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Notes

Middle Cenozoic uplift and concomitant drying in the central Rocky Mountains and adjacent Great Plains

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ABSTRACT

When and how the central Rocky Mountains (Rockies) of western North America gained modern topography remain controversial questions. We reconstruct the middle and late Cenozoic topography along a transect that extends from the Great Plains of western Nebraska across the central Rockies in Wyoming, based on reconstructed surface-water δD values from volcanic glass δD values. Our data show gradual increases of surface-water δD values in both the central Rockies and adjacent Great Plains during middle and late Cenozoic time, and the establishment of a similar-to-present surface-water δD gradient between the central Rockies and western Great Plains before earliest Oligocene time. These observations suggest that the region underwent differential uplift to form relief similar to that of today before earliest Oligocene time. This uplift has caused regional drying and the gradual increase of surface-water δD values over the past 35 m.y. When placed in the context of other paleoaltimetry studies, our work suggests that along our transect, the central Rockies and adjacent Great Plains underwent uplift during the late Eocene, and have not undergone any large-magnitude (>~500 m) uplift since that time.

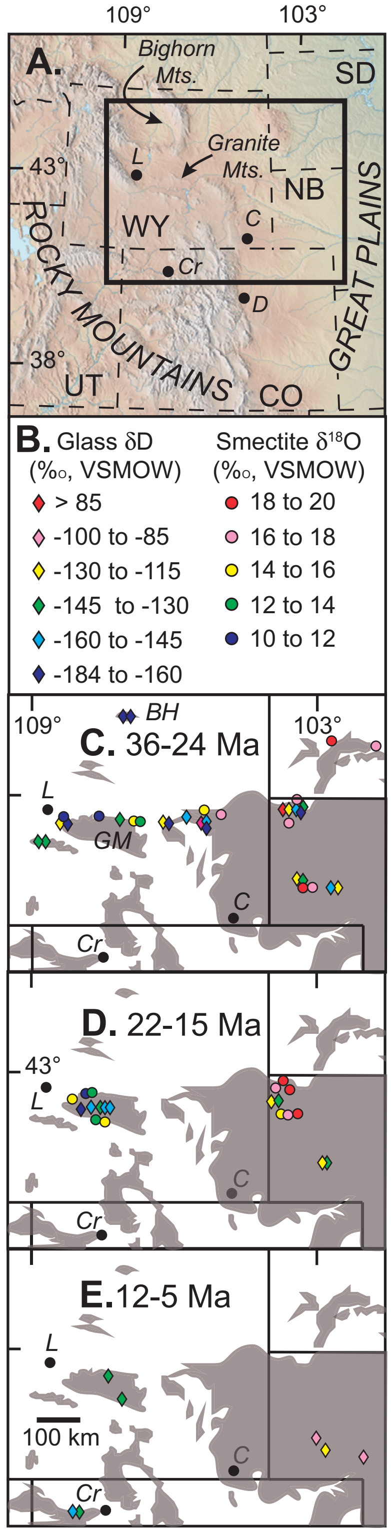

Figure 1. A: Map of study area. B: Key to analyzed volcanic glass δD values in central Rocky Mountains and adjacent Great Plains. C: Values from 36 to 24 Ma. D: Values from 22 to 15 Ma. E: Values from 12 to 5 Ma. Digital elevation model is from the U.S. Geological Survey National Map (http://nationalmap.gov/index.html). Smectite $\delta^{18}O$ data are from Sjostrom et al. (2006). Gray areas in C–E represent distribution of middle and late Cenozoic sedimentary rocks. VSMOW—Vienna standard mean ocean water; WY—Wyoming; UT—Utah; CO—Colorado; NB—Nebraska; SD—South Dakota; BH—Bighorn Mountains; GM—Granite Mountains; Cr—Craig; C—Cheyenne; D—Denver; L—Lander.

INTRODUCTION

The origin and timing of elevation and relief of the present Rocky Mountains (Rockies) in western North America are not well known. The distribution of marine sedimentary rocks indicates that the central Rockies were close to sea level in Late Cretaceous time, but the regional average elevation of Wyoming today is ~2050 m (Fig. 1). Current understanding of regional uplift focuses mainly on two periods: latest Cretaceous–early Eocene time (ca. 70–50 Ma), during which shortening of the Laramide orogeny led to creation of isolated uplifts (Dickinson et al., 1988), and late Miocene–Pliocene time (ca. 8–4 Ma), during which regional surface uplift may have occurred (McMillan et al., 2002; Duller et al., 2012). While Laramide orogeny produced much of the topography, post-Laramide changes in topography have not been well constrained. Proposals include continuous subsidence of the Laramide intermontane basins during late Eocene–middle Miocene time (McMillan et al., 2006), and dynamic uplift during Oligocene–Miocene time due to removal of lower mantle lithosphere or the Farallon oceanic slab (Liu and Gurnis, 2010; Roberts et al., 2012).

