Neogene evolution of paleoenvironments in the North American Great Plains from a stable isotope study

Livia Manser[1] (lmanser@student.ethz.ch), Jeremy K. Caves Rugenstein[1], Tyler Kukla[2], Sean Willett[1]

[1]Institute of Geology, ETH Zürich, CH-8092 Zürich, Switzerland; [2]Department of Geological Sciences, Stanford University, Stanford, CA 94305, USA

Summary

Motivation

• The Neogene presents an opportunity to probe hydroclimate and landscape evolution changes in response to long-term changes in global climate and atmospheric pCO_2.
• Enhance stable isotope data resolution, especially in the Southern Great Plains.

Possible Mechanisms

• Weakening in moisture supply since the Miocene might have lead to an eastward shift of the aridity gradient towards the 100th meridian.
• Shift from a C_3 to C_4 vegetation will be reflected in an increase in $\delta^{13}C$ due to the reduced isotopic fractionation of C_4 plants.
• Global climate cooling and declines in CO_2 are likely responsible for a decrease in primary productivity due to a decrease of the CO_2-fertilization effect, consistent with increasing $\delta^{13}C$ value due to a decrease in soil-respiration.

Approach

• We analyse $\delta^{18}O$ and $\delta^{13}C$ trends versus latitude, longitude and age in order to compare paleoclimate records in space and time. In addition to the data from the Ogallala and the Rio Grande Rift, we compare with existing data in order to get a higher spatial and temporal coverage.
• We create maps of $\delta^{18}O$ and $\delta^{13}C$ to understand the spatial patterns of these isotope systems.

Modern climate in the Great Plains

• Moisture transport by the Great Plains Low-Level Jet (GPLLJ) originating from the Gulf of Mexico towards the Great Plains during summer (Jiang et al., 2007; Ting & Wang, 2006) (Figure 2).
• GPLLJ partly generated due to radiational cooling of the earth's surface (Parish, 2017).
• Strong association between GPLLJ strength and orography of North America (Jiang et al., 2007).
• In the Great Plains, where evaporation is not energy limited but controlled by precipitation, a hot spot of land-atmosphere coupling strength during June, July, and August (JJA) exists (Koster, 2004).

Sampling material

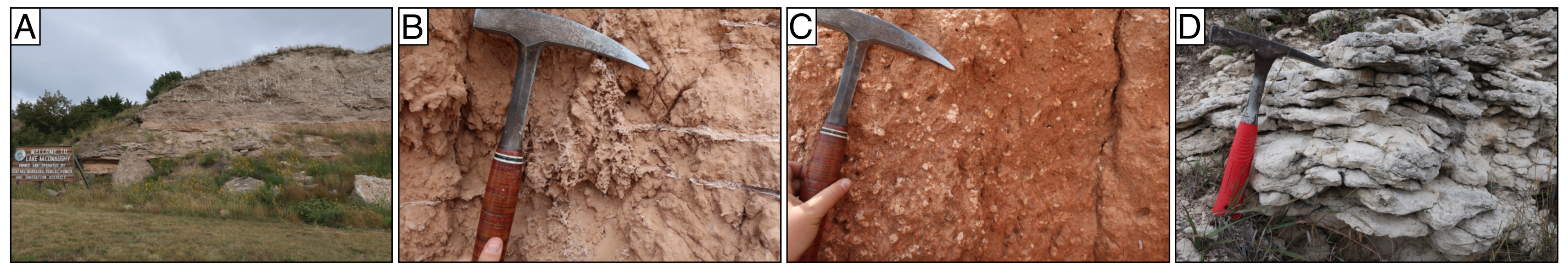

Figure 1: Sampling material. A: Section showing a mixture of large burrows, root casts and sand layers containing interstitial carbonate; B: Rootcasts; C: Carbonate nodules; D: Calcrete. Samples were collected from all layers containing calcium carbonate (rootcasts, nodules, burrows or bulk samples with interstitial carbonate).

