

Lower Silurian Black Shales of North Africa: The Role of Glaciation on the Distribution of Source-Rock Quality Facies*

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Search and Discovery Article #30240 (2012)**

Posted July 30, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

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Abstract

A key exploration risk in the Lower Paleozoic of North Africa is the local absence of source rock facies in the lower Silurian shale. Following the Late Ordovician glaciation, decaying ice sheets left a residual topography that included a series of “underfilled” glacial incisions, carved by ice and/or meltwater. Some models explain the patchy distribution of high TOC shales as deposition in anoxic pools within this topography during Silurian post-glacial transgression. In some parts of North Africa, however, a high TOC shale “blanket” occurs, whereas in other parts a clear connection with fault activity is observed. We present data from Al Kufrah Basin in southern Libya, which includes a continuous section straddling the Mamuniyat (Late Ordovician) and Tanezzuft (Late Ordovician-Silurian) formations respectively. The topmost Mamuniyat Formation comprises glaciogenic sandstones, which pass upward into mixed facies of the Tanezzuft Formation. At its base, the Tanezzuft Formation includes a basal carbonate facies association, comprising bioturbated peloidal micrites and wackestones, bearing fragmented crinoids, bryozoa and orthocones (interpreted as reworked coolwater carbonates deposited under oxygenating conditions). Above, the remainder of the Tanezzuft Formation comprises hummocky cross-bedded and graded sandstone intervals intercalated with shale and siltstone (interpreted as storm influx onto a muddy shelf). These latter deposits, however, are interrupted by several lonestone-bearing intervals (interpreted as ice-rafted debris), a striated pavement (interpreted as glacial in origin), manganese crusts and concretions. The putative glacial deposits occur at the same stratigraphic level as high TOC shales elsewhere in North Africa. Deposition of the manganese concretions is interpreted as the result

of a drop in sea level, a result of glaciation, which was accompanied by a fresh water influx, flushing out the potential for anoxia to develop and hence high TOC shales to accumulate.

Reference

Luning, S., D.K. Lydell, O. Sutcliffe, A. Ait Salem, E. Zanella, J. Craig, and D.A.T. Harpel, 2000, Silurian-Lower Devonian black shales in Morocco: Which are the organically richest horizons?: *Journal of Petroleum Geology*, v. 23/3, p. 293-311.

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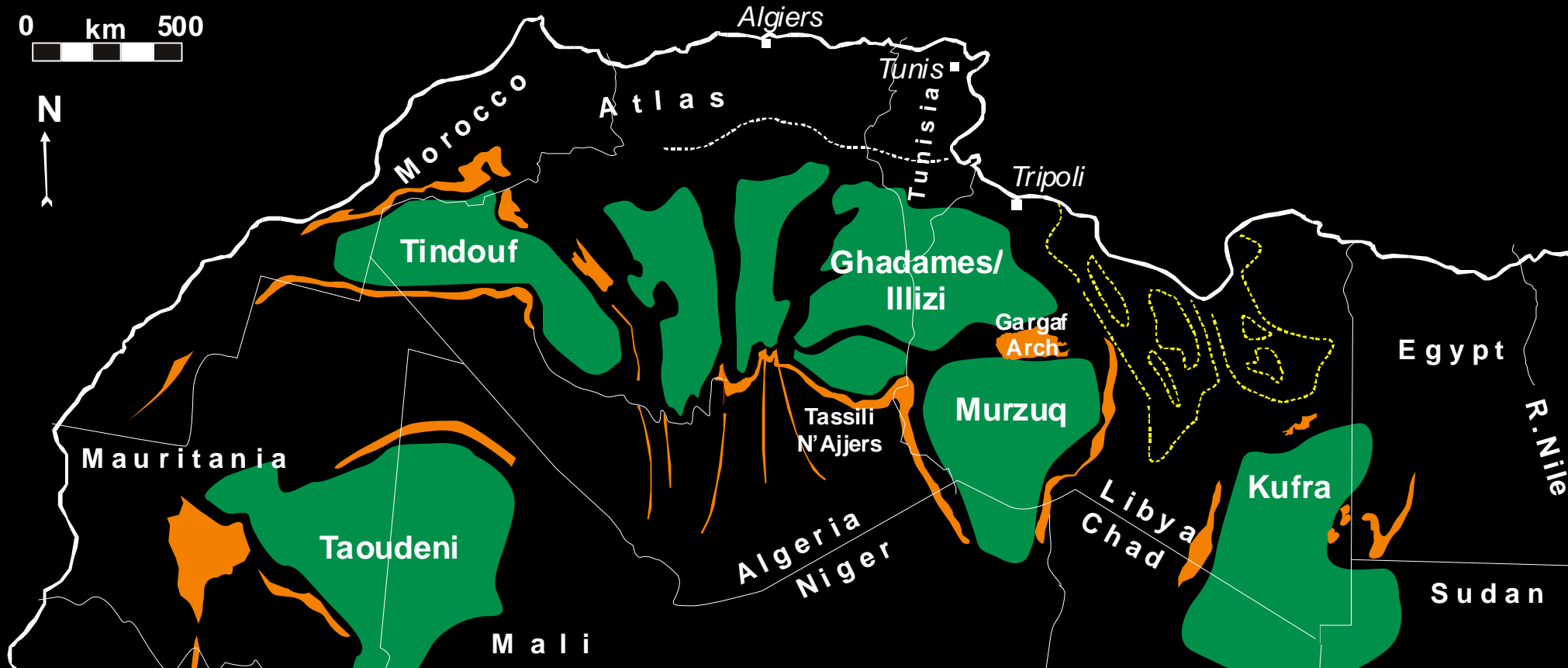
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North Africa and the Saharan basins



