Holocene turbidite records off 2 margin segments of Algeria

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FRAMEWORK - AIMS

Marine paleoseismology aims to identify the indirect signature of earthquakes from the analysis of turbiditic successions (*e.g.*, Goldfinger et al., 2003). Its first challenge is to establish a causal link between earthquakes and turbidites, that can be assessed by comparison with historical records and observed events such as submarine cable breaks (Cattaneo et al., 2012).

The second challenge is to extend back in time the record of earthquakes beyond the limit of other methods to better constrain seismic cycles (*e.g.*, Ratzov et al., 2015).

These time series can then be used to correlate to known historical tsunamis or their previous onshore geological signatures (Papadopoulos et al., 2014).

Studies off South Iberia have shown that the marine paleo-seismology approach may apply well to the Africa-Eurasia plate boundary and that deep-sea basins indeed preserve a record of episodic deposition of turbidites (Gràcia et al., 2006; Papadopoulos et al., 2014).

In the frame of the **ASTARTE** Project, we have developed a comparison of turbidite time series both in the Cheliff (Ratzov et al., 2015) and in the Algiers offshore domains (Babonneau et al., 2017; **Figure 1**) over long periods of time (throughout the Last Glacial Maximum). We try to test: (1) if the number of turbidites is consistent and correlates among the most distal cores of the area; (2) what are the recurrence intervals (return periods) of recorded paleo-earthquakes and their link to tsunamis in the Holocene; and (3) if the paleo-earthquake signal related to turbidites can be extracted beyond the Holocene.

SEISMICITY BACKGROUND AND STUDY AREA

The Algerian margin is a Cenozoic passive margin located at the diffuse plate boundary between Eurasia and Africa, presently reactivated in compression. It is among the most seismically active areas of the Western Mediterranean and it suffered from numerous devastating earthquakes, for example the El Asnam earthquake in 1980 (Ms = 7.3) and the Boumerdès earthquake in 2003 (Ms = 6.9).

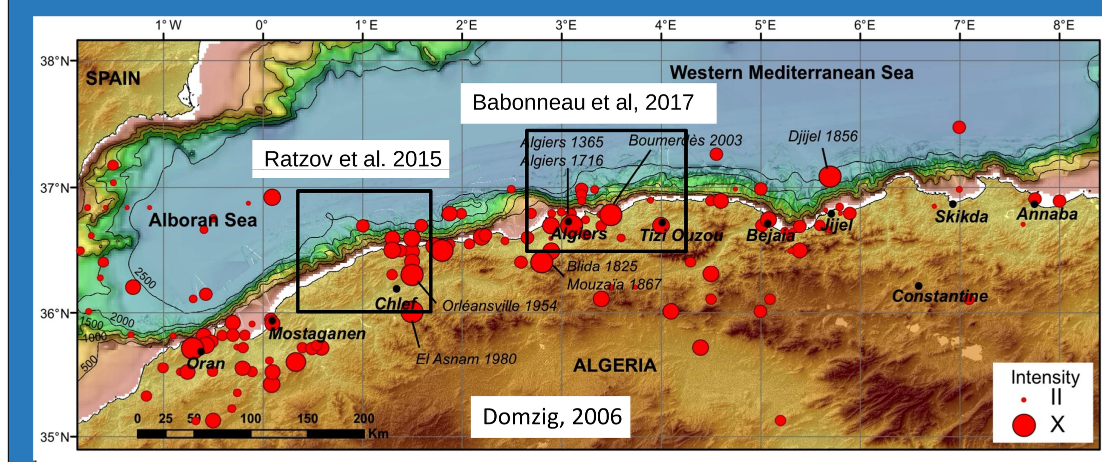


Figure 1. Location map of North Algeria with topography and bathymetry (isobaths every 500 m). Historical earthquakes are indicated by red circles. The 2 black frames locate the Cheliff (west) and the Algiers (east) segments.