Spatial distribution of $\delta^{18}O$

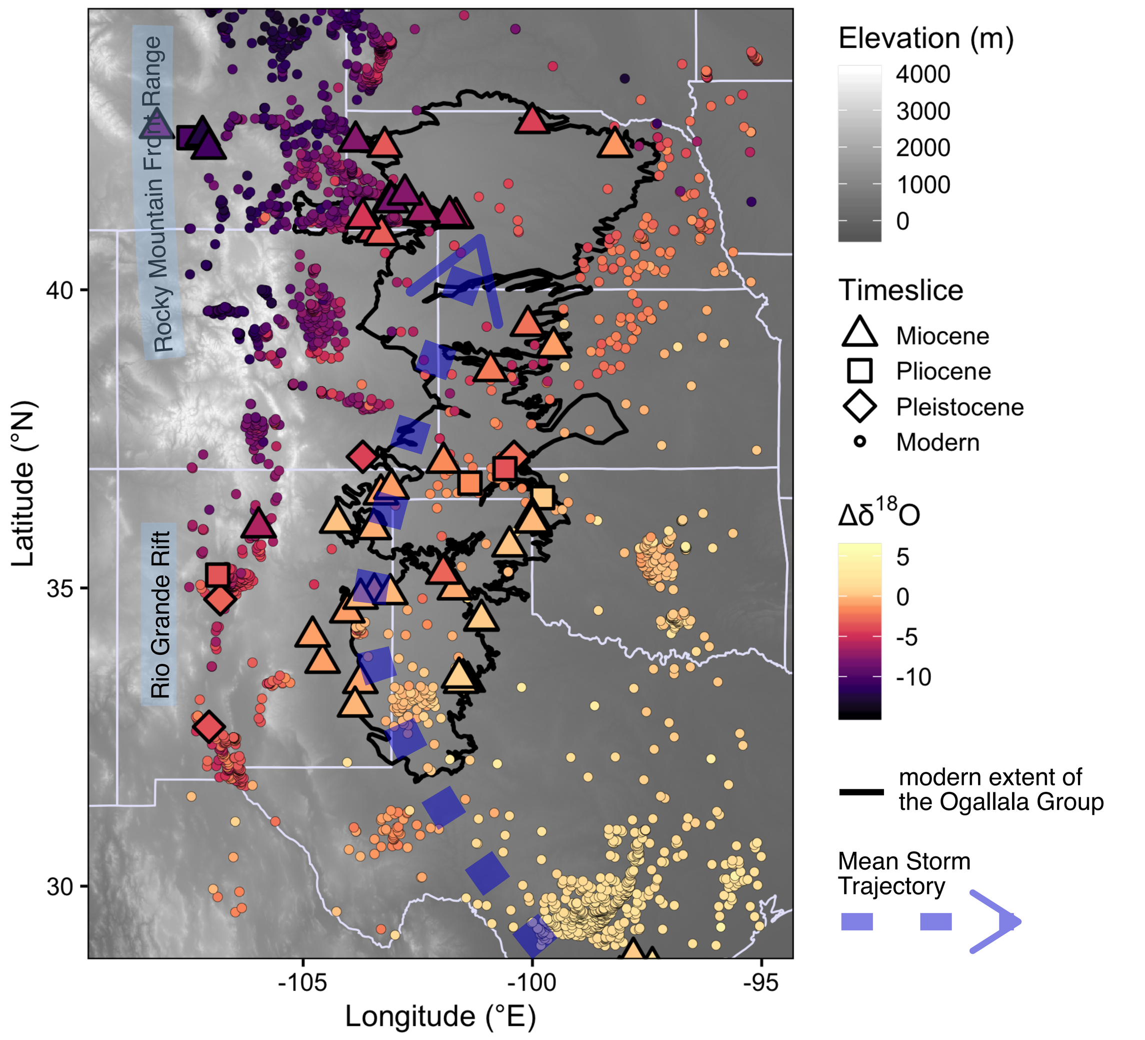

Figure 2: Map showing the spatial distribution of modern (Waterisotopes Database, 2019) and paleo $\Delta\delta^{18}O$ (this study and compilation of Chamberlain et al., 2012) between -95°E and -107°E, binned into three timeslices (Miocene (23.9–5.3 Ma), Pliocene (5.3-2.6 Ma) and Pleistocene (2.6–0.01 Ma)). For gradient comparison $\Delta\delta^{18}O$ was calculated by anchoring modern and paleo data at the most upstream (coastal) paleo site. The extent of the Ogallala Group is within the black line. The arrow denotes the mean precipitation-producing storm track of the GPLLJ originating from the Gulf of Mexico calculated by back-trajectory modelling (Caves et al., 2015) using HYSPLIT.

