# Timing, Magnitude, Rate, and Drivers of Eustasy: A Review of the Cretaceous Period

Andrew Davies, Mike Simmons, David Ray, Benjamin Gréselle, Frans van Buchem, and Chris Robson

# Agenda

- The importance of recognising eustasy in the rock record
- Estimating Magnitudes
- Likely drivers

- More information on the ideas presented herein can be found in:
  - Ray, D.C., F.S.P. van Buchem, G. Baines, A. Davies, B. Gréselle, M.D. Simmons and C. Robson 2019. The magnitude and cause of short-term eustatic Cretaceous sea-level change: A synthesis. Earth-Science Reviews, v. 197, https://doi.org/10.1016/j.earscirev.2019.102901
  - Davies, A., B. Gréselle, S. Hunter, G. Baines, C. Robson, A. Haywood, D.C. Ray, M.D. Simmons, F.S.P. van Buchem 2020 .Assessing the Impact of Aquifer-Eustasy on Short-Term Cretaceous Sea Level. Cretaceous Research, 112, https://doi.org/10.1016/j.cretres.2020.104445
  - Simmons, M.D., K.G. Miller, D.C. Ray, A. Davies, F.S.P,. van Buchem, B. Gréselle. In press. Phanerozoic eustasy. In: Gradstein, F.M., Ogg, J., Schultz, M., Ogg, G. (Eds) A Geological Timescale 2020, Elsevier.

Stratigraphic architectural response to sea-level fluctuations in Barremian strata at La Montagnette in the Vercors region, France. The prominent cliff is dominated by highstand progradation.

# The importance of recognising eustasy in the rock record

- Eustasy contributes to the stratigraphic organisation of depositional sequences and is thus an important consideration in predicting depositional architecture and sedimentary facies

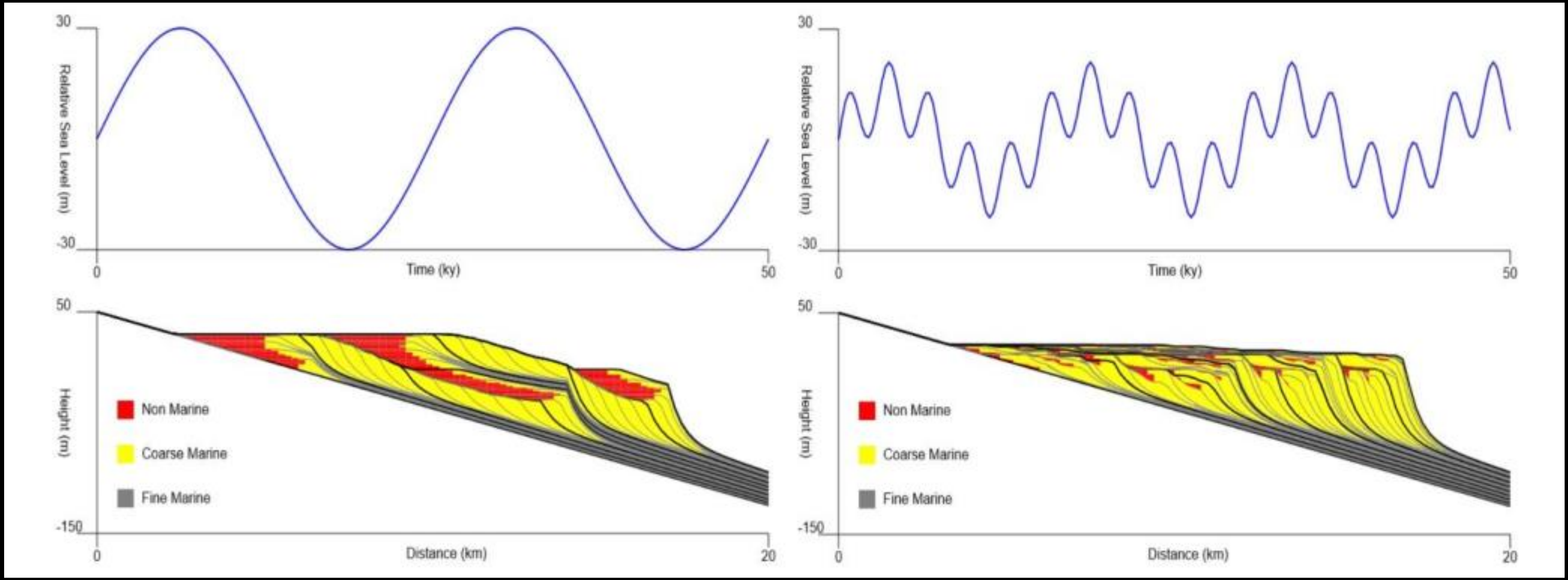
- Eustasy helps understand the often-incomplete nature of the stratigraphic record

