



Establishing an integrated stratigraphic framework for the Berriasian to early Barremian interval of the Essaouira-Agadir Basin:

Project Updates February 2019

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Agenda



Project Introduction

Early Cretaceous Overview

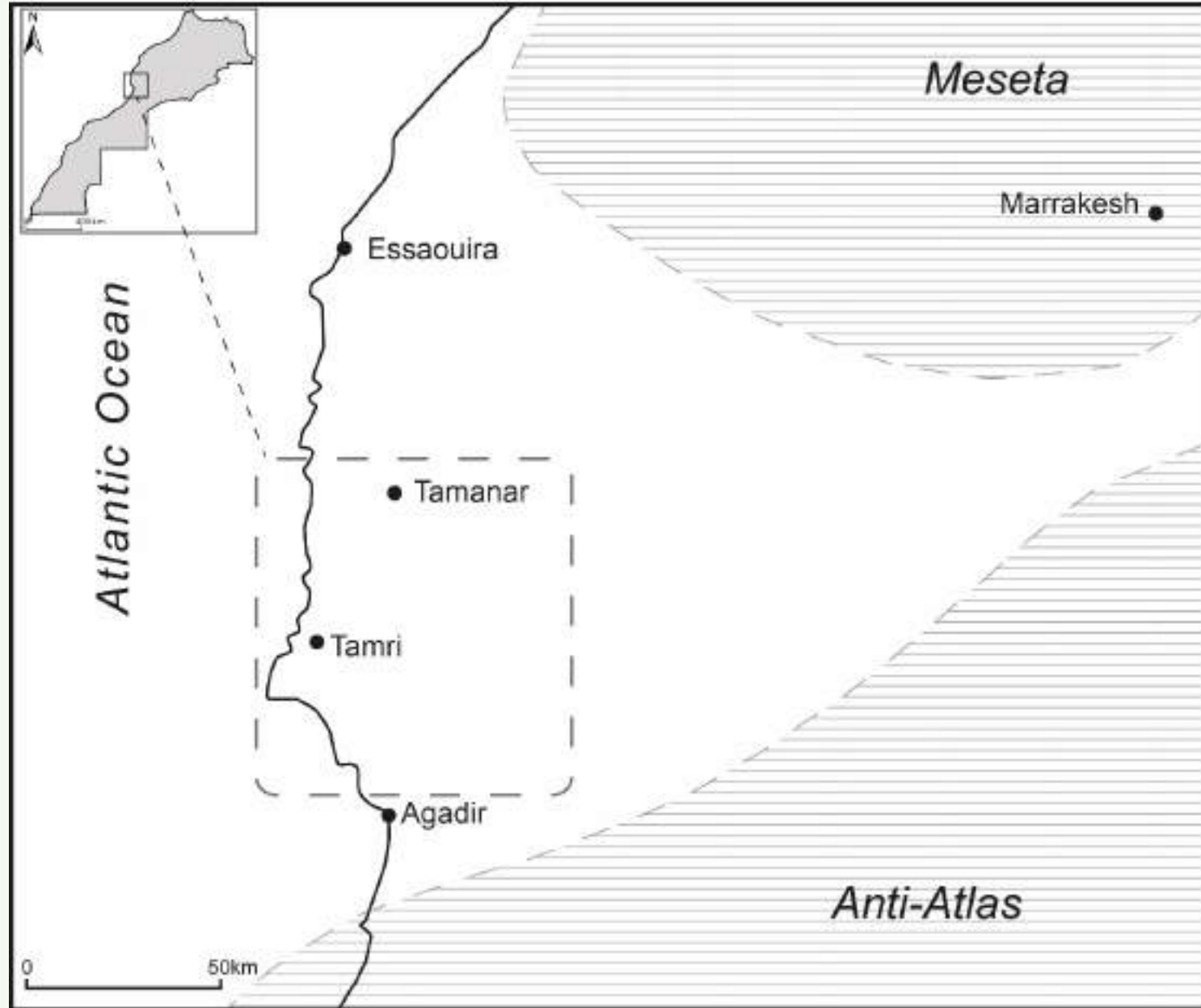
Field Season 1

Initial Interpretations

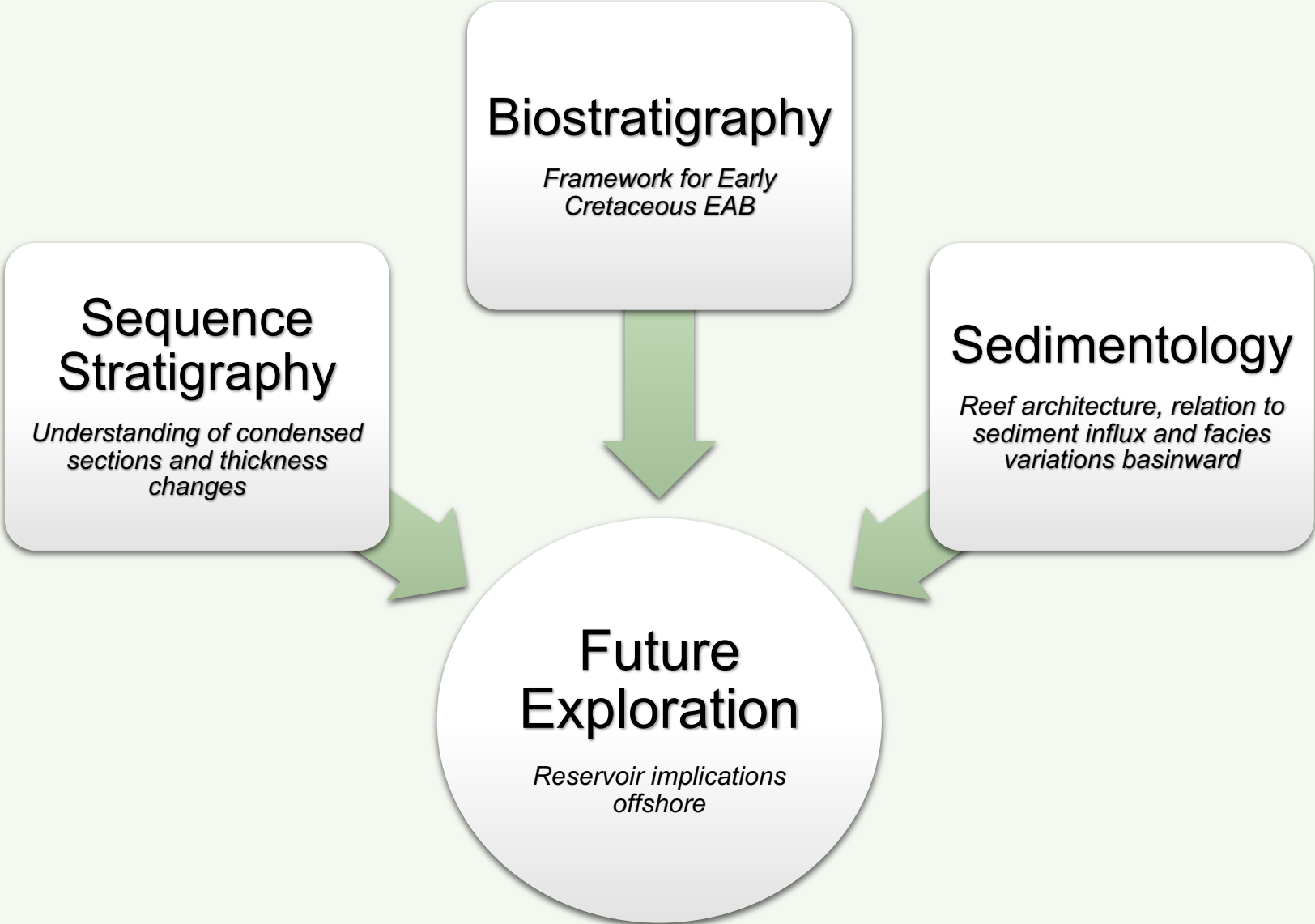
The Offshore Record

What's Next?

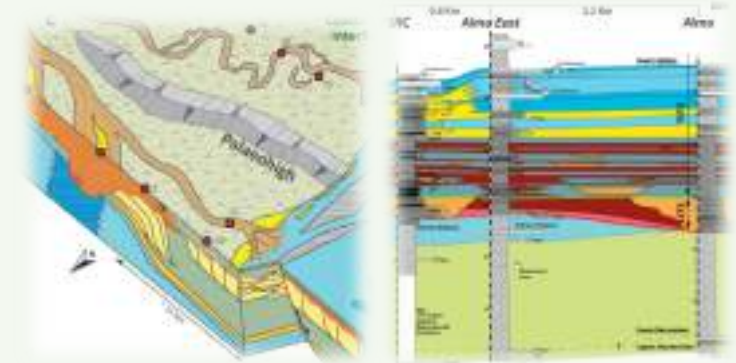
Study Area



Project Rationale



1. Establish a high-resolution biostratigraphic framework for the EAB which can be integrated with previous NARG work on the younger Barremian to Aptian and tied to global type sections
2. Improve understanding of the controlling factors on condensed section formation in passive margin settings
3. Characterise, map and constrain the age of the early Hauterivian reefal build-ups and assess their geometrical impact on post-Hauterivian sedimentation
4. Provide an onshore-offshore stratigraphic tie in the lower Cretaceous intervals of the EAB



Depositional and stratigraphic models



Biostrat ID and section correlation



Field logging and sampling



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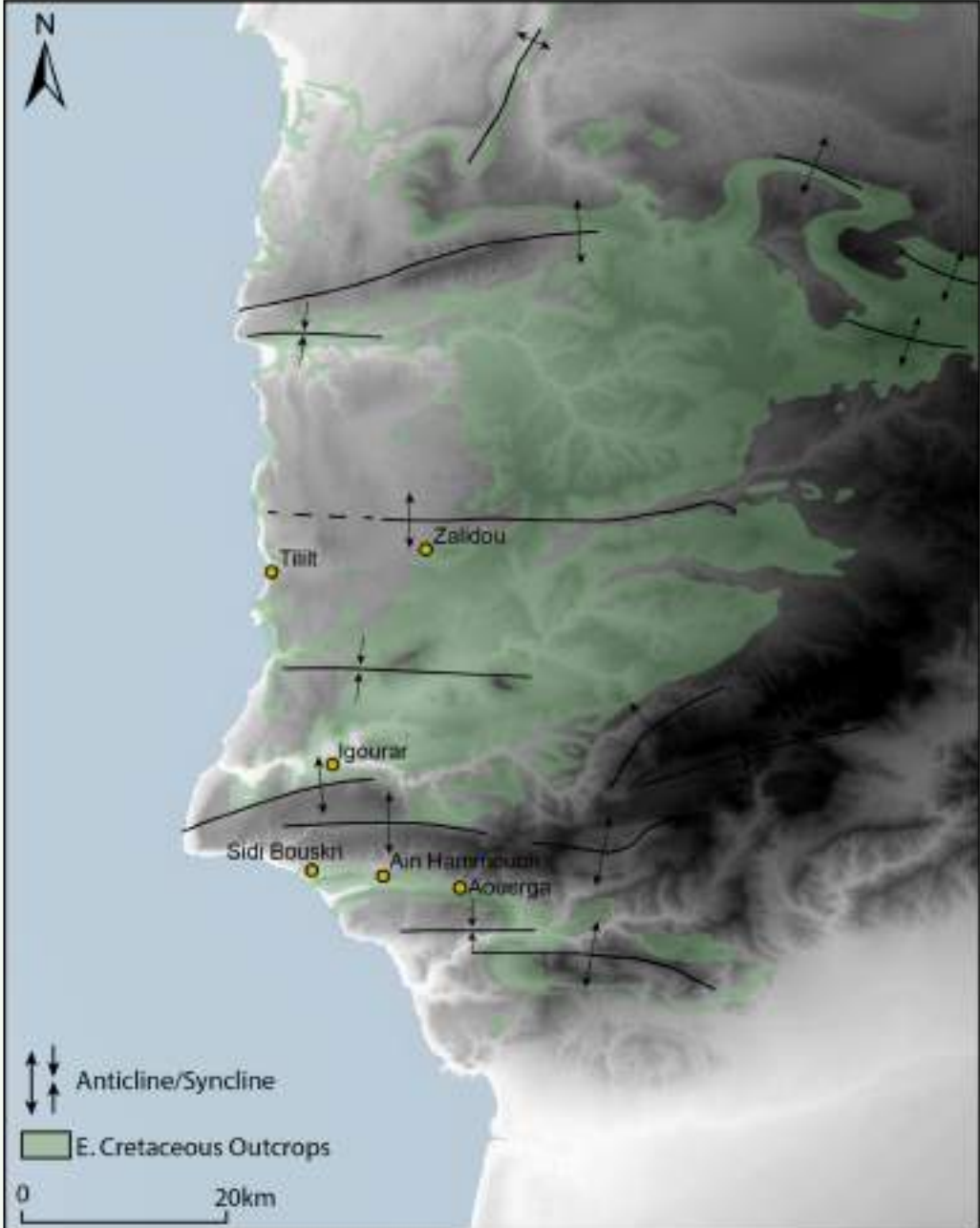
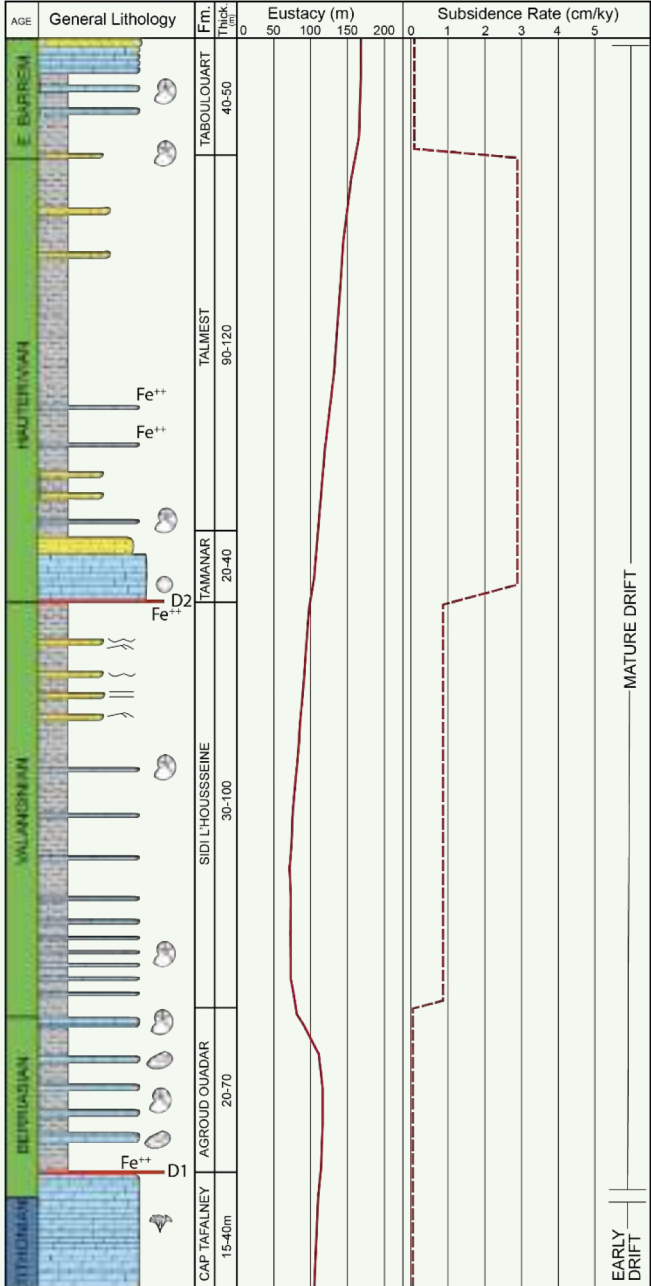
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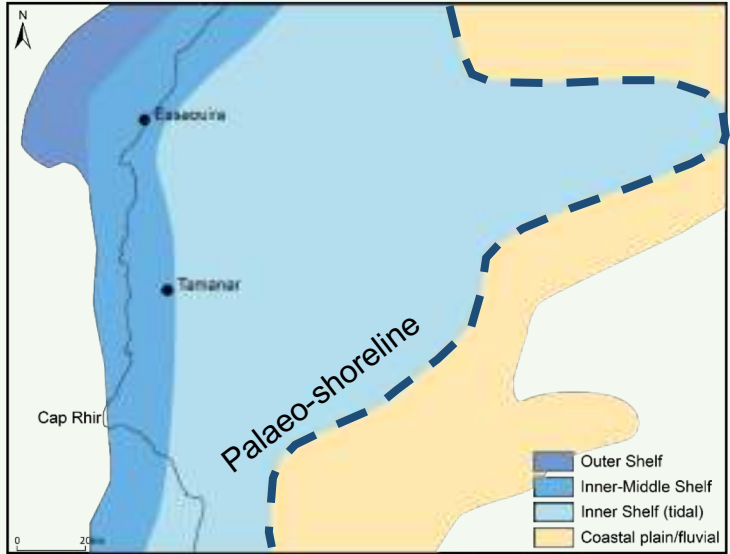
Geological Setting



