Development of a Petroleum System in a Young Rift Basin Prior to Continental Breakup: The Albertine Graben of the East African Rift System*

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Abstract

The Albertine Graben forms the Northern termination of the Western arm of the East African Rift System (EARS). It stretches from the border between Uganda and Sudan in the north to Lake Edward in the south. It is a Tertiary intra-cratonic rift that developed on the Precambrian orogenic belt of the African Craton. Rifting is interpreted to have been initiated during Early Miocene about 17 Million Years ago.

The East African Rift System has been interpreted as a continental extension probably caused by a plume head underneath East Africa. It is a classic example of the processes of continental break up, from incipient rifting in the Botswana Rift, southwestern branch, to initiation of sea floor spreading in the Afar depression at the Red Sea, Gulf of Eden triple junction.

The tectonic evolution of the Albertine Graben is little understood. It does not fit well with traditional models of rifted continental basins, defined by discrete basin-bounding faults opposed by a low gradient flexural margin especially over Lake Albert. Almost similar amounts of displacement on the eastern border faults and western border fault produce close to a full graben structure that gently dips towards the west in contrast to half graben structures of the Tanganyika and Malawi rifts.

The available geological and geophysical data indicate that the Graben has gone through extension and compression episodes resulting in a variety of structures. Deformation and prevalence of flower structures in the shallow sedimentary section in some basins in the graben indicate that the neo-tectonic processes are compressional.

The Albertine Graben has undergone substantial tectonic movements and thick sediments (approximately 6 km) have been deposited in lacustrine and fluvial – deltaic environments. The sedimentary layers dip gently towards the depo-centre on the western margin of the rift. Rapid tectonic subsidence coupled with limited sediment input led to deep stratified lakes with the accompanying deposition of source rocks. The hydrocarbon exploration wells drilled in the Albertine Graben have proved deposition of source, reservoir and cap rocks.

The Graben is characterized by highly asymmetrical deep tertiary basins that are separated by complex transfer zones. These zones act as pathways for sediment input into depo-centers as well as favorable areas for development of diversity of hydrocarbon traps. Both structural and stratigraphic traps have been interpreted from geophysical data acquired in the Albertine Graben; however, only structural traps have been tested for hydrocarbons by drilling. All wells that have been drilled in the Albertine Graben have been on either positive flower (Palm tree) structures or on fault blocks. Fault closures against basin bounding faults or even intrabasinal faults have proved prolific for hydrocarbon trapping.

Commercial hydrocarbon production has not yet started in the Albertine Graben, but its hydrocarbon generating potential is no longer in question. Though under explored, a total of 22 exploration and 17 appraisal wells have been drilled in the Graben, and of these, 36 have encountered hydrocarbons, making this one of the highest success rates globally and confirming a working petroleum system. At the moment, two of the discoveries have progressed to Field Development level. The reasons behind development of a working petroleum system in a young rift basin, probably the youngest in the world to have generated, expelled and trapped hydrocarbons, are not yet clearly understood. However, this could be attributed to a high geothermal gradient, lack of initial sufficient clastic sediments due to drainage change allowing deposition of source rocks, rapid deposition during the Pliocene, creating thick sedimentary column and a late compression phase that has created structural traps.

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DEVELOPMENT OF A PETROLEUM SYSTEM IN A YOUNG RIFT BASIN PRIOR TO CONTINENTAL BREAK UP; THE ALBERTINE GRABEN, OF THE EAST AFRICAN RIFT SYSTEM

Presented at the AAPG International Conference and Exhibition 2010, Calgary, Canada

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PRESENTATION OUTLINE

1. OBJECTIVE OF THE PRESENTATION
2. INTRODUCTION
3. STRUCTURAL SETTING
4. CHRONOSTRATIGRAPHY
5. EXISTENCE OF A PETROLEUM SYSTEM
6. CONCLUSION

OBJECTIVES OF THE PRESENTATION

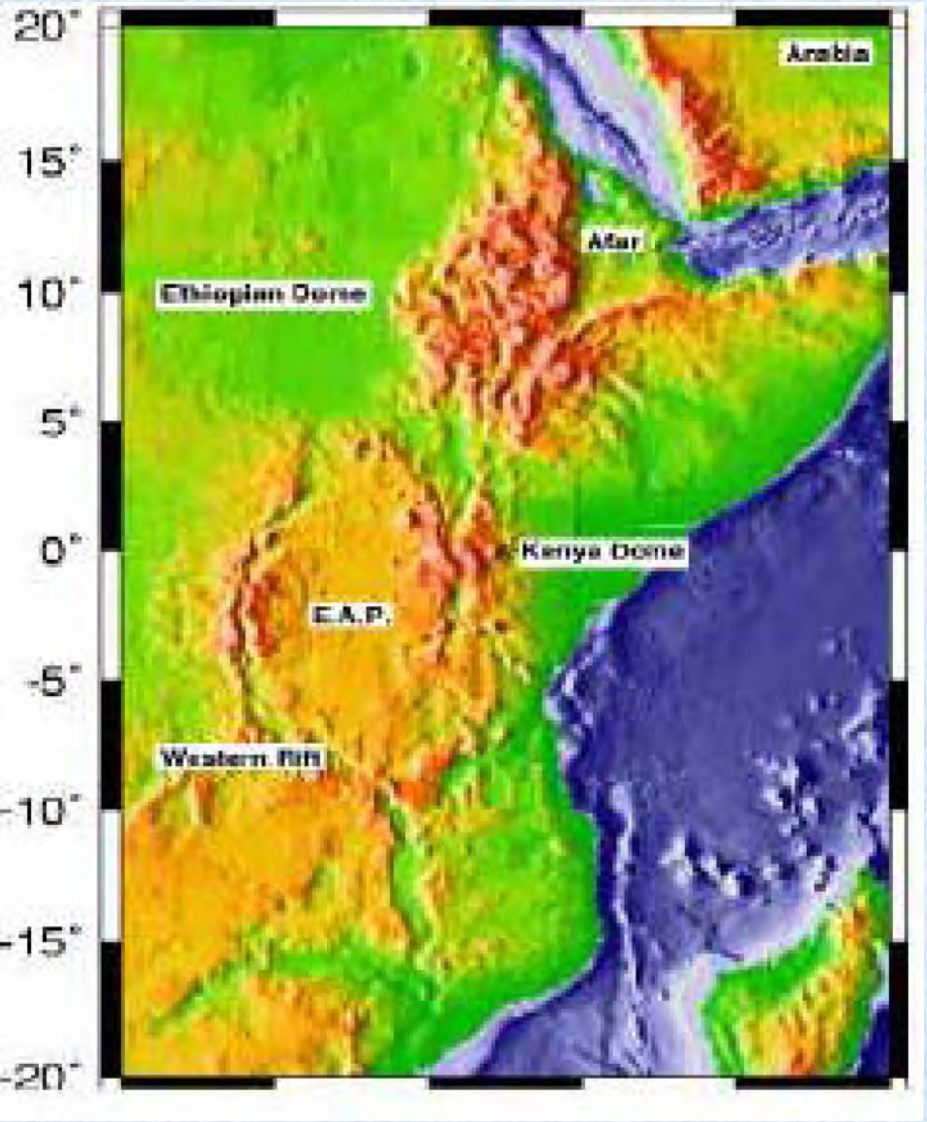
1. Demonstrate that the Albertine Graben is a young Rift System