- Short-term ($10^5$–$10^6$ yrs) eustasy is a particularly dominant feature of the stratigraphic record, yet its driving mechanisms remain cryptic

- An ability to isolate the magnitude, frequency and pace of eustasy is critical in determining its driving mechanism and thereby informing models of paleoclimate and Earth systems science

Depositional cyclicity relating to short-term sea-level change in the mid-Cretaceous succession of the Oman Mountains

# The importance of recognising eustasy in the rock record

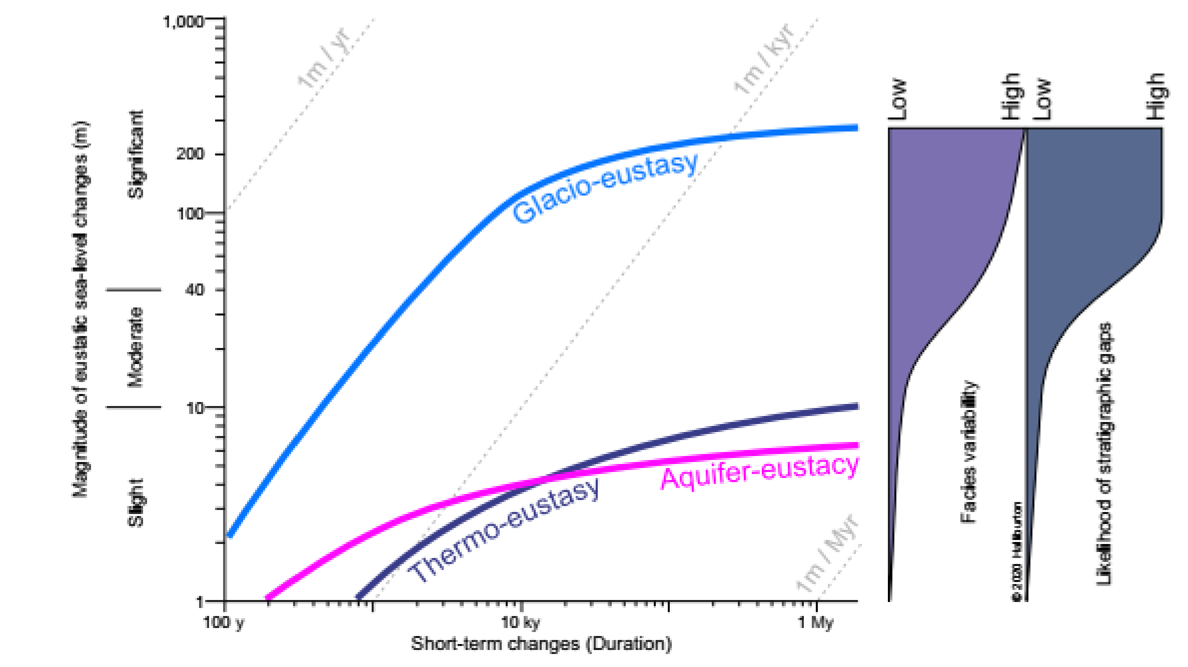



- Outputs from a simple 2D depositional model of clastic deposition (http://nm2.rhul.ac.uk/wpcontent/uploads/2015/03/DeltaModel3.html), where eustasy is the dominant factor controlling deposition (i.e., subsidence and sediment supply are constant).

- This is obviously an oversimplification from reality, but is useful to demonstrate the influence magnitude and rate of eustasy can have on depositional completeness and facies distribution.