Surface uplift of the central Rockies may have affected atmosphere circulation in North America and caused regional climate change that differed from global patterns (Zachos et al., 2001). Although major cooling in global climate occurred at the time of the Eocene-Oligocene boundary, reconstructed mean annual precipitation (MAP) and mean annual temperature show no trends in Montana (Retallack, 2007), suggesting that regional drying took place either by surface uplift of the central Rockies, or across the Cordilleran hinterland farther west before early Oligocene time (Mix et al., 2011). In the Great Plains, just east of the central Rockies, reconstructed MAP shows a gradual decline during latest Eocene–early Oligocene time, suggesting that regional topography buffered but did not completely mask global climate cooling at the Eocene-Oligocene boundary (e.g., Hembree and Hasiotis, 2007; Retallack, 2007). On the contrary, MAP was relatively stable in Montana and Nebraska during late Cenozoic time (Retallack, 2007), showing no response to late Cenozoic global cooling. These observations imply that the central Rockies were not high enough to completely alter local climate during early Oligocene time, but were high enough to cause steady semiarid climate during the late Cenozoic. However, none of these data are from the interior of the central Rockies, and therefore

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changes of local climate in response to surface uplift of the region were not fully evaluated.

Most paleoelevation studies in the central Rockies focus on the period of the Laramide orogeny, suggesting that, by the end of the orogeny, the regional landscape contained uplifts as high as 4.5 ± 1.3 km (e.g., Wolfe et al., 1998; Fan and Dettman, 2009), while intervening basins were only ~500 m above sea level (MacGinitie, 1969; Fan et al., 2011). There has been one stable isotope paleoelevation reconstruction in the central Rockies, in which $\delta^{18}O$ values of smectite samples show that similar-to-present isotopic gradients existed between the western Great Plains and central Rockies during the early Oligocene and middle Miocene (Sjostrom et al., 2006). We used 60 new hydrogen isotope data from volcanic glass (δD_{vg}) of latest Eocene–Miocene age in order to reconstruct the history of surface uplift and its impact on local climate. These samples were collected along a west-east transect from the central Rockies to the western Great Plains, mostly between 41°N and 43°N (Fig. 1). By systematic comparison of the reconstructed surface-water δD (δD_{sw}) values along the transect, we reduce the uncertainties on paleoelevation reconstruction caused by changes in climate that took place during that time.

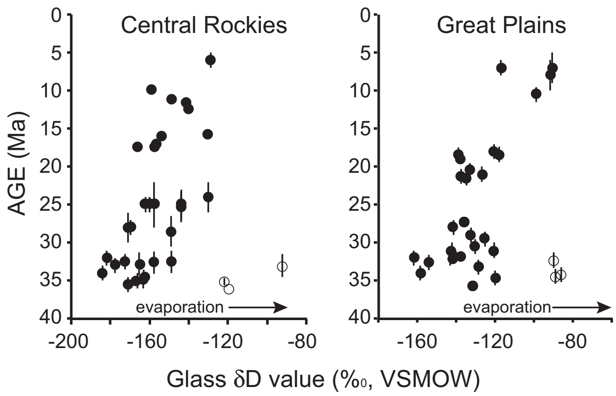

Figure 2. Volcanic glass δD values in the past ~35 m.y. in both central Rocky Mountains and western Great Plains. Values represent averages of multiple analyses of each sample. Open circles represent samples potentially hydrated by highly evaporated water. Vertical lines represent the error bars of estimated age. Data are in Table DR1 (see footnote 1). VSMOW—Vienna standard mean ocean water.

STRATIGRAPHY AND METHODS

Middle-late Cenozoic deposits in the central Rocky Mountains and western Great Plains are primarily composed of eolian and fluvial fine-grained sandstone and siltstone ranging in thickness from <100 m to ~1500 m (Fig. 1). Volcanic glass was separated from latest Eocene–Miocene units exposed in sedimentary basins in the lower parts of the Rockies as well as from small isolated deposits trapped high in the Granite and Bighorn Mountains. The strata contain abundant glass shards and pure ash beds derived from the widespread middle-late Cenozoic ignimbrite flareups in western North America (Best et al., 2013). All the volcanic glass samples were treated in 5% HF for ~30 s and washed in deionized water repeatedly to remove clay alteration (based on our comparison of processing methods; see the GSA Data Repository[1] for details). Age constraints of the samples are based on stratigraphic correlation and linear extrapolation of radiometric ages of ash beds (Table DR1 in the Data Repository).

RESULTS

Water contents in the majority of volcanic glass samples vary between 2% and 6%. A few of the samples having water content <2% also show high δD values. These samples are most likely not fully hydrated and contain magmatic water, and are excluded from discussion. Although the δD values of our samples display large variations, the gradual change of δD values to higher values occurs in both the central Rockies and Great Plains (Fig. 2). The large variations may reflect different sources of surface water and depositional environments, degree of evaporation, and elevation of the sampling sites. A few high δD values at 35–30 Ma are offset from the main trends of the δD values (Fig. 2). These samples are most likely hydrated with evaporated surface water and therefore are not representative of local precipitation values. We consider the lowest and/or mean δD_{vg} values to reflect precipitation δD values that were least influenced by evaporation. The lowest and mean δD_{vg} values, respectively, increase with decreasing stratigraphic age from –184‰ and –167‰, to –130‰ and –129‰ in the central Rockies, and from –142‰ and –139‰ to –115‰ and –100‰ in the western Great Plains during the past ~35 m.y. (Fig. 2). The mean and minimum δD_{vg} values, and calculated δD_{sw} values based on Friedman et al. (1993a), also show an eastward increase with a lapse rate of 5‰–11‰ per degree longitude, similar to the present isotopic gradient (Fig. 3).

REGIONAL DRYING AND HIGH RELIEF IN THE PAST 35 m.y.

Our results show concomitant overall increase in δD_{vg} values in both the central Rock-