2. Demonstrate the existence of a petroleum system in the Albertine Graben

3. Explain the development of a petroleum system in a young rift

INTRODUCTION

Regional Setting

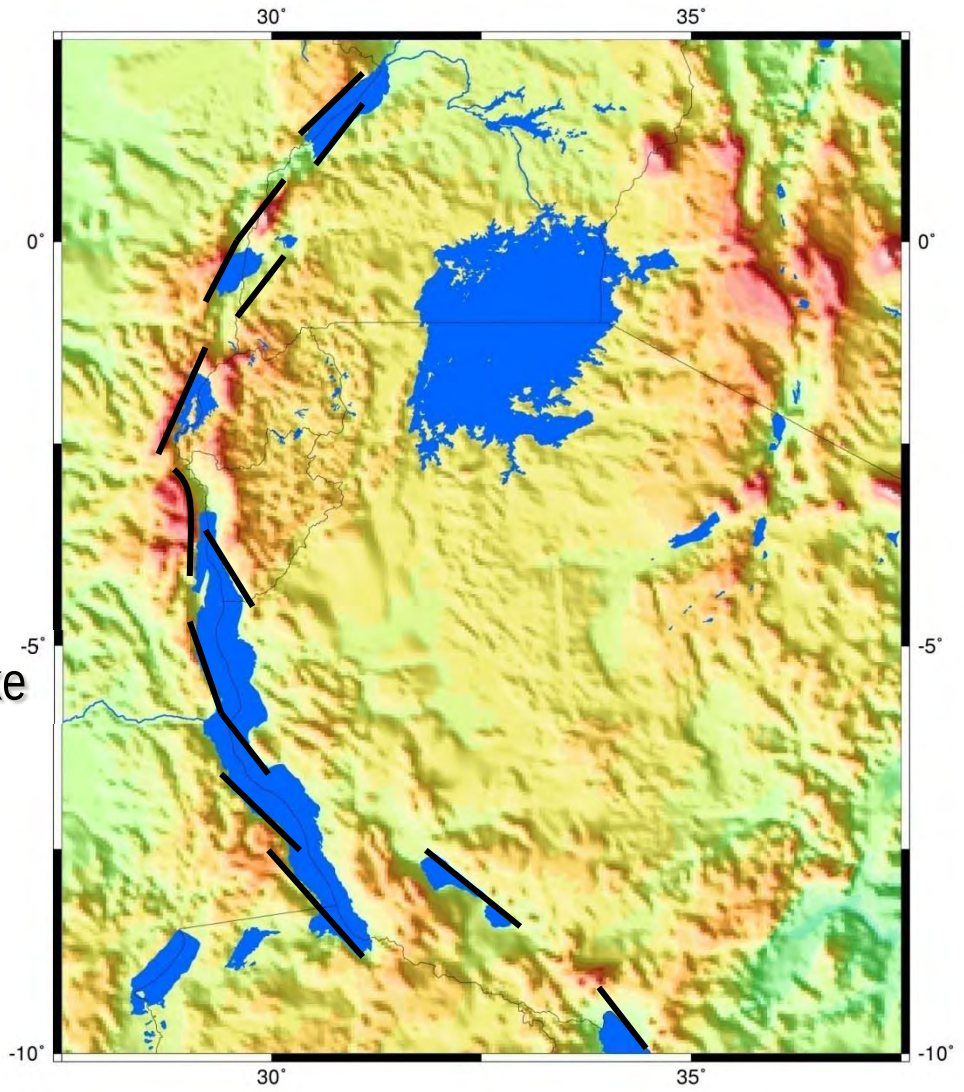


- East African Rift System is a classic example of the initiation processes of continental break up
- 3500 km long, 50-150km wide
- Two dominant trends; eastern and western branch
- Eastern branch, initiated Early Miocene (20 Ma), is more volcanic
- Oceanic crust indicative of continental break up already manifest at the Afar depression
- Western branch, initiated during Mid Miocene (17 Ma), is less volcanic and contains lakes Malawi, Tanganyika and Albert
- Extension direction WNW -ESE

INTRODUCTION

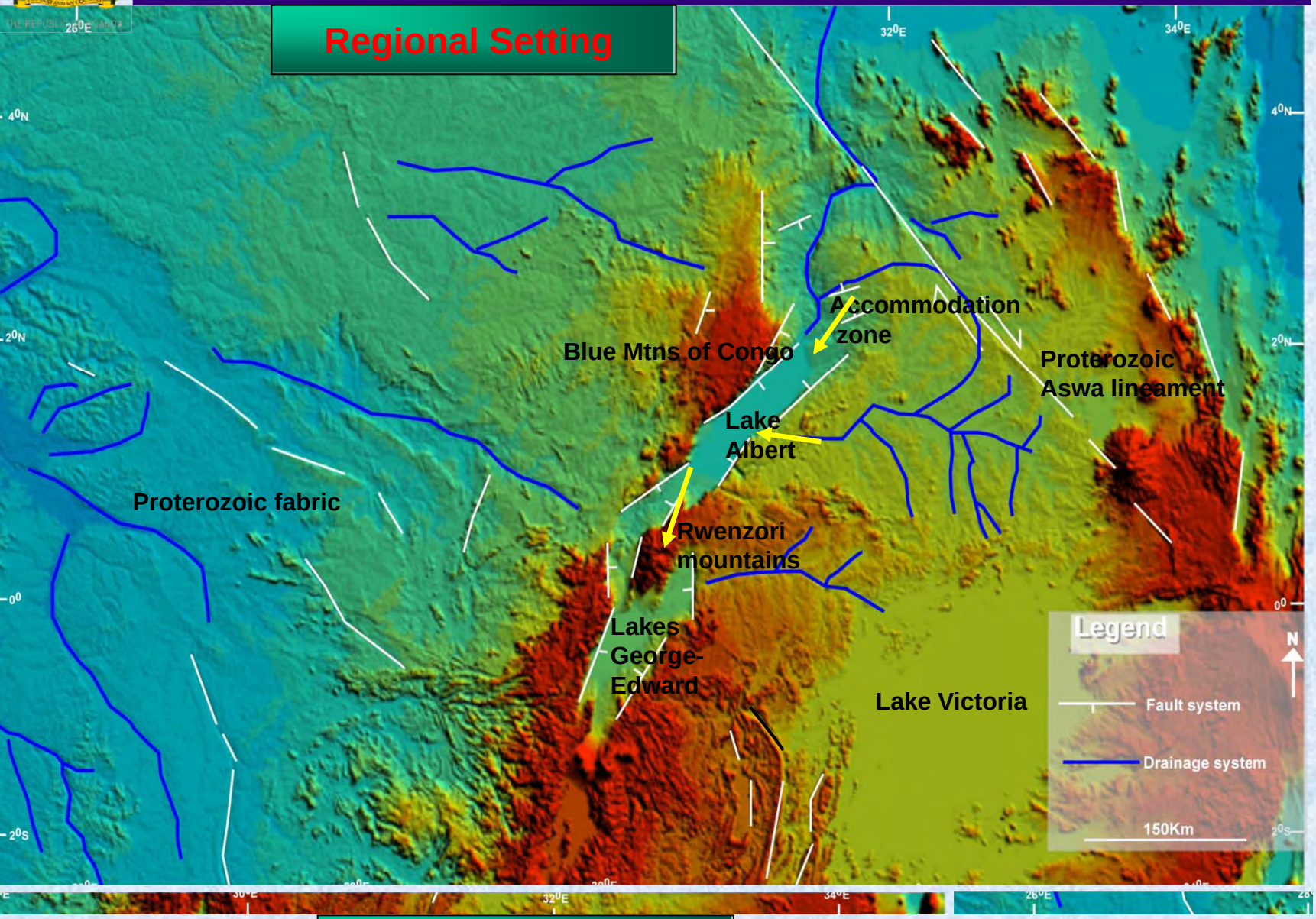
Regional Setting

- The Albertine graben is the northern most part of the Western branch of EARS
- Segmented into ~ 80-130 km long basins
- Rifting avoided the stable cratons, Utilised the mobile cratons, Pre-Cambrian fabric influenced rift orientation and geometry
- Central/southern basins (Kivu, Tanganyika, Malawi) show half-graben geometry, while Lake Albert basin previously not well studied shows an almost full graben geometry
- Recent volcanism reported only from Lake Edward/Kivu parts of the graben



INTRODUCTION

Regional Setting



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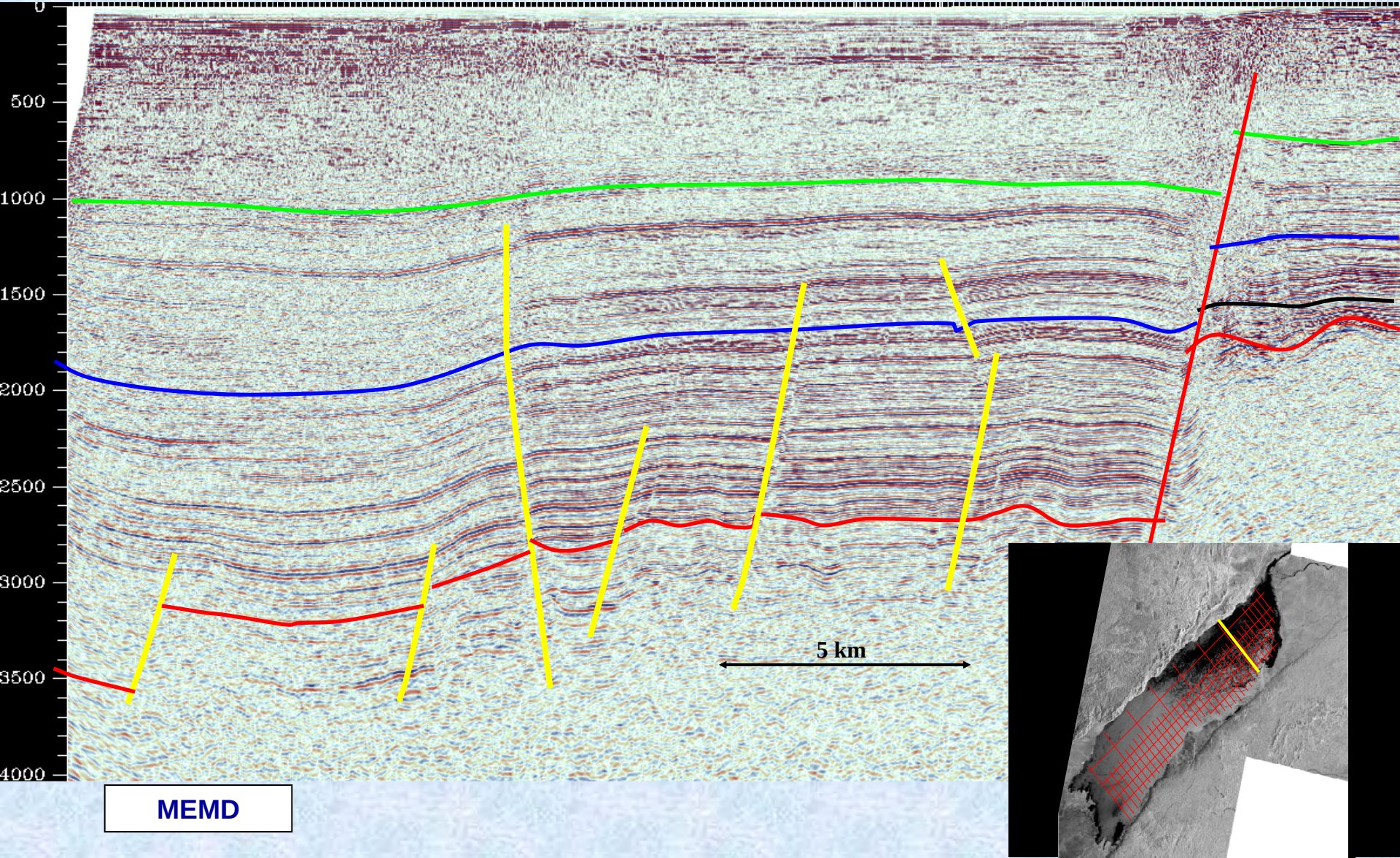
Source of map: ftp://e0srp01u.ecs.nasa.gov/

