ACCELERATION IN SEA-CLIFF EROSION?

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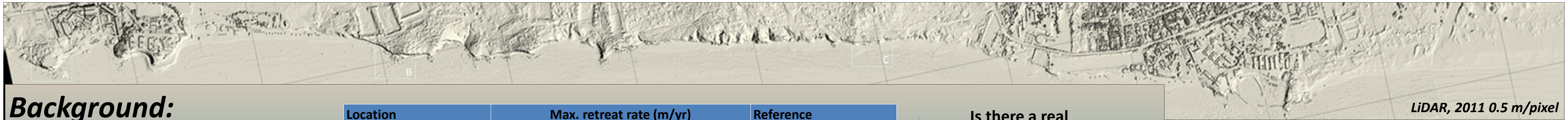
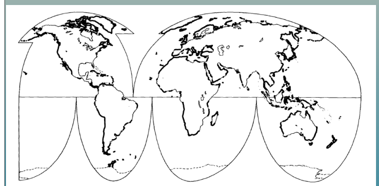
The problem: Can 'conventional' 1-D retreat rate measurements (m/yr) be used to detect acceleration in sea-cliff retreat



Background:

60% of the worlds coasts consist of sea cliffs



Global distribution of coasts that consist mainly of sea cliffs (black). From Emery & Kuhn, 1982.

Location *Obs. Window (yr) →*	Max. retreat rate (m/yr) *1*		*10*		*100*		*1000*		Reference
Point Loma, CA	9.9			0.17					Young et al., 2011
Santa Barbara, CA		3.7		0.8					Hapke & Plant, 2010; Kapke & Reid, 2007
Pakri cliff, Estonia	14					0.2			Orviku et al., 2013
Sharon escarpment, Israel	10			0.5		0.05		0.05	Present Study
San Diego, CA	1.2		1.0						Hapke & Plant, 2010; Kapke & Reid, 2007
Whidbey Island, WA								0.08	Rogers et al., 2012

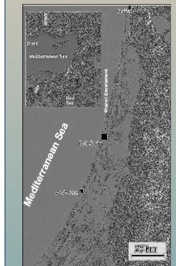
Table 1: Selected examples of 'soft rock' sea-cliff retreat rates measured over different time-scales

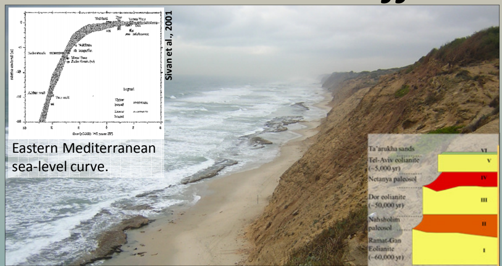
Historical-geologic time-scale sea-cliff retreat rates are often significantly lower than recent retreat rates determined over yearly time-scales

Is there a real acceleration in sea-cliff retreat rates or is this a sampling artifact?

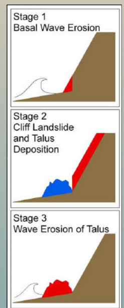
Recent cliff collapse along Israel's Mediterranean coast.

Israel's Mediterranean sea-cliff

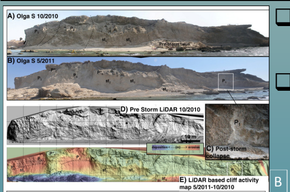




View northwards along the 30-km long Sharon sea-cliff (18 m average height).
Bottom right - Stratigraphic cross-section.

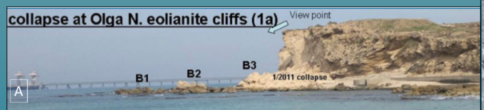


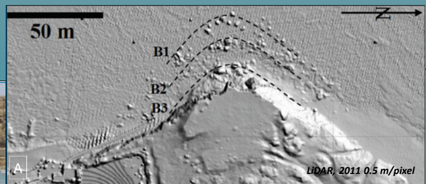
Retreat Process



Ground-based LiDAR monitoring of cliff erosion following a strong winter storm (from Katz & Mushkin 2013) .