(Based on Butt et al., 1982 and Lubet, 2018)

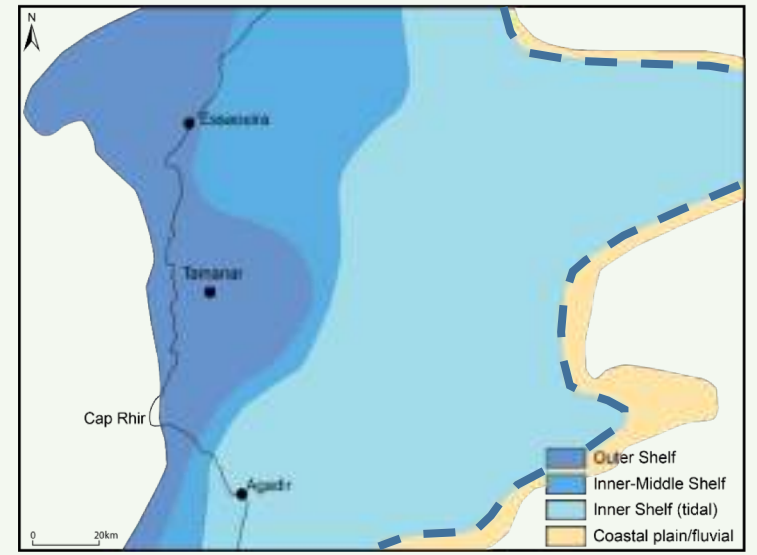
Palaeogeography

1 Berriasian



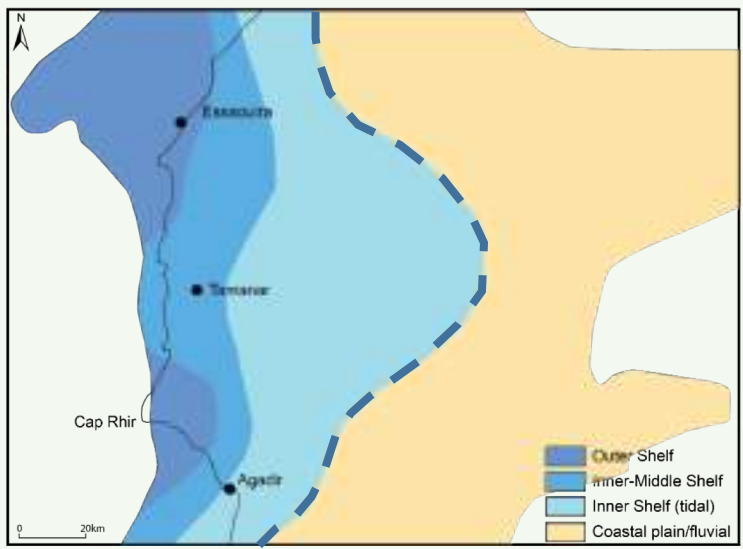
Local deepening with opening of "finger-like" embayment

2 Valanginian



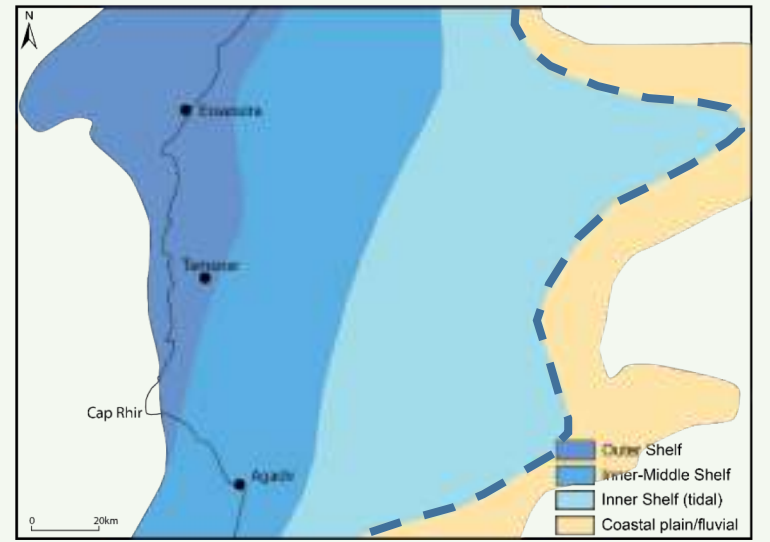
Deepening trend continues attributed to global transgression

3 L. Hauterivian



Shoreline moves forward with regression that began in the Upper. Val

4 L. Barremian



Transgression pushes shoreline inland



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Objectives



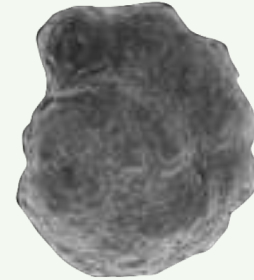
- Identify suitable reference sections for the earliest Cretaceous marine system
- Build sedimentary logs and carry out bed-by-bed biostratigraphic sampling of chosen sections for the Berriasian-early Hauterivian
- Identify new sections to complete the Late Hauterivian to early Barremian age gaps




(Google Earth, 2018)

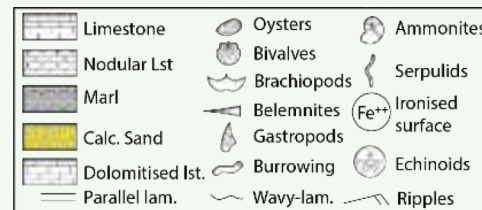
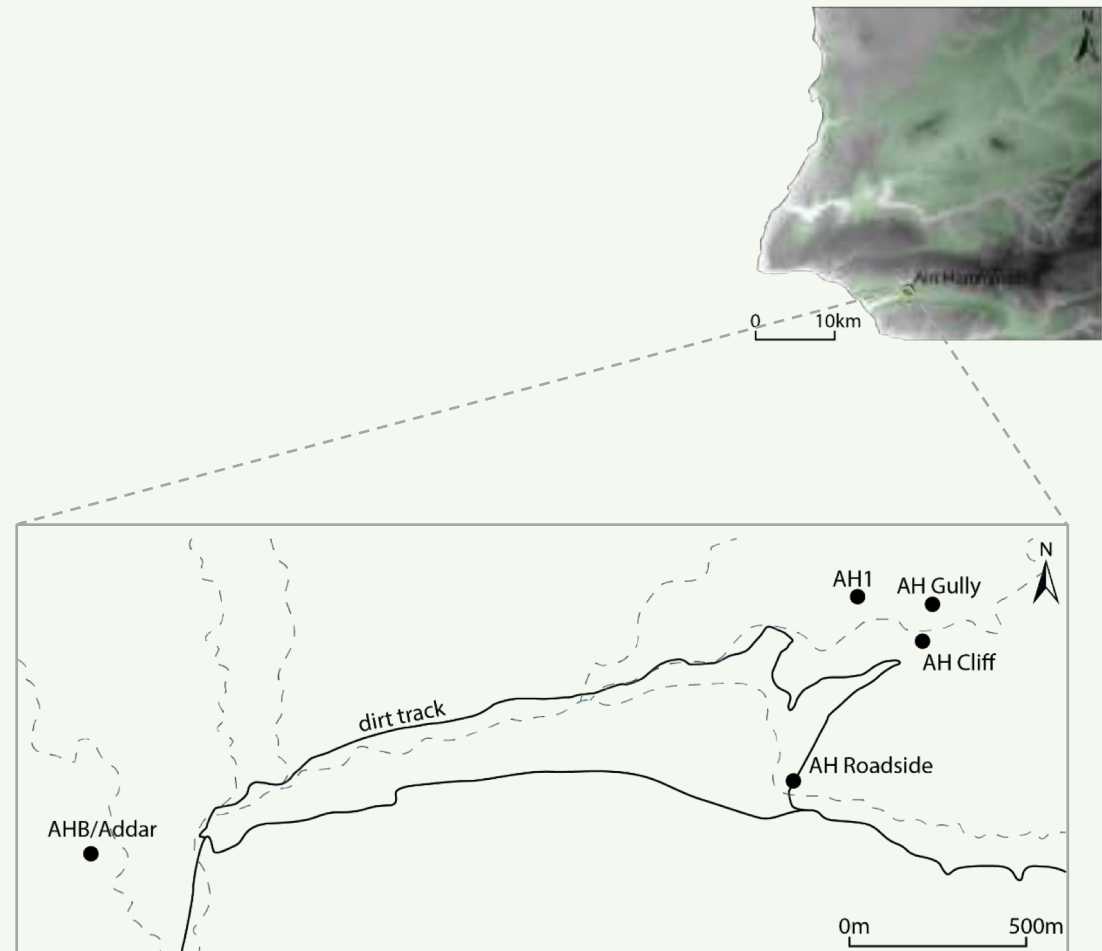
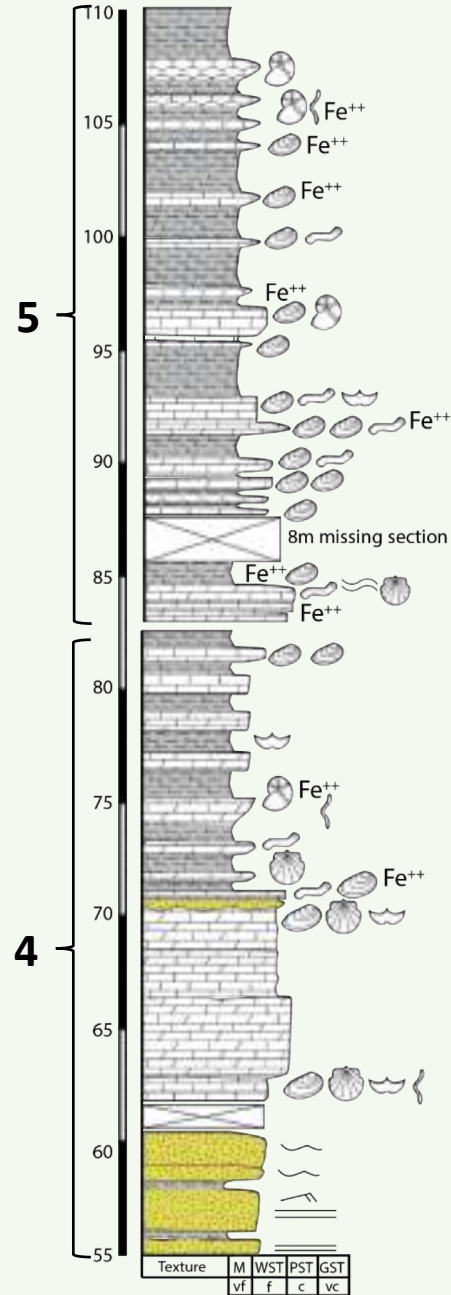
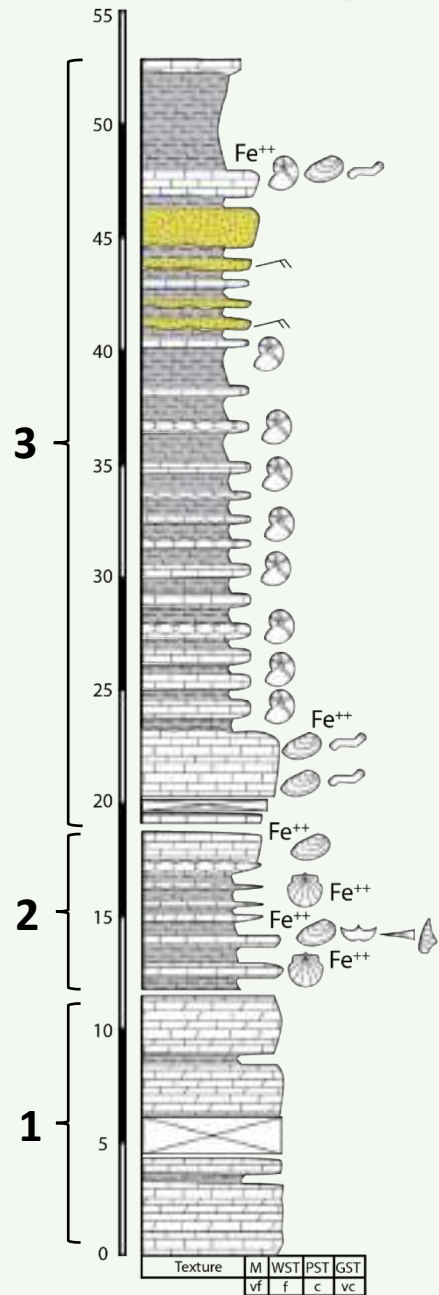
Chronometers:

- **Calcareous nannofossil** bioevents are documented widely in the Mesozoic
- **Calpionellids** have a shorter age range with biozones restricted to the late Jurassic (Tithonian) to Lower Valanginian
- **Ammonites** in the EAB have a world-renowned Cretaceous assemblage

