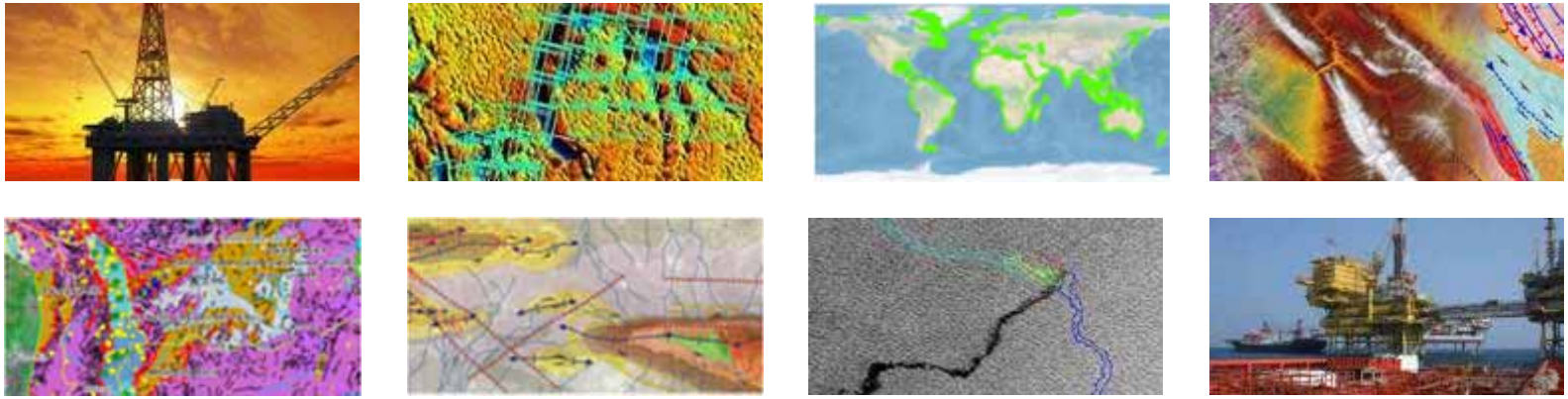

The East African Rift System – The Contribution of Earth Observation to Hydrocarbon Exploration

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All the space you need

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- Introduction
- Regional setting
- Earth observation datasets
- Review of key geological features

GEO-Information Services within Astrium and EADS

** France, Germany, UK, Spain, Netherlands*

GEO-Information Services: Key Facts & Figures

- Staff: +900, located in 12 countries
- Combining the talent and capabilities of Spot Image and Infoterra teams, integrated within the GEO-Information division of Astrium Services
- An international network of partners & customers

Satellite Imagery

- A satellite operator, with strong partnerships with other operators and our own airborne capabilities
- Multi-source, multi-resolution optical & radar satellites down to 50cm:
- **PLEIADE-1, SPOT 4 & 5, FORMOSAT-2, DEIMOS,**
- **TerraSAR-X, TanDEM-X,**
- **Coming soon: PLEIADE-2, SPOT 6 & 7**

Introduction

- **East African Rift increasingly viewed as an hydrocarbon exploration hot spot:**
  - **Discoveries in the Albertine Rift and Turkana County, Kenya**
  - **Offshore discoveries in Tanzania and Mozambique**
  - **Common oil seeps**
- **Lack of consistent regional datasets and seismic information**

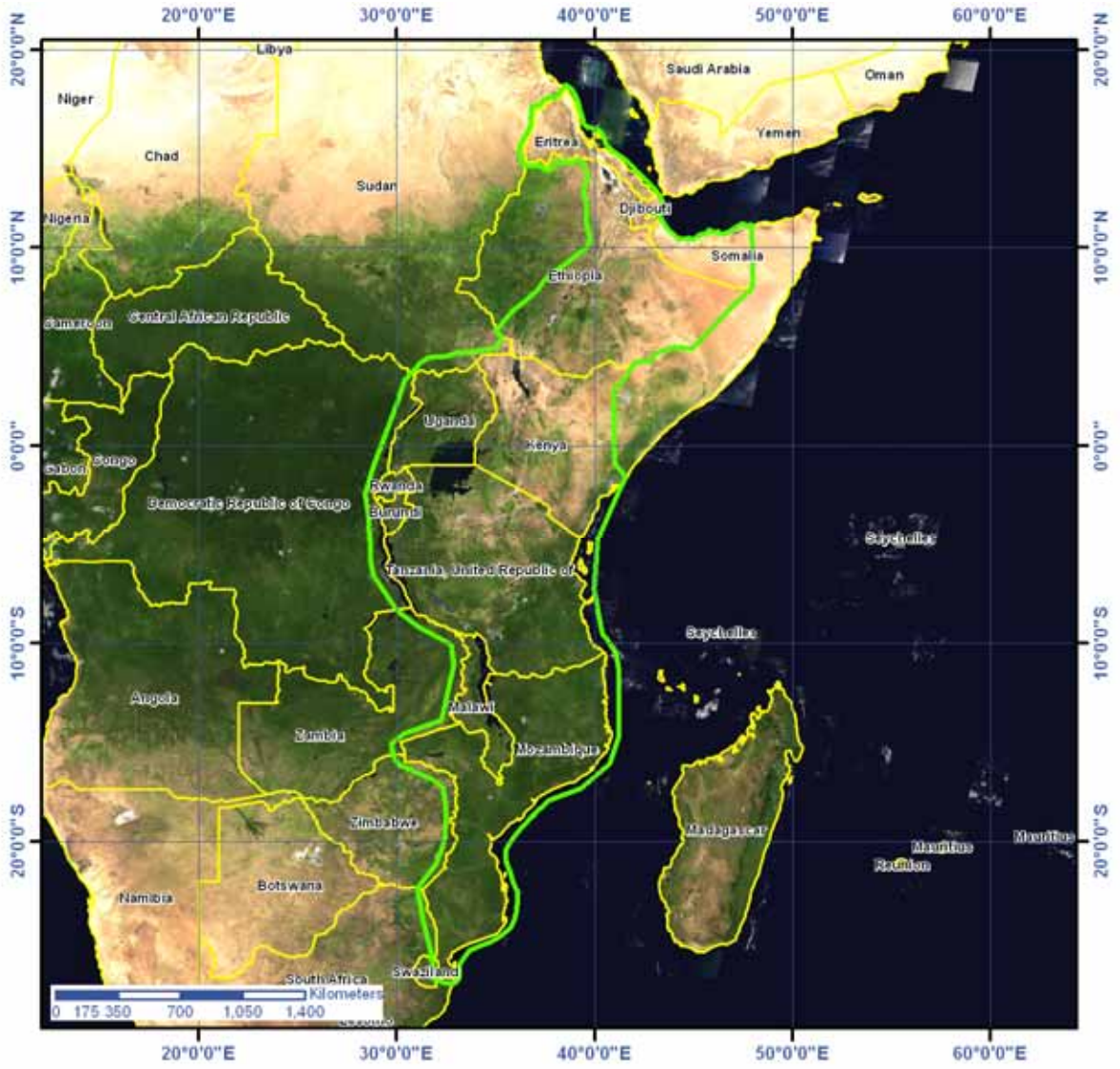
Potential for a consistent regional interpretation of surface geology and oil seep location to provide geological context and to assist in guiding further exploration activity

- **Geological remote sensing:**
  - **Retrieval of surface geological information from satellite imagery is a proven mature technique**
  - **Astrium's experience in producing the Global Seeps Database of hydrocarbon seeps in offshore basins, enabled the effective cataloguing of offshore and lake oil seeps**

Why Use Remote Sensing Data?

- **Enables the interpretation of onshore surface geology, which can indicate subsurface structure**
- **Large areas can be rapidly interpreted as an initial assessment of regional geology in a cost effective manner**
- **Valuable in areas where access difficulties make seismic data difficult or expensive to obtain**
- **Exploration can be targeted to key areas**
- **Enables the detailed study of surface geology at the licence block scale using high resolution data**
- **Offshore and lake oil seeps can be directly observed using Radar data**

EARS Study Area



- Study area covers ~4.5 million square km
- Elongate system of extensional faults, extending 5000km in a general N-S direction
- Characterised by two rifting trends defined as the Eastern and Western Branches
- Several phases of rifting have occurred with significant overprinting between events

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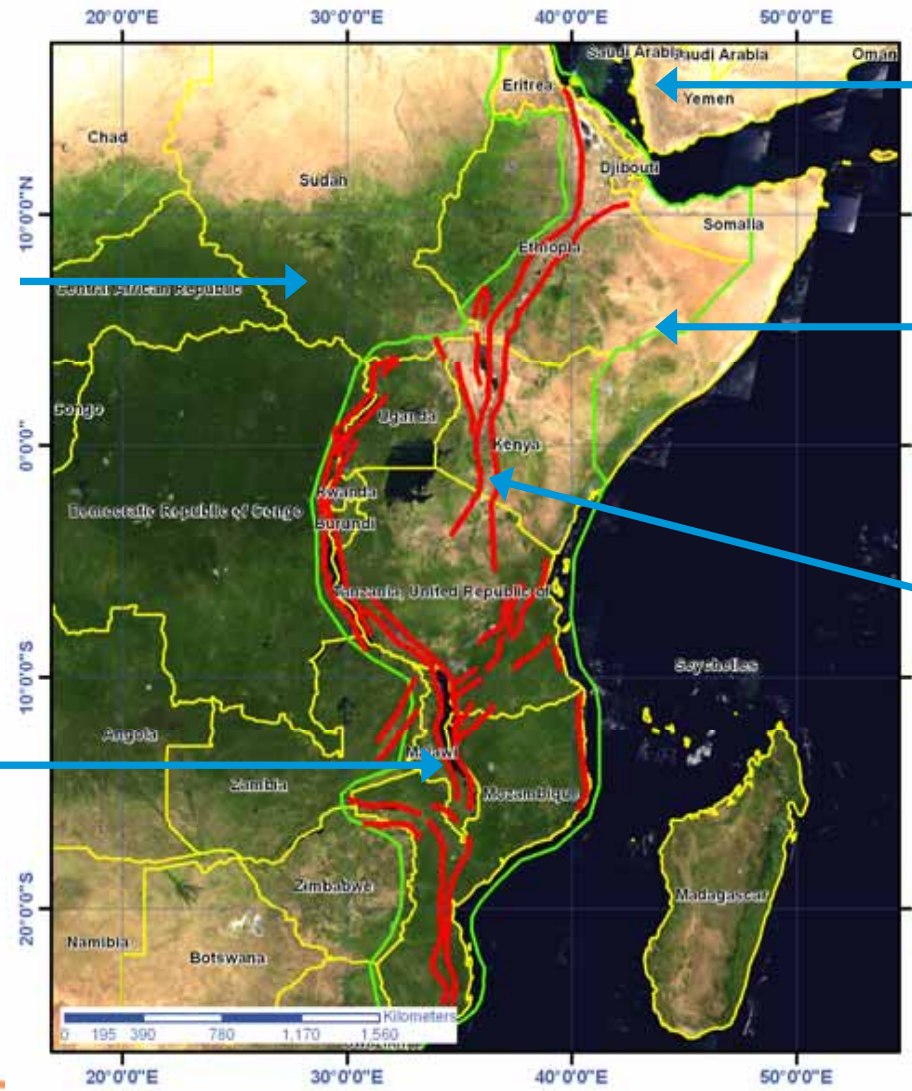
Regional Setting