Offshore seismicity is known since 3 centuries at least, but poorly estimated (Hamdache et al., 2010). The main facts are the following:

ÅLarge earthquakes are generally close to shoreline (i.e. <100 km from coastline)

Å1700-1950 AD: 5 events display intensities I > IX (6.5<M<7.5)

ÅSince 1950, 14 events display M > 5

ƒ Among events M > 6.4, two have triggered a tsunami and/or submarine cable breaks: 1954 and 2003

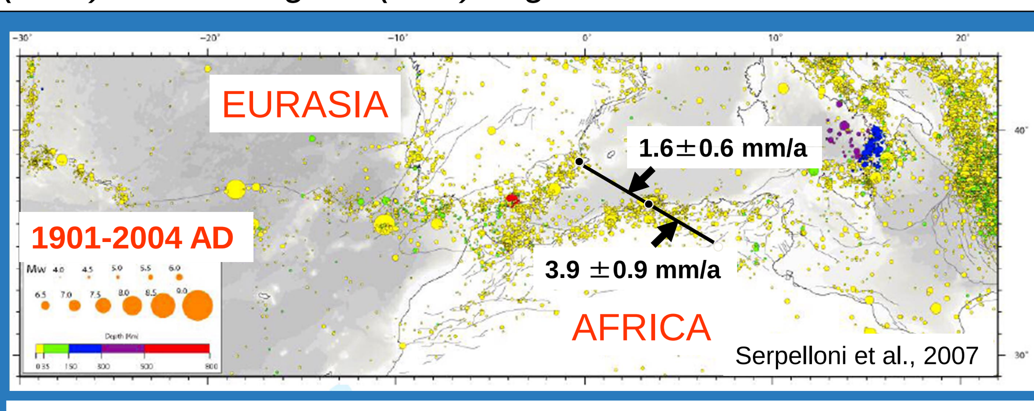


Figure 2 . Seismicity and strain rates across Iberia-Africa from GPS results: ~2mm/yr shortening is assumed offshore.

Northern Algeria is affected by a remarkable seismic activity resulting from the slow convergence motion between African and European plates (Serpelloni et al., 2007; **Figure 2**). Earthquakes activate fault segments partly located offshore and have important effects on the stability of the sediments on the Algerian continental slope (Déverchère et al., 2005; Cattaneo et al., 2010, 2012).

DATA & METHODS

A consistent dataset of sediment cores (west: 8 cores, 3 fully correlated; east: ~30, 5 shown here, see figures 3 & 4) was collected between 2003 and 2007 during the cruises MARADJA 2003 & MARADJA2 2005 (R/V Le Suroît) and PRISME 2007 (R/V LÕAtalante). A sedimentological and stratigraphic approach was performed on the most distal sediment cores of the area and on most complete proximal cores.

The age model obtained is based on radiocarbon dating and measurements of oxygen stable isotopes on planktonic foraminifera collected from the pelagic intervals (hemipelagites) interfingered with the turbidites. Correlation is made bed by bed and by the use of a marker: the megaturbidite of Rothwell et al. (1998) offshore Algiers. Age models are obtained by Oxcal software.

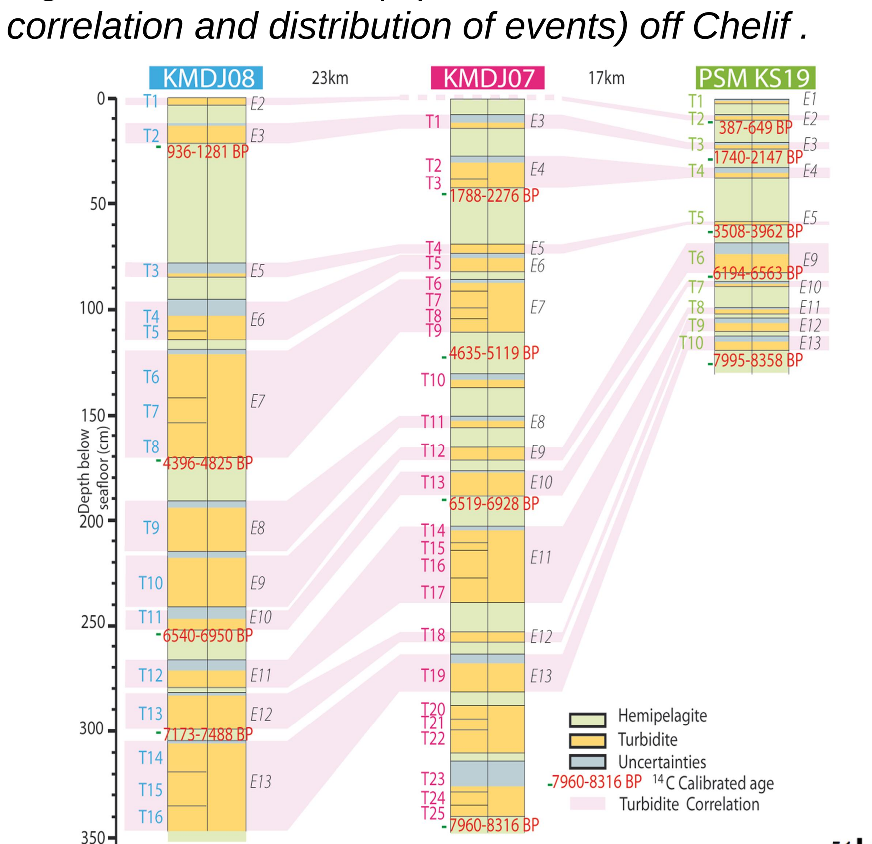
COMPARISON OF PALEOSEISMIC RECORDS OFF ALGERIA (WEST and CENTER)