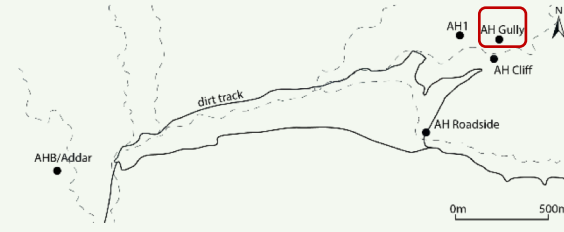


| Suitable Outcrop | Lithology | Calp/ Nanno |
|--|-----------|----------------|
|  | | C |
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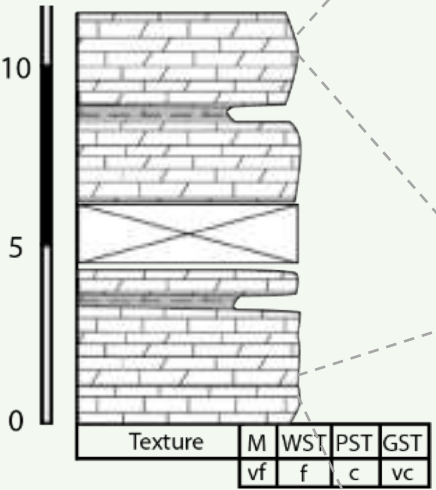
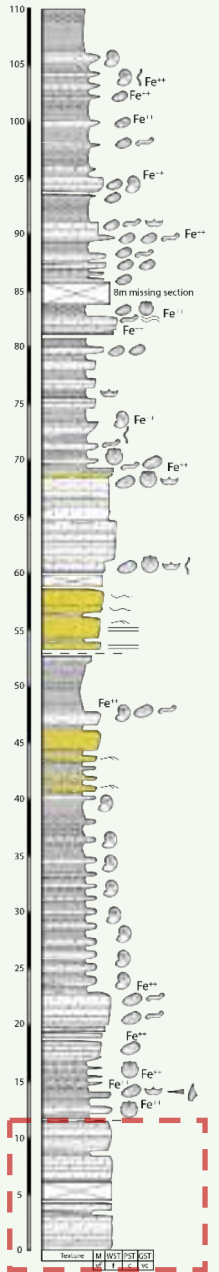
1. Ain Hammouch



Ain Hammouch Gully



- Massive limestone beds, usually heavily dolomitised
- Similar facies to other Tithonian outcrops on SW coast but poor fossil assemblage yet to allow confident age-calibration



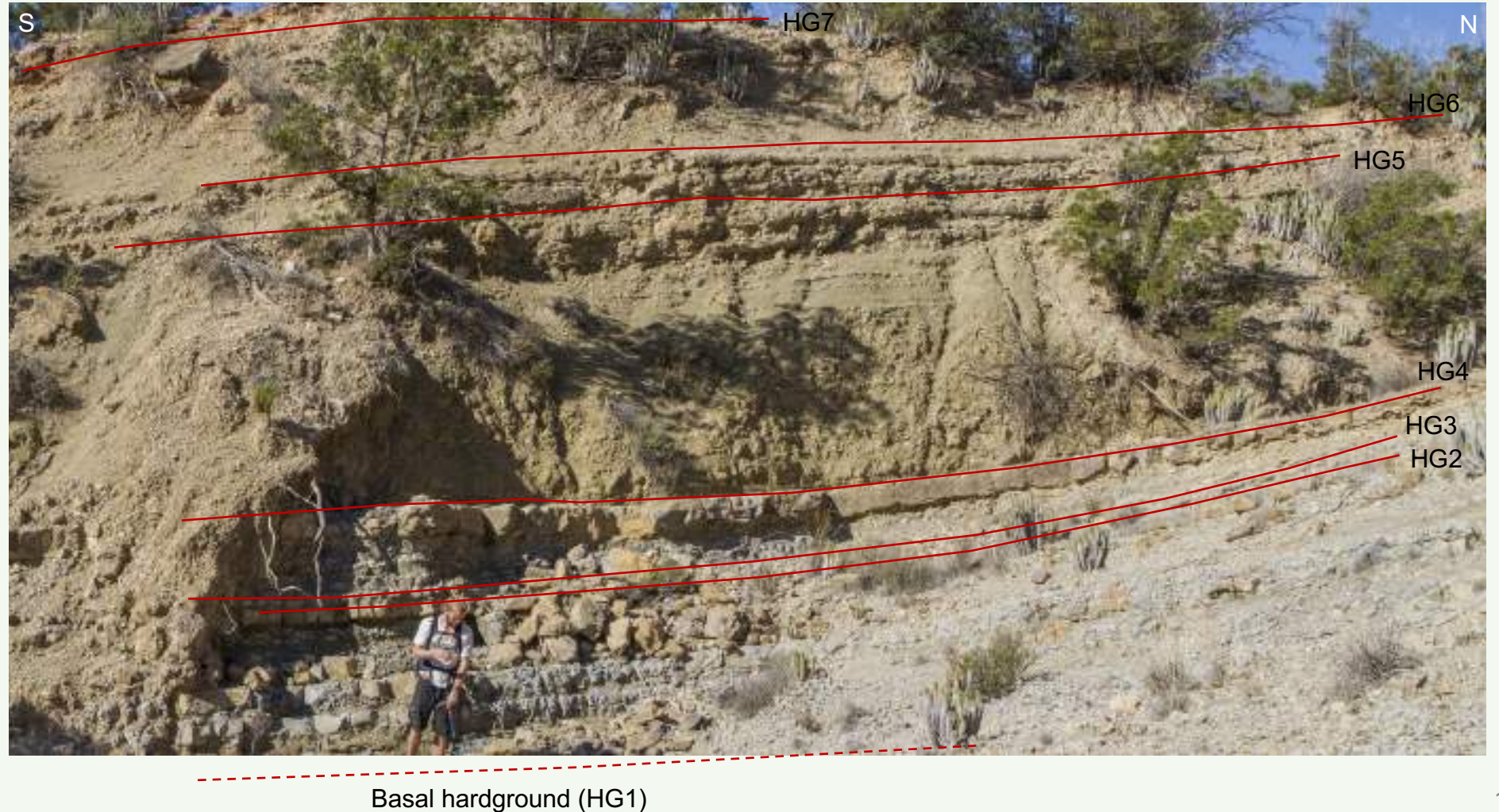
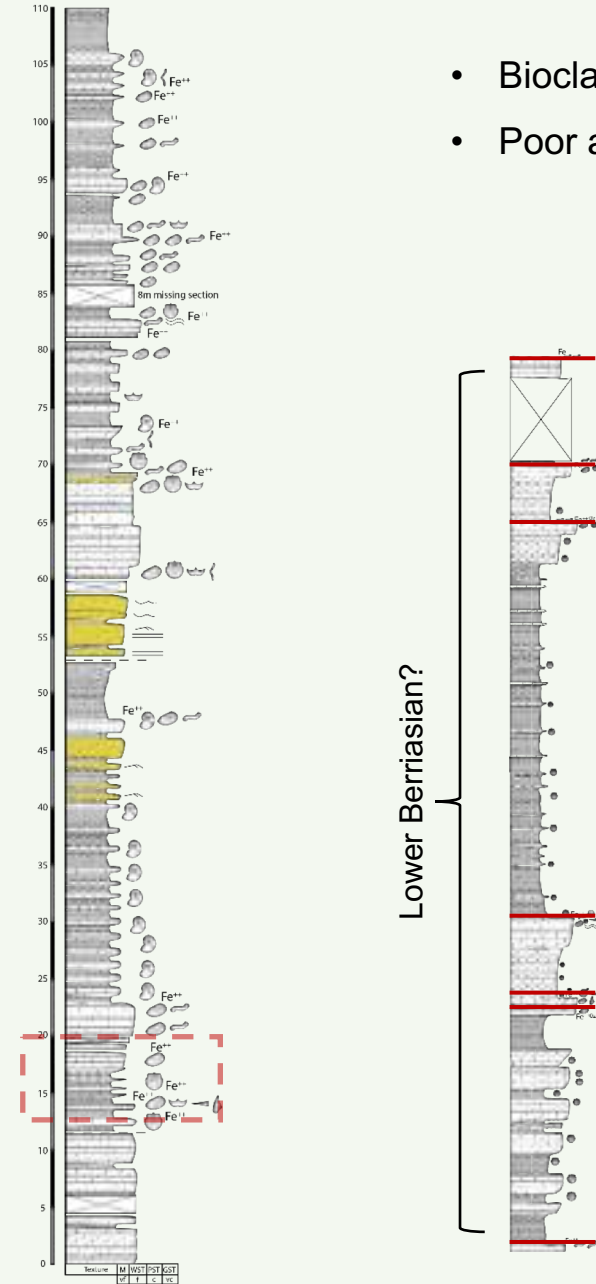
Massive and karstified beds



Deformed algal mats

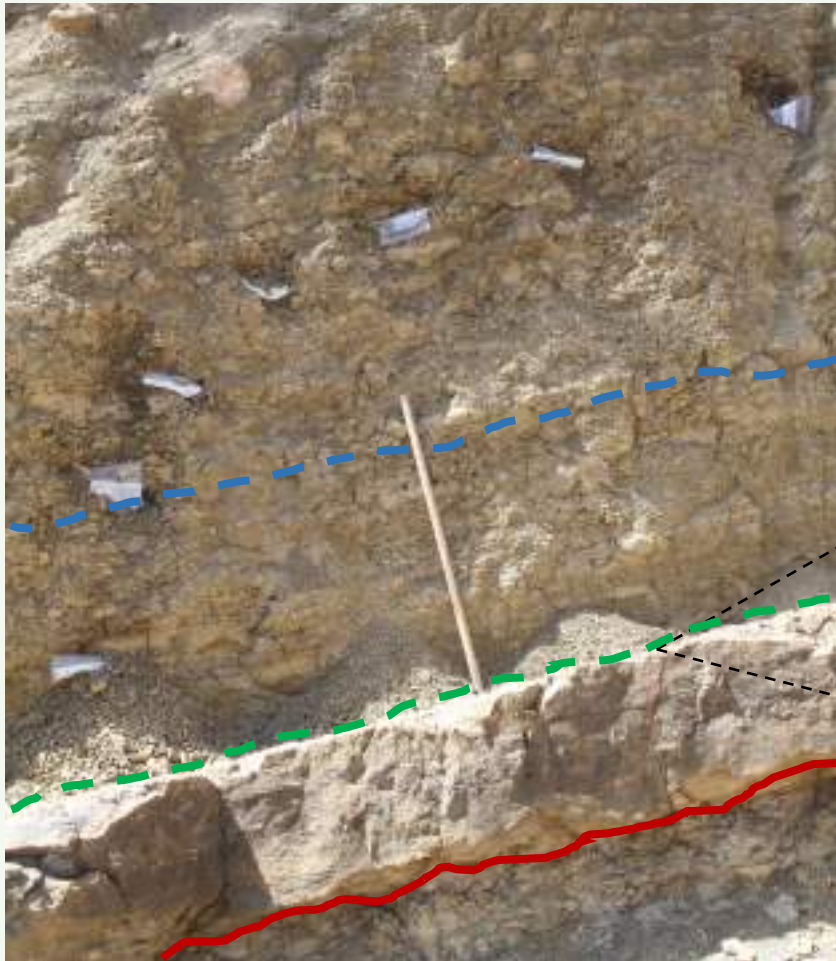
Ain Hammouch 1

- Bioclastic and sandy limestones interbedded with grey-yellow marls
- Poor ammonite assemblage but suitable for calpionellid and nanno-fossil sampling



Ain Hammouch 1 – Hard Grounds

- Limestones commonly topped with ferruginous/pyritic surface rich in oysters, brachiopods, bivalves and typically very burrowed
- “hard grounds” –surface forming due to prolonged periods of sub aerial exposure and low sedimentation rates. They represent a transgressive surface and may also be overlain by marls representing the maximum flooding surface of a sequence (Catuneanu et al., 2009).



MFS?

