# Neogene Southwestern U.S. Temperatures Paced by Global Temperature Change

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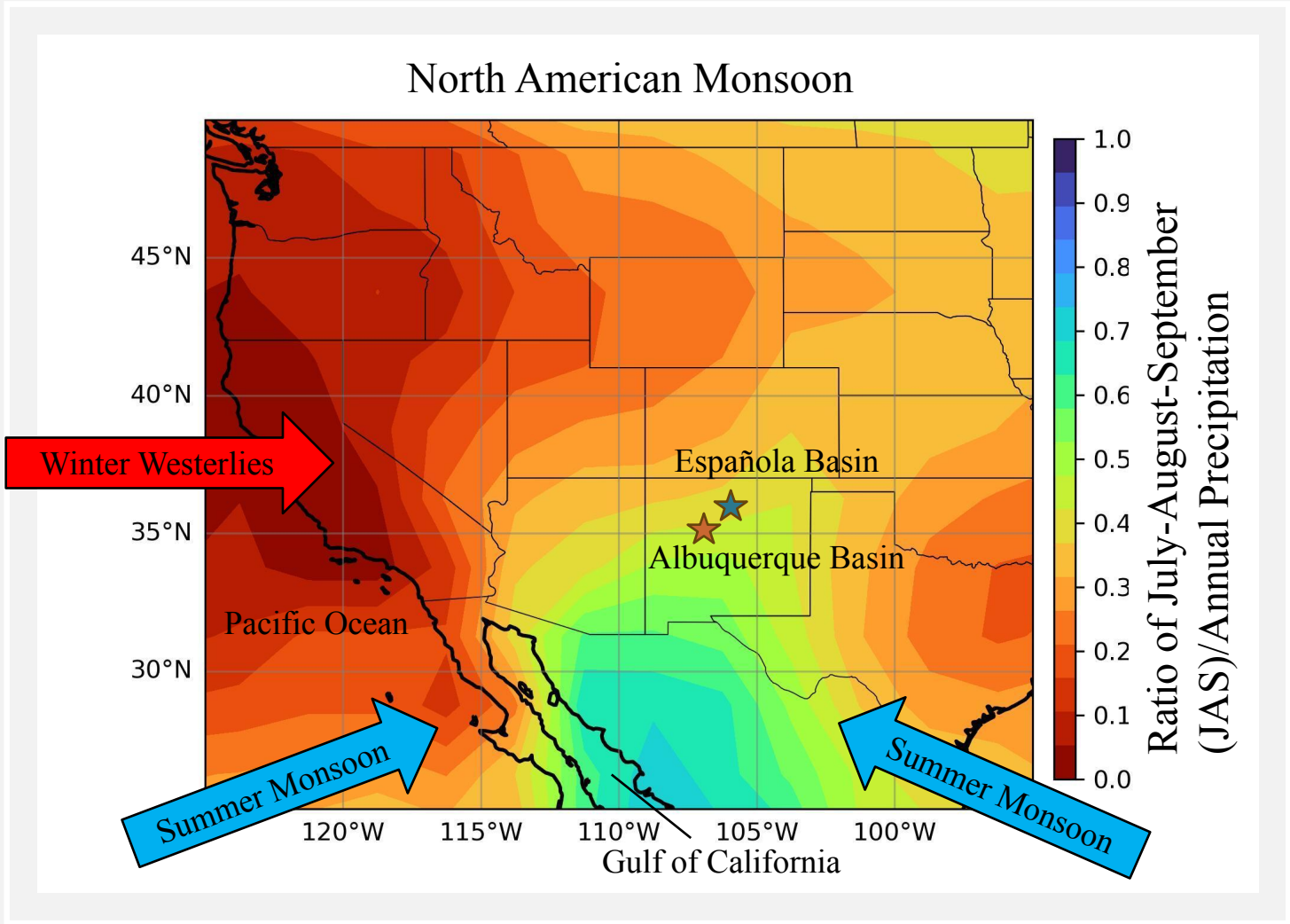
Early-middle Miocene sediments of Española, New Mexico. Photo: Jeremy Rugenstein

**AGU Fall 2025 Meeting**

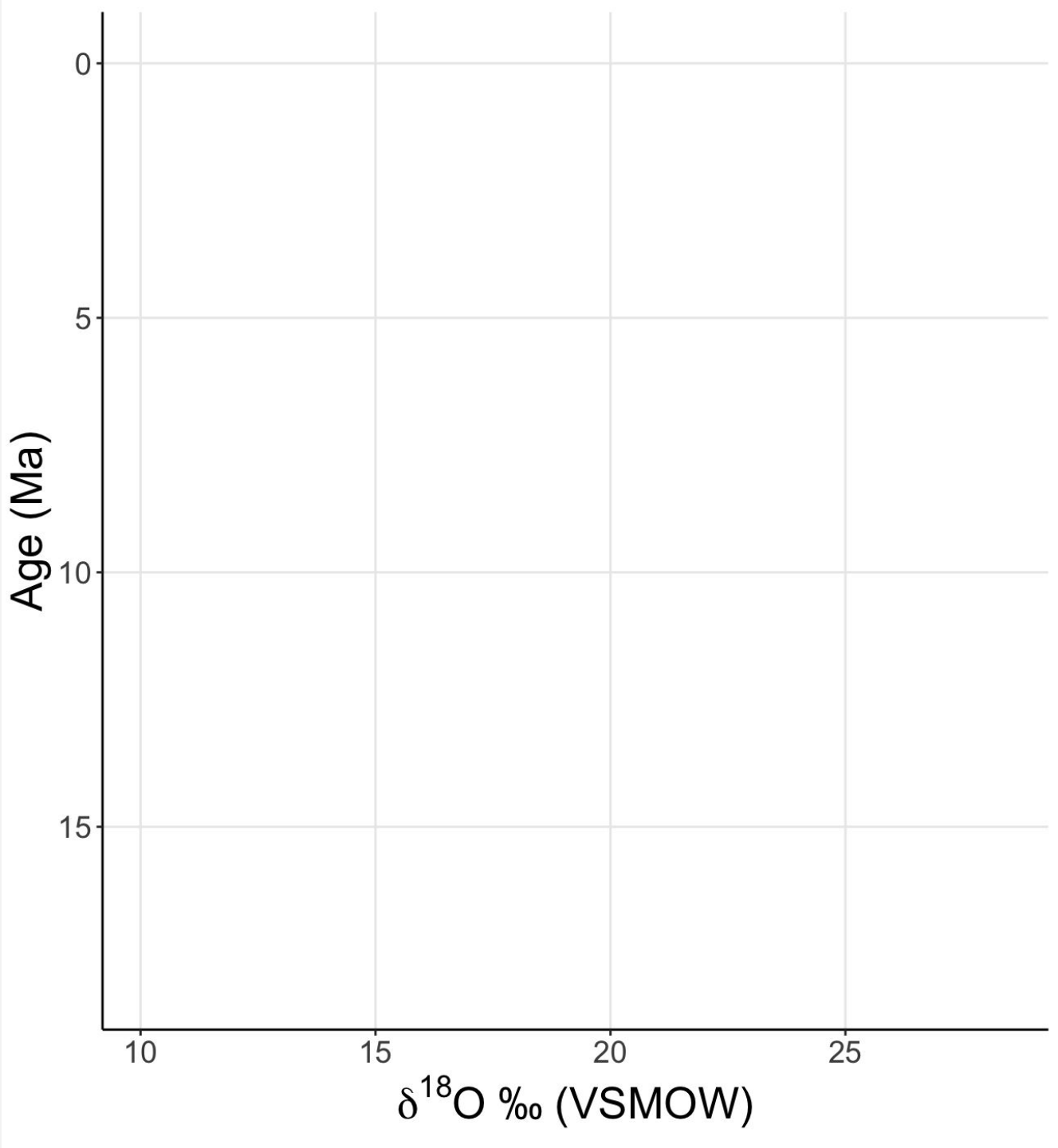
# Southwestern Hydroclimate

- Dual wet-season today with two moisture sources
- North American Monsoon (NAM) brings summer moisture
- How do the NAM and southwestern U.S. hydroclimate respond to warming?




Global Precipitation Climatology Project (GPCP)

Carbonate Stable Isotope Data



Higher proportion of winter moisture

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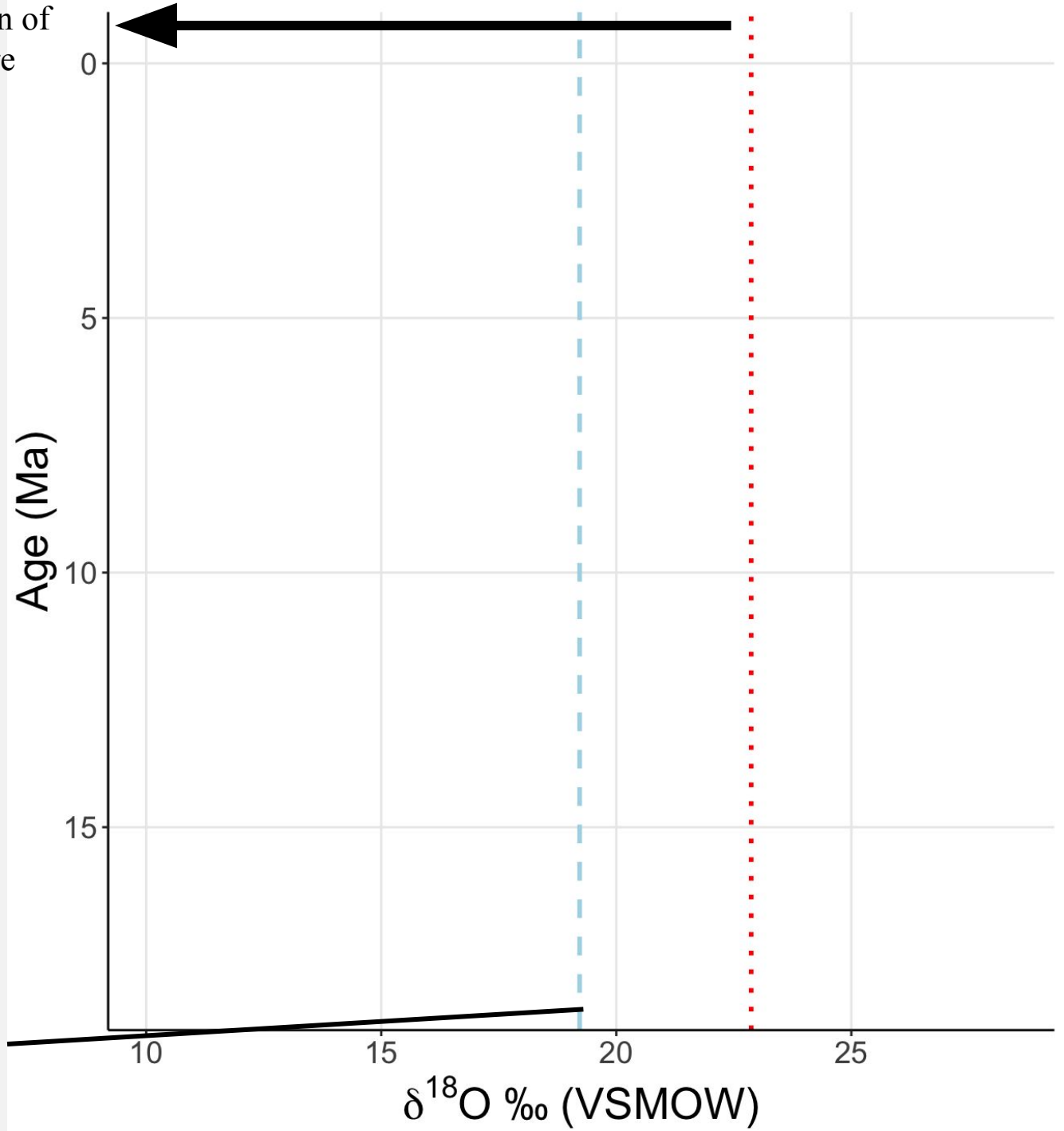


Predicted carbonate $\delta^{18}O$ from modern Española winter and summer precipitation $\delta^{18}O$, assuming modern Española winter and summer average temperatures