African Plate - Nubian

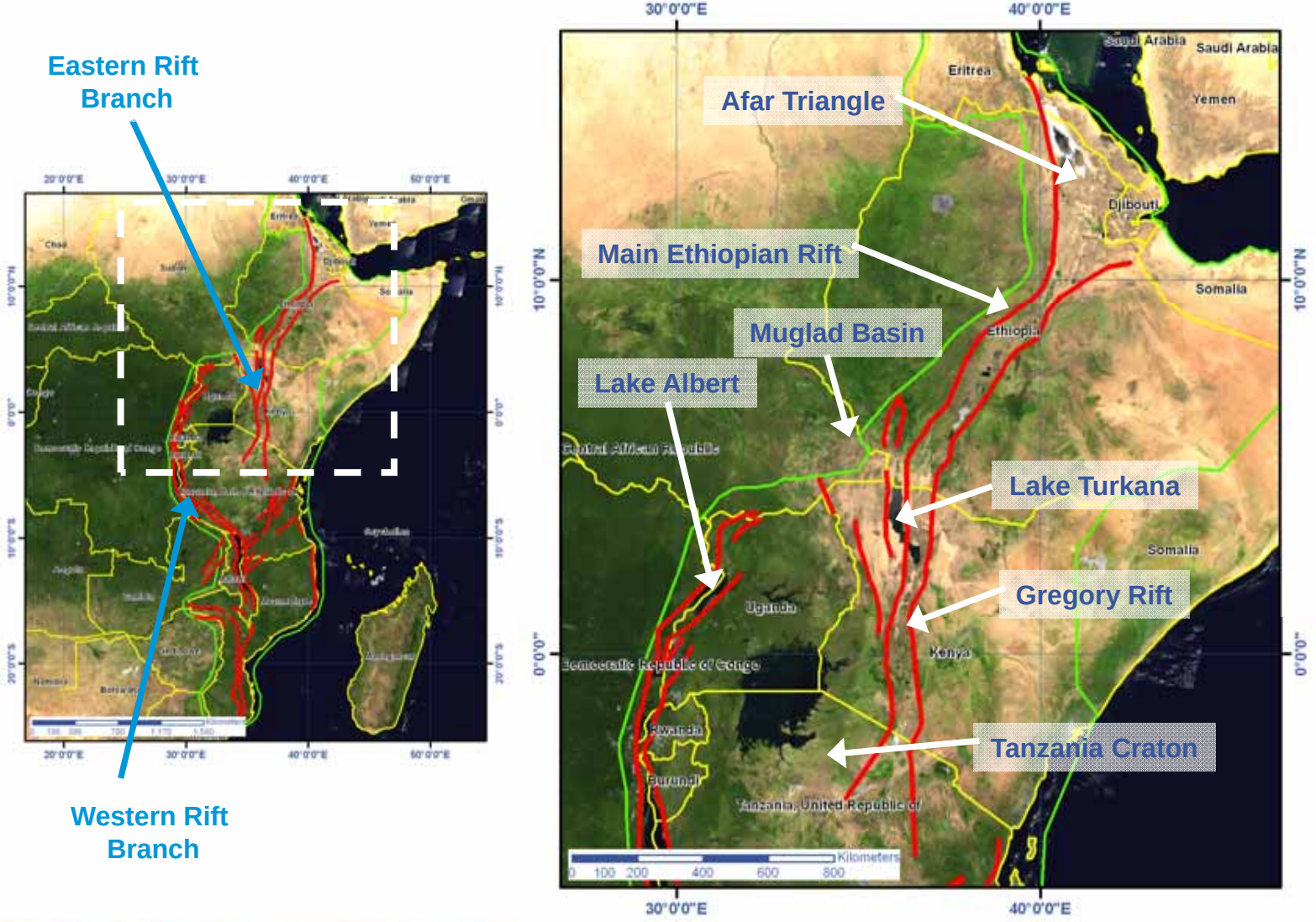
Arabian Plate

African Plate - Somalian

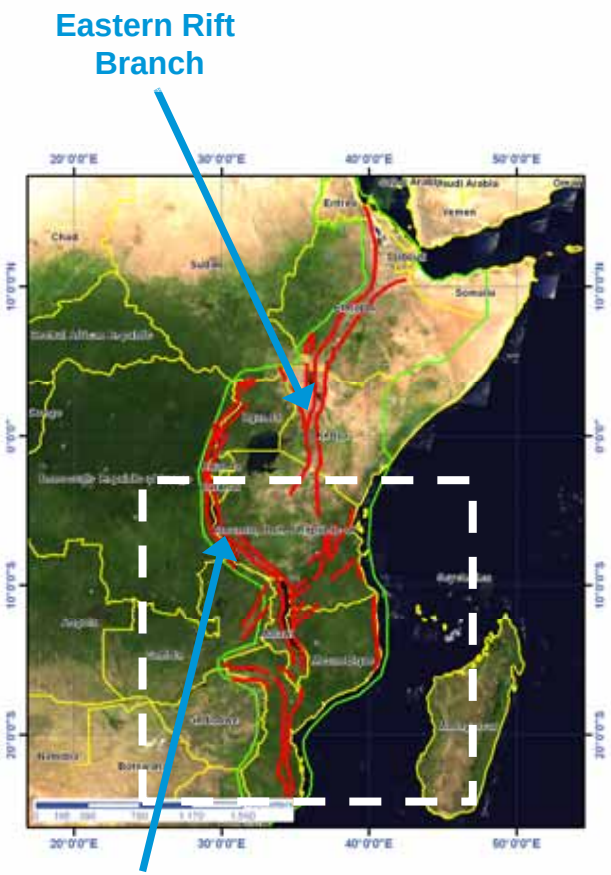
Eastern Rift Branch

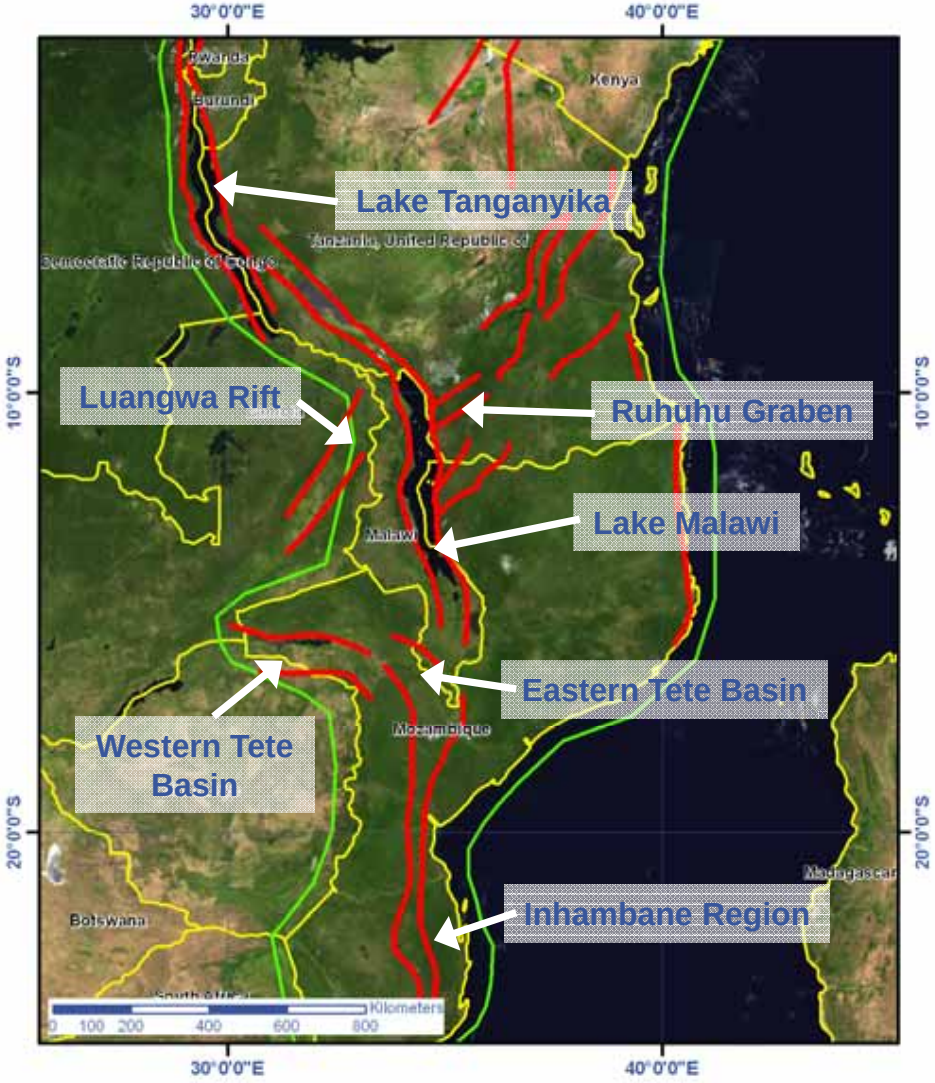
Western Rift Branch

Regional Geological Setting - Major Rift Features (North)

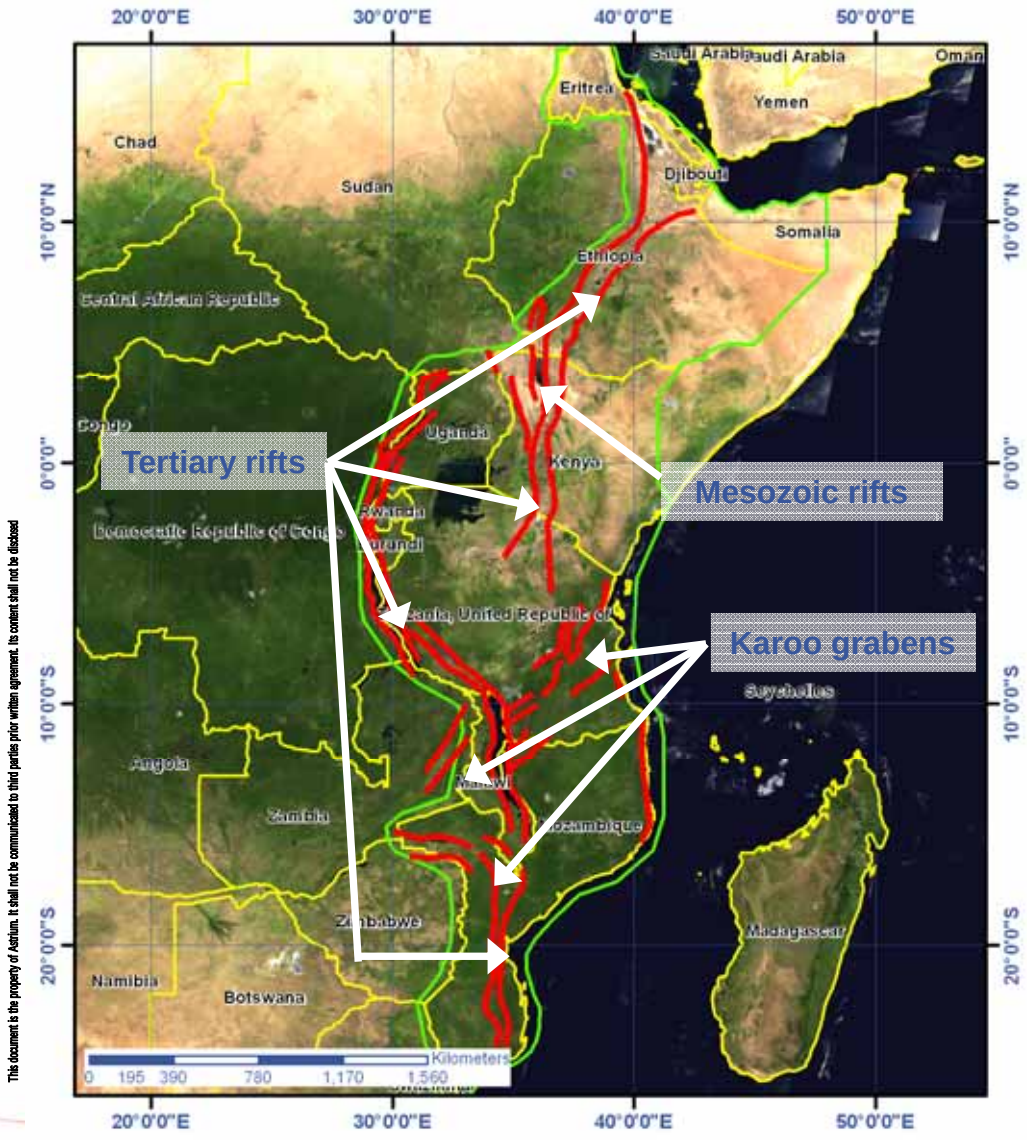


Regional Geological Setting - Major Rift Features (South)





Main Rifting Events



- Main Rifting events:
  - Permian to Jurassic
  - Mesozoic
  - Tertiary-Quaternary
- Karoo grabens represent the Early Permian to Early Jurassic phase of rifting trending NE-SW (Selous Graben, Luangwa Valley, Mpotepote Basin, Metangula Basin) or E-W (Upper Zambezi, Tete Basin)
- Late Jurassic to Cretaceous rifting represented by the NW-SE trending Anza Rift, Kenya, along trend from the Sudanese Muglad Basin.
- Tertiary–Quaternary rifting orientated N-S truncates earlier rifts

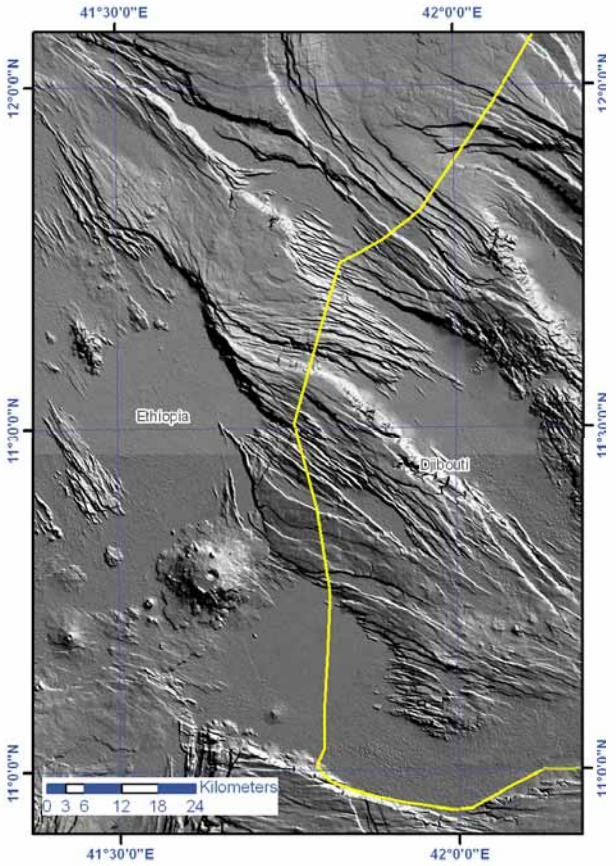
Petroleum Systems

- Tertiary fluvio-lacustrine deposits within the rift grabens and older Karoo Supergroup deposits are the main onshore Petroleum Systems
- High TOC shales have been identified beneath a number of small East African Lakes such as Tanganyika, Baringo and Albert
- The Karoo Supergroup has many potential reservoir horizons of coarse sandstones and contains potential source rocks, but lacks regional seals in places
- Volcanic material found within the sandstones may limit their viability as reservoir rocks
- In Somaliland Similarities are thought to be found with the Petroleum Systems of Southern Yemen, with Jurassic shales being the most important source rocks with seals formed by Eocene anhydrites.