Trends in Latitude/Longitude

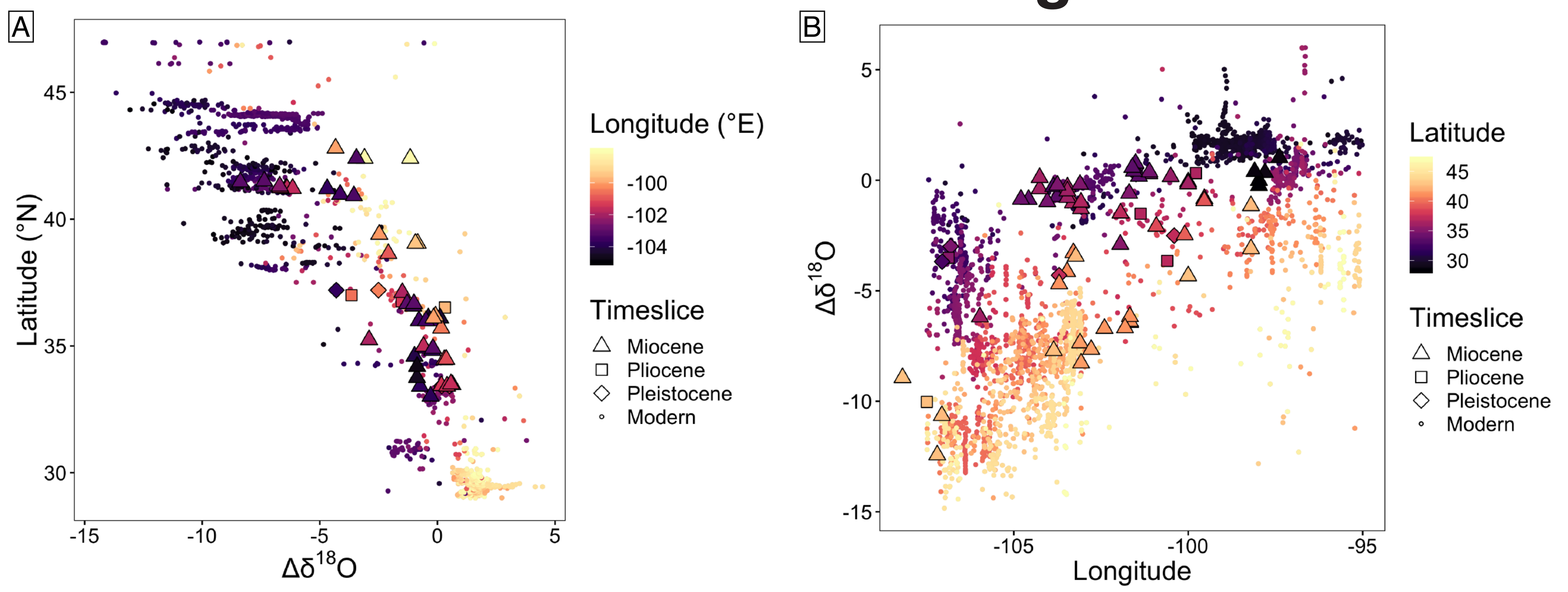

Figure 3: Paleo $\Delta\delta^{18}O$ of the Great Plains (this study and compilation of Chamberlain et al., 2012) and modern water $\Delta\delta^{18}O$ (Waterisotopes Database, 2019) plotted versus latitude and longitude, binned into three timeslices (Miocene (23.9–5.3 Ma), Pliocene (5.3-2.6 Ma) and Pleistocene (2.6–0.01 Ma)). For gradient comparison $\Delta\delta^{18}O$ was calculated by anchoring modern and paleo data at the most upstream (coastal) paleo site. A: $\Delta\delta^{18}O$ versus latitude, data points colored after longitude; B: $\Delta\delta^{18}O$ versus longitude, data points colored after latitude.