Higher proportion of winter moisture

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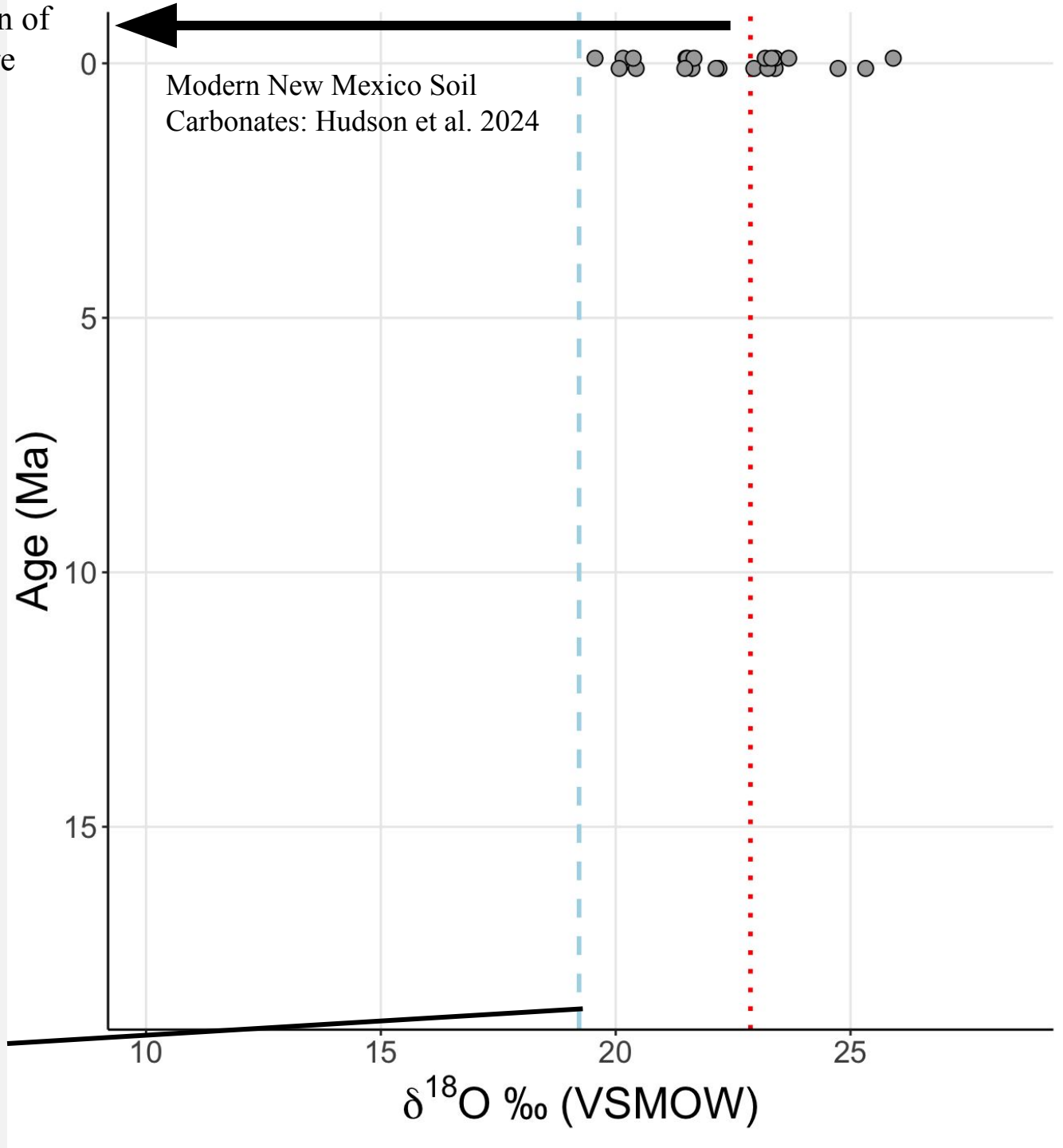


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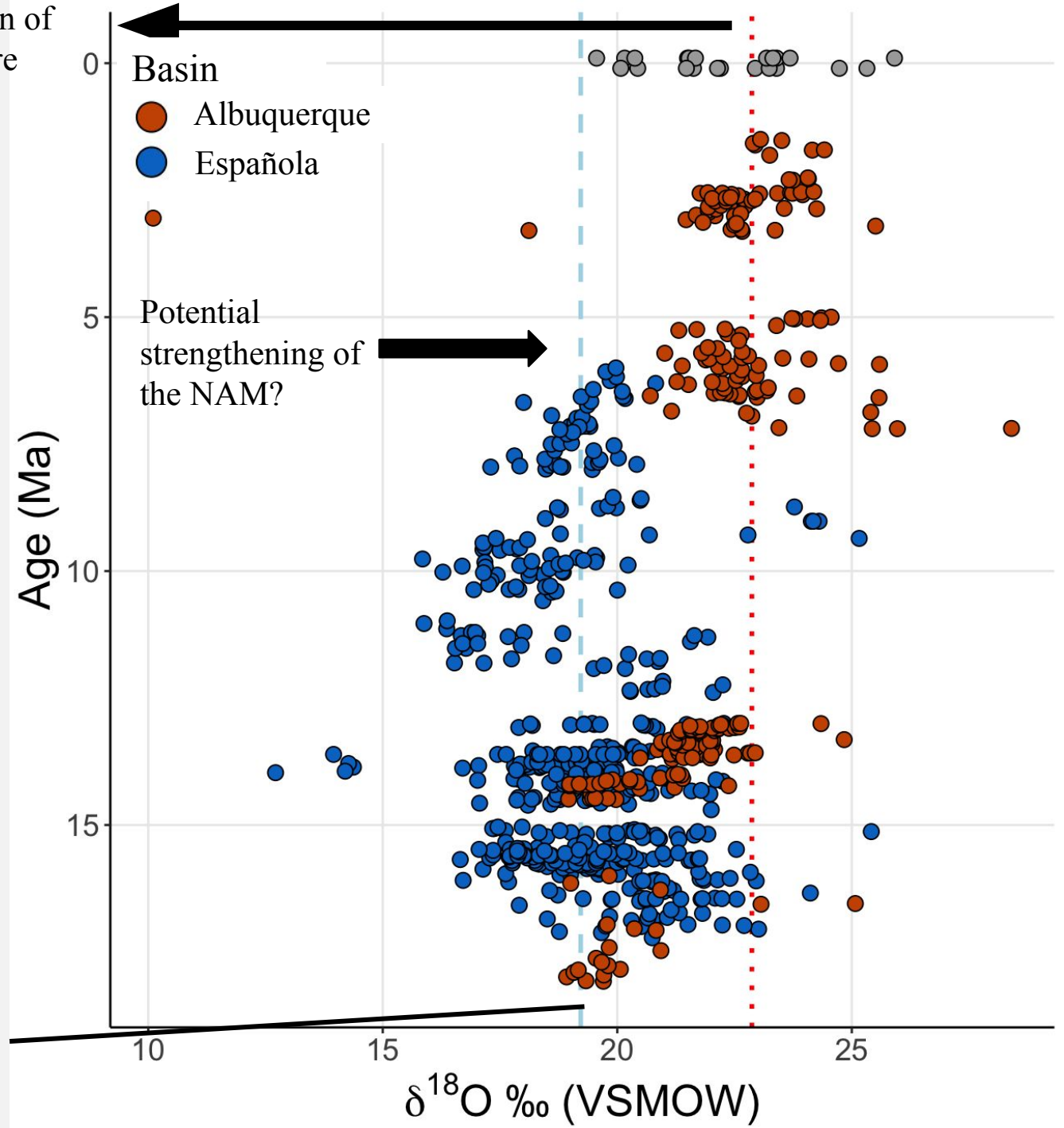
Modern New Mexico Soil Carbonates: Hudson et al. 2024

# Carbonate Stable Isotope Data

- Winter-wet conditions during mid-Miocene Climatic Optimum (MCO) and middle Miocene (S. Spaur et al. 2025, Paleo-Paleo)
- Hypothesized increase in summertime precipitation over time; possible that the NAM turned on in late Miocene (CE Chapin 2008, Geosphere)

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- Approx. 20 samples selected for clumped isotope analysis

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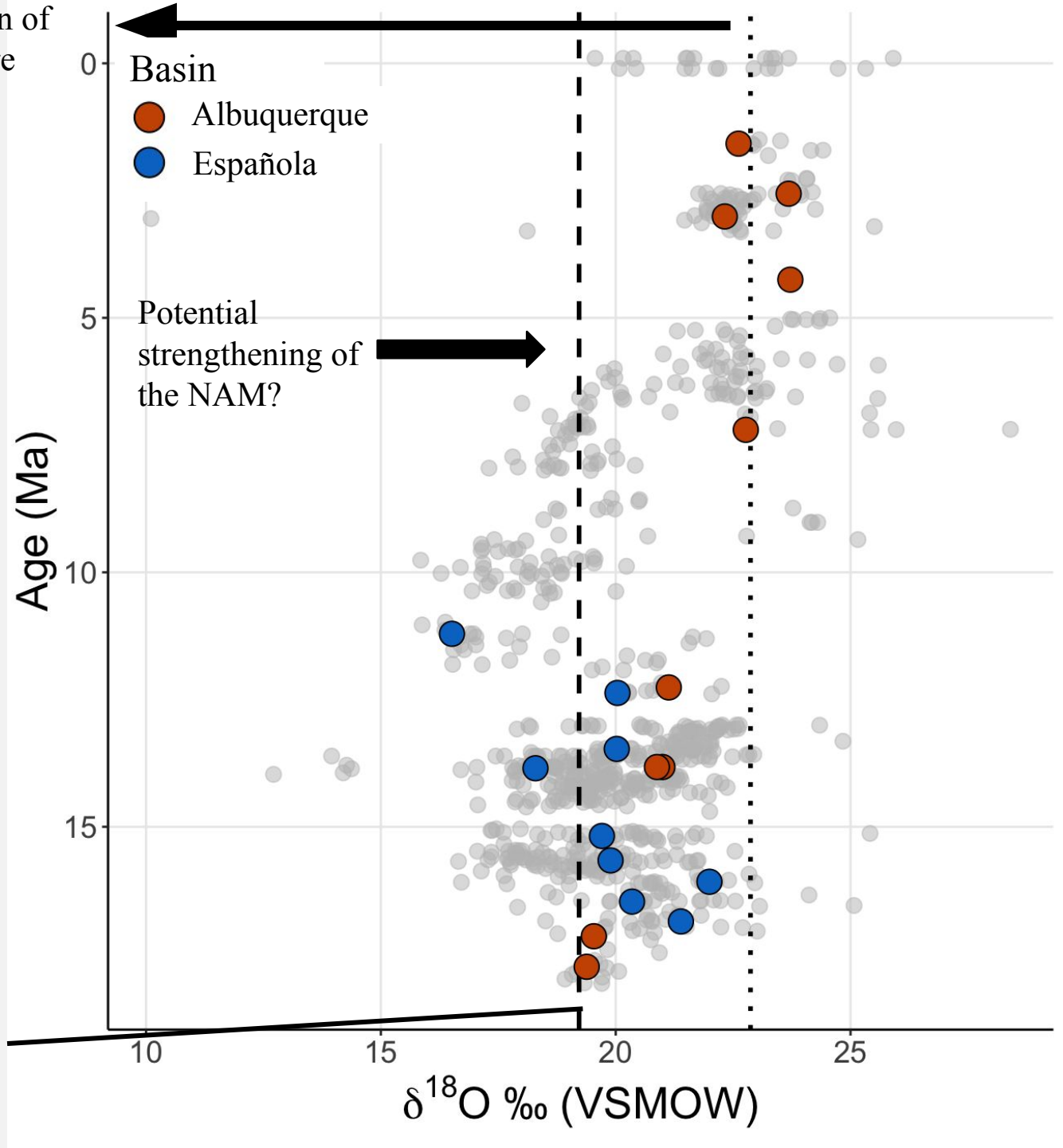
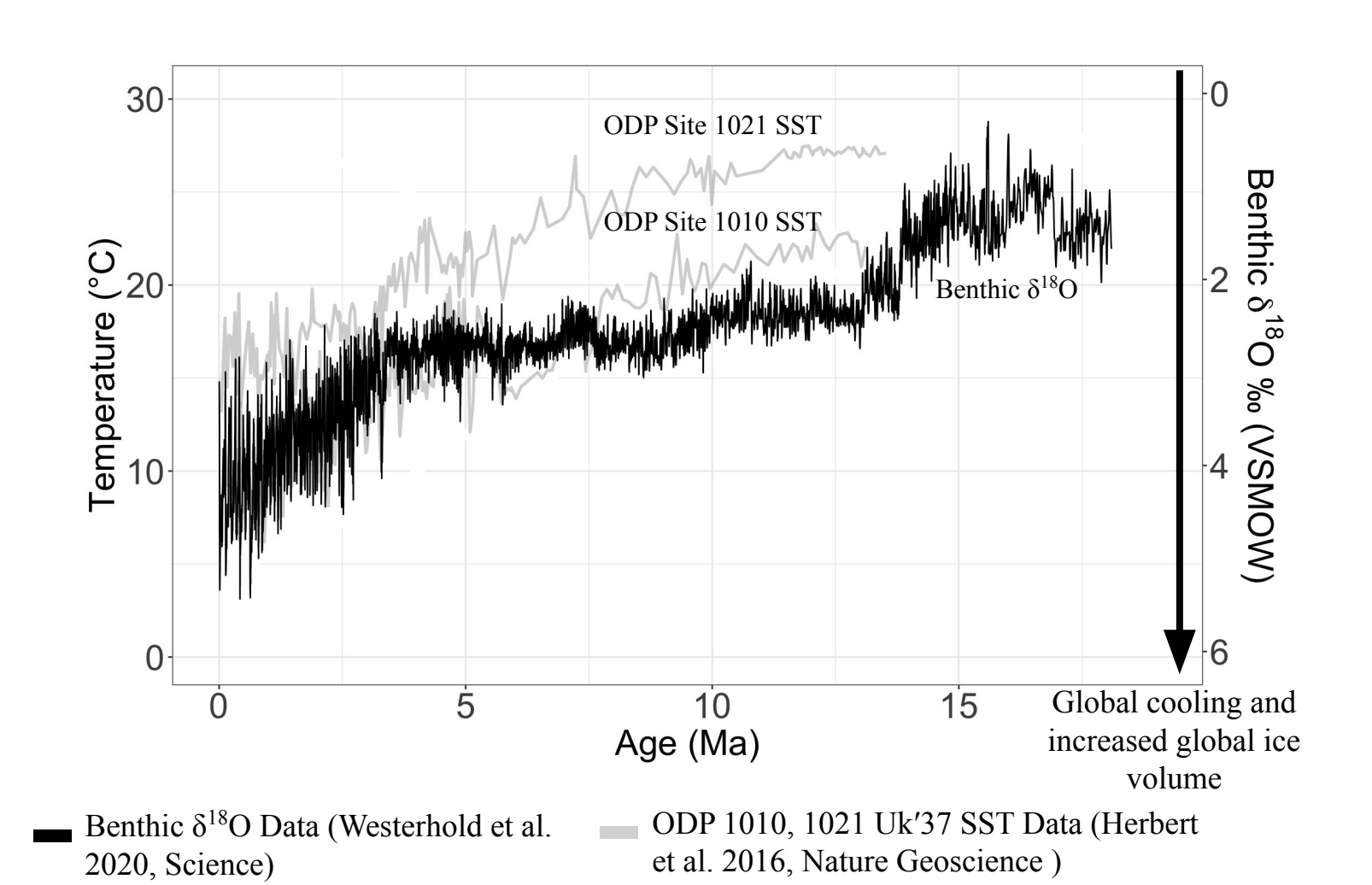
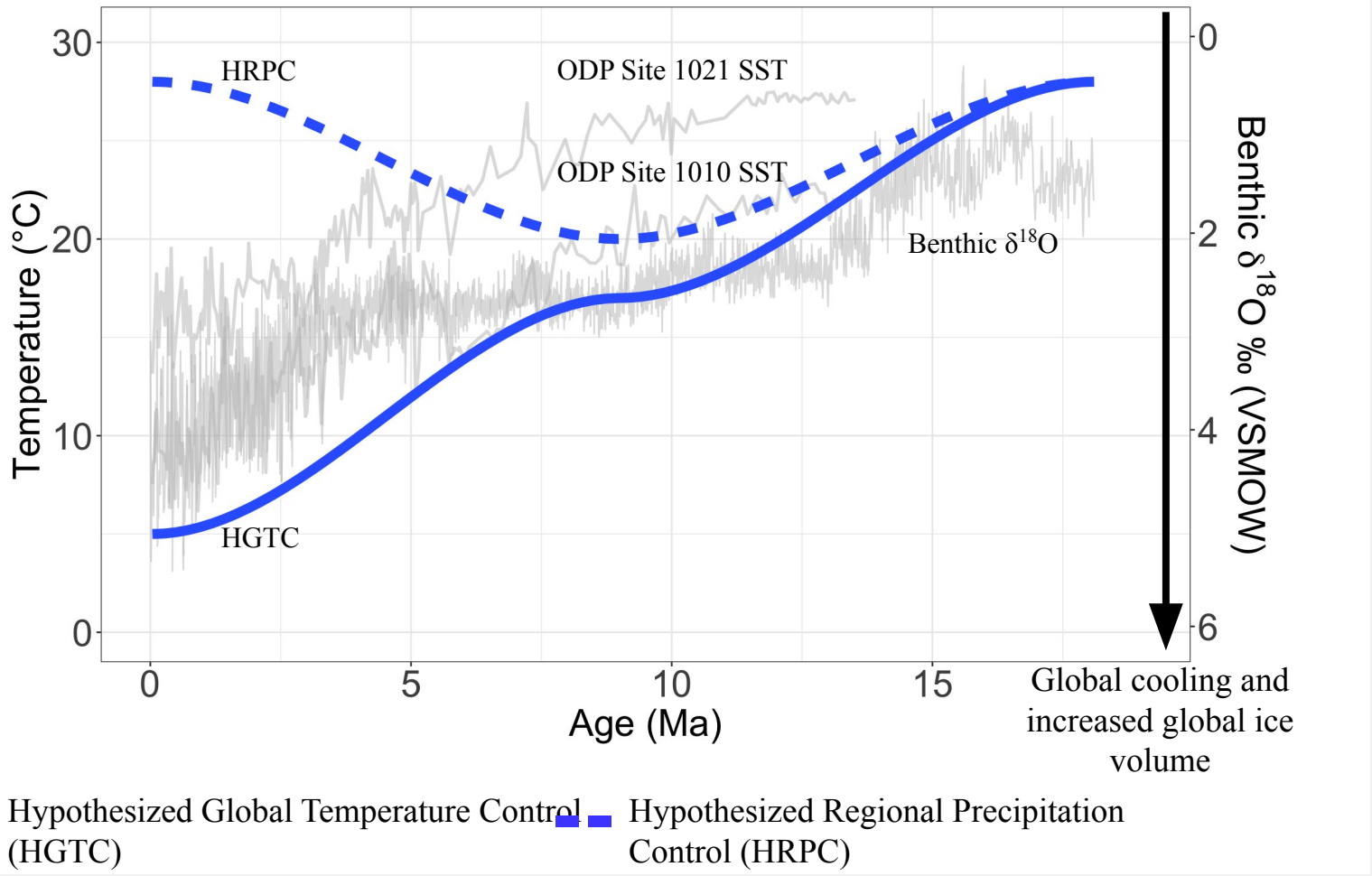


