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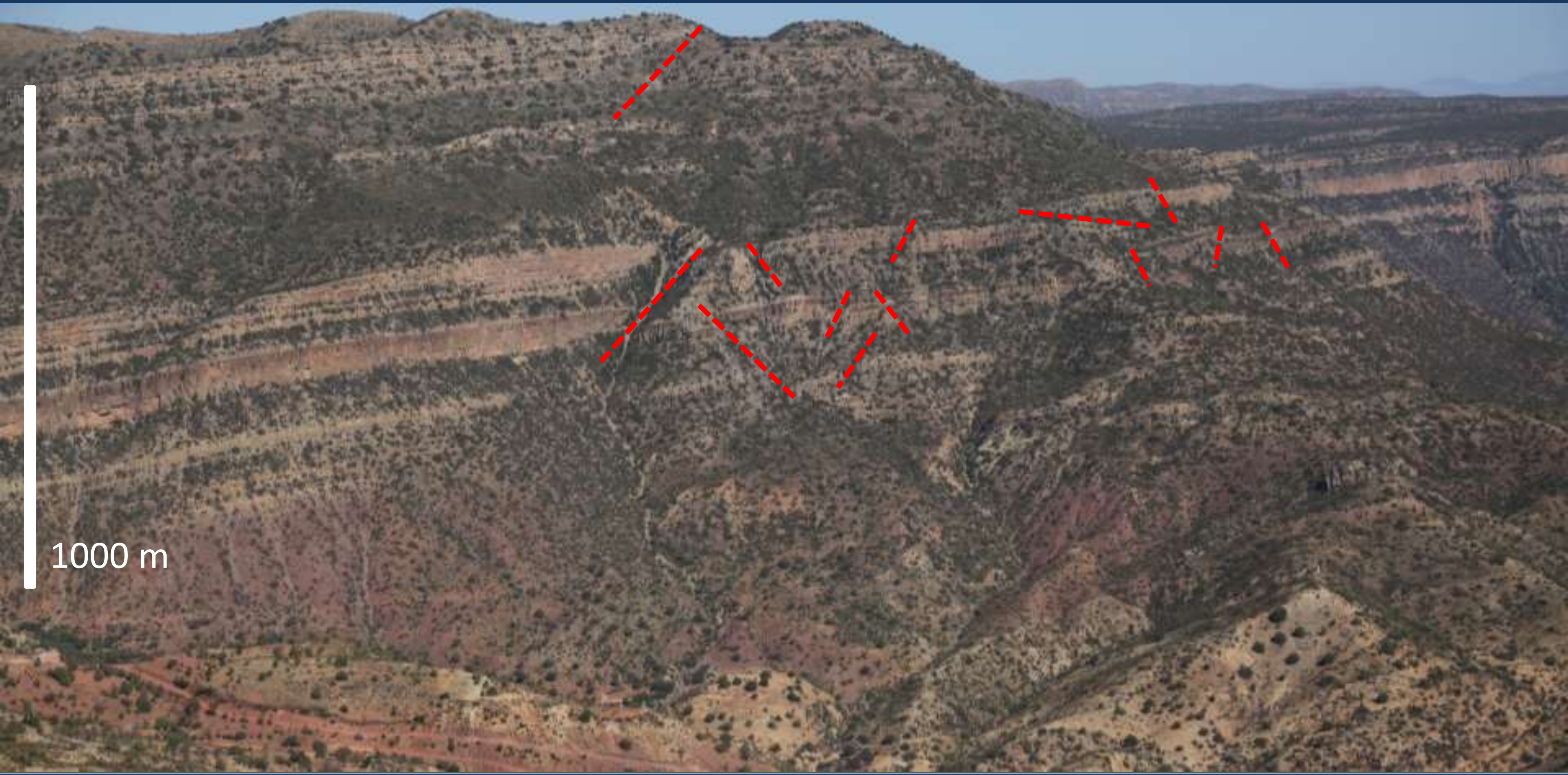
Dolomitization of Jurassic Carbonates in the Western High Atlas of Morocco: processes and implications for reservoir properties



Nawwar Al-Sinawi, Aude Duval-Arnould, Cathy Hollis, Giovanni Bertotti, Stefan Schröder, Jonathan Redfern

AGENDA

1. Introduction
2. Regional Tectonics and diapirism
3. Dolomitization phases and timing
4. Hydrothermal dolomitization
5. Porosity distribution in dolomitized facies

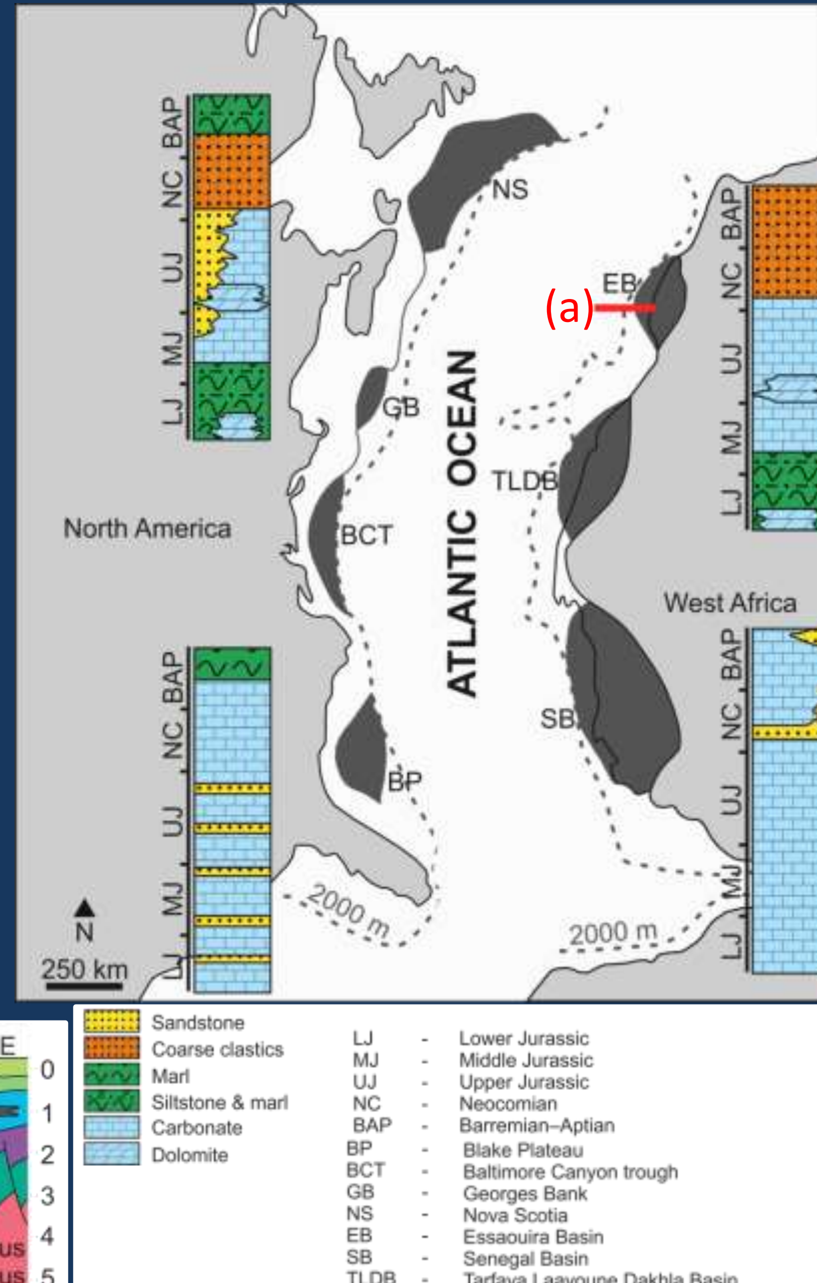
Introduction

- Dolomitized Oxfordian reefs constitute a proven carbonate reservoir in the undeveloped Cap Juby Field and a good gas reservoir in the developed Panuke gas field, Canada (Wierzbicki et al. 2006).
- The processes that lead to dolomitization remain unclear ➡ Determining reservoir quality has proven challenging

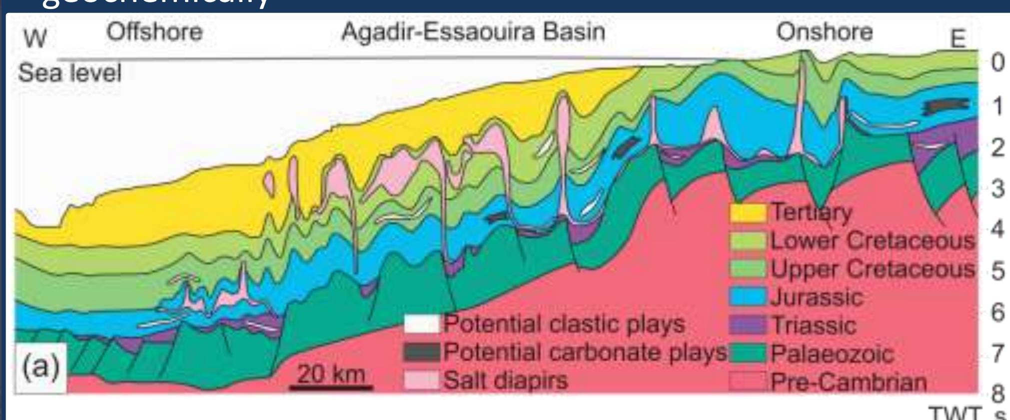
Aims and objectives

✓ **Aims:** Determine the distribution, controls and origin of dolomite within the Jurassic facies of the Agadir-Essaouira Basin and assess its impact on reservoir properties

✓ **Objectives:** Log & map the dolomite, assess its stratal relationships and describe petrographically and geochemically



Extent of Jurassic carbonate banks on NE America and NW African conjugate margins (*modified after Leprêtre et al. 2017*)



Simplified Tectonic framework of the offshore and onshore AEB (*modified from Tari et al. 2013*)

