

Triassic syn-rift depositional systems, provenance and reservoir characterisation: Eastern Morocco

James Lovell-Kennedy Jonathan Redfern

North Africa Research Group, University of Manchester

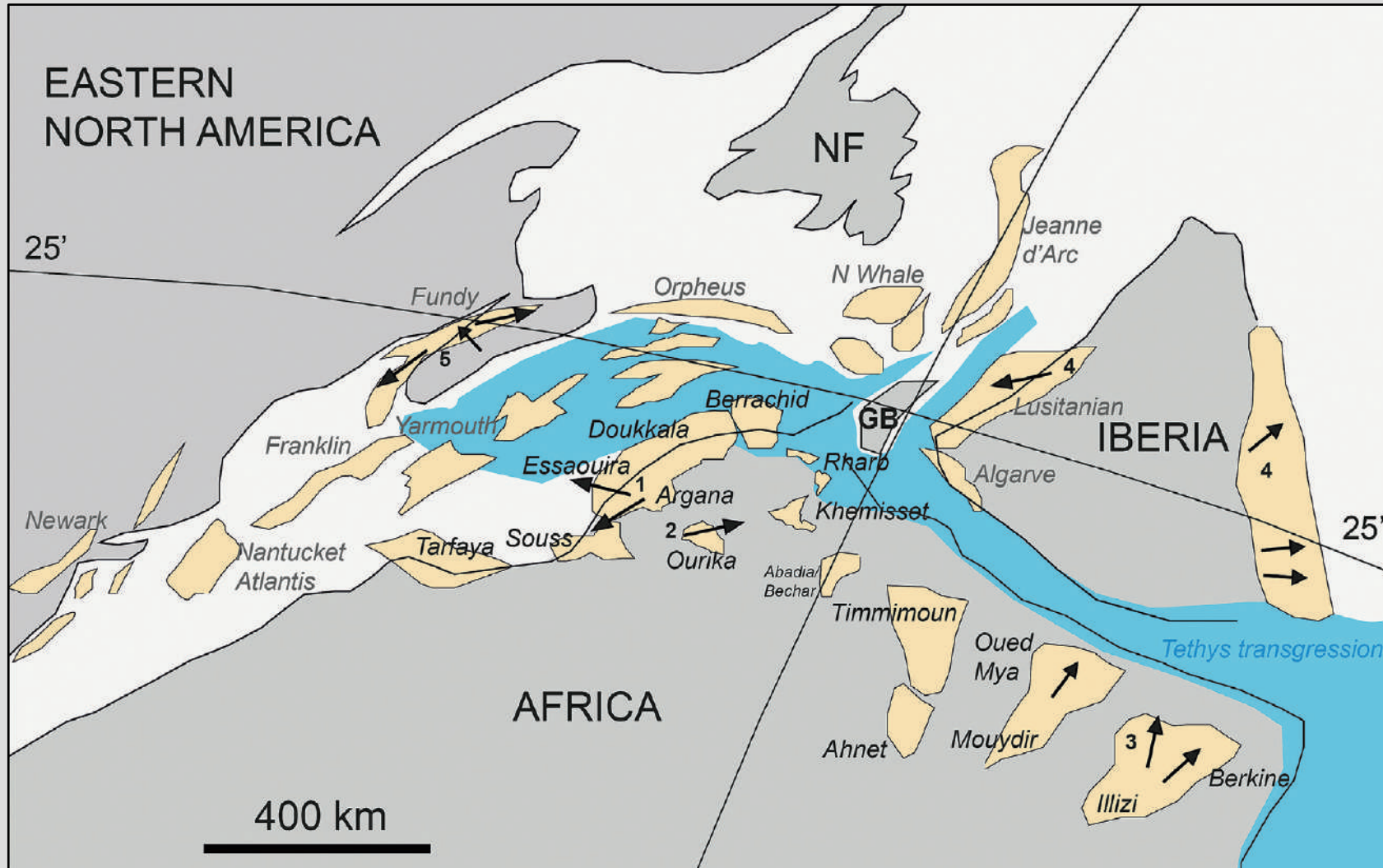
Talk Outline

1. Regional Setting
2. Previous Work
3. Field and Core Analysis
4. Provenance Data
5. Previous Provenance Work
6. Applications to Reservoir Characterisation
7. Future Work
8. Fluvial Modelling MSc Project

1. Regional Overview



Triassic of North Africa



- Formed during rifting associated with the break up of Pangea
- Continental, with increasing marine influence through time
- Complex fluvial-aeolian sedimentology

The TAG-I across North Africa

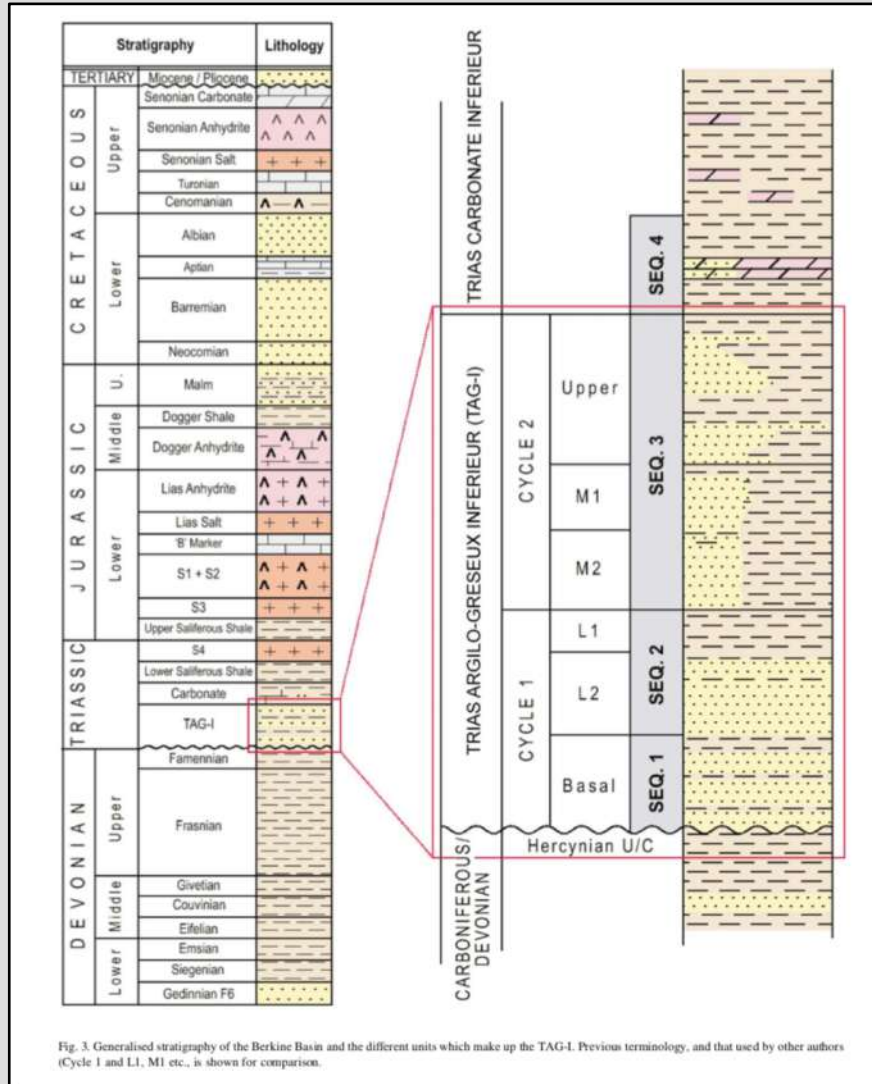
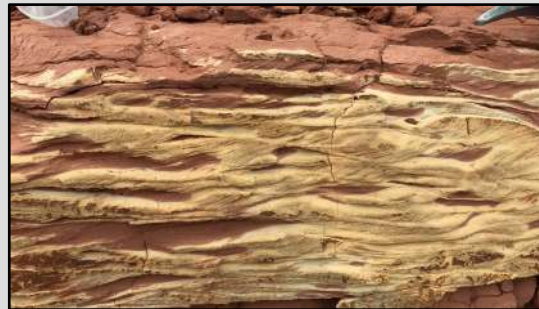


Fig. 3. Generalised stratigraphy of the Berkhine Basin and the different units which make up the TAG-I. Previous terminology, and that used by other authors (Cycle 1 and L1, M1 etc., is shown for comparison.

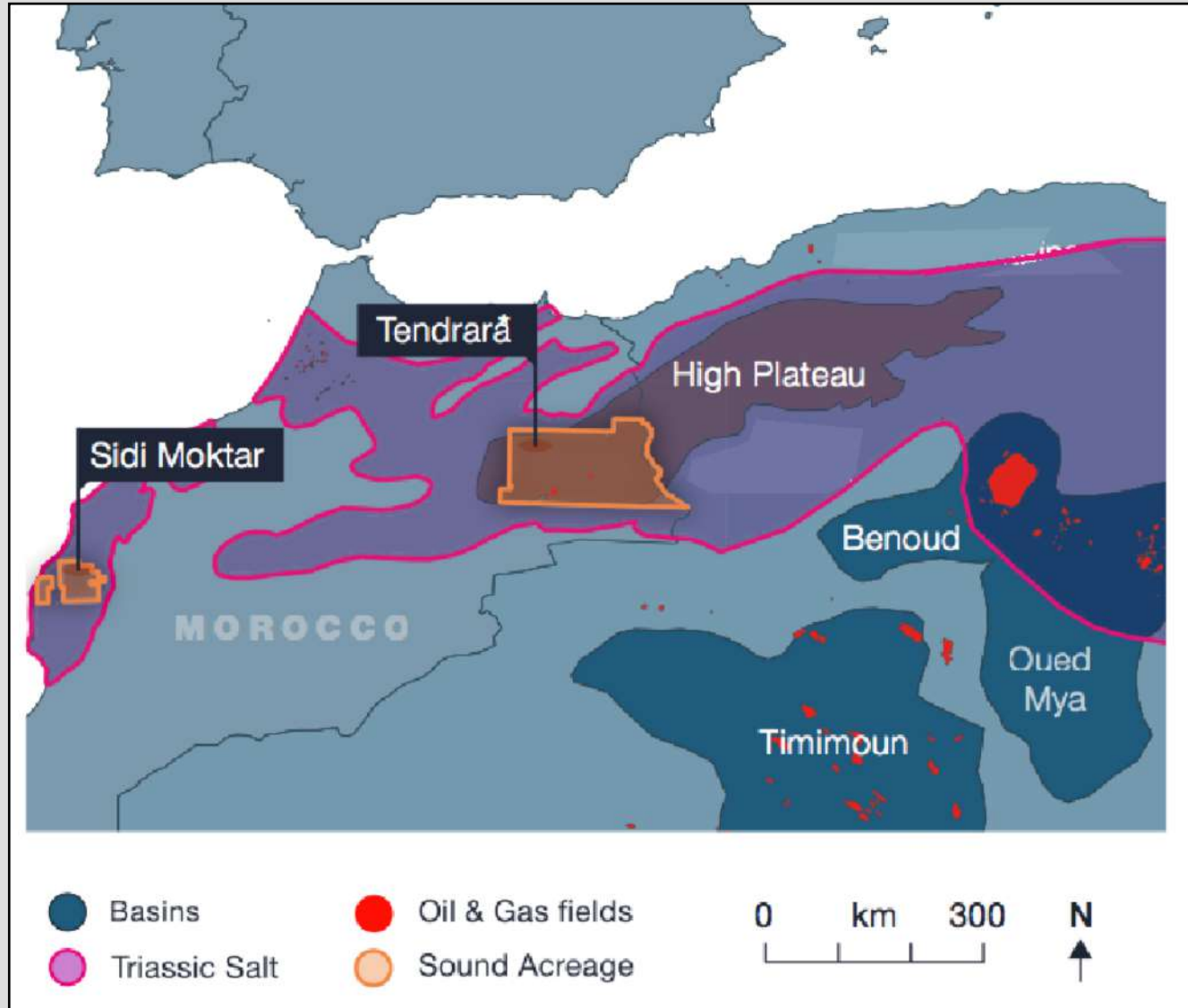


- Triassic petroleum play present across North Africa
- Continental sediments deposited within rift basins upon Hercynian Basement
- Silurian or Devonian source rock
- Triassic evaporites provide a regional seal
- Structural traps

(Turner *et al.* 2001)