# What do we expect?

- Benthic $\delta^{18}O$ and California Margin SST records show cooling



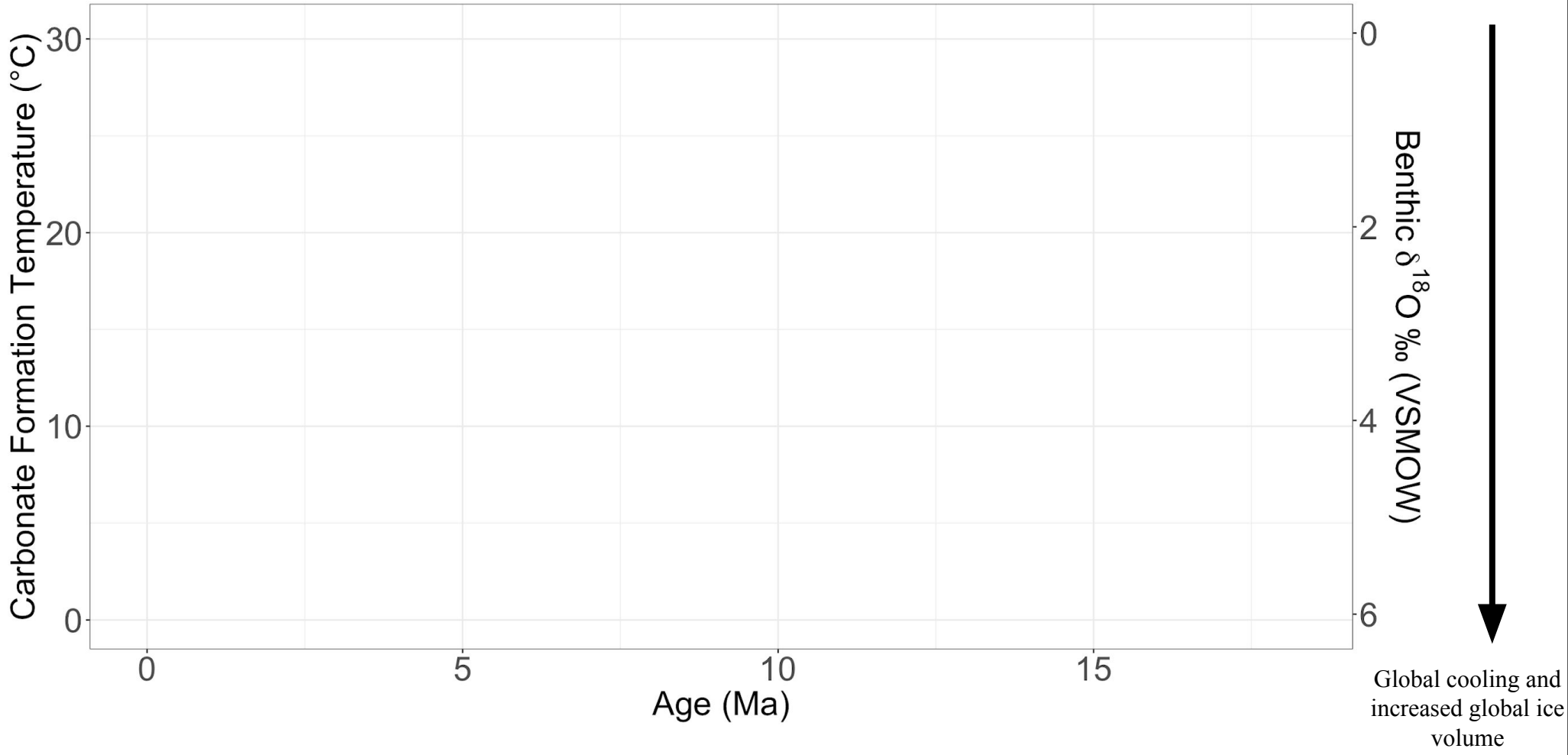



## What do we expect?

- Benthic $\delta^{18}O$ and California Margin SST records show cooling
- Possible precipitation seasonality shift could be a regional control
- Increase in summertime precipitation might lead to summertime carbonate formation and warmer clumped isotope temperatures

Uk′37 SST Data: Herbert et al. 2016, Nature Geoscience
Benthic $\delta^{18}O$ Data: Westerhold et al. 2020, Science

# What do we see?



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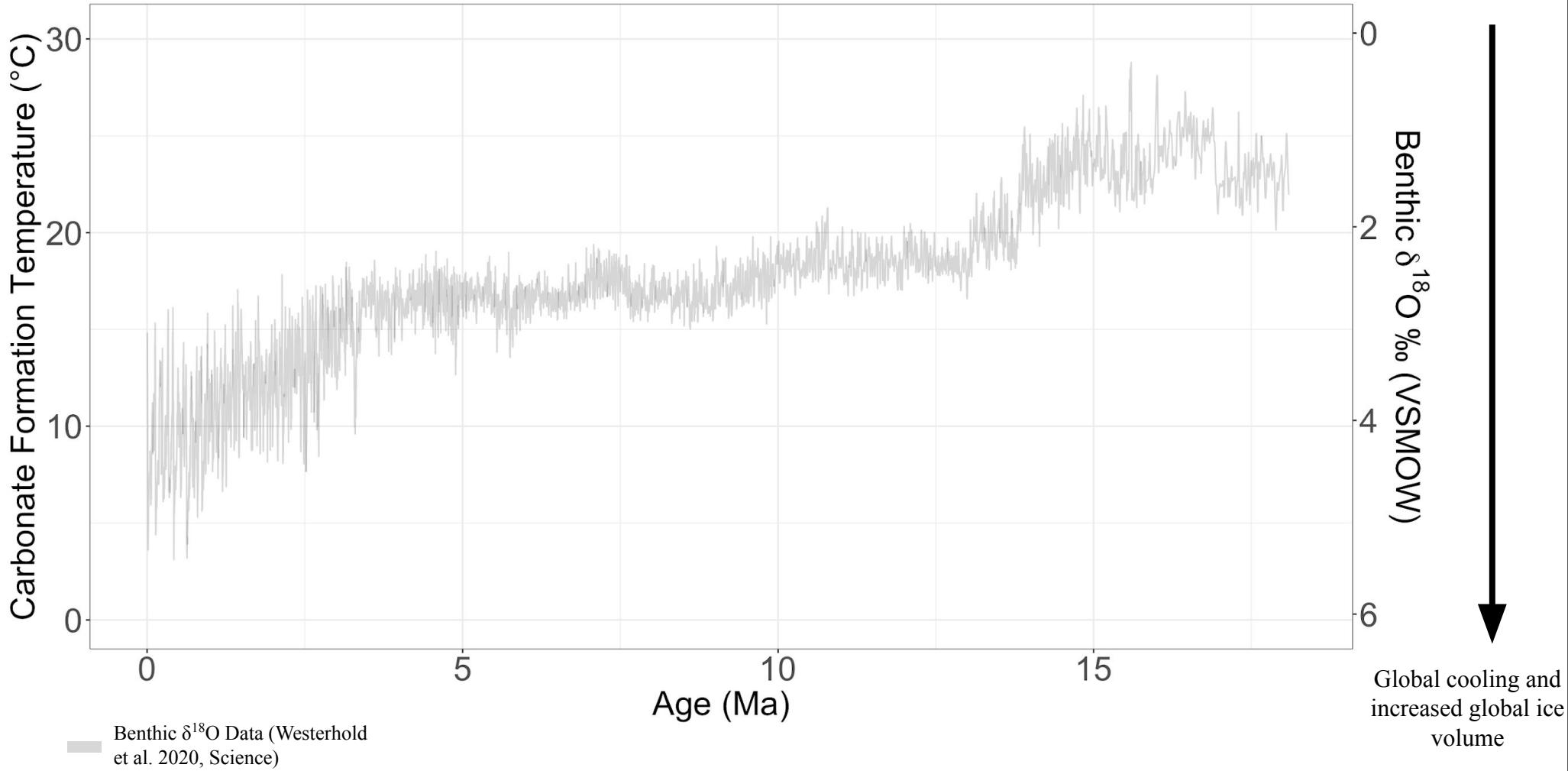