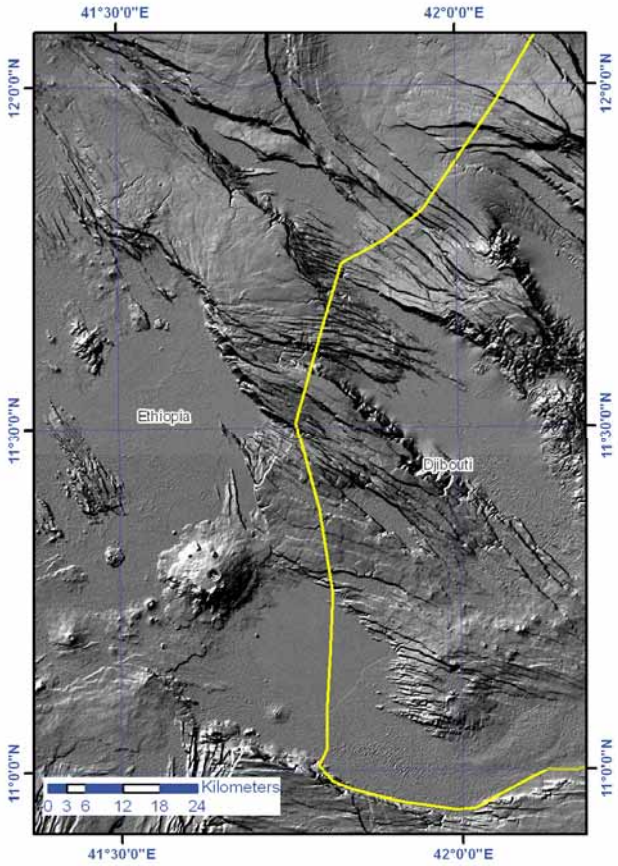
Earth Observation Datasets

- Medium resolution remotely sensed imagery offers an effective method for rapid geological interpretation over extensive areas
- Onshore geological interpretation
  - **Optical**
    - **Landsat 7 ETM + 15m resolution**
  - **Digital Elevation Model**
    - **Shuttle Radar Topography Mission (SRTM) 90m post spacing**
- Offshore and lake hydrocarbon seep identification
  - **Radar**
    - **ERS 1**
    - **ERS 2**
    - **Radarsat**
    - **Envisat**

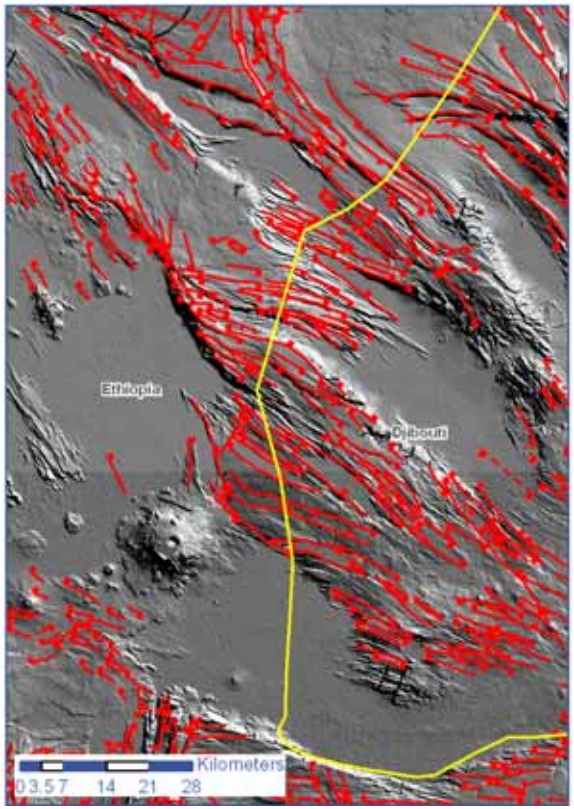
SRTM



Shaded relief SRTM image, illumination azimuth angle perpendicular to dominant fault orientation (illuminated from NE)



Shaded relief SRTM image illumination azimuth angle parallel to dominant fault orientation (illuminated from NW)



Structural interpretation

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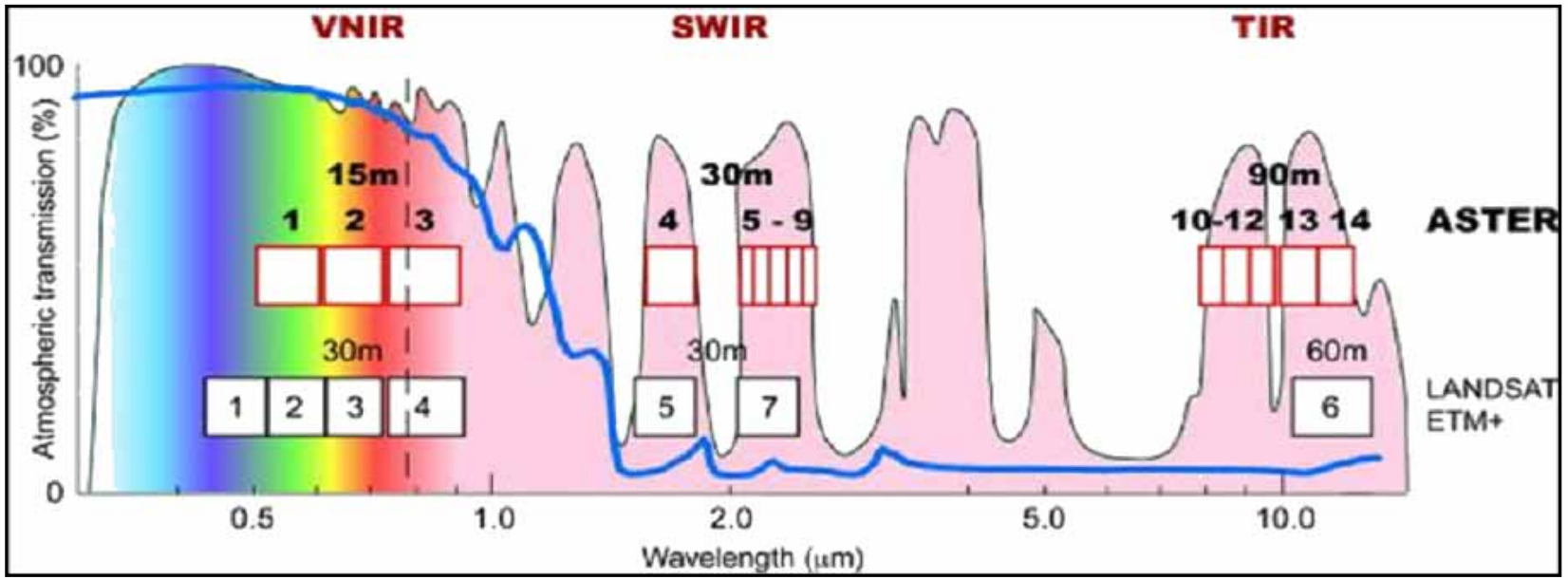
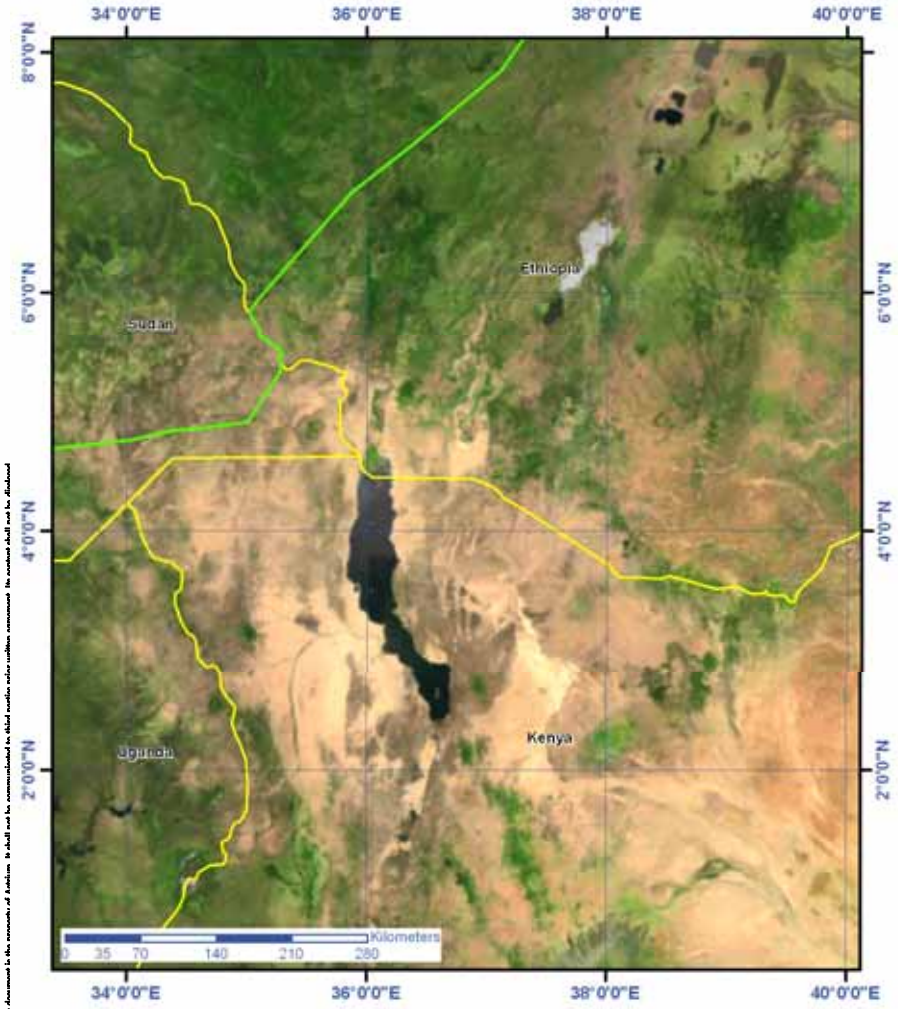
Landsat 7 Spectral Bands