The TAG-I in Morocco



Essaouira Basin

- Producing Meskala Field – gas condensate
- Exploration ongoing

High Plateau

- Tendrara gas discovery, being commercialised

2. Previous Work



Previous Work

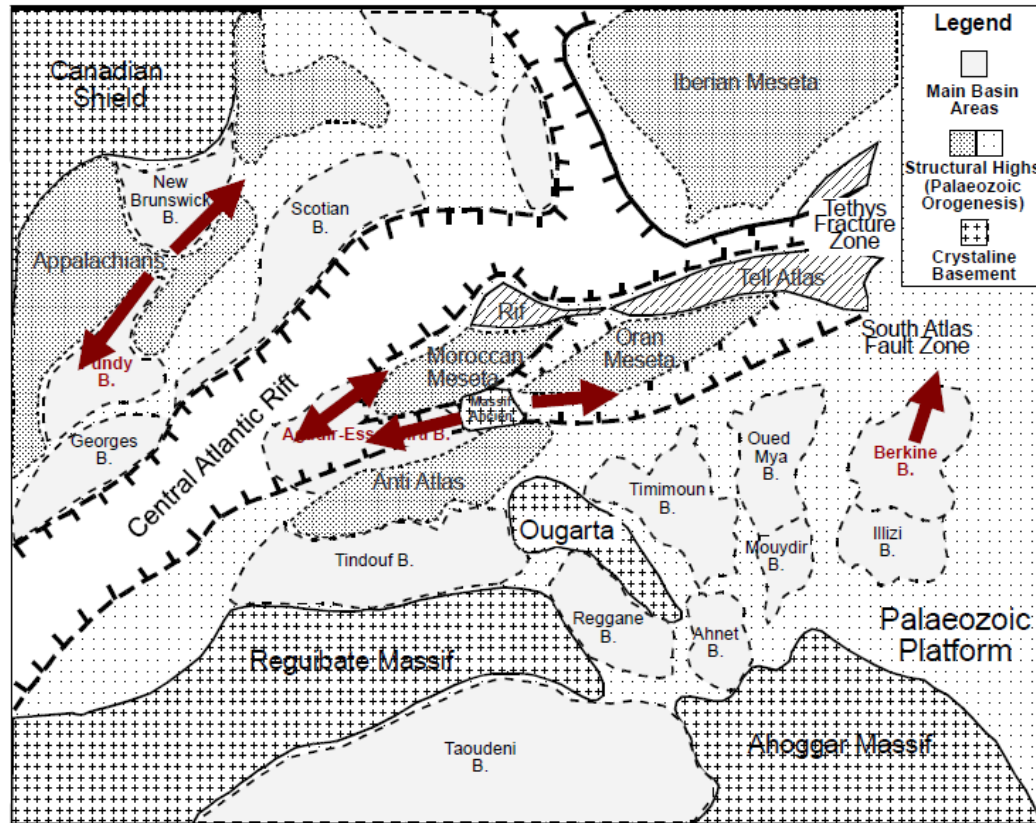


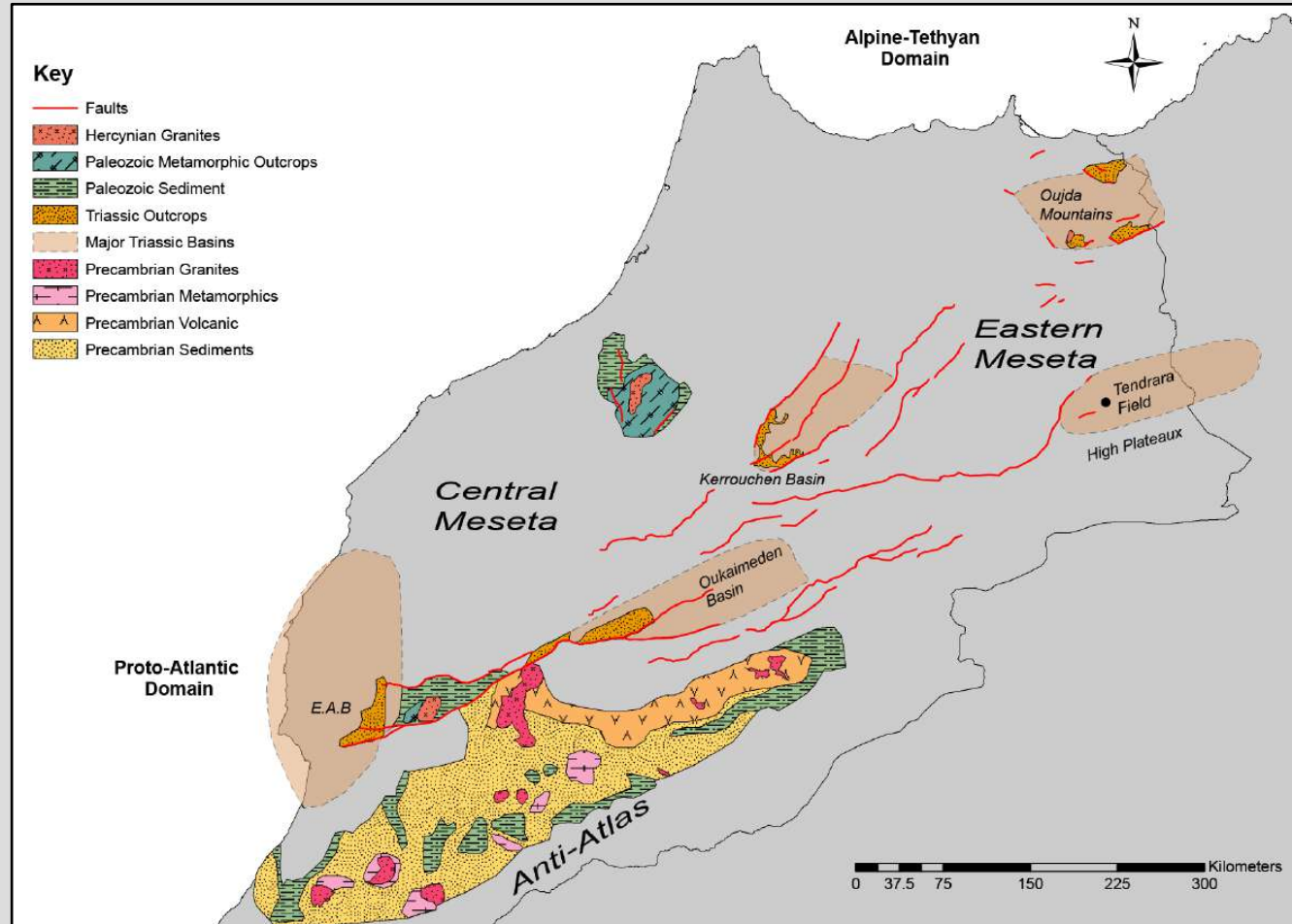
Figure 70 Simplified map, displaying the basin distribution on the Pangaea continent during the Upper Triassic. The red arrows mark fluvial flow and major transport directions of Upper Triassic (Carnian-Norian) fluvial systems along the newly developing rift system.

(Mader 2005, p. 256)

- Focused on the sedimentology of the fluvial-aeolian sandstones and structural styles of the Triassic Basins
- Drainage divide indentified between Oukaimeden and Argana
- Focusing on the provenance of the Triassic of Eastern Morocco



Key Questions

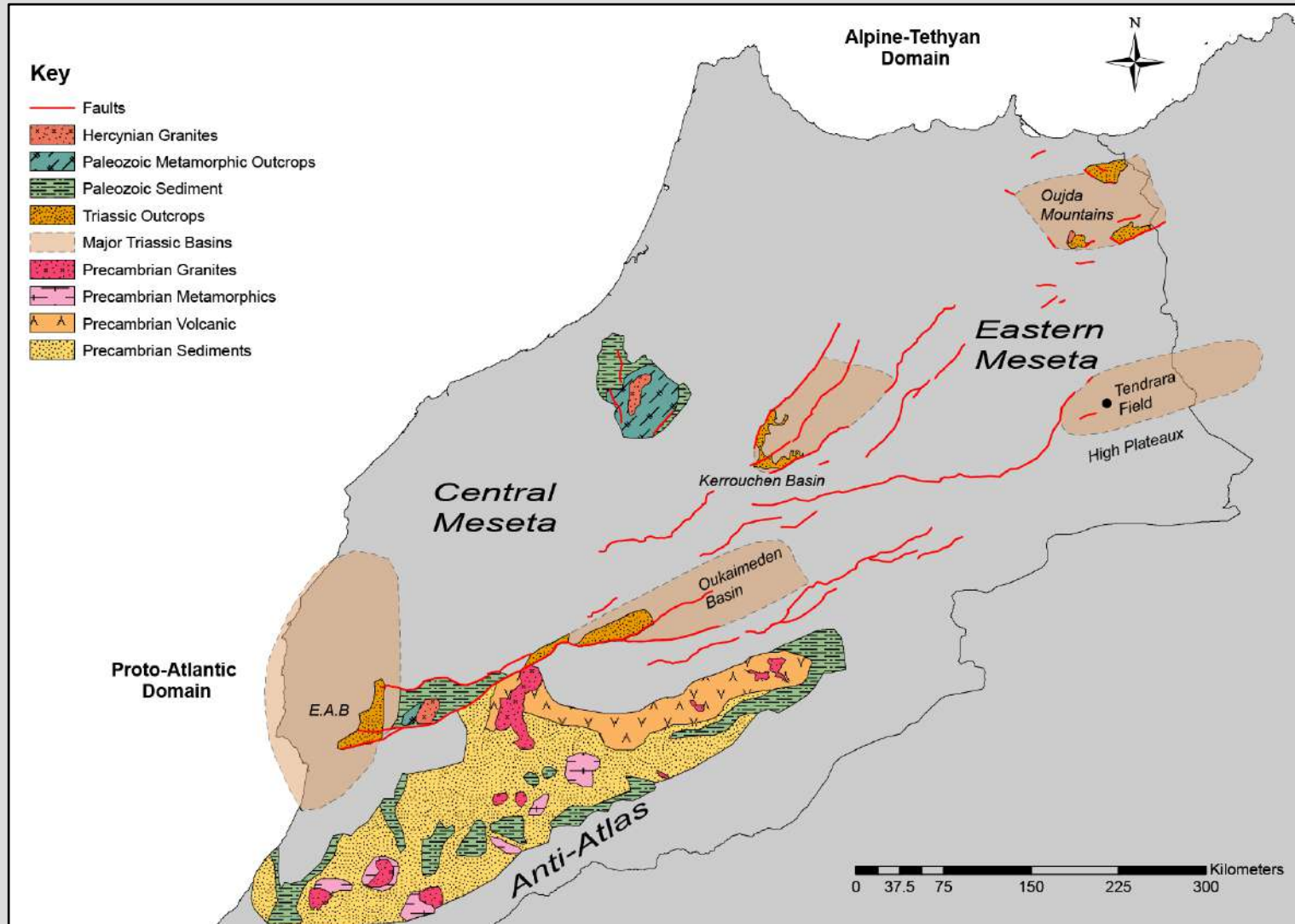


- Did a regional drainage network link the Moroccan Triassic Rift Basins and how far did it extend?
- Can local and regional drainage networks be distinguished by using provenance data?
- Can provenance data be used to predict reservoir distribution and quality?