Regional Tectonics and diapirism in the WHA

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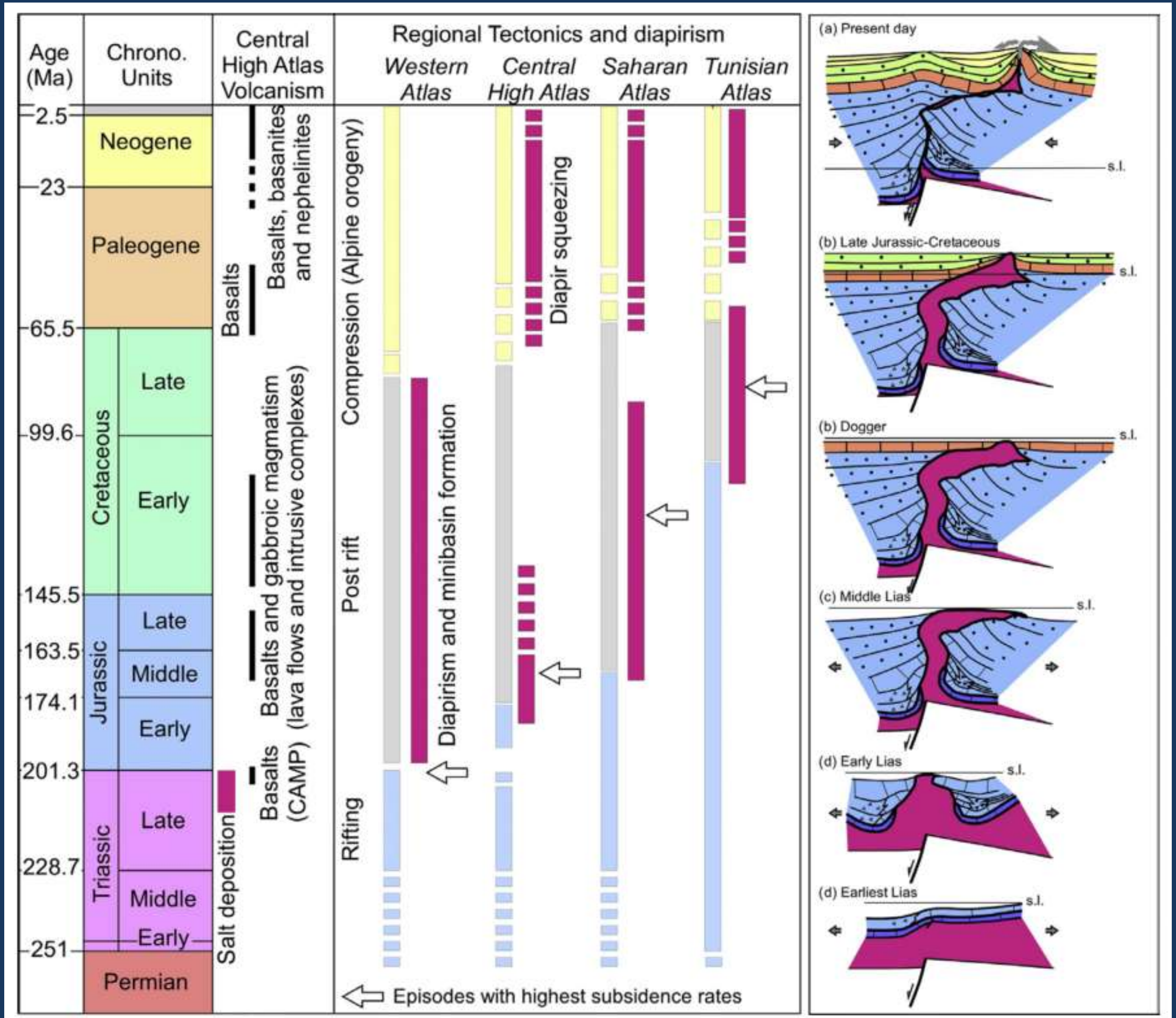

From Vergés, et al. (2017)

Study Area

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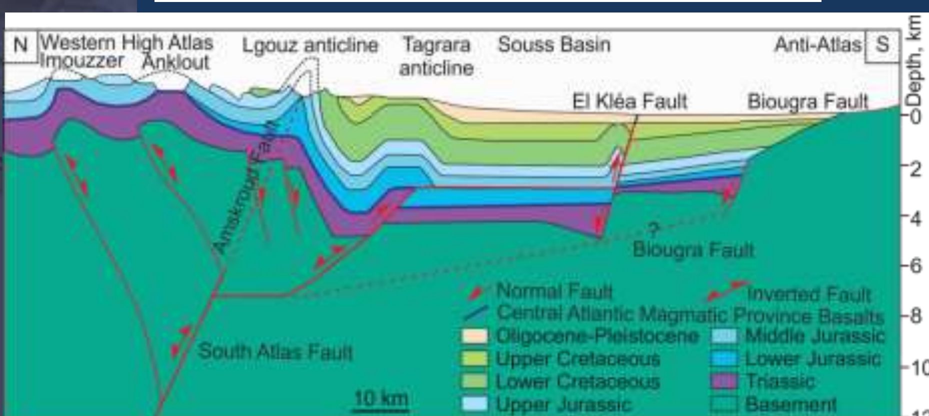
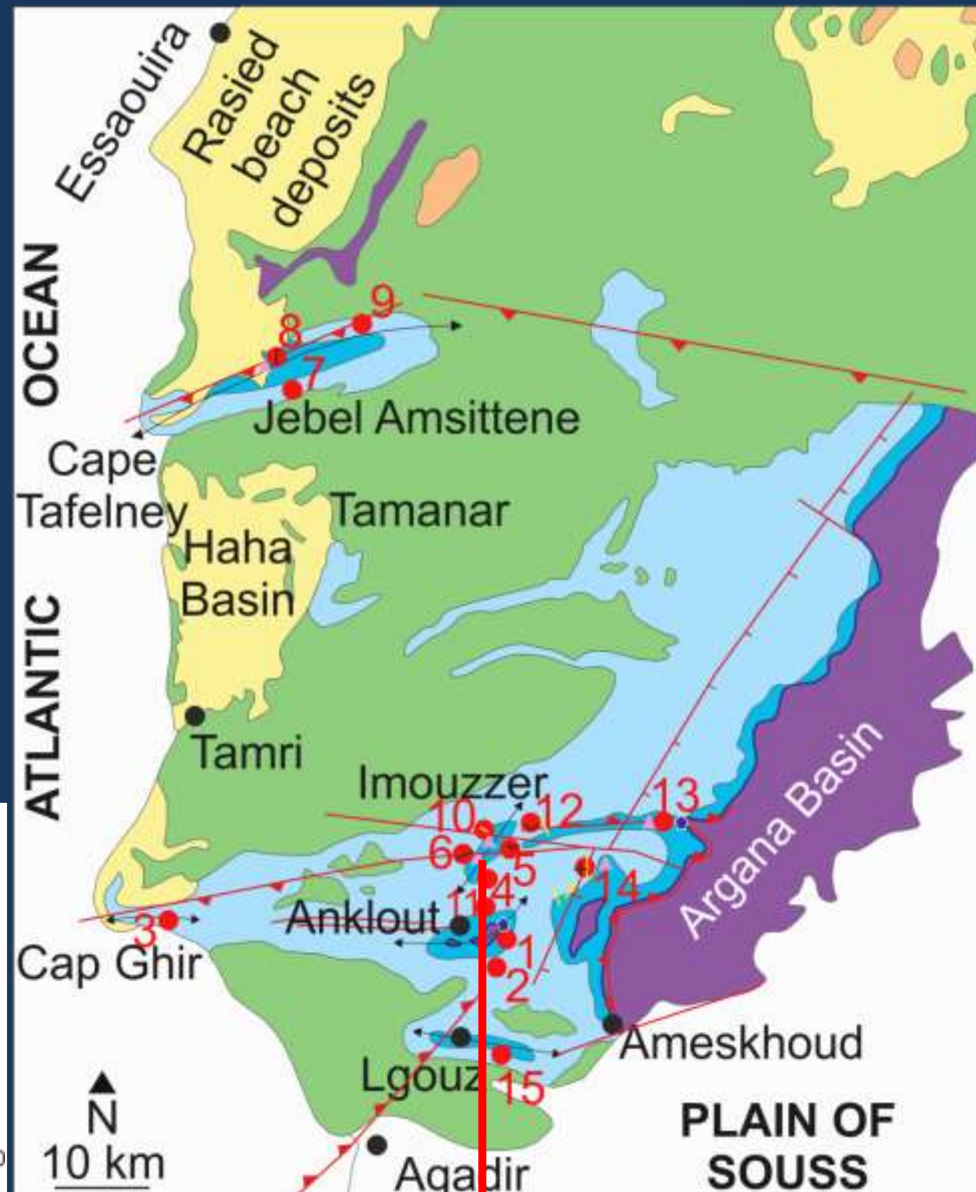
- Quaternary
- Eocene
- Cretaceous
- Upper Jurassic
- L. & M. Jurassic
- Triassic
- Central Atlantic Magmatic Province basalts
- Upper Cretaceous-Tertiary Anticlines
- Normal fault
- Strike-slip or transfer fault
- Upper Cretaceous-Tertiary Reverse faults
- Local fault, not-to-scale
- Dominant veins, not-to-scale
- Study area
- Salt/evaporite
- Outcropping Basalt

1	- Barage Aquesri	10	- Assif Al Hade
2	- Paradise Valley	11	- Tizgui
3	- Cap Ghir	12	- Tikki West
4	- Imouzzer	13	- Tikki East
5	- P1004 Road Cut	14	- Tizgui N'Chorfa
6	- Tidili Road Cut	15	- Askouti
7	- Amsittene South		
8	- Amsittene North		
9	- Amsittene North East		



Modified from Frizon de Lamotte et al. (2008)



Modified after Ager (1974a), Mustaphi et al. (1997), Zuhlke et al. (2004), Hafid et al. (2006) and Frizon de Lamotte et al. (2008)