# Estimating Magnitudes

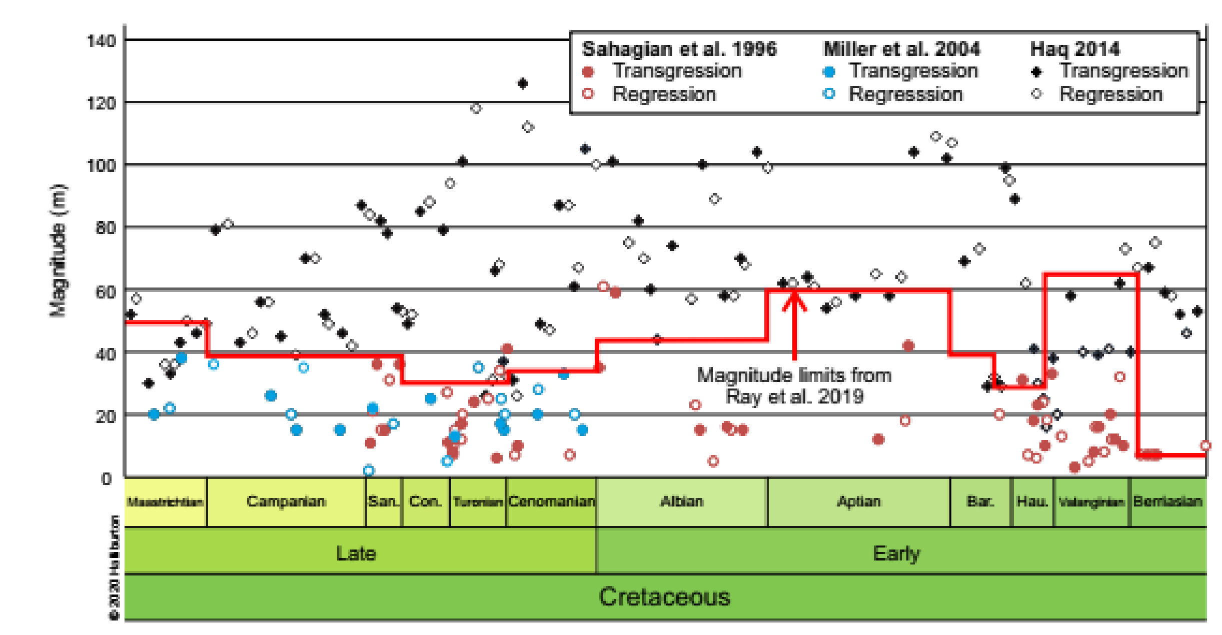
- As short-term eustasy is principally the result of climatic processes that have characteristic upper magnitude limits, the magnitude of sea-level change can be used to identify the dominant process (i.e. glacio-eustasy, thermo-eustasy, or aquifer-eustasy)
- Most likely aquifer-eustasy estimates are decimetre scale. Modern data indicate that climate is a primary control on water table depth. Using this constraint, the hydrological response in Cretaceous climate simulations to large changes in atmospheric $CO_2$ are insufficient to generate reported eustatic magnitudes (Davies et al., 2020).
- Even using optimistic values for the impact of lakes and assuming the water table depth was reduced from the modern average to 0 m globally, the total aquifer-eustasy response remains smaller than 5 m.
- Glacio-eustasy must be implied in magnitudes of short-term sea-level change that are >20m




A schematic representation of the duration, magnitude, and rate of known drivers of short-term eustasy, alongside the impact upon the stratigraphic record. The curves for thermo-, aquifer-, and glacio-eustasy reflect the upper limits of the climatic drivers of eustasy (modified from Figure 7 of Ray et al., 2019).

# Estimating Magnitudes

- Estimates of the magnitudes of short-term magnitudes of Cretaceous eustasy vary markedly and large magnitudes may over-estimate the non-eustatic component of observed water-depth changes
- Commonly used methods for estimating the magnitude of sea-level change include: backstripping; $\delta^{18}O$ analysis; sedimentological and palaeontological observations (e.g. erosional and depositional relief); facies juxtaposition; fossil assemblages; and seismic and stratigraphic geometries.
- Rygel et al. (2008) pioneered a comparative synthesis methodology for the study of Late Palaeozoic eustasy, and more recently Ray et al. (2019) followed a similar approach to determine Cretaceous eustatic magnitude limits, supported by a data sensitivity analysis
- Such an approach avoids the biases of any single method