STRUCTURAL SETTING

Dip line section across Lake Albert

NW

SE



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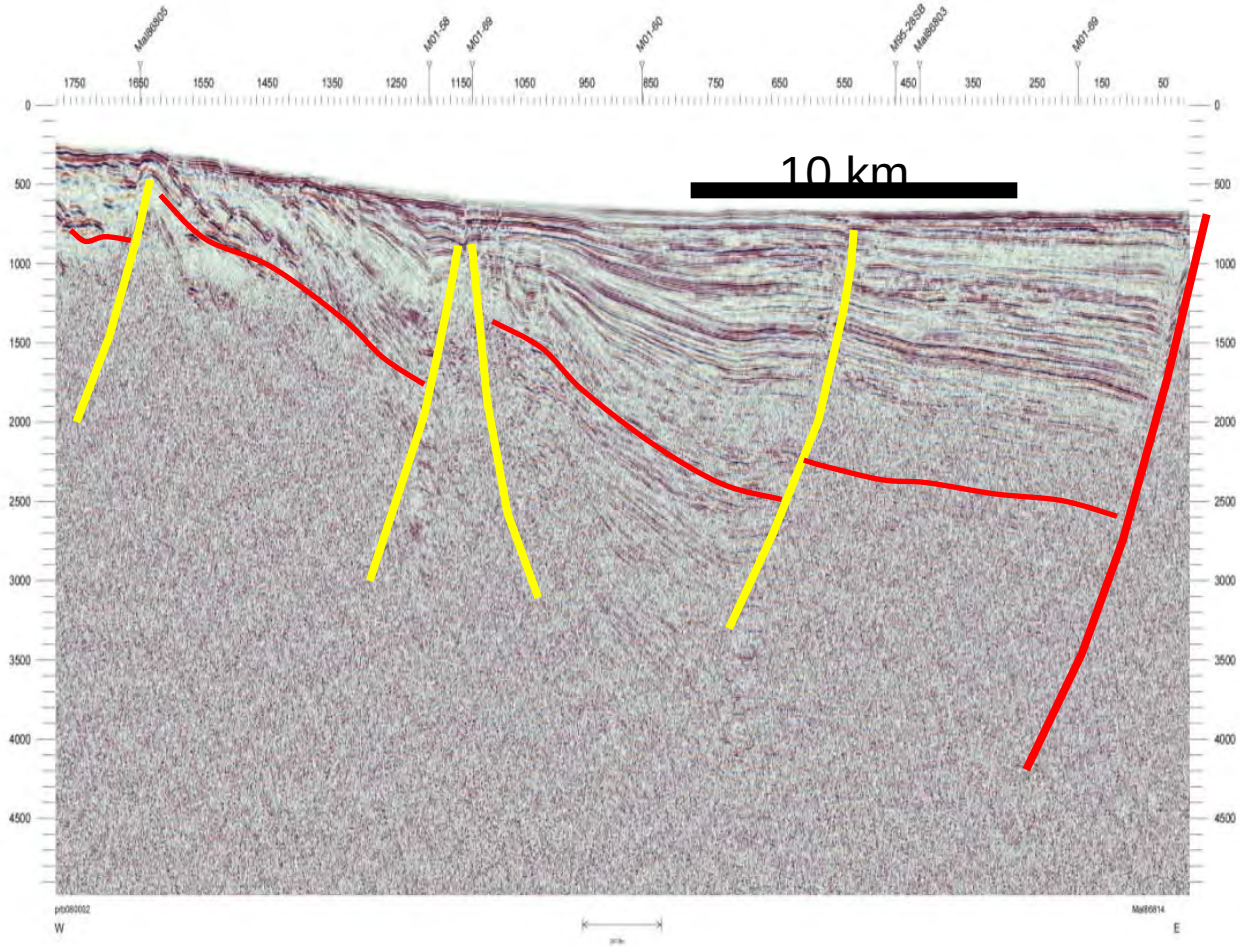
STRUCTURAL SETTING

Dip line section across Lake Malawi



Half-graben geometry of the Malawi rift compared to an almost full Graben geometry of the Albertine graben