Study Area

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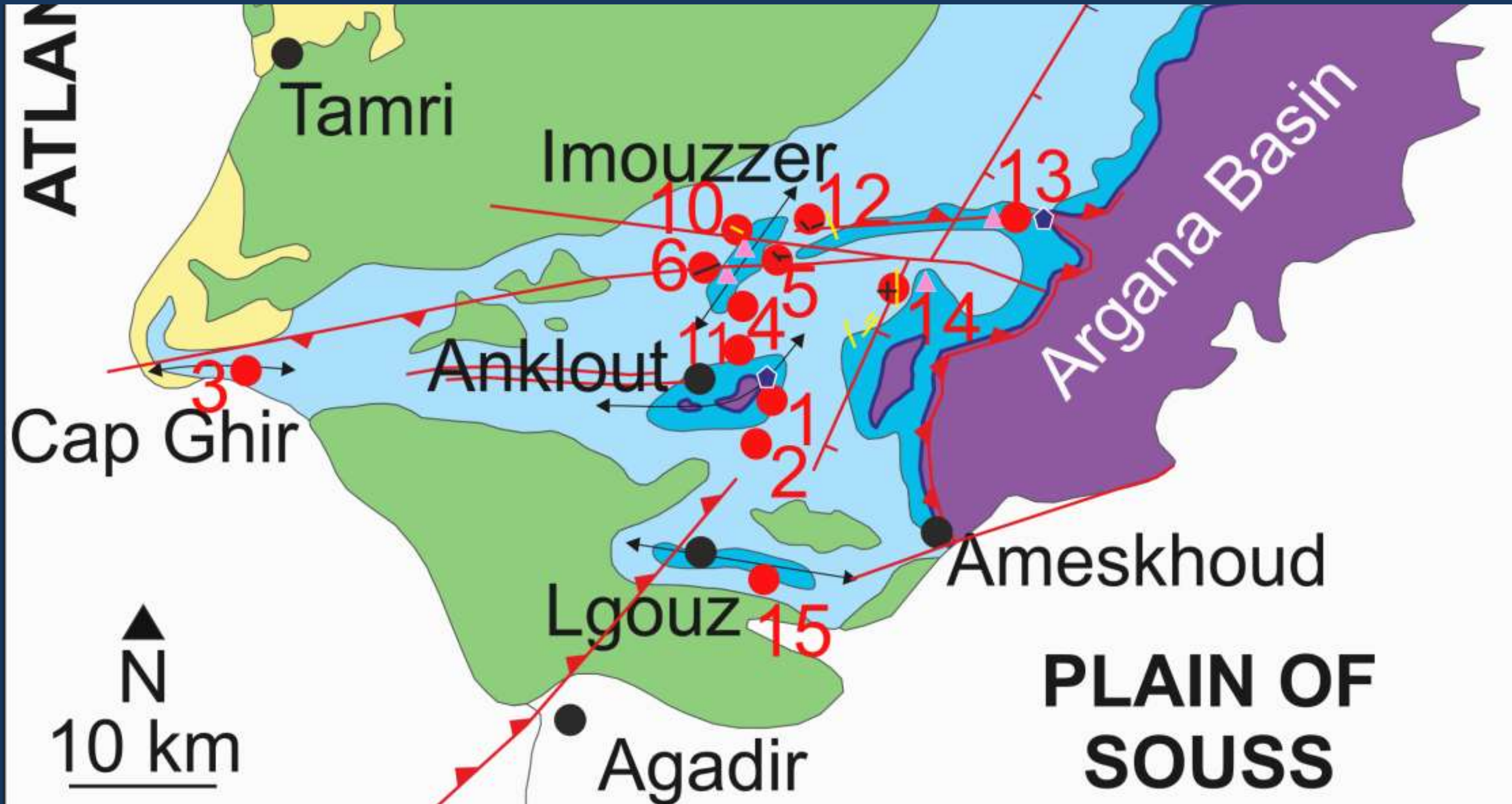

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Dolomitization phases and timing- Barrage Aquesri, Toarcian

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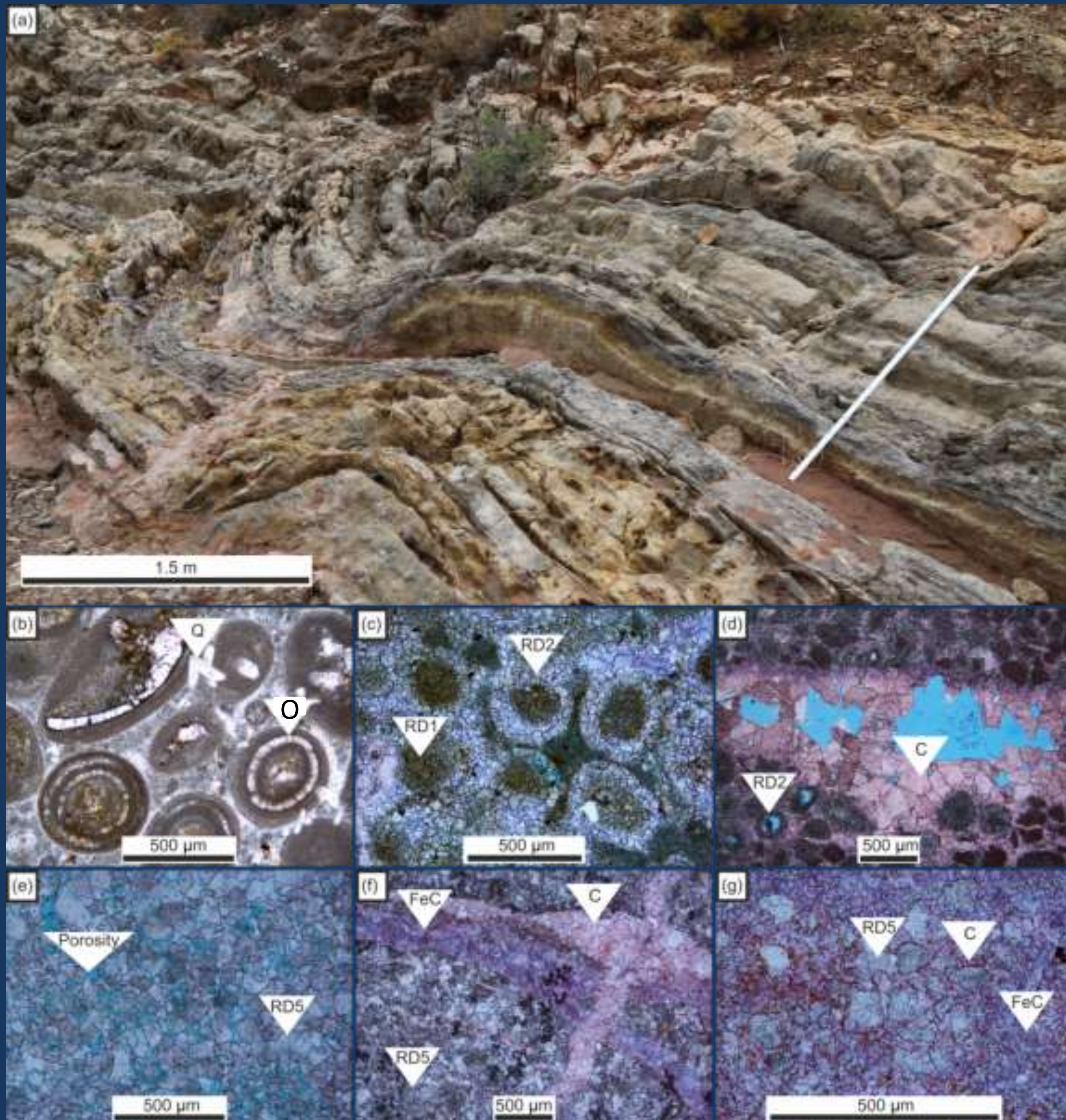
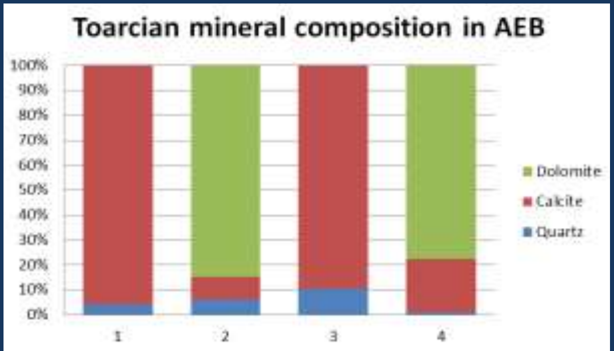


- **Stratabound dolostones**

•Dolomitized facies:

- Oolitic packstones-grainstones
- Mudstones

Early stage dolomitization



Dolomitization increased porosity of the host limestones

Dolomitization phases and timing- Tizgui N' Chorfa

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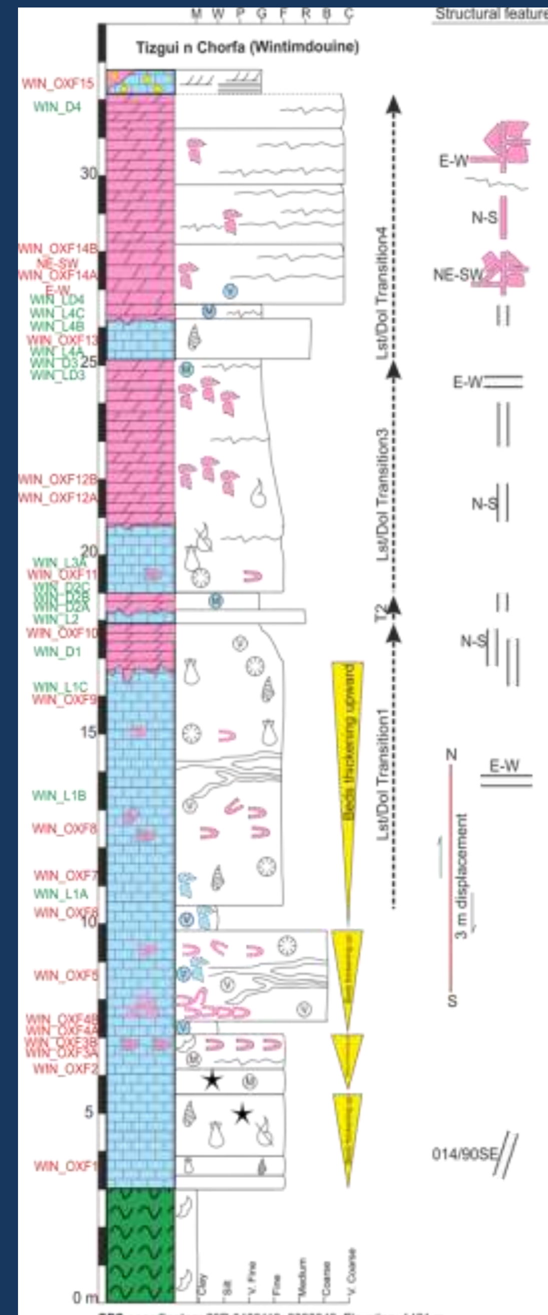