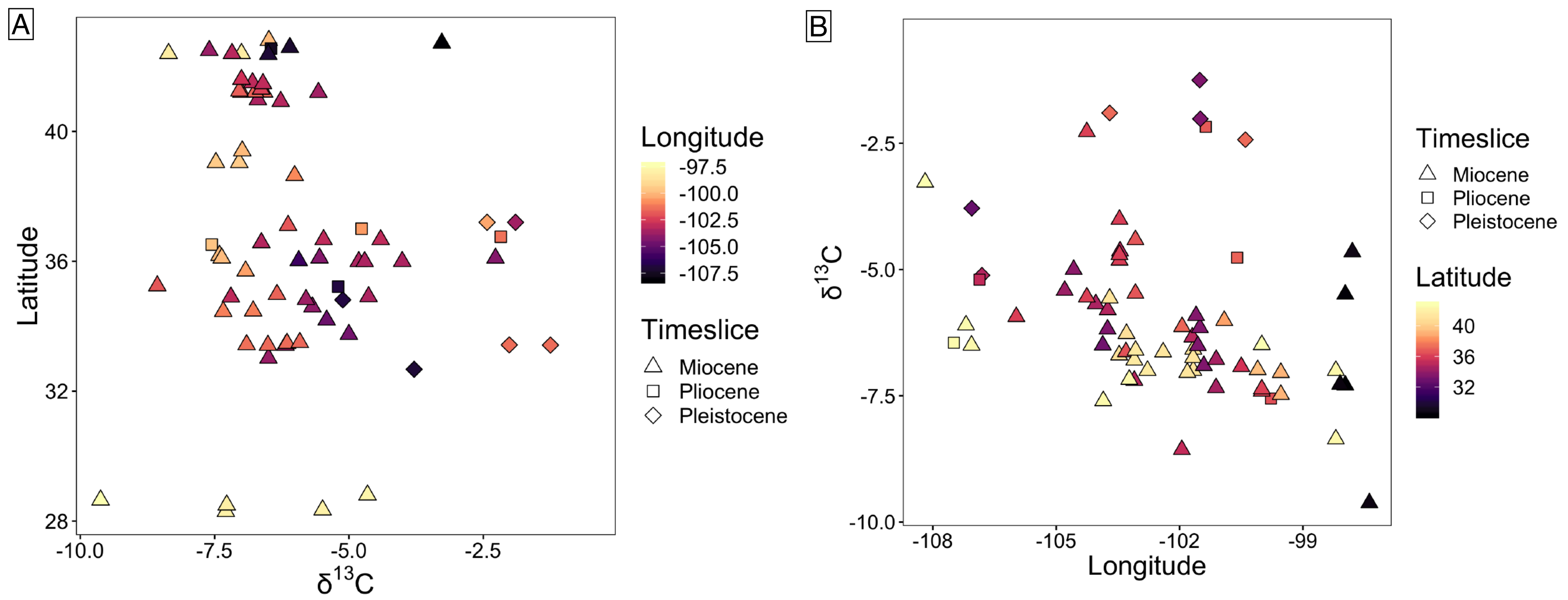

Figure 4: Paleo $\Delta\delta^{18}O$ of the Great Plains (this study and compilation of Chamberlain et al., 2012) plotted versus latitude and longitude, binned into three timeslices (Miocene (23.9–5.3 Ma), Pliocene (5.3-2.6 Ma) and Pleistocene (2.6–0.01 Ma)). A: $\delta^{13}C$ versus latitude, data points colored after longitude; B: $\delta^{13}C$ versus longitude, data points colored after latitude.