Orange
Green

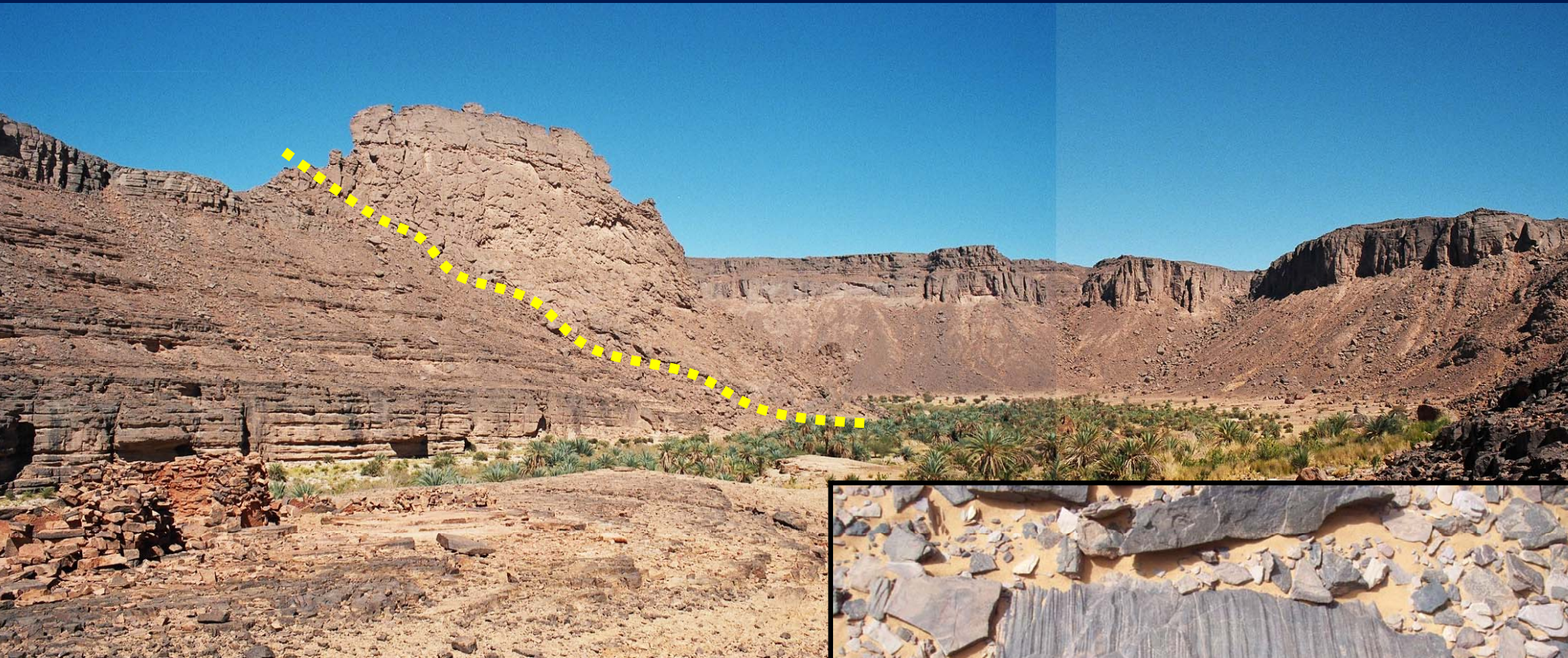
Late Ordovician sediments at outcrop

Late Ordovician sediments in subcrop (sedimentary basins)

Exposures are excellent but widely scattered!

Late Ordovician (Hirnantian, ~443 Ma)