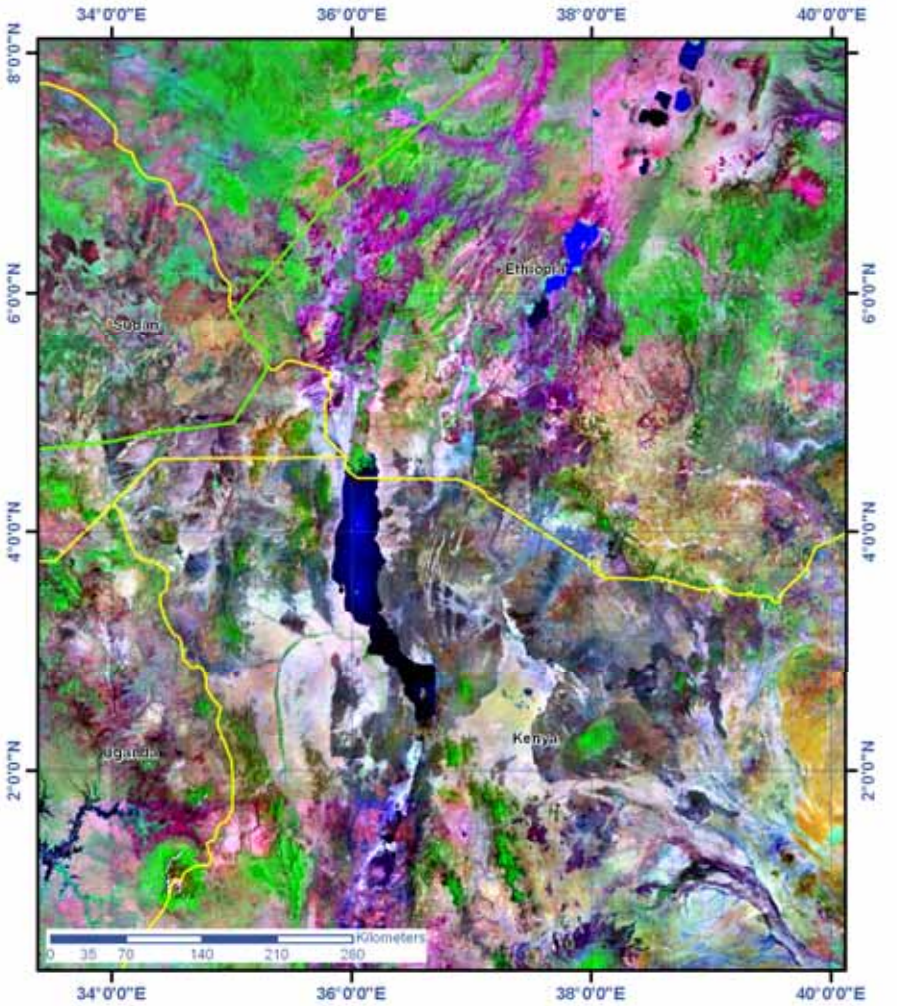


Slide graphics content by Mike Abrams of JPL - 2005

Landsat

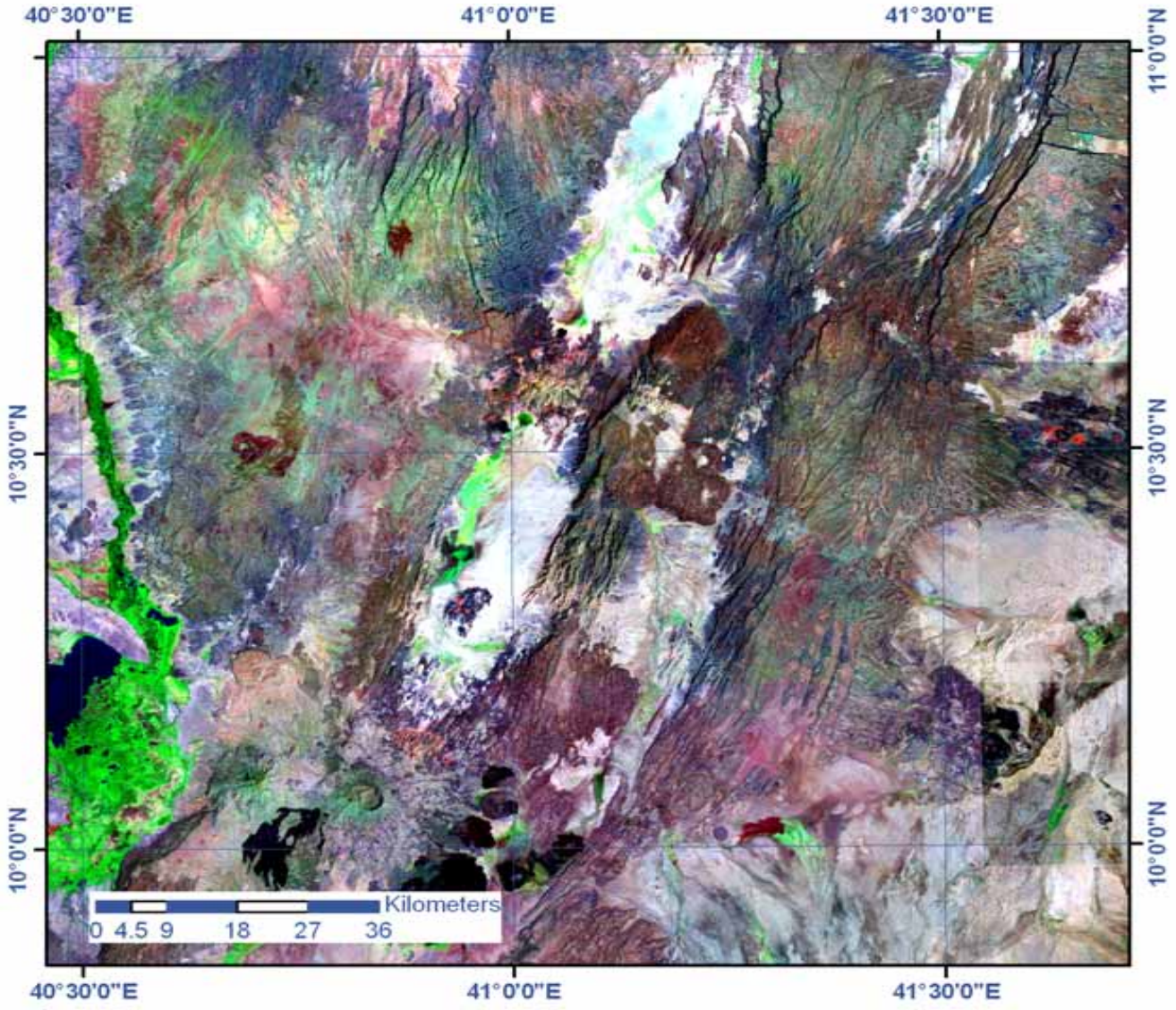


- 321 (RGB) true colour

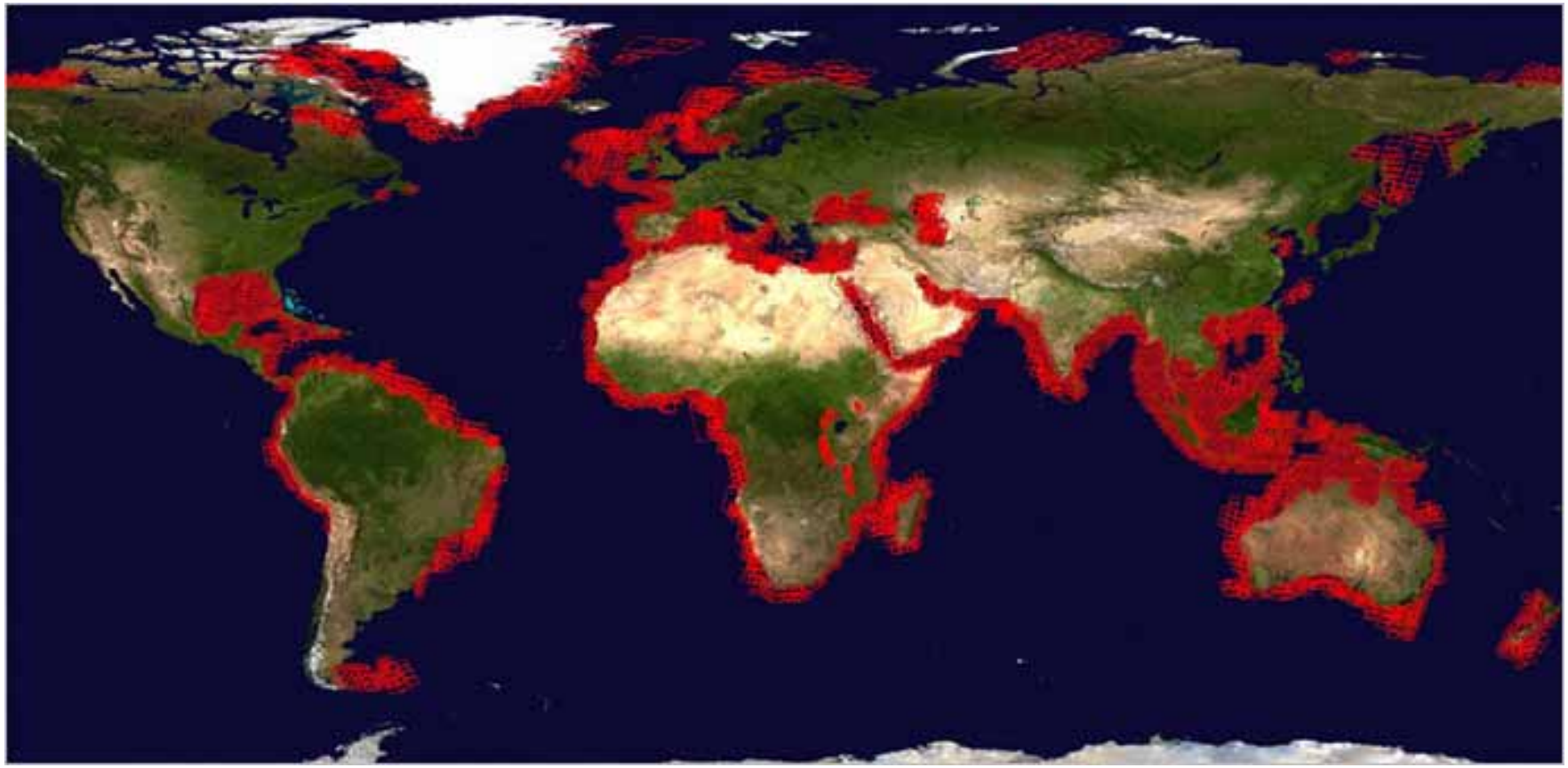


- 742 (RGB) pseudo colour

Landsat

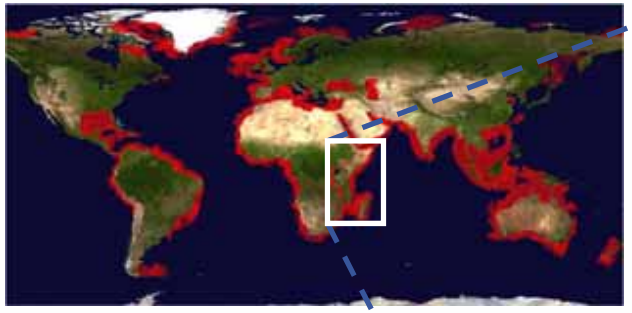


Earth Observation Datasets – Radar Scenes

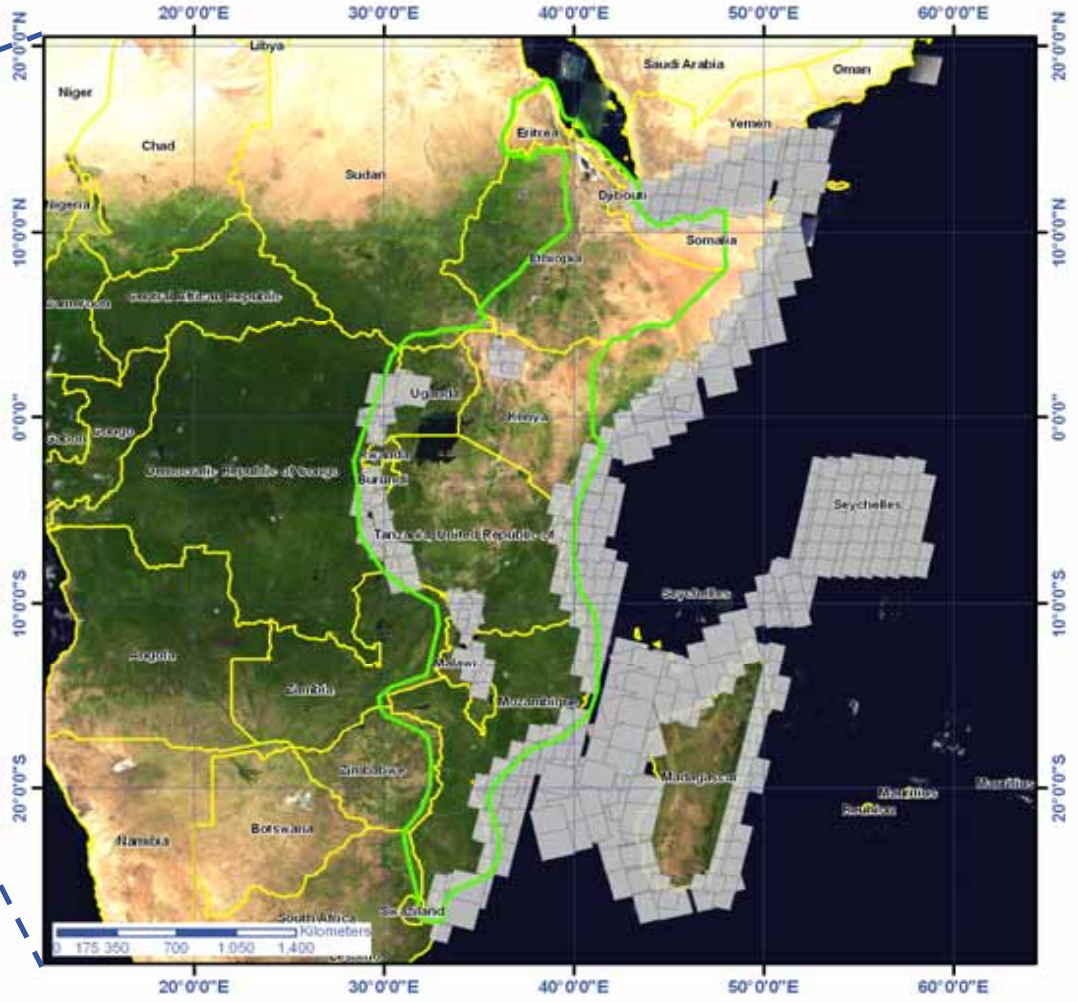


Global Seeps Database - Coverage

Earth Observation Datasets – Radar Scenes

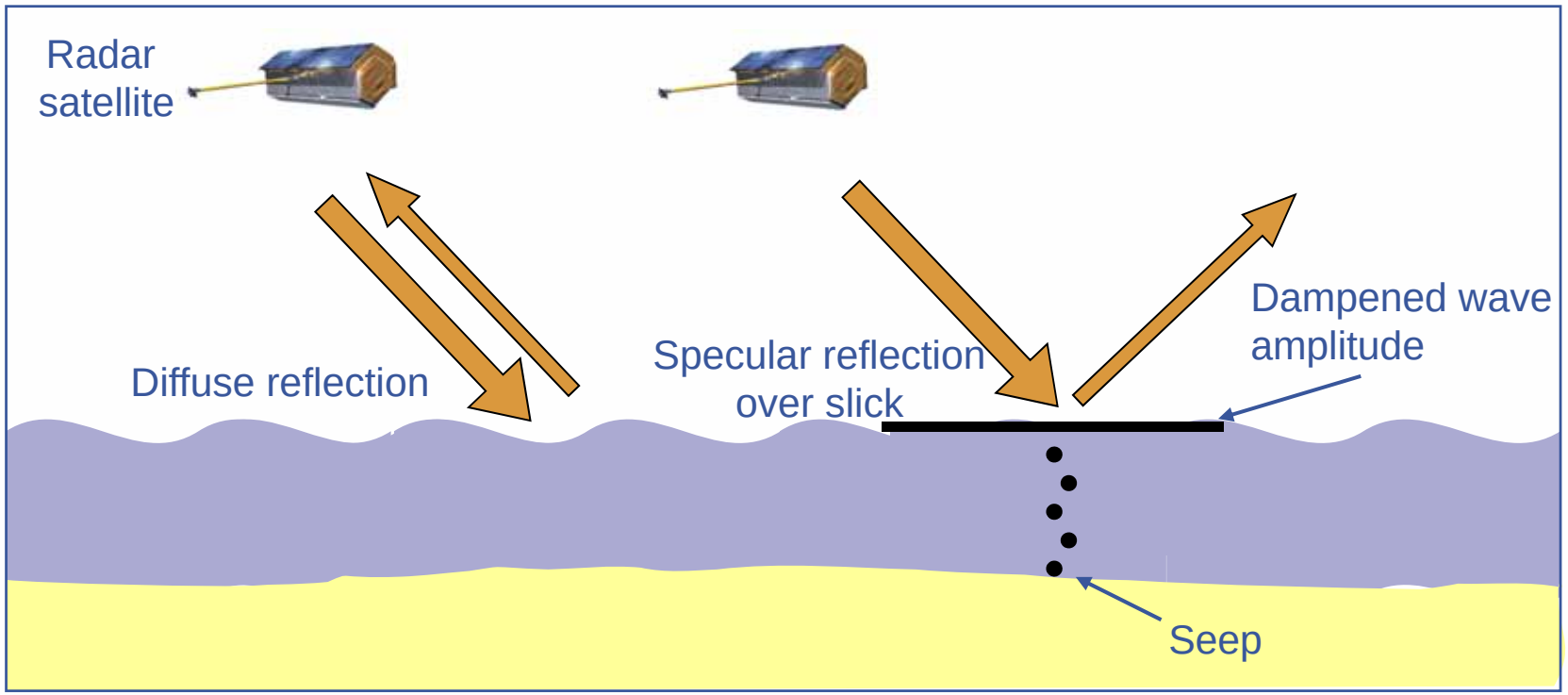


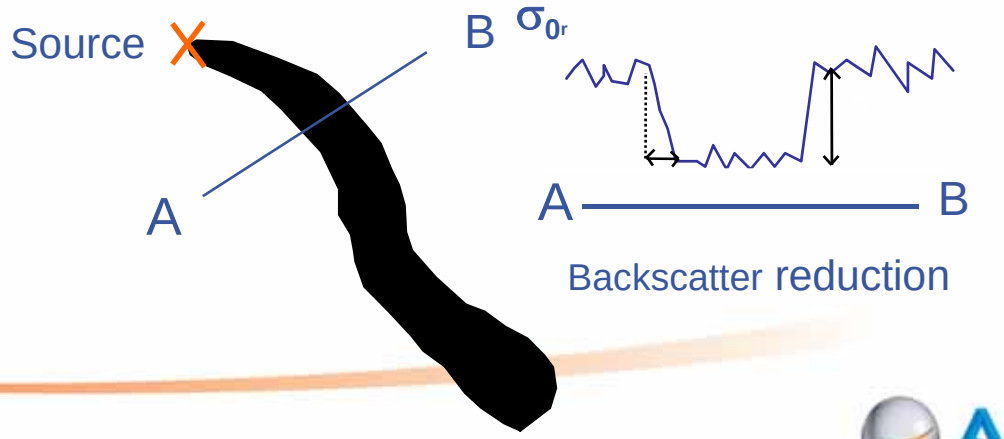
Global Seeps database

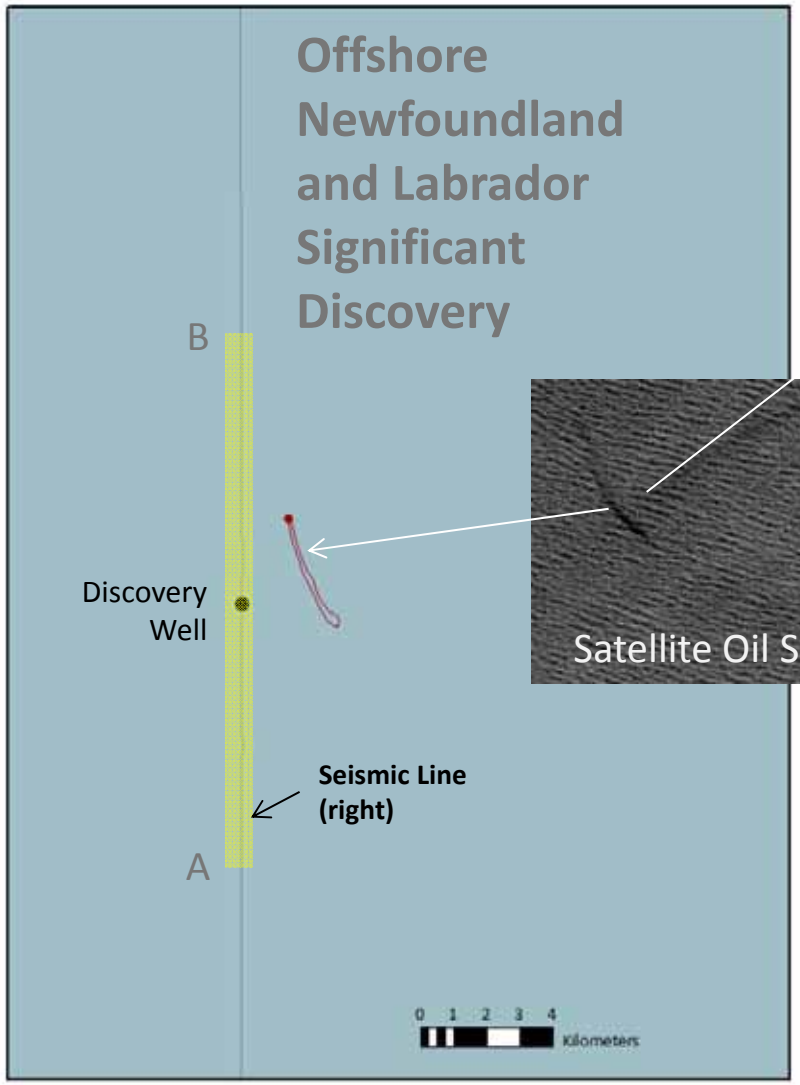