$\delta^{13}C$ evolution through time

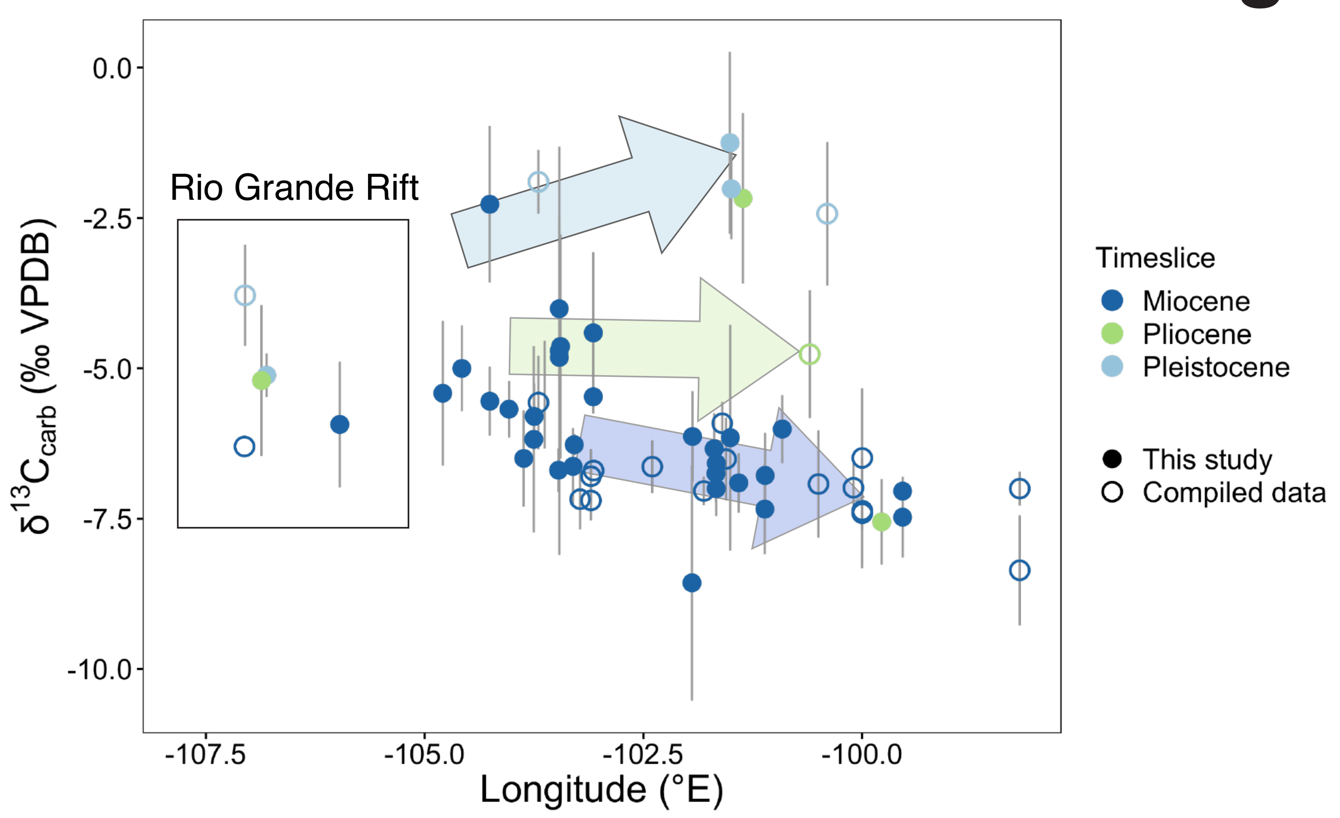

Figure 5: Paleo $\delta^{13}C$ from paleosol and authigenic carbonate binned into three timeslices (Miocene (23.9–5.3 Ma), Pliocene (5.3-2.6 Ma) and Pleistocene (2.6–0.01 Ma)) plotted versus Longitude. Samples were collected from the Great Plains and the Rio Grande Rift, to improve spatial coverage compiled data (Chamberlain et al., 2012) was used as well. Arrows denote the trend of $\delta^{13}C$ from west to east according to each timeslice.

Any comments or suggestions on the processes or interpretation are welcome! Please contact Livia

