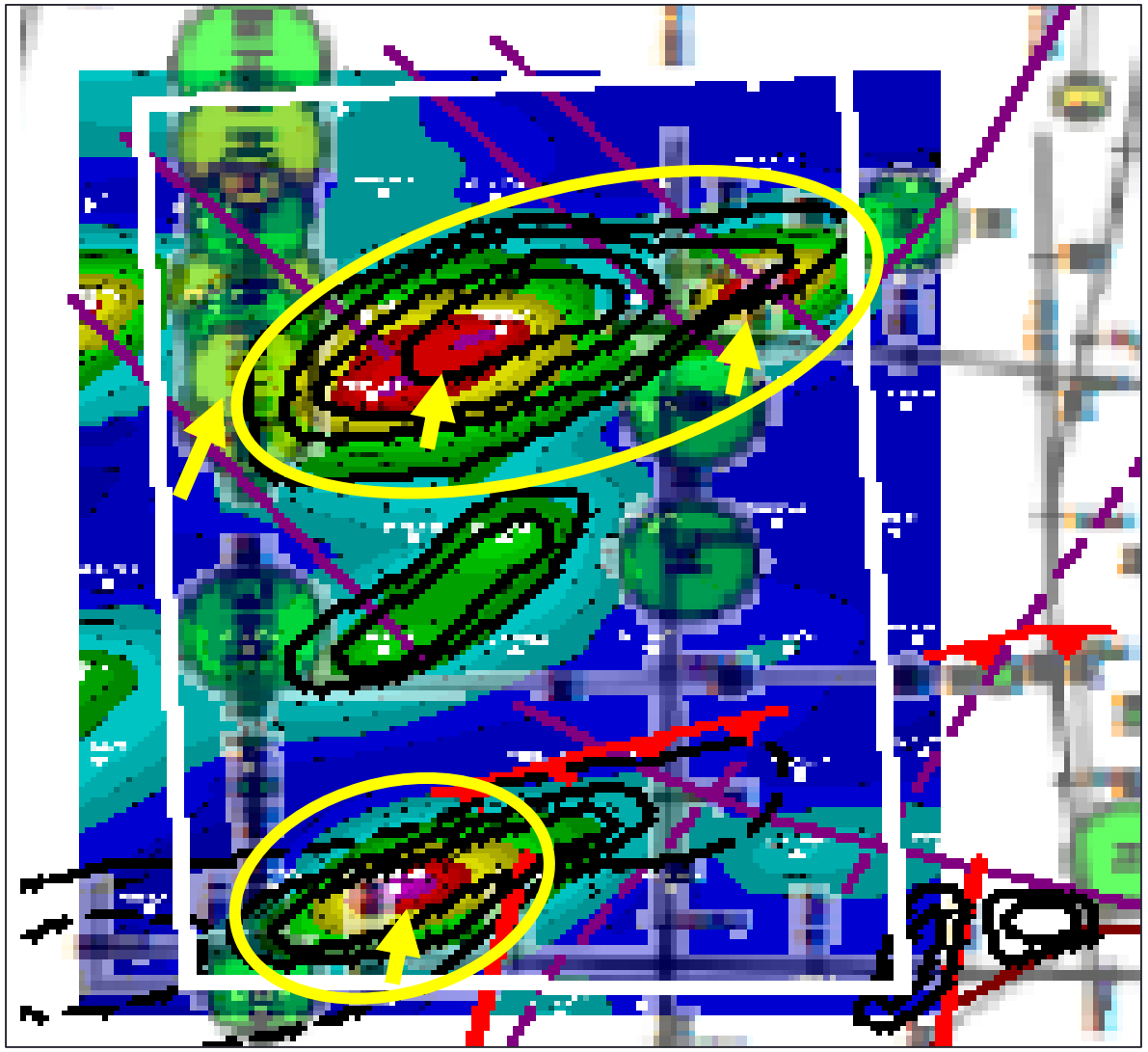
Recent Findings

Hydrocarbon Indicators

- Soil gas samples indicate oil rather gas origin
- Passive seismic as well as soil gas maxima (ethane as proxy) coincide largely with anticlinal crests