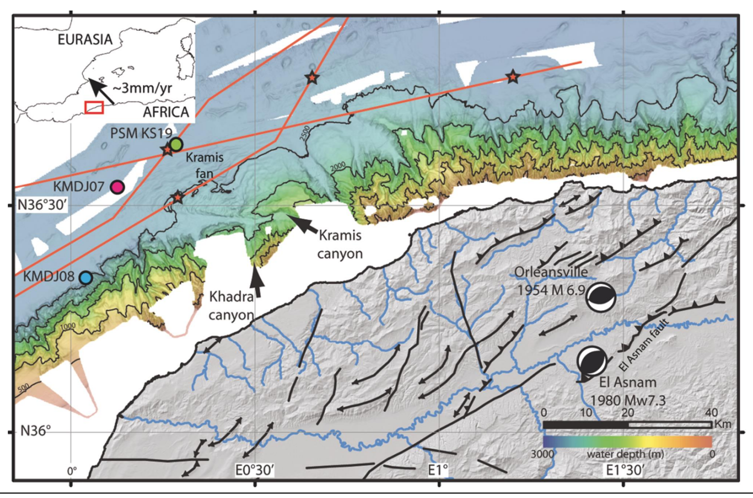
Paleoseismology of Kramis (Chelif) segment (Ratzov et al., 2015):

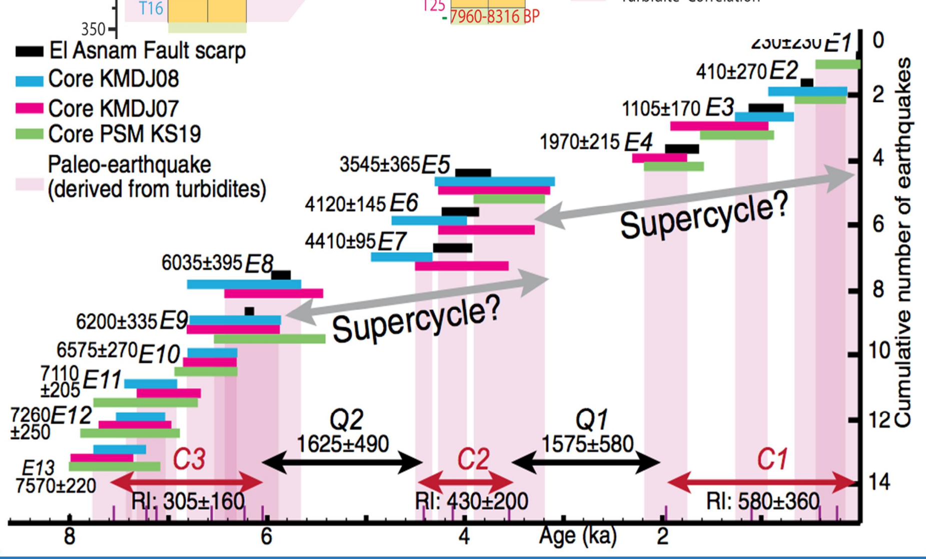
WEST

- First ~8 ka-long paleoseismicity catalog in Northern Africa marine region
- Correlation of offshore turbidites and onshore fault trench (Meghraoui et al., 1988)
- Strongly variable earthquake cycles (bimodal distribution)
- Earthquake supercycles (clusters and quiscence periods)
- Supercycles = common pattern for strain release in slow deformation settings?

