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REVIEW OF PETROLEUM SYSTEMS IN NAMIBIA

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Reconnaissance Energy Namibia

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ReconNAMIBIA

UES Namibia
Upstream Exploration Services Namibia

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Objectives and Definition

Objectives of Talk

- Provide an overview of known and likely present petroleum systems in the various Namibian basins

- Offshore
  - Past and Present Concepts
- Onshore
  - Basin Overview and Exploration History
  - New observations

Defenition Petroleum System (Magoon and Leslie, 1994)

"A petroleum system encompasses a pod of active source rock and all genetically related oil and gas accumulations. It includes all the geologic elements and processes that are essential if an oil and gas accumulation is to exist"

With this definition:

- The source rock is the first and foremost element of the system required to produce a petroleum play
  - Petroleum Systems usually refer to stratigraphic level of source
  - In contrary, Plays usually refer to stratigraphic level of reservoir
- Emphasis is on the sequence of geological processes of HC generation, migration and entrapment

The Beginning and Now

Onshore

- 1928: The first exploration well Berseba-1 was drilled by SW Africa Petroleum Corporation
  - Gas reported at shallow level during operation
  - Motivation: Hydrocarbon shows in southern Namibia and exposed sedimentary strata, defining a basin
- 2022: 18 mostly shallow wells drilled, in 2021 two wells prove an active petroleum system in Kavango – 93 years after first well

Offshore

- 1974: Namibia's first offshore well Kudu 9A-1 drilled by Chevron-Texaco
  - Discovery of the Kudu gas field
  - Motivation: Sparse geophysical data indicated shallow Upper Cretaceous Target on progradational wedge; discovery was made when decided to continue drilling deeper as stratigraphic test
- 2022: 26 wells drilled, in early 2022 two large discoveries in Orange Basin – after 48 years of offshore exploration

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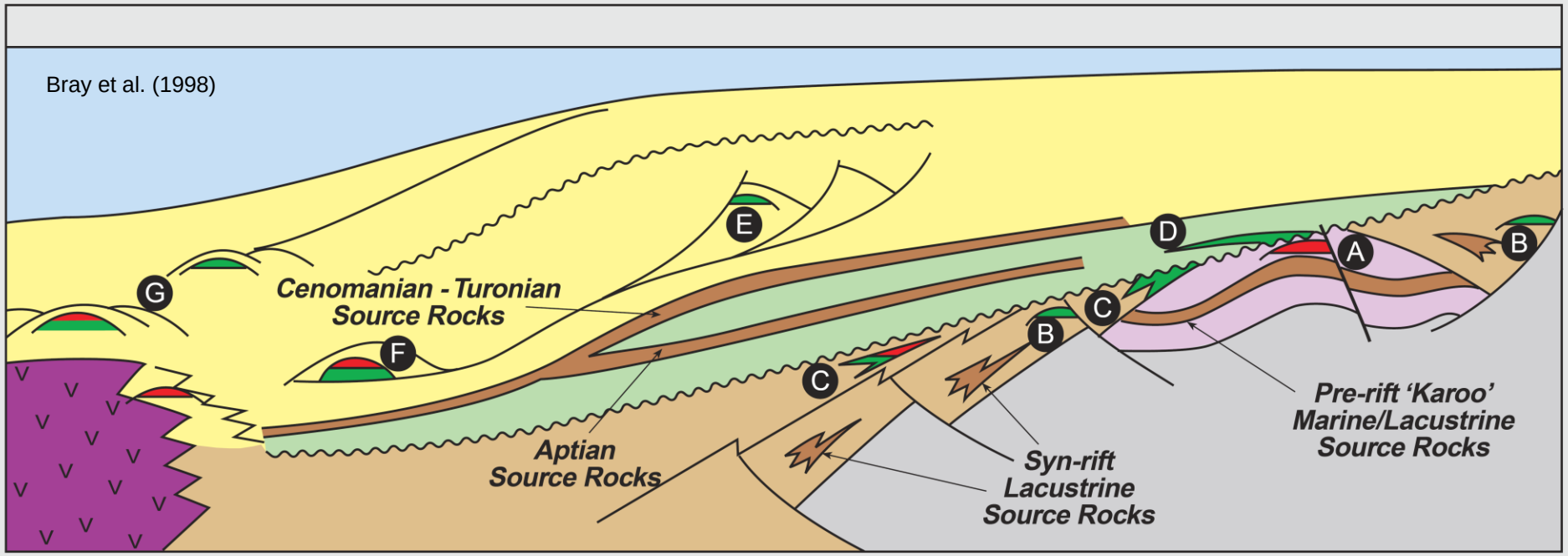
1998 Passive Margin Play and Systems Concept



Play-Types

- A Structural traps in Pre-rift sequence
- B Structural traps in Syn-rift sequence
- C Stratigraphic wedge-out traps in Syn-rift sequence
- D Stratigraphic wedge-out traps in Early Drift sequence
- E Gravity fault/roll-over structural traps in Late Drift Sequence
- F Toe-thrust structural traps in Late Drift sequence
- G Deep water slump and fan related stratigraphic traps

- Includes possible plays in all sequences of passive margin development
- Pre-rift, syn-rift, transitional, post-rift

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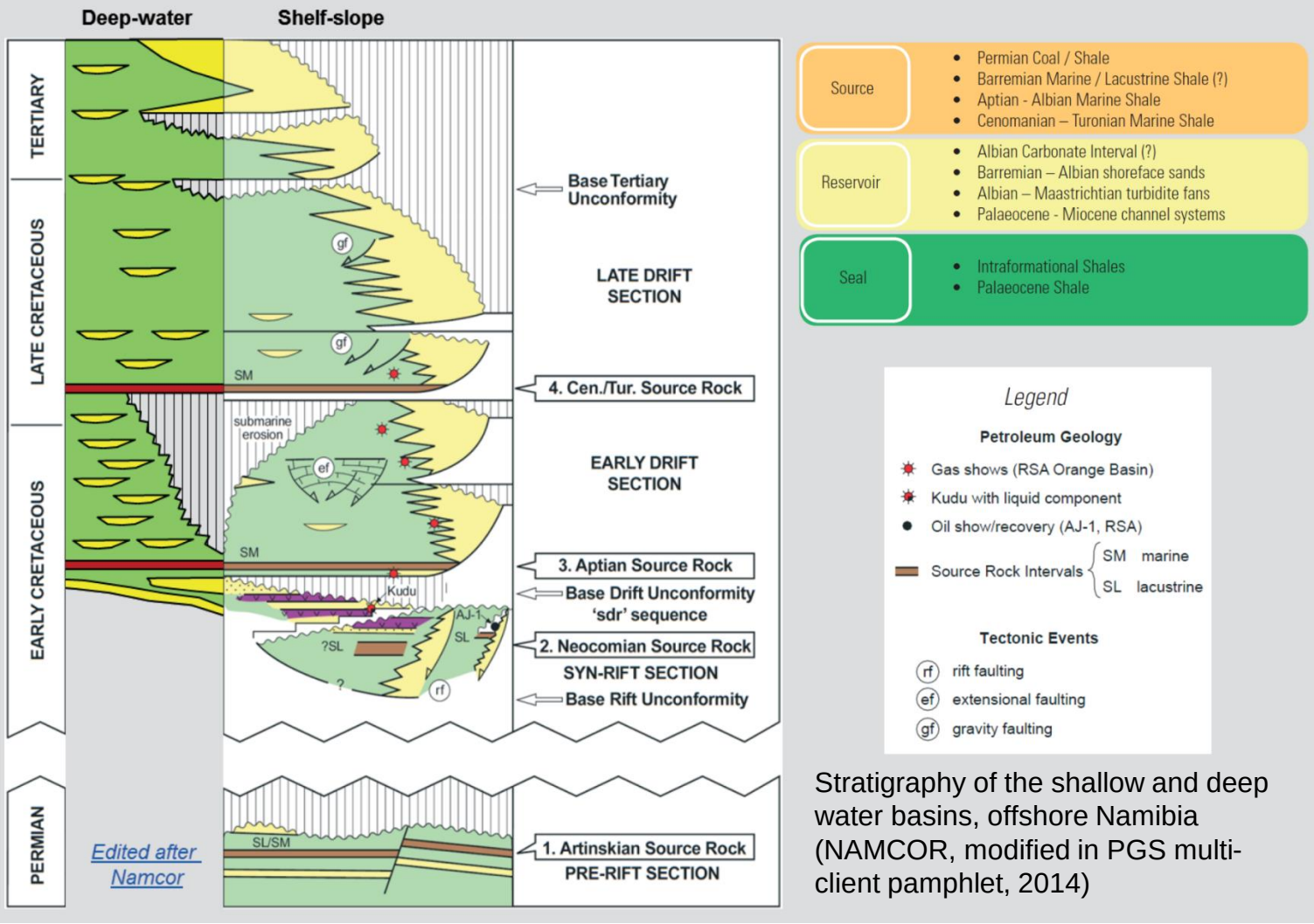
SRs considered since the 1900ies



Stratigraphy of the shallow and deep water basins, offshore Namibia (NAMCOR, modified in PGS multi-client pamphlet, 2014)

- SR in the pre-rift (Gzelian to Artinskian Karoo shales)
  - Not drilled, but SR quality shales exists offshore from uppermost Carboniferous to L Permian in various Karoo basins
- Syn-rift and transitional shales (Hauterivian-Barremian)
  - Hauterivian postulated in AJ Graben (Block 2B SA)
  - Barremian drilled in Kudu Welles
- Barremian-Aptian
  - Drilled in some wells (e.g. Kudu, Wingat, Murombe)
- Cenomanian-Turonian
  - Drilled in most wells, lateral variable, small potential kitchen areas as largely shallow