Oxfordian HT dolomites

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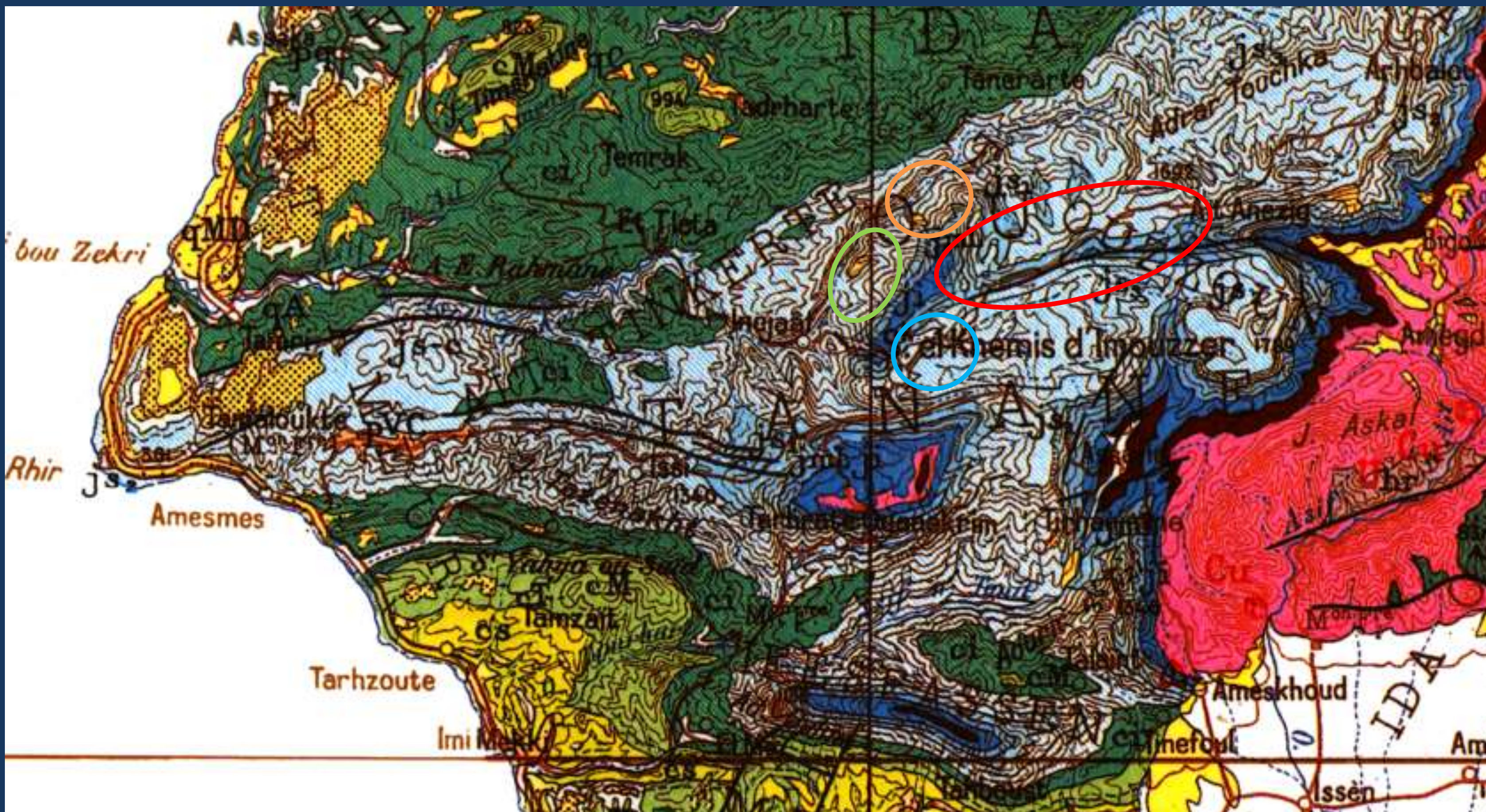
- High temperature dolomitization in the Imouzzer anticline (IA) is found in skeletal packstone-grainstones (minor), coral reefal limestones (abundant) and cross-bedded sandy carbonates (abundant).
- In map view, the areas of intense dolomitization are concentrated in: Tikki, P1004, Tidili and Assif Al Hade



Basin studies

Oxfordian HT dolomites

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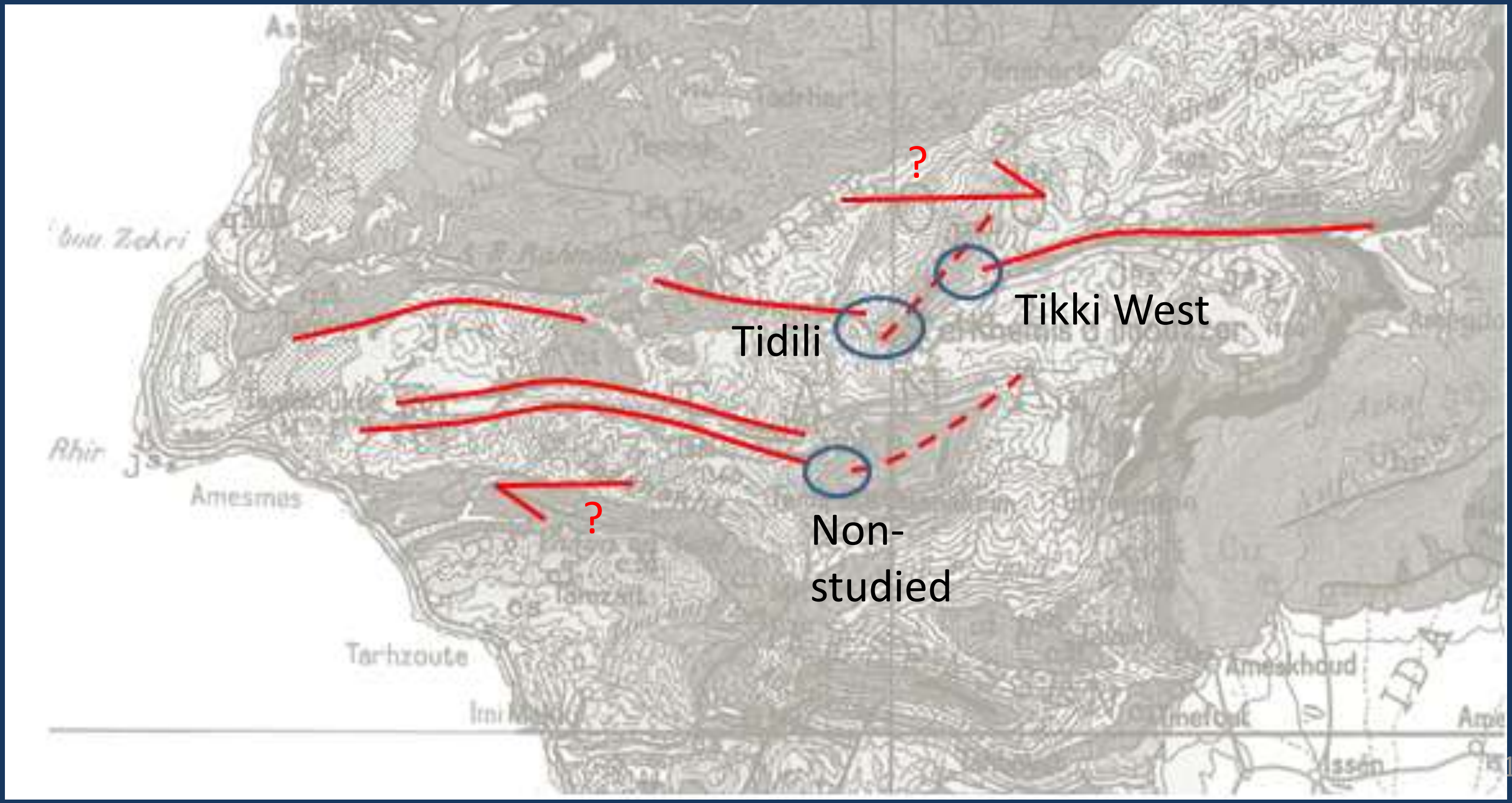
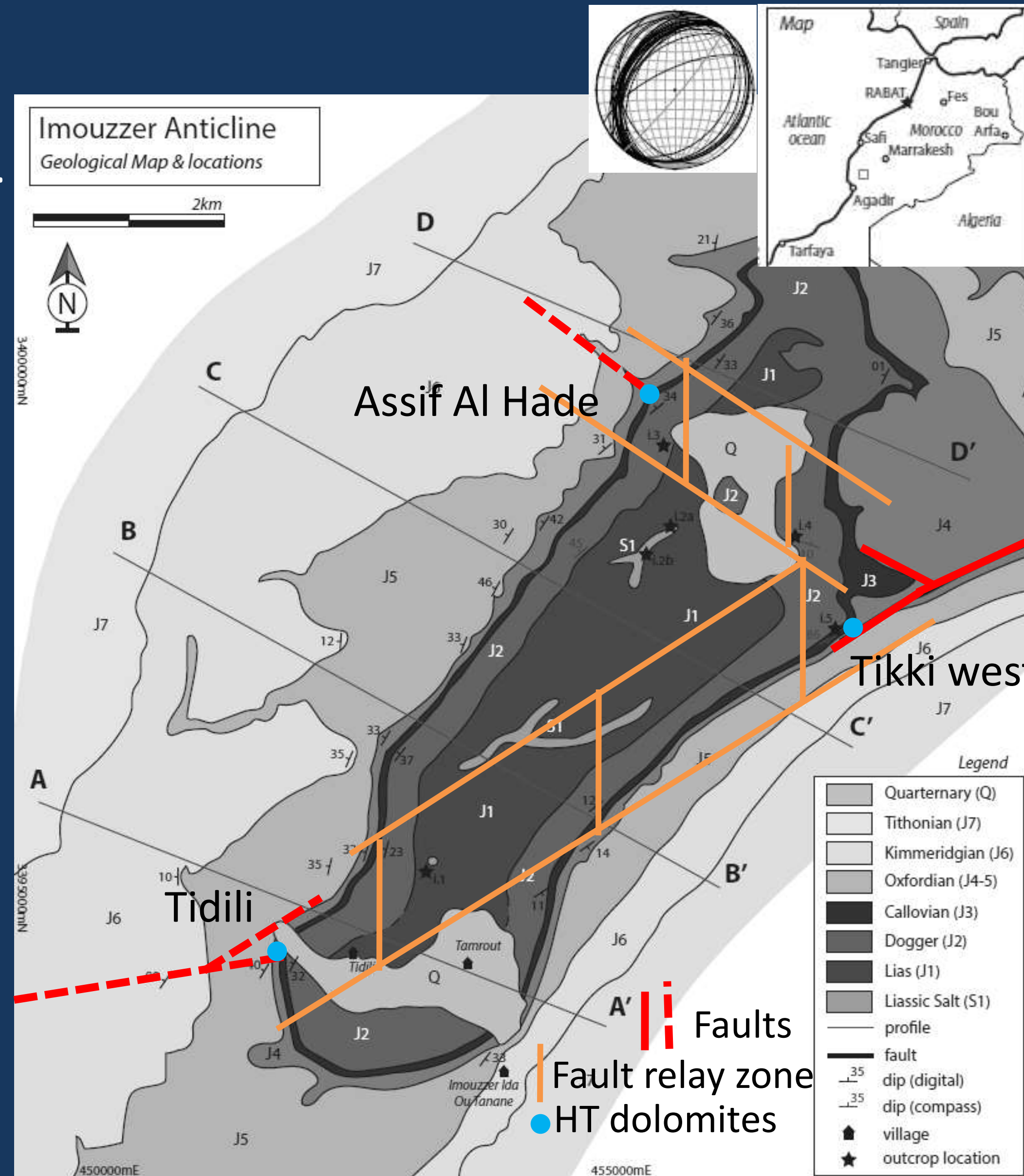
- The Imouzzer anticline is located within a system of E-W trending faults stretching from Cap Rihr to the Argana valley.
- These faults cut through Upper Jurassic to Lower Cretaceous layers and, in the Argana valley, they cross the Triassic basalts.
- Interestingly the faults do not cross the Imouzzer anticline (neither the Anklout anticline further to the S).
- The faults seem to end at the NE-ward and SW-ward terminations of the Imouzzer anticline, regions where HT dolomitization is particularly intense.