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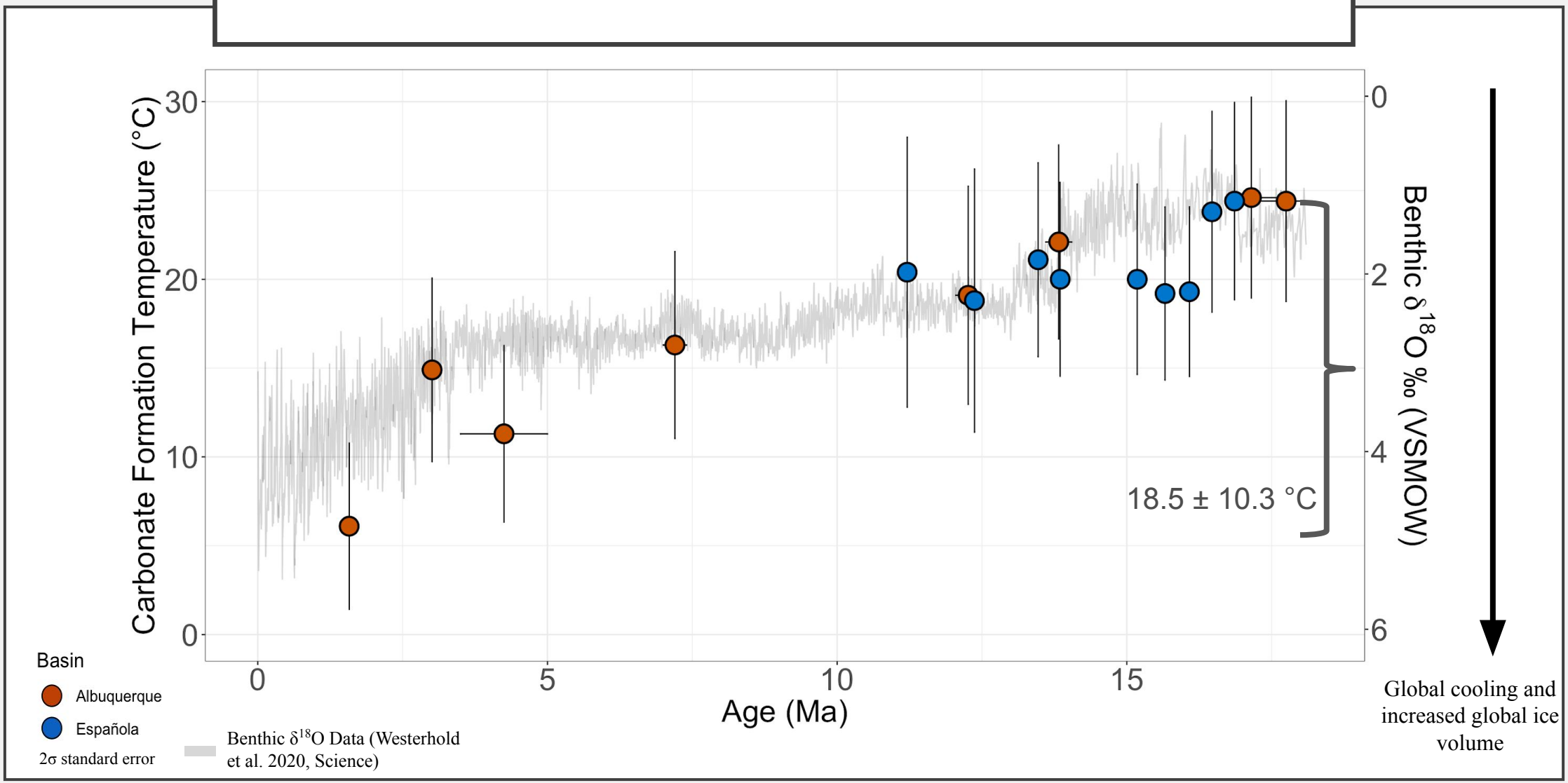

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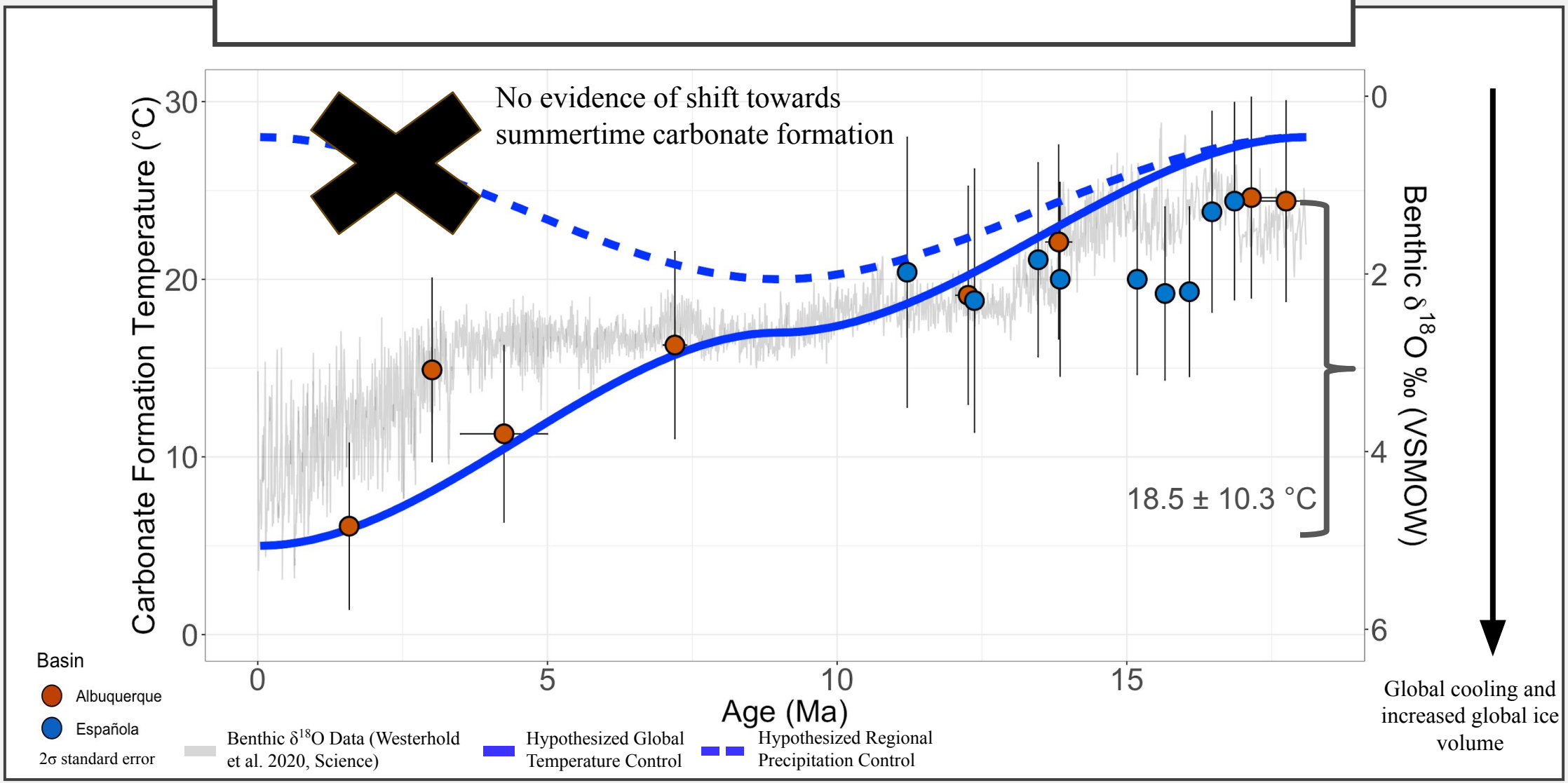

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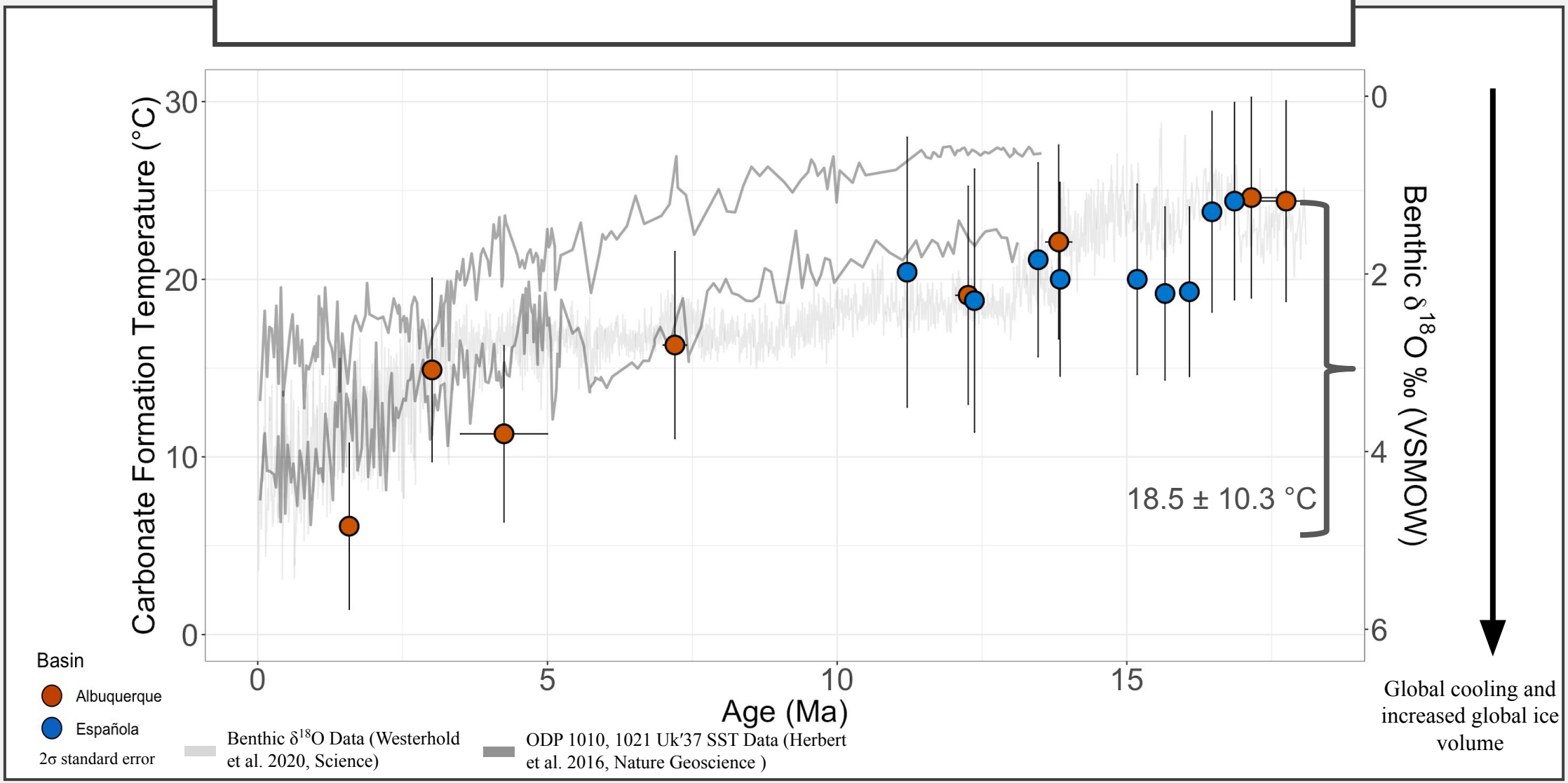
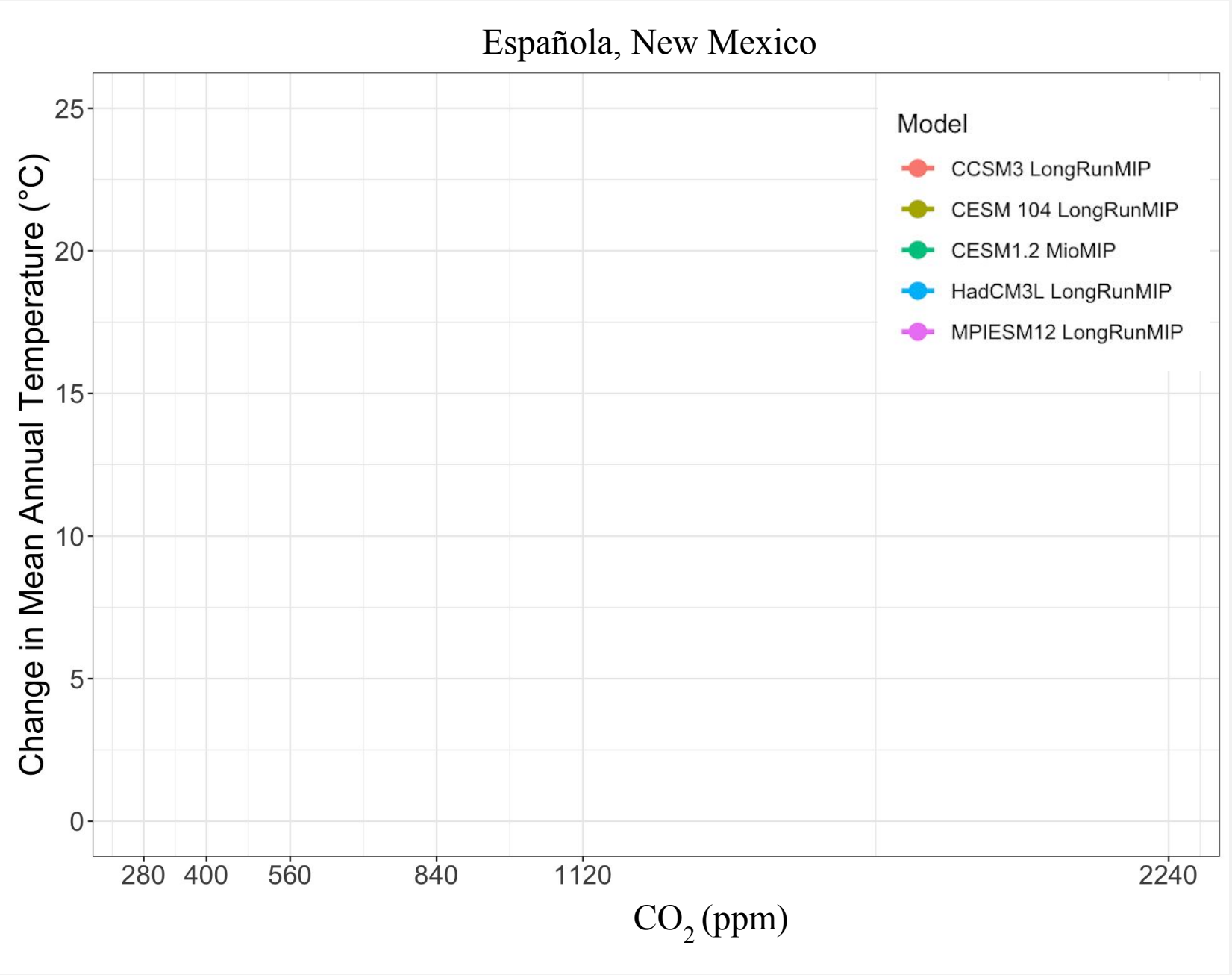