Shift of aridity gradient

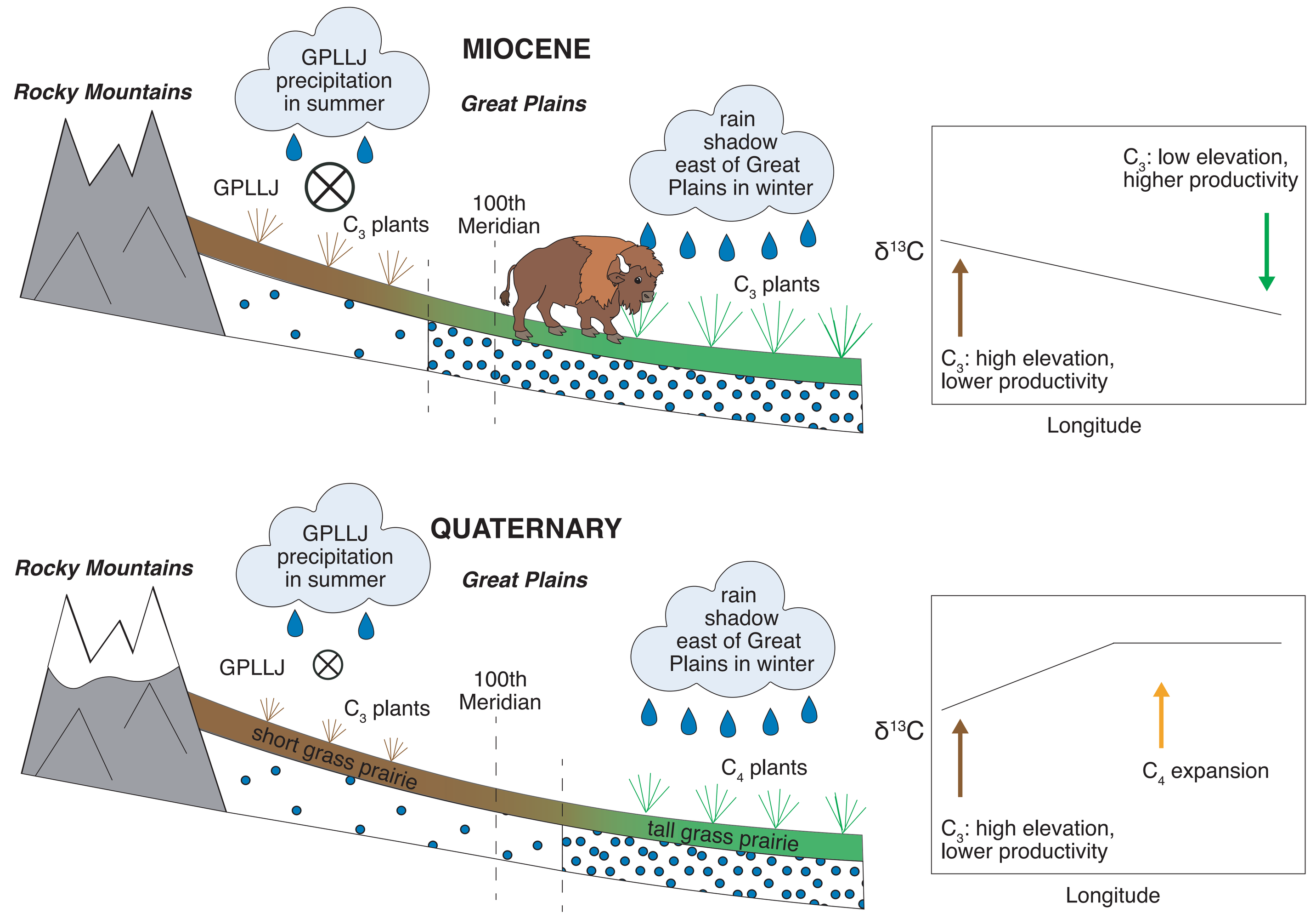

Figure 6: Cartoon of main processes east of the Rocky Mountains in a one-dimensional domain. A sharp aridity gradient at around the 100th meridian occurs today, with a more humid climate to the east and an arid climate to the west, which is reflected in soil moisture (Seager et al., 2018). Data suggest a shift of this aridity gradient to the west in the Miocene compared to the location of the modern gradient. Bison represents greater large herbivore diversity in the Miocene.

Conclusions

Moisture supply

• There is not much change in $\delta^{18}O$ between the late Miocene and today. This could be due to some countervailing processes like weakening of the GPLLJ resulting in decreasing $\delta^{18}O$ values and an increase in moisture recycling along a storm track wich would result in increasing $\delta^{18}O$ values.

Vegetation

• C_4 expansion since late Miocene could explain higher $\delta^{13}C$ values towards the east.
• A decrease in productivity since late Miocene, due to aridification or pCO_2 decline could explain the higher $\delta^{13}C$ values in the west.
• The Rio Grande Rift shows much less variation in $\delta^{13}C$ values compared to the eastern sites on the Great Plains, suggesting that changes in precipitation or elevation that may drive shifts in C_3 to C_4 plants affected the eastern Great Plains more. Further, the Rio Grande Rift sites have higher $\delta^{13}C$, which shows that plant productivity was lower.

Future Work

• Run soil respiration model using $\delta^{13}C$, to model vegetation evolution.
• Run vapor transport model using $\delta^{18}O$, to solve for water balance through time.
• Thin sections to classify types of carbonate.
• ^{14}C on selected samples to check for new formed carbonate overprinting carbonate during the Miocene.

References

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