Initial
Transgressive
surface

Sequence
boundary



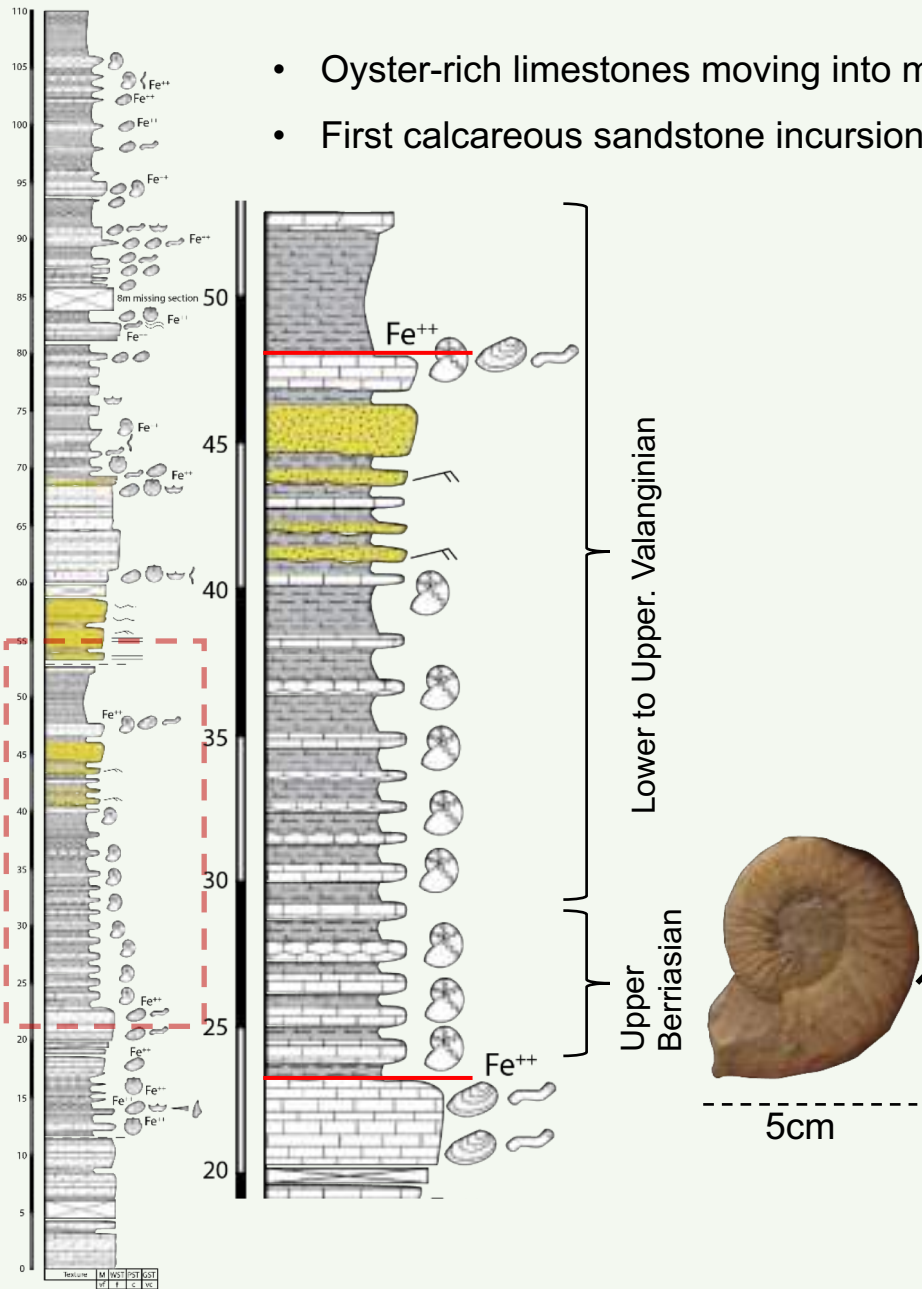
Oyster and
other shell
fragments



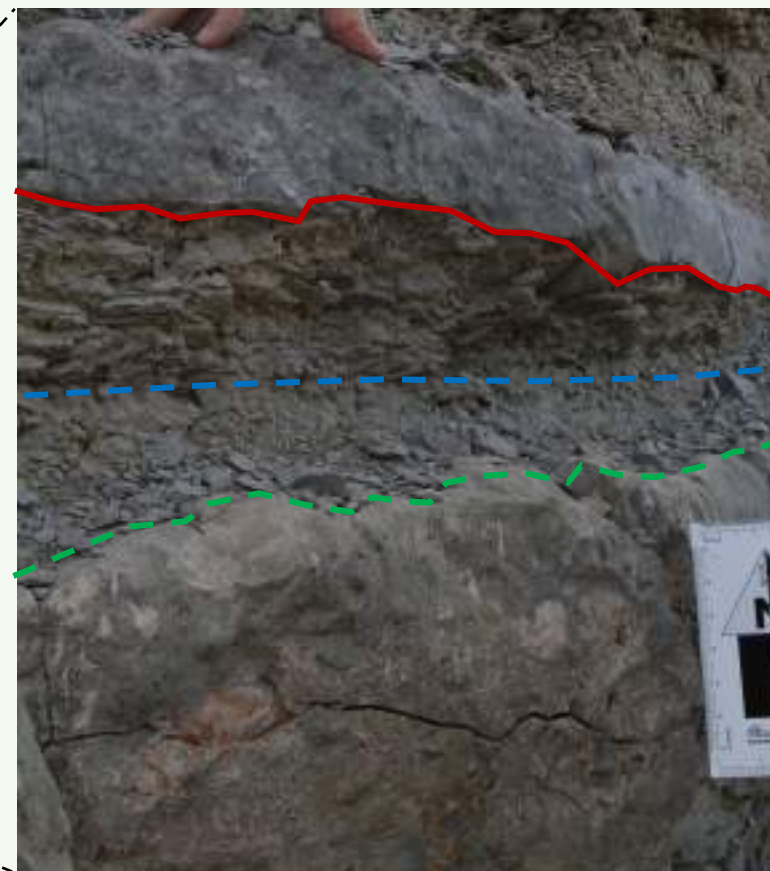
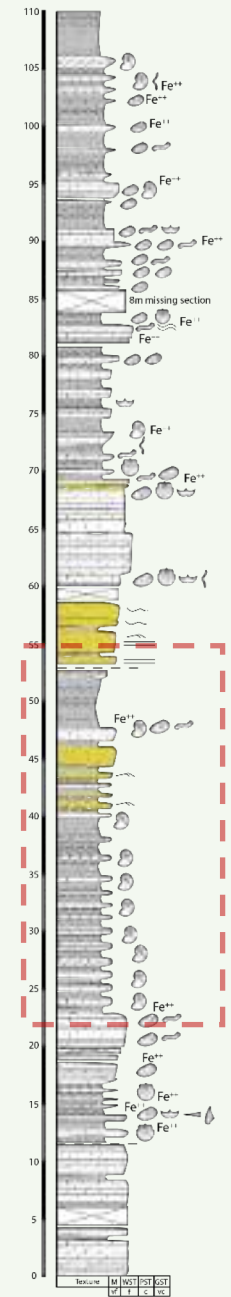
Large
bivalves

Ain Hammouch Cliff Section

- Oyster-rich limestones moving into marl and limestones which thicken towards the top.
- First calcareous sandstone incursion with sharp erosive bases on marls – result of forced regression?



Ain Hammouch Cliff Section

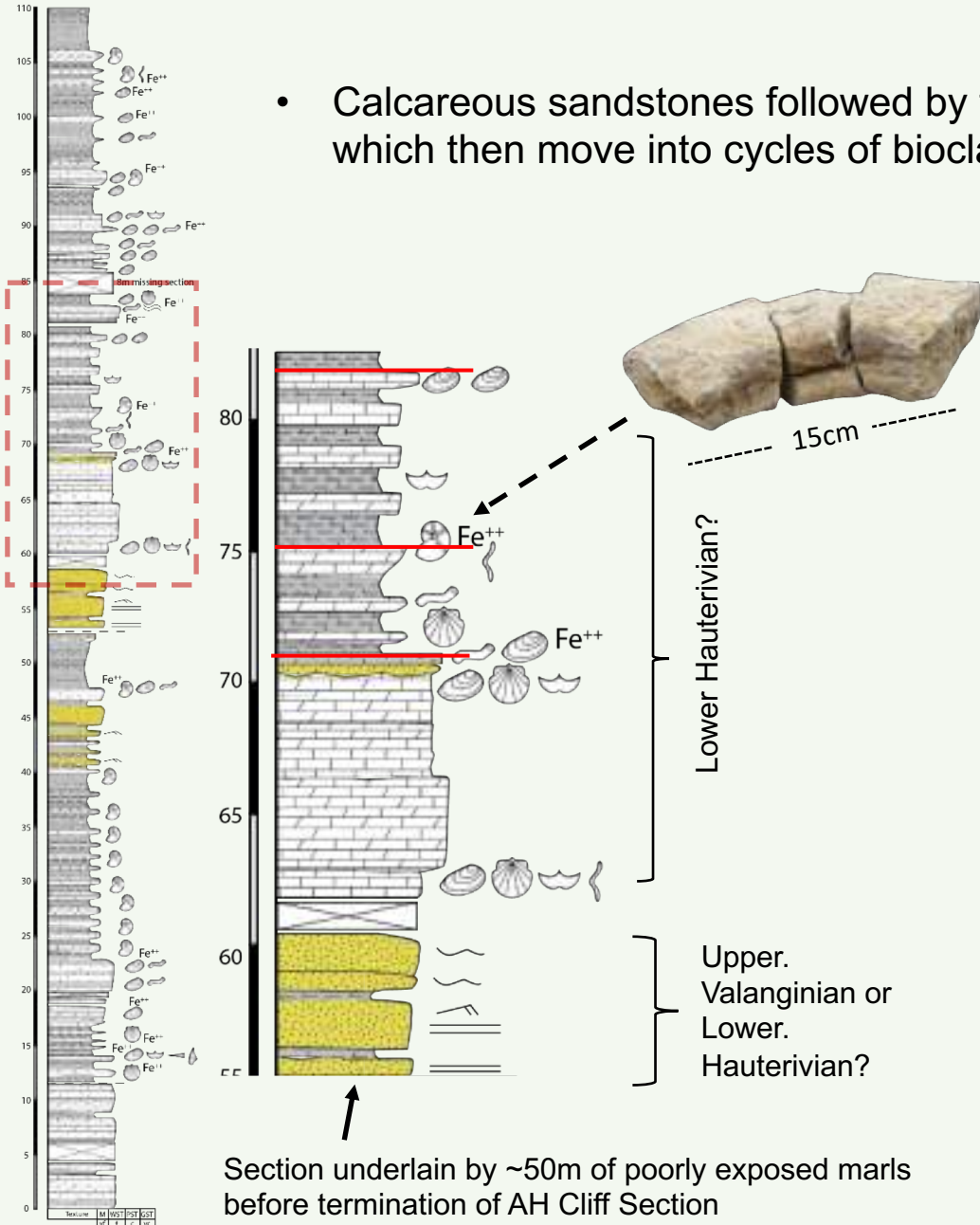


Sequence boundary
MFS
ITS

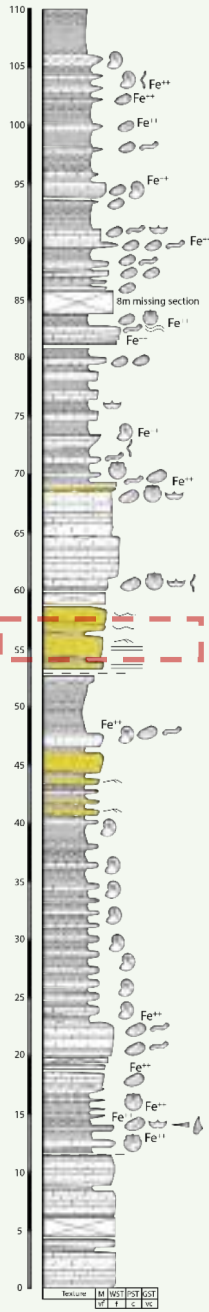
Ain Hammouch Roadside



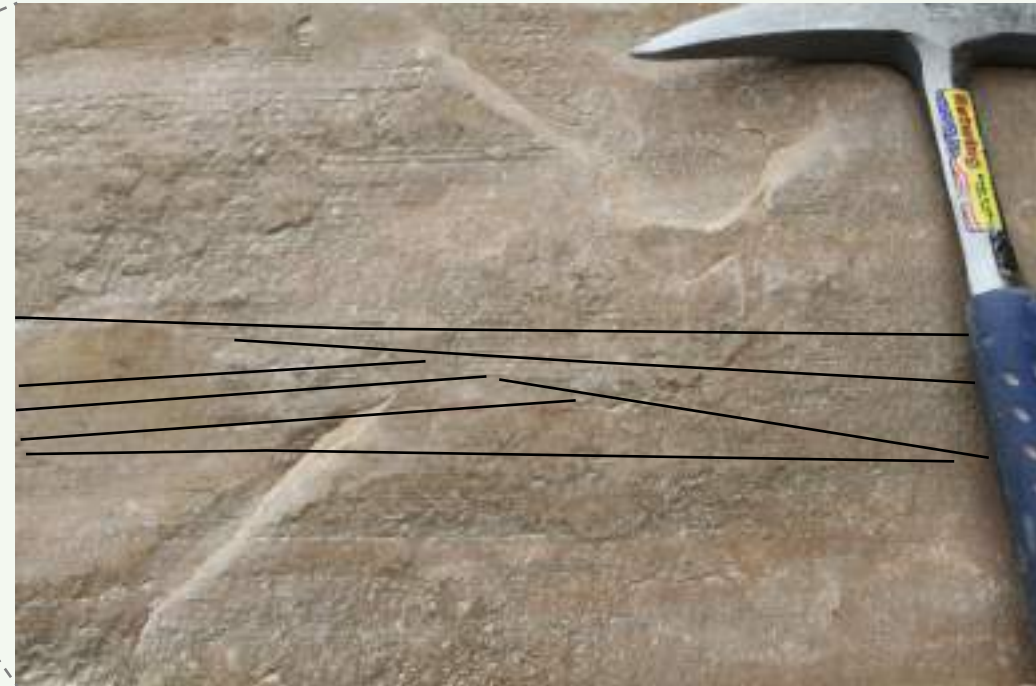
- Calcareous sandstones followed by thick and massive dolomitised limestone which then move into cycles of bioclastic limestones and green weathered marls



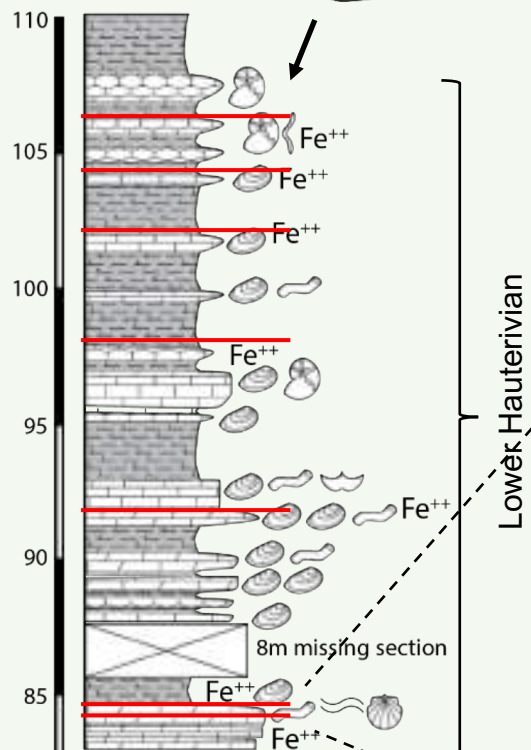
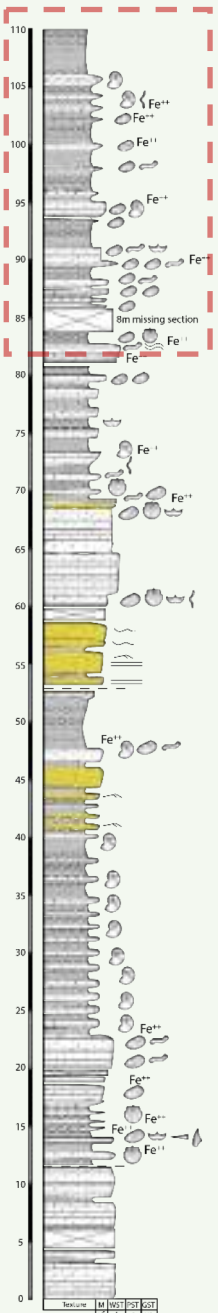
Ain Hammouch Roadside - Sands



- Fine-medium grained, horizontally laminated and cross-bedded in places and lie sharply on marl facies
- Could be far-reaching prograding beach facies occurring during forced regression