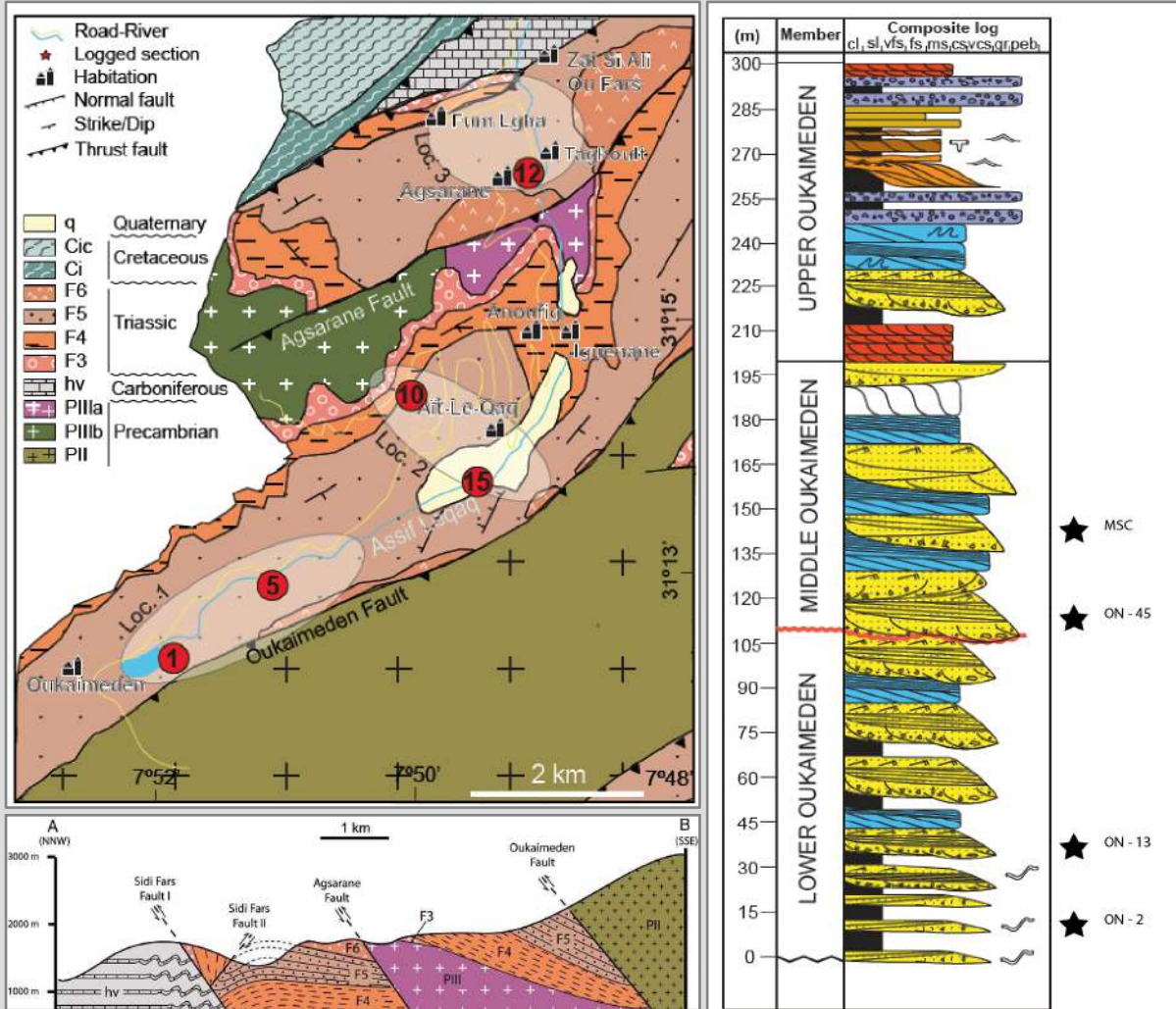
3. Field and Core Analysis



The Oukaimeden Basin



The Oukaimeden Basin



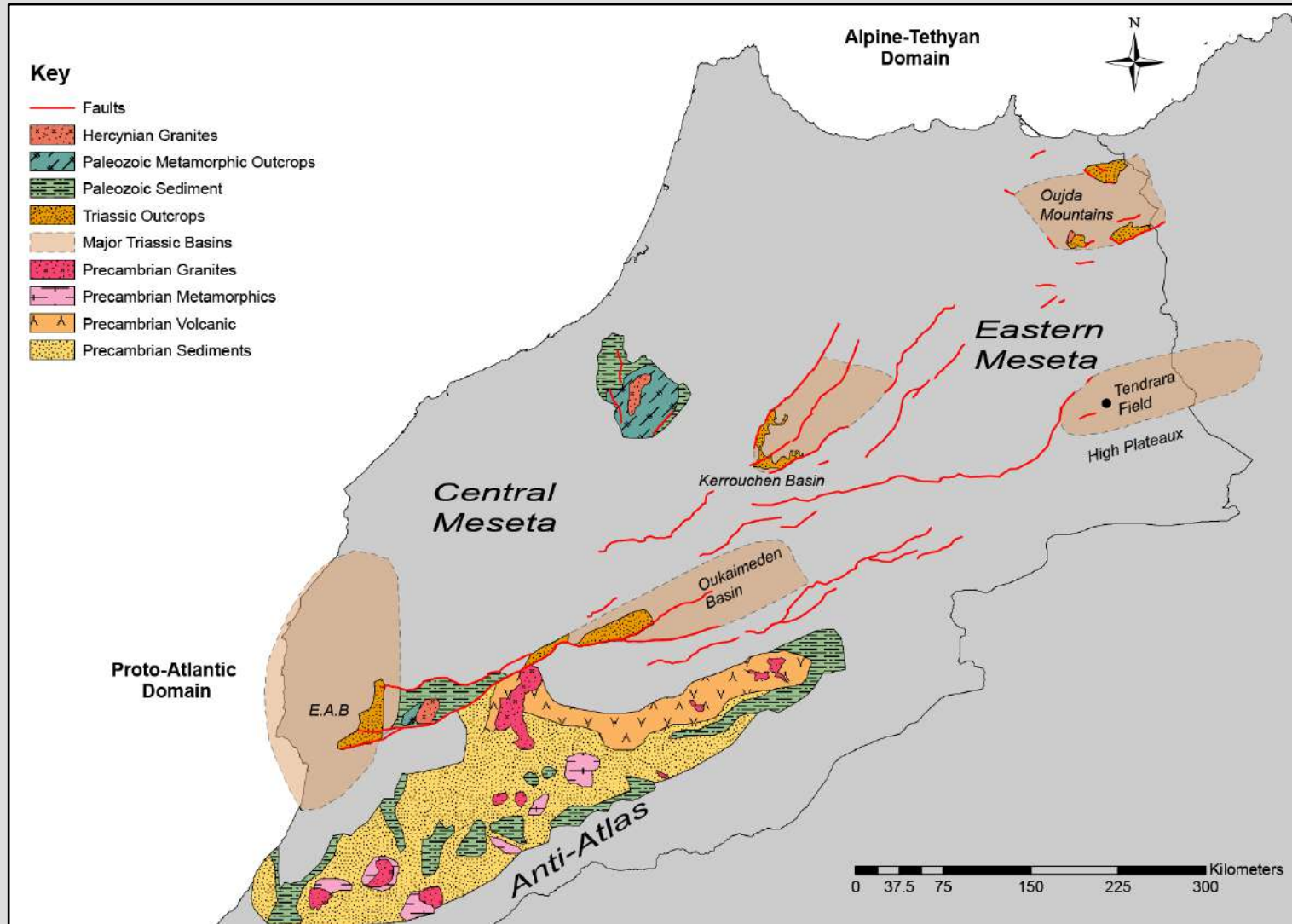
Map, cross section and log from (Fabuel-Perez *et al.* 2009)

2. Field Areas



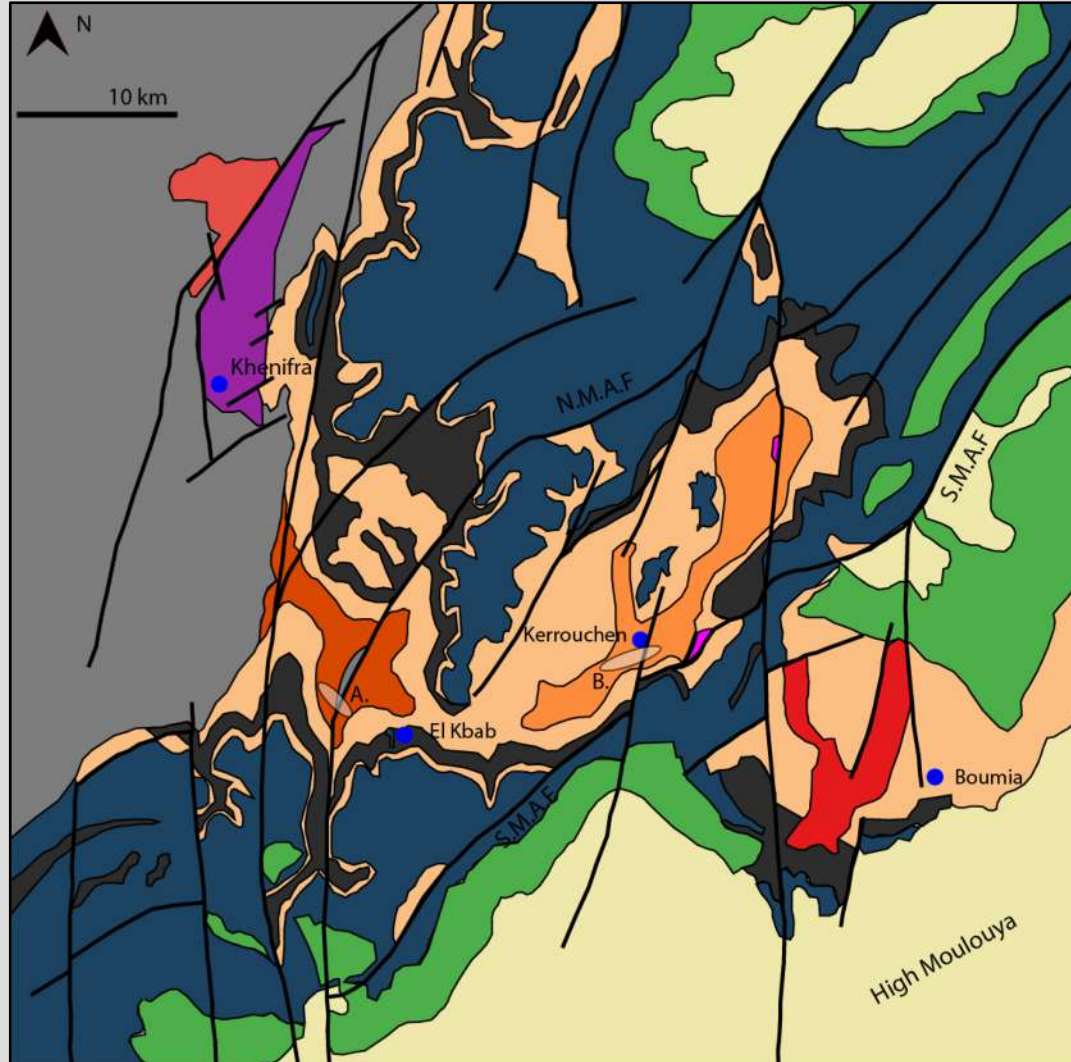


The Kerrouchen Basin

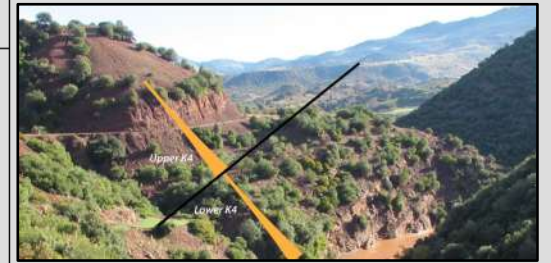
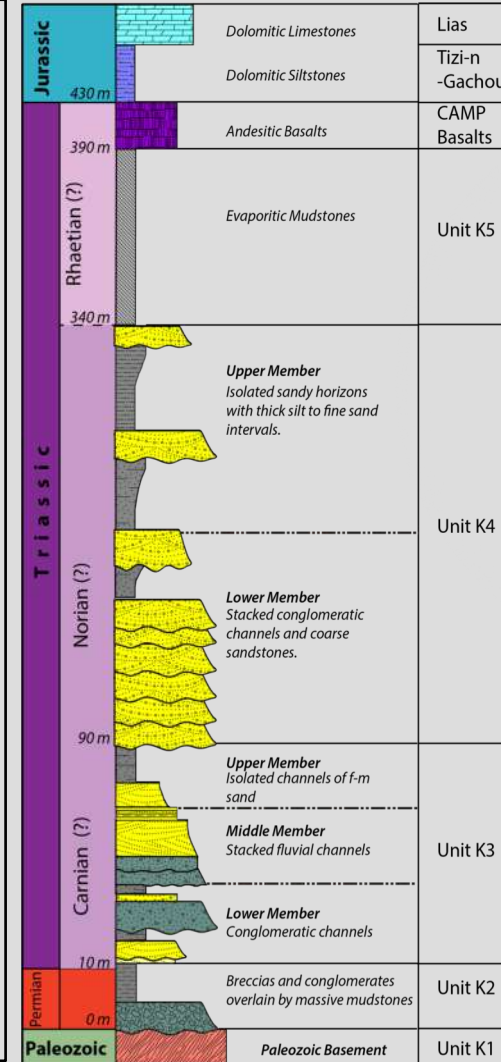




The Kerrouchen Basin

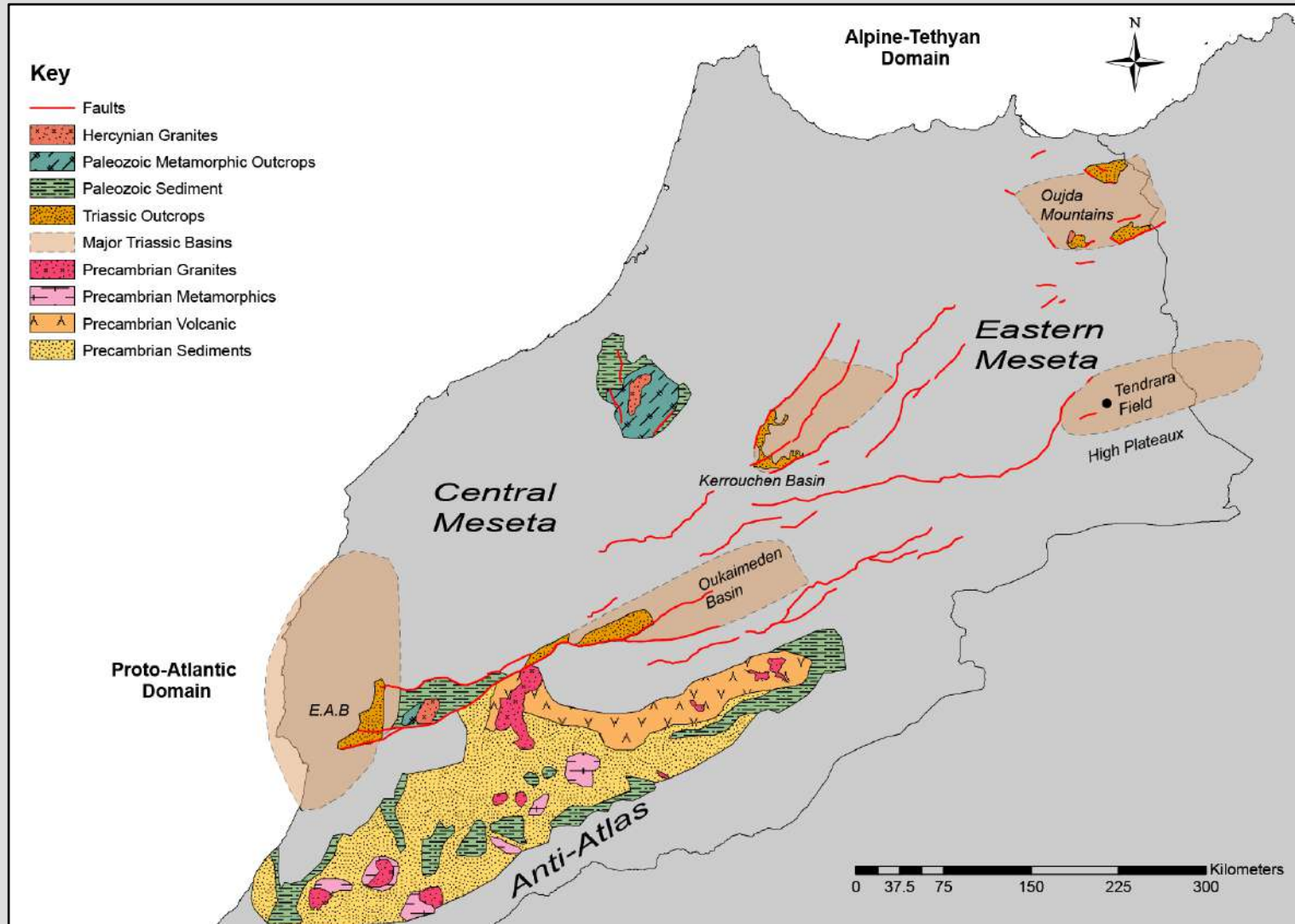


- Tertiary
- Cretaceous
- Jurassic
- CAMP
- K5 Formation
- K4 Formation
- K3 Formation
- Permian
- Permian Andesites
- Bouda Granite
- E. Paleozoics
- W. Paleozoics