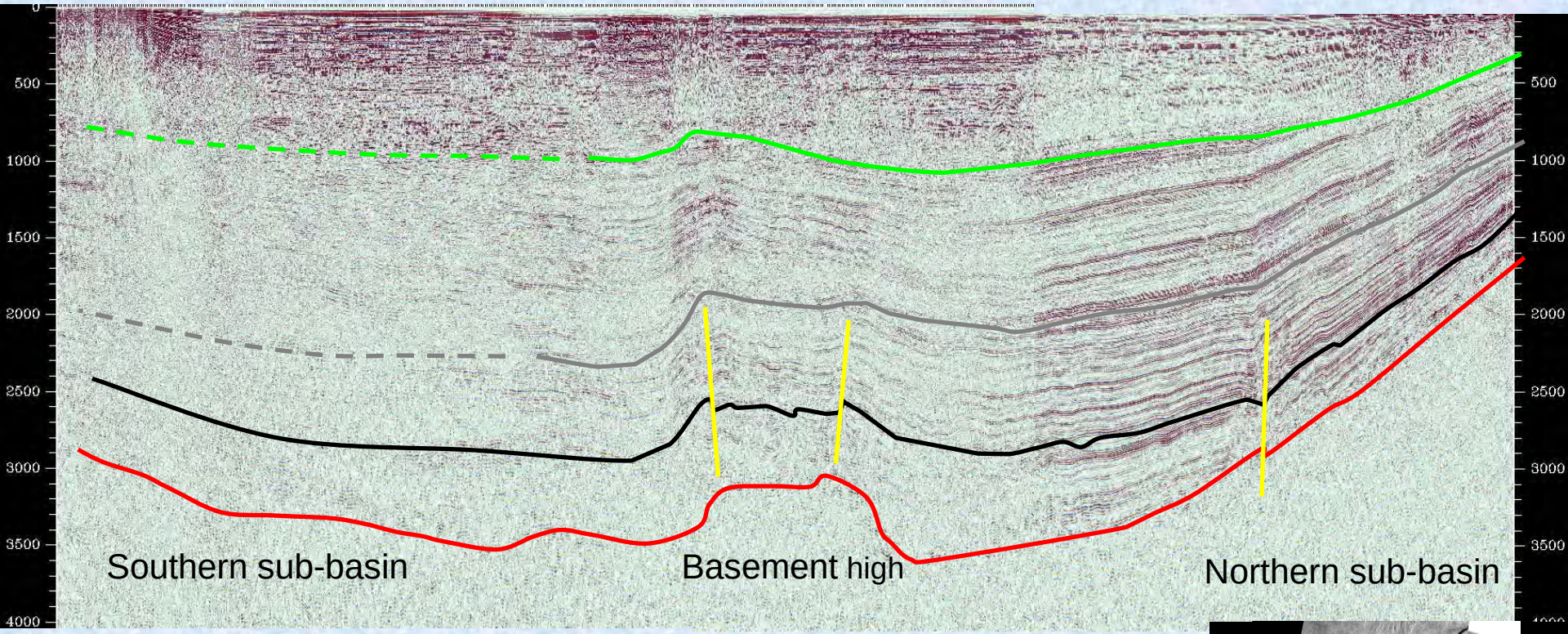
Courtesy: Chris Scholz

STRUCTURAL SETTING

Strike line section along Lake Albert

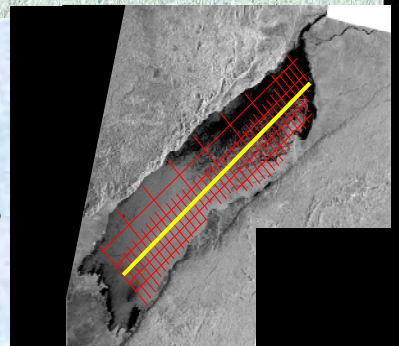
S

N



Along strike: Broad along strike synclinal structure divided by a basement high

Poor resolution in southern basin probably due to shallow gas



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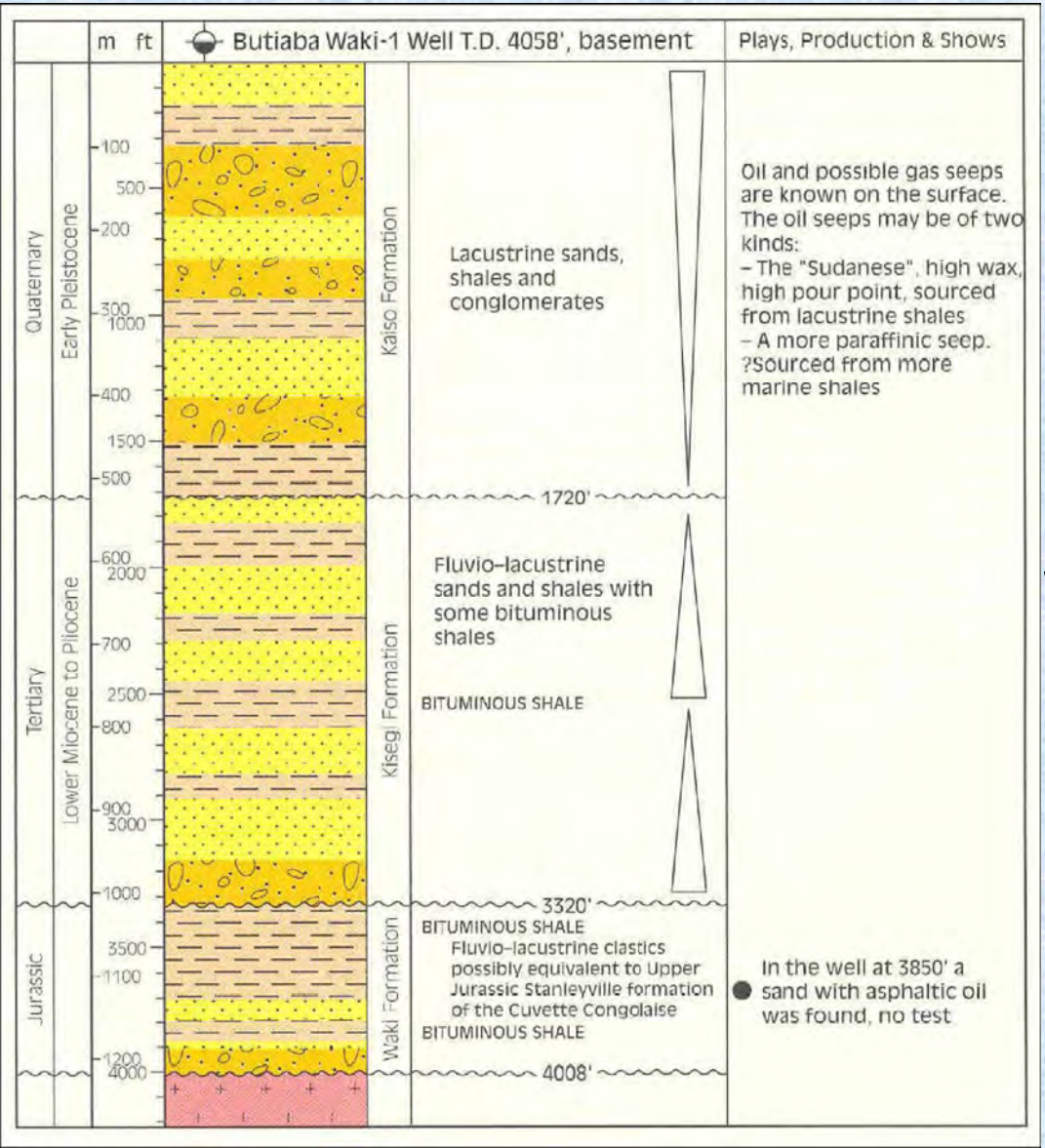
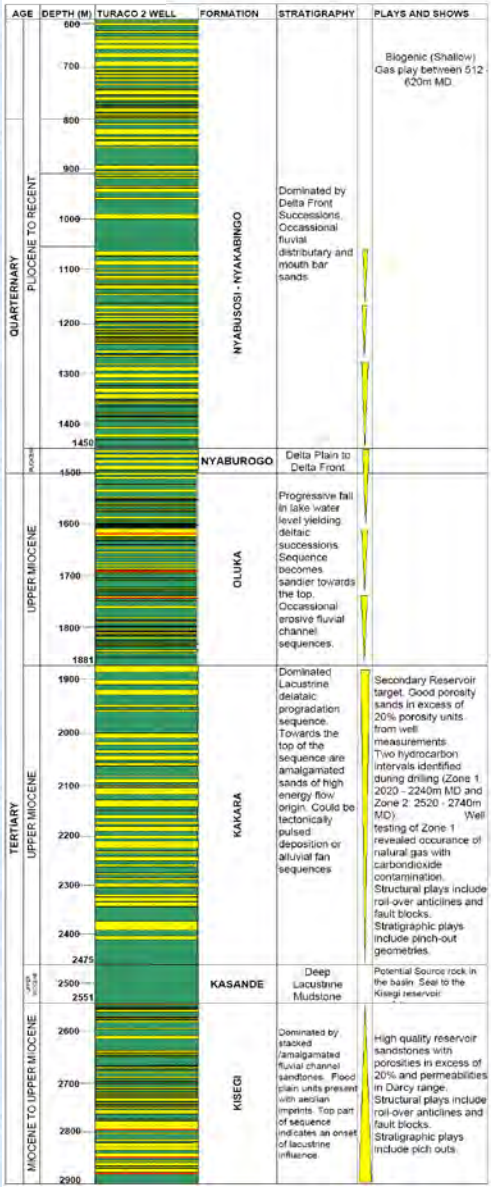
CHRONOSTRATIGRAPHY OF THE GRABEN

Interpreted from Waki -1 and Turaco well logs



The ages were deduced from surface exposure dating and wells from neighbouring basins



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CHRONOSTRATIGRAPHY OF THE GRABEN

Interpreted from age dating of Kingfisher and Turaco wells

Period	Epoch	Group	Formation
Quaternary	-	Recent	
	Holocene	H2	
		H1	
	Late Pleistocene	PL2	PL2b
			PL2a
	Early Pleistocene	PL1	PL1b
			PL1a
Tertiary	Late Pliocene	P4	P4b
			P4a
		P3	P3b
			P3a
	Early Pliocene	P2	P2d
			P2c
			P2b
			P2a
		P1	P1e
			P1d
			P1c
			P1b
			P1a
	Late Miocene	M6	M6c
			M6b
			M6a
		M5	M5c
			M5b
			M5a
Pre-Mesozoic	?Permo - Trias?	Karoo	
		Meta Sediments	Weathered Zone
			Chlorite Schist

Proposed Chrono-Stratigraphic Units after dating by Heritage oil and Gas Ltd on the Kingfisher and Turaco wells (2009)