Glacial valley at Iherir, Tassili N'Ajjer, Algeria



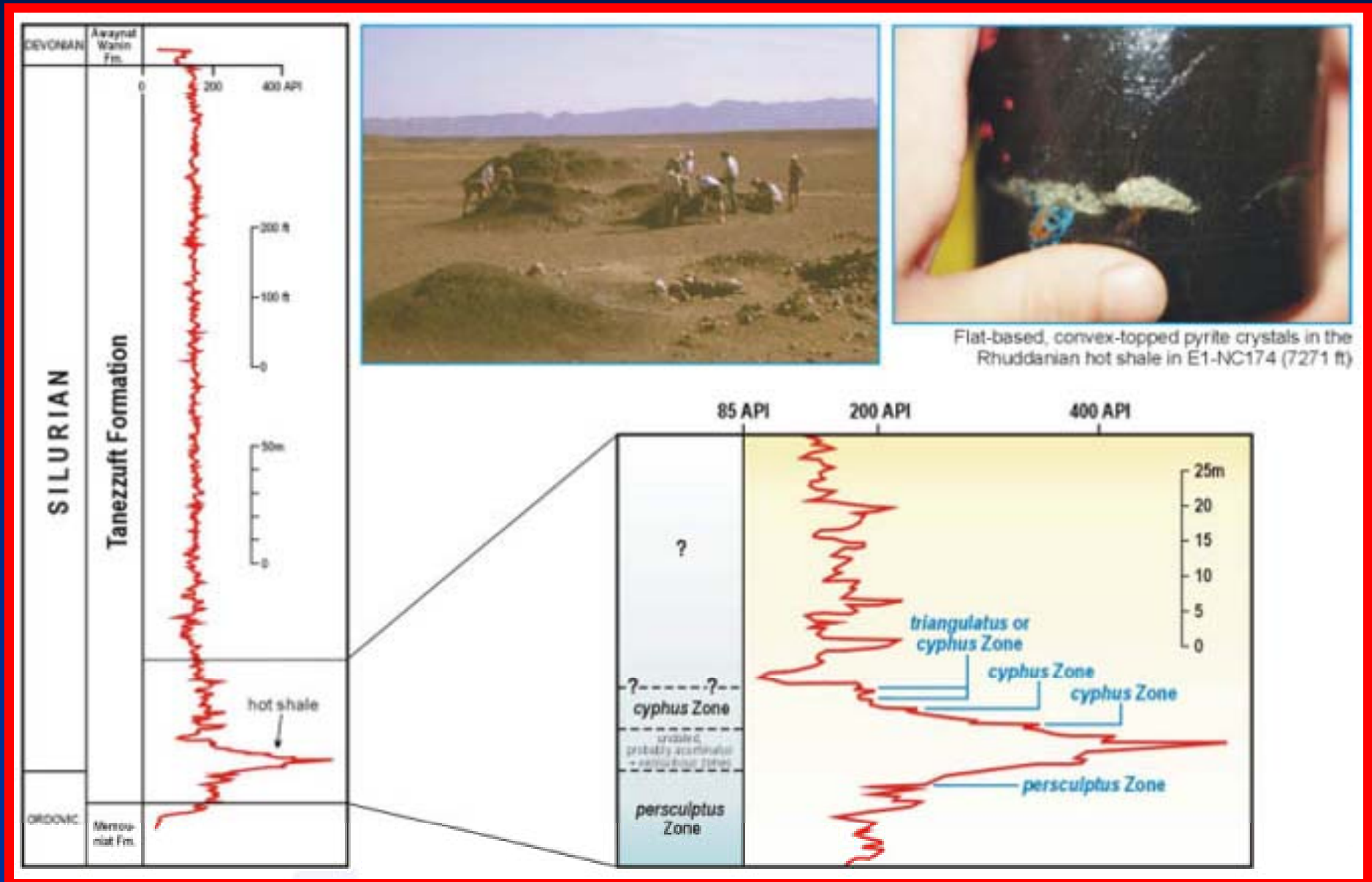
- Unconformity >150 m relief
- Glacially-related incision
- Coarser grained, sometimes chaotic deposits above: major reservoir interval, intensely studied



Early Palaeozoic of North Africa

Chrono-stratigraphy		MOROCCO		ALGERIA		LIBYA	
		High Atlas	Anti Atlas	Illizi Basin	Tassili N'Ajers	Murzuq Basin	Al Kufrah Basin
sil.	Llandovery 443.7 Ma	Black Graptolitic shale	Ain Deliouine Fm	Argiles a Graptolites	Oued Imirhou Fm	Tannezuft Fm	Tannezuft Fm
	Hirnantian 445.6 Ma	Un-named	Upper 2nd Bani Fm	UNIT IV	Tamadjert Fm	Mamuniyat Fm Melaz Shuqran	Mamuniyat Fm
Ordovician	Katian	No formal stratigraphy	Lower 2nd Bani Fm	UNIT III (3)	In Tahouite Fm	Haouaz Fm	
	Sandbian		Ktaoua Fm				
	Darriwilian		1st Bani Fm				
	Dapingian		Outer Fejas Shale Group	UNIT III (2) (Hamra Quartzites)	El Gassi Shales Vire de Mouflon	Ash Shabiyat Fm	
	Floian			UNIT II			
	Tremadocian						
Camb.					Tin Taradjelli Fm	Hassouana Fm	Hassouana Fm

Typical section of Silurian “hot shale”



Model for high TOC shale, Early Silurian

NW

Morocco

Algeria/Tunisia

Libya

Chad/Sudan

SE

A *Hirnantian: LST modulated by glacial-interglacial high frequency cycles. Deposition of glaciogenic reservoirs.*

Glacially sculpted topography
(palaeo-ice stream fairways,
underfilled tunnel valleys,
glaciotectonic features,
+/- isostatic rebound relief)

Palaeo-ice stream fairway
(~50 km wide x 300 km
long; hundreds m deep)

Retreating
ice sheet

--- sea level ---

Ice maximum

Tunnel valley fairway
(~4-8 km wide x 30 km long;
100 m deep)

Push moraines
(several km along strike,
max ~50 m high)