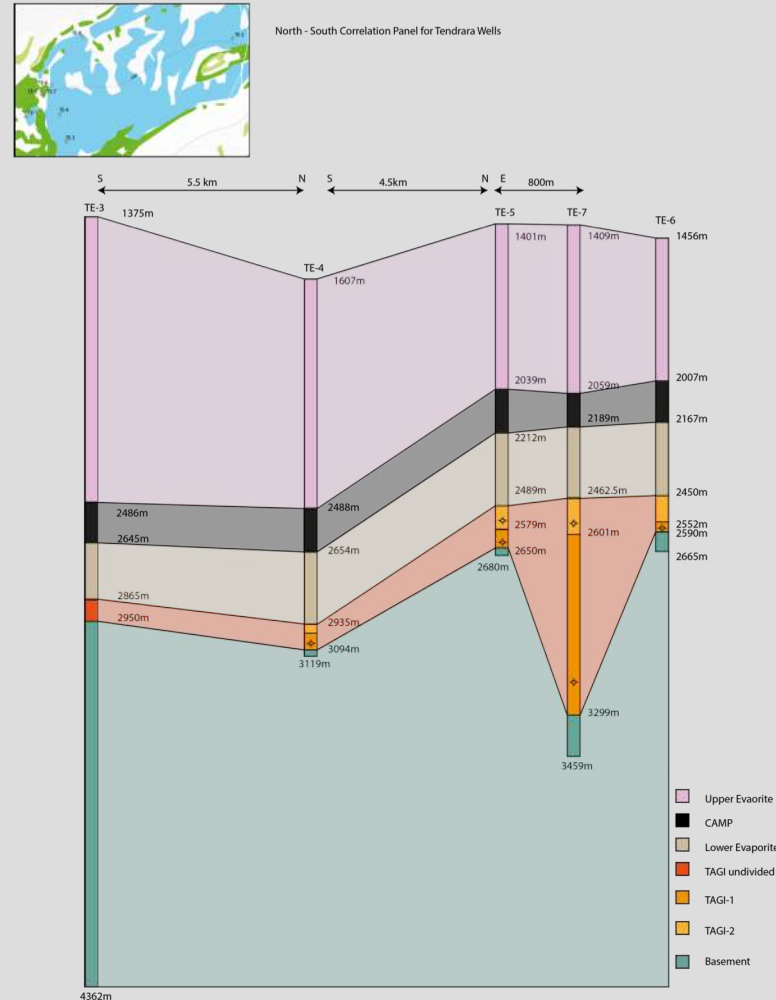
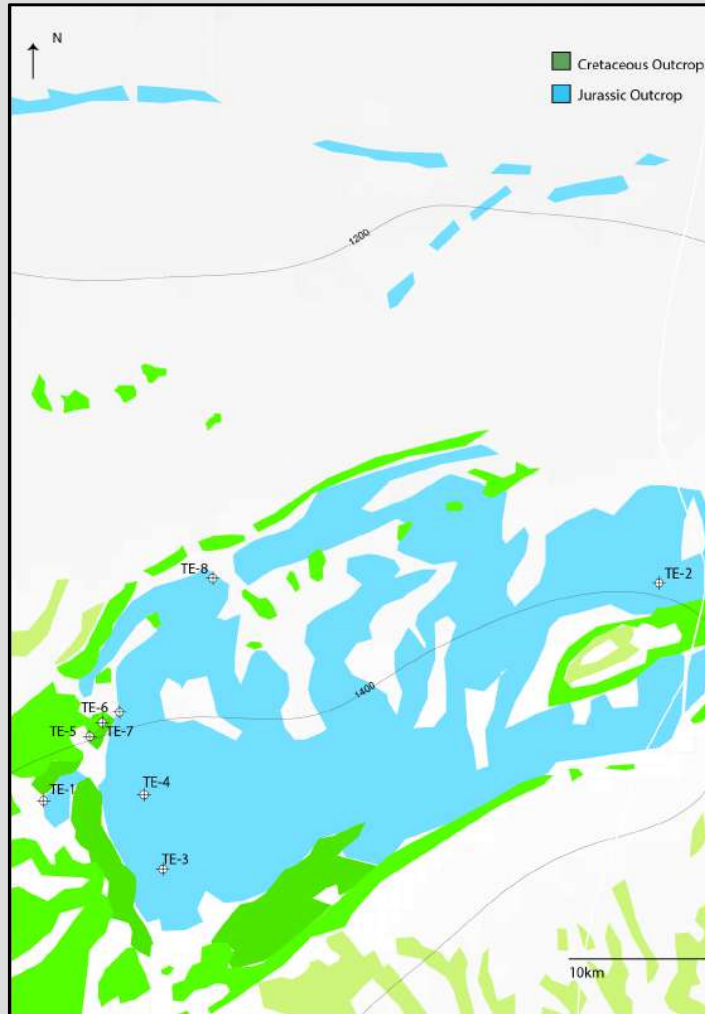


The Tendirara Field





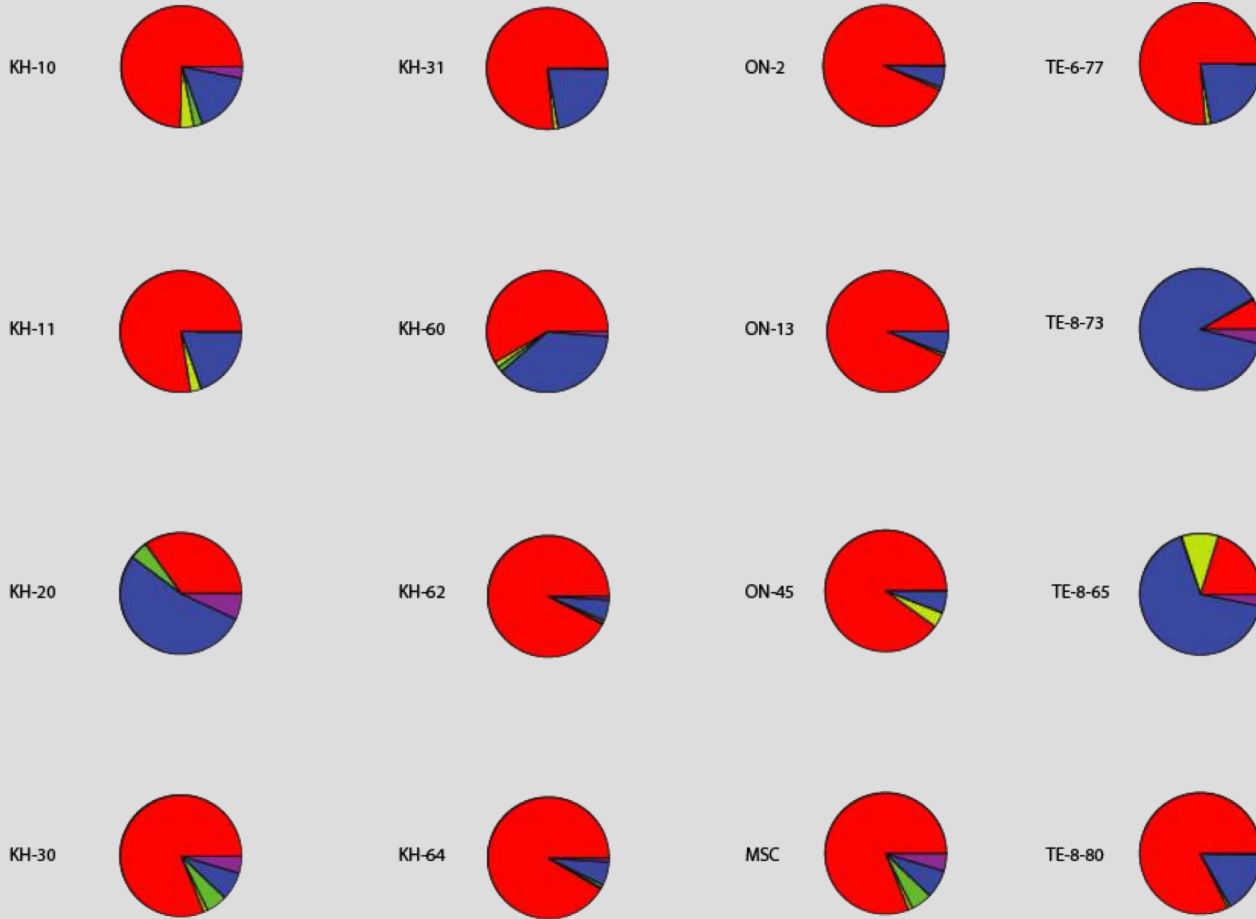
The Tendirara Field



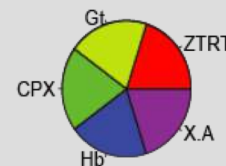
- Samples analysed from TE-6 and TE-8
- Further samples collected from TE-1 and TE-4

4. Provenance Data

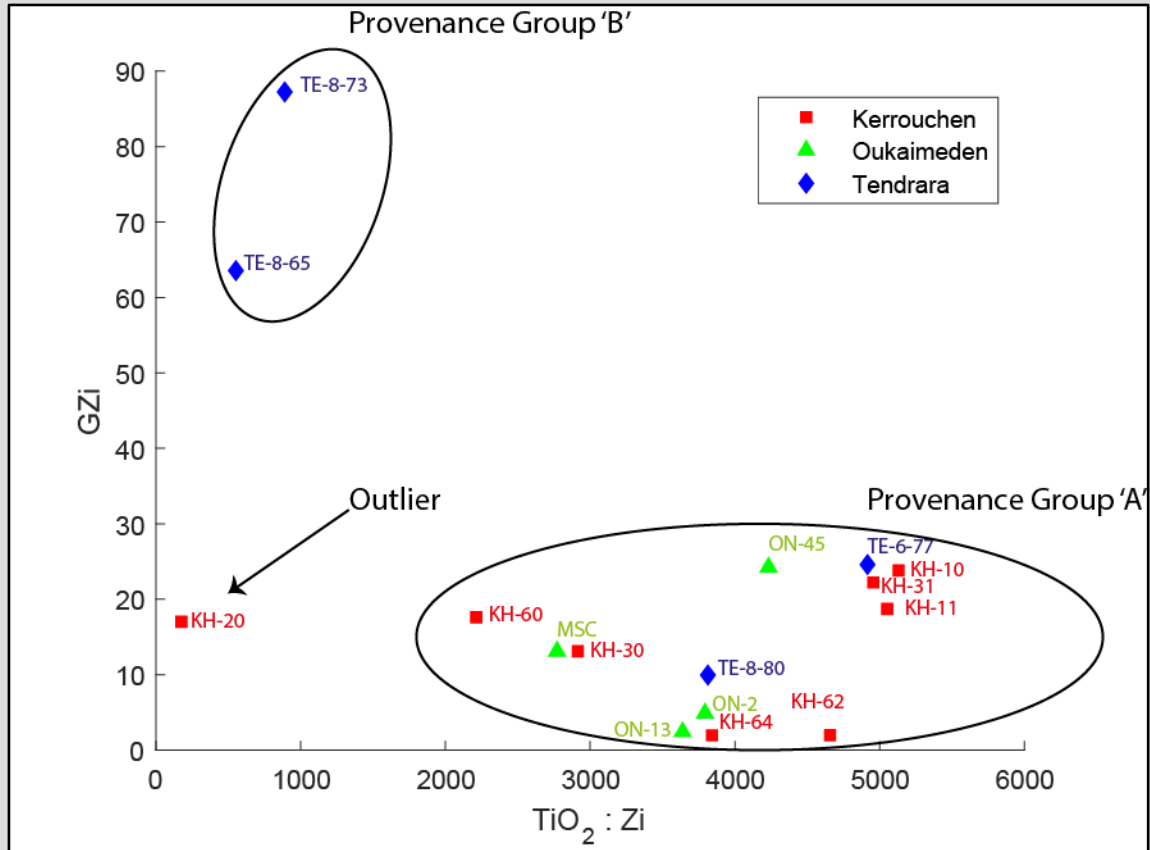
Heavy Mineral Analysis



- Majority of samples are dominated by Zrn, Tur, Rt and other titanium minerals, with secondary hornblende.
- KH-20, TE-8-65 and TE-8-73 samples dominated by hornblende.