Passive Seismic Theory
Resonance effects in HC saturated media cause amplification of low frequencies (2-8 Hz)
Low frequencies are ubiquitous, some derive from ocean surf



Combined structural interpretation (based on magnetic gravity and widely spaced vintage 2D seismic), soil gas concentrations, and passive seismic amplitude.
Red areas: positive passive seismic amplitude anomaly interpreted as DHI
Green circles: low to moderate soil gas
Yellow circles: moderate to high soil gas

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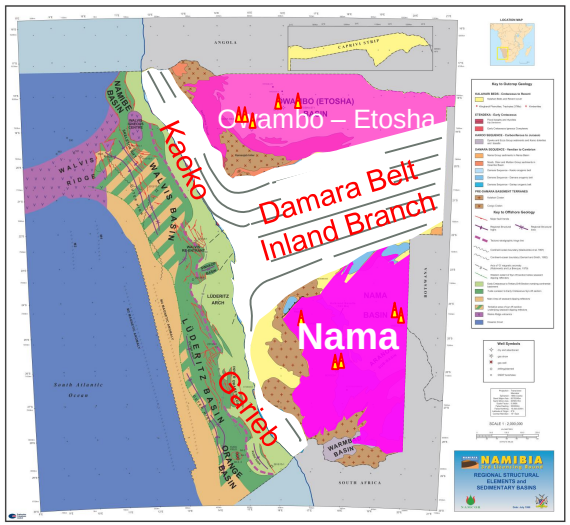
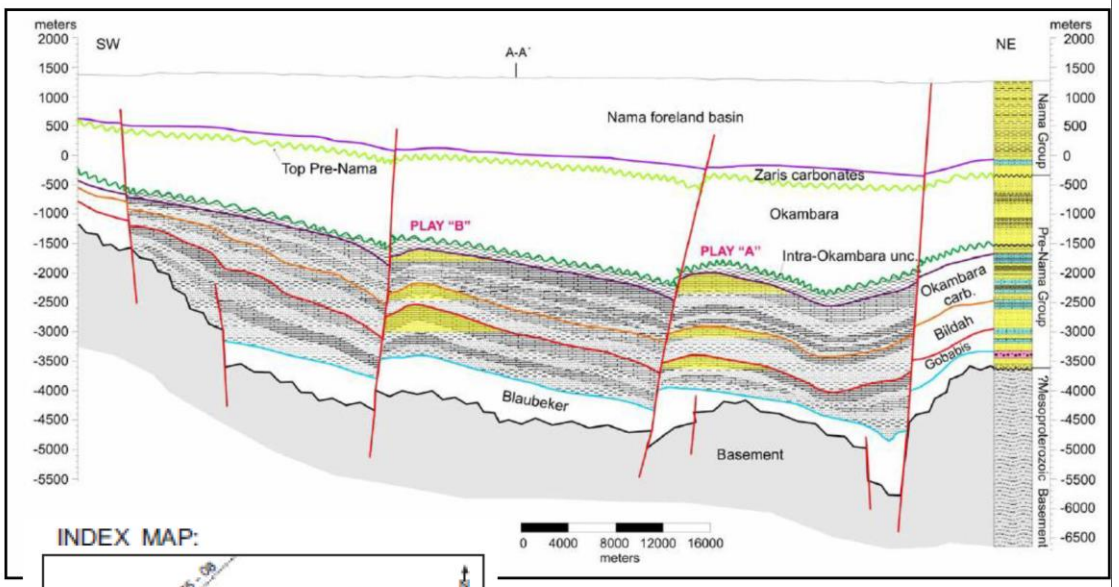
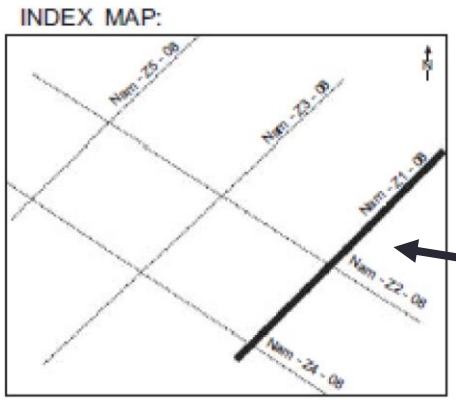
Nama Basin