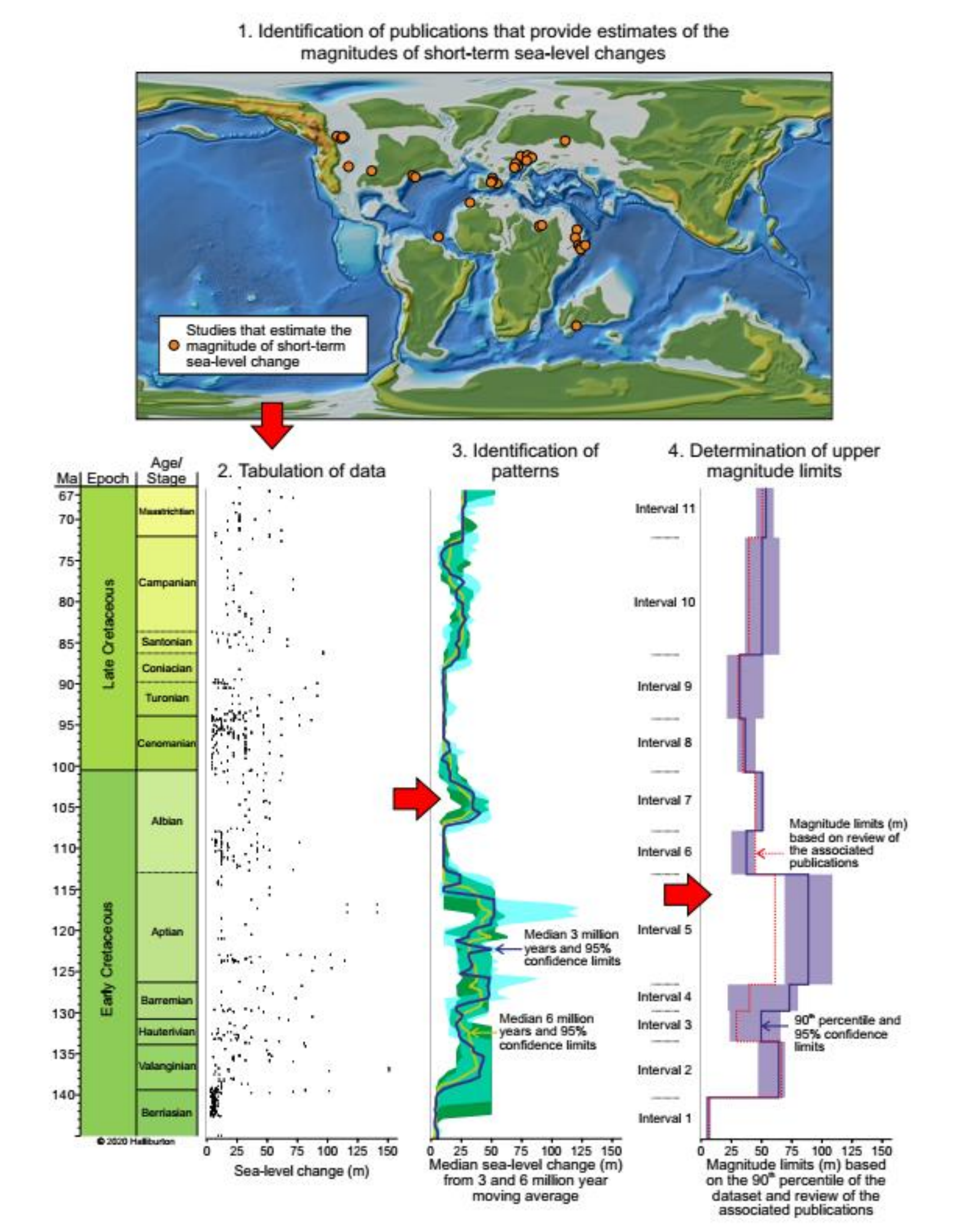



A comparison of the eustatic sea-level changes calculated by Sahagian et al. (1996), Miller et al. (2004), Haq (2014), and Ray et al. (2019), illustrating the marked difference in magnitude estimates. Estimates are shown of individual sea-level rises and falls derived from Sahagian et al. (1996), Miller et al. (2004), and Haq (2014), alongside the magnitude limits from Ray et al. (2019). Note, maximum values are shown where upper and lower limits were given, otherwise best estimate values were taken. The data points identify the age and magnitude of sea-level rises and falls.