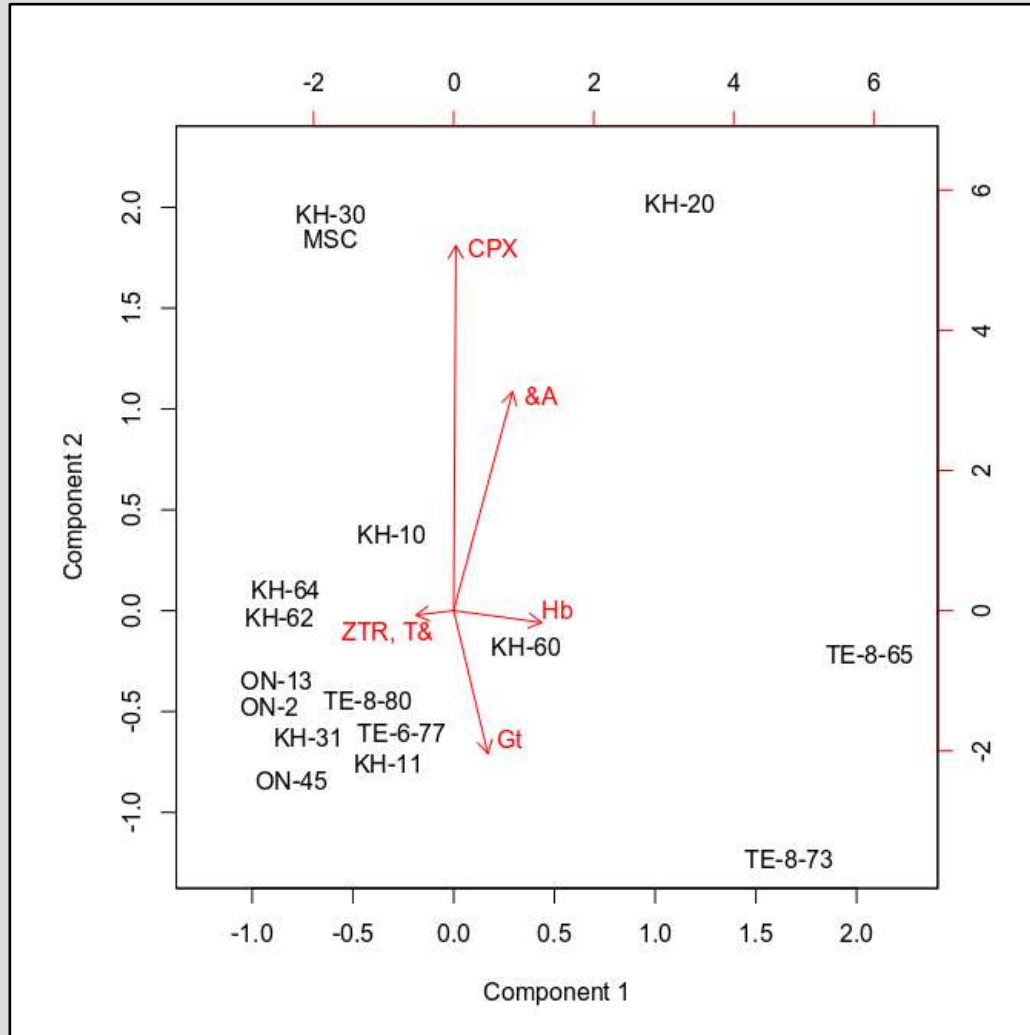
Heavy Mineral Analysis



- Majority of samples are dominated by Zrn, Tur, Rt and other titanium minerals, with secondary hornblende.
- KH-20, TE-8-65 and TE-8-73 samples dominated by hornblende.

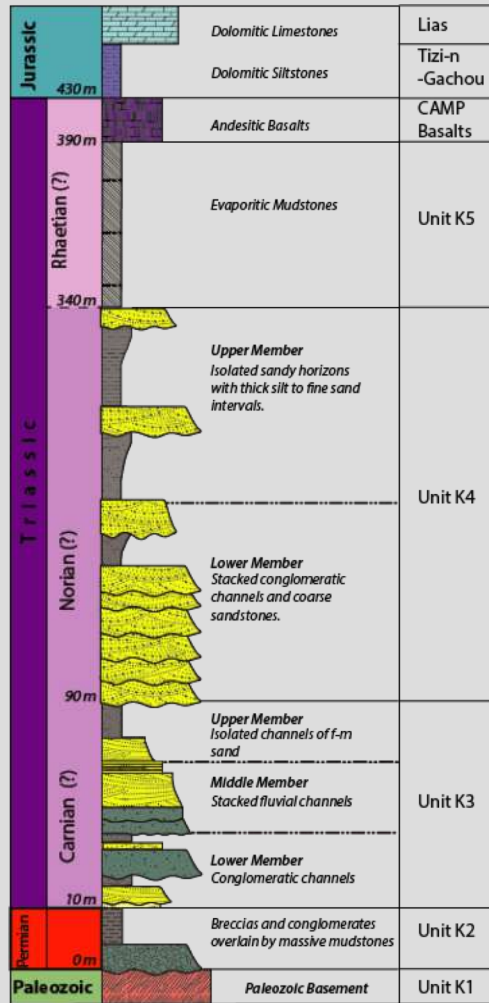


Heavy Mineral Analysis

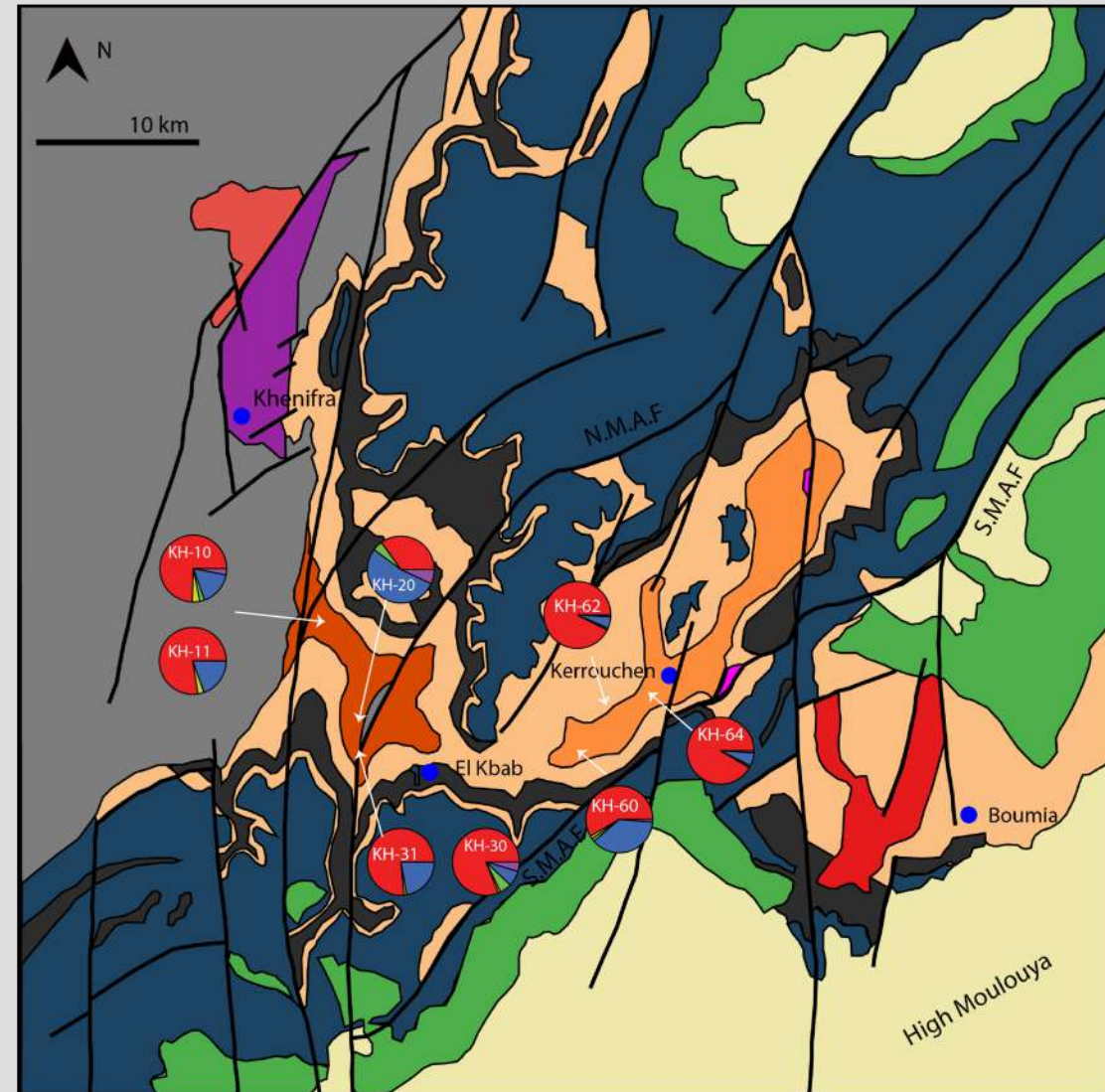
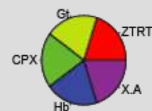
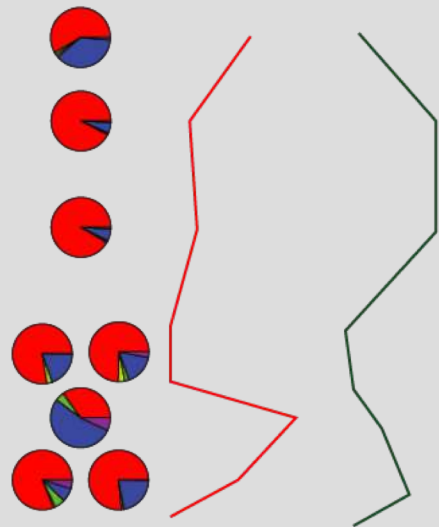


- Majority of samples are dominated by Zrn, Tur, Rt and other titanium minerals, with secondary hornblende.
- KH-20, TE-8-65 and TE-8-73 samples dominated by hornblende.

Heavy Mineral Analysis



Heavy Mineral Indices $\frac{\text{Ti-Oxides:Zrn}}{5000}$ 0 25 GZi 0

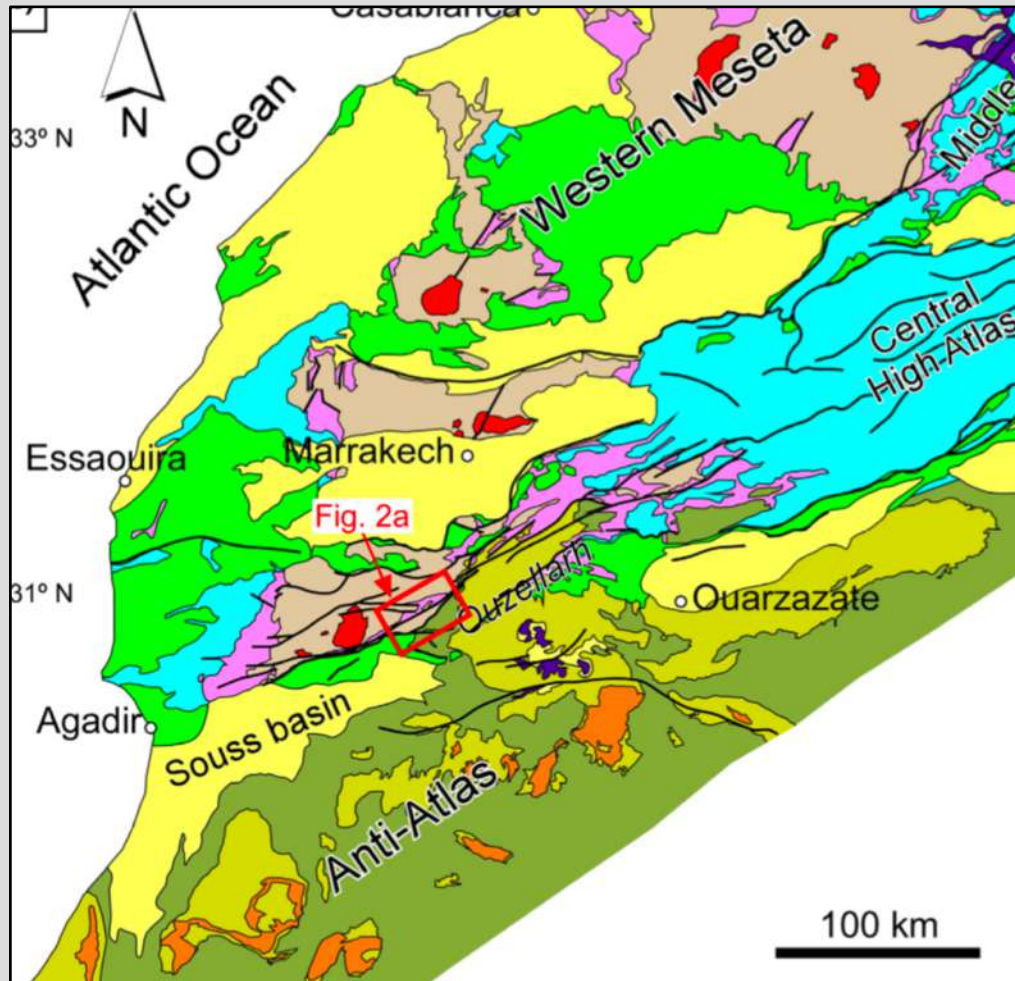


- Tertiary
- Cretaceous
- Jurassic
- CAMP
- K5 Frm
- K4 Frm
- K3 Frm
- Permian
- Permian Andesites
- Bouda Granite
- E.Paleozoics
- W.Paleozoics