- Geologically roughly the southern counterpart to the Owambo Basin
  - Less knowledge on deeper parts of the basin
- Long exploration history inspired by surface oil shows
- 5 wells drilled (1928, 63, 68, 92), all <2300m TD
- Aeromagnetic (1992)
- 360 km vintage 2D seismic (1968)
- 500 km 2D (2008)
  - Indicates an at least 7km deep basin containing three megasequences
- Geochemical studies on oil shows (Summons et al., 2007)

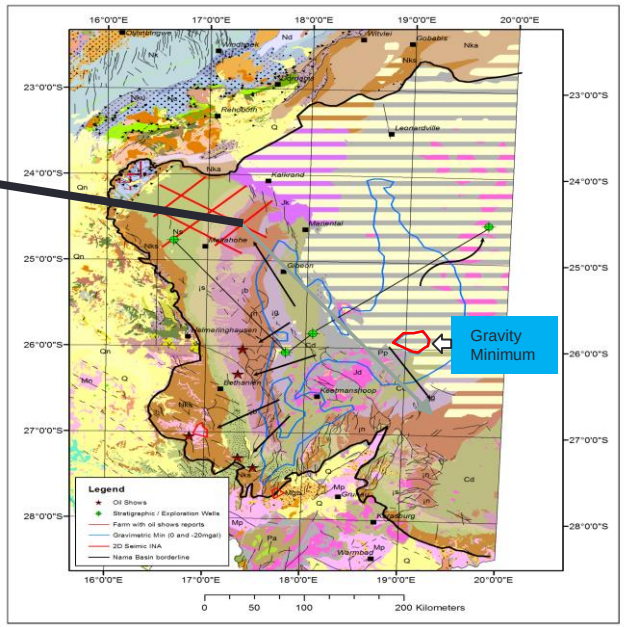


Map of main foreland basins, adapted from Bray & Lawrence (1998)





SW-NE cross section with petroleum plays of the Zaris Subbasin, northern Nama Basin. The map shows the outline of the Nama Basin in outcrop and the subsurface. Copied from Toirac (2012) as adapted from INA (2008).