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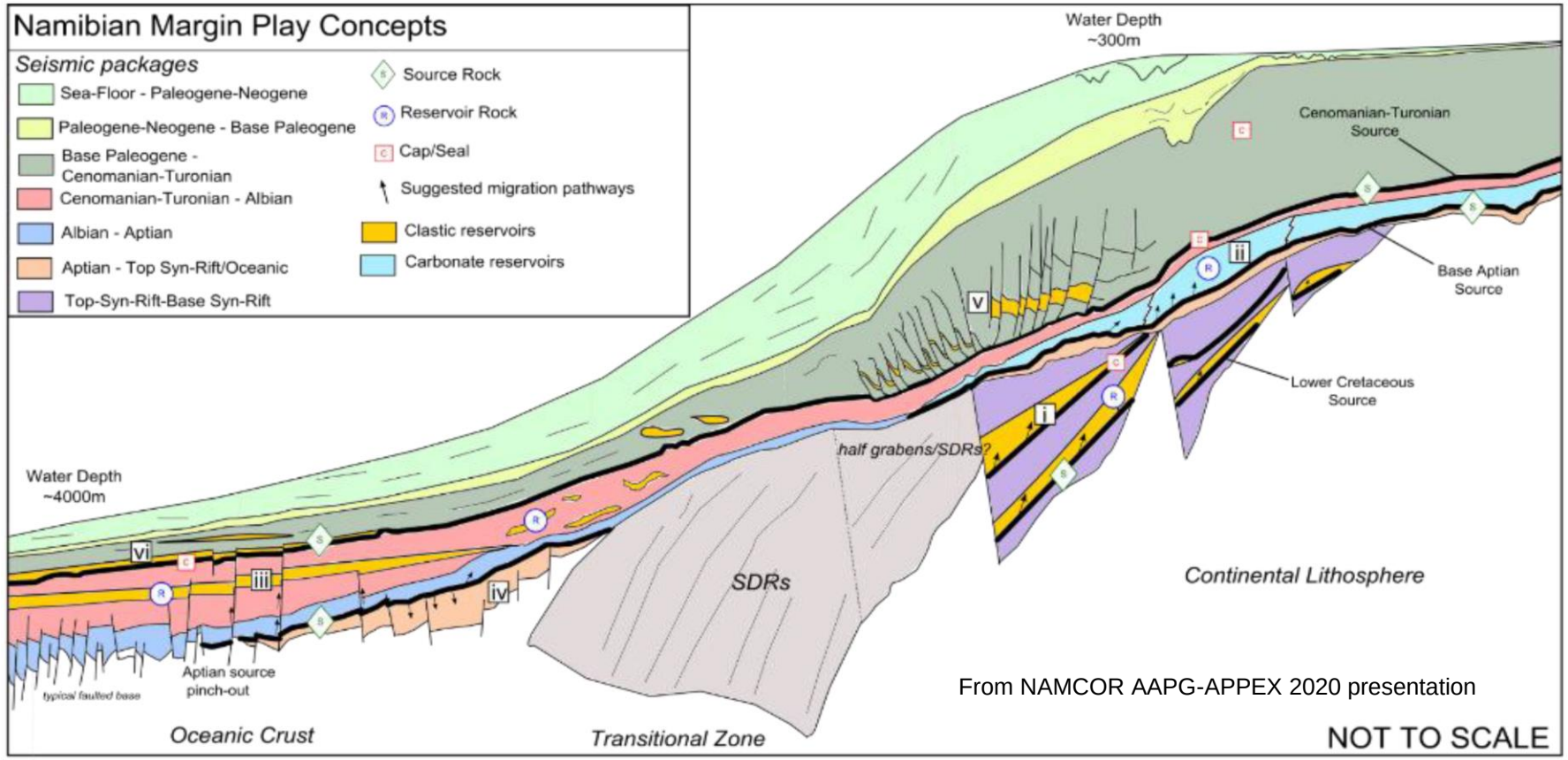
2022 Passive Margin Play and Systems Concept



From NAMCOR AAPG-APPEX 2020 presentation

- Essentially same concepts as over 24 years back
- Early Cretaceous plays added
  - E.g. Carbonate plays
- More emphasis on deep water (channel, ultra-deep water lobes)

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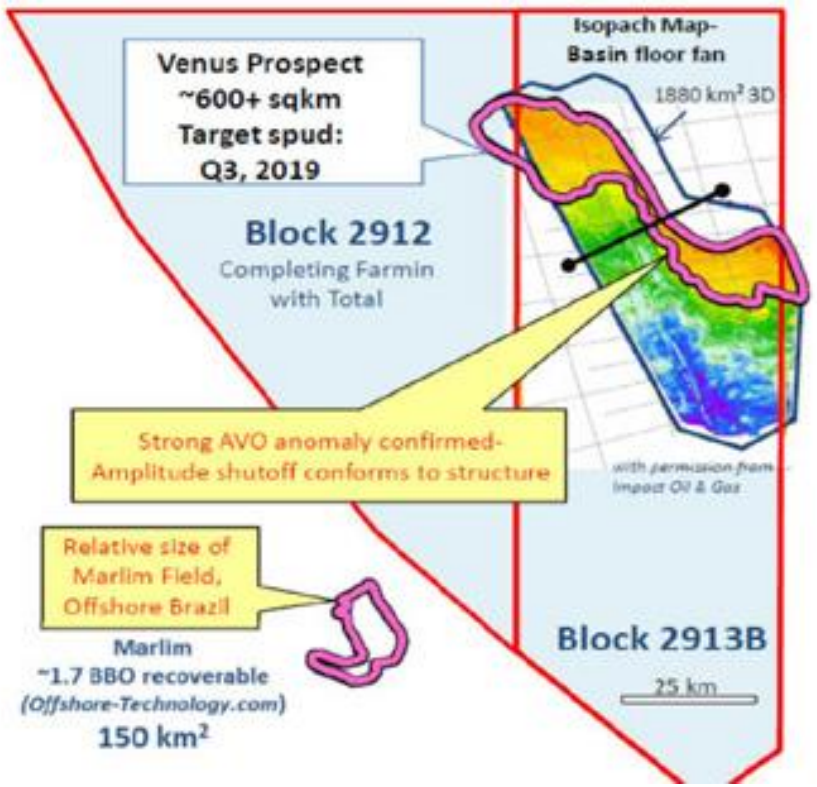
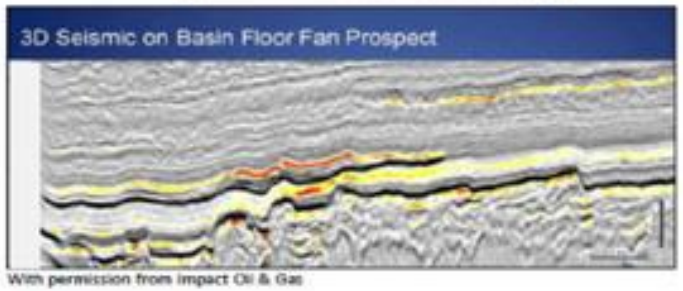
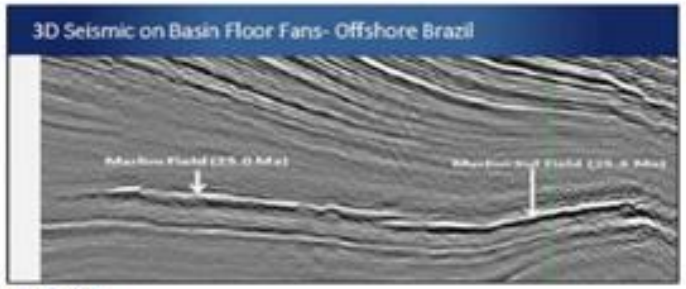
2022 Orange Basin Venus-1 Play Opener





With permission from Impact Oil & Gas



- Large Basin Floor Fan
  - Early Cretaceous
  - Close to source rock
  - Shallow mounded geometry causing large closure (dip reversal)
  - AVO supported
  - Ultra deep water
- Super Giant
- Play Opener

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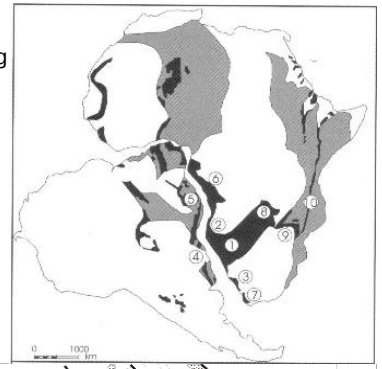
Neoproterozoic / Early Palaeozoic Basins

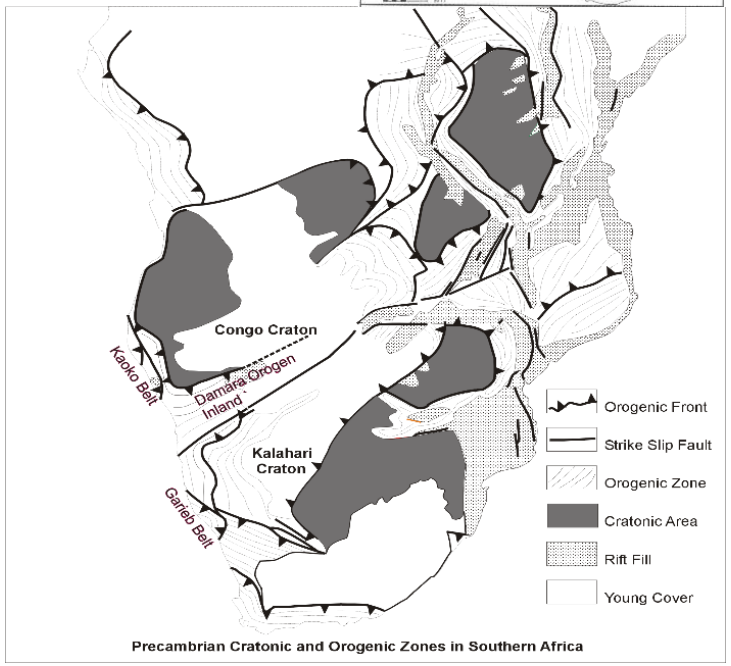
Owambo-Etosha and Nama Basin

- Architecture closely controlled by pan-African basement fabric
- Foreland Basin Architecture
- Well expressed in potential field depth to basement models