5. Previous Provenance Work



Source to Sink Models

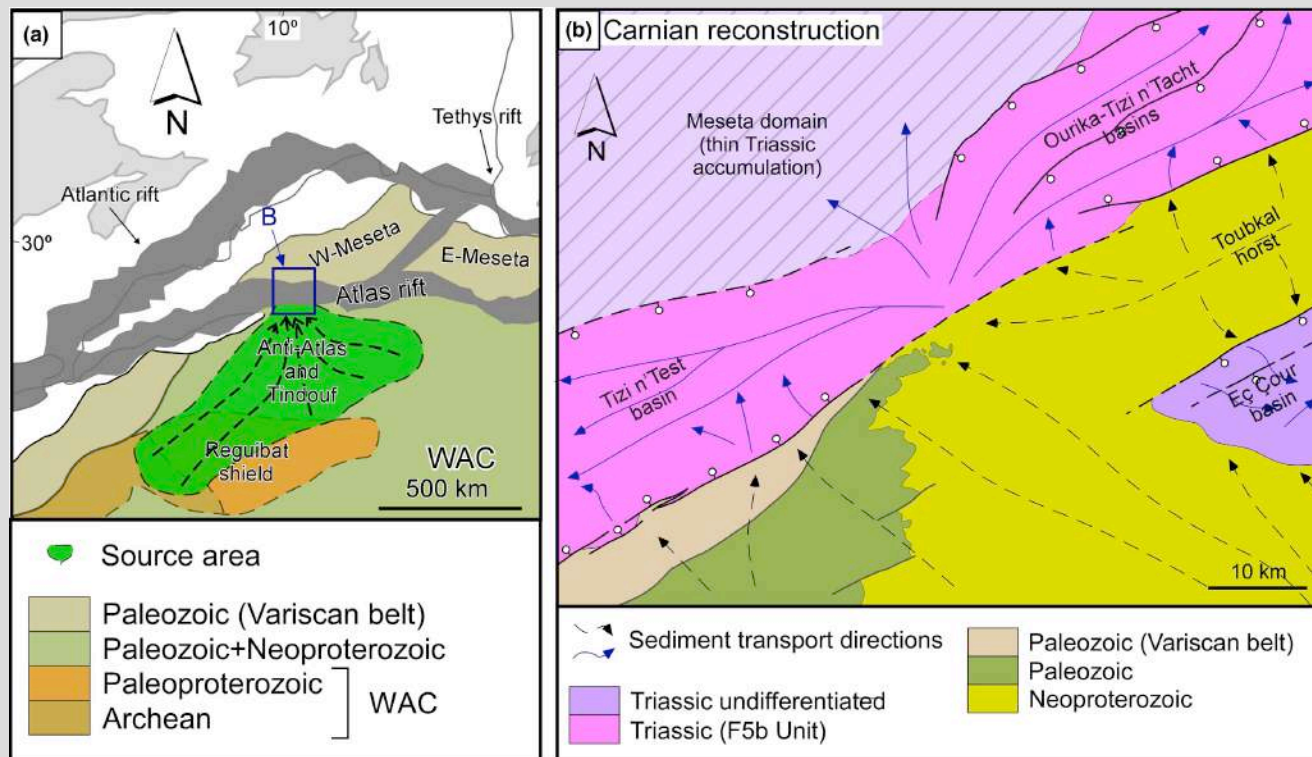


(Domènech *et al.* 2018)

- The Tizi n'Test Basin, Marrakech High Atlas
- West of the Oukaimdedn Basin and the Massif Ancien drainage divide
- Significant contribution from Pan-African, Eburnean and Liberian Orogenic Cycle zircons



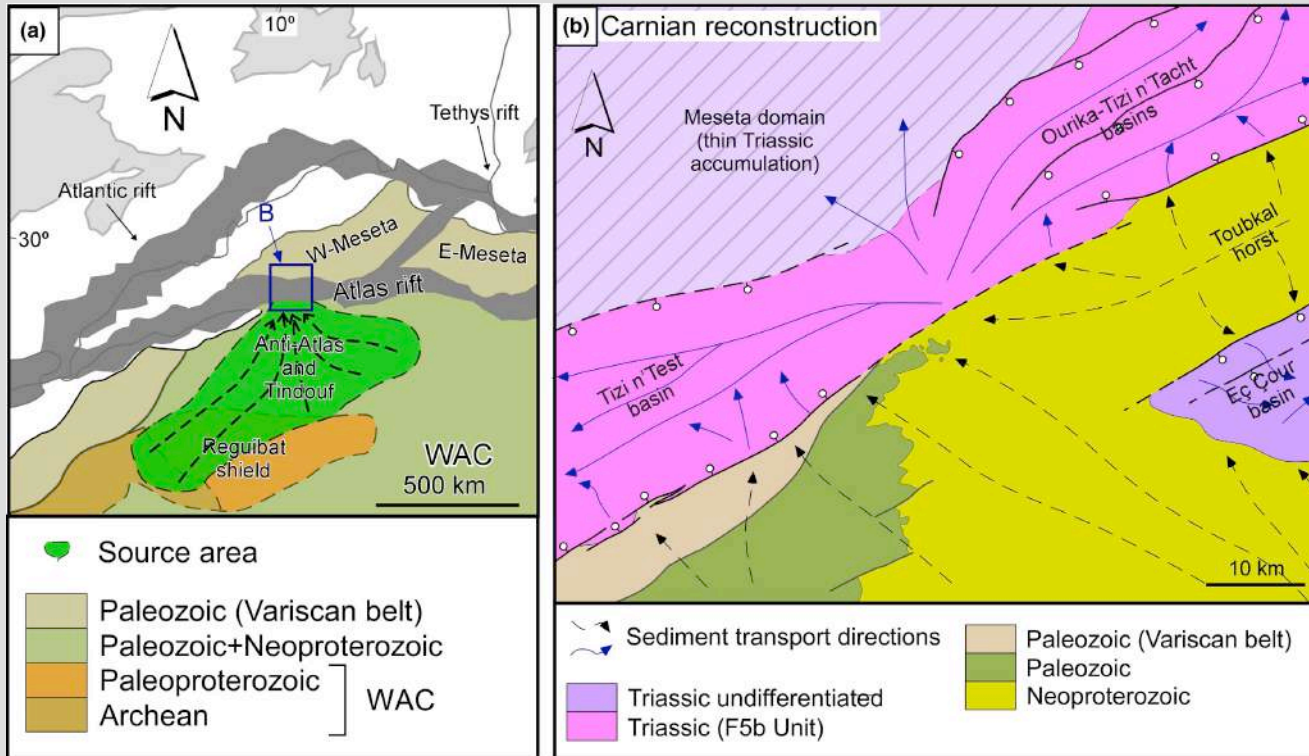
Source to Sink Models



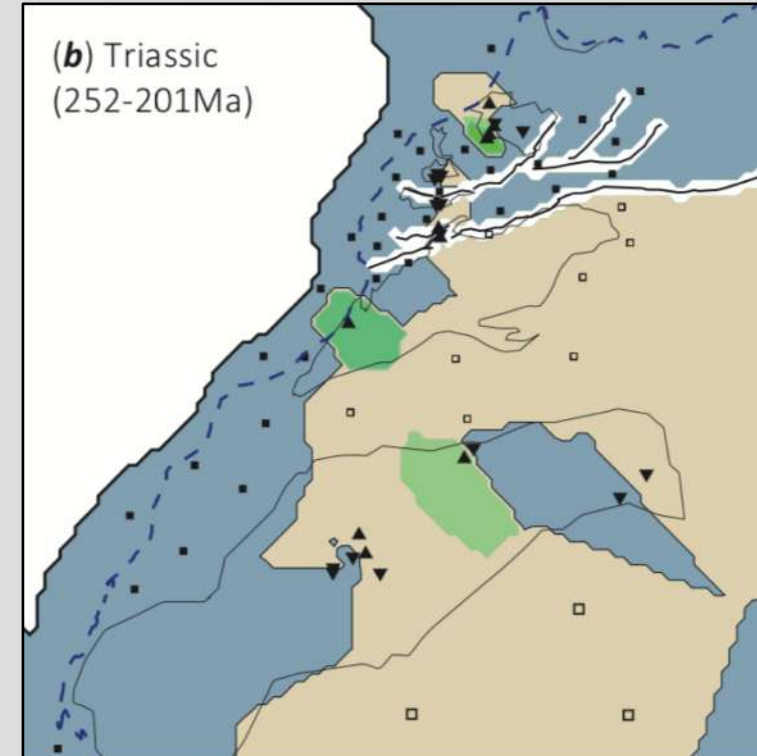
(Domènech *et al.* 2018)

- The Tizi n'Test Basin, Marrakech High Atlas
- West of the Oukaimdedn Basin and the Massif Ancien drainage divide
- Significant contribution from Pan-African, Eburnean and Liberian Orogenic Cycle zircons

Source to Sink Models



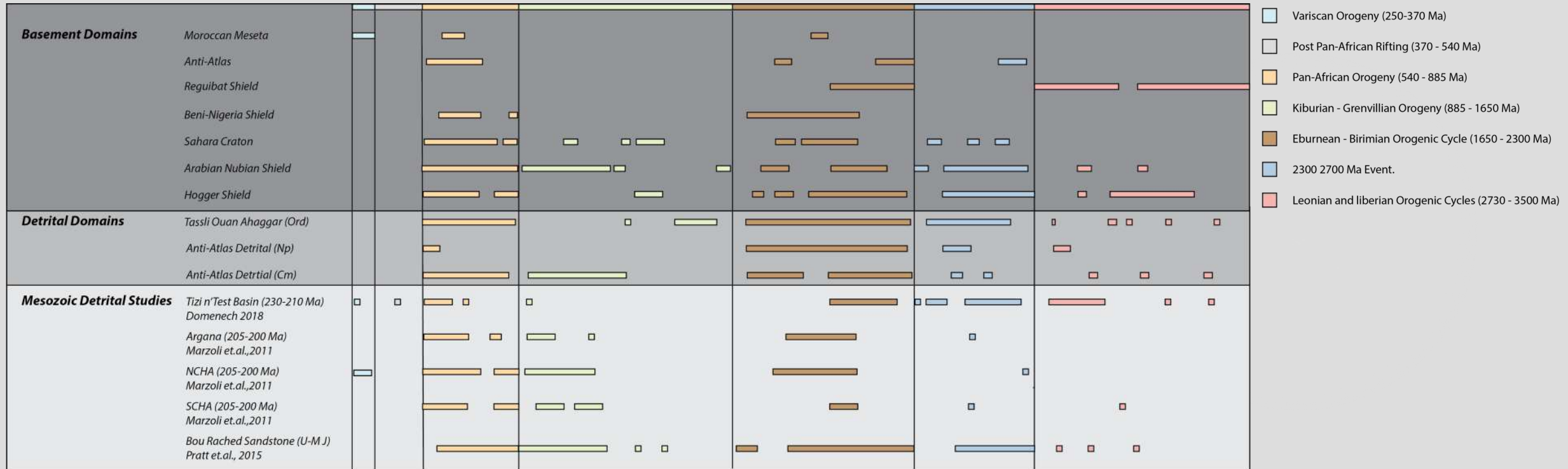
(Domènech *et al.* 2018)



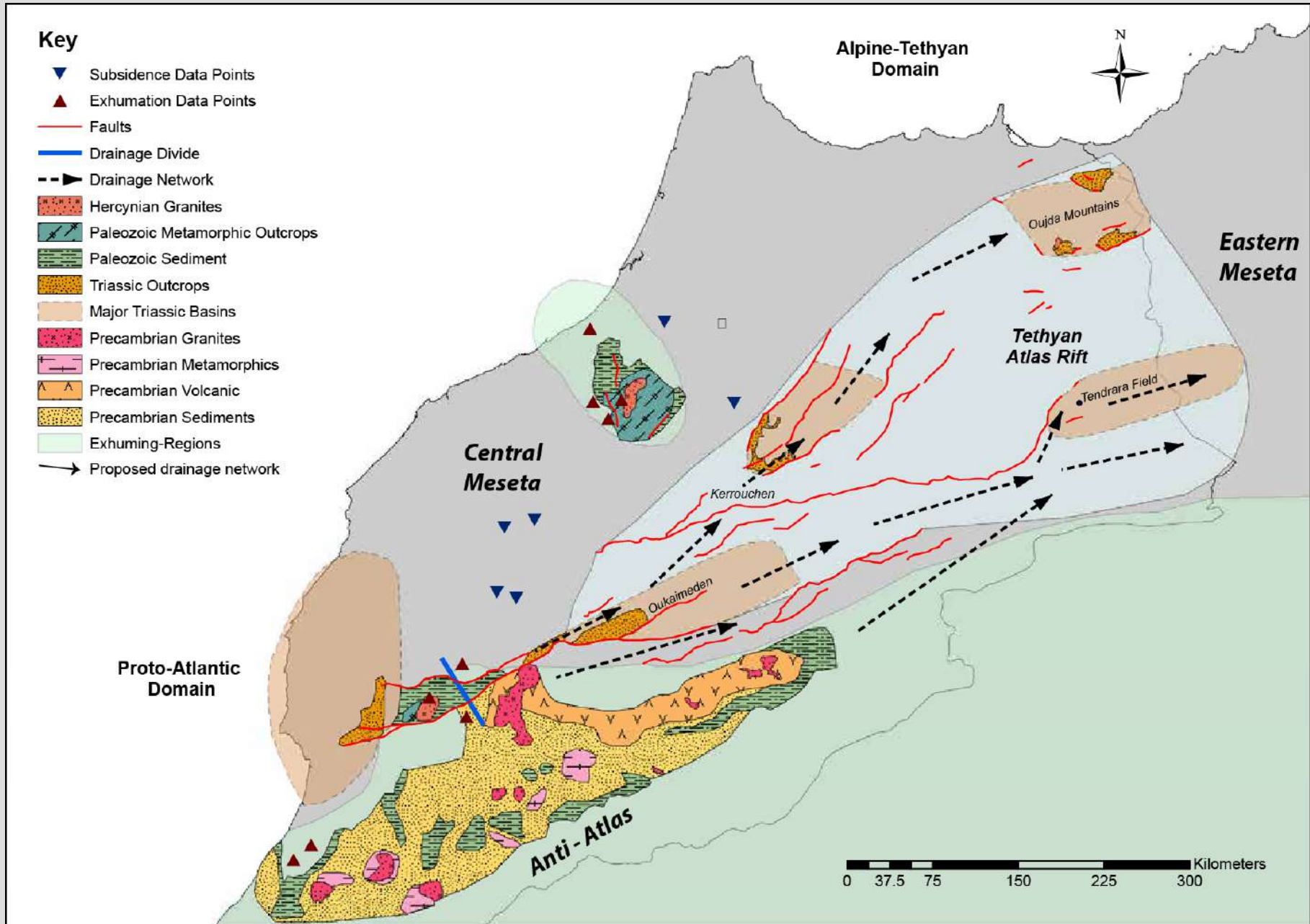
(Charton 2018, p. 81)