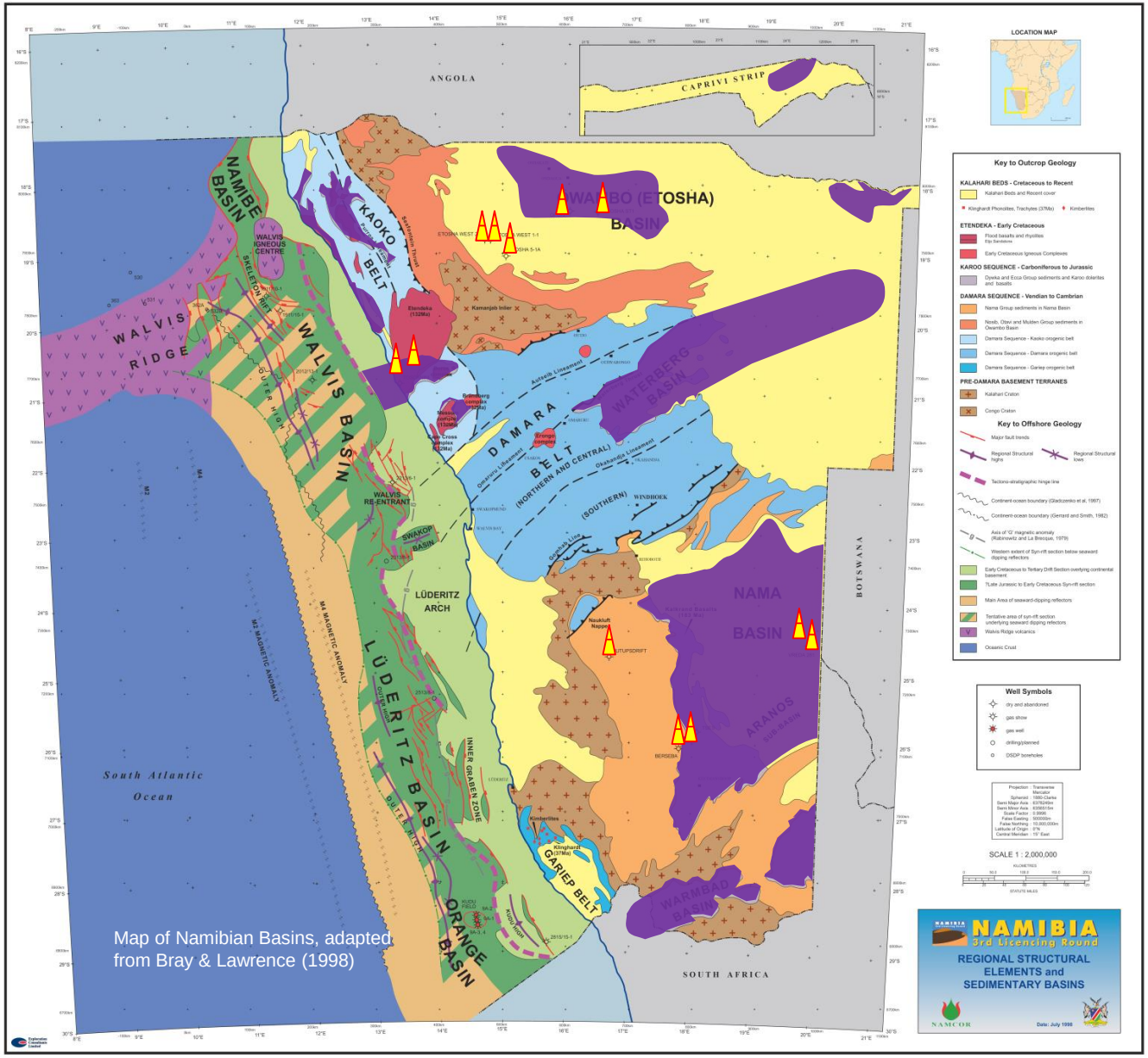


Karoo Basins

Depocenters defined by:

1. Sag/rift Basins
2. Over-deepened glacial valleys
3. **Transfer basins**

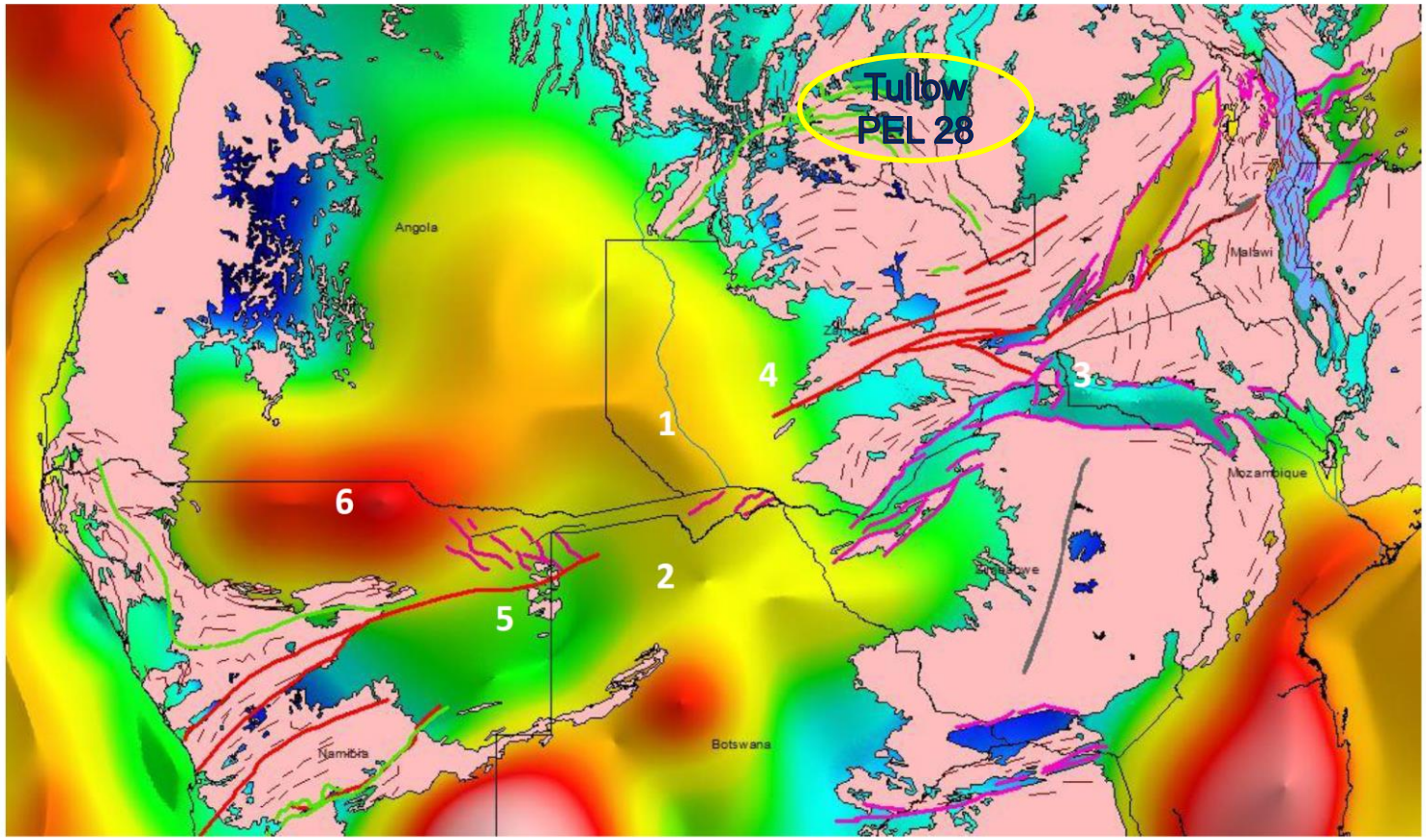
- Most basins shallow
  - < 1000m,
  - CBM potential, no or limited conventional potential
- Transfer Basins potentially deep
  - High conventional and unconventional potential
  - Lokichar style analogue?

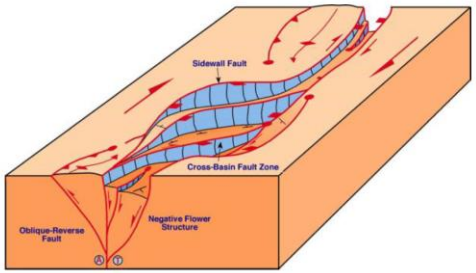


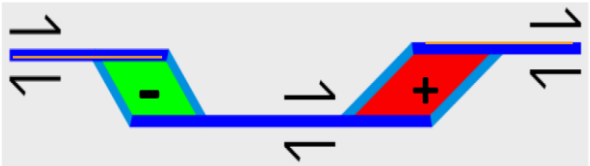
Map of Namibian Basins, adapted from Bray & Lawrence (1998)