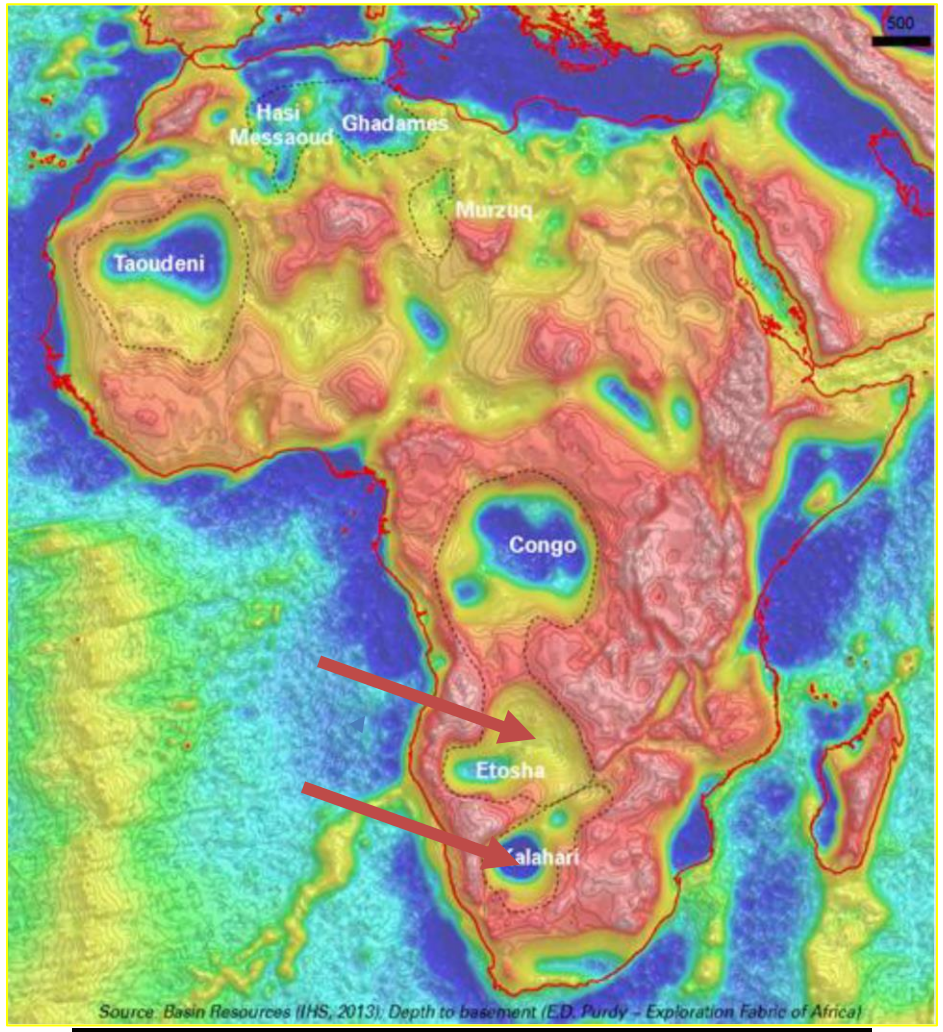
- Basins Largely covered
  - Cainozoic (Kalahari)
  - Karoo

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





Precambrian Cratonic and Orogenic Zones in Southern Africa



Depth to Basement: Purdey – Exploration Fabric of Africa

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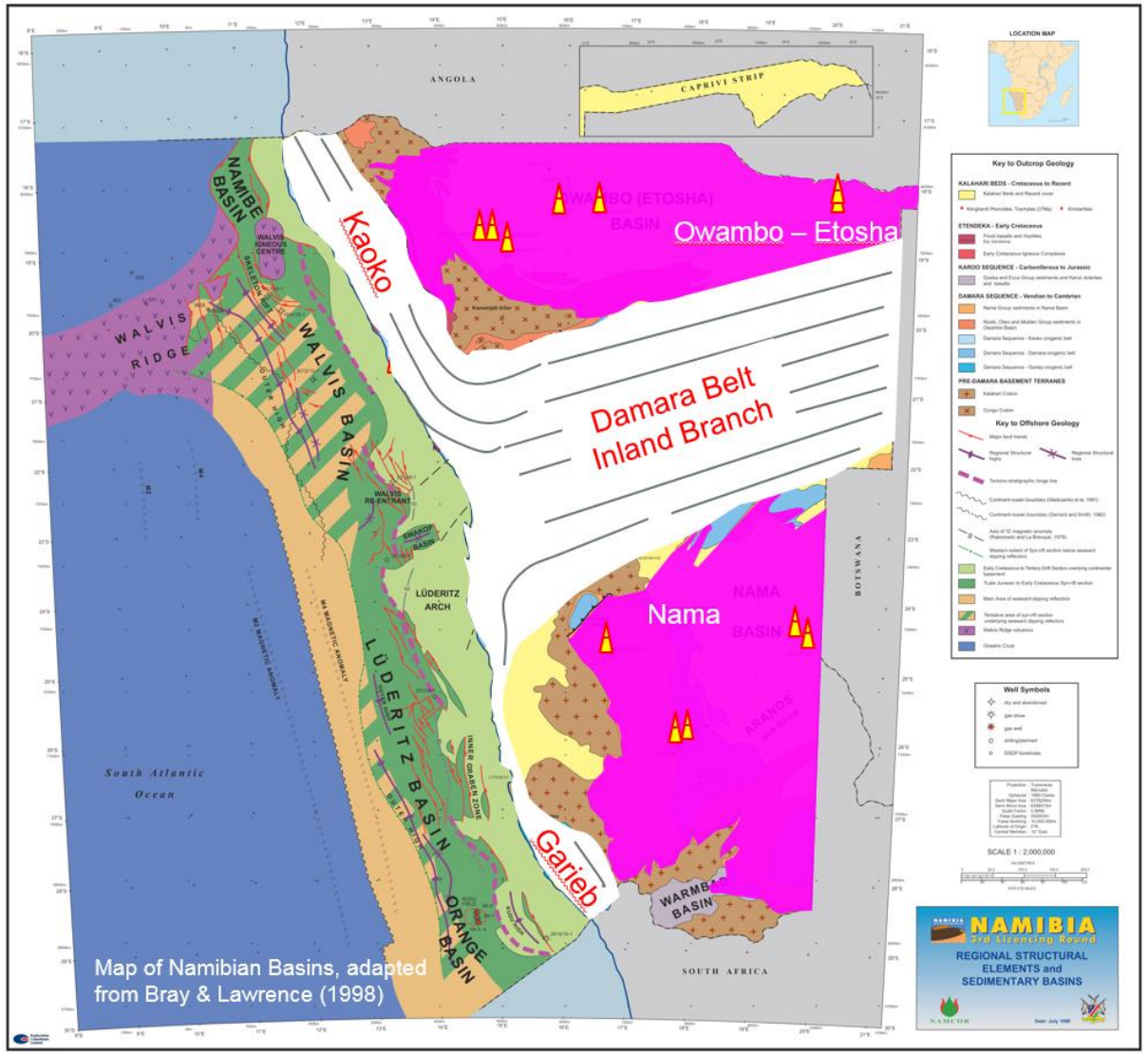
Neoproterozoic / Early Palaeozoic Basins

Two vast Basins

- Owambo-Etosha and Nama Basin
- Both Basins are bordered by early Cambrian Orogenic Belts
  - Bivergent Damara Belt borders both basins

Tectonostratigraphy

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



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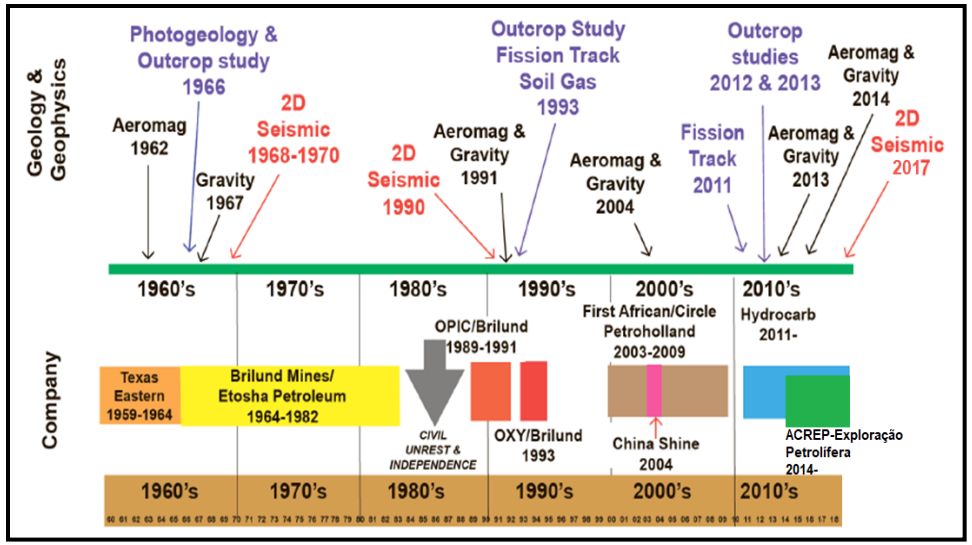
Owambo-Etoscha Basin