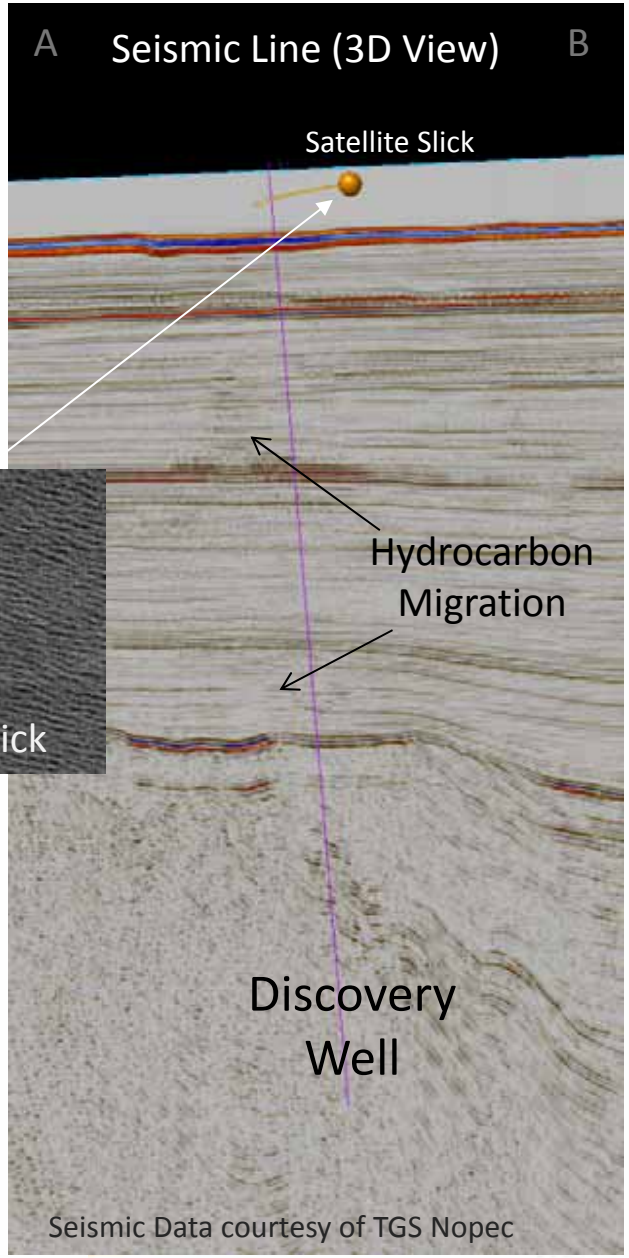
- Radar acquisition from 1992
- 800 + scenes

Seep Identification Process









"Surface slick likely related to subsurface hydrocarbon migration

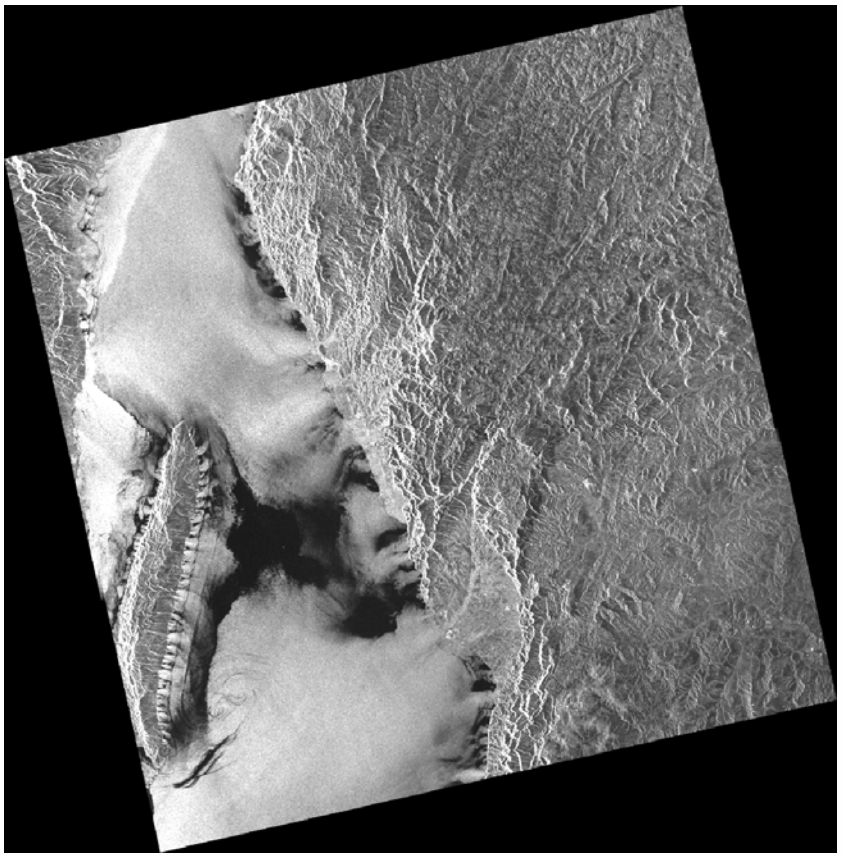
Demonstrates that satellite slicks can be a useful frontier exploration tool to optimally position new seismic lines to improve chances of finding hydrocarbons and evidence of active petroleum systems"

Richard Wright – NALCOR Energy

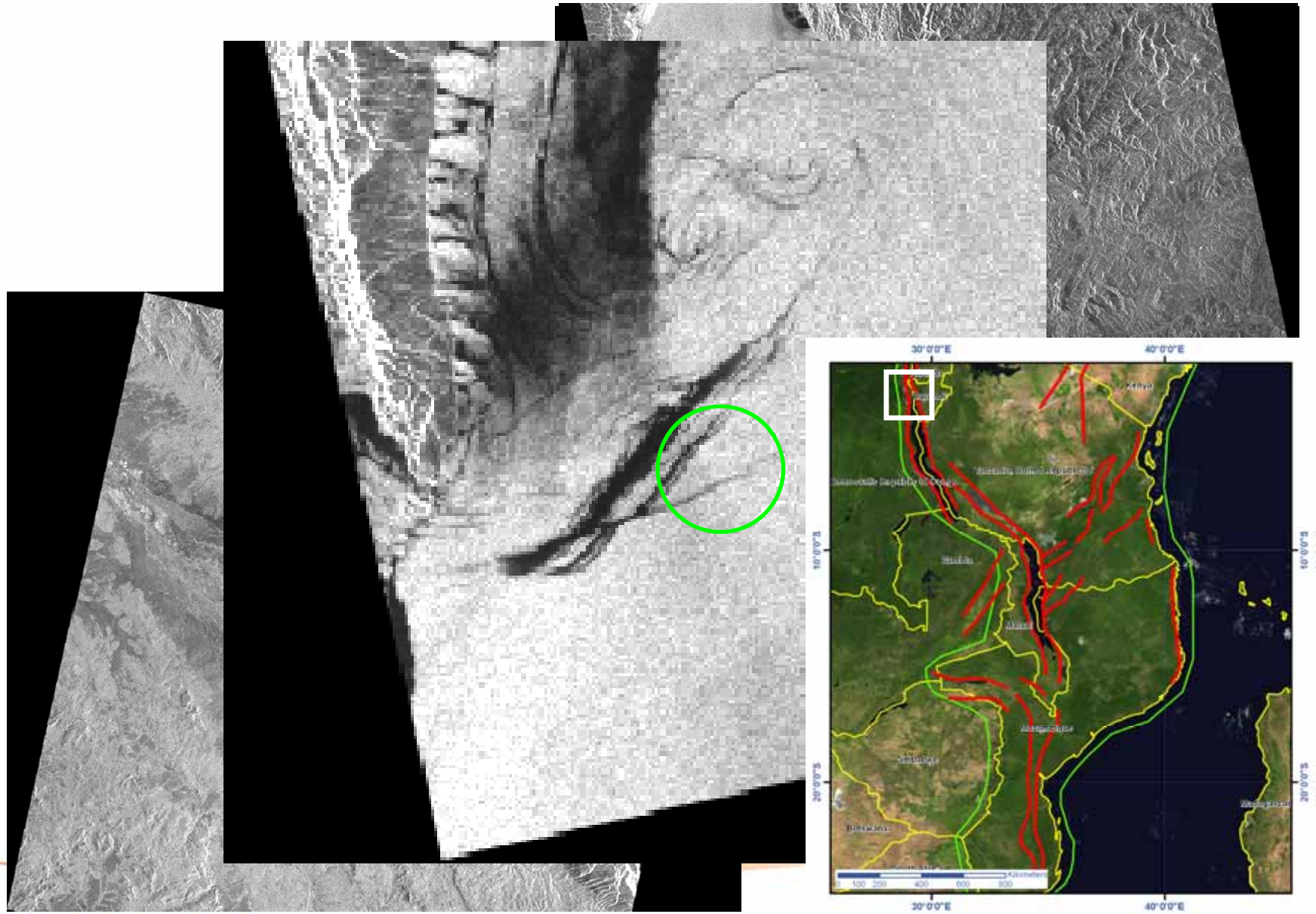
This type of result in in a new frontier area would significantly advance exploration in the area