# Estimating Magnitudes

- A workflow for determining the magnitude of short-term Cretaceous sea-level change (modified from figures in Ray et al., 2019):
  - 1. Identification of publications (n=37) that provide estimates of sea-level change (m);
  - 2. Tabulation of point data (n= 791) according to the age and magnitude of sea-level change;
  - 3. Identification of patterns based on a statistical review of the short-term magnitude of sealevel change (moving averages resulting from a data sensitivity analysis given here, see Ray et al., 2019);
  - 4. Determination of maximum magnitude limits based on the 90th percentile of the entire dataset and a review of the associated literature

- The identification of intervals characterized by short-term sea-level changes of particular magnitudes strongly suggests the dominance of a global eustatic signal, rather than the presumably random signal that might be expected from relative sea-level changes derived from local variations in subsidence and sedimentation rates

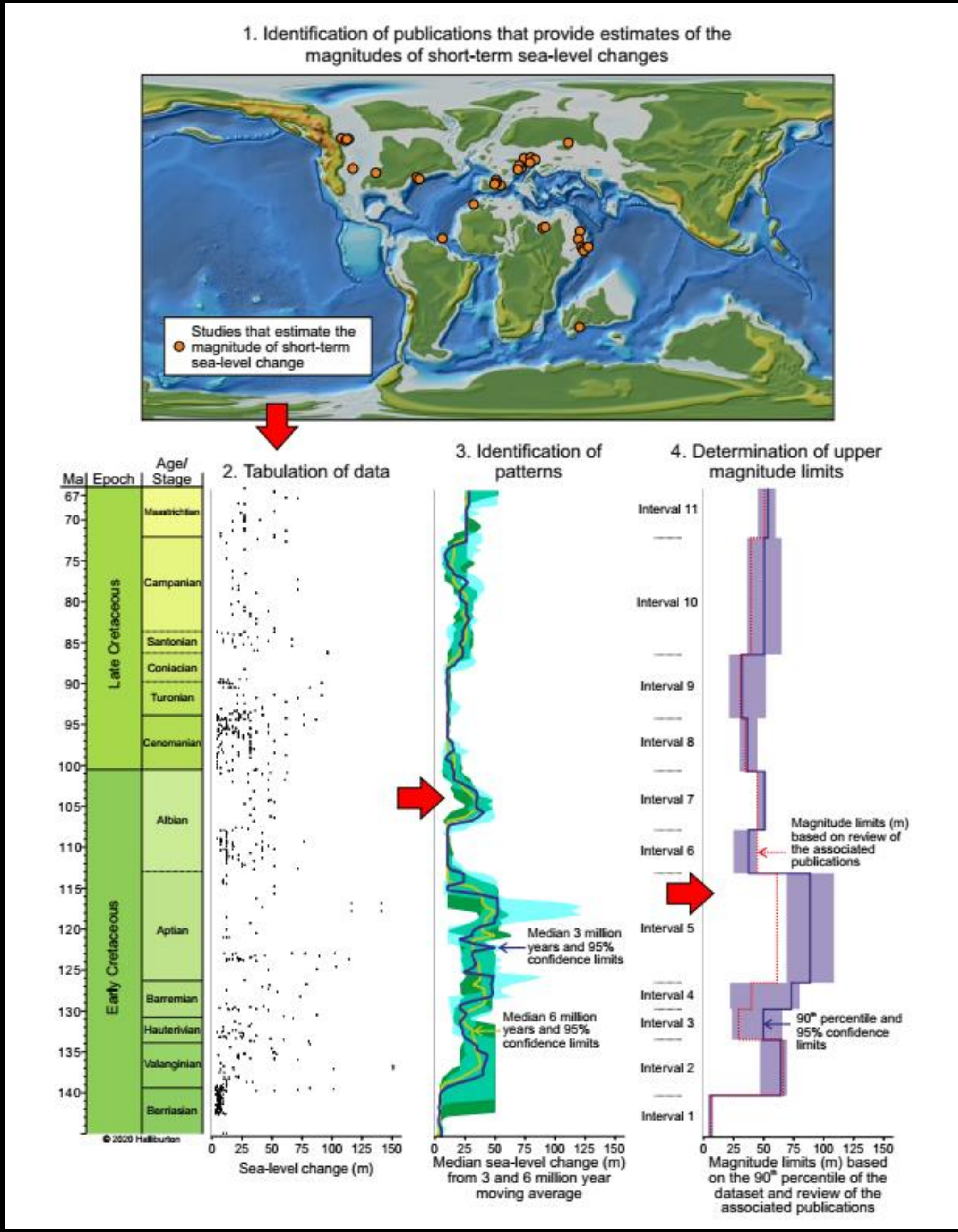