Vintage Exploration

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

From 2000

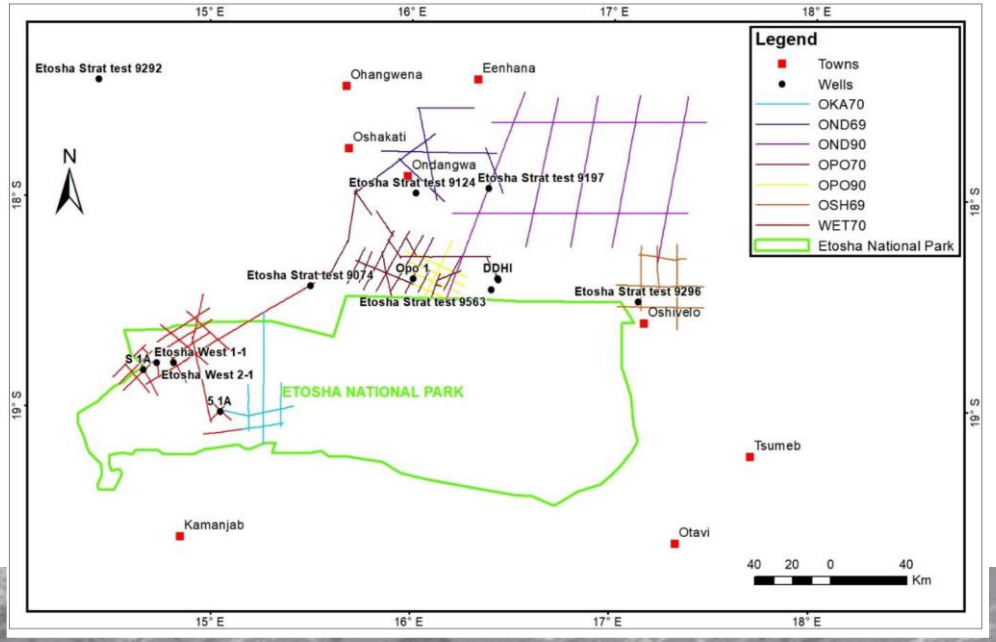
- Four aerial surveys (mag/gravity) (2004, 11, 13, 14)
- Soil gas sampling north and east of Etosha (2012)
- 120km 2D test lines (2017)
- Remote sensing study (2018)
- Passive seismic (2018)



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

Well	Year	Operator	TD (m)	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

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



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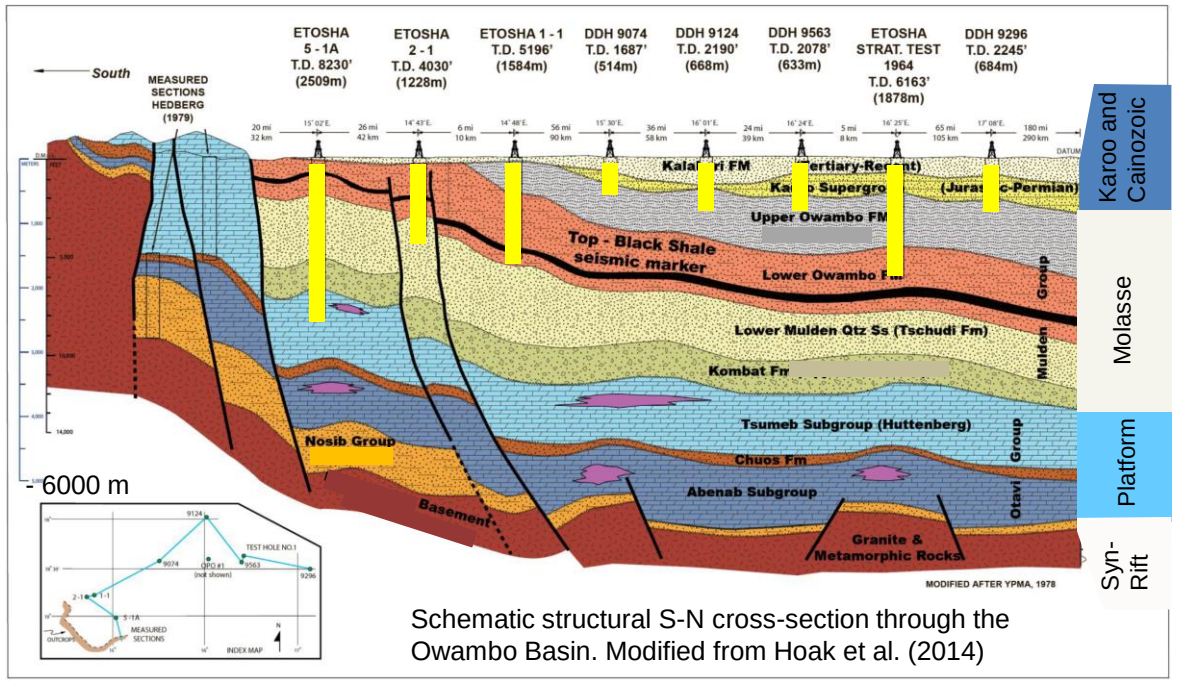
Owambo-Etoscha Basin

Well Results

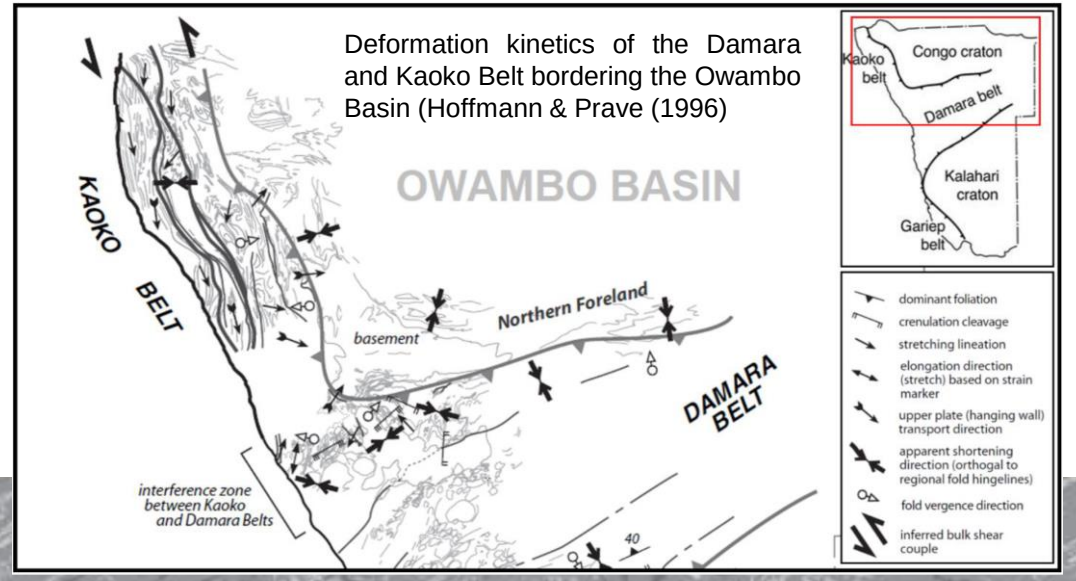
- Three wells pass through Mulden Black Shale marker (2.8% TOC)
  - Only one exploration well reaches top of platform sequence at TD 2509m
  - Two deeper source rock levels expected, better chance of maturity
- Sandstones of good RQ and fractured carbonates intersected (<15% porosity)
- HC show in one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

Seismic and other Findings

- Anticlines and roll-overs towards basin margin, carbonate built-ups in carbonate platform
- correlation of aeromagnetic defined anticline structures, soil gas HCs (C2), and passive seismic for DHSs



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



Deformation kinetics of the Damara and Kaoko Belt bordering the Owambo Basin (Hoffmann & Prave (1996)

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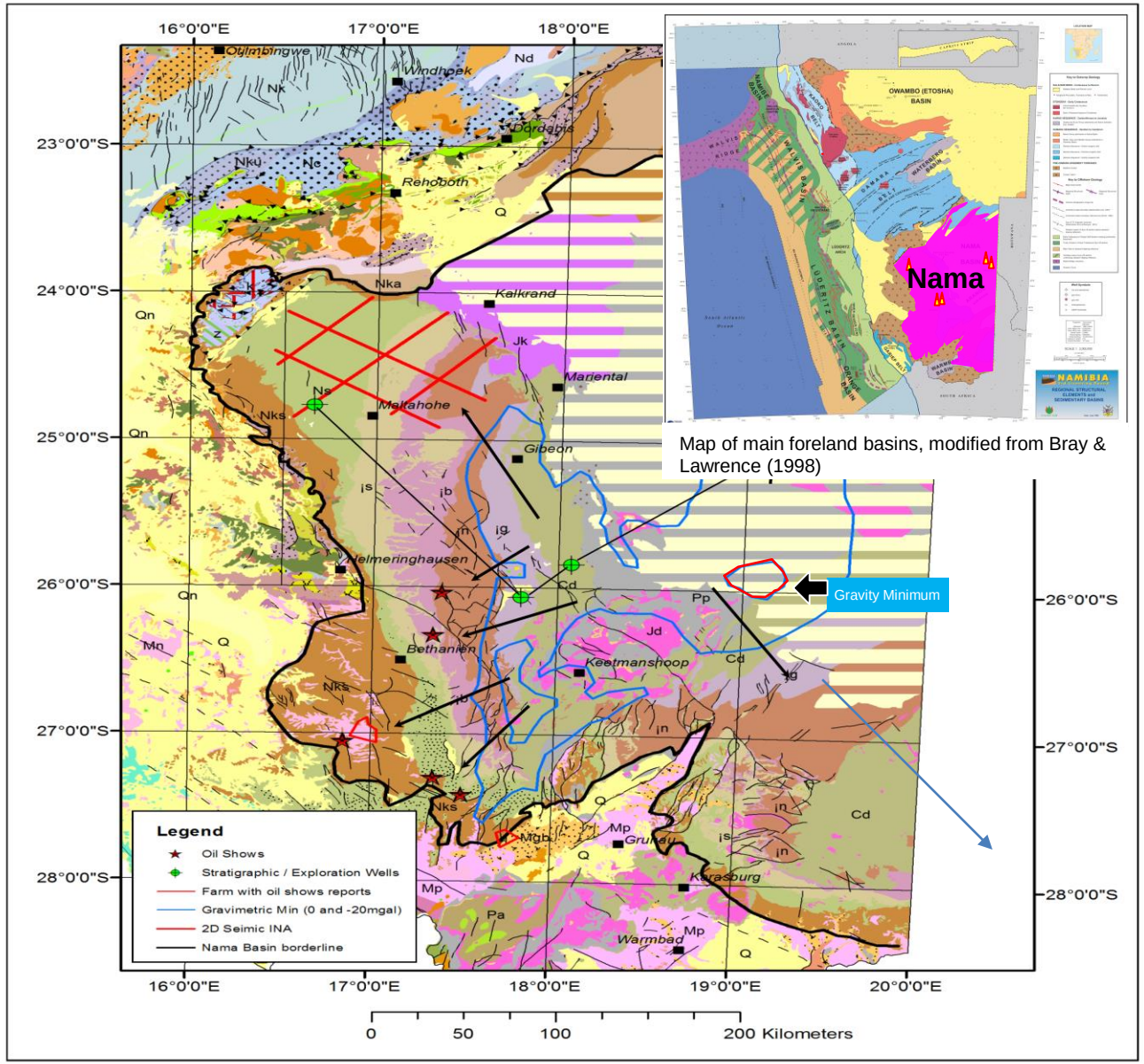
Nama Basin