Source to Sink Models



(Abati *et al.* 2010; Linnemann *et al.* 2011; Avigad *et al.* 2012; Pereira *et al.* 2016; Domènech *et al.* 2018)



6. Applications to Reservoir Characterisation

6. Applications to Reservoir Characterisation

To utilise provenance data for reservoir characterisation a shift in provenance is required

1. Well defined mineralogical event
2. Long term source region evolution
3. Weathering or transport changes related to alluvial storage or climatic changes
4. Mixing of two depositional systems

Applications to Reservoir Characterisation

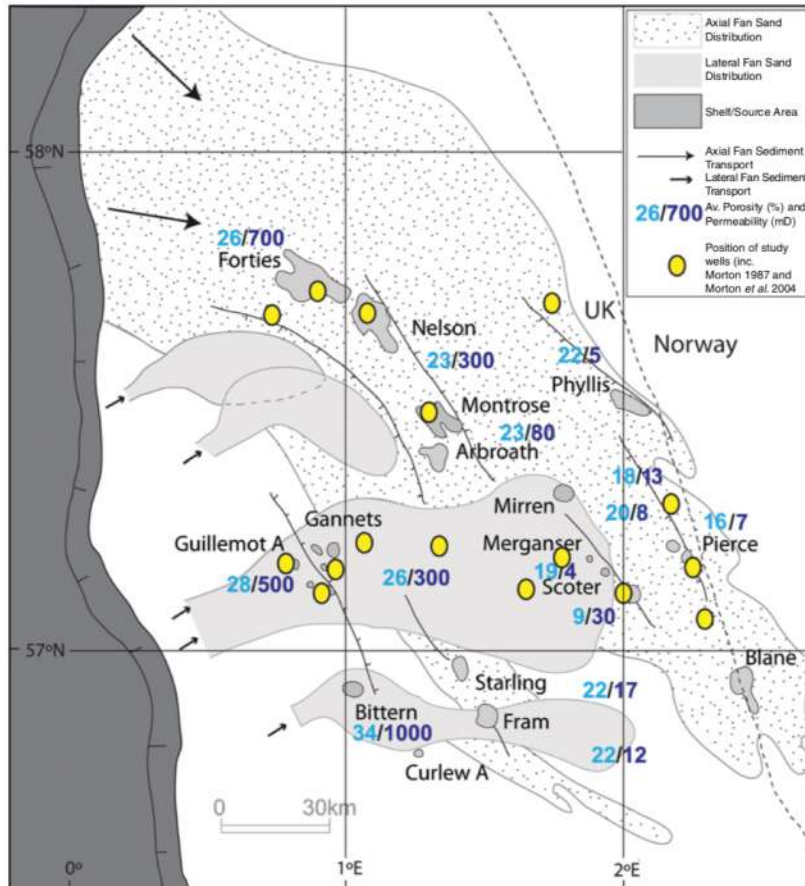


Fig. 3. Map showing the interpreted extent of the axial and lateral Sele Formation basin-floor fan units. Yellow dots show the positions of the data utilized in this study, including those from Morton (1987) and Morton *et al.* (2004). Approximate porosity (%) and permeability (mD) data are also shown. Modified from Hempton *et al.* (2005).

- Heavy Minerals and Provenance proxies have been useful within the North Sea
- Their use has helped identify and constrain different depositional systems
- Sele Formation, Paleocene deep-water reservoir (Kilhams *et al.* 2014)

Applications to Reservoir Characterisation

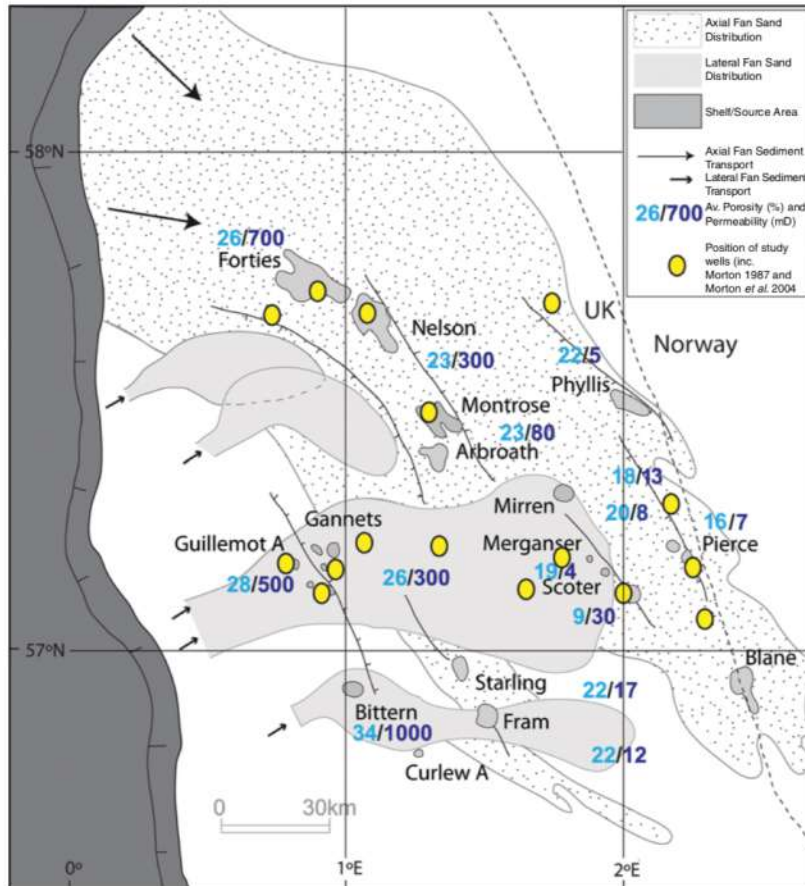


Fig. 3. Map showing the interpreted extent of the axial and lateral Sele Formation basin-floor fan units. Yellow dots show the positions of the data utilized in this study, including those from Morton (1987) and Morton *et al.* (2004). Approximate porosity (%) and permeability (mD) data are also shown. Modified from Hempton *et al.* (2005).

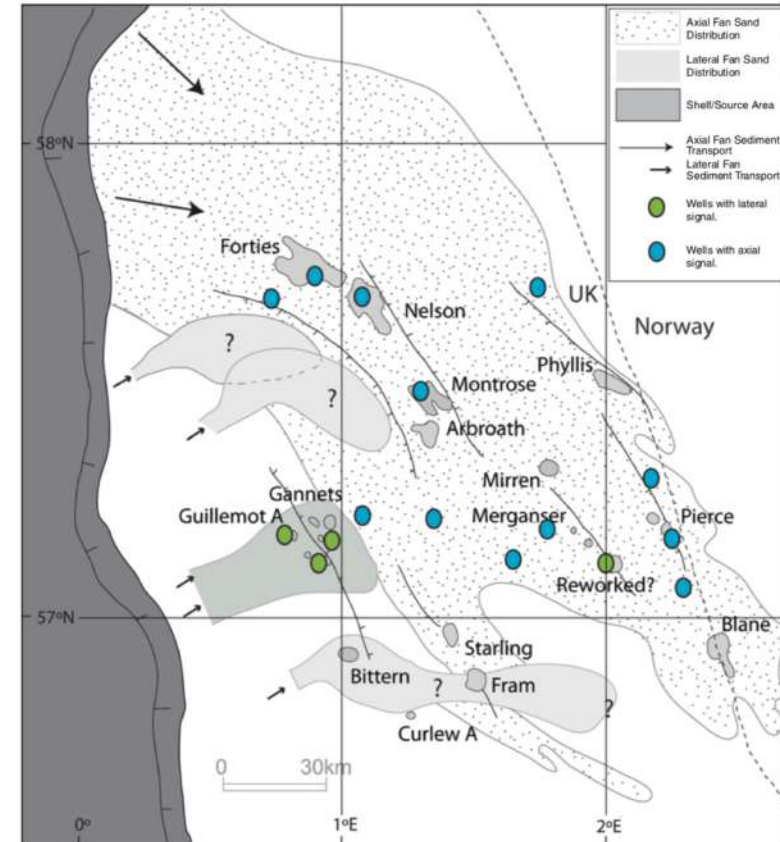
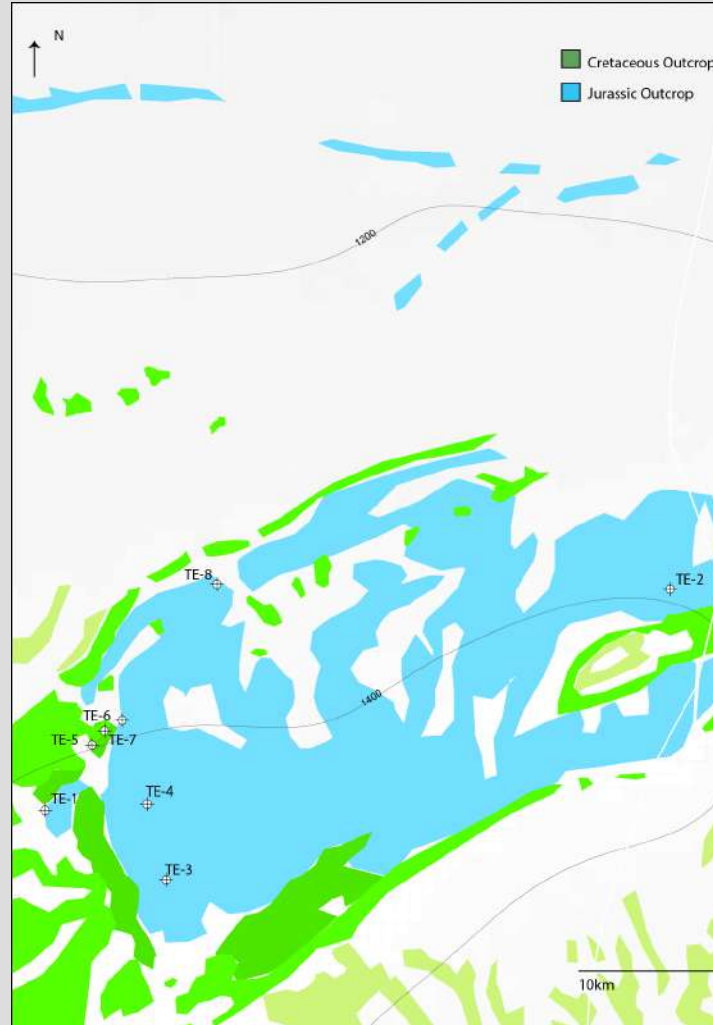
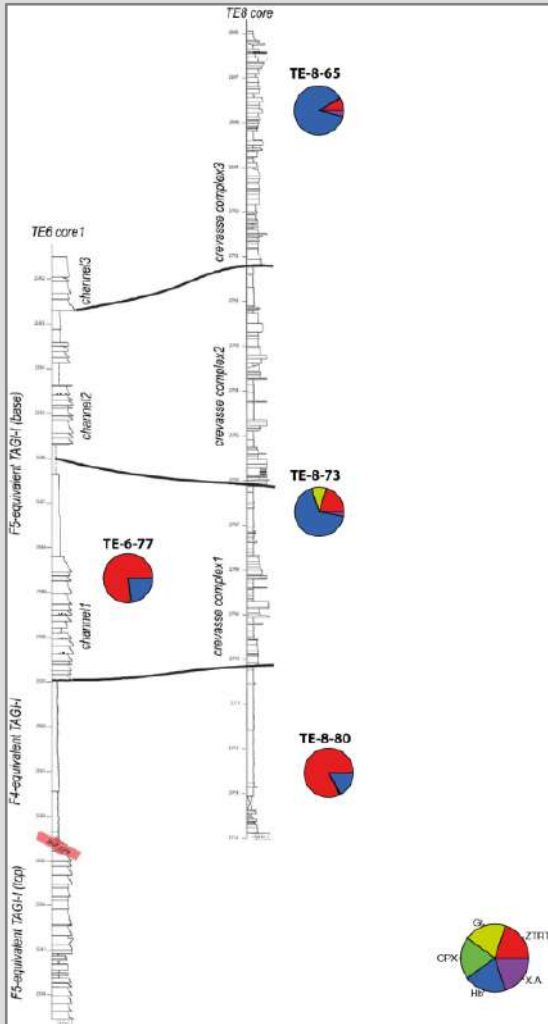


Fig. 10. Reinterpreted map showing the wells utilized in this study alongside those from Morton (1987) and Morton *et al.* (2004). Those with axial garnet signatures are shown in blue and those with lateral signatures are shown in green. Based on the distribution of these results a new limit for the main lateral fan system (in the area of the Gannet Fields) has been proposed. More work is required to understand the precise extent of the lateral fans to the north and south. Modified from Hempton *et al.* (2005).