Ain Hammouch B/Addar

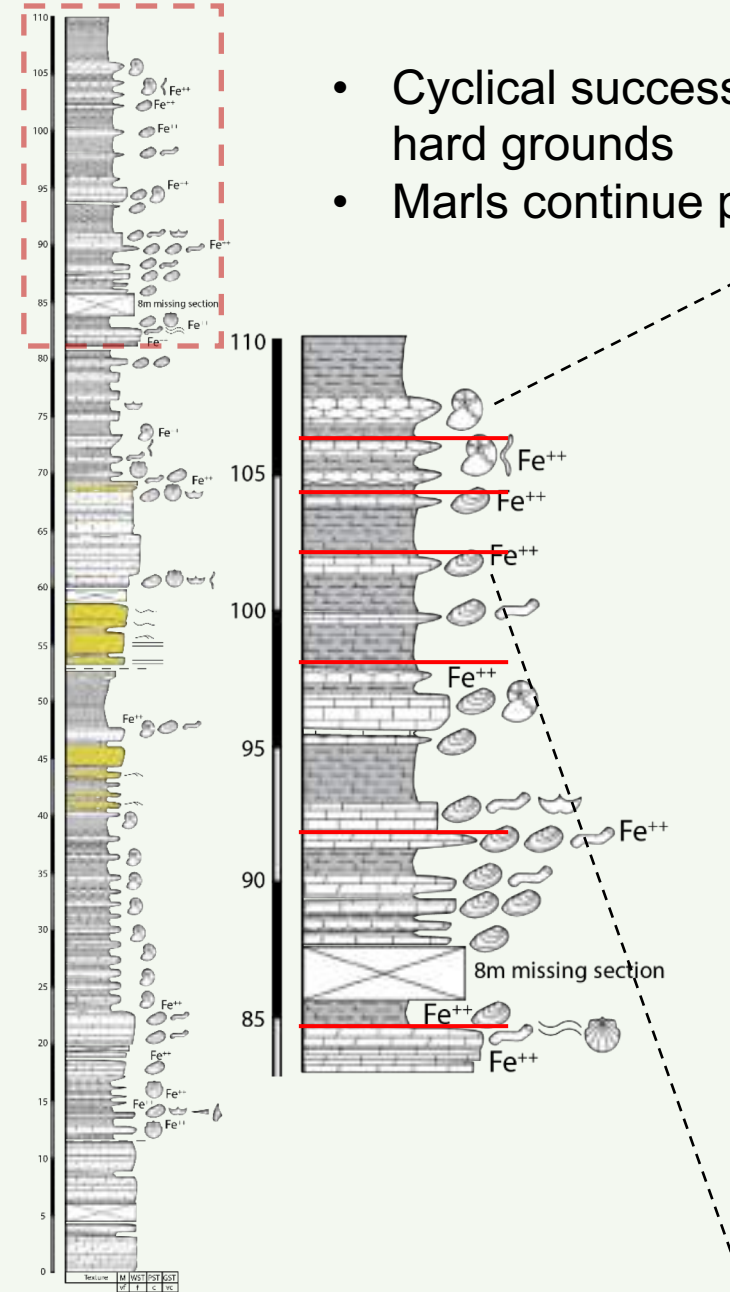


MFS?
ITS
SB
MFS?
ITS
SB

Ain Hammouch B/Addar



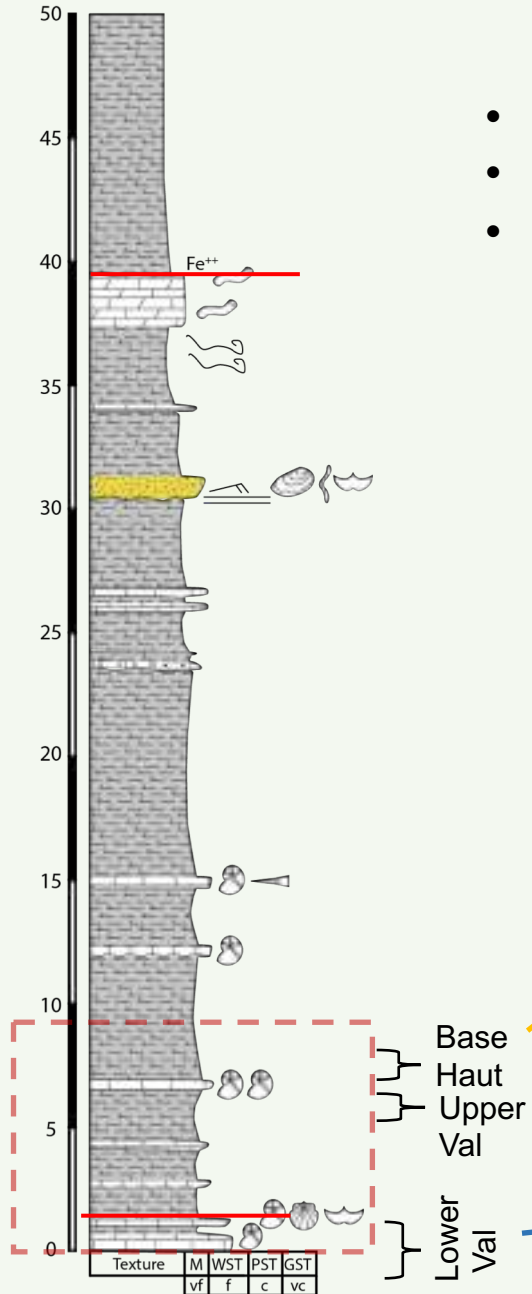
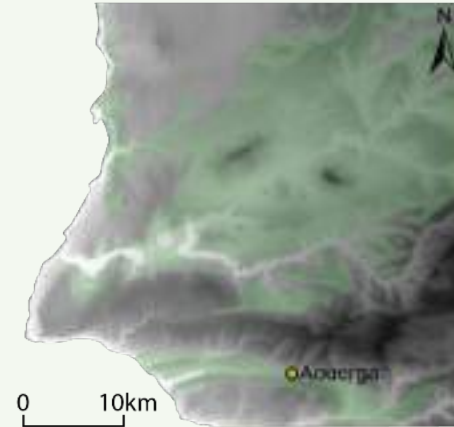
- Cyclical successions of greenish-grey marls and oyster-rich carbonate hard grounds
- Marls continue poorly exposed until reaching Lower Barremian cliff top



Stacked
Oyster-rich
HG beds

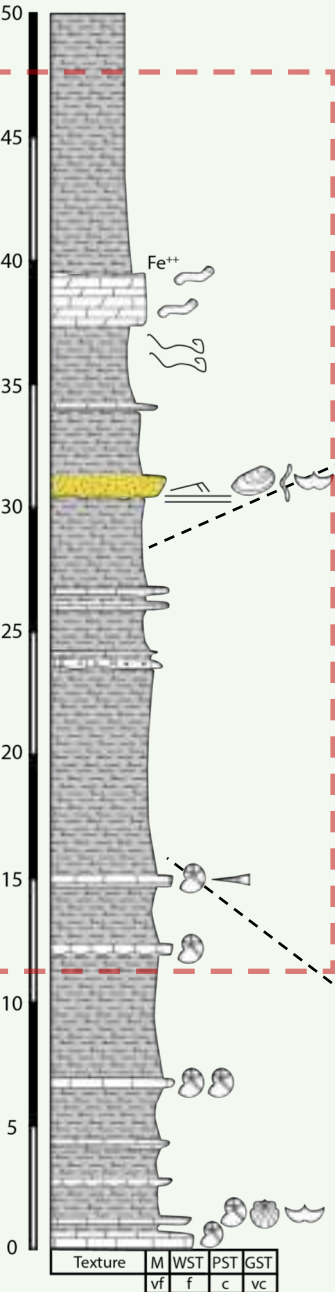
2. Aouerga

- 6km east of Ain Hammouch
- Within <10m, identified ammonite zones of the Lower to Upper Valanginian
- Suggests Valanginian highly condensed here, with several sub zones missing completely

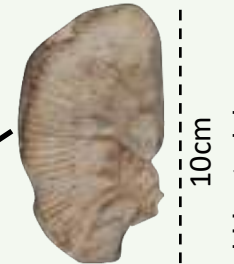


2. Aouerga

- Progressively thickening-up marls with several fossiliferous limestone interbeds and a cross-bedded calcareous sand incursion



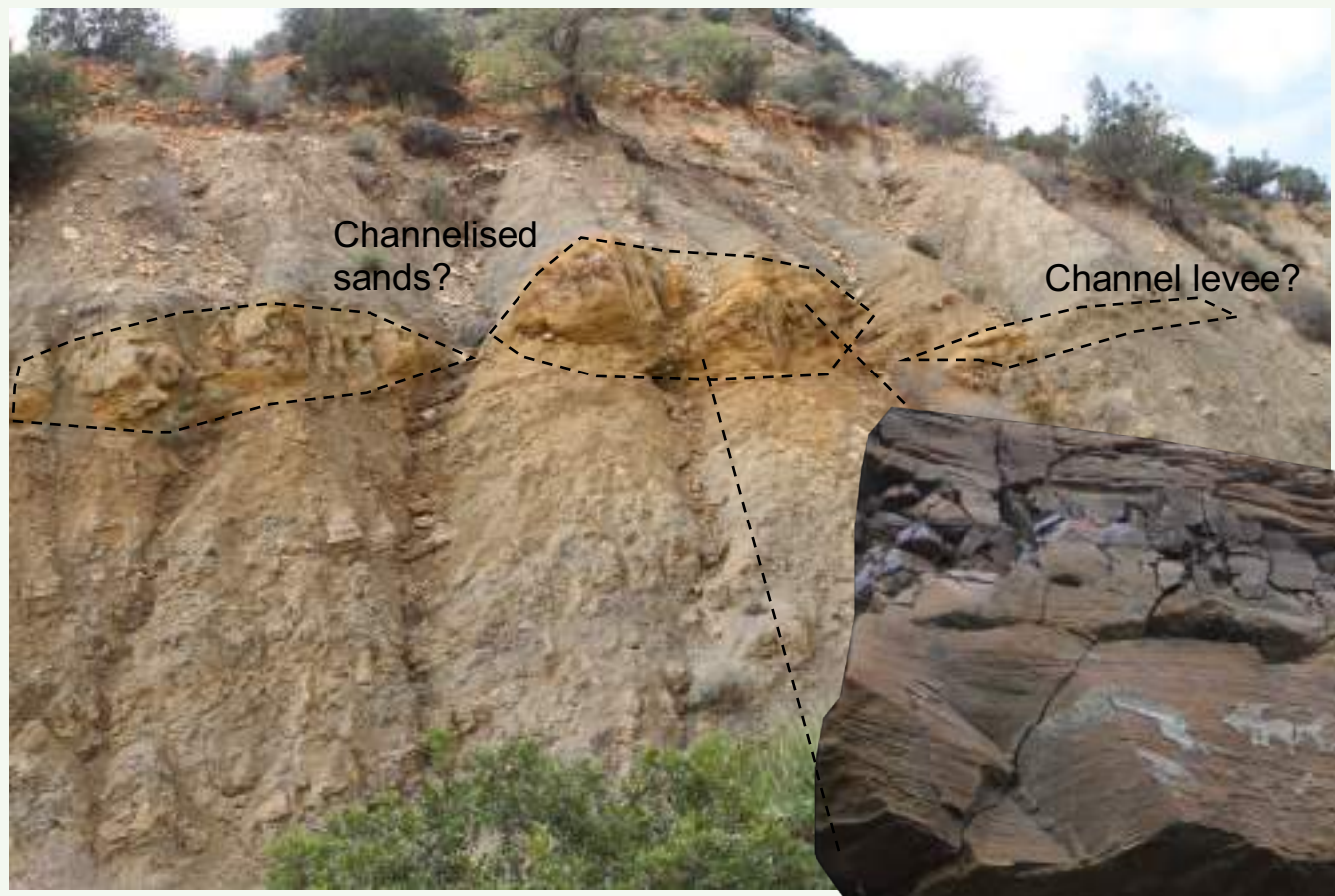
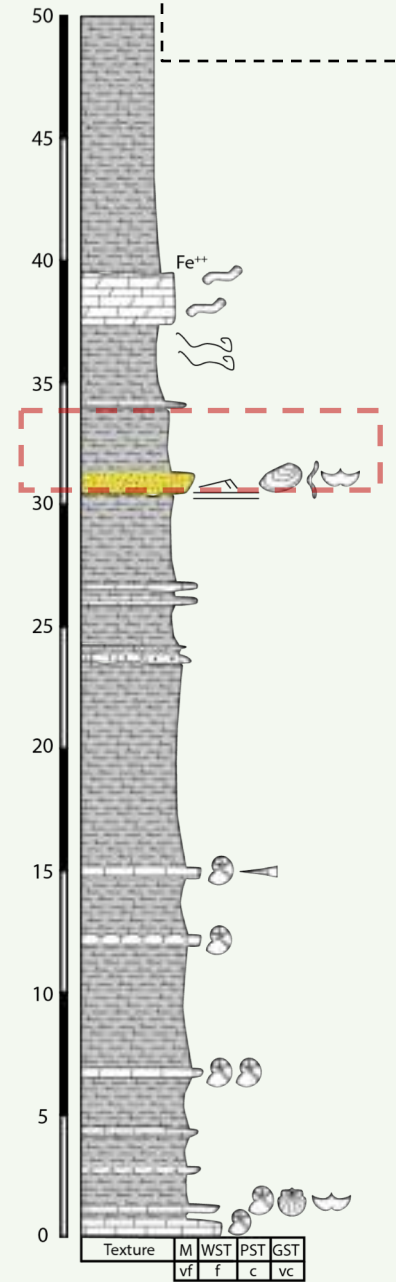
Lower Hauterivian



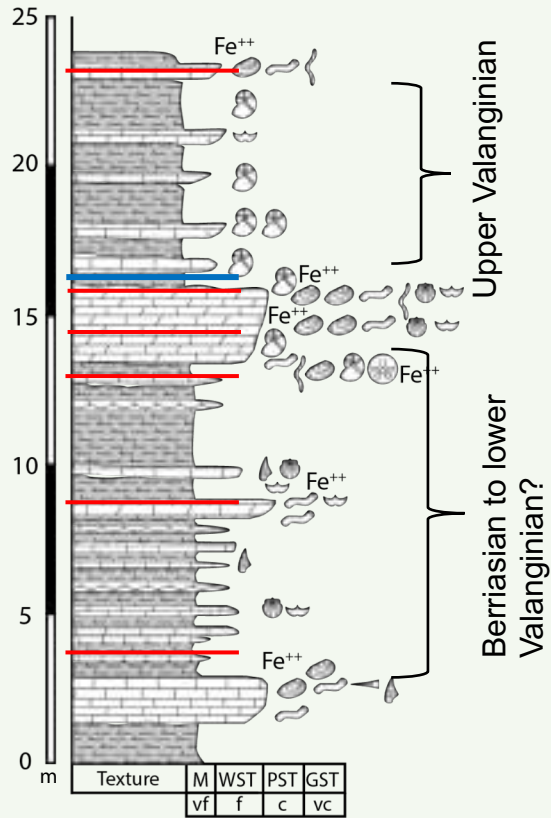
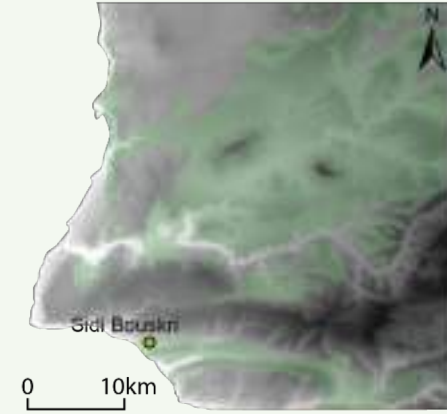
10cm

Basal Hauterivian ammonite

2. Aouerga – Sand Interval



3. Sidi Bouskri



- Cycles of MST to WST/PSTs with common hard grounds on top surfaces
- Bedding variable in lateral continuity, many nodular limestones in the marl
- Section highly condensed compared to Ain Hammouch (6km east)