B *Rhuddanian: Early TST, deposition of hot shales*

North Gondwanan
upwelling

initial
transgression

restricted
circulation

--- sea level ---

"Hot shales" in
underfilled glacial
palaeovalleys

C *Post-Rhuddanian: TST, deposition of organically leaner shales*

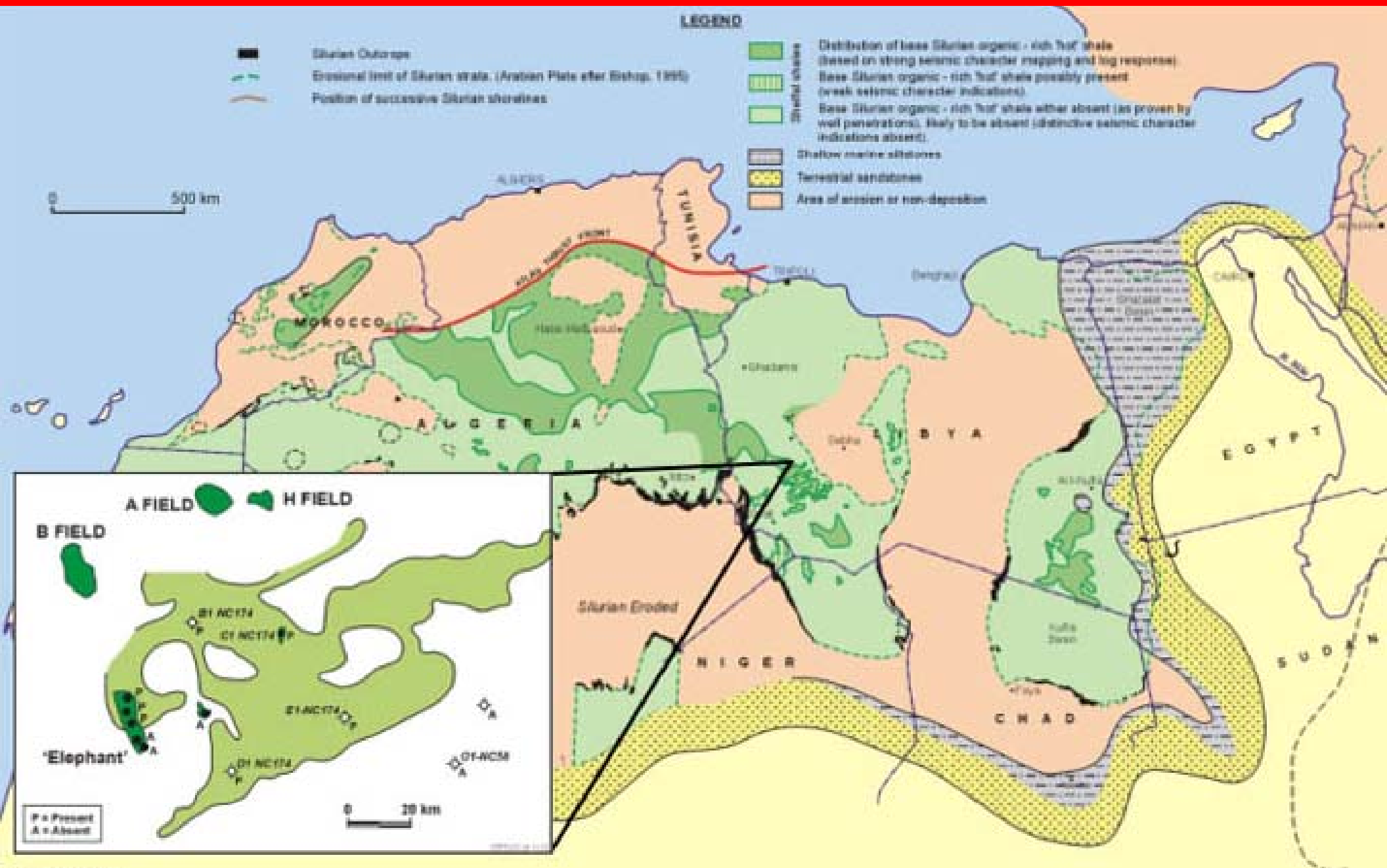
Continuing sea level-rise leads to
deposition of shales with lower
organic content

--- sea level ---

Tanezuft Fm.

*Modified from
Lüning et al.
(2000)*

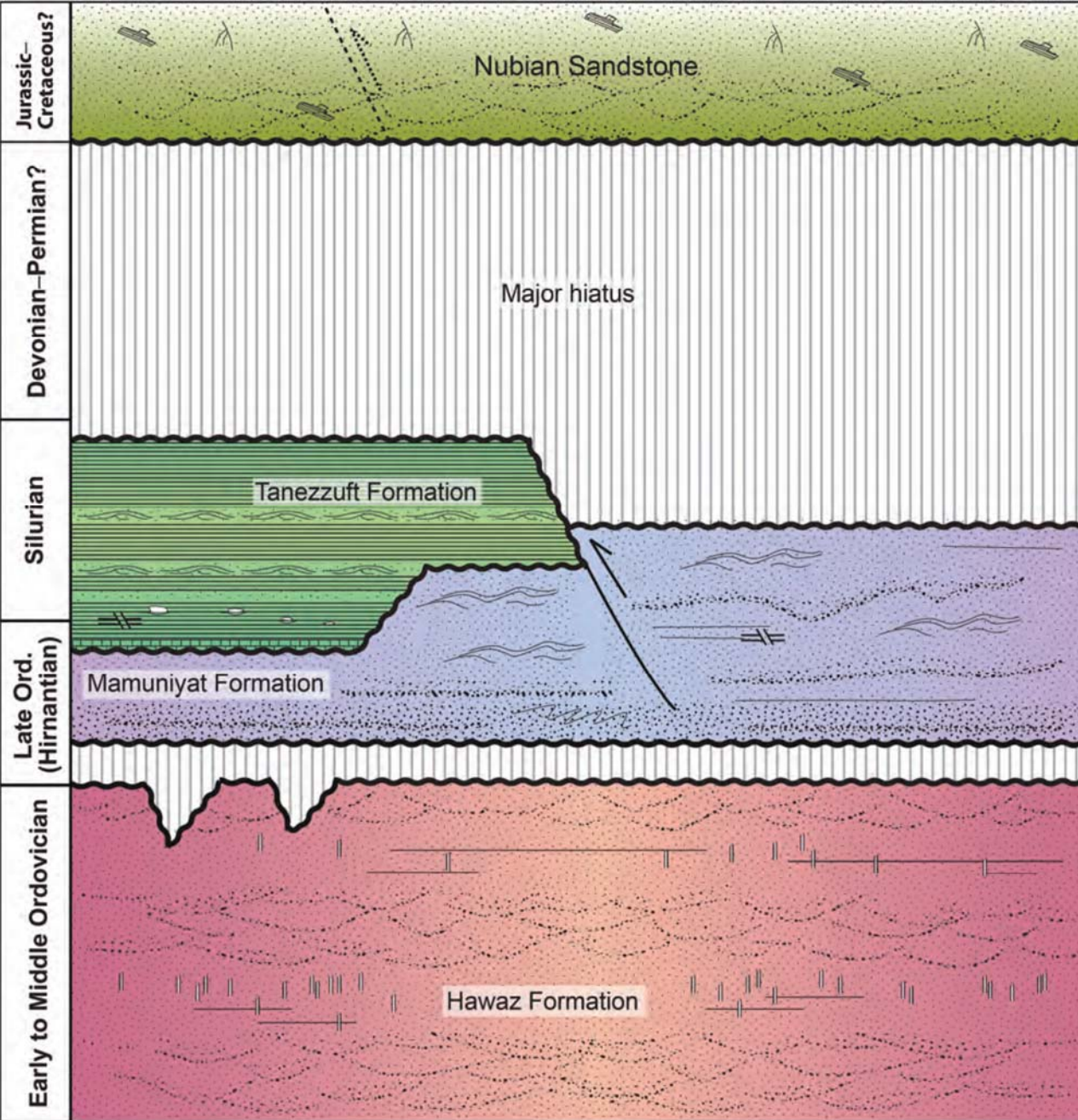
Distribution of Silurian “hot shale” (source rock)