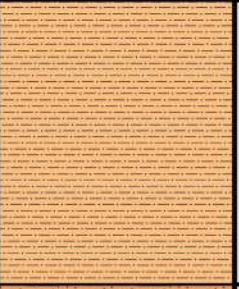





Applications to Reservoir Characterisation



- Well to well correlation potential within Tendrara Field
- Tool for constraining distribution of key reservoir intervals and the scale of depositional systems

7. Future Work



		Petrographic Analysis	Compositional Data	HMA	Geochronological Data
Sinemurian	Jurassic				
	CAMP				
Rhaetian	K5 Formation				
Norian	Upper- K4 Formation		5	5	2
Carnian	Lower - K4 Formation		3	3	2
	K3 Formation		13	13	16
Carboniferous - Permian	K2 Formation				
	W.Paleozoics		2	2	4
	E. Paleozoics				

Future work

1. Compositional Data
2. Heavy Mineral Database
3. Thermal Geochronology of the Kerrouchen Basin
4. Detrital Zircon Study
5. Secondary Isotopic Proxy

MSc project

Kerrouchen Basin

Tess Oude Essink

Field area



South side of gorge



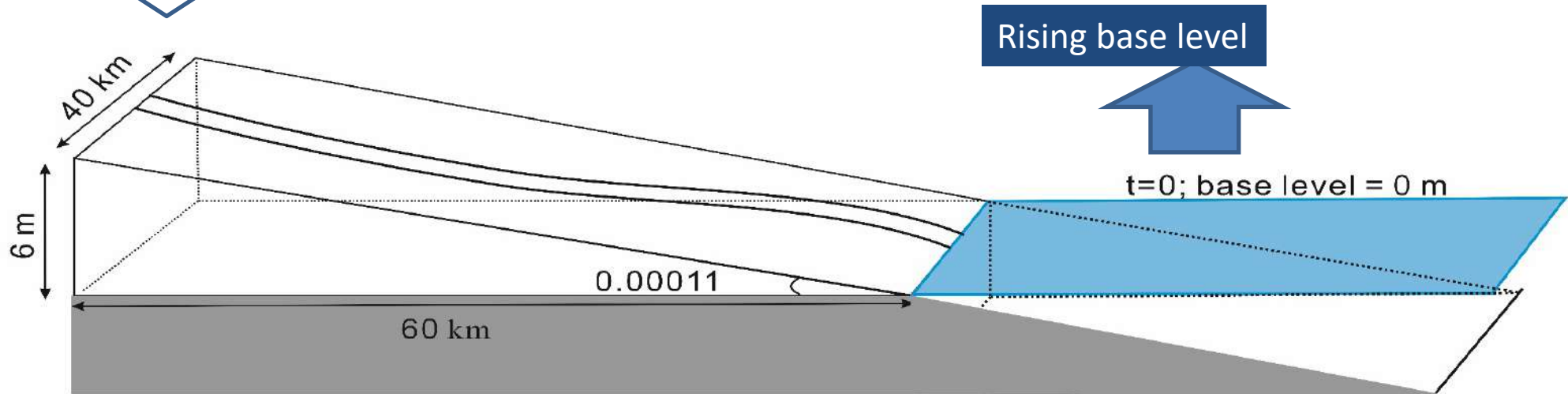
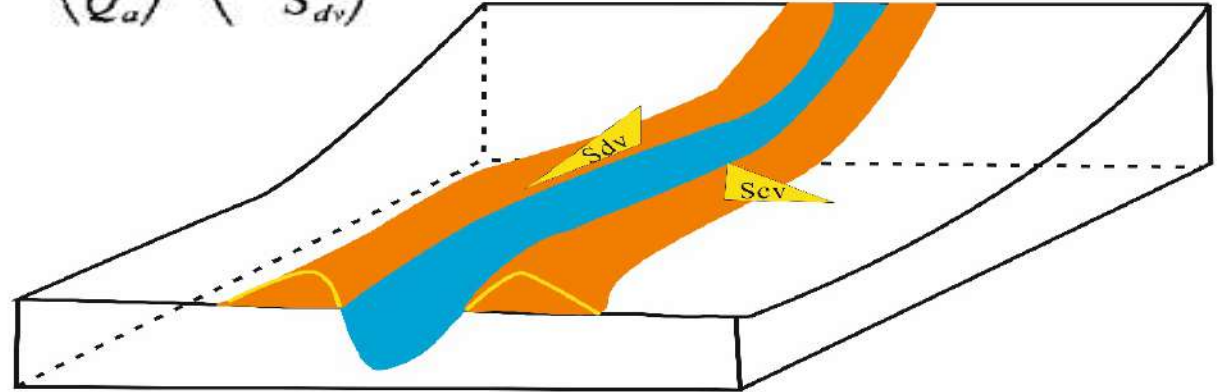
Numerical model inputs

Qs and Qw input



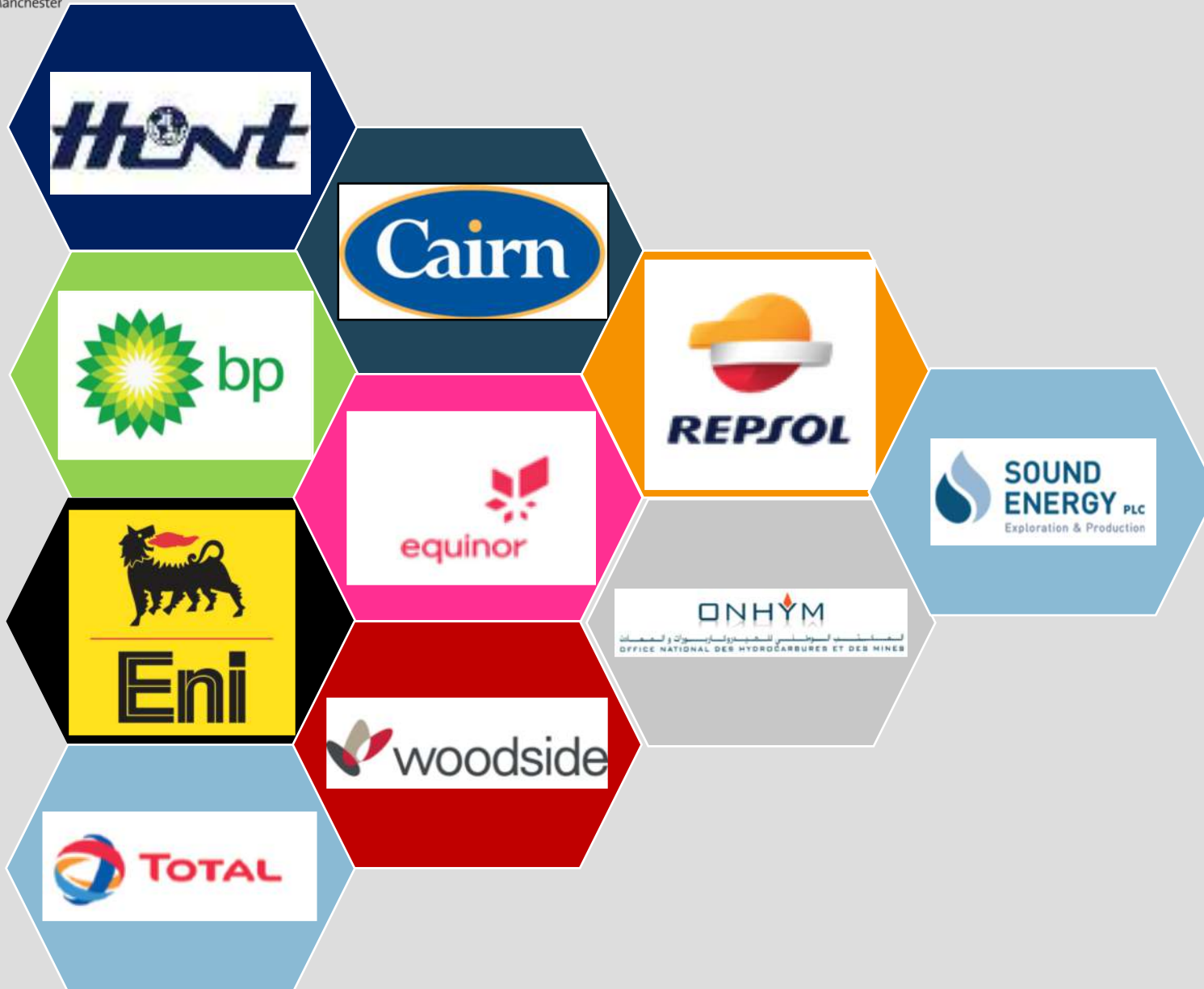
$$P(a) = \left(\frac{Q_f}{Q_a}\right)^{eq} \left(k_s \frac{S_{cv}}{S_{dv}}\right)^{es}$$

- **Dependent avulsion**
- Slope advantage
- Flood magnitude and frequency





Sponsors





References

- Abati, J., Aghzer, A.M., Gerdes, A. & Ennih, N. 2010. Detrital zircon ages of Neoproterozoic sequences of the Moroccan Anti-Atlas belt. *Precambrian Research*, **181**, 115–128, <https://doi.org/10.1016/j.precamres.2010.05.018>.
- Avigad, D., Gerdes, A., Morag, N. & Bechstädt, T. 2012. Coupled U-Pb-Hf of detrital zircons of Cambrian sandstones from Morocco and Sardinia: Implications for provenance and Precambrian crustal evolution of North Africa. *Gondwana Research*, **21**, 690–703, <https://doi.org/10.1016/j.gr.2011.06.005>.
- Benvenuti, M. (Dipartimento di S. della T.U. di F. 2016. *Interim Report on the Sedimentological and Stratigraphic Analysis of the TE6 Well-Core1*.
- Benvenuti, M. (Dipartimento di S. della T.U. di F. 2017. *Report on the Sedimentological and Stratigraphic Analysis of the TE8 Well-Core*.
- Charton, R. 2018. *Phanerozoic Vertical Movements in Morocco*.
- Domènech, M., Stockli, D.F., Teixell, A. & Geologia, D. 2018. Detrital zircon U-Pb provenance and paleogeography of Triassic rift basins in the Marrakech High Atlas. 0–2, <https://doi.org/10.1111/ter.12340>.
- Fabuel-Perez, I., Redfern, J. & Hodgetts, D. 2009. Sedimentology of an intra-montane rift-controlled fluvial dominated succession: The Upper Triassic Oukaimeden Sandstone Formation, Central High Atlas, Morocco. *Sedimentary Geology*, **218**, 103–140, <https://doi.org/10.1016/j.sedgeo.2009.04.006>.
- Kilhams, B., Morton, A., Borella, R., Wilkins, A. & Hurst, A. 2014. Understanding the provenance and reservoir quality of the Sele Formation sandstones of the UK Central Graben utilizing detrital garnet suites. *Sediment Provenance Studies in Hydrocarbon Exploration and Production*, <https://doi.org/10.1144/SP386.16>.
- Linnemann, U., Ouzegane, K., Drareni, A., Hofmann, M., Becker, S., Gärtner, A. & Sagawe, A. 2011. Sands of West Gondwana: An archive of secular magmatism and plate interactions - A case study from the Cambro-Ordovician section of the Tassili Ouan Ahaggar (Algerian Sahara) using U-Pb-LA-ICP-MS detrital zircon ages. *Lithos*, **123**, 188–203, <https://doi.org/10.1016/j.lithos.2011.01.010>.
- Mader, N.K. 2005. Sedimentology and sediment distribution of Upper Triassic fluvio-aeolian reservoirs on a regional scale (Central Algeria , SW Morocco , NE Canada): an integrated approach unravelling the influence of climate versus tectonics on reservoir architecture Vo. I.
- Morton, A., O'B. Knox, R.W. & Hallsworth, C. 2002. Correlation of reservoir sandstones using quantitative heavy mineral analysis. *Petroleum Geoscience*, **8**, 251–262, <https://doi.org/10.1144/petgeo.8.3.251>.
- Pereira, M.F., Gama, C., et al. 2016. Evidence for multi-cycle sedimentation and provenance constraints from detrital zircon U–Pb ages: Triassic strata of the Lusitanian basin (western Iberia). *Tectonophysics*, **681**, 318–331, <https://doi.org/10.1016/j.tecto.2015.10.011>.
- Turner, P., Pilling, D., Walker, D., Exton, J., Binnie, J. & Sabaou, N. 2001. Sequence stratigraphy and sedimentology of the Late Triassic TAG-I (Blocks 401/402, Berkine Basin, Algeria). *Marine and Petroleum Geology*, [https://doi.org/10.1016/S0264-8172\(01\)00039-3](https://doi.org/10.1016/S0264-8172(01)00039-3).