## Modeled New Mexico Land Surface Temperature Response to $CO_2$

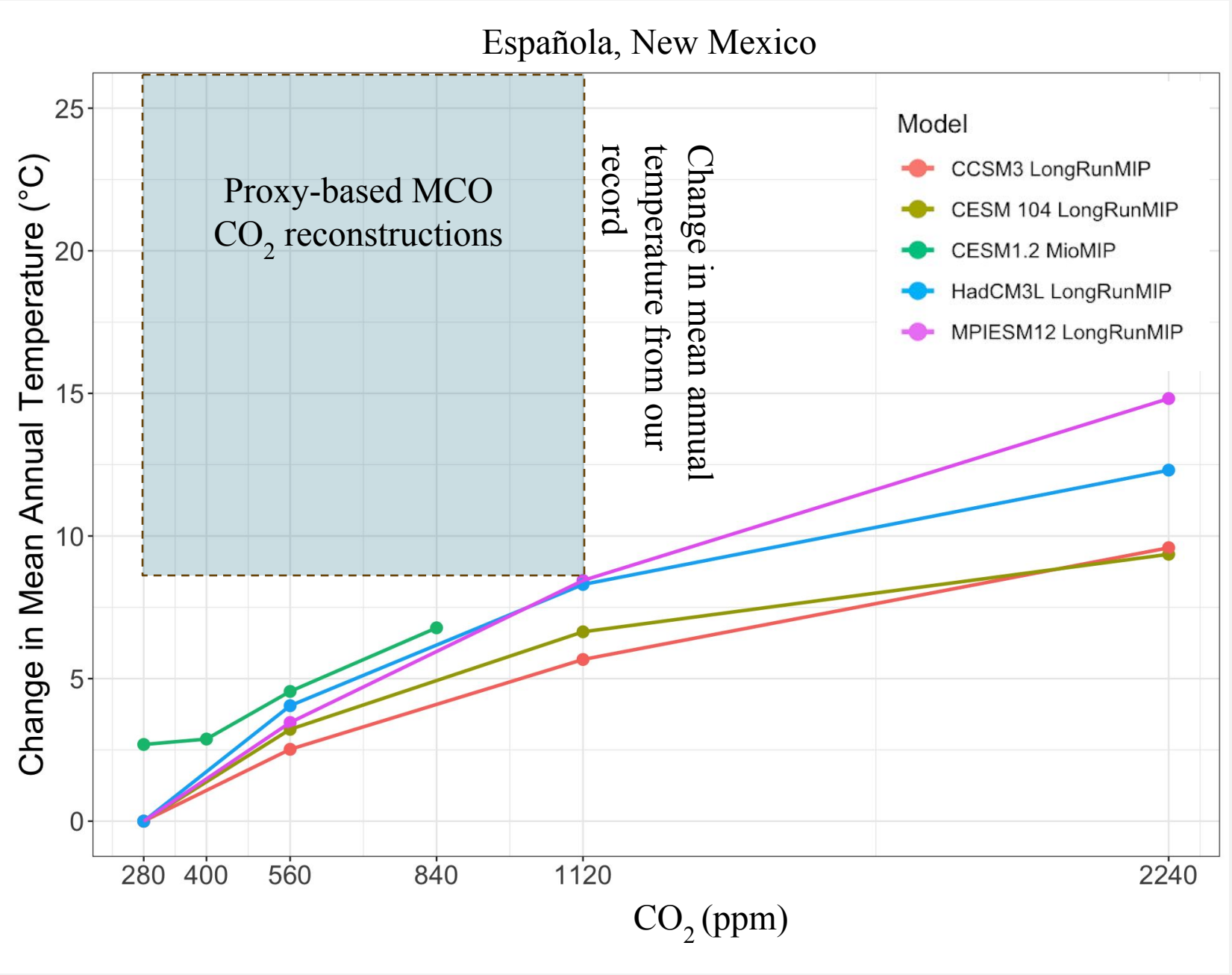
- Ocean-equilibrated (LongRunMIP) model runs at 1,000+ years using modern boundary conditions
- Miocene boundary conditions (MioMIP) and paleogeography
- Modeled change in mean annual temperature (MAT)




LongRunMIP: M. Rugenstein et al. 2020, Geophysical Research Letters

## Modeled New Mexico Land Surface Temperature Response to $CO_2$

- Magnitude of MCO warmth documented in data not replicable with full range of proxy-based MCO $pCO_2$ estimates… Why?
- Models might be underpredicting temperature response to warming
- Our record might be overestimating temperature change:
  - Currently assuming youngest sample is representative of 280 ppm
  - Maybe incorporating regional uplift signal




LongRunMIP: M. Rugenstein et al. 2020, Geophysical Research Letters

# Thank You!

## Conclusions

- Temperature trends in New Mexico since the MCO are reflective of global drivers
- Models using modern and Miocene boundary conditions are unable to replicate MCO warmth from this record even at 8x $CO_2$

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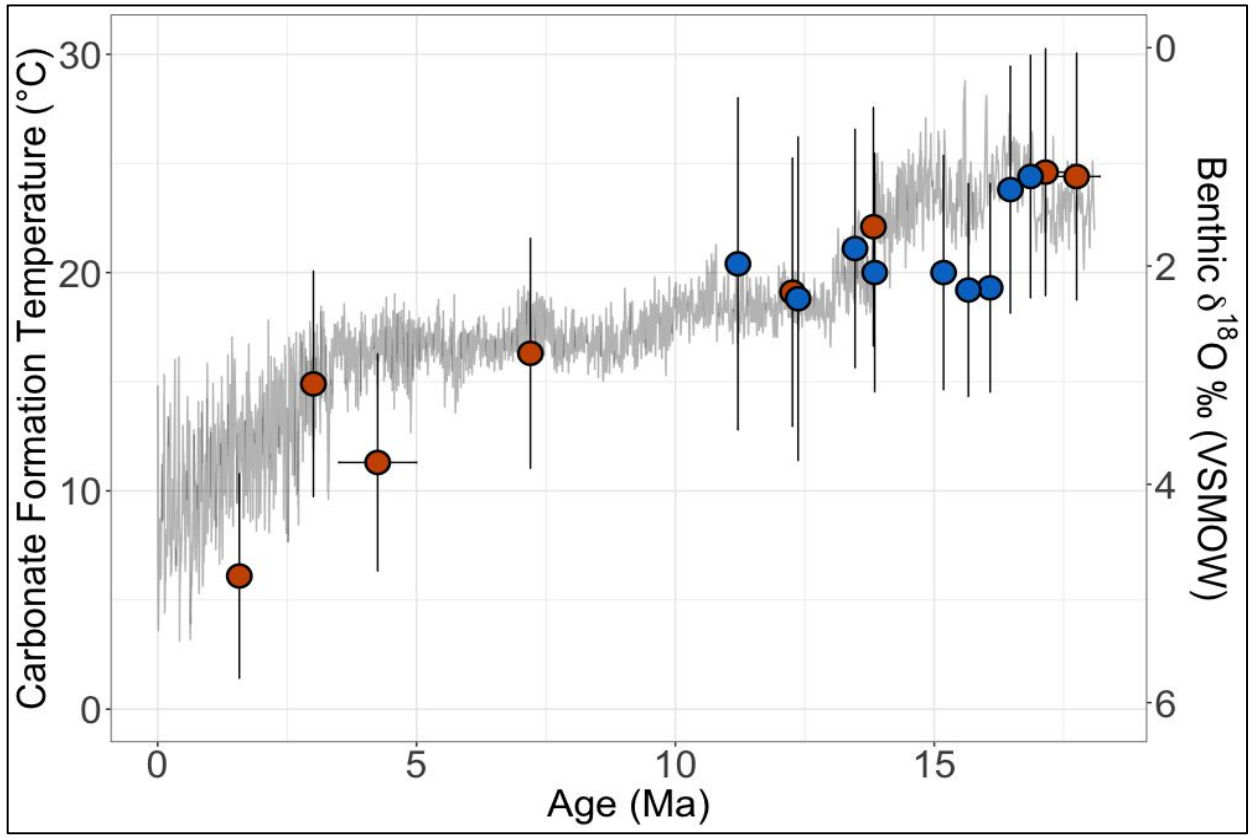
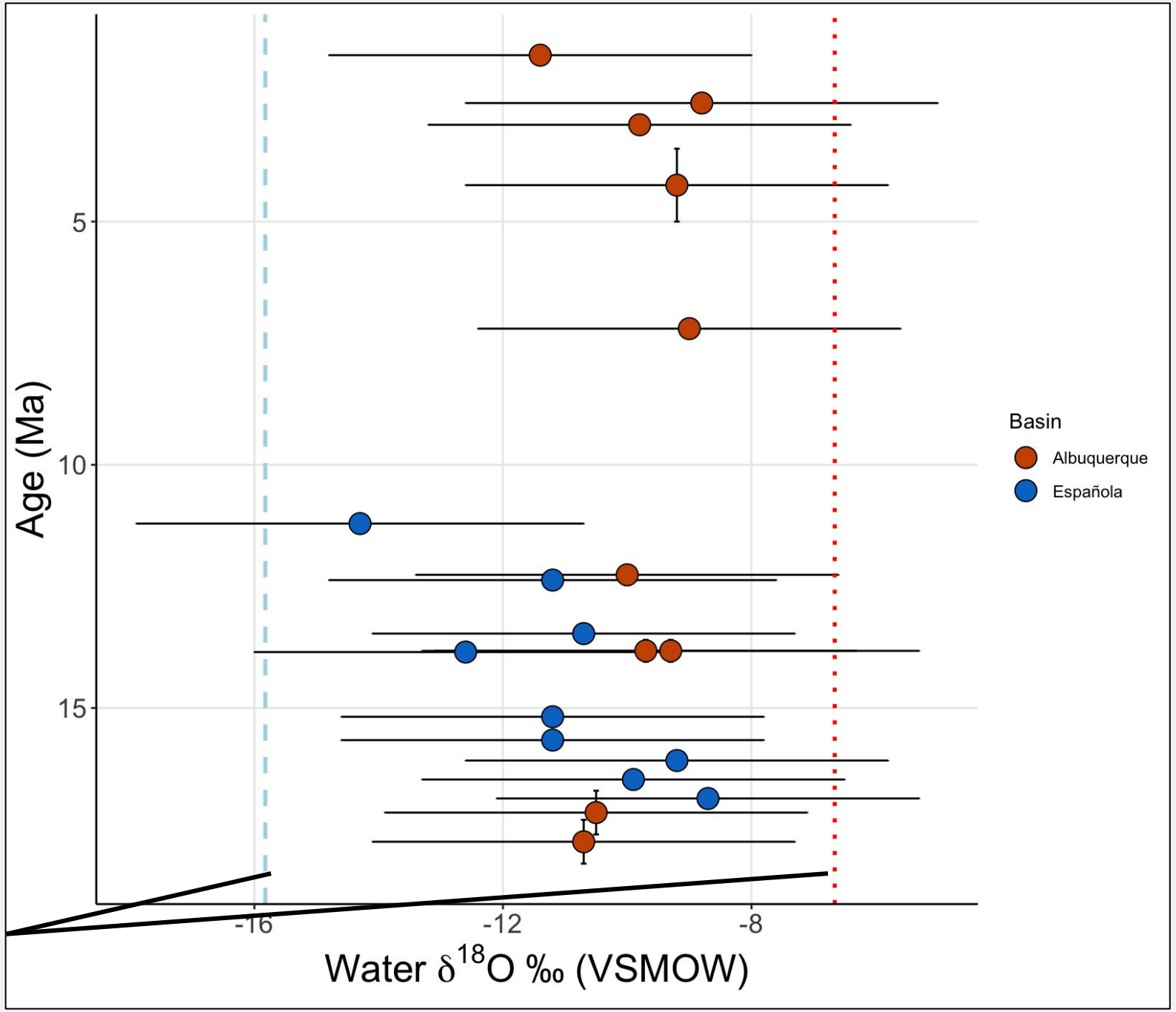
## Future Work

- Continue replicating incomplete samples
- Investigate precipitation $\delta^{18}O$
- Constrain potential uplift signal in record



# Appendix

Precipitation $\delta^{18}O$




Large error bars due to uncertainty on clumped T measurements

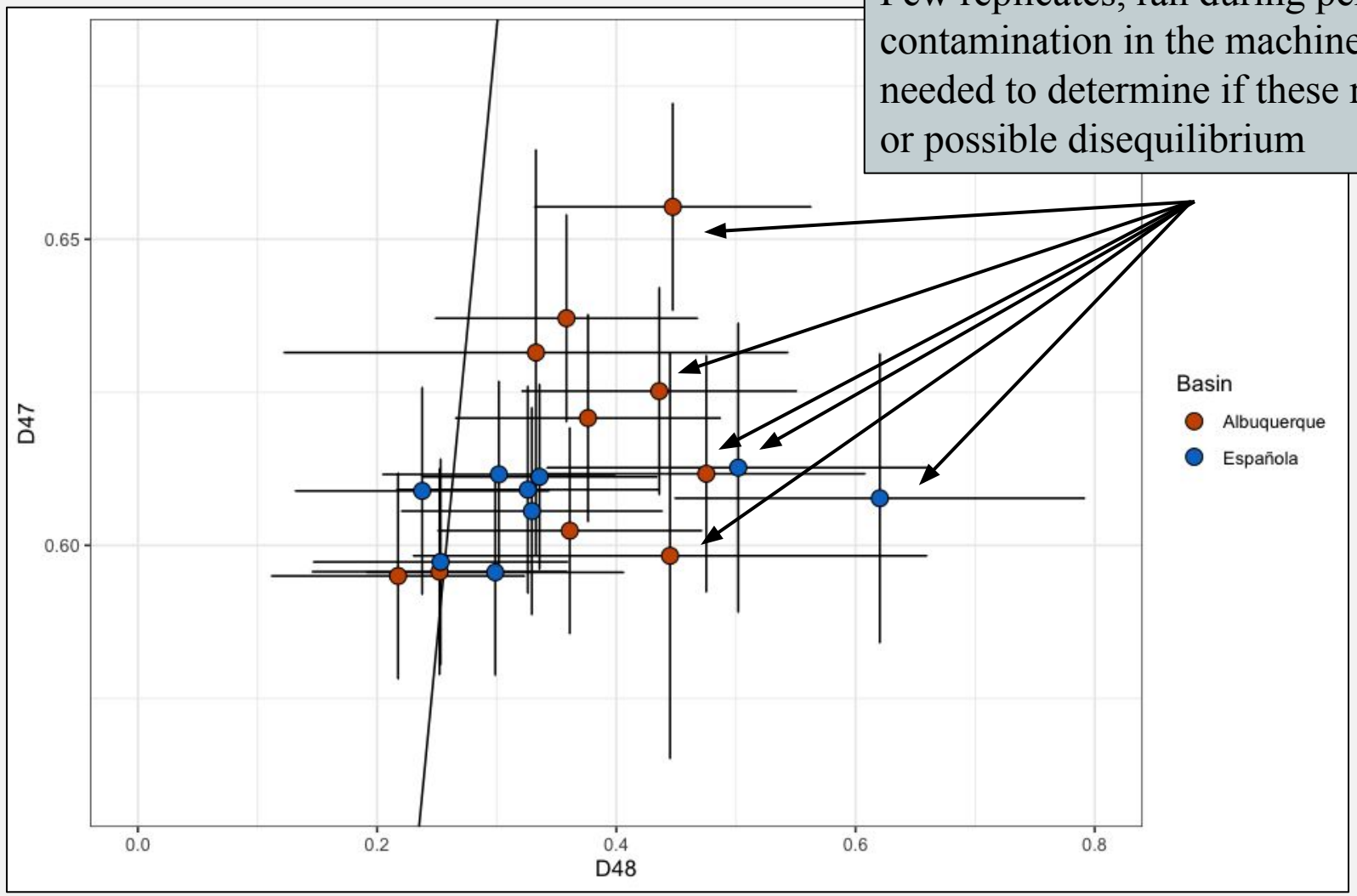
No distinct shift in $\delta^{18}O_w$ suggests that shift in $\delta^{18}O_c$ is reflecting temperature change