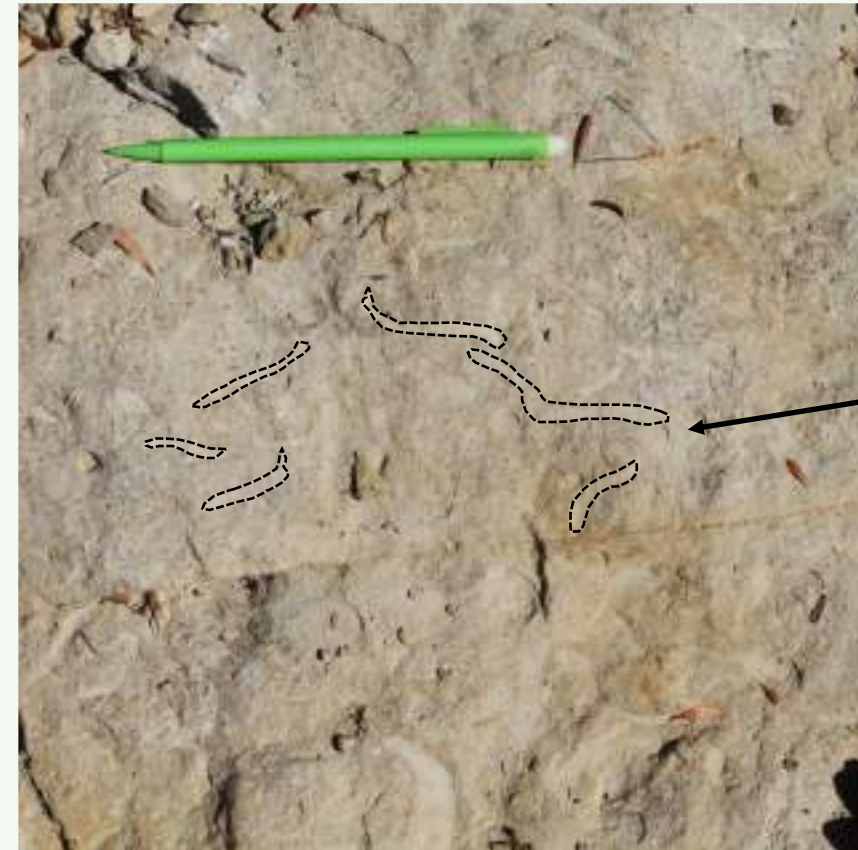
Sidi Bouskri



Vertical burrows

Vuggy porosity in burrows (dolomitised)

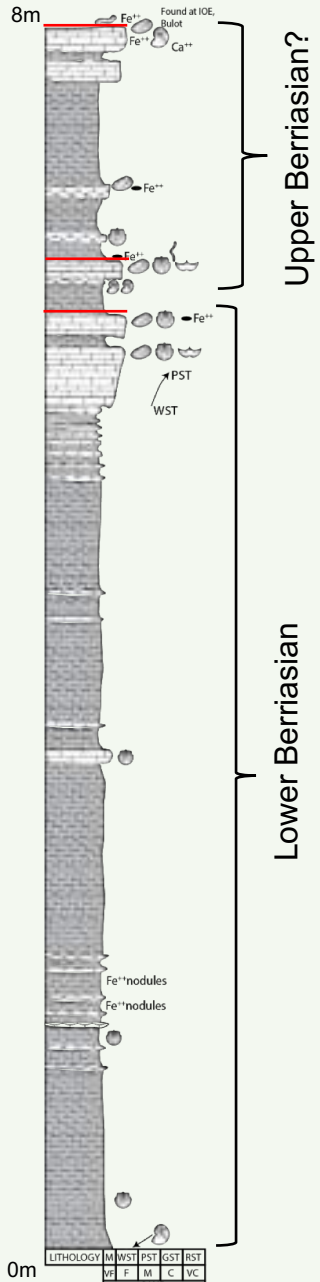
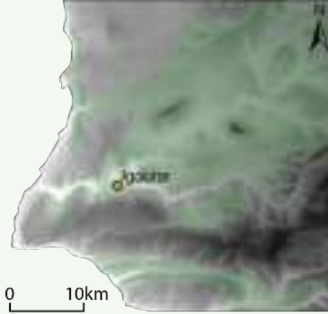
Soft-sediment deformation



Bioturbated tops with marine ichnofacies (nereites?)

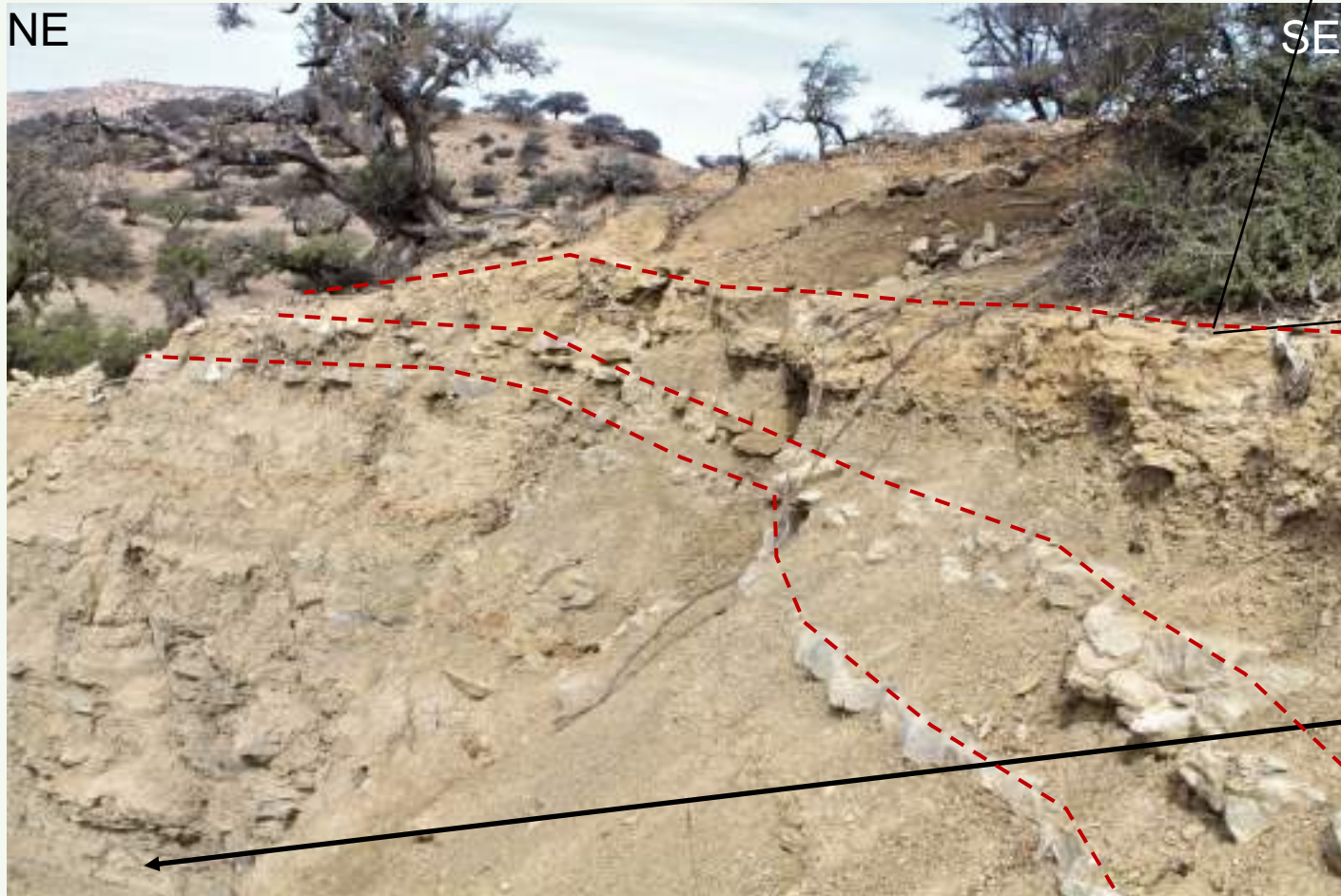
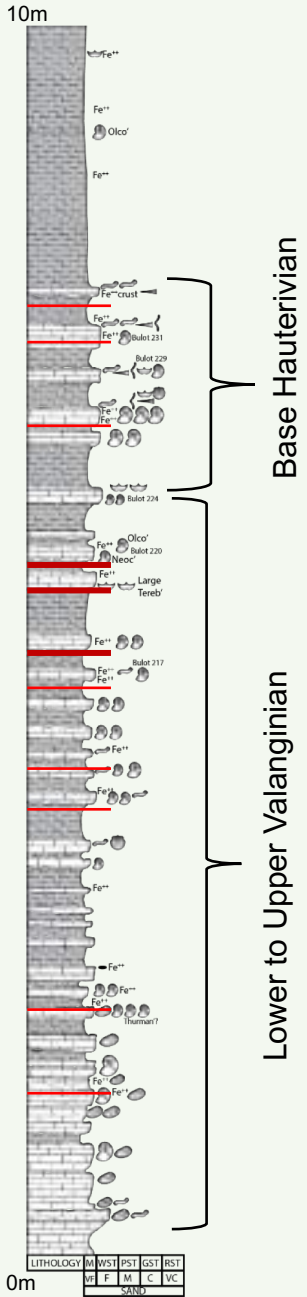
4. Igourar West (i)

- ~11km NW of Ain Hammouch, green marls moving into bioclastic limestone sequences
- J/K boundary confirmed by calpionellid biostratigraphy several m's below start of log

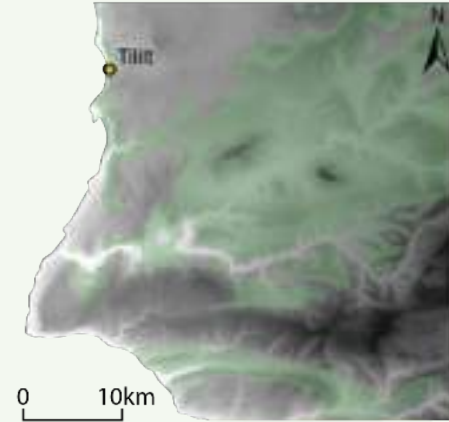
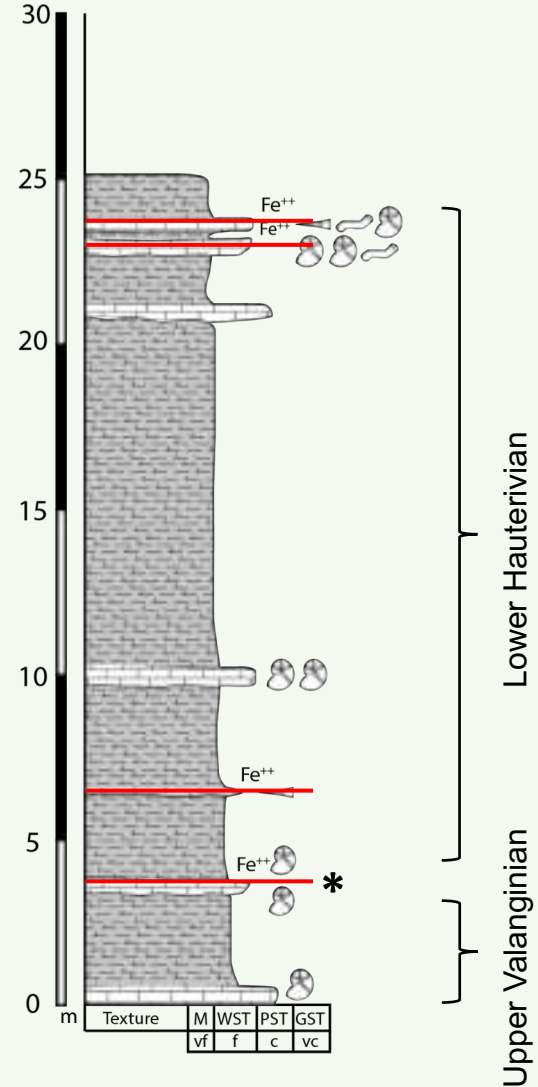


4. Igourar West (ii)

- Found ~400m from IW1 with excellent ammonite harvest
- High frequency marl-bioclastic limestone sequences with marls thickening overall up the section



6. Tililt

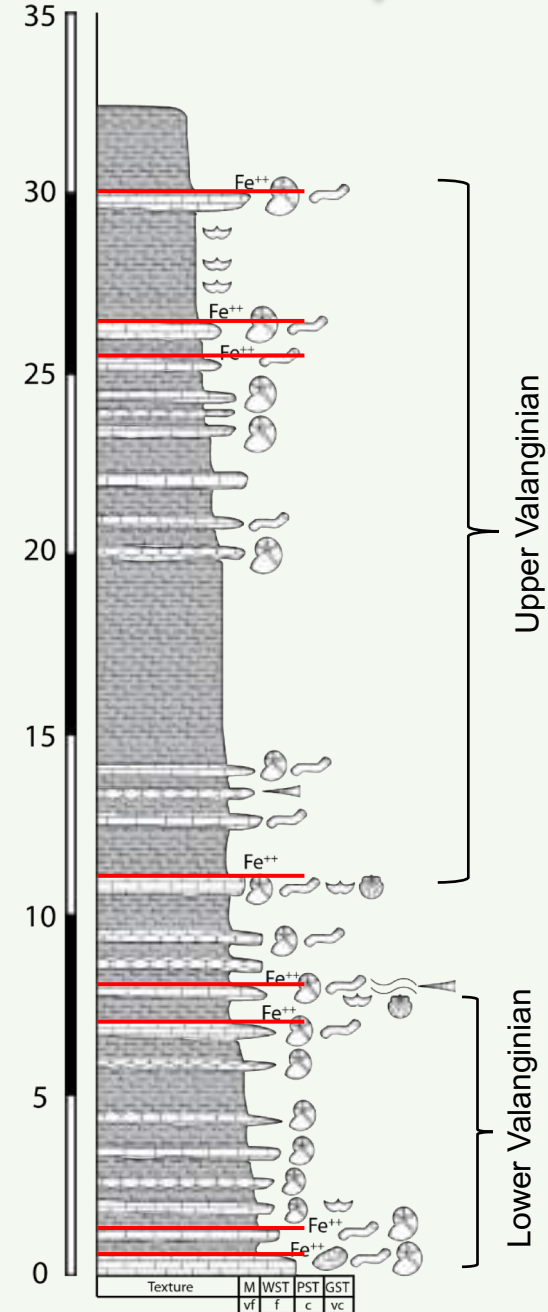
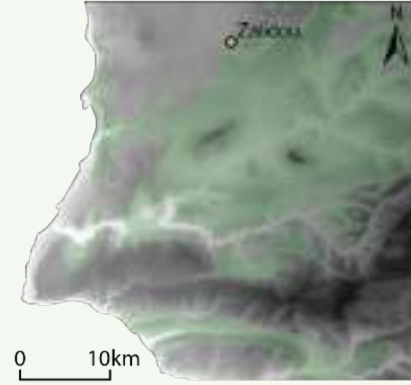