EXISTENCE OF A PETROLEUM SYSTEM

Source Rock

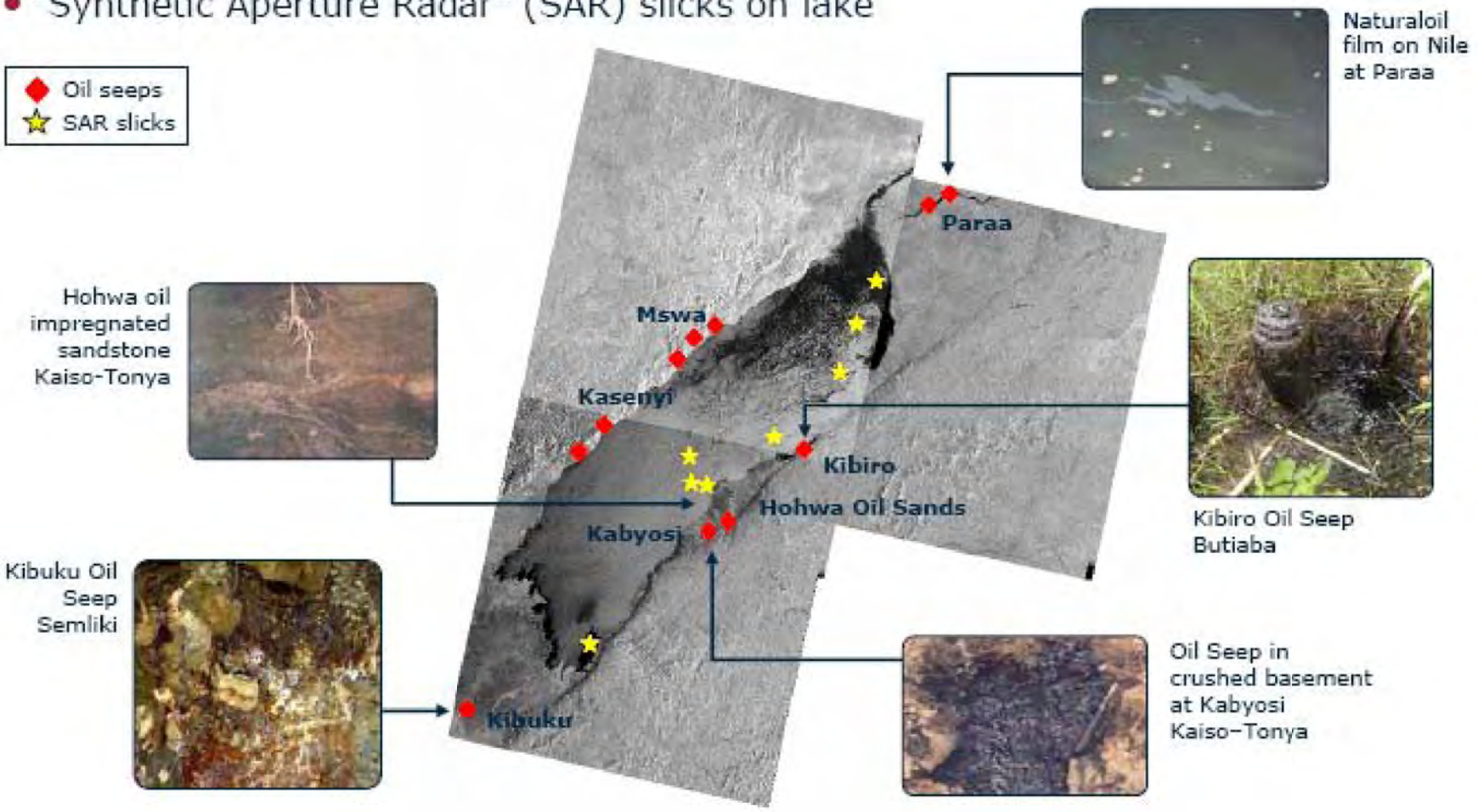
- Rocks with good source potential have been mapped in the Graben at Kaiso
- Good source rocks reported in the Waki B-1 well in Butiaba
- Thick sequences of high quality lacustrine mature source rocks encountered in the wells drilled in the Graben

Kaiso shale exposed on the shores of Lake Albert

EXISTENCE OF A PETROLEUM SYSTEM

Oil Seeps along basin margin faults

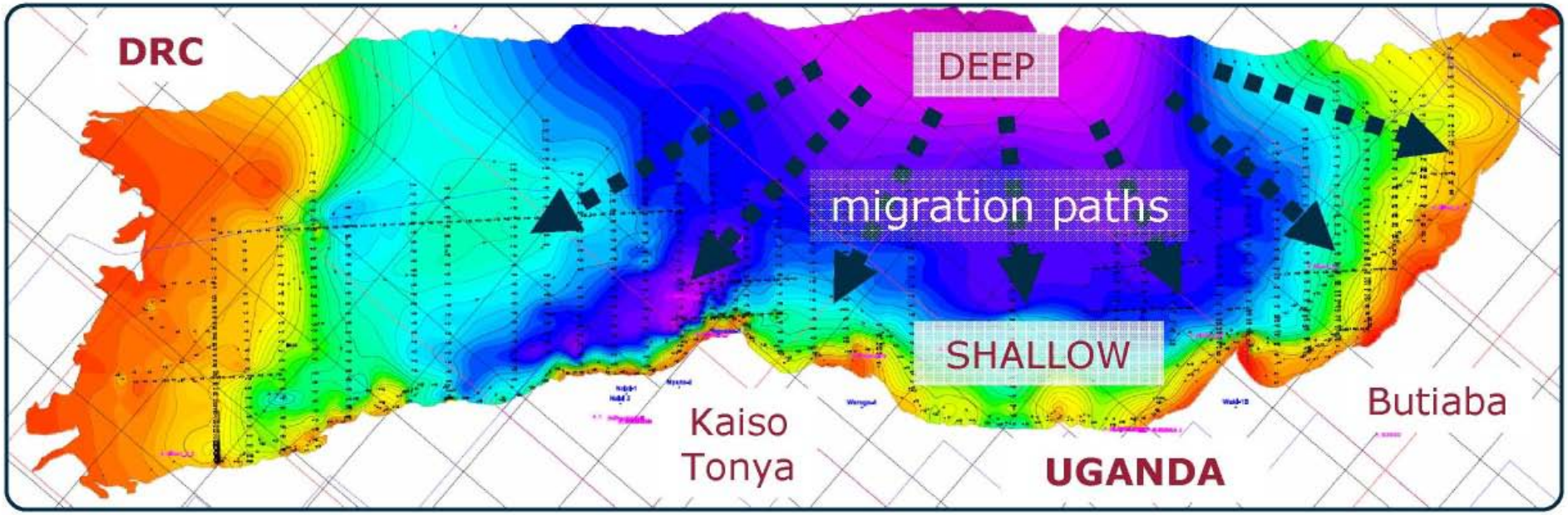
- Abundant surface oil seeps (no sulphur, waxy, 30-34° API in wells)
- "Synthetic Aperture Radar" (SAR) slicks on lake



Oil seeps and drilled wells indicate that oil has been generated and expelled

EXISTENCE OF A PETROLEUM SYSTEM

Lake Albert depth map

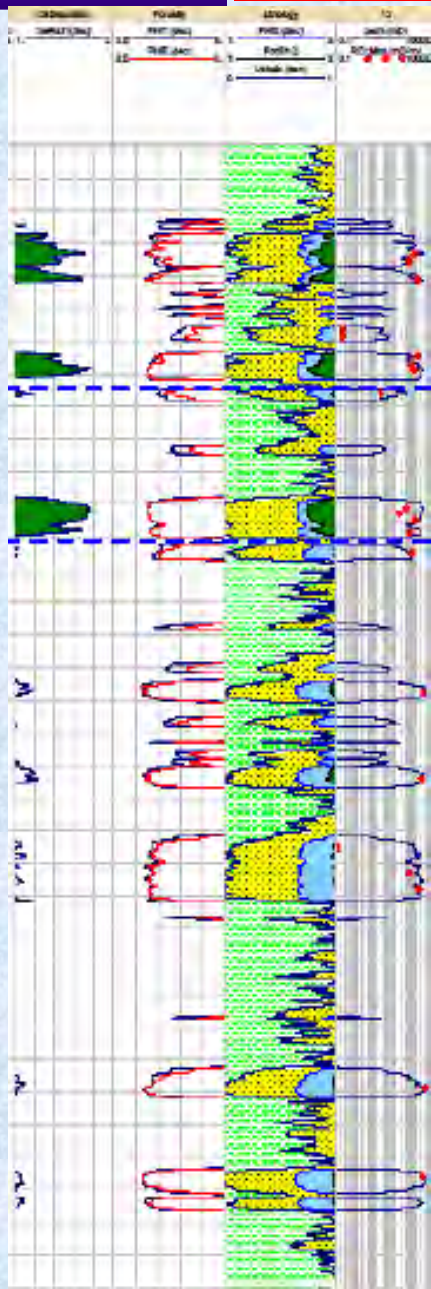


- Up to 6km of sediments interpreted in the depocentre
- Sufficient for source rock maturation given high geothermal gradient (28 – 67)^{0}c/km
- Efficient migration predicted from drilled wells and oil seeps