# Estimating Magnitudes

- The initial review of the entire Cretaceous dataset, weighing each data point equally, gave a median value for short-term eustatic change of 12 m, hence the majority of sea-level estimates are of relatively low magnitude with few examples of large magnitude

- Examining median estimates at a stage level, following standard statistical resampling procedures, demonstrated that elevated magnitude values occurred during the Valanginian, Barremian to Aptian, and Santonian to Maastrichtian, with low magnitude values in the Berriasian, Hauterivian, and Albian to Coniacian

- Maximum magnitude limits were derived from an assessment of the contributing publications and statistical analysis, and are in keeping with most estimates derived from backstripping

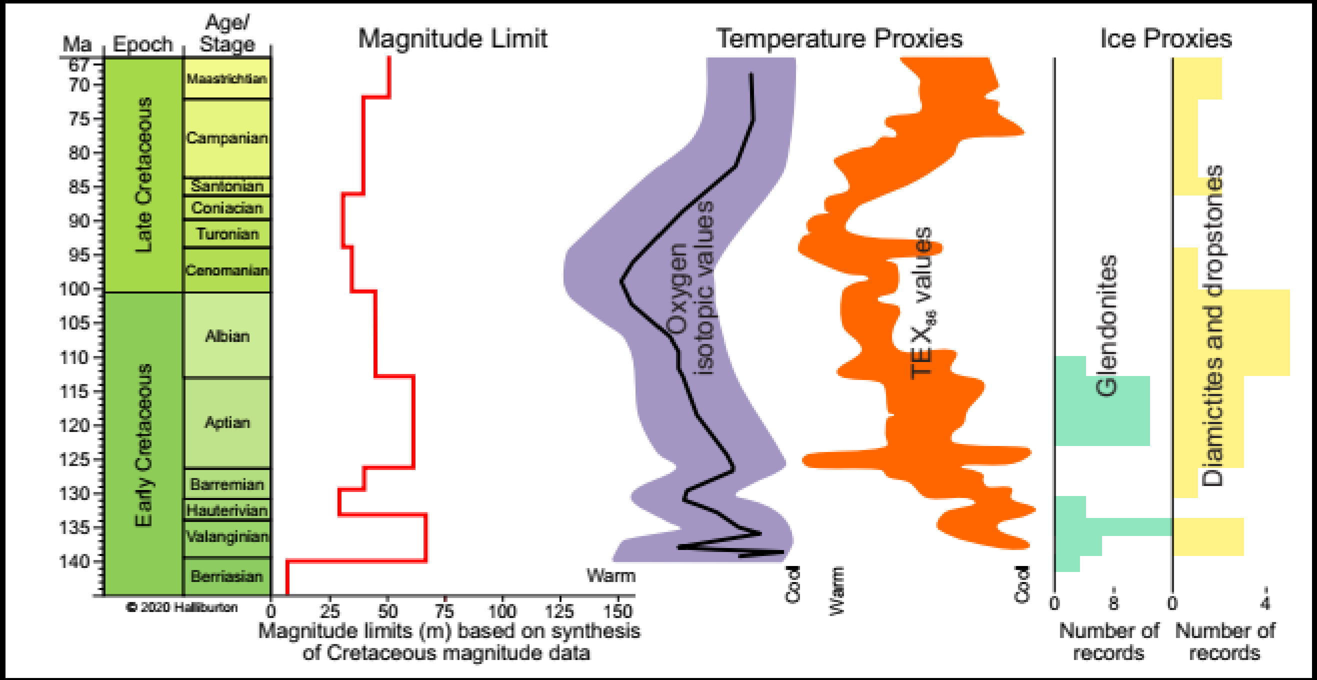


# Drivers of Short-term Cretaceous Eustasy

- Even though the Cretaceous eustatic limits suggested are relatively modest (5 to 65 m), 50% of the Cretaceous (Valanginian, Aptian, Albian, and Maastrichtian) is associated with significant (>40 m) eustatic changes that may be considered highly characteristic of glacio-eustasy.