Predicted carbonate $\delta^{18}O$ from **modern** Española winter and summer precipitation $\delta^{18}O$, assuming **modern** Española winter and summer average temperatures

# $\Delta_{47}$ - $\Delta_{48}$ Plot

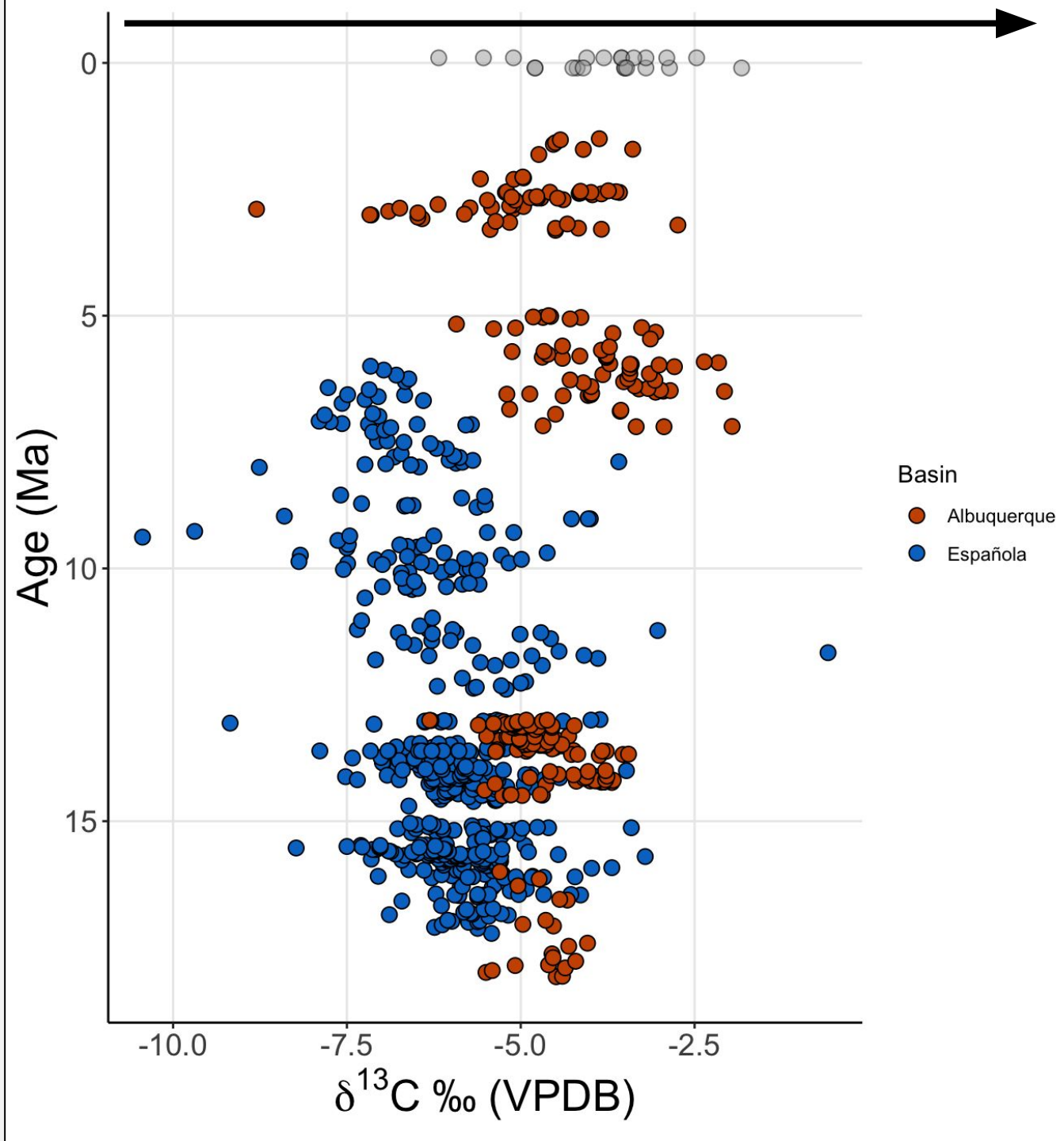
(possible disequilibrium?)

Note all samples pretreated with 3% bleach solution following protocol of Fiebig et al. 2024



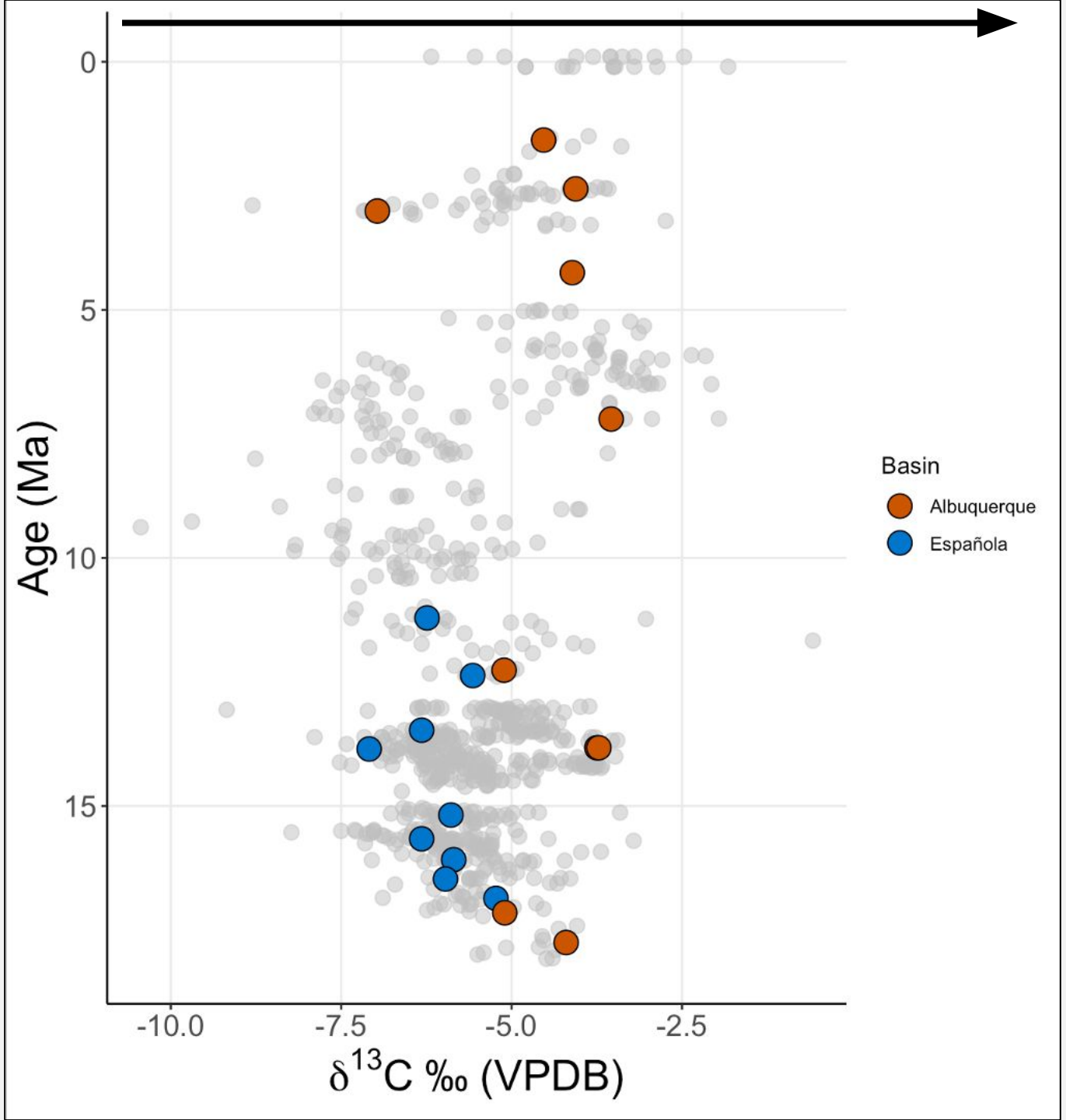

Few replicates, ran during period of contamination in the machine: more replication needed to determine if these represent $\Delta_{48}$-excess or possible disequilibrium

Carbonate $\delta^{13}C$



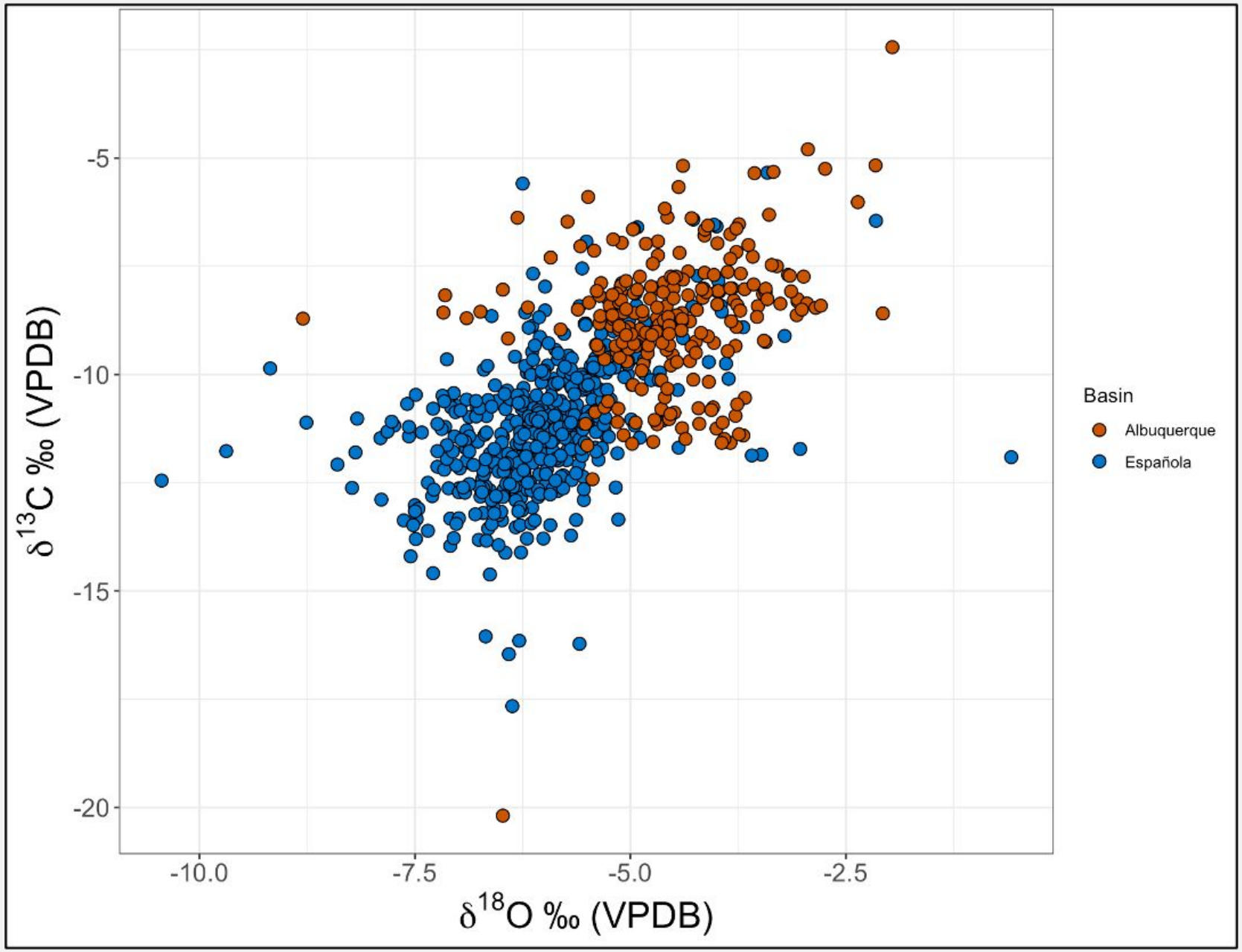

Increasing aridity (smaller relative contribution to $\delta^{13}C_c$ via soil-respired $CO_2$)