Figure 3. Location map (with submarine cables, core correlation and distribution of events) off Chelif .







In the last 8 ka :
- 13 synchroneous turbidites = 13 large paleo-earthquakes
- 3 EQ clusters with recurrence intervals (RI) of 300-600 years.
- 2 quiescence periods (~1.6 ka each) without earthquakes on any major fault in the region

We evidence **~3-4 ka-long supercycles** (broad phases of strain loading and multiple shorter phases of strain release) A **bimodal distribution** is shown: short C1, C2, C3) and long (Q1, Q2) recurrence intervals.
- E1 is likely related to the Orléansville (M 6.7) 1954 earthquake.
- E2 could relate to the 1790 Oran (M 7.5) earthquake which produced a tsunami along the Spanish coast (Bouhadad et al., 2001).

Paleoseismology of the Algiers segment (Babonneau et al., 2017):

EAST

- Link between regional turbidites / earthquakes proved by 2003 event
- The 4 last events can be associated with 4 historical earthquakes
- 36 significant events in the last 9 ka (13 major events)
- Frequency of turbidite-(tsunami?) events: 3-4 events/ka, relatively constant (considering the 36 events)

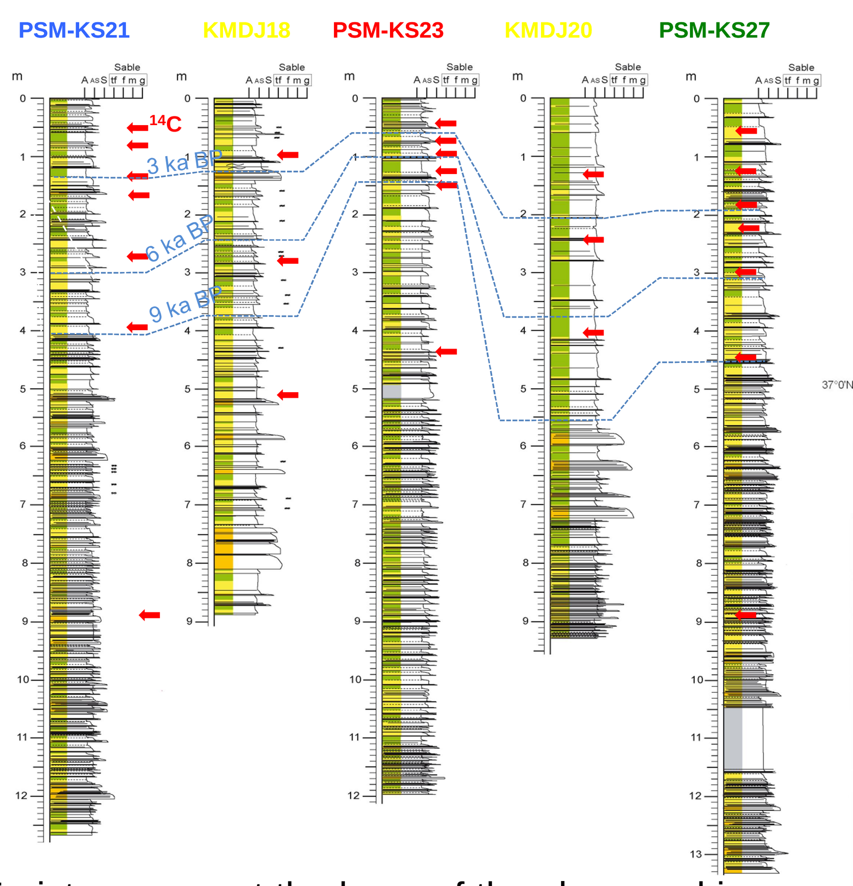
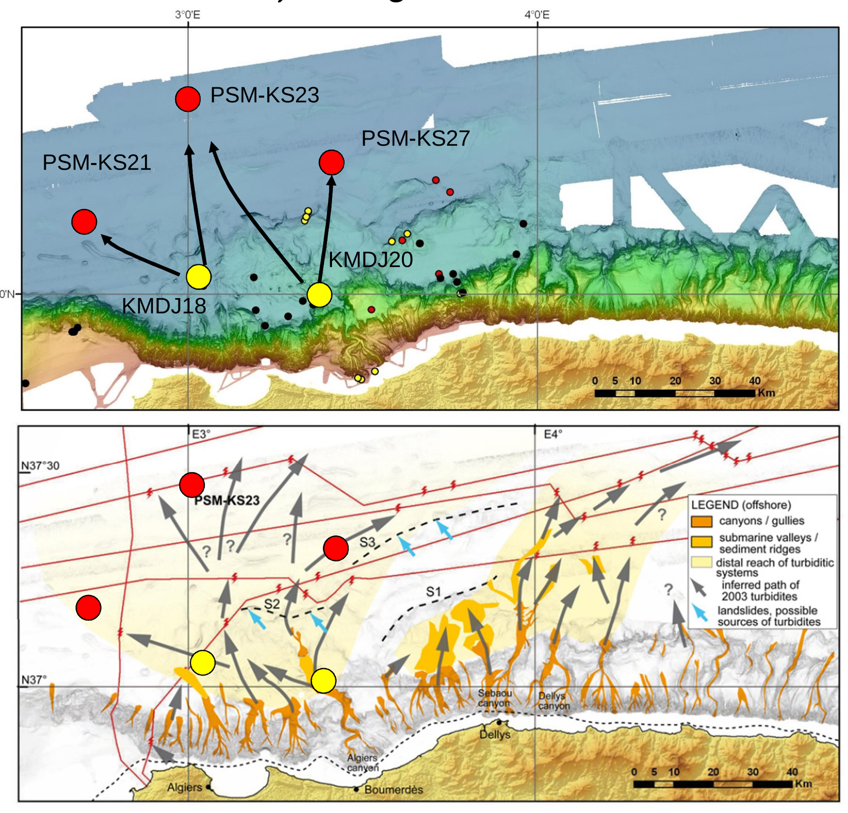