**Jabal
Eghei-Nuqay**

Stratigraphy



*Post-glacial shale
(source rock and seal)*

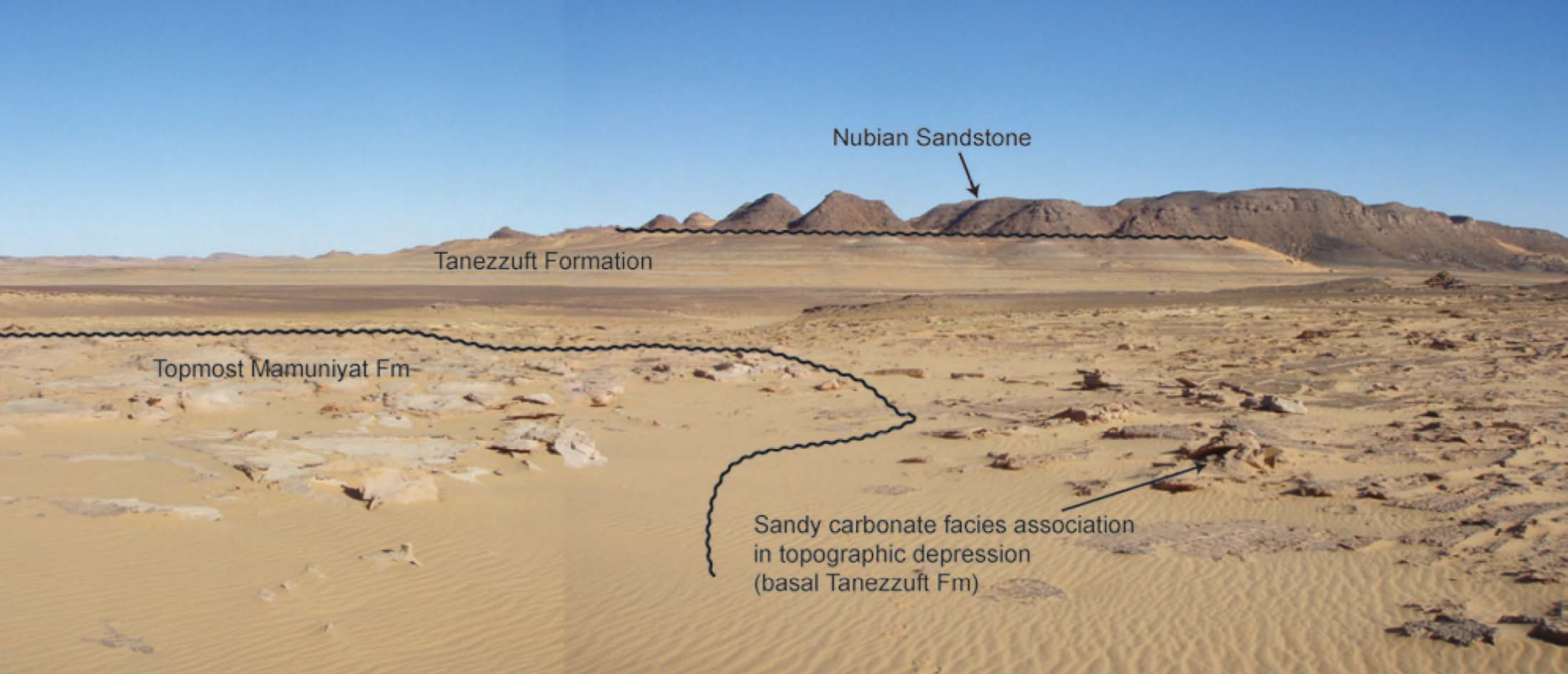
*Glacial deposits
(major reservoir interval)*

*Late Ordovician (Hirnantian)
Glaciation: regional incision*

Fluvial to shallow marine deposition

LEGEND

	Siltstone and shale		Striated pavement		Cross-bedding
	Sandstone (fine)		Lonestones		Climbing dunes
	Sandstone (med-coarse)		Wood fragments		Plane beds
	Granules		Hummocky cross-strata		Palaeosols
	Calcareous sandstone/ sandy limestone		Unconformity		Skolithos