Oxfordian HT dolomites

- The anticline becomes more open and eventually disappears both towards the NE and the SW.
- The proto-Imouzzer anticline started developing in Late Jurassic time, documented by coeval layers which thin from the flanks towards the hinge of the anticline (sedimentary).
- A series of reefs have used the topographically higher position of the anticline hinge.
- Jurassic folding could be related to tectonics, diapirism or to an interaction between the two.
- The largest part of folding is obviously of Alpine age.



Geological Map of Imouzzer Anticline showing outcropping HT dolomites (After Kluge, 2018)

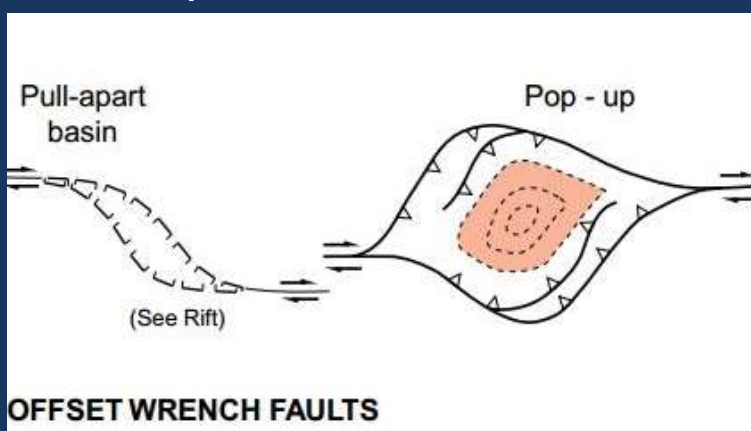
Oxfordian HT dolomites

Proposed model:

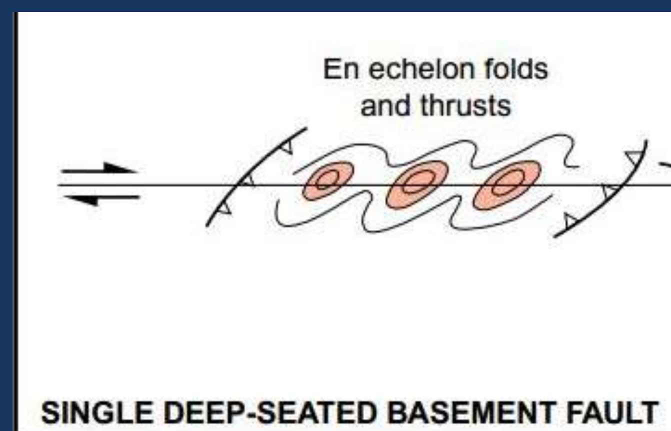
1) The Imouzzer anticline is a contractional structure developed as a constraining bend or pop-up associated with dextral strike slip movements along the E-W trending faults
2) This strike slip system acted as a conduit for the HT fuids.

Imouzzer anticline and E-W faults:

- The association between the two is the only possible way to explain the fact that the faults cut in older layers in the Argana valley but do not do this in the Imouzzer anticline itself.
- The displacement of the fault must therefore be taken over by the anticline and transferred to the southern E-W trending fault.
- Not mutually exclusive models are indicated below:

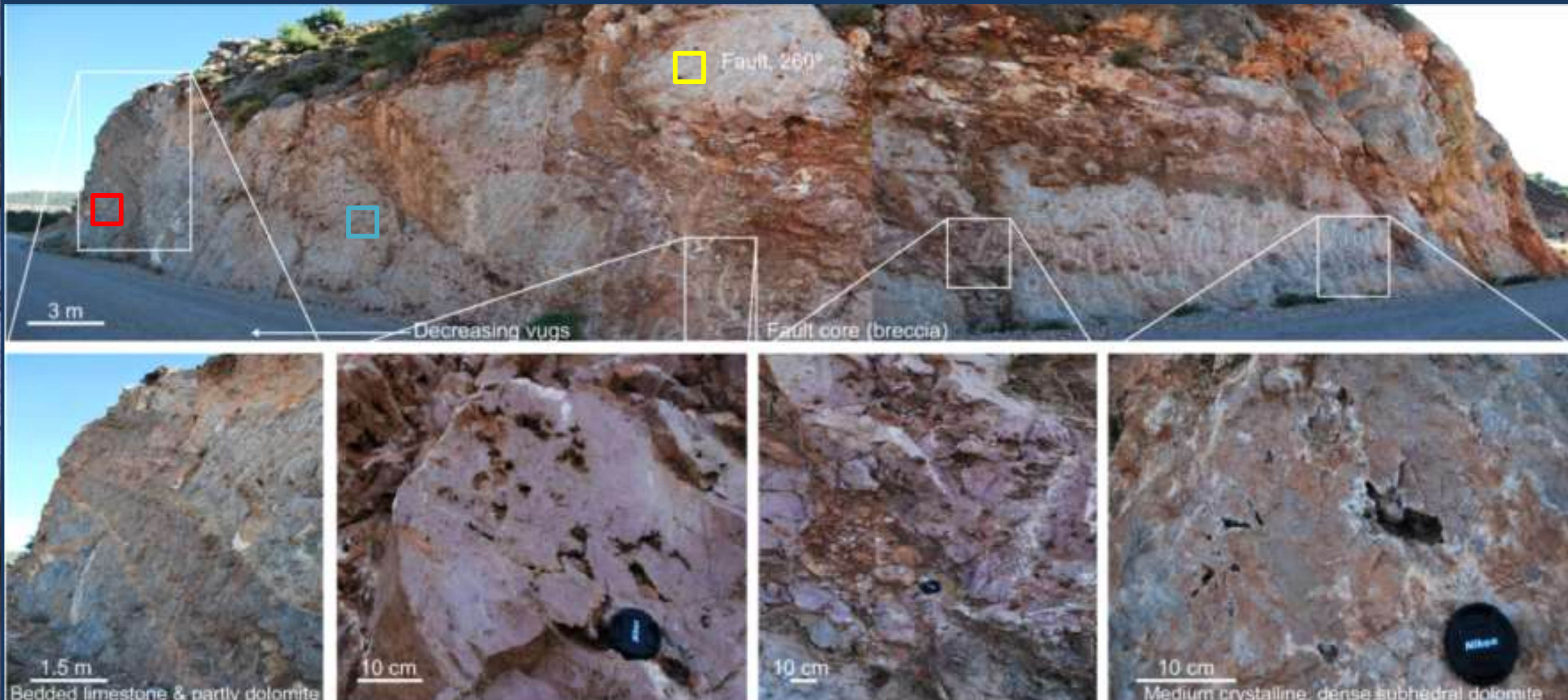


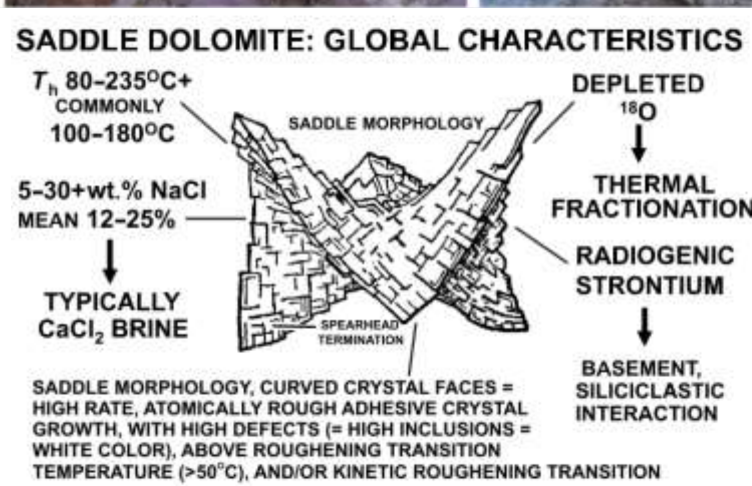
OFFSET WRENCH FAULTS



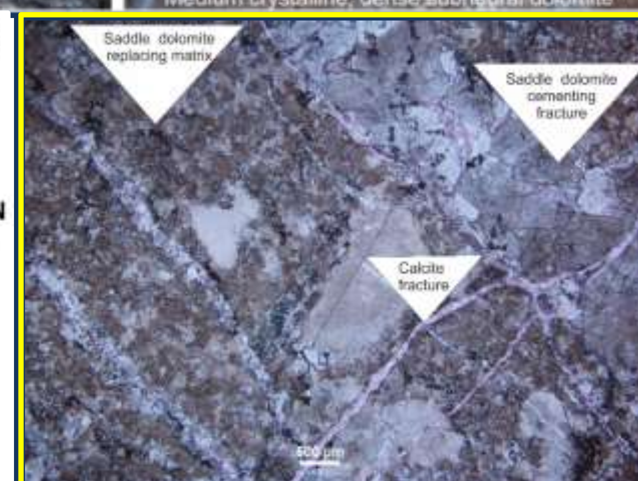
SINGLE DEEP-SEATED BASEMENT FAULT

HT dolomitization- Tidili

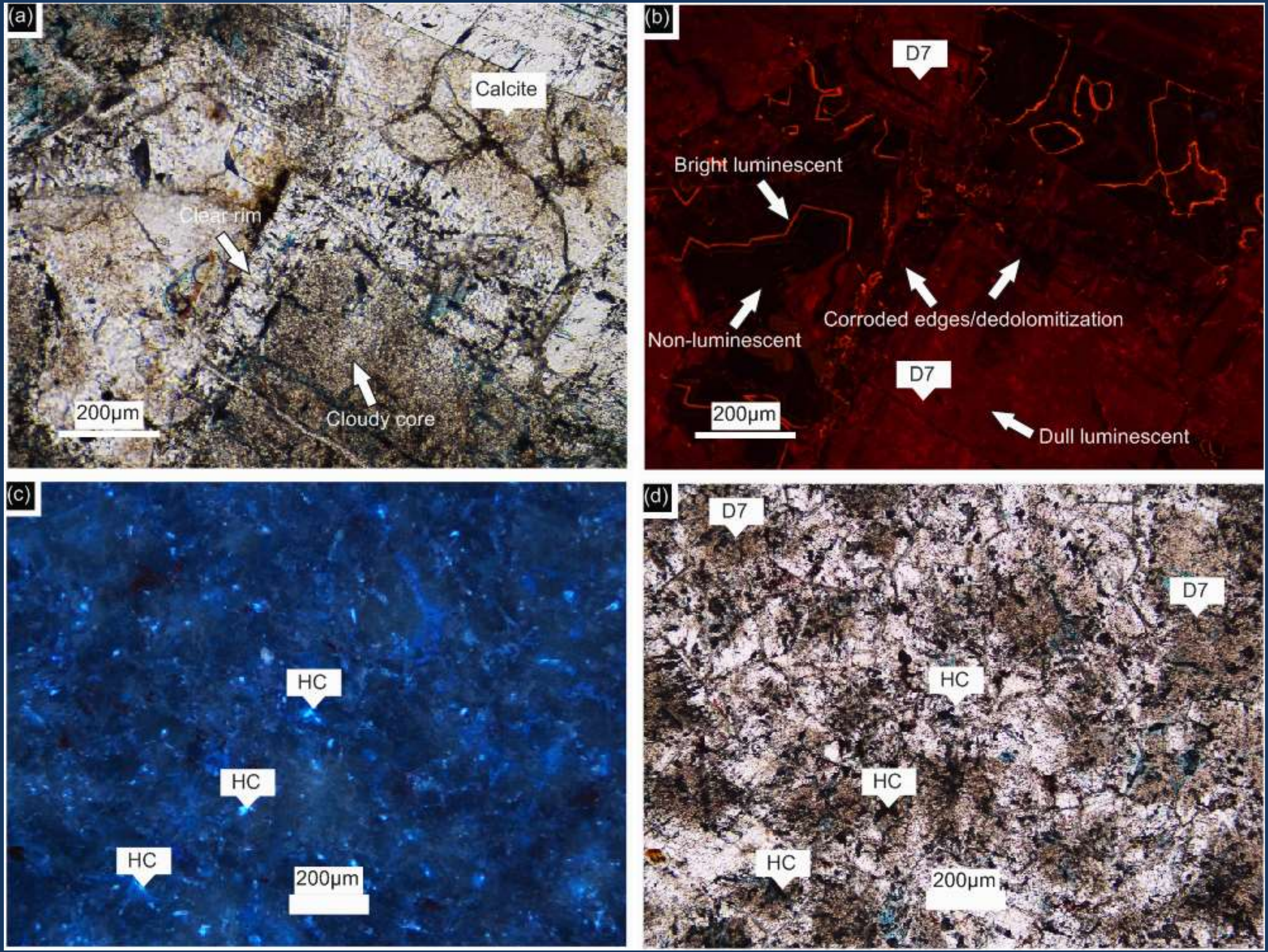




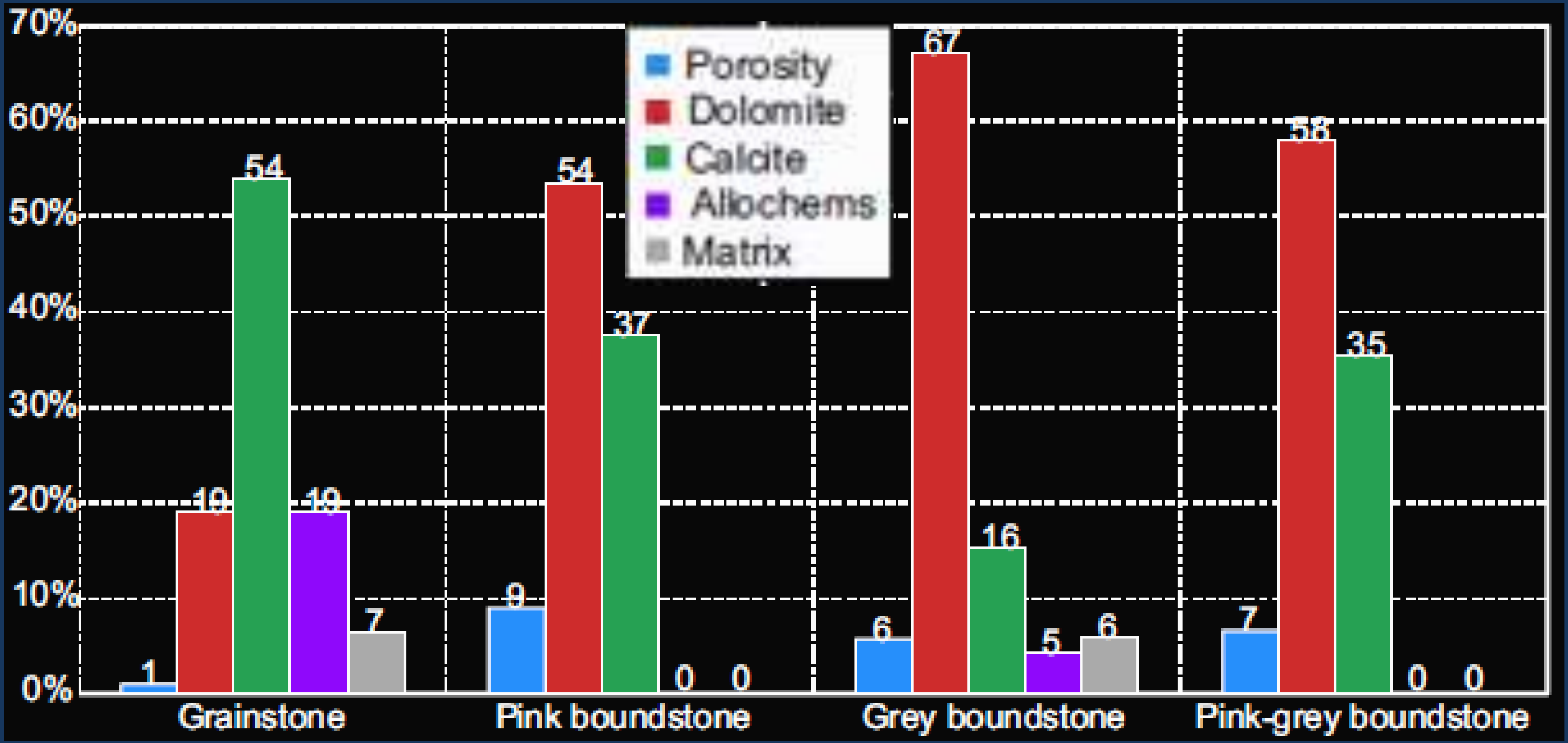
Davies and Smith, 2006



Dolomitization phases and timing- Tidili



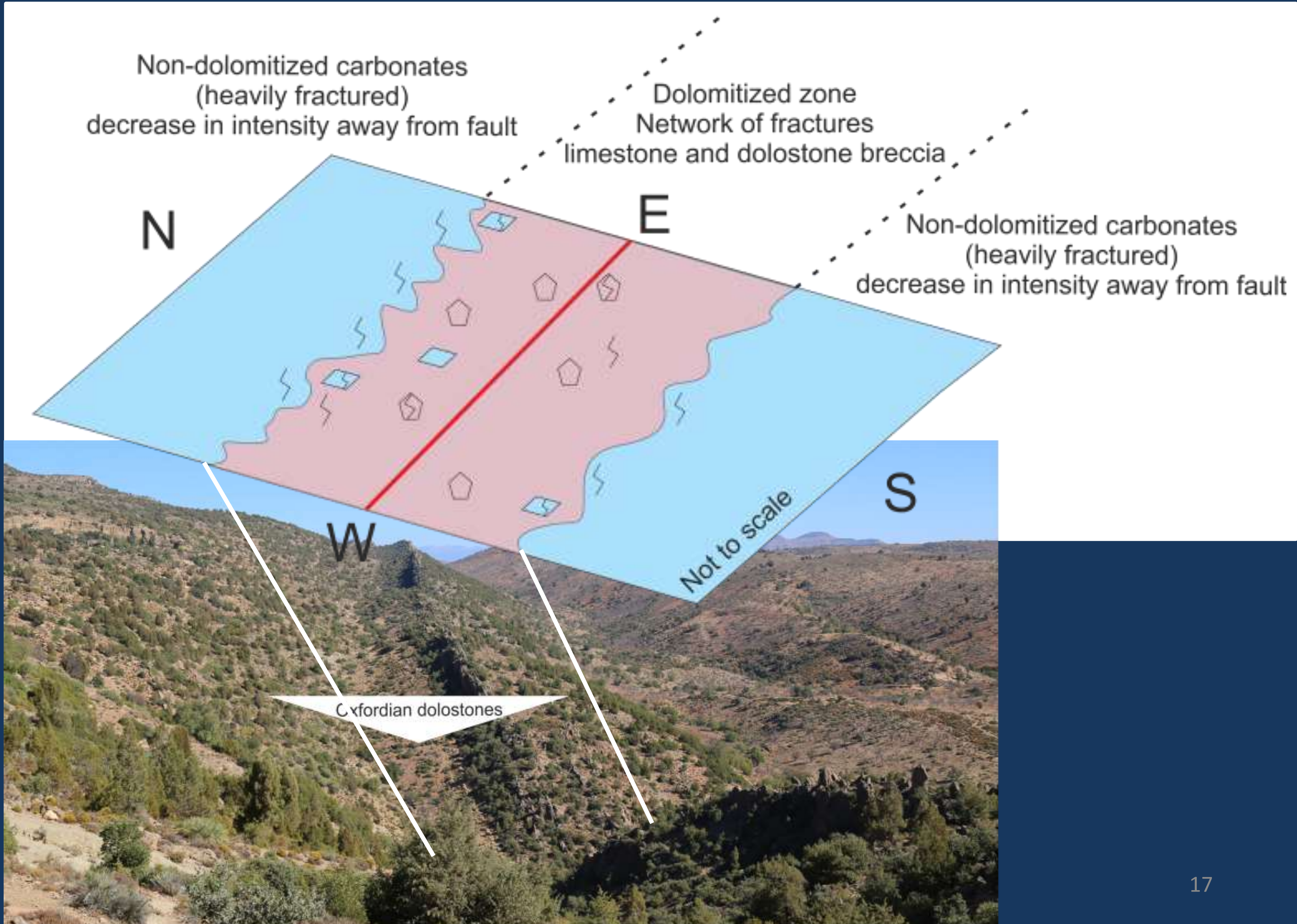
Porosity distribution vs. dolomitized facies



- Oxfordian carbonates were analysed quantitatively by modal analysis.
- Grainstones have been least dolomitized among the other facies.
- Boundstones consist of 54-67% dolomite (mostly saddle) with an average porosity ranging between 6-9%.