Carbonate $\delta^{13}C$ with clumped samples

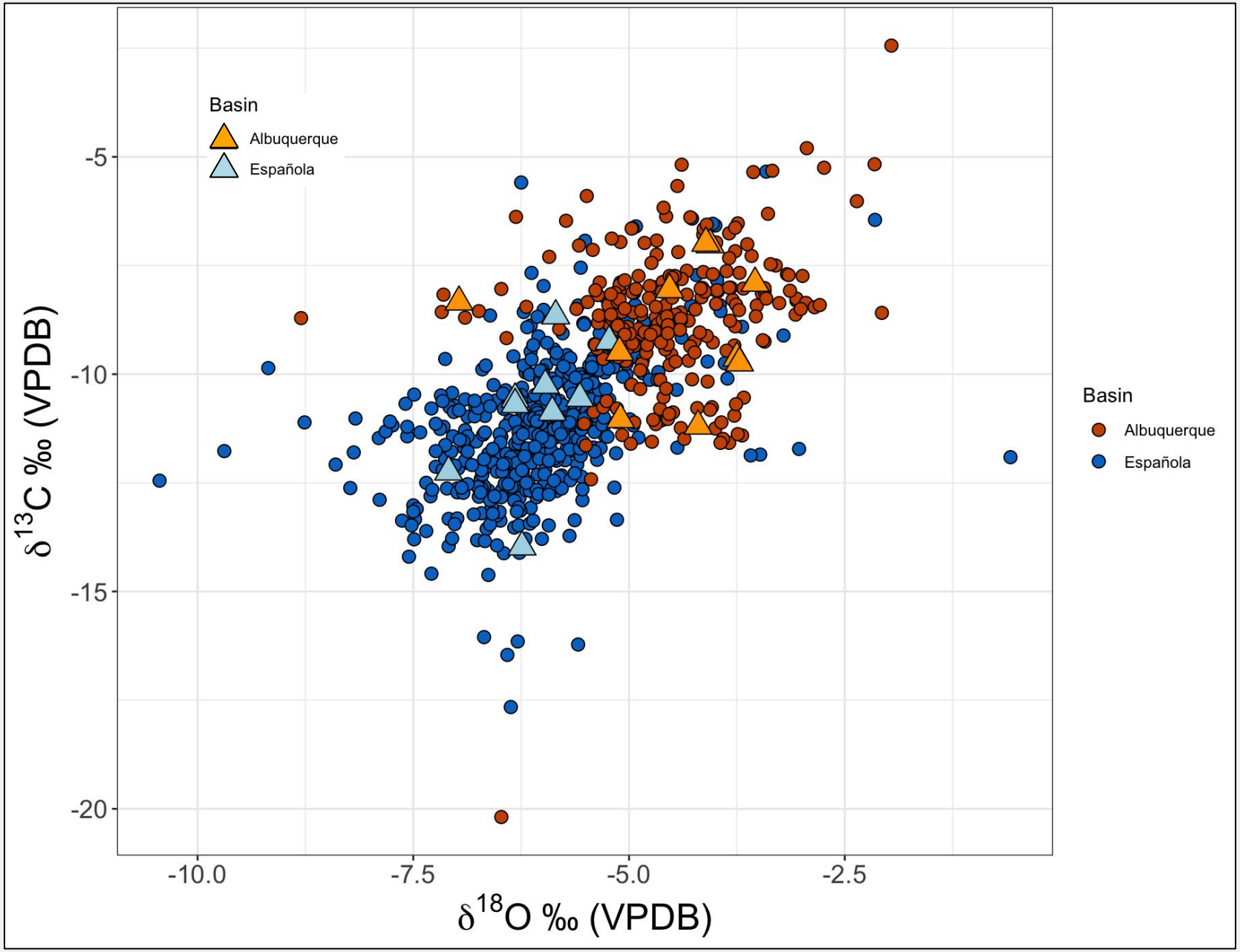



Increasing aridity (smaller relative contribution to $\delta^{13}C_c$ via soil-respired $CO_2$)

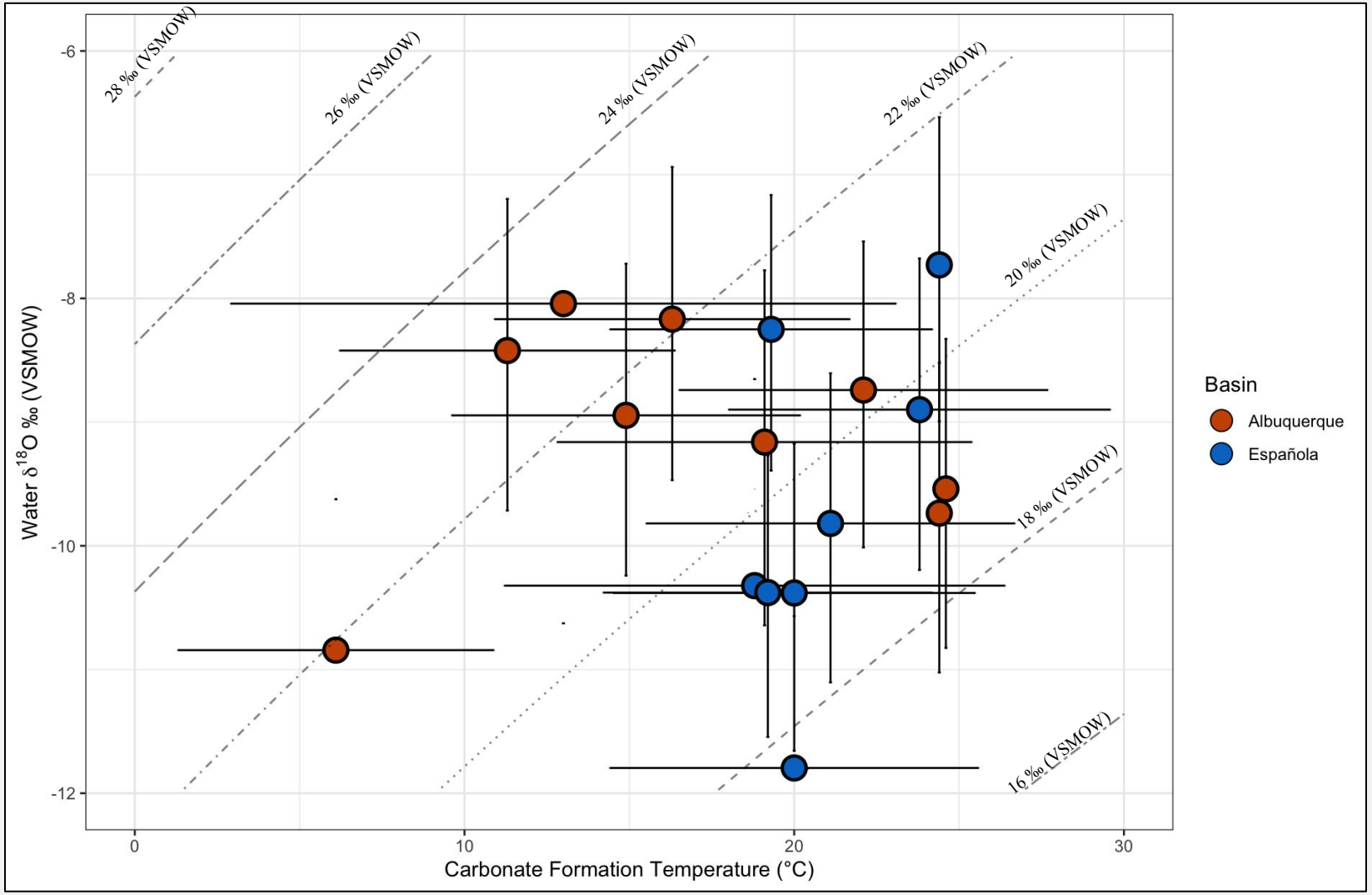
Carbonate $\delta^{13}C$ vs $\delta^{18}O$



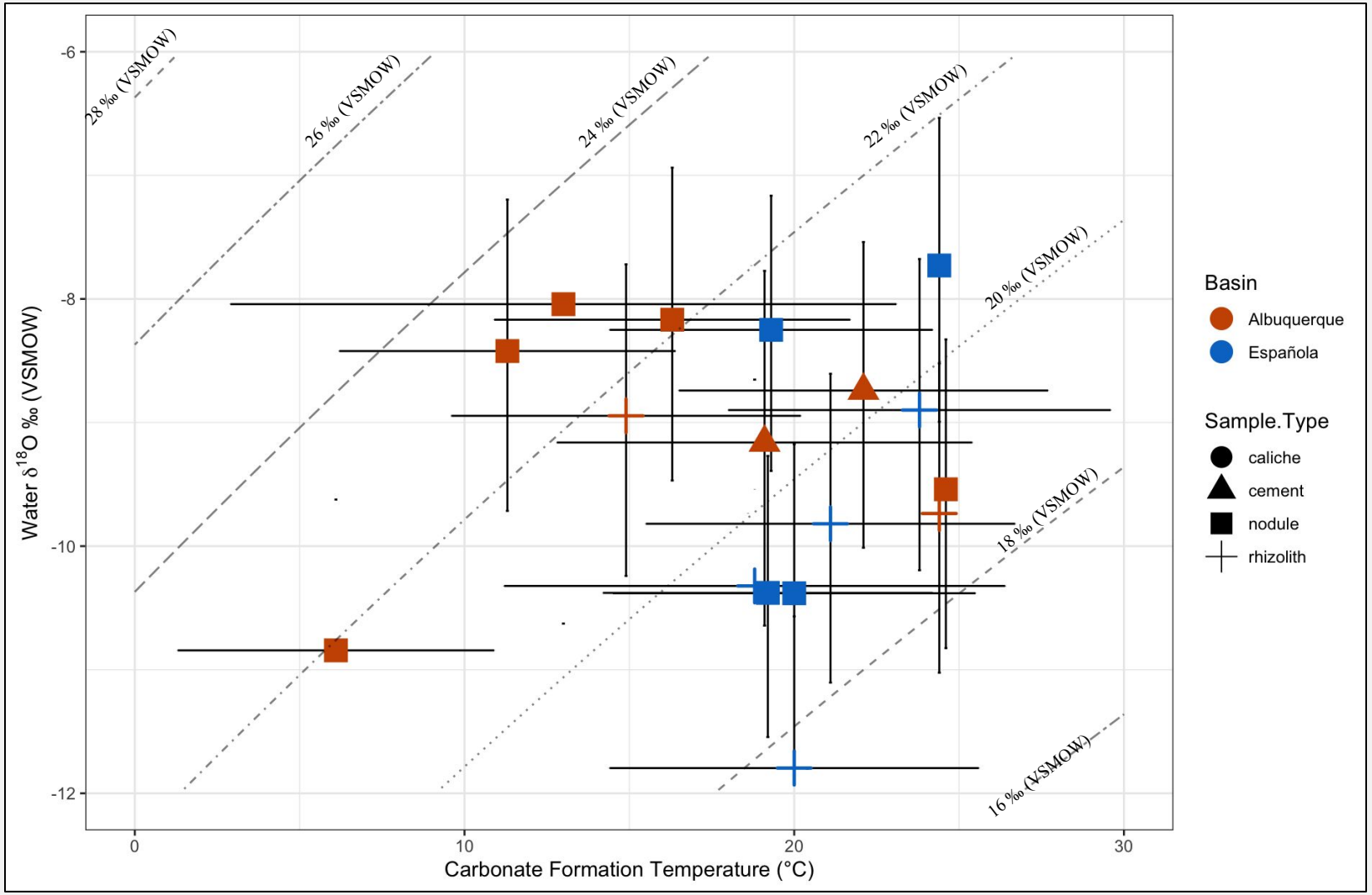
Carbonate $\delta^{13}C$ vs $\delta^{18}O$
with clumped samples



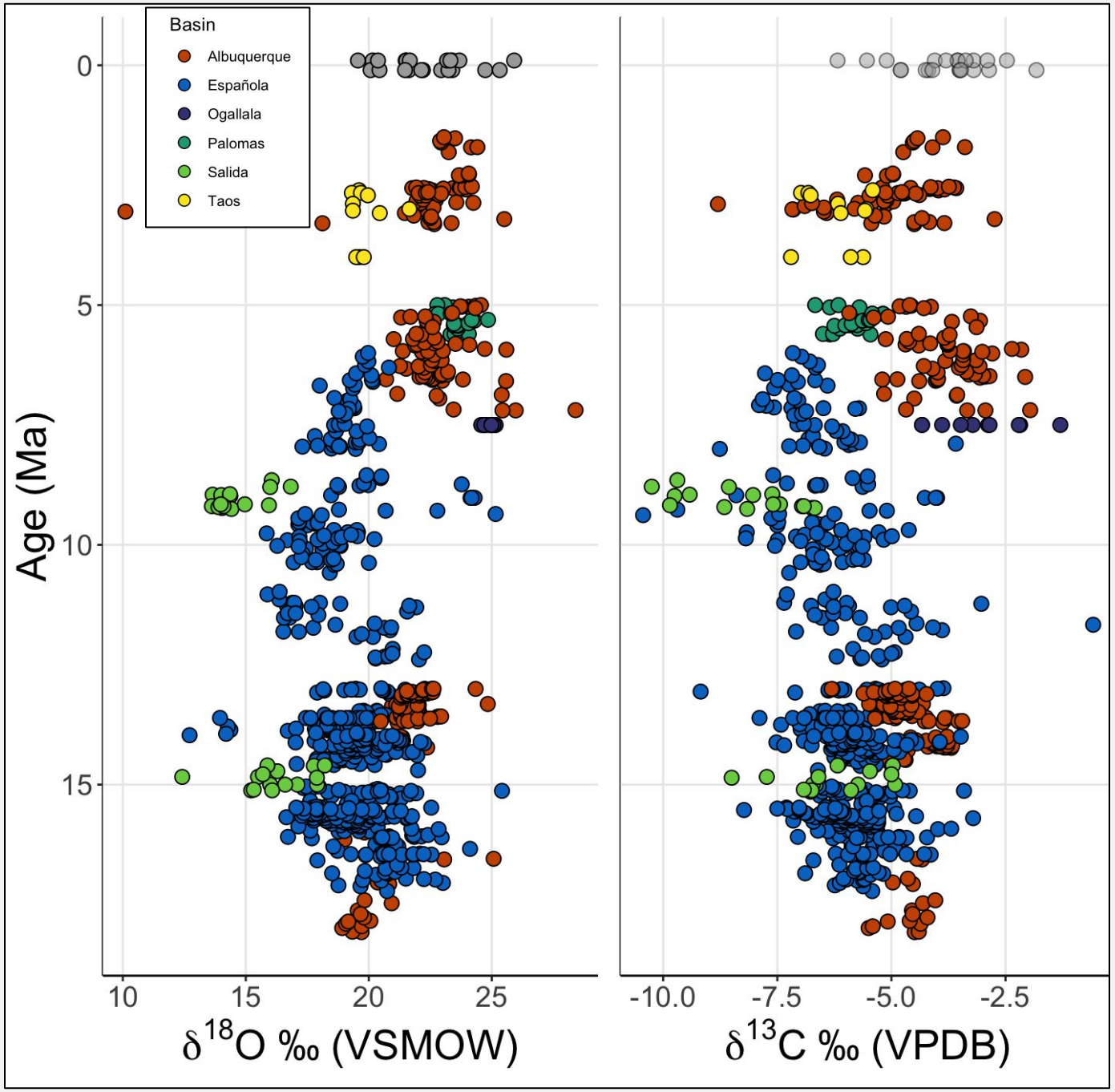
# Precipitation $\delta^{18}O$ vs Clumped T