Transfer and Rift Basins in Southern Africa and Namibia

MARIMBA sediment thickness inversion

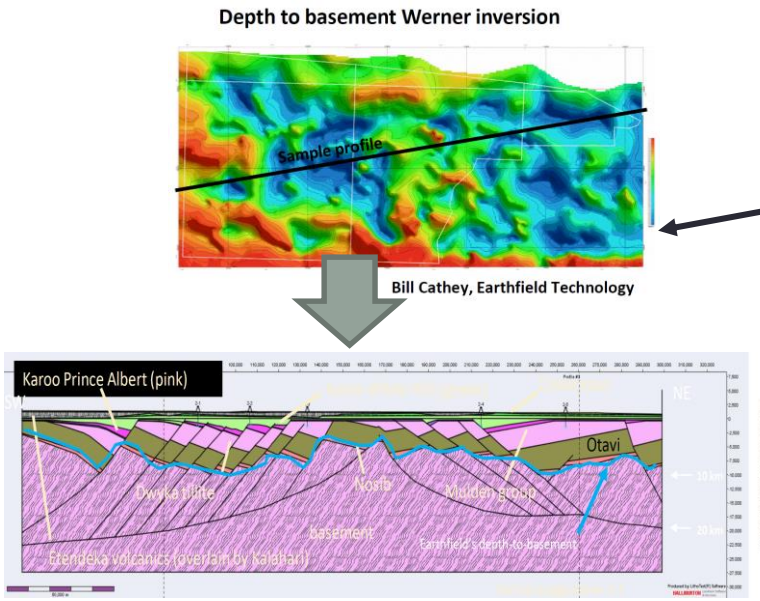




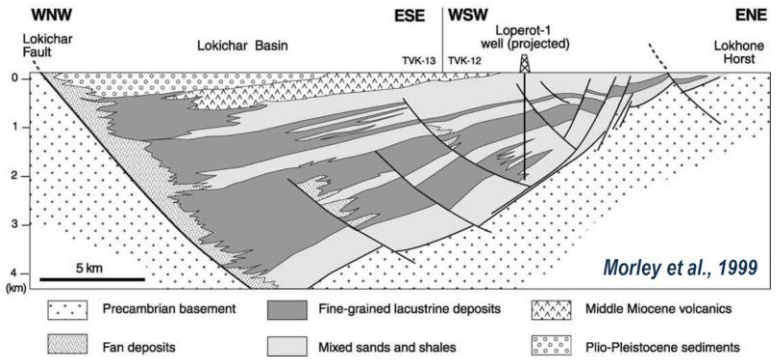


Southern African Tectonic Elements SW-NE cross section underlain by MARIMBA sediment thickness inversion (Granath & Dickson, 2018)