Figure 4. Location map (with submarine cables and core correlation) off Algiers.



5 piston cores at the base of the slope and in the basin (> 2300 m w.d.)

PSM-KS23: distal record of the largest gravity events

Turbidity currents recorded in PSM-KS23 show thicker record in proximal sites.

- Sedimentation rates extend from 14 to 66 cm / kyr.

In the last 9 ka :
- 4 minor events (retrieved in only one core)
- 19 proximal events (including 3 amalgamed events)
- 13 large events correlated in the 5 cores

⇒ **36 significant events with a regional signature, potentially generated by earthquakes or tsunamis**

⇒ Age models based on hemipelagic sedimentation are limited to the last 9 ka.
⇒ The main historical earthquakes in the Algiers area (2003, M6.9; 1716, I > IX, and 1365, I > X) correlate with three out of the four last turbidites. It has been evidenced that at least the 2003 and 1365 events have triggered significant tsunami waves, and also the 1773 event (Amir et al., 2012).

CONCLUSIONS

Based on the analysis of the turbidite layers in cores collected off Algeria, we find that:

1) The 2 segments of the Algerian margin off Chelif (West) and off Algiers (East), distant of about 200 km, show **different time series and recurrence intervals**; however, **mean recurrences** of wide-extent turbidite events **are similar (about 600-700 years) over the last 8-9 ka**.
2) The **cycles are irregular** in both cases, with short and long periods between events.
3) The differences of cycles between both segments likely result from **a variable distance of the sources of 6.5<M<7.5 events from zones of sedimentary instabilities at the slope break**.
4) If this variability is taken into account, then the **1st and 2nd order cyclicities** of both segments (for M > 6.5 events at similar distances of the coast) **could be very similar** and should be taken into account in hazard assessment.
5) Not all large earthquakes near the coast induced a tsunami, for which the area has a moderate potential (Papadopoulos et al., 2014); however, **moderate to large tsunamis are expected**, threatening the northern coasts of the Western Mediterranean Sea.
6) **Bed-to-bed correlation of turbidites is possible beyond the Holocene.**
7) Number of turbidites beyond the Holocene and back to the LGM increases significantly.
8) The attribution of all turbidites to earthquakes could be speculative, especially beyond the Holocene, since availability of large volumes of unstable sediments is likely variable and competes with other processes (e.g., river floods). However, the **main historical events over the last 700 years have clearly triggered large turbidity flows**, and a good part are linked to reported tsunami of moderate importance.

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Acknowledgments

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