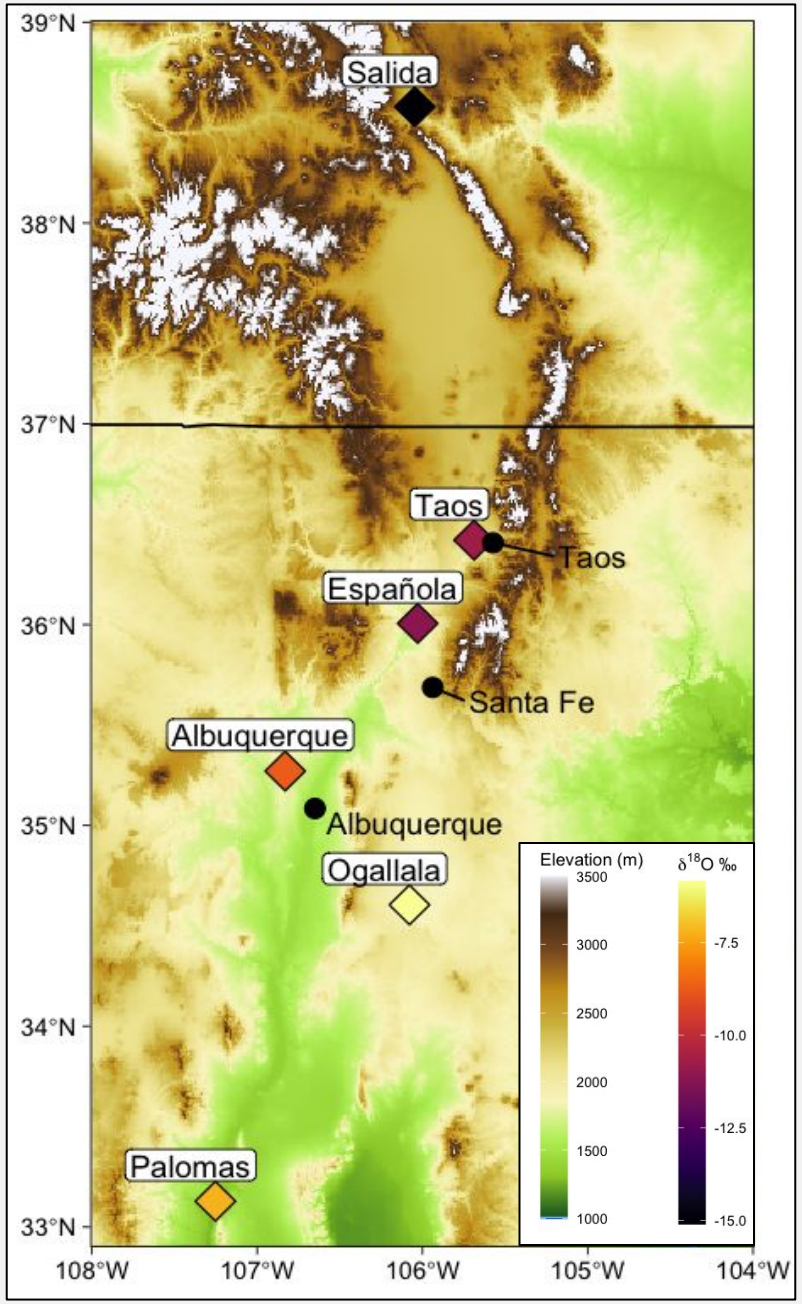
Precipitation $\delta^{18}O$ vs Clumped T
with sample type



Stable Data:
All Basins



Modern Topography Map:
All Basins



# Methods: Carbonate Clumped Isotope Thermometry

## Sample Collection & Prep

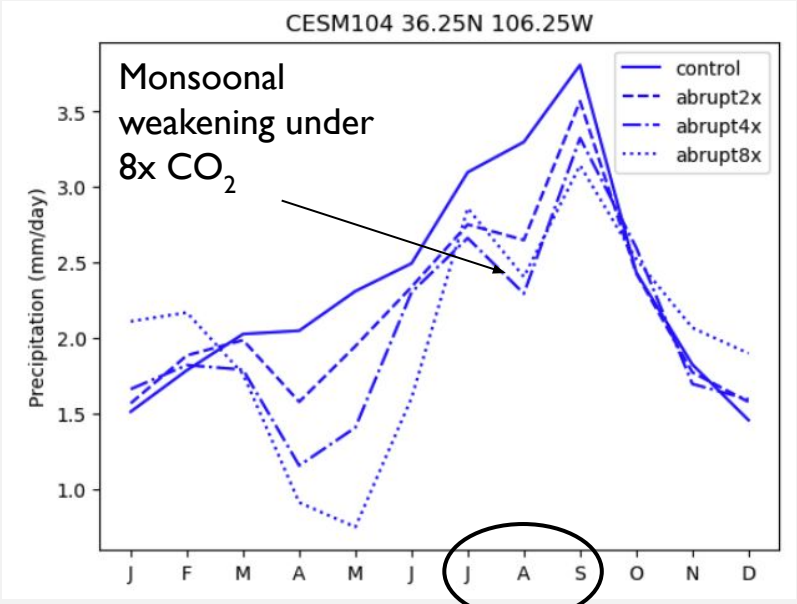
- Authigenic, well-dated carbonates are abundant across basins
- Sample types include nodules, rootcasts/rhizoliths, matrix, and carbonate cements
- Samples fizzed with dilute HCl in the field and transported in plastic bags
- Indurated samples powdered and homogenized using a Dremel
- Soft samples powdered and homogenized using agate mortar and pestle

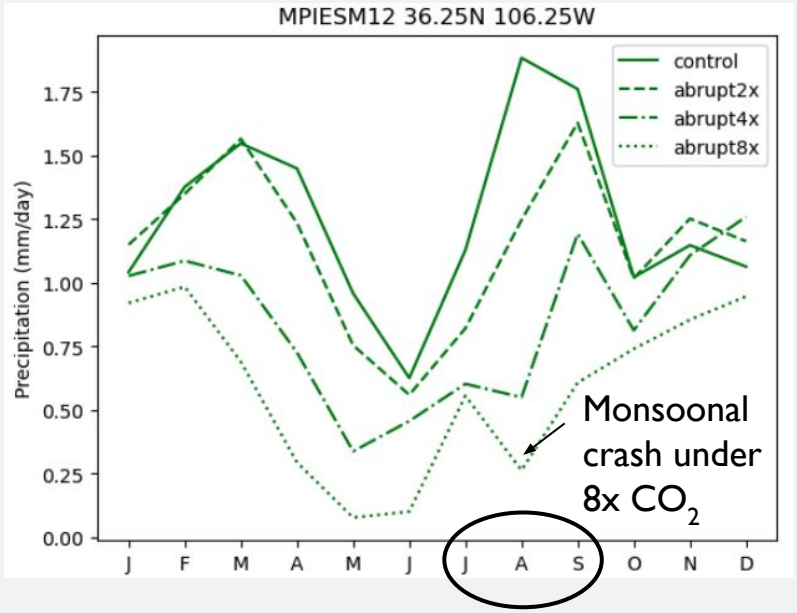
## Stable Isotope Analysis

- 350±20 µg of powdered carbonate was weighed into Exetainer® 12ml round bottom vials using a Sartorius Cubis® Micro Balance
- Samples dried overnight, flushed with helium, injected with phosphoric acid, and analyzed with a Delta V IRMS, coupled to a GC-isolink unit, with a Gas Bench
- Samples selected for clumped isotope analysis based on temporal and spatial distribution, sample type, and weight % carbonate

## Clumped Isotope Analysis

- Samples were soaked in 3% bleach solution, rinsed and centrifuged with MQ water 5 times, and dried in vacuum oven at 25°C
- Replicates of 7.8-14 mg were weighed into 6x4 mm silver capsules and dissolved in a 90°C common acid bath before analysis with a Thermo 253+ dual inlet mass spectrometer
- 4-6 replicates analyzed per sample until standard error of each sample was below 2°C

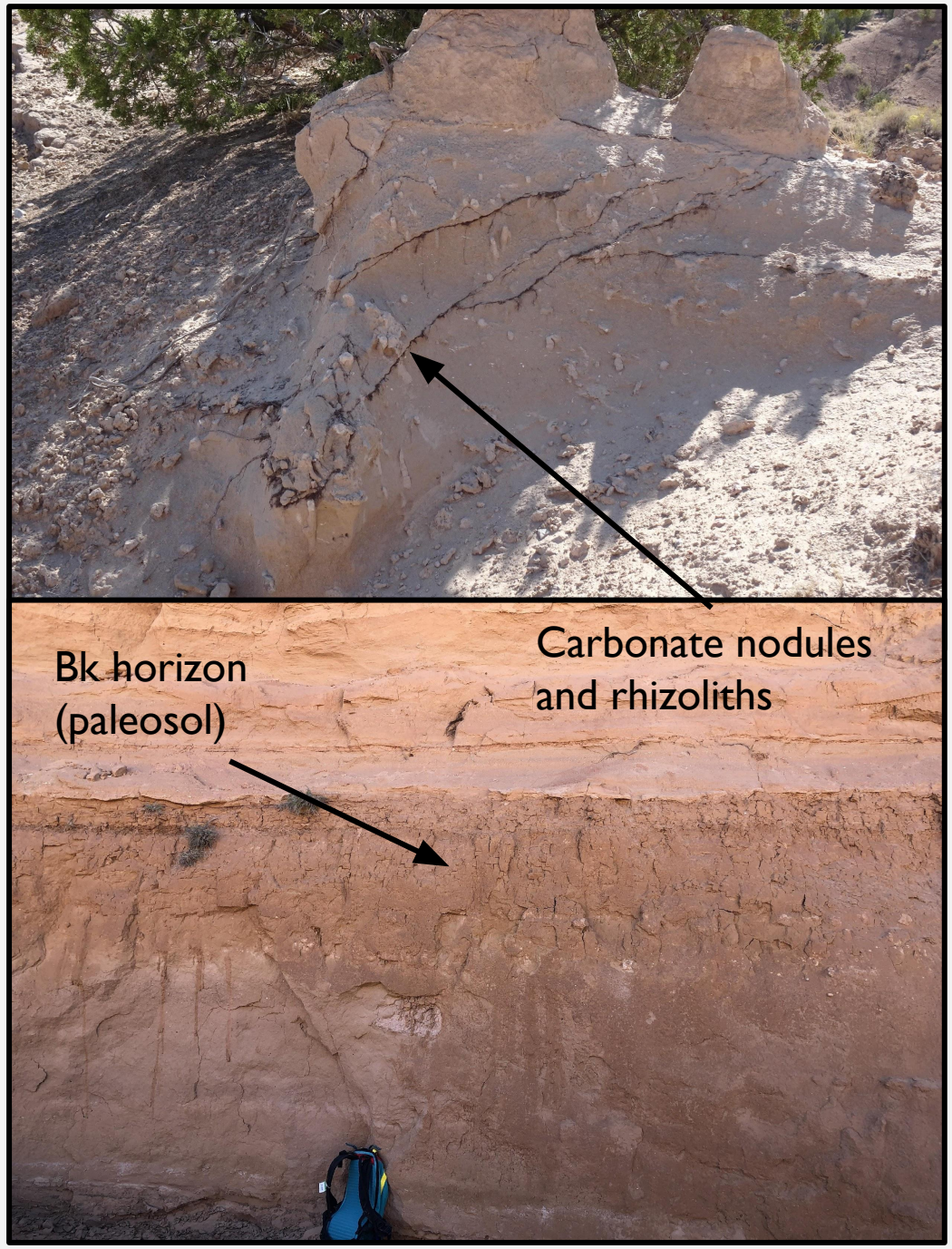



M. Rugenstein et al. 2020, Geophysical Research Letters

# NAM in Response to Warming

- Ocean-equilibrated (LongRunMIP) model runs at 1,000+ years
- Significant uncertainty in monsoonal response to $CO_2$-driven warming
- Model-dependent




# Field Photos (Samples)

- Rio Grande Rift filled with Neogene sediments in Española and Albuquerque Basins (Santa Fe Group)
- Abundant authigenic carbonates across well-dated sections
- Previous and new analysis of carbonate $\delta^{18}O$ and $\delta^{13}C$; new clumped isotope analysis