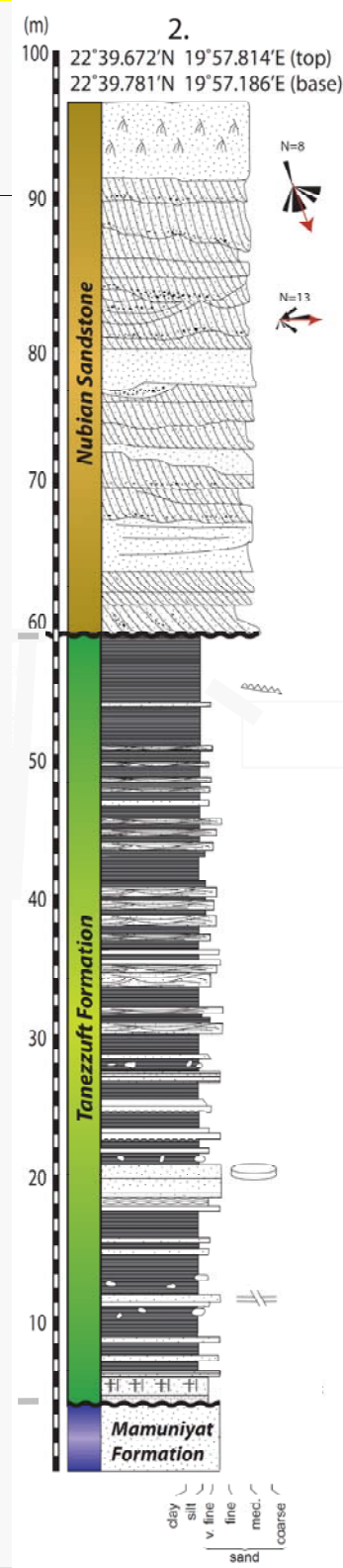
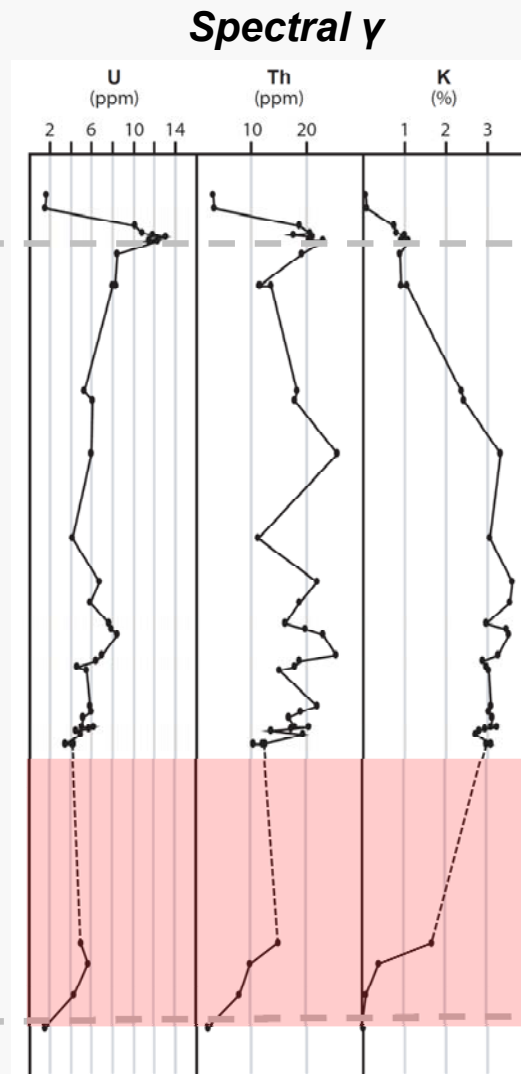
Sedimentary log and gamma ray results

Base Mesozoic U/C

Tannezuft Fm.
(Early Silurian)

Expected
"hot shale"
interval

Mamuniyat Fm.
(Late Ordovician)



Legend

Lithology

- Calcareous sst / sandy lst.
- Mudrocks
- Mudrocks with limestones
- V. fine & fine-grained sst.
- Coarse & medium sst.
- Conglomerate
- Cylindrical concretions

Sedimentary structure

- Bioturbation
- Trough x-beds.
- Climbing dune x-beds.
- Planar x-beds.
- Current ripple x-lam.
- Wave ripple x-lam.
- Planar bedded sst.
- Flute casts