Vast Basin

- Geologically roughly the southern counterpart to the Owambo-Etosha 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

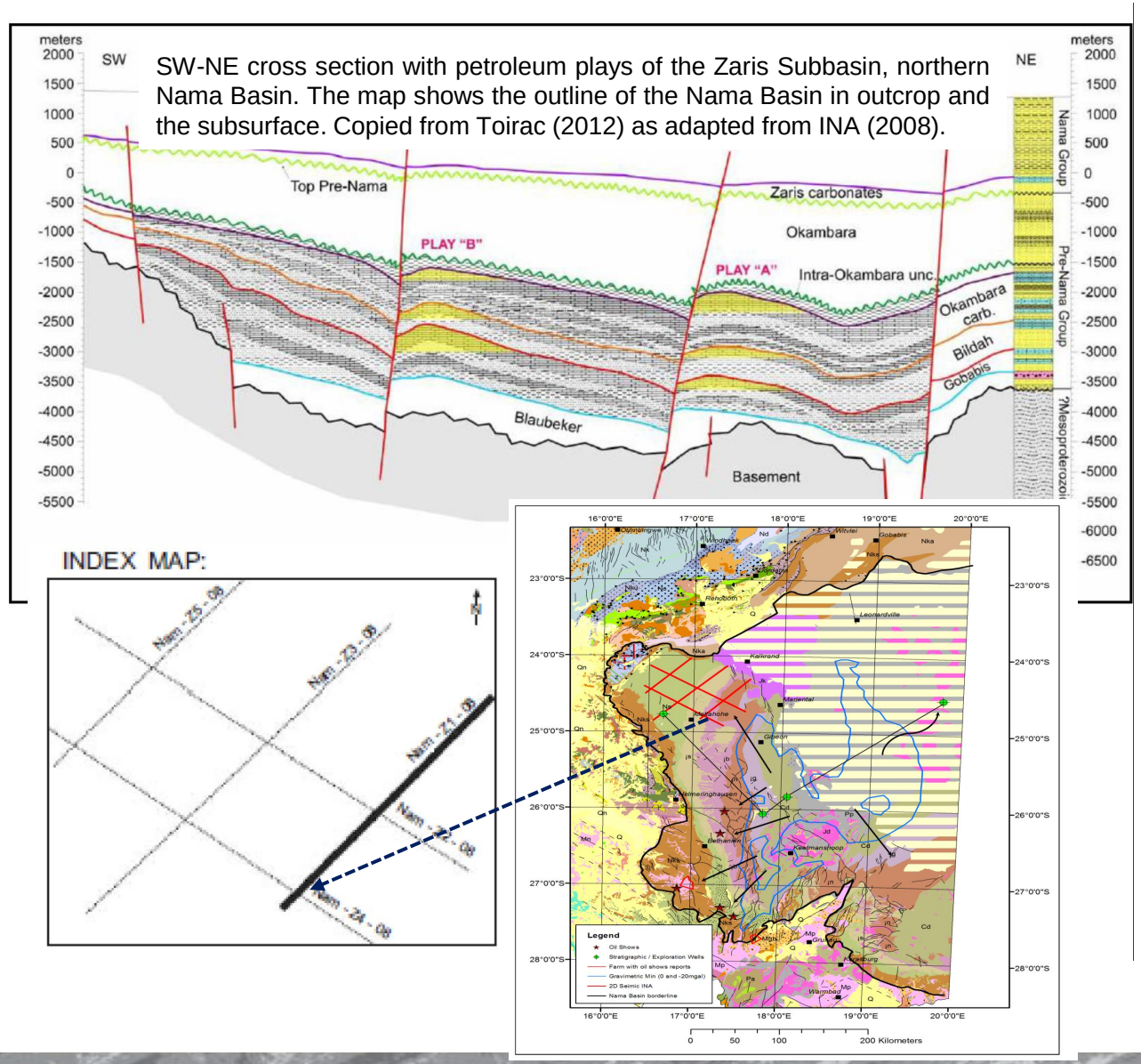


Map of main foreland basins, modified from Bray & Lawrence (1998)

Nama Basin

Findings and Concepts

- Three megasequences (at least 7km deep)
  - Nama
  - Pre Nama (likely Witvlei Gp equivalent)
  - Pre Witvlei Cryogenian (Blaubeker)
- SR and Reservoir
  - SR expected in deeper Witflei Gp Equivalent Carbonates and possible shales
  - Possible Reservoirs in carbonates (grainstones, reefs) and clastics of Nama and pre-Nama Gps



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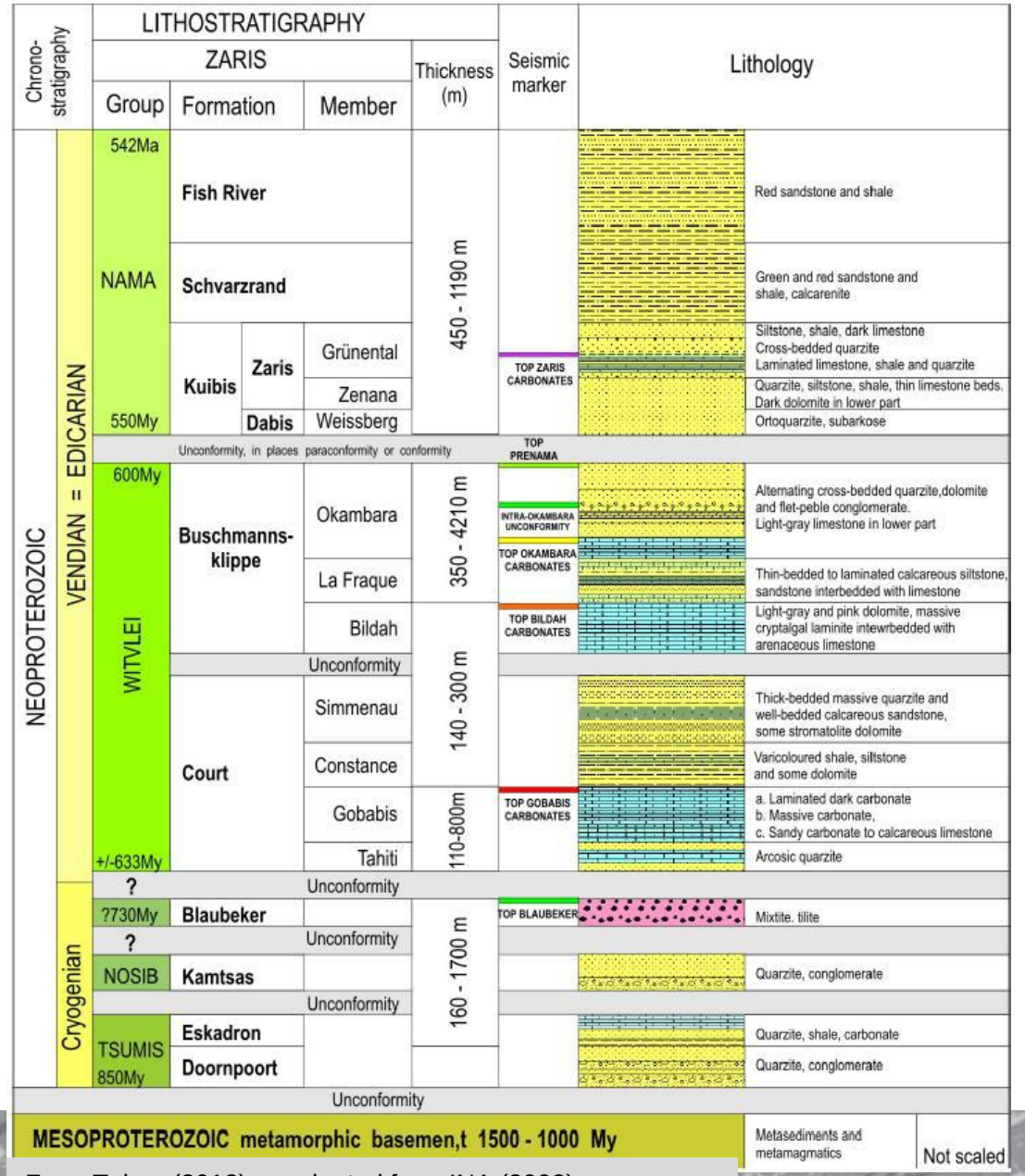
Nama Basin

Lower Nama Carbonates (Kuibis Subgroup) in the Zaris sub-basin



From Toirac (2012) as adapted from INA (2008).