- Thick green to grey marls excellent for nanno-fossil sampling with several key ammonite levels in bioclastic limestone interbeds
- Allowed constraint of Upper Valanginian to Base Hauterivian to a 40cm interval*



5. Zalidou

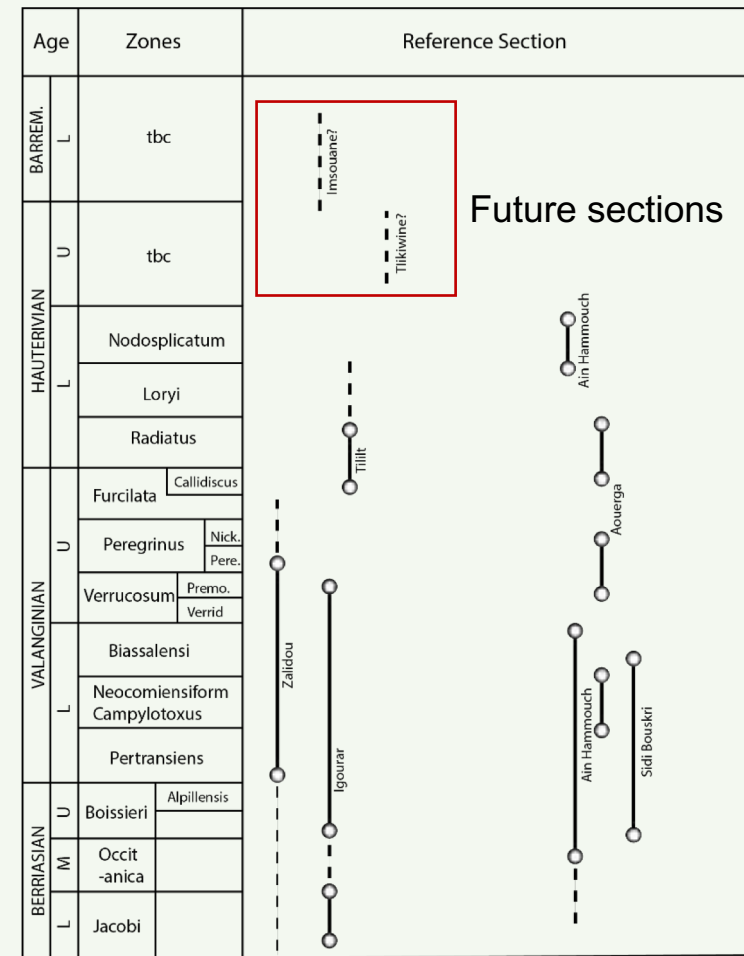
- Well exposed marls and ammonite-rich limestone beds which show similarities to the sections e.g. Igourar in the south



Distinct iron-stained hardground beds may act as markers to help with correlations to southern reference logs

Field Trip Key Outcomes

- Built a strong foundation for the integrated bio- and sequence stratigraphic framework through ammonite, nannofossil and calpionellid sampling
- Unconformities recognized e.g. Middle Berriasian. Key ammonite subzones missing thus far...linked to global-scale unconformity?
- Sampled for ammonites, calcareous nanofossils and calpionellids at a scale
- Likely 4 new ammonite species found in the early Hauterivian for the EAB at new section (Tikiwine; discussed later).





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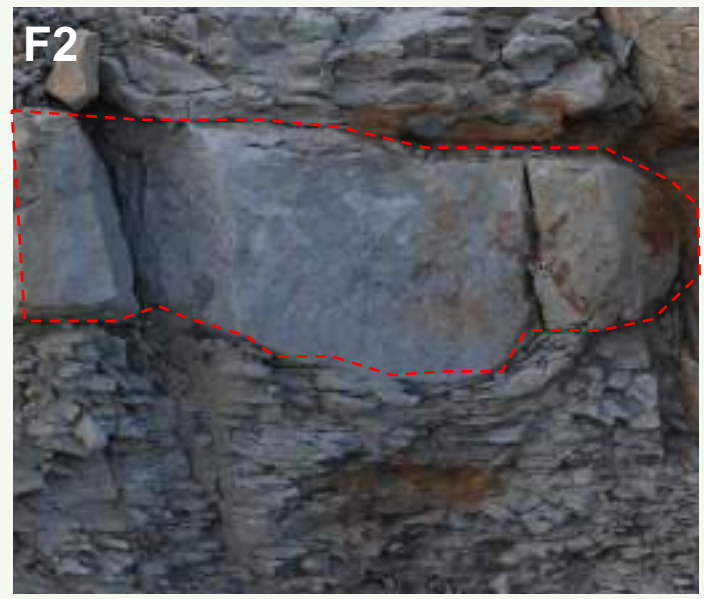
The Offshore Record

What's Next?



| Lithofacies | Observation | Interpreted Depositional Environment |
|---|---|---|
| F1: Calcareous marl | <i>Varicoloured; grey-dark grey, yellowish and greenish. Can contain small (<1cm diameter) bivalves and brachiopods and rare ammonites which may be pyritised.</i> | Middle-Outer Shelf |
| F2: Calpionellid-rich limestone | <i>Light grey, micritic with fractures that break conchoidally suggesting calpionellid microfossils make-up. Wackestone texture with small bivalves, brachiopods and gastropods</i> | Inner-Middle Shelf |
| F3: Bioclastic wackestone/packestone | <i>Grey-dark grey Rich in marine fossils; brachiopods, bivalves, oysters, gastropods, serpulids and belemnites. Commonly topped by hardened layer with iron staining, bioturbation and various shell fragments. Can be orange from iron staining and/or dolomitisation. Beds are generally continuous but can be nodular/lenticular</i> | Inner-Middle Shelf |
| F4: Calcareous sandstone | <i>Fine-medium grained, sub rounded, sharp erosive base with cm-scale horizontal lamination, undulating ripples and cross bedding. Quartz grains observed</i> | Upper-Lower Shoreface |
| F5: Oyster “conglomerate” | <i>Made up of oyster (exogyra)-dense beds with both full and fragmentary pieces, commonly ferruginous surfaces and bound together by limey matrix</i> | Lower Shoreface? |

Facies Overview

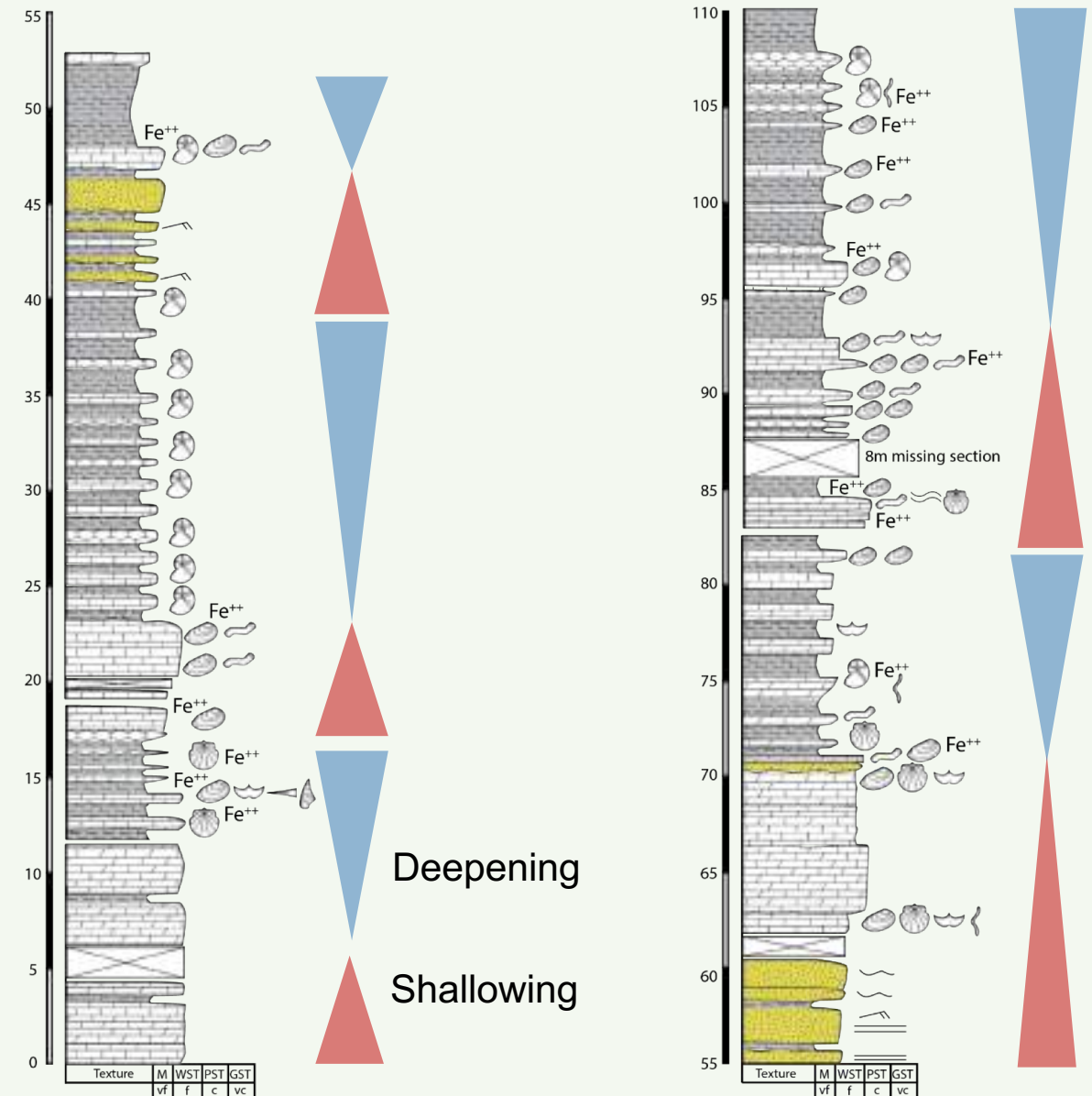


Tbc...

Sea Level Trends

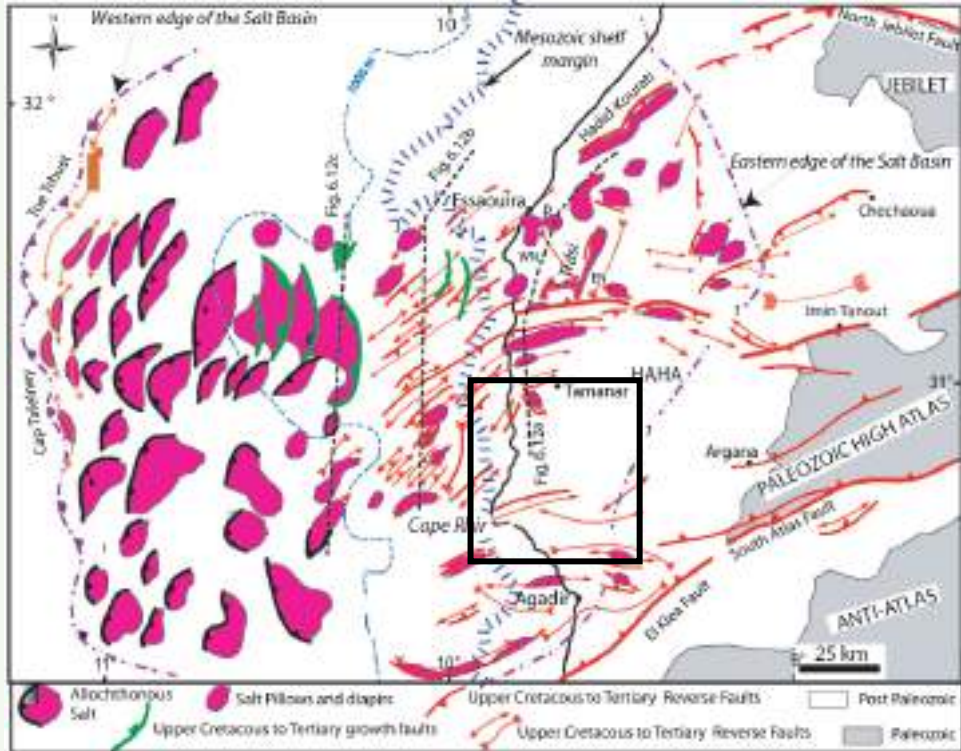
- Observable transgression and regressions of the shoreline within logged sections
- Reflect high frequency changes in local sea level and overall shallowing and deepening trends of the earliest Cretaceous

Ain Hammouch Comp Log

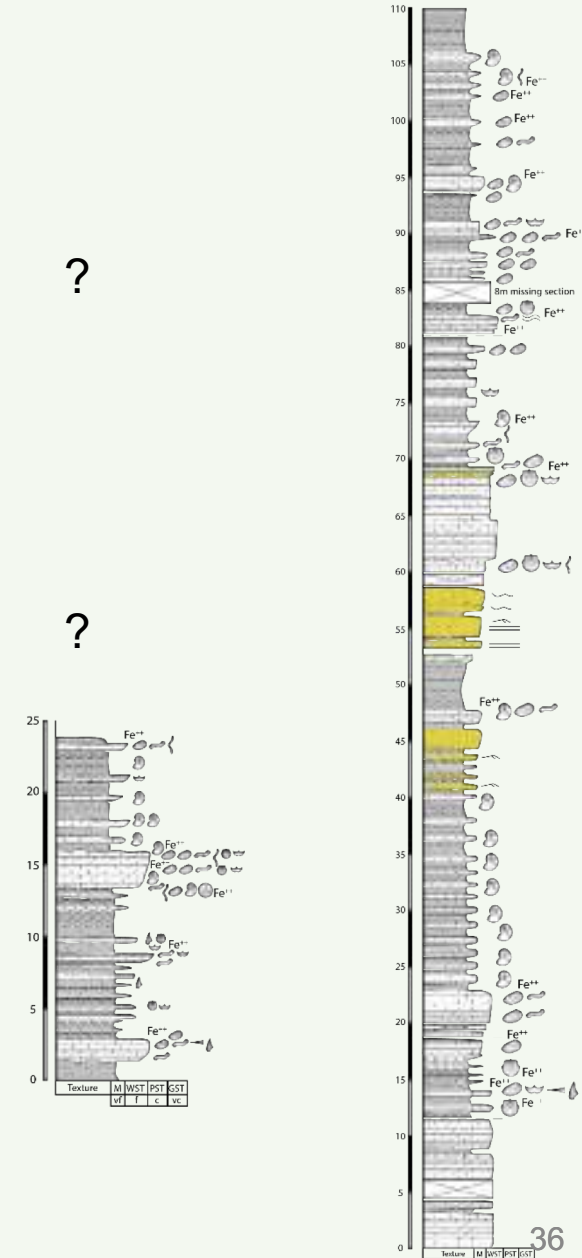
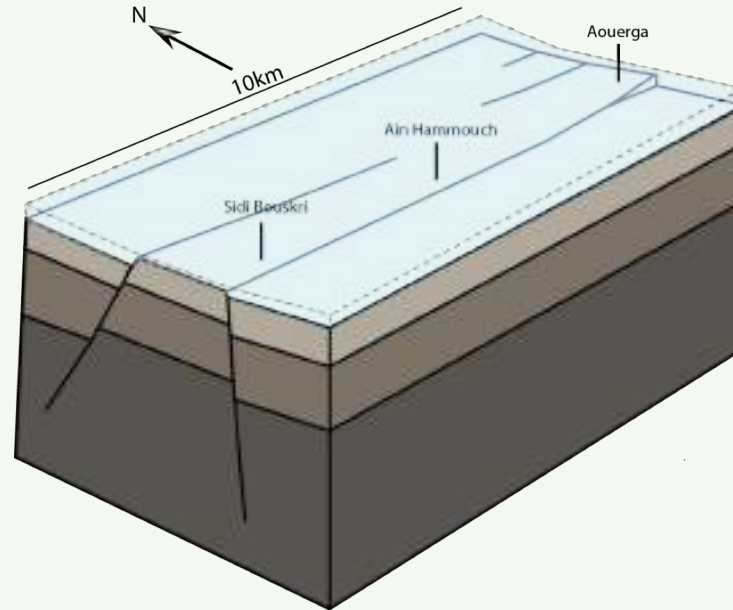


Thickness Variations

- Significant thickness variations and clear condensed sections along short strike distances
- Location on a pre-existing submerged footwall could result in palaeohighs creating topographic disparities and variable accommodation space
- Could salt tectonic movements be linked to such condensed sections and subtle palaeohighs?
- High-resolution biostratigraphy will be key for assessing timing of salt movements in earliest Cretaceous...