- **Retreat is driven by localized collapses events triggered by basal wave erosion** (cartoon from Young et al., 2009).
- **Up to ~5 % of the cliff-length experience erosion per year. ~50 % of the cliff length experience erosion between 1945-2004.**





- **Capes typically display collapsed boulder fronts that separated by 15±5 m from the cliff and from each other indicating recurring characteristic collapse episodes.**

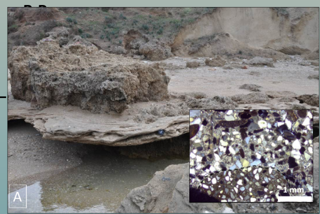
Retreat Rates

Annual **– up to ~10 m/yr, LiDAR** (Katz & Mushkin, 2013)

Decadal **– up to ~0.5 m/yr, Aerial Photos** (Zvieli & Klein, 2004, Katz et al., 2007)

Centennial **–up to ~0.05 m/yr**

Luminescence, <0.05 m/yr since ~600 B.P.



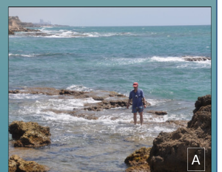
Preliminary OSL dates for B1 and B2 breach rock yielded 570 ± 60 yr and 330 ± 60 yr, respectively.

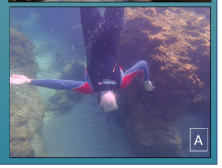
Archeology, <0.04 m/yr since 1247 A.D.

Up to ~30 m of the Apollonia Crusader castle have been lost since its abandonments in 1247 A.D.

Millennial **– up to ~0.05 m/yr, Wave-cut platform.**

Cliff-parallel, 150-250 m wide submerged erosional platforms provide a 1st order approximation for the initial seaward extent of the eolianite ridges into which the escarpment is carved (see header image). I.e., retreat rate of 0.04-0.06 m/yr since mid-Holocene stabilization of sea-level in this region

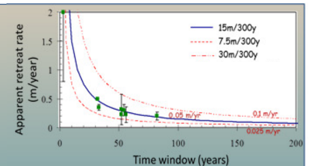




Top: The wave-cut platform at the Olga-N site overlain by collapsed boulders from the cliff .
Bottom: Underwater surveys along of the wave-cut platform revealed the same eolianite lithologies as exposed along the cliff.

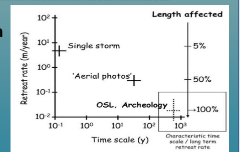
Discussion

- **Plotted as a function of their observation window, retreat rates decrease predictably as a reciprocal function of time. → The apparent increase in cliff retreat rates reflects a sampling bias.**



Maximum measured retreat rates (green squares) and apparent rates predicted for episodic retreat (blue/red lines) plotted as a function of observation interval.

- **Integration across space and through time of episodic (several hundred year recurrence intervals) localized 15±5 m 'retreat events' is driving cliff-parallel retreat of the Sharon sea-cliff.**



- **Increased wave erosion (e.g., by stormicity and/or sea-level rise) is not expected to change the length-scale of retreat events , which is controlled by the mechanical properties of the cliff, but rather the recurrence interval between collapse events, which is controlled by the efficiency of talus removal and subsequent basal erosion.**

Therefore:

Detection of accelerated erosion for this sea-cliff with 'conventional' 1D yearly-decadal time-scale retreat measurements is unlikely.

- **We propose that 3D measurements of the annual erosion volume along the entire 30 km sea-cliff (can be achieved with repeat airborne LiDAR surveys) will provide a more efficient indicator for acceleration in sea-cliff retreat. The 'background' volumetric erosion rate for this sea-cliff can be estimated as the volume of material removed from the wave-cut platform since the mid-Holocene stabilization of sea-level in this region ~4 kyr ago.**

Conclusions

- **The apparent acceleration in sea-cliff retreat rates in the eastern Mediterranean since the mid 20th century reflects a sampling artifact of an episodic erosion process.**
- **Conventional 1D cliff retreat measurements over yearly-decadal time-scales are inadequate for detecting acceleration in the rates of episodic (centennial time-scale recurrence intervals) sea-cliff retreat.**