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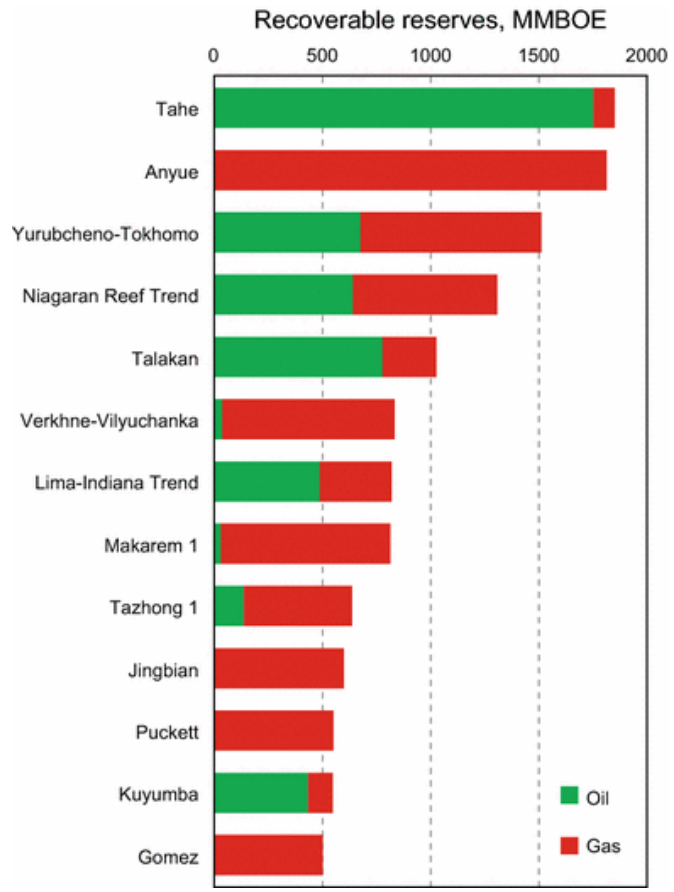
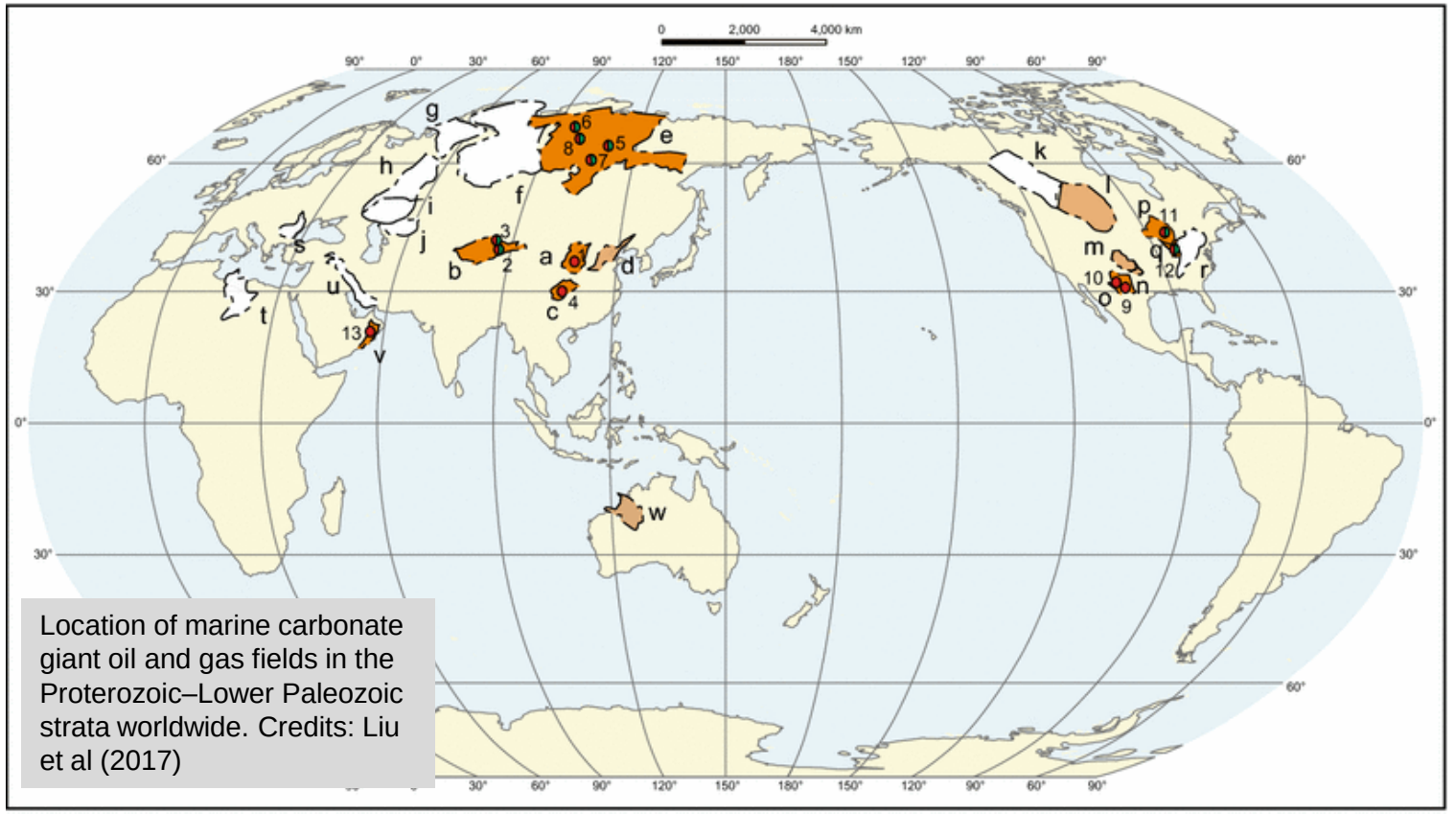
Proterozoic – Lower Palaeozoic Giant Oil and Gas Fields





Location of marine carbonate giant oil and gas fields in the Proterozoic–Lower Paleozoic strata worldwide. Credits: Liu et al (2017)

Gas fields
Oil and gas fields
Boundary of basin
Sea
Land
Basin with giant oil and gas field
Basin with oil and gas field
Basin without oil and gas field

Basin

a Ordos Basin
b Tarim Basin
c Sichuan Basin
d Bohaiwan Basin
e East Siberian Basin
f West Siberian Basin
g Timan-Pechora Basin
h Volga-Urals Basin
i PreCaspian Basin
j Northern Worcester Chult Basin
k Alberta Basin
l Williston Basin
m Anadarko Basin
n Arkoma Basin
o Permian Basin
p Michigan Basin
q Indiana-Ohio Platform
r Appalachian Basin
s Carpathian Basin
t Sirte Basin
u Zagros Basin
v Oman Basin
w Canning Basin

Giant oil and gas field

1 Jingbian
2 Tazhong
3 Tahe
4 Anyue
5 Verkhne Vilyuchanka
6 Kuyumba
7 Talakan
8 Yurubcheno-Tokhomskoye
9 Puckett
10 Gomez
11 Niagaran
12 Lima-Indiana
13 Makarem 1

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Owambo-Etosha and Nama Basin Prospectivity

Encouraging

- HC shows and indicators
- Potential Source Rocks, Reservoir, Seal and Traps identified
- Thermal maturity in large parts of basins likely
- Peak expulsion likely soon after Damara orogeny (Early Paleozoic)
  - Minor tectonic events thereafter
- Analogues show that old basins can host large reserves
  - e.g. East Siberia Tunguska

Main Risks

- Preservation (tertiary migration and biodegradation over time)
  - Good seal and high seal integrity are imperative
- Trap failure due to subsequent tectonic events
- Igneous events (Jurassic Karoo Basalt)

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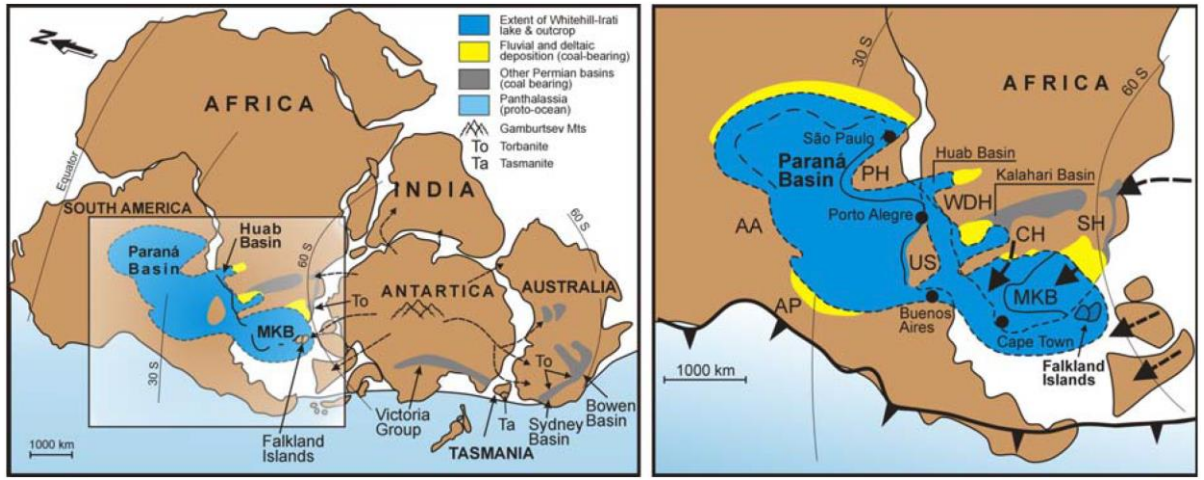
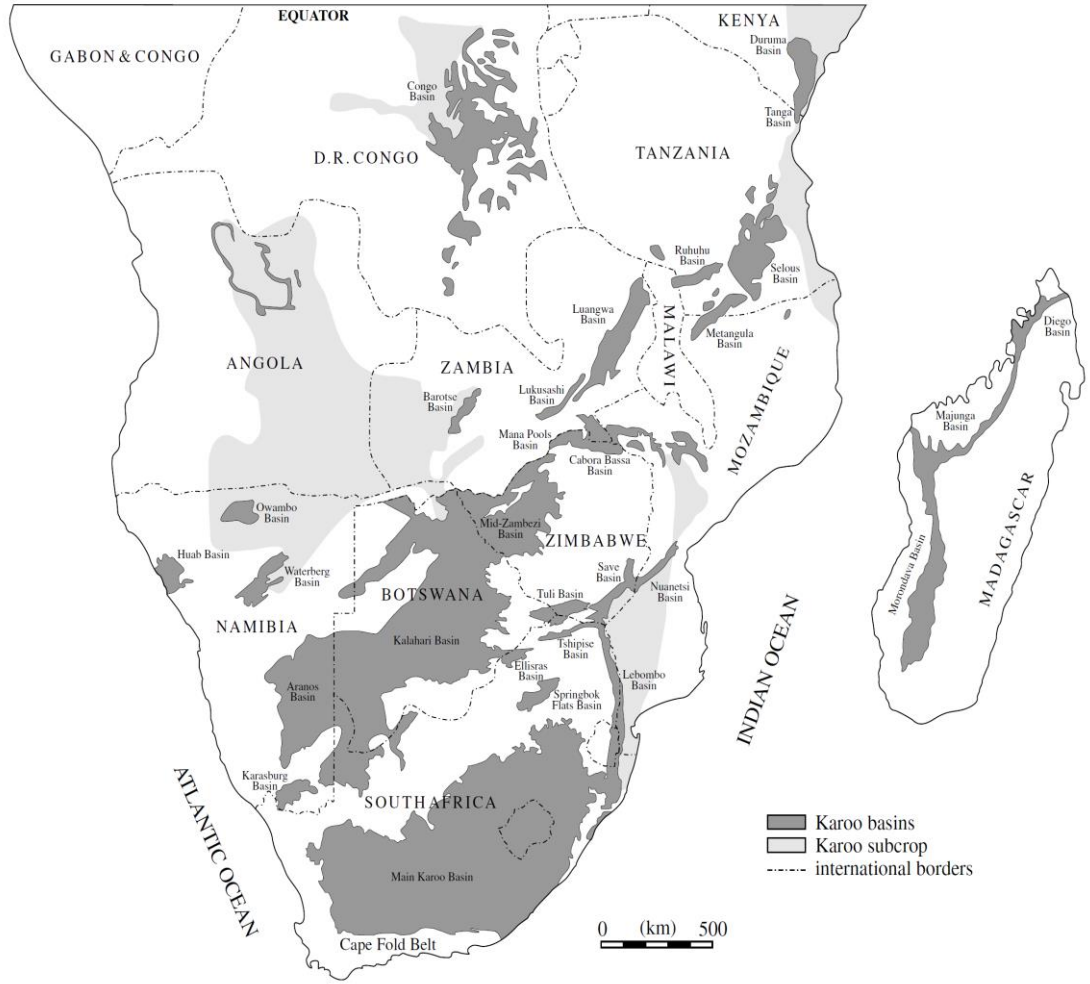
Southern African Karoo Basins