- In the presence of significant eustatic change, the immediately older and younger intervals of modest magnitude changes (10 to 40 m) may be interpreted as representing the growth and demise of land-grounded icecaps. Based on these criteria, it is only within the Berriasian that glacio-eustasy may be considered equivocal.

- The link between short-term sea-level magnitudes and climate is supported by broad trends within Cretaceous temperature proxies, such as $TEX_{86}$ and $\delta^{18}O$. These proxies illustrate that cooling is associated with larger magnitude, short-term sea-level changes, while globally warmer climates correspond to smaller magnitudes; as would be expected if eustasy were controlled by icecap volume.

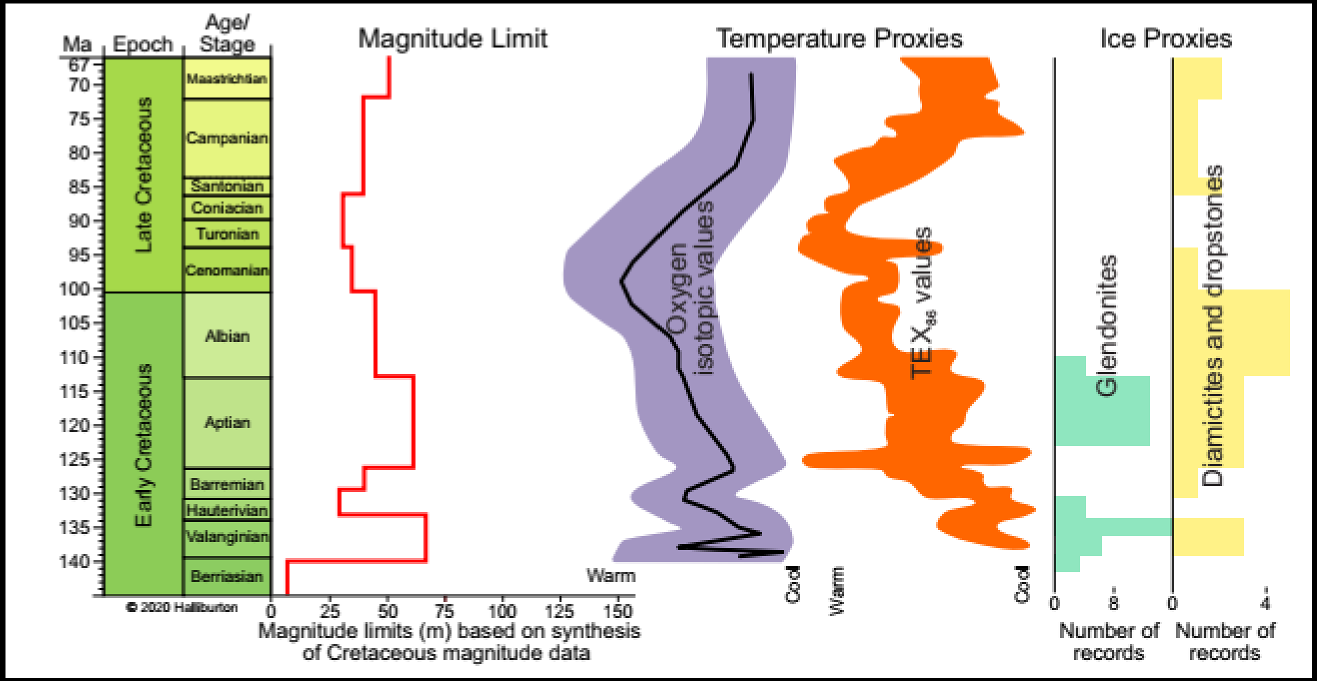



A comparison of the magnitude limits of Cretaceous short-term eustasy and Cretaceous climatic proxies (modified from Figure 9 of Ray et al., 2019).

# Drivers of Short-term Cretaceous Eustasy

- Sedimentological proxies for ice, such as glendonites, diamictites, and dropstones, are reported for intervals of cooling and periods of relatively large magnitude short-term eustatic change.

- Glacio-eustasy appears to be the dominant driver of Cretaceous short-term eustasy.

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# References

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