(Tari & Jabour, 2013)



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Early Cretaceous Overview

Field Season 1

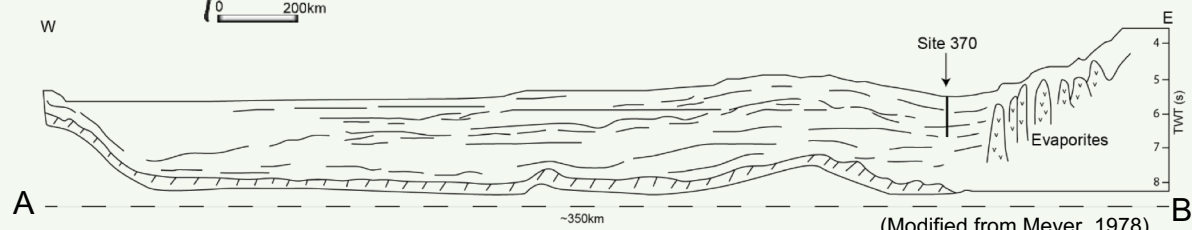
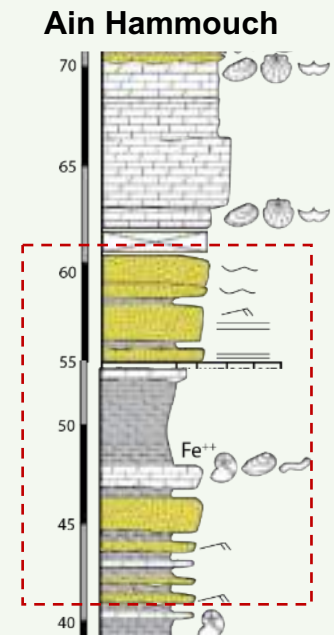
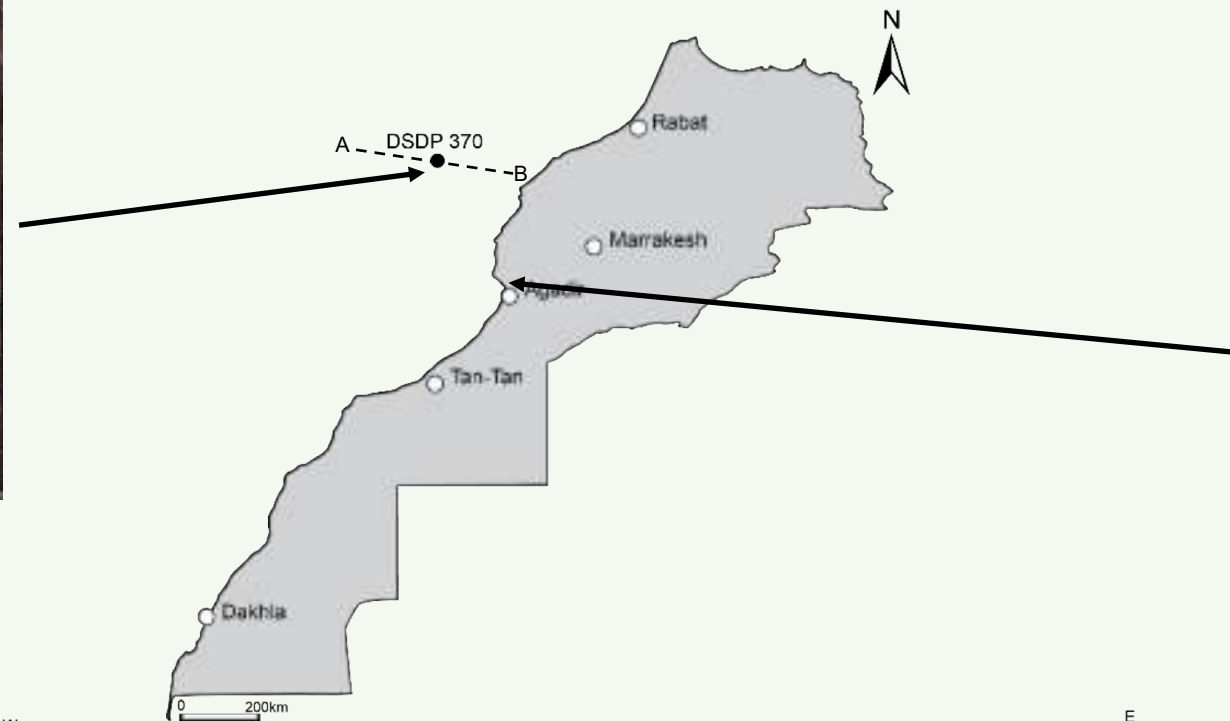
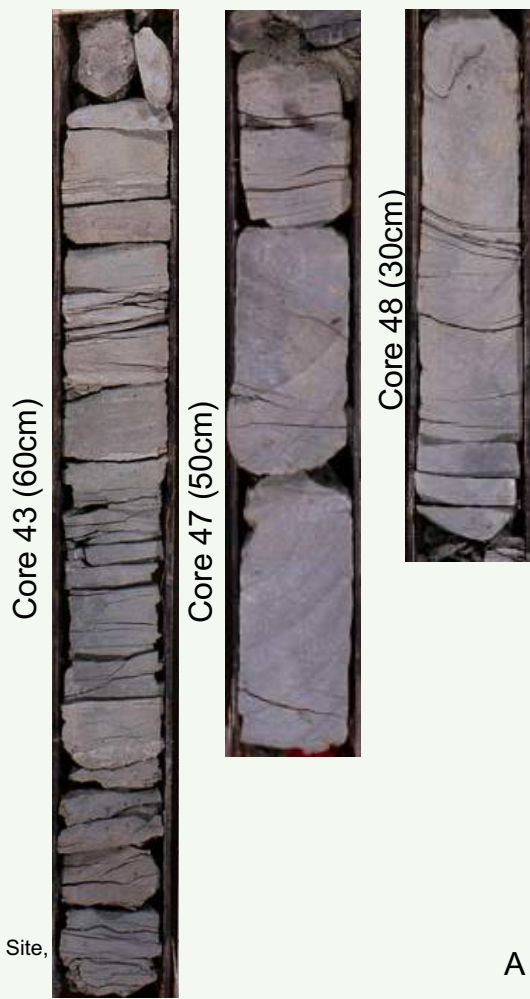
Initial Interpretations

The Offshore Record

What's Next?

Site 370 – The Offshore Record

- Visited Bremen DSDP Core Repository (MARUM) to nanno-sample 430m Upper Valanginian-early Barremian interval and to develop onshore-offshore correlation
- Identified repeated sequences of graded (silt to fine sand) calcareous and terrigenous turbidites dated by microfossils as Upper Valanginian to Hauterivian; may be distal fan equivalent to sands found at onshore sections



(Photos courtesy of DSDP Site, 2019)

(Modified from Meyer, 1978)

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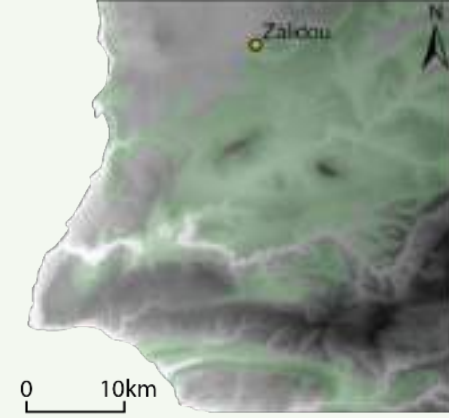
What's Next?

Field Season 2 – Zalidou

Section could be extended into thick marls of Hauterivian and the lower Barremian

Start of Valanginian logged section

Excellent Berriasian (50m+?) exposure rich in ammonites

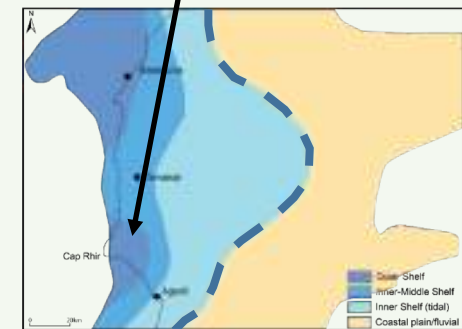
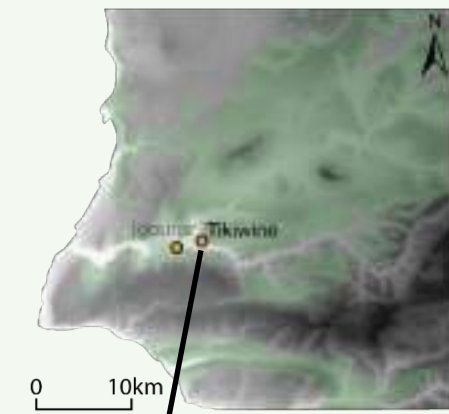


New Section - Tikiwine

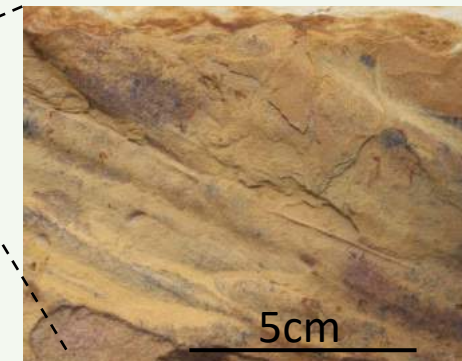
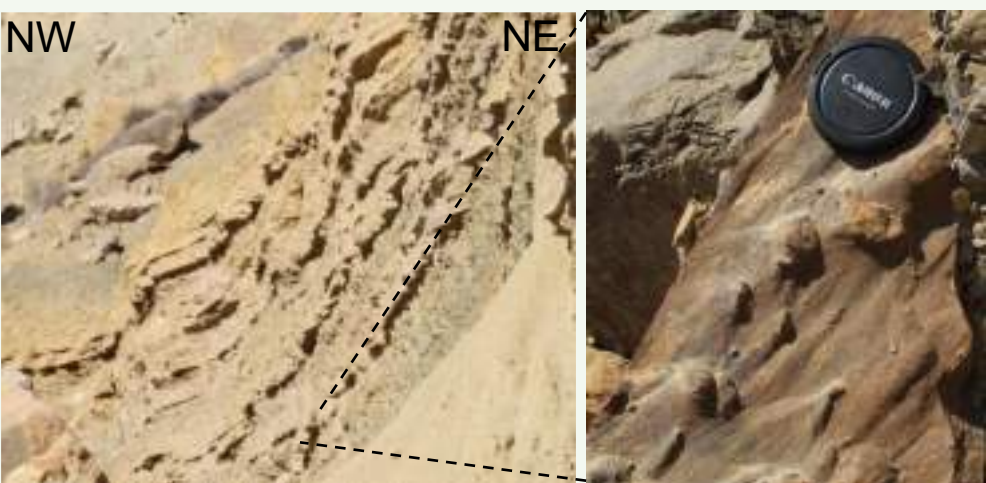
- Cyclical beds of calcareous mud and very fine-fine grained sands with flute marks on bases which may represent more proximal turbidites
- Evidence of an Upper Valanginian-Lower Hauterivian turbidite system more proximal than anticipated? Requires detailed logs and reliable and in-situ palaeocurrents measures...

Continuous Lower Haut with possibility of extending into next hill (Lower Barremian)

Upper Val

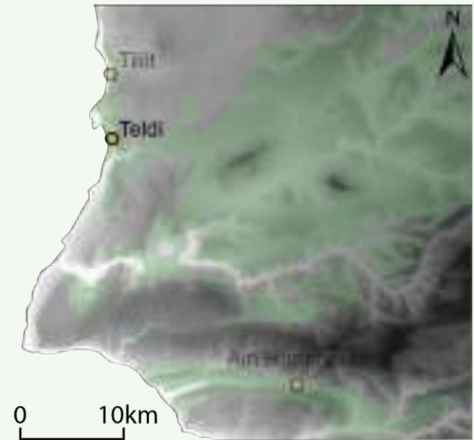


(~U.Val-L Haut GDE)



Field Season 2 – New Section - Teldi

- Late Hauterivian to early Barremian exposure, 23km NW of Ain Hammouch
- Likely suitable ammonite levels and nannofossil-rich marls





- Field Season 2 April – continue biostratigraphic sampling methods for the EAB marine sections (Tikiwine, Teldi and extension of Zalidou into Berriasian)
- On return of samples, develop high-resolution correlation of local reference sections and tie proximal to distal facies changes across the basin
- Continue work on DSDP offshore wells; analyse nanno samples for Hole 370, look at facies changes and correlate with onshore
- Detailed facies analysis including thin section for microfacies
- Field Trip 3 (late 2019) – dedicated outcrop study of the complex Tamanar patch-reef system along the SW margin of Morocco
- AAPG ACE May 2019 San Antonio - Presentation slot





- Preparation and archiving of ammonites collected (early Cretaceous EAB) in Marrakesh (with Prof Mohssine Ettachfini, Universite Cadi Ayadd) followed by Agadir (with Prof. Moussa Masrour, Universite Ibn Zohr)
- Has identified 4 new species of Lower Hauterivian ammonites in new section (Tikiwine)
- Has also been working on global Albian-Aptian biostratigraphic framework (work with Max Casson). Visited University of Tübingen and is currently working on revision of the historical collections of ammonites from Maio.
- Will be joining Orrin Bryers in second field season (~April 2019) to continue ammonite biostratigraphy in Berriasian to early Barremian

Thank you to all our sponsors



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Questions?





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Appendix

Tamanar Reefal facies – near Tamanar town in Northern study area