EXISTENCE OF A PETROLEUM SYSTEM

Reservoir Rocks

Excellent reservoir quality sandstones identified during geological mapping

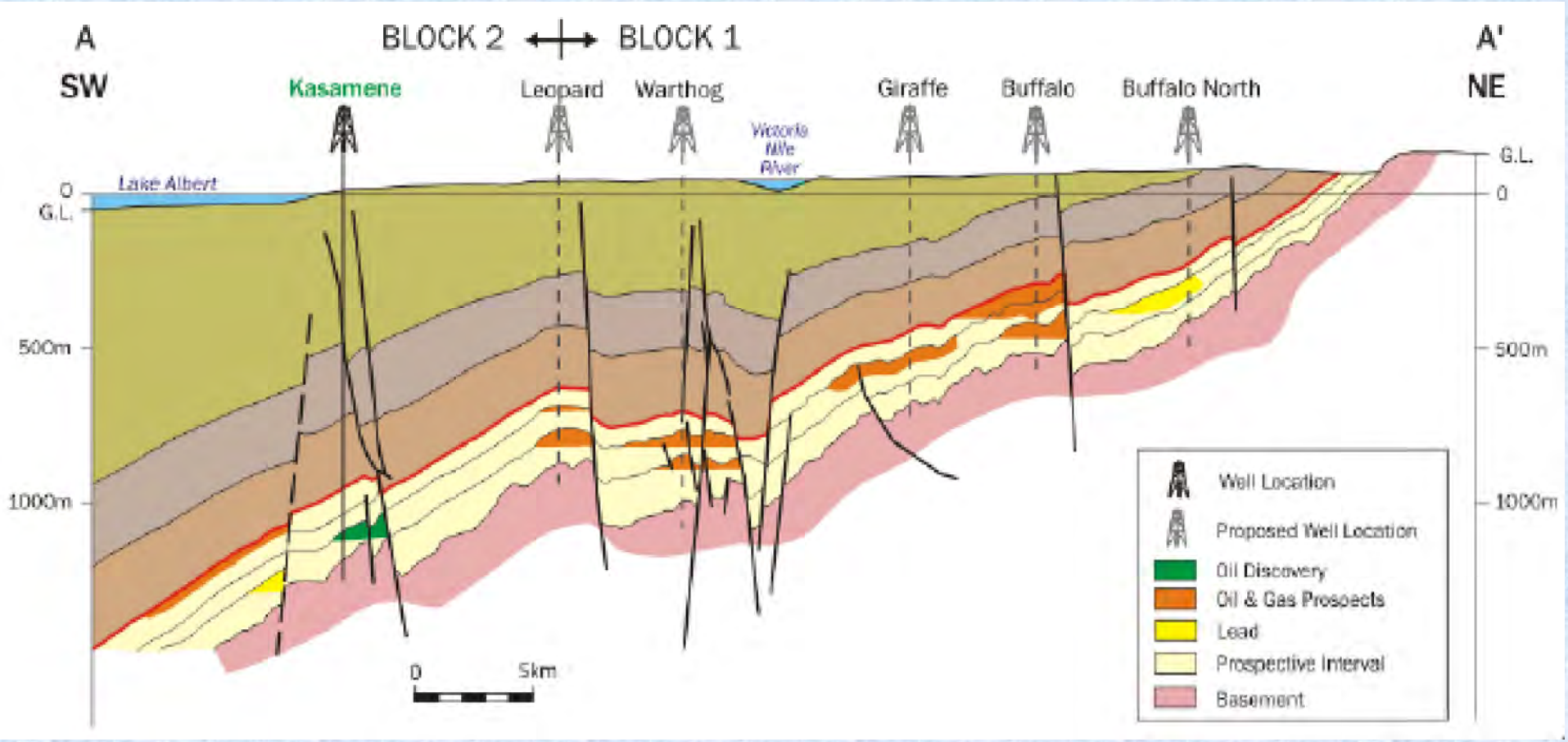


Drilling has confirmed stacked, high quality reservoir rocks in the subsurface

Porosities of between 20-30%

EXISTENCE OF A PETROLEUM SYSTEM

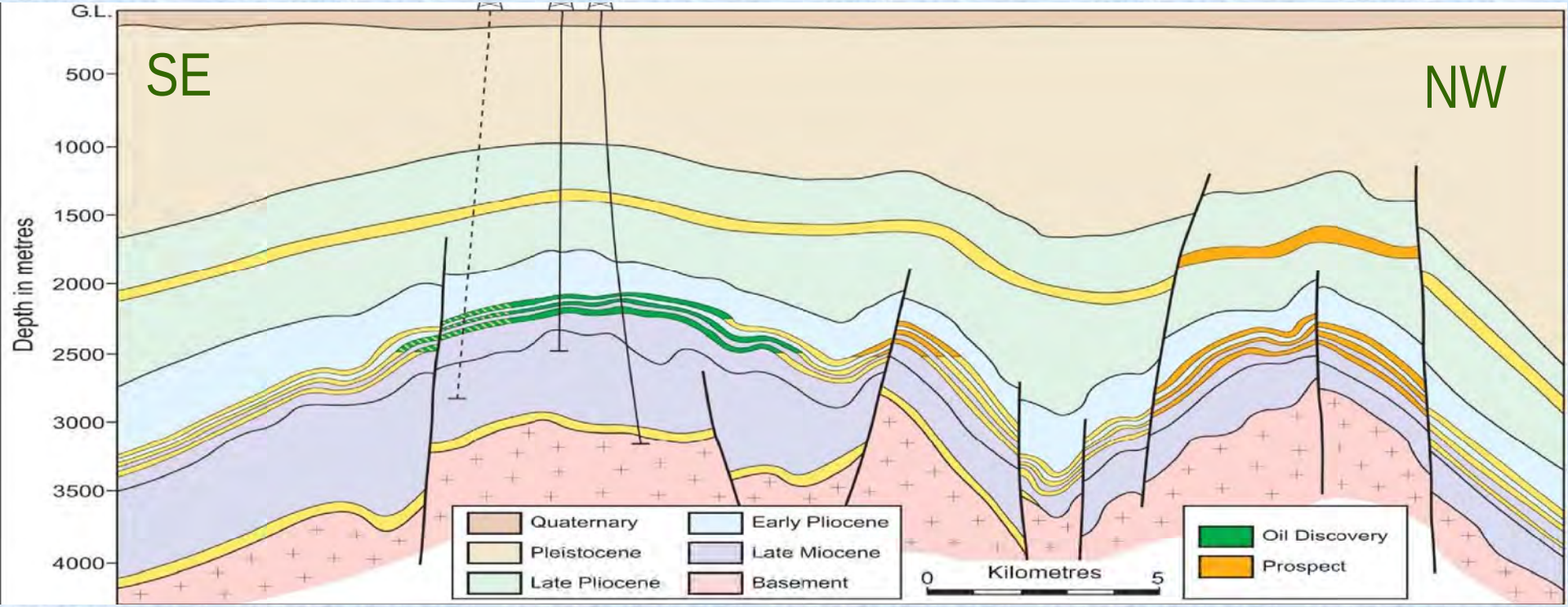
Traps



Nile delta play characterised by tilted fault blocks (Dip line)

EXISTENCE OF A PETROLEUM SYSTEM

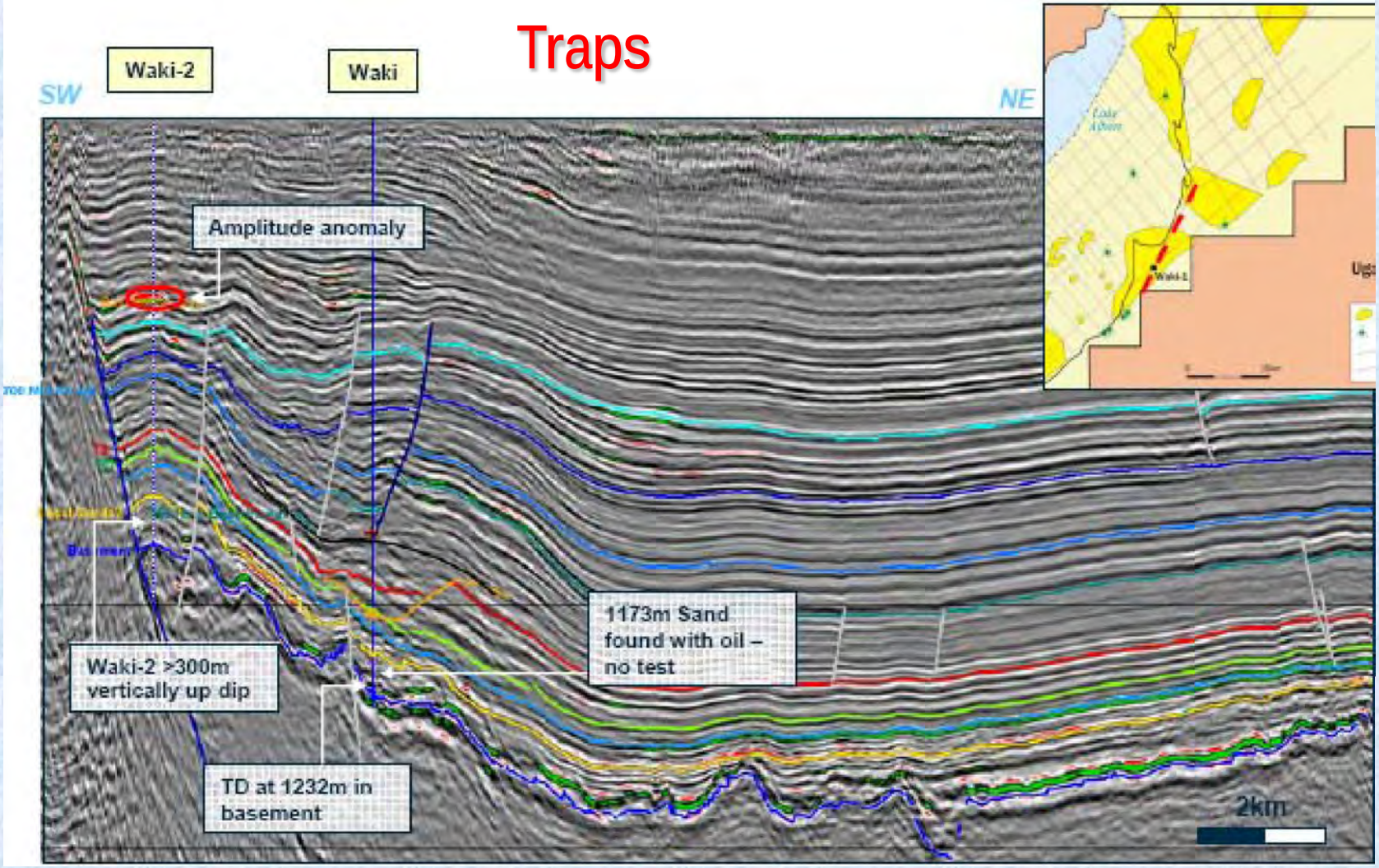
Traps



Nile delta play characterised by tilted fault blocks (Strike line)