Seep Identification Process

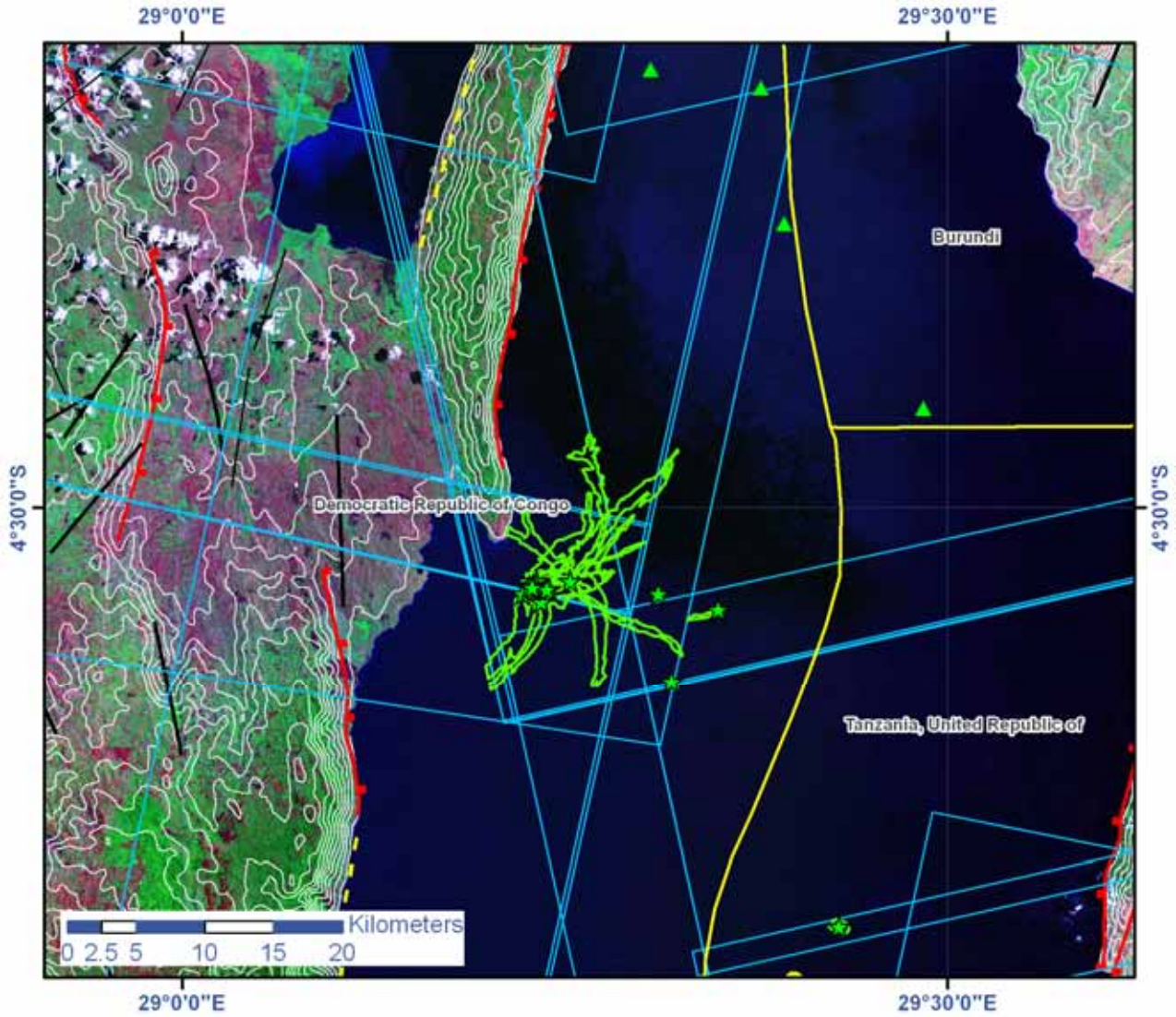
- All scenes are weather screened for suitability
- A minimum of dual coverage is used where possible
- Scenes are manually interpreted for the presence of potential seepage slicks, as well as rigs, ships and weather effects
- Each slick is assigned a confidence level of being a seep of natural origin



Seep Identification – Lake Tanganyika – Radar Scenes



Seep Identification – Lake Tanganyika – Slick Outlines



Country Outlines

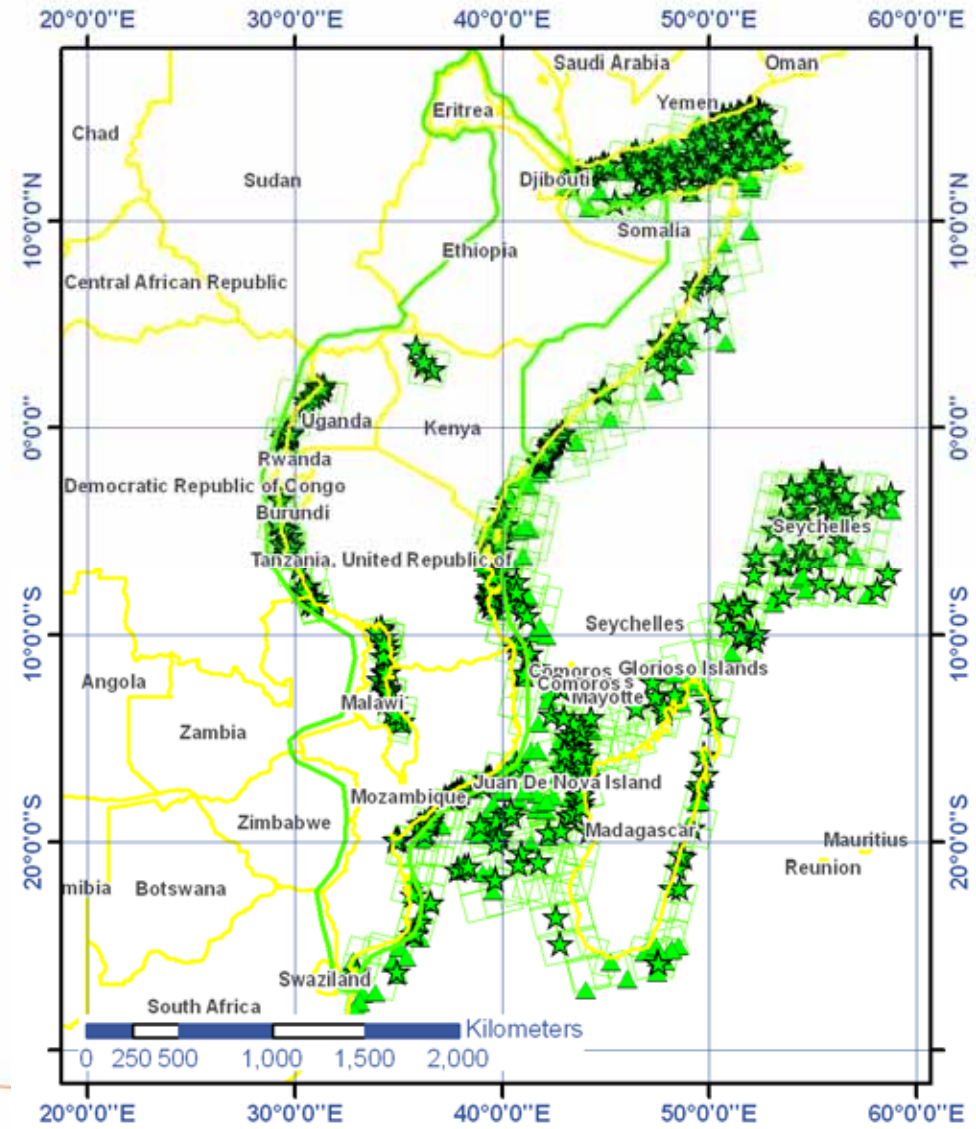
East Africa Slick Points

Ships & Rigs

East Africa Slick Outlines

Radar Scenes

Indentified Hydrocarbon Seeps



- 500 individual slick points recognised

AOI

Country Outlines

East Africa Slick Points

Ships & Rigs

East Africa Slick Outlines

Radar Scenes

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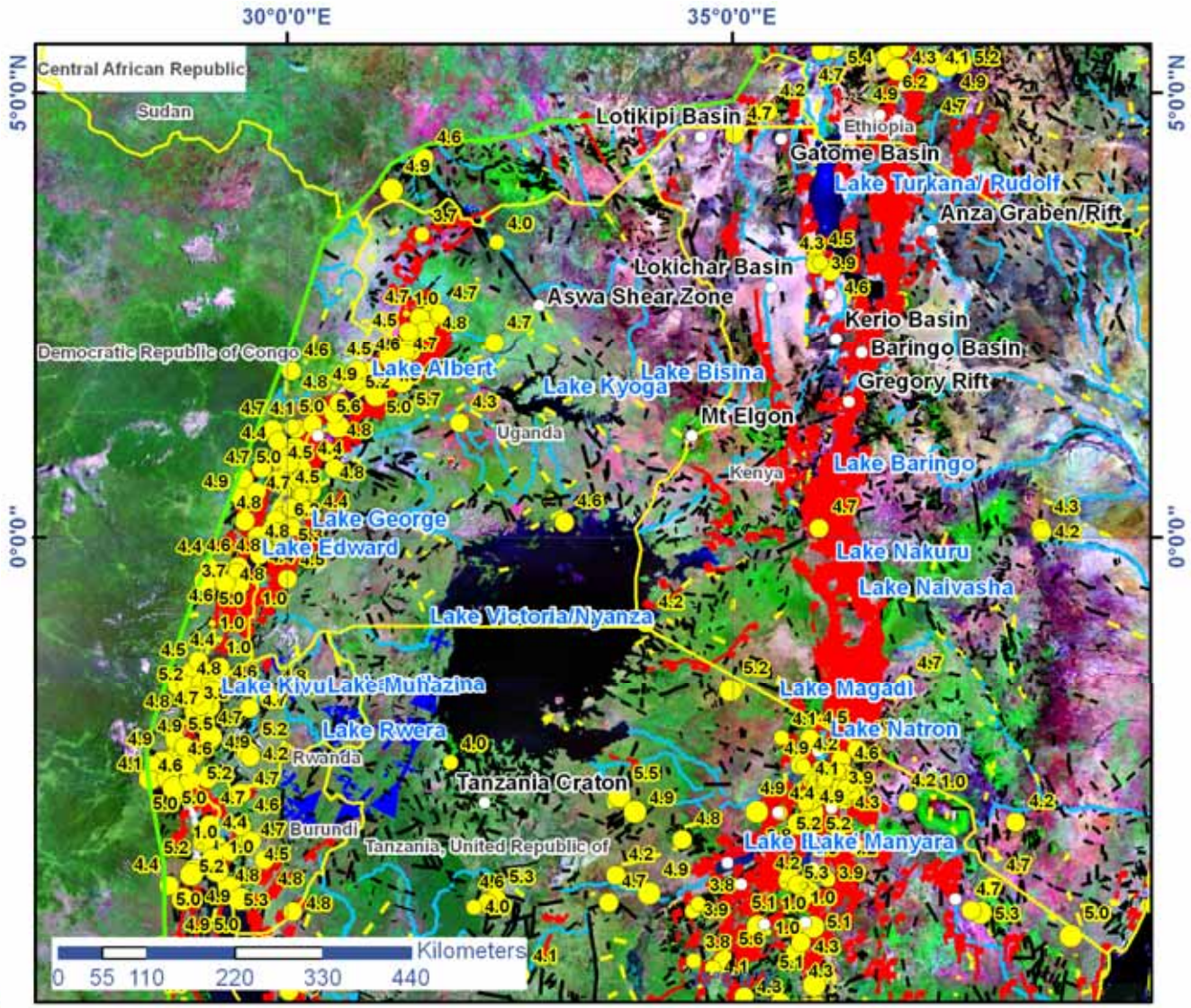
Existing Geological Mapping

- Existing geological mapping was used for virtual ground truthing including the USGS stratigraphic map of Africa (Persits *et al*. 1997) based on from a 1:5,000,000 UNESCO geological map.