Source Potential

- Late Carboniferous – Early Permian Transgressions
  - Marine and Lacustrine shales in depocentres
    - E.g. Whitehill and Irati black shales
  - Paralic coals in deltaic and coastal settings
    - E.g. Witbank and Wankie coals



Paleogeographic maps showing the position of the Whitehill-Irati (Mesosaurus) Inland Sea within SW Gondwana during the Early Permian. These maps were originally compiled by Faure & Cole (1999) and slightly modified by Werner (2006).



The distribution of Karoo basins (outcrops, subcrops and inferred) in sub-equatorial Africa (Catuneanu et al., 2005)

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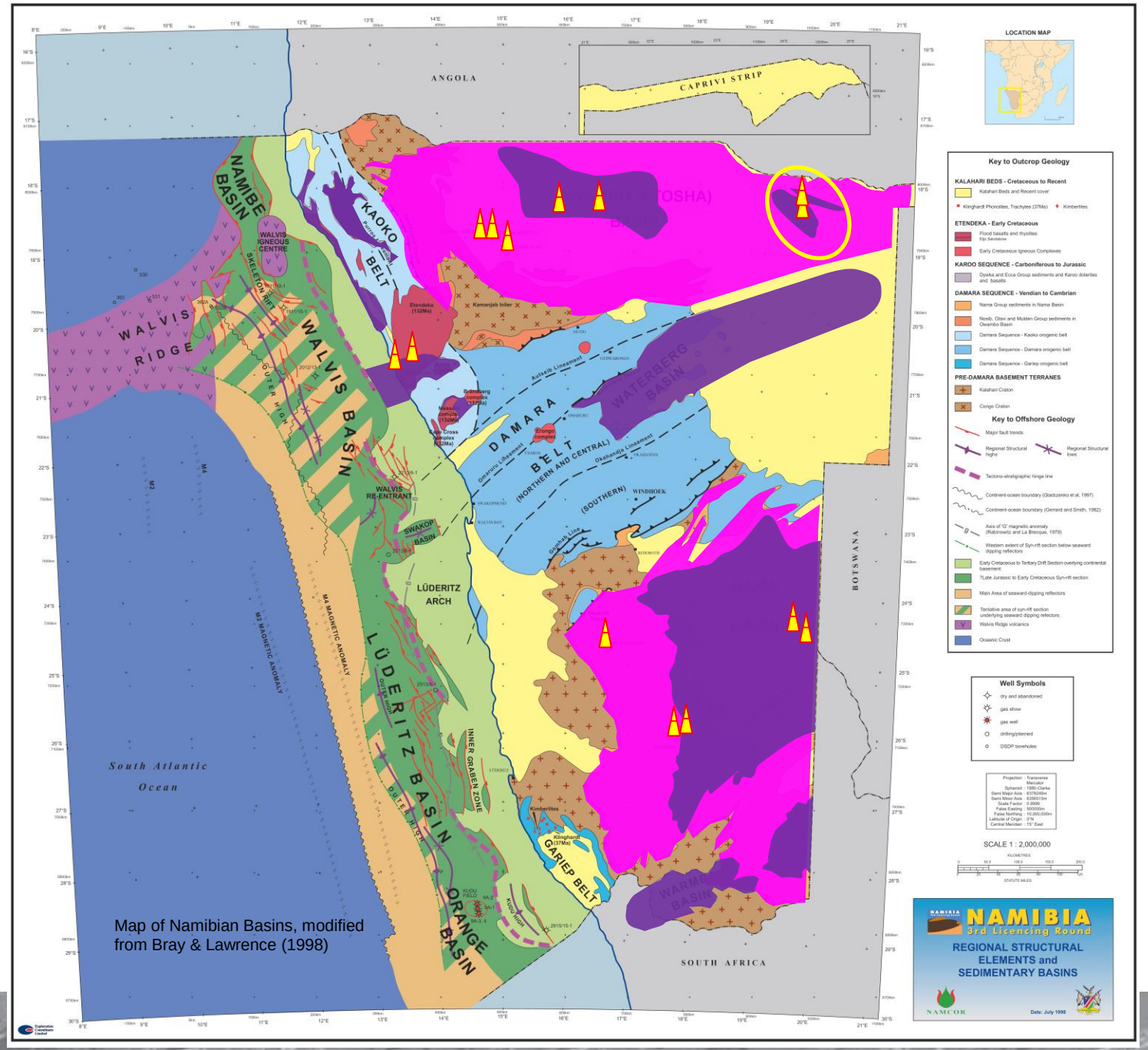
Karoo Basins in Namibia

- Depocenters defined by:
  - Sag basins
  - Over-deepened glacial valleys
  - Transfer/rift basins
- Most basins shallow < 1000m,
  - No or limited potential,
- Transfer/rift Basins potentially deep
  - Deep basins allow oil maturity >1200m
  - Recent wells and 2021/22 Seismic in NE Namibia identified Kavango Basin
    - Substantial HC shows



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

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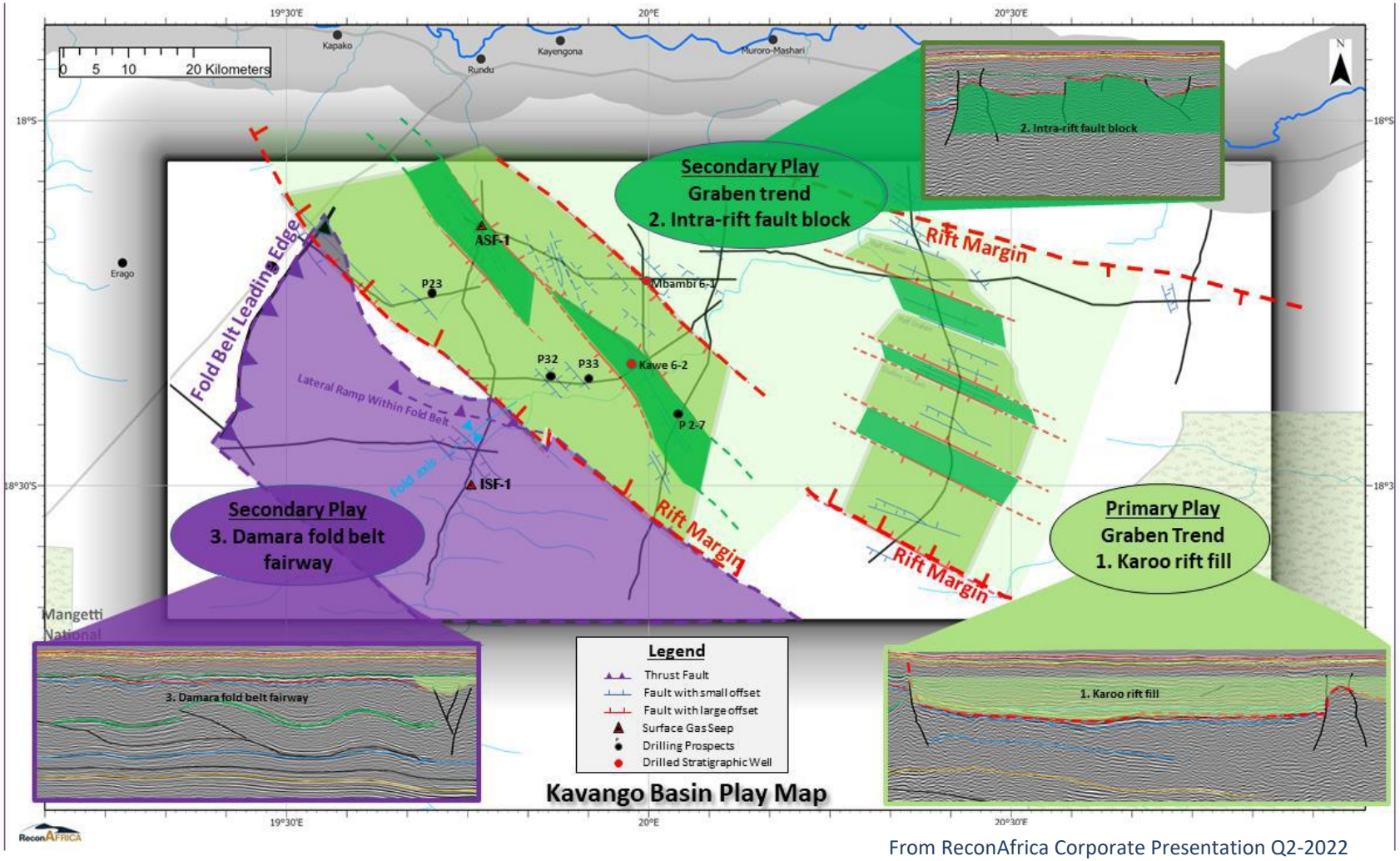
Kavango Basin Plays