EXISTENCE OF A PETROLEUM SYSTEM

Traps



Basin margin play characterised by hanging wall anticlinal closures resulting from compression

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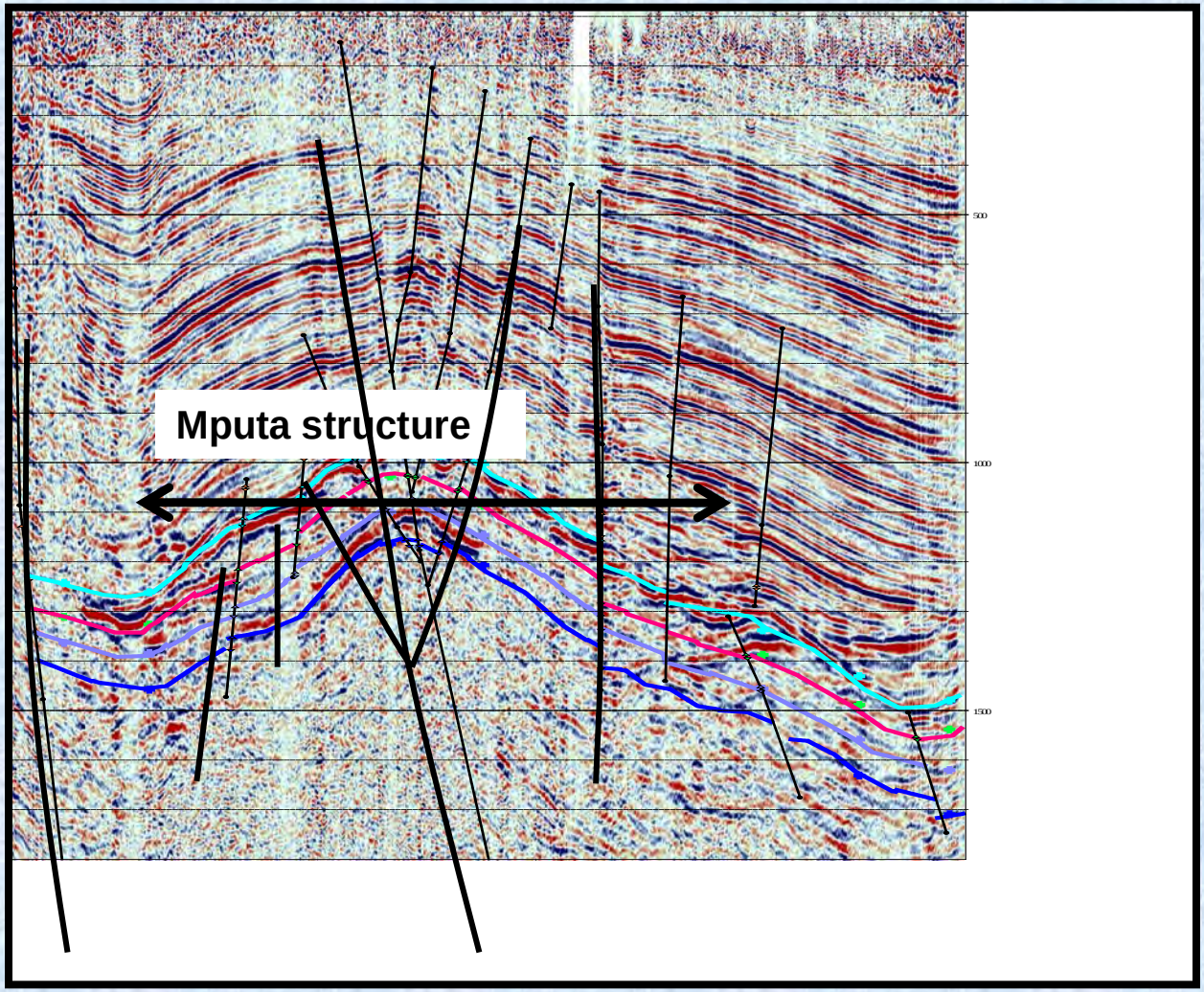
EXISTENCE OF A PETROLEUM SYSTEM

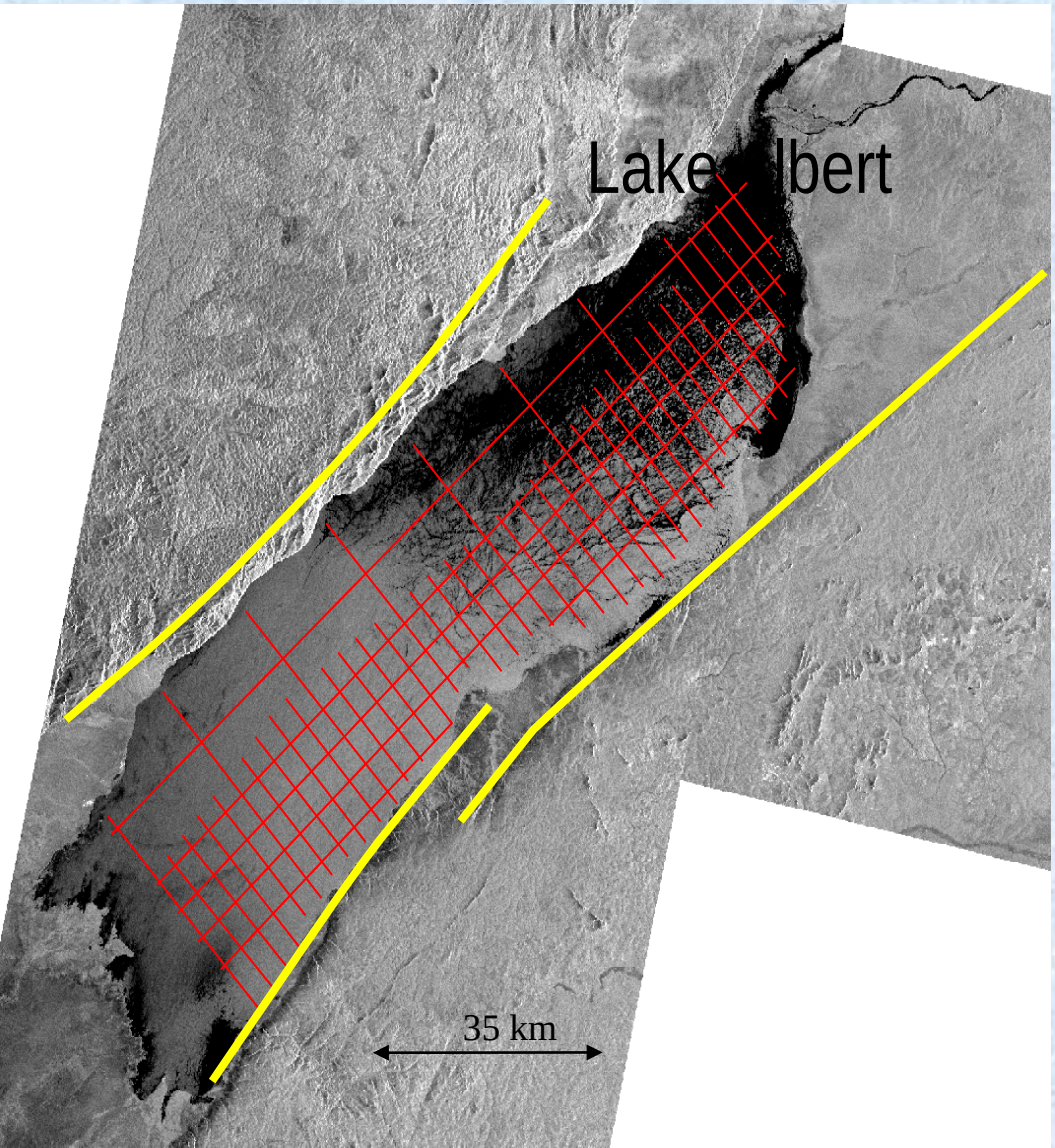
Traps



Basin margin play characterised by hanging wall anticlinal closures resulting from compression