Soft-sed. deformation

- Striae

Fossil material

- Rootlets
- Graptolites

First known occurrence
of intra-Tannezuft
glacial deposits in North
Africa

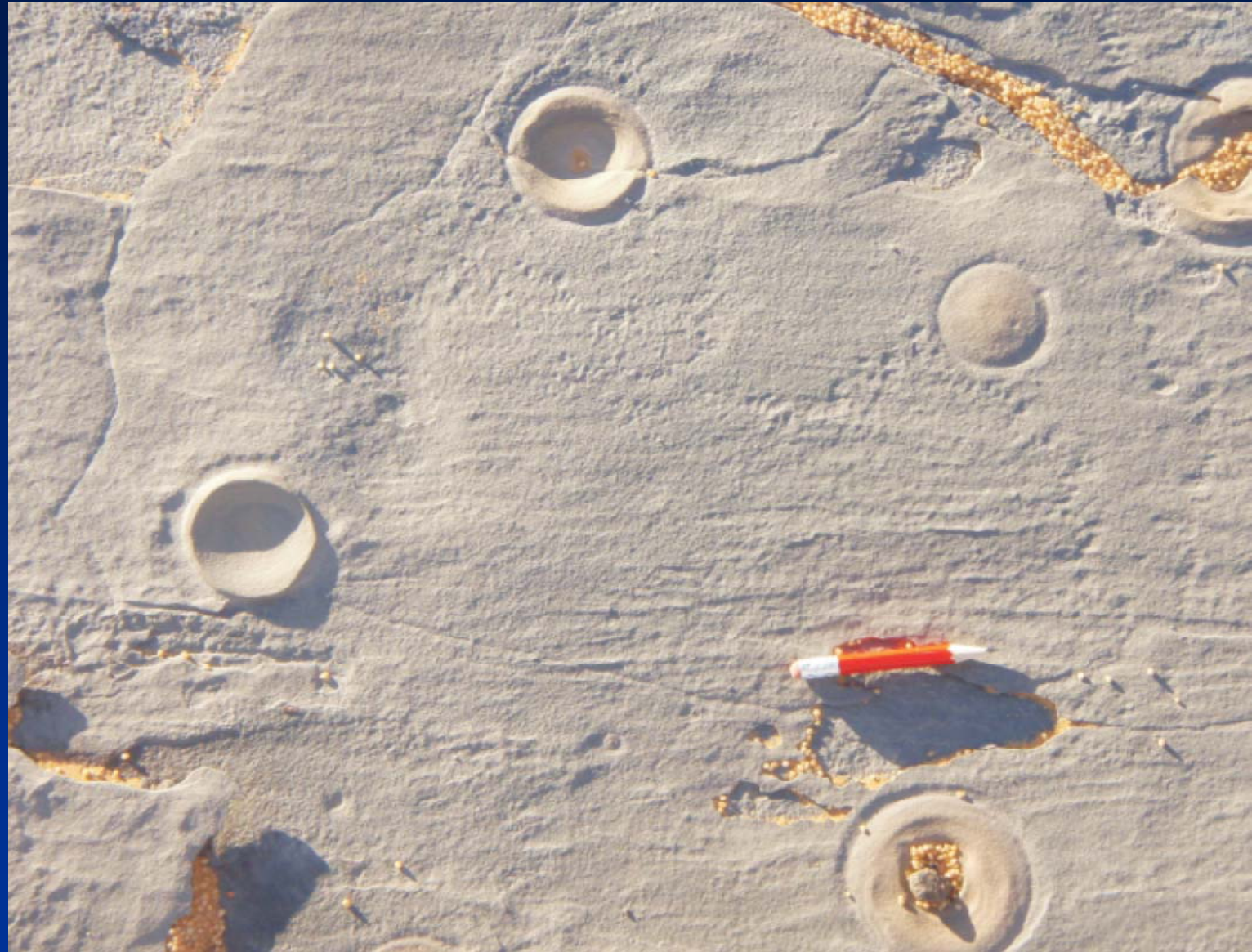
Soft-sediment striated surface



Calcareous limestones



MnO₂ concretions

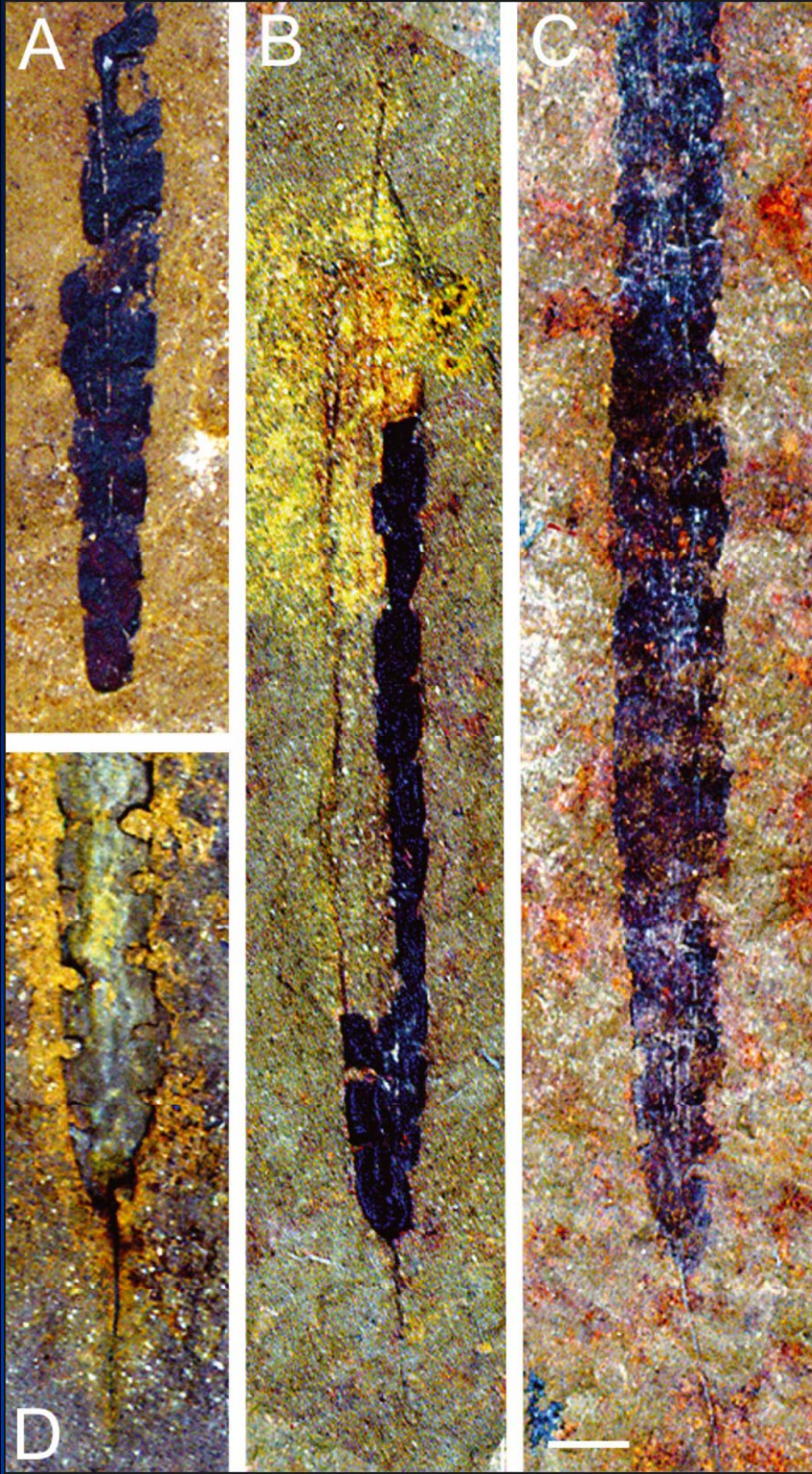


Graptolites

New species:-
Normalograptus
kufraensis nov. sp.

**Age: Rhuddanian-
Hirnantian**

Page, A., Meinhold, G.,
Le Heron, D.P., Elgadry,
M. (in review). A new
species of graptolite from
the western margin of the
Kufra Basin, Libya.
Geological Magazine.



MnO_2 concretions



MnO_2 concretions