HT dolomitization-Tikki West

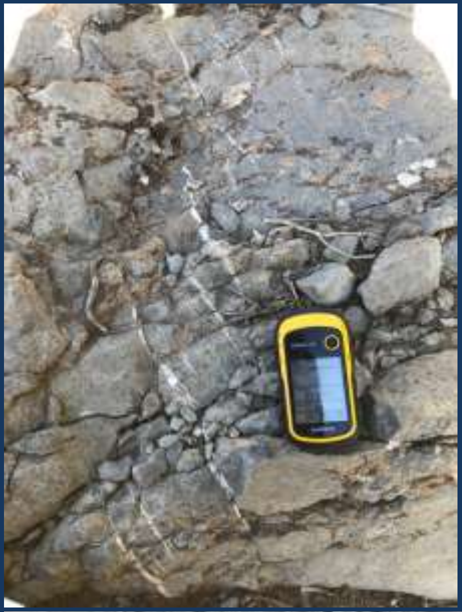
HT dolomitization-Tikki West



HT dolomitization-Tikki West

Flow patterns

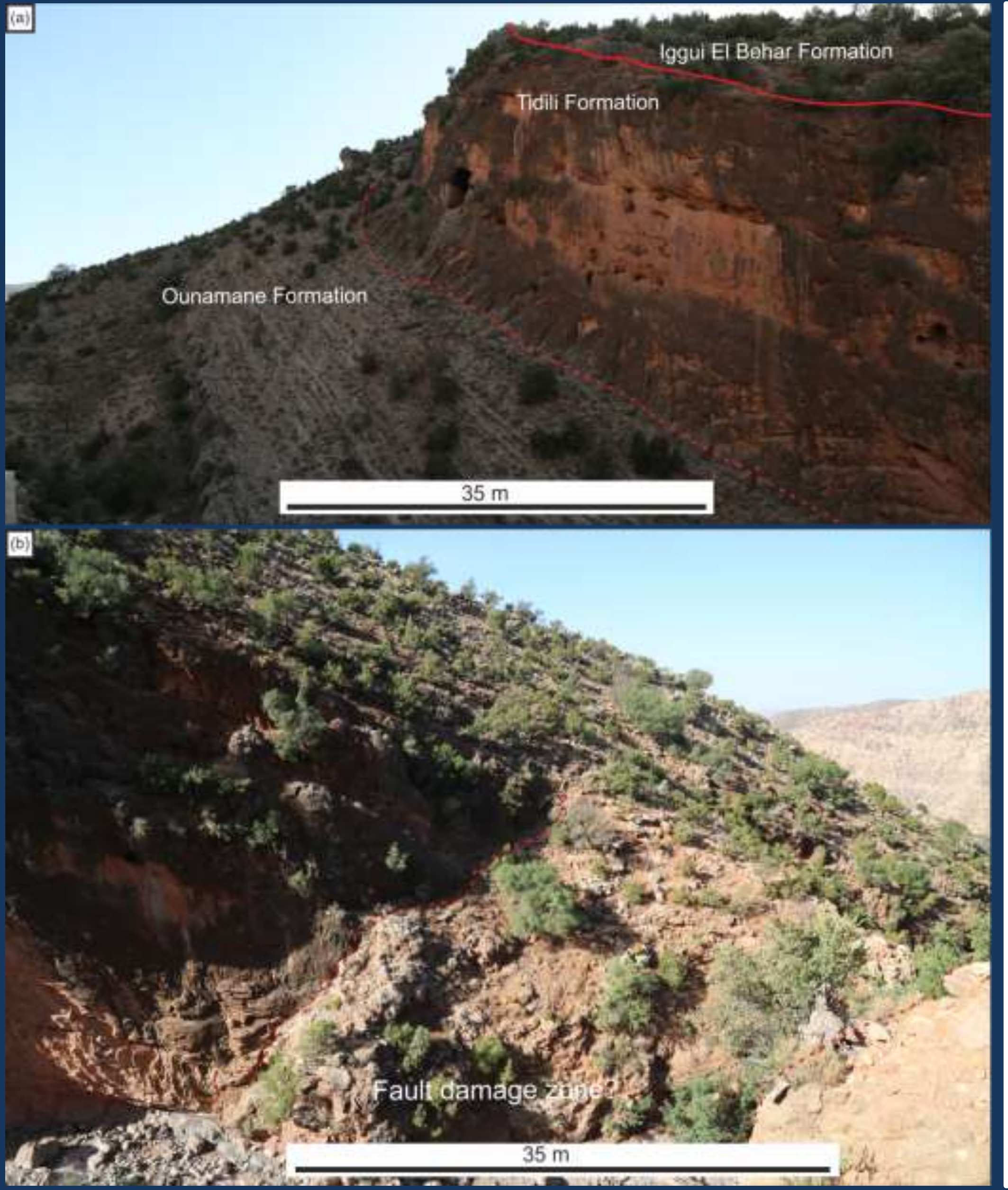
- The fault between the Imouzzer and the Argana valley is composed of a poorly described, few tens of meters thick fault zone characterized by the ubiquitous presence of sub-vertical veins.
- Rocks in the fault zone and in the immediate surroundings are intensively dolomitized characterized by saddle dolomite.
- Dolomitization ends a few tens of meters to the N and the S of the fault.
- This evidence suggests that abundant fluids were circulated along the Argana-Imouzzer fault, with flow being very much localized to the fault zone itself.

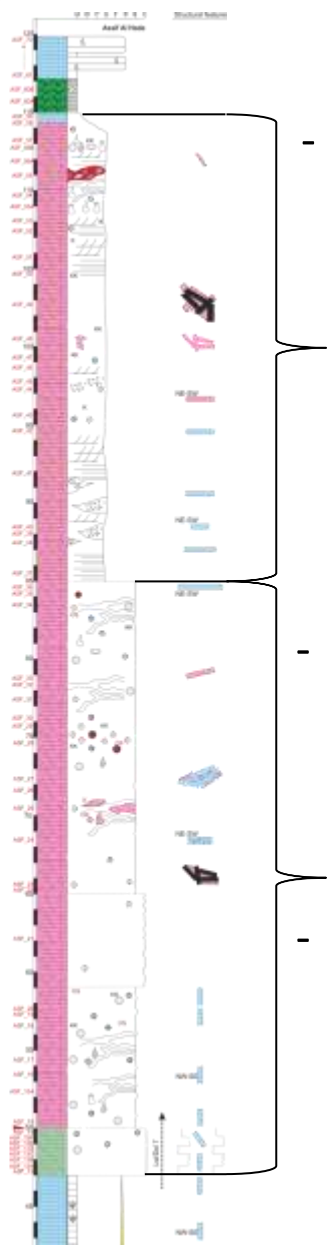


HT dolomitization

- Such localized flow was not possible in the Imouzzer anticline because of the lateral disappearance of the fault.
- Hot, dolomitizing fluids were therefore compelled to follow the high permeability layers of the Imouzzer anticline expanding laterally driven by density difference.
- Layers such as the originally coral rich limestones had a pronounced primary permeability.
- Distributed fracturing in specific layers such as coral boundstones, sandy dolostones had also an important role.