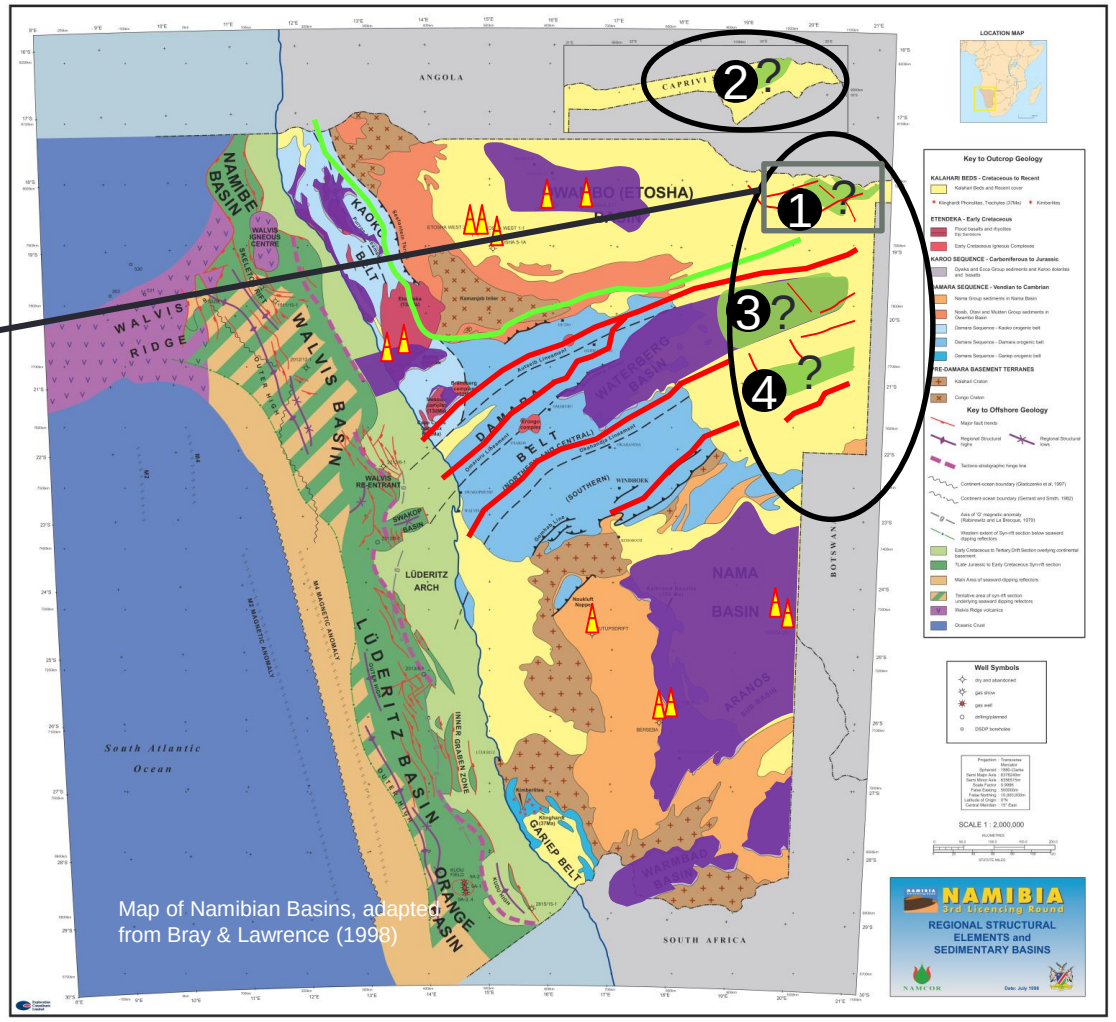
Karoo Basins



Kavango Basin depth to basement magnetic modelling and structural modelling (Granath & Dickson, 2018)



Cross section through the Lokichar Basin, Kenia (Morley at al. 1999).



Map of known (purplish-blue) and postulated (green) Karoo Basins in northern and eastern Namibia. (1) Kavango Basin, (2) East Zambezi, (3) Waterberg East, and (4) Eiseb-Omatako. Postulated basins are expected to have a similar size and possibly a similar tectonic architecture as the Lokichar Basin in Kenia.

Conclusions

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- Namibia > 40% covered by basins
- Two large Neoproterozoic-Cambrian Basins with HC indicators
  - Geophysics indicate deep depocenters and structural/stratigraphic closures
- Deep transfer basins with Karoo fill likely hidden under Cainozoic cover
  - Localized pull-apart/releasing bend basins hosting thick Permian – Jurassic packages
  - Could be similarly prospective as East African rift basins of similar size
- How to explore?
  - High resolution gravimetry/magnetics
  - Low cost HC indicators (soils gas, passive seismic, etc.)
  - Stratigraphic wells > 3000m, thereafter seismic
- Why?
  - Relatively low costs to start
  - Strong Local geoscience expertise support
  - Easy field access