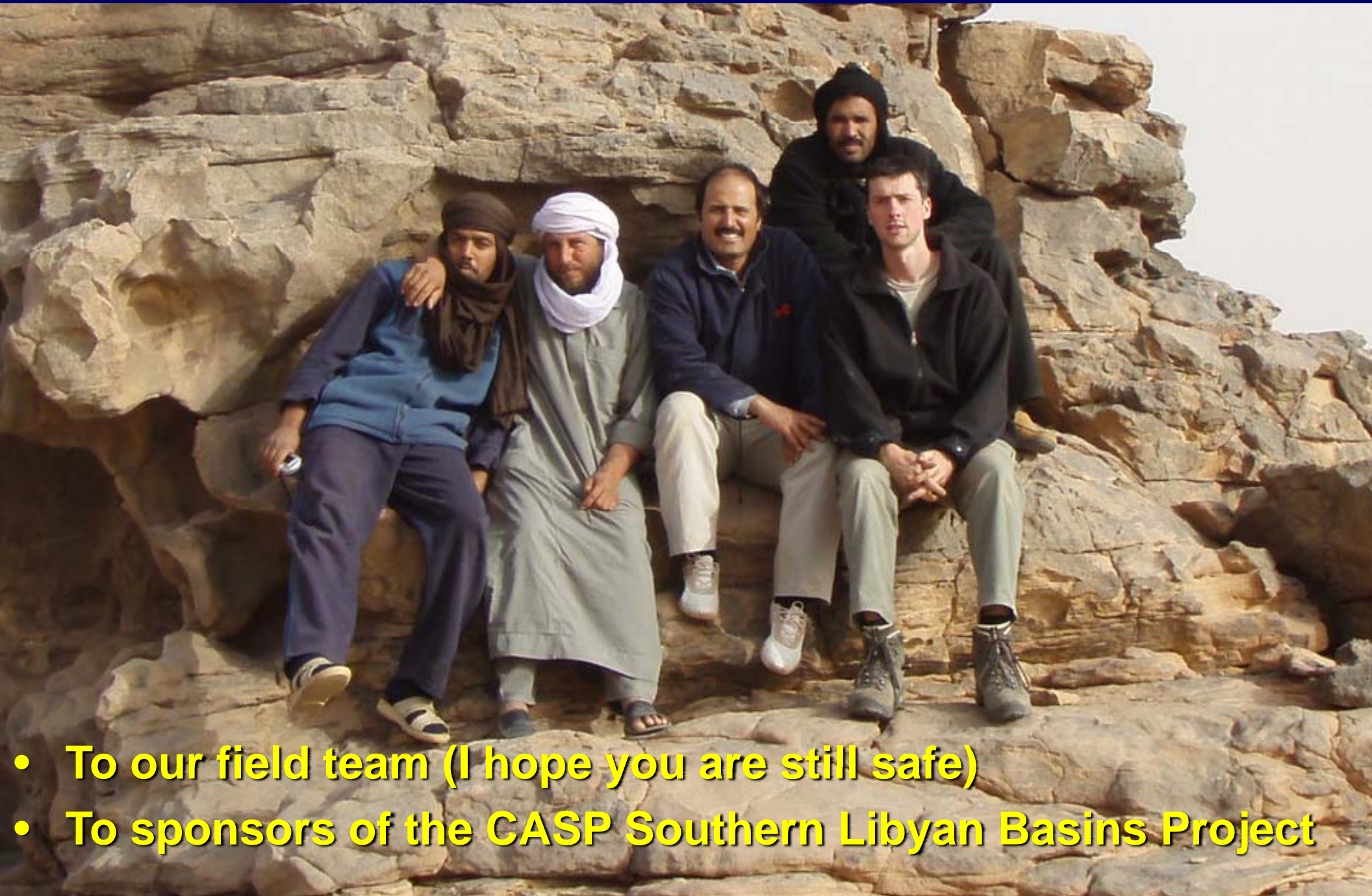
Hummocky cross-stratification



Conclusions

- *Previous model:* diachronous flooding of glacial topography in Early Silurian explains patchy organic enrichment in the Tanezzuft (Lüning et al., 2000)
- *New model:* glacial re-advance “flushed out” potential for anoxia in some areas. Oxidative processes confirmed by MnO₂ concretions
- New data does not overturn interpretations of Lüning et al but adds another layer of complexity

Thankyou



- To our field team (I hope you are still safe)
- To sponsors of the CASP Southern Libyan Basins Project

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