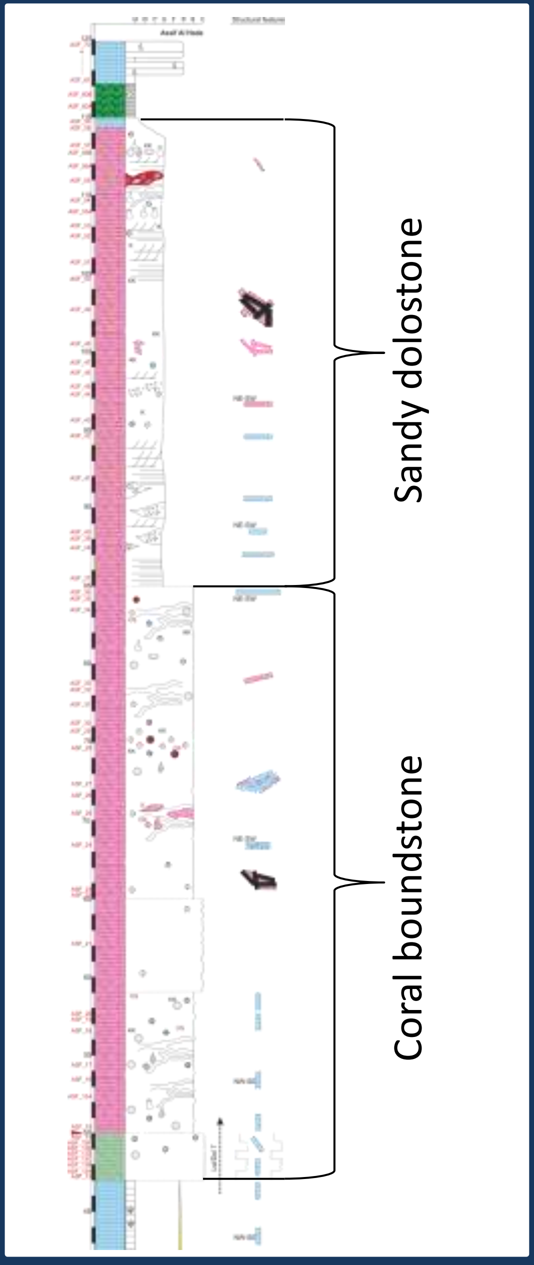
HT dolomitization- Assif Al Hade

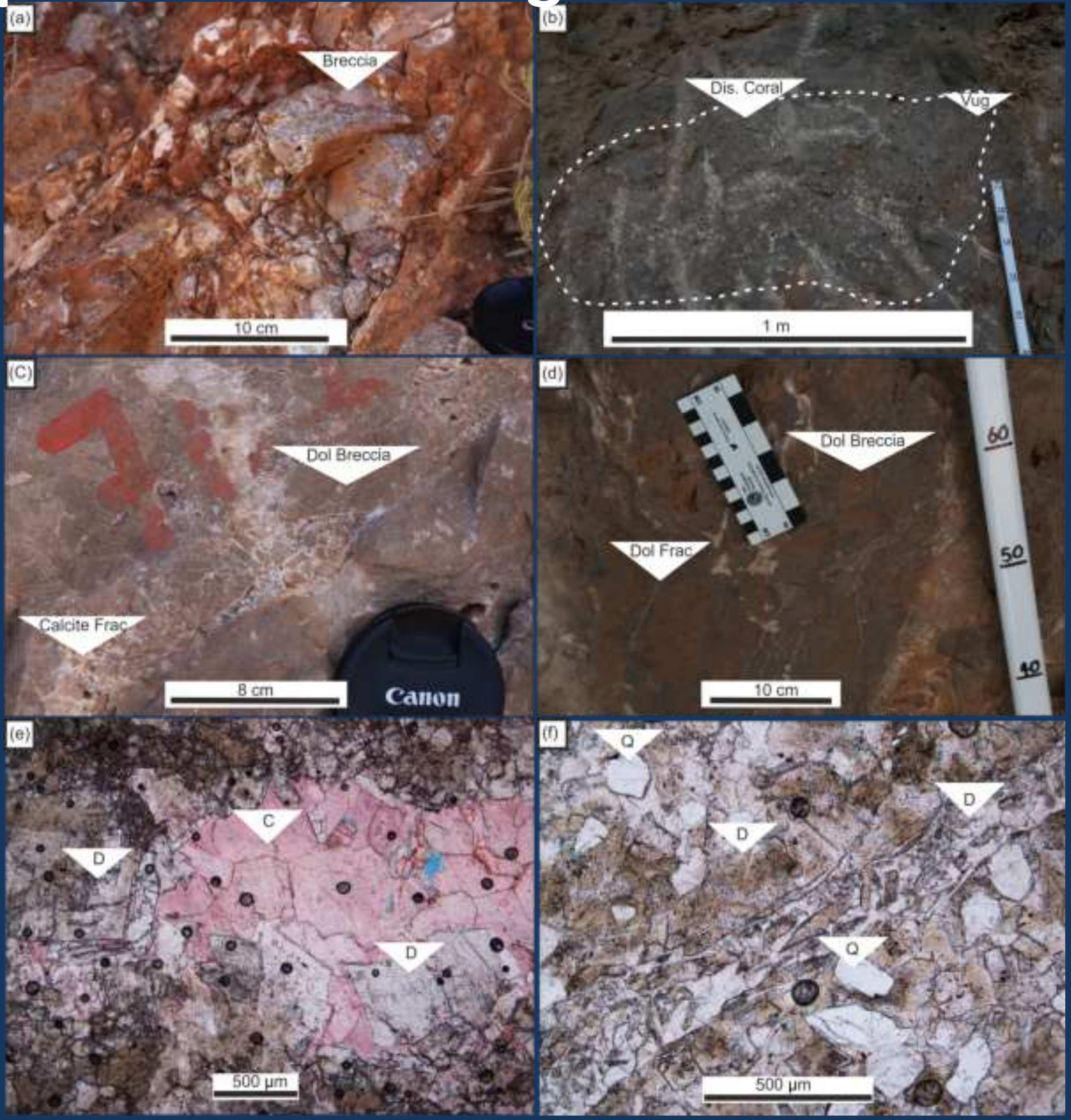




- 30 m of cross-laminated sandy dolostones, kerogenous with dolomite cemented fractures
- 38 m of heavily dolomitized coral boundstones
- Kerogenous, oil stained, fractured and brecciated

Dolomitization phases and timing- Assif Al Hade

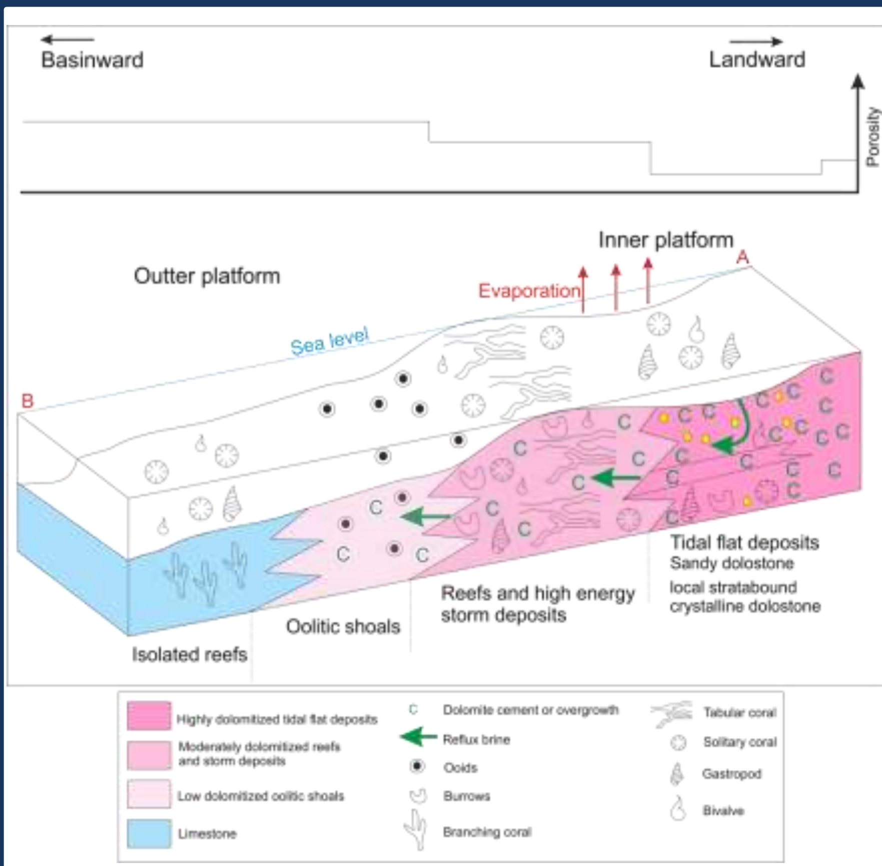


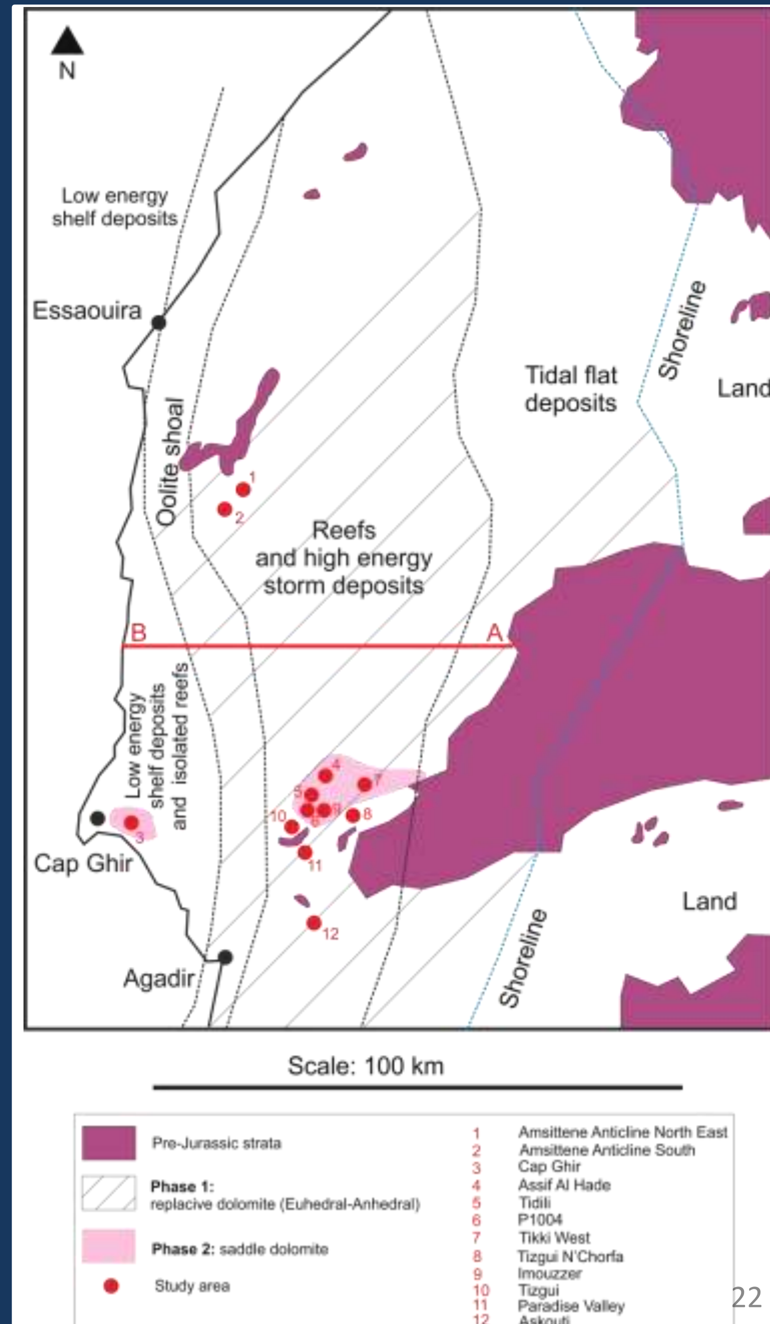


Plieminary hypothesis

Phase 1 dolomitization (Euhedral-anhedral): reflux, salt diapirism

Phase 2 dolomitization (saddle): Fault controlled





SUMMARY AND CONCLUSIONS

Toarcian

- Laterally, extensive stratabound, mimitic, planar-euhedral crystals are characteristic of low temperature (<50oC) dolomitization (*sensu* Sibley & Gregg, 1987) by seawater in a shallow burial setting (Warren, 2000).
- Selective nucleation of euhedral dolomite within ooids is most likely related to reactive surface area, where more nucleation points occur.
- Seepage-reflux model is proposed for these dolomites.
- Generally, dolomitization improved effective porosity compared to the parent limestone by developing intercrstyalline porosity.

SUMMARY AND CONCLUSIONS

Oxfordian

- Stratabound and non-stratabound dolomites are up to 10s of meters wide with changes in fabric and textures away from fault indicating multiple phases of dolomitization.
- Fabric preserving planar, euhedral dolomites incompletely replaced a range of facies and occur away from faults.
- Fabric destructive (saddle) textures imply fault-controlled dolomite formation in high fluid temperature (>50oC).
- Polymodal nature of the dolomite indicates heterogeneous nucleation and differential rates of crystal growth, evidenced by different crystal sizes.
- Presence of zoned crystals suggest relatively slow rate of crystal growth from fluids with changing chemical composition.
- Gradational contact between dolomites and limestones could be attributed to the permeability and porosity of the limestone at the time of dolomitization.

SUMMARY AND CONCLUSIONS

Oxfordian

- Gradational contact between dolomites and limestones could be attributed to the permeability and porosity of the limestone at the time of dolomitization.
- Fault controlled dolomitization is contemporaneous with hydrocarbons.
- Dedolomitization has led to occlusion of the initial porosity created during dolomitization.
- Overall, investigated dolomite bodies are porous, where porosity distribution is highly variable in pore size and connectivity.
- Over dolomitization commonly appear at the fault core, where dolomitization intensity decreases 10s of meters away from the fault.

RESEARCH PLANS

	Action points	2018									2019		
		04	05	06	07	08	09	10	11	12	01	02	03
Third year (2018/2019)	XRD	■	■	■	■	■	■						
	O/C isotopes	■	■	■	■	■	■	■					
	fluid inclusion			■	■	■	■	■					
	Trace element analysis (microprobe)			■	■	■	■	■					
	Standard Optical Microscopy- 2nd field season samples			■	■	■	■	■	■				
	CL Microscopy- 2nd field season samples			■	■	■	■	■	■				
	Literature review	■	■	■	■	■	■	■	■	■	■	■	■
	NARG sponsors meeting		■										
	Poster presentation at ACE, Utah, USA (20-23rd May)		■										
	QemScan			■	■								
	clumped isotope analysis			■	■								
	Total Organic Content (TOC)				■								
	Gas chromatogram				■	■	■						
	Conjugate Margins Conference, Canada (19-22 August)					■							

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