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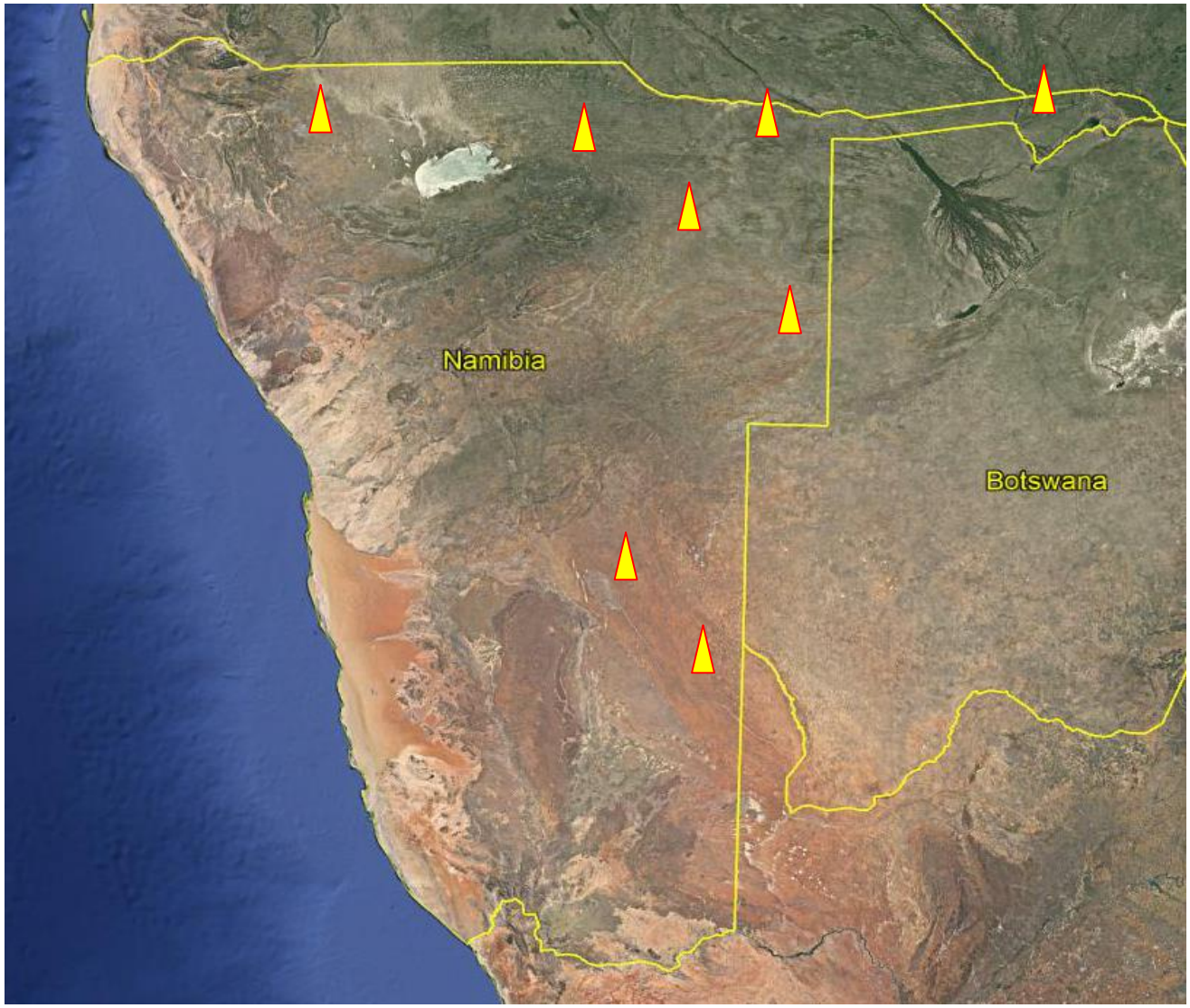

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