EXISTENCE OF A **PETROLEUM SYSTEM**

Petroleum generation in a young rift

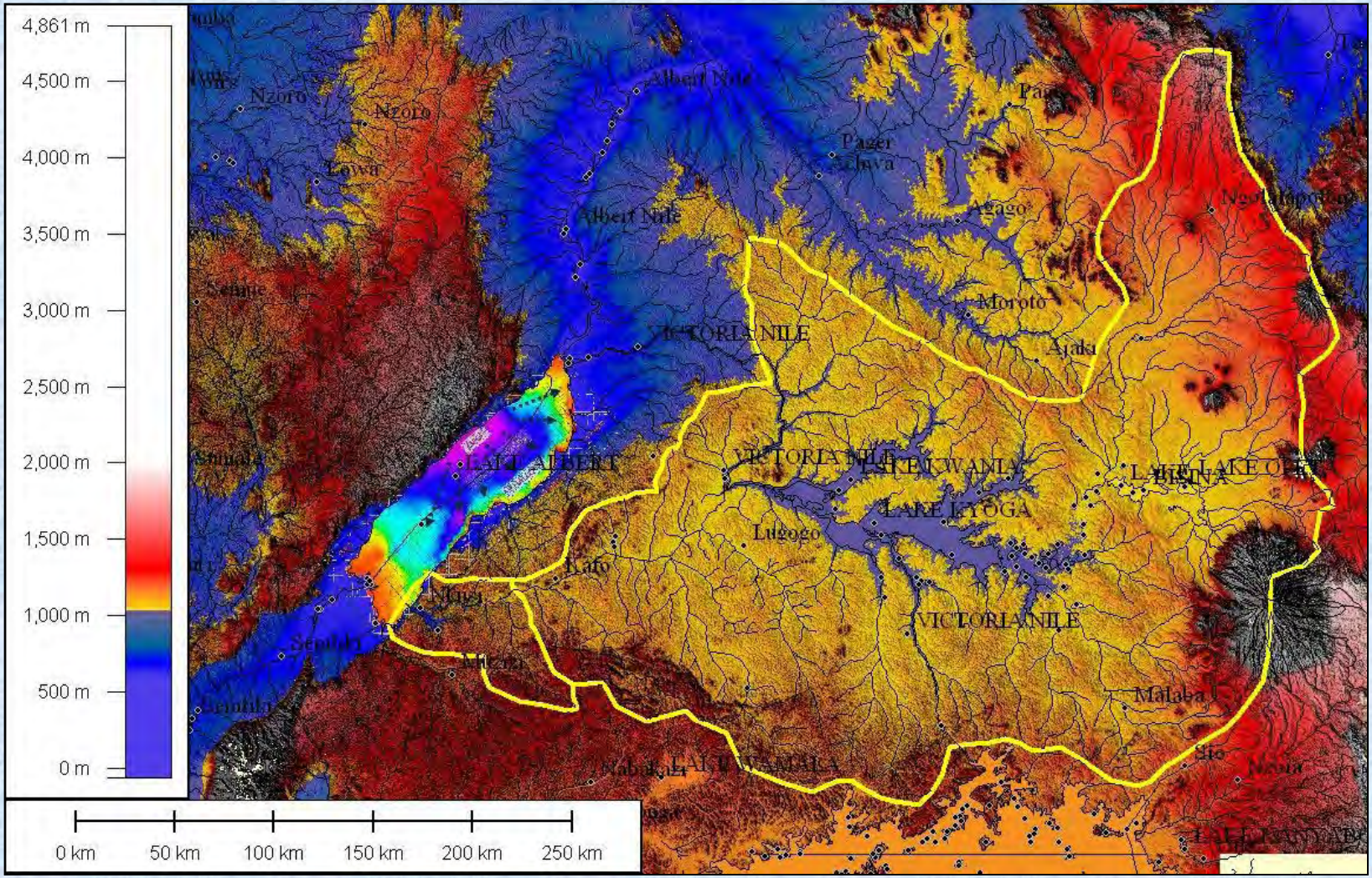


Graben controlled by

- One major basin bounding fault to the west
- Two relay faults to the East
- Full Graben diverted drainage and limited clastic sediment input into the basin enabling deposition of source rock

EXISTENCE OF A PETROLEUM SYSTEM

Petroleum generation in a young rift



Drainage diversion created by footwall uplift

EXISTENCE OF A PETROLEUM SYSTEM

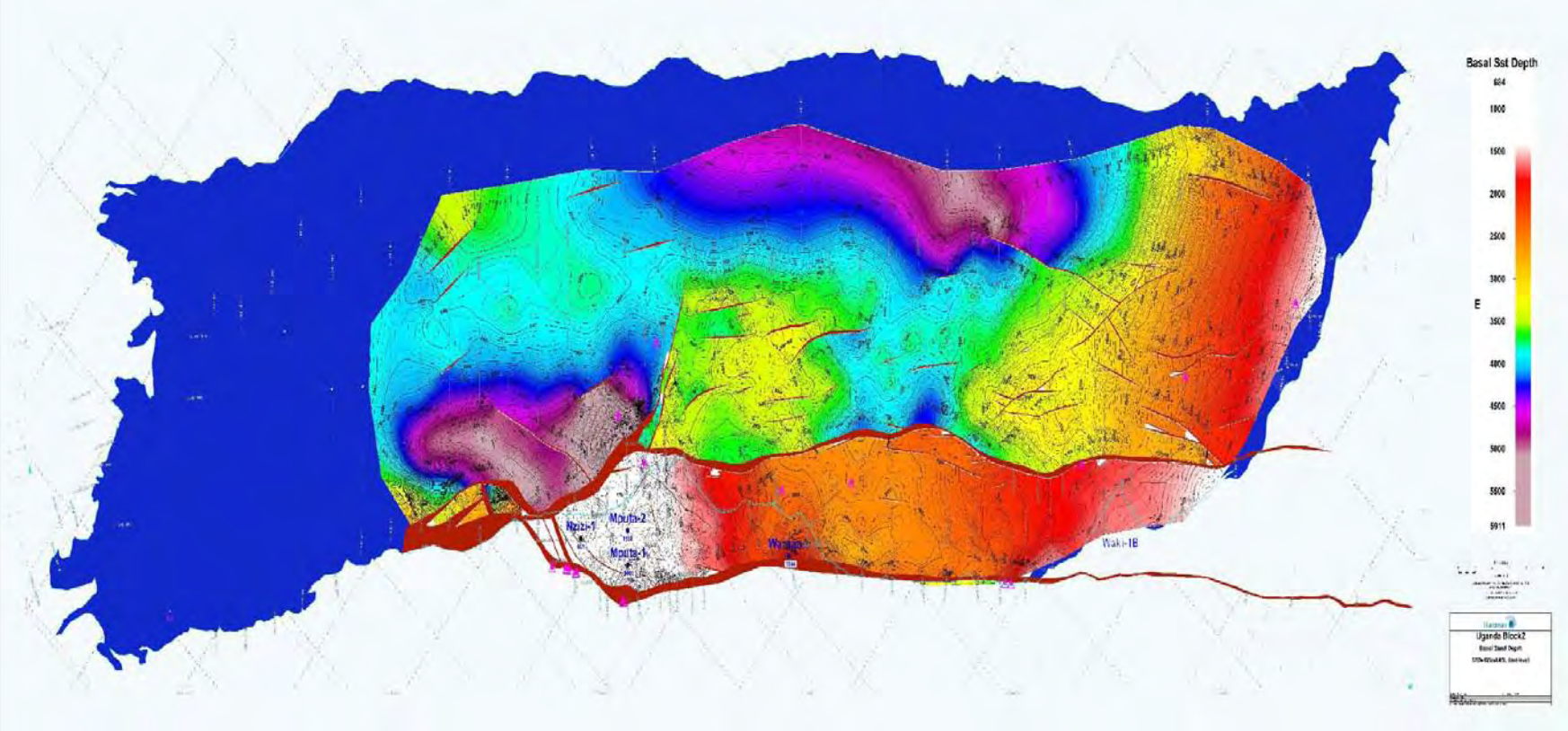
Petroleum generation in a young rift

MEMD

Abandoned river channels that flowed to the west

EXISTENCE OF A PETROLEUM SYSTEM

Petroleum generation in a young rift



Rapid subsidence, coupled with limited clastic sediment input created deep stratified lakes with deposition of organic rich source rock

EXISTENCE OF A PETROLEUM SYSTEM

Petroleum generation in a young rift

- The Sempaya hot springs in the graben indicate high geothermal gradient
- The geothermal gradient interpreted from well data indicate up to 67^0 c/km
- The geothermal gradient is sufficient to mature source rock at 2.5 km depth

CONCLUSION

- The East African Rift System of Early Miocene is a classic example of the initiation of continental break up. Oceanic crust is already manifest in the Afar depression

- The available geophysical and geological data in the Albertine Graben indicate that rifting was initiated from the western side during mid Miocene about 17 ma

- Hydrocarbon Exploration in the Albertine graben has confirmed presence of a working petroleum system in a young rift basin.

CONCLUSION

- The reasons behind early hydrocarbon generation and accumulation are not obvious but could include:
  - Limited clastic sediment input during initial stages of rifting coupled with rapid subsidence creating deep stratified lakes
  - High geothermal Gradient
  - Late episode of compression creating structural traps

- Geologic Joke: At the oil discovery in the Albertine Graben, one of the Geologists remarked that ‘geologists who were living during deposition of the reservoirs, are still living to witness the same reservoirs accumulate hydrocarbons’.

Thank You