Country	Geological Map	Scale	Year	Origin/Author
Burundi	Carte Géologique	1:5,000,000	1950	Koninklijk Belgisch Koloniaal Instituut
Rwanda	Carte des Gîtes Minéraux du Rwanda	1:250,000	1982	Ministère des Resources Naturelles
Kenya	Kenya Geological Map, Second Edition	1:3,000,000	1962	Survey of Kenya
Somaliland	Geological Map of Somaliland Protectorate	1:1,000,000	1950	C Mackay
Ethiopia and Eritrea	Geological Map of Ethiopia, First Edition	1:2,000,000	1973	Geological Survey of Ethiopia, V Kazmin
Mozambique	Carta Geomorfológica	1:2,000,000	1983	Minisério dos Recursos Minerais
Tanzania	Geological Map of Tanganyika	1:2,000,000	1959	Tanganyika Geological Survey

Earthquake Activity (1973 to 2007)



Earthquake Information from USGS Earthquake Hazard Program

All the space you need

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Identified Features

- Geological Features
- AOI
- Country Outlines
- East Africa Slick Points
- East Africa Slick Outlines
- Minerals
- Mining
- Topographic Lineaments
- Drainage
- Earthquake

- Qv - Quaternary Igneous
- T - Tertiary
- Q - Quaternary Superifical
- Ti - Tertiary Igneous
- J - Jurassic
- K - Cretaceous
- K1 - Lower Cretaceous
- JK - Jurassic to Cretaceous
- KS - Karoo Supergroup
- PMi - Palaeozoic to Mesozoic Igneous
- pC - Precambrian Unclassified
- Sea
- Water Body


Strike Slip - Certain


Strike Slip - Inferred


Extensional - Certain


Extensional - Inferred

Unclassified major - Certain

Unclassified major - Inferred

Unclassified minor - Certain

Unclassified minor - Inferred


Syncline - Certain


Syncline - Inferred


Syncline - Periclinal - Certain


Syncline - Periclinal - Inferred

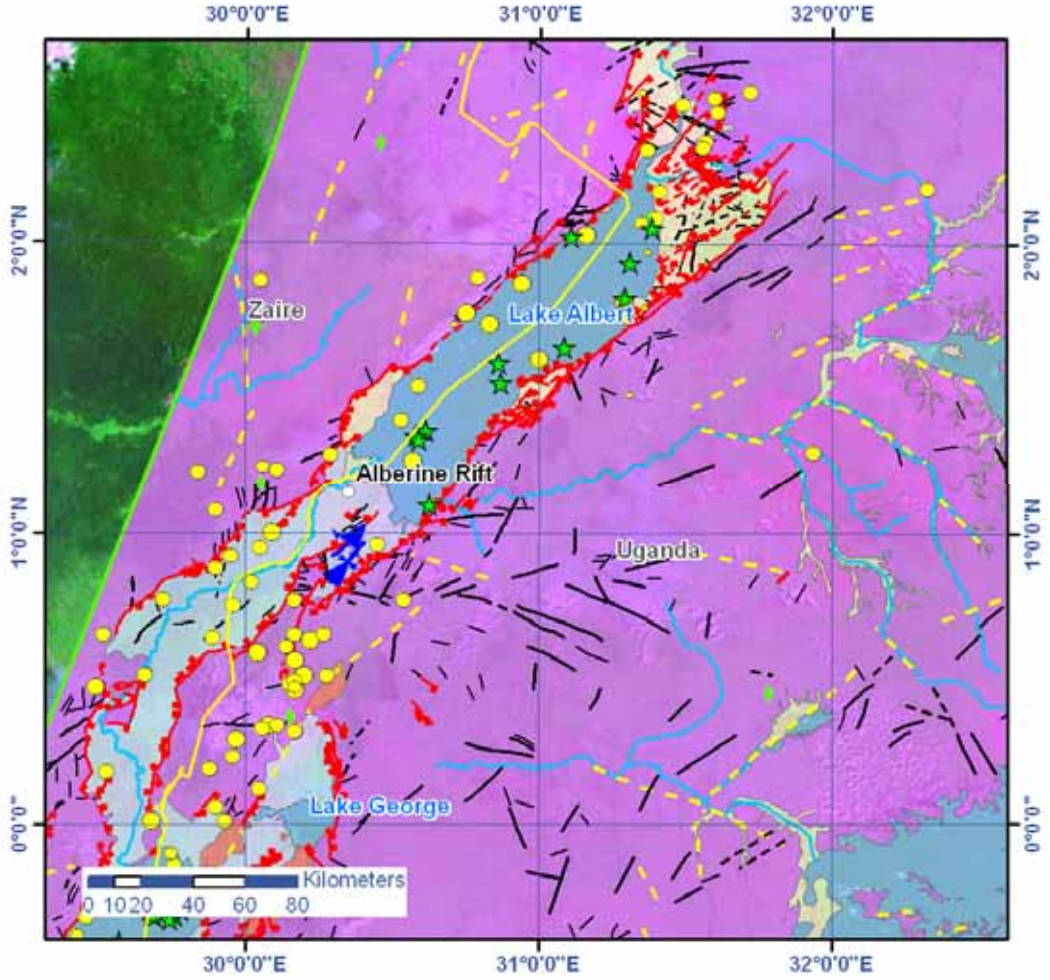

Anticline - Certain


Anticline - Inferred


Anticline - Periclinal - Certain

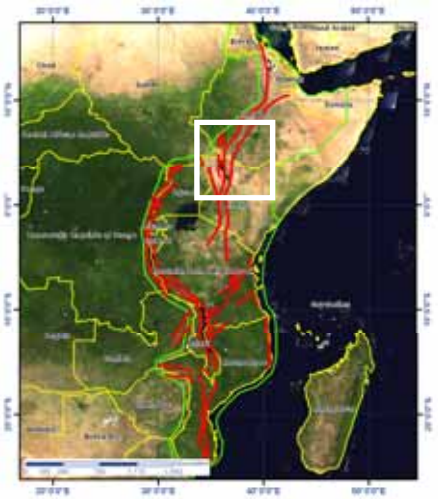

Anticline - Periclinal - Inferred

Albertine Rift - Well defined graben structure with multiple lake oil seeps

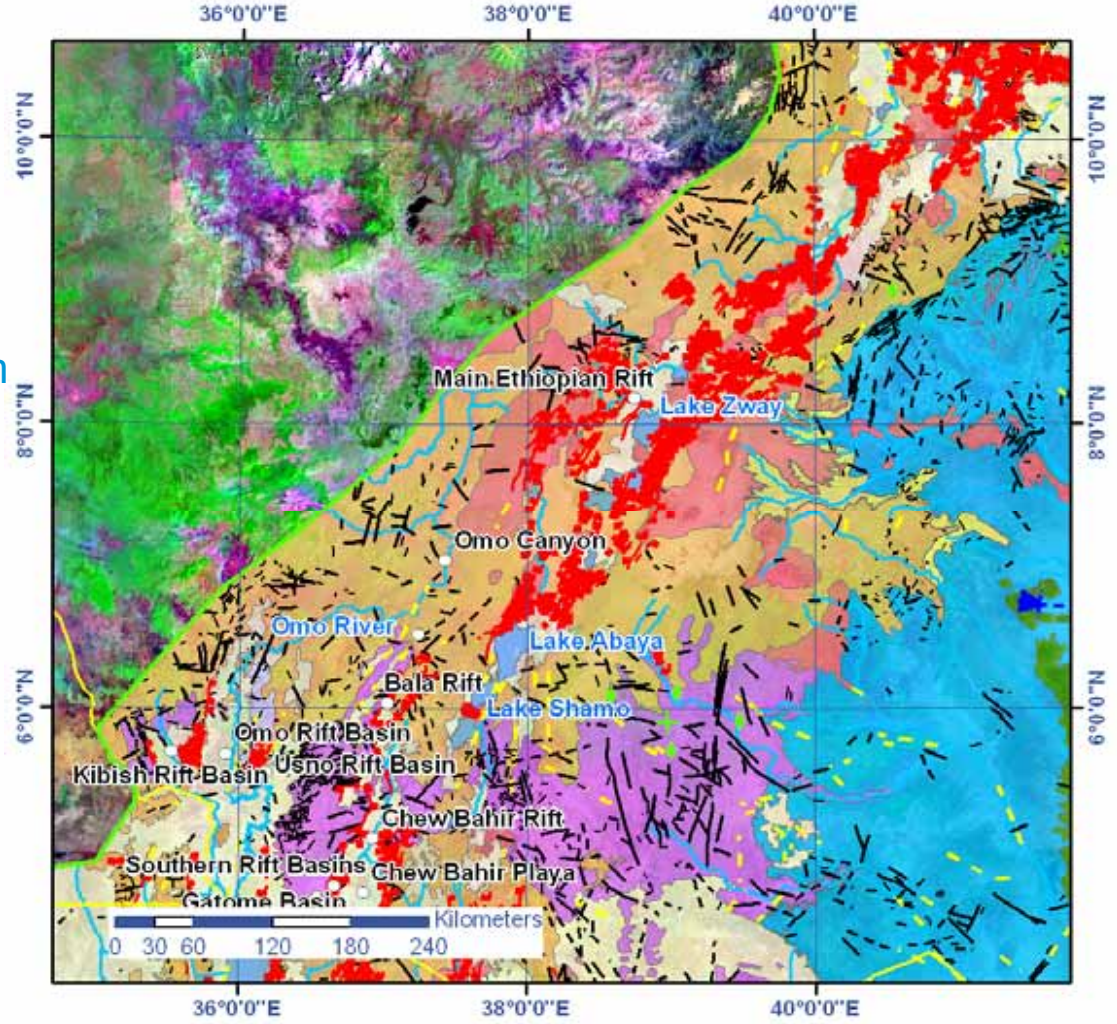


- Albertine Rift stretches from the northern border of Uganda to Lake Edward in the South trending NE-SW
- Forms the northern limit of the Western arm of the EARS
- Low level of volcanic activity may lead to the increased likelihood of a higher quality reservoir rock
- Multiple oil seeps identified on Lake Albert and Edward

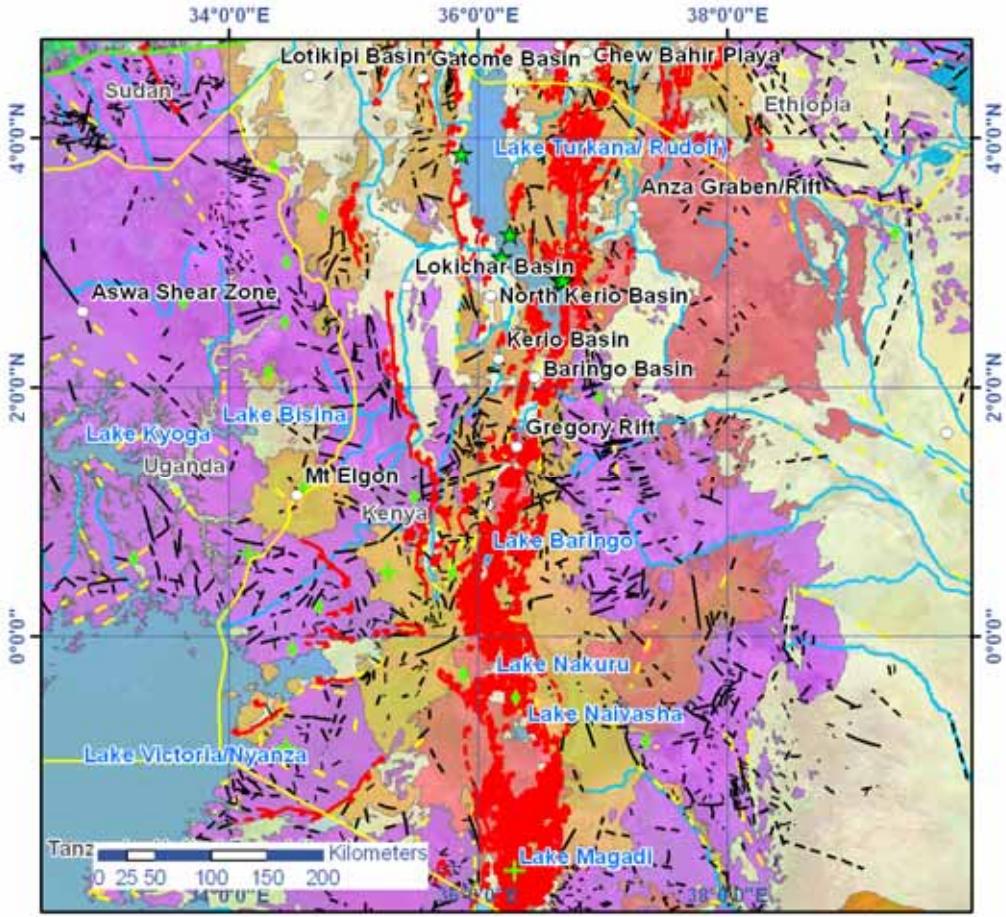
Eastern Rift – Northern Section



- Runs from the Afar Triangle to south east of Lake Victoria in Tanzania
- High fault density
- Characterised by both Tertiary and Quaternary Volcanic activity and contains the Ethiopian Rift - thought to be oldest part of the tertiary rift
- Sediment thicknesses and lake depths are generally less than the Western Branch