- 450km Seismic (phase-1)
- Two wells
  - TD 2780m, 2294m
  - Both with HC shows
- Initial Geochemical Survey
  - Active thermogenic gas seep
- Plays
  - Rift Fill
  - Intra-rift fault blocks
  - Damara fold belt



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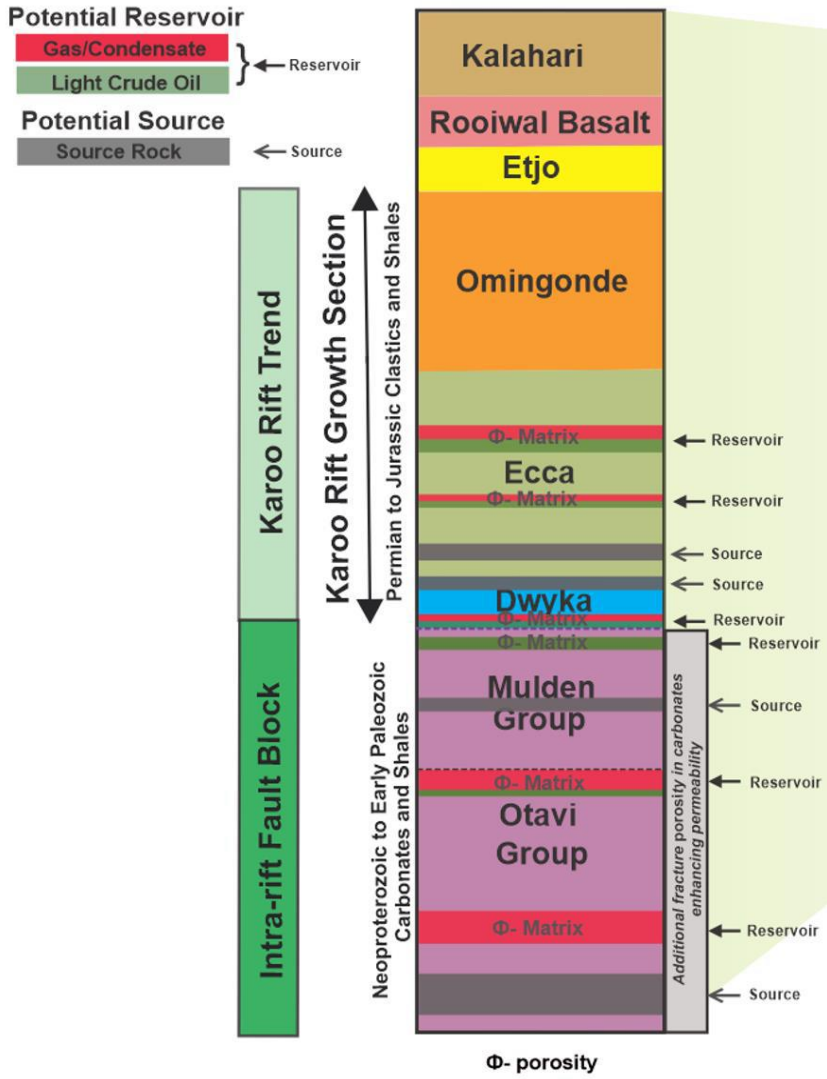
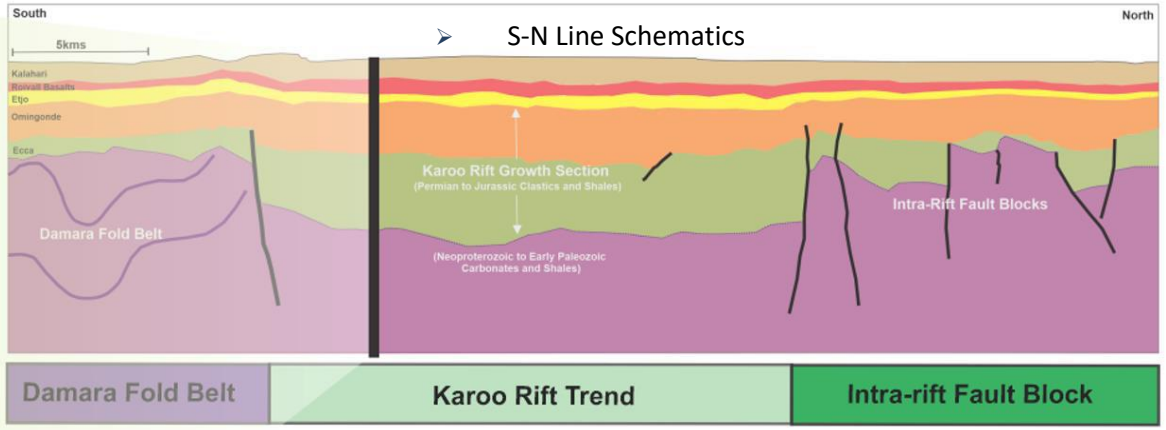
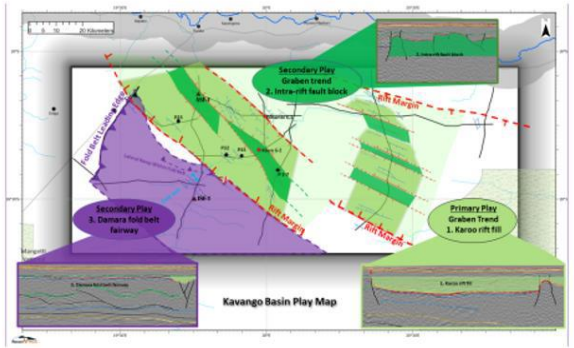
Kavango Basin Schematics





- S-N Line Schematics

Potential for multiple stacked reservoirs and source rocks



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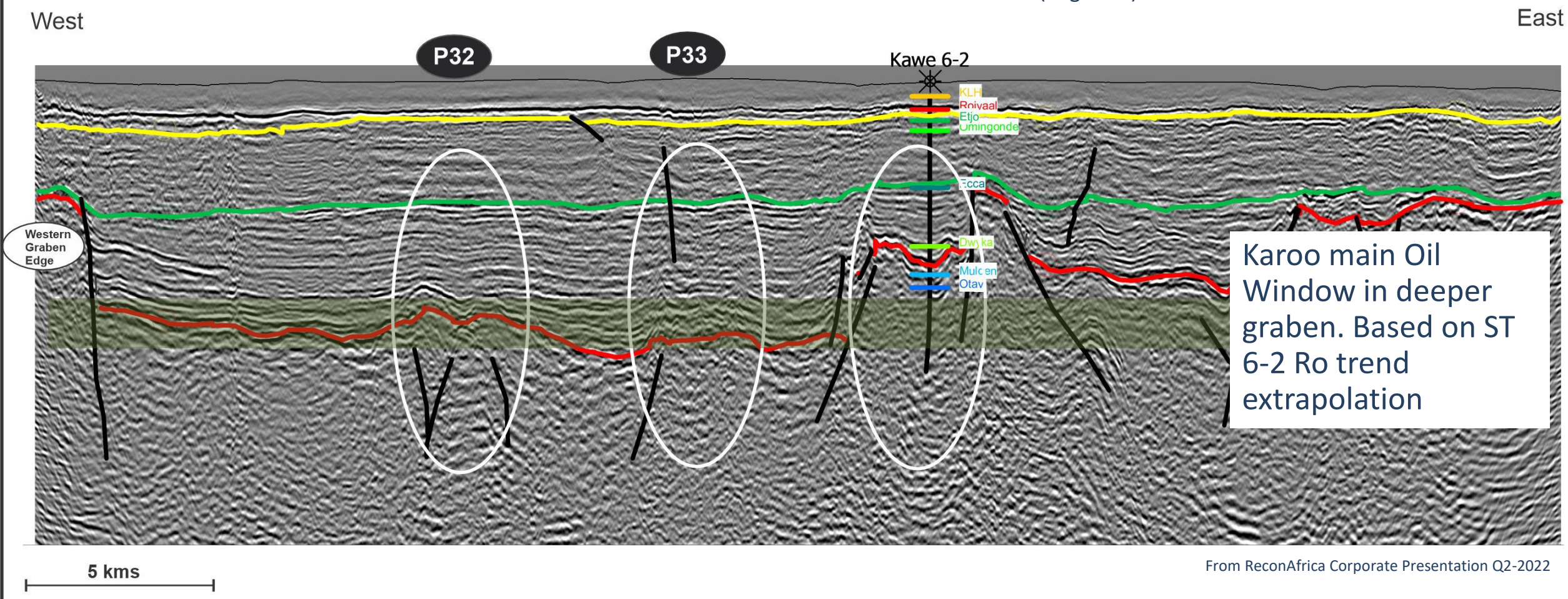
Kavango Basin W-E Seismic through Well ST 6-2

Well drilled on structural high, no trapping configuration,
still over 200m HC indicators (migrated)



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Conclusions

Offshore

- Approx. 50 years exploration history, much seismic acquired
- Post-rift potential proven by large discoveries
- Pre- and Syn-rift still to be tested
  - Focus will likely remain on early Cretaceous SR Petroleum Systems

Onshore

- 94 years exploration history – minor data acquisition so far
- Owambo-Etosha and Nama Basin largely underexplored
- Recently defined Kavango Graben/Rift hosts thick Karoo Strata
  - Substantial HC shows
  - Additional Damara foldbelt fairway