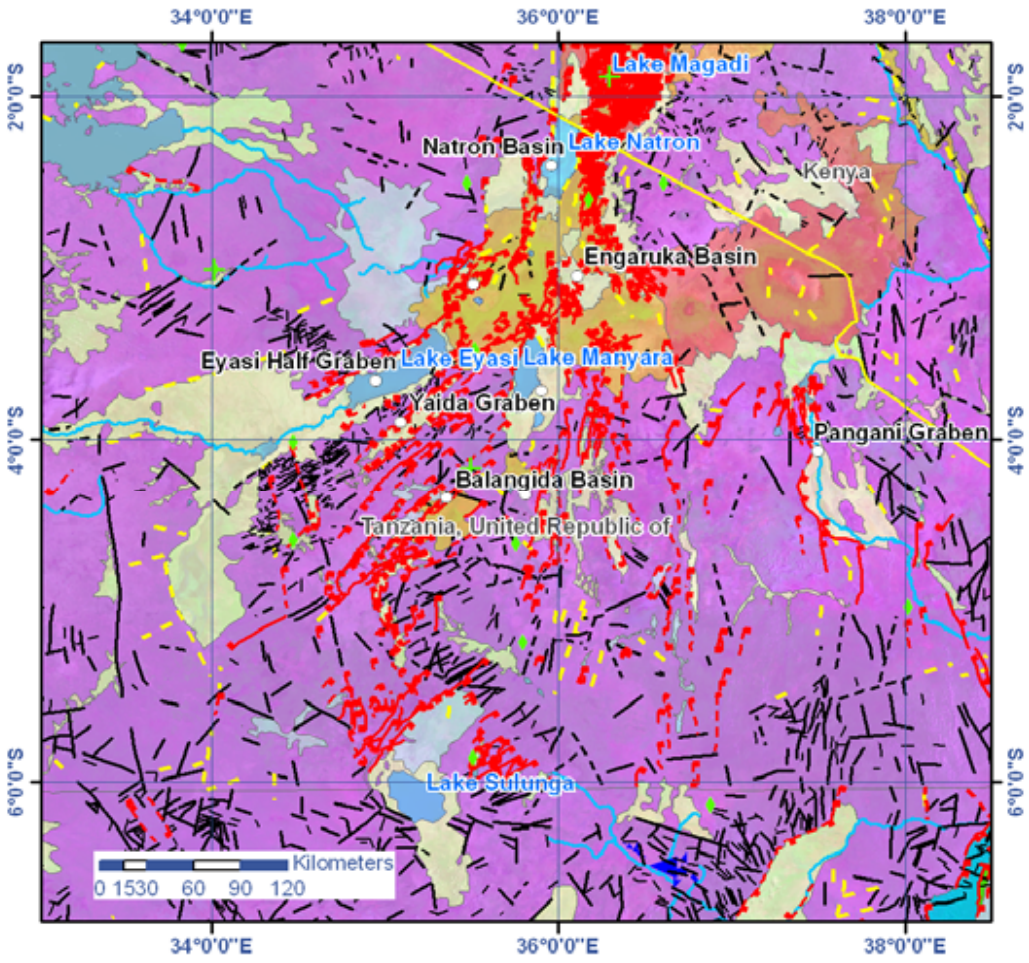


Eastern Rift – Central Section



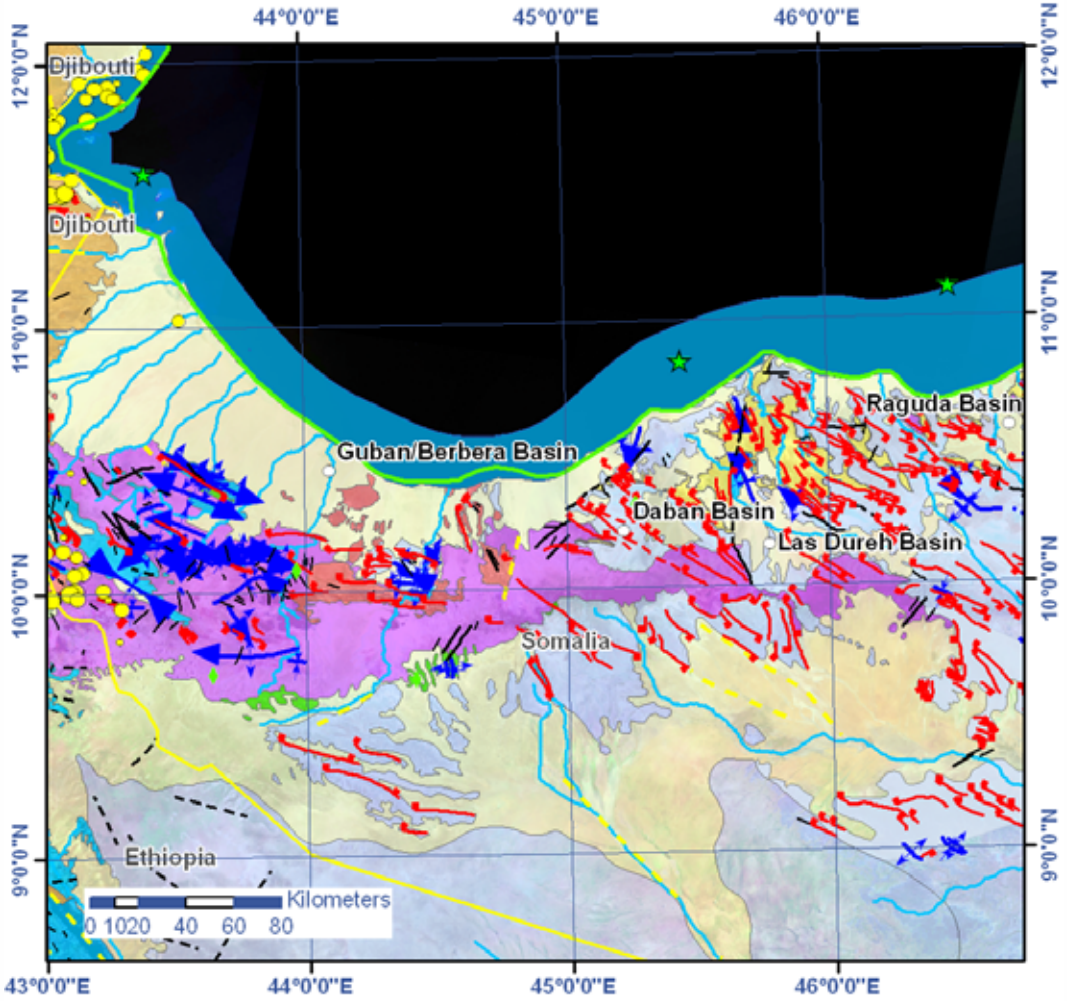
- Series of small rifts branch off from the main structure at Lake Turkana, before terminating directly north in Southern Ethiopia
- Frequently closely spaced extensional faults are associated with the Kenya Dome, directly E of Lake Victoria
- A small number of oil slicks have been identified on Turkana. Talbot *et al.* (2003) suggest good quality source (Miocene) and reservoir rocks in the adjacent Lokichar and Kerio Basins

Eastern Rift – Southern Section - Tanzanian Divergence



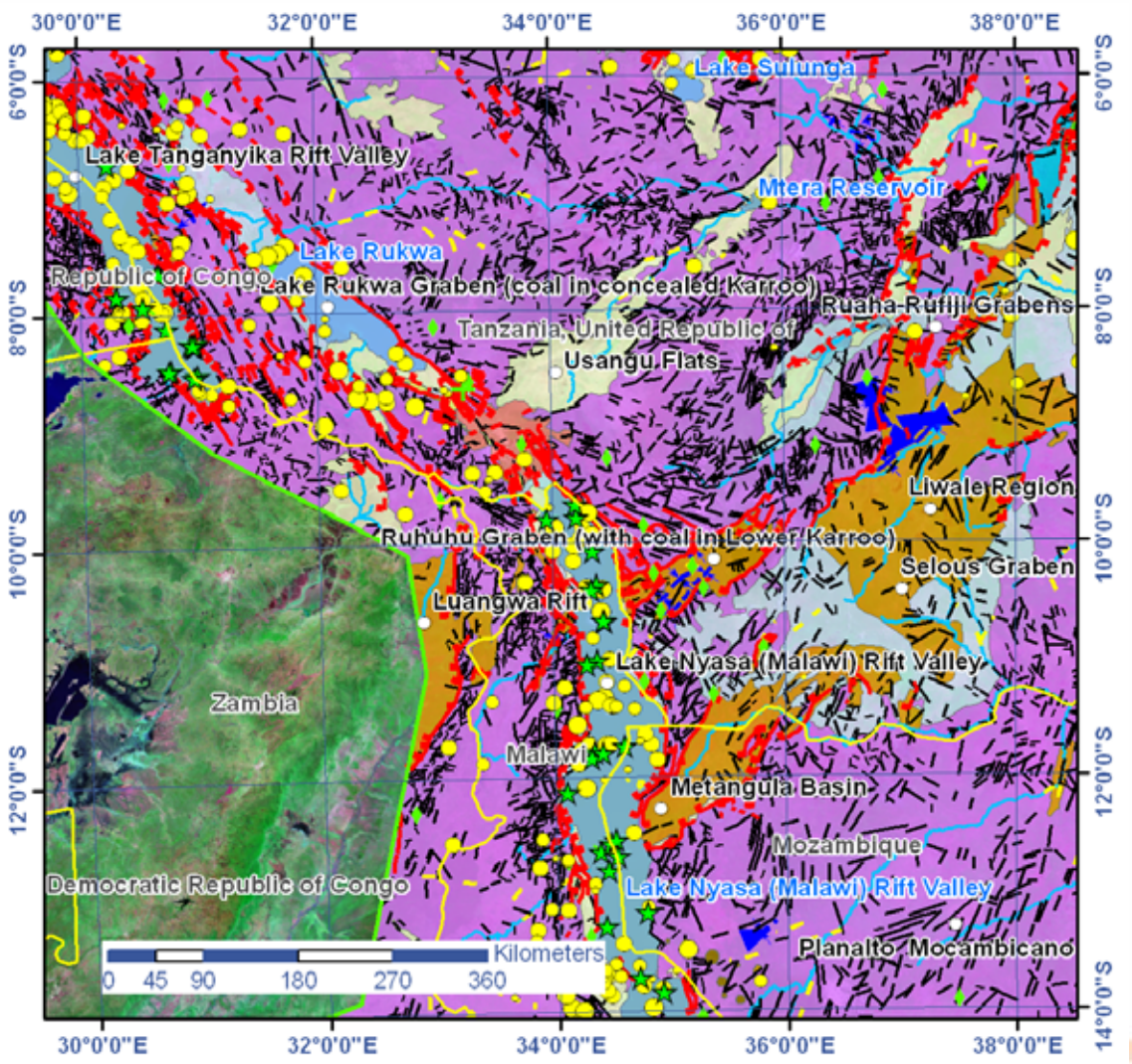
- The termination of the rift into the Tanzania Craton and the subsequent fault spread (Tanzanian Divergence) clearly seen in the EO data
- Coincident with this termination is a cluster of seismic activity, indicating ongoing neotectonic displacement in this area
- A series of other smaller basins are also found including the Manyara, Balangida, Engaruka and Natron Basins which include sediments interbedded with basalts and tuffs
- Natron Basin, is thought to have a depth of 3.3km (Ebinger *et al*. 1997)

Somaliland



- Similarities exist between the petroleum system in Somaliland and the proven hydrocarbon regions of Yemen. For example the Balhaf Graben in Yemen is though to be a continuation of the Berbera Basin in Somaliland
- Three main fault trends can be identified as defined by Somaliland Oil Exploration Company (1954); 'Gulf of Aden' (E-W to ENE-WSW), 'Red Sea' (NW-SE to WNW-ESE) and 'East African' (approx. N-S)
- Predominately steeply dipping extensional faults
- A number of roll over anticlines have been identified which are thought to be associated with this listric fault growth

Northern Mozambique – Karoo Grabens

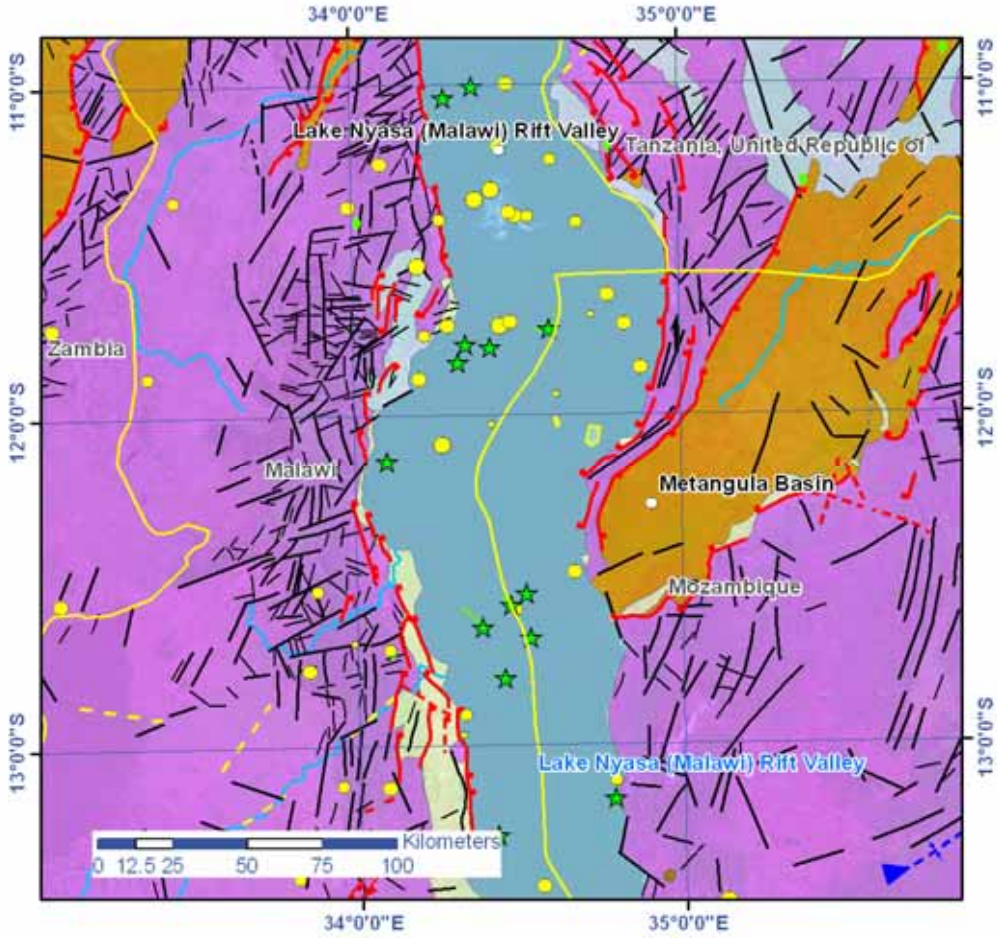


- The older, Karoo grabens represent an earlier Early Permian to Early Jurassic phase of rifting trending NE to NNE (Selous Graben, Luangwa Valley)
- The NE Karoo trend is cut by the later Tertiary N-S trend
- Contained within the NW trending Rukwa Graben, are over 10km of post-Precambrian sediments (Wescott *et al.* 1996)

Metangula Basin and Lake Malawi

- Southern part of Lake Nyasa (Malawi) contains slicks from natural oil seeps probably emanating from sub-lake Karroo or younger Mesozoic to Tertiary sections

- The underexplored Metangula Basin trends NE and contains similar prospective coal sections and potential source rocks in the early Karoo section, as in the Ruhuhu Graben to the north



Detailed Studies and Correlation with Gravity and Magnetic Data

- A number of detailed follow up projects have been completed using high resolution imagery
- Good correlations have been observed between structures visible on gravity and magnetic data and the remote sensing interpretation
- Remote sensing interpretation has provided a link between the subsurface and surface structures to assist with seismic planning

Conclusions

- Earth Observation data has given a unique perspective allowing large regional structures to be defined and the detail of smaller geological features to be captured and placed in context
- The techniques used in this study have allowed a consistent geological interpretation to be efficiently completed for the entire region
- A comprehensive database has been produced showing potential hydrocarbon seeps for the lake and offshore areas
- There is considerable potential to explore specific areas of interest using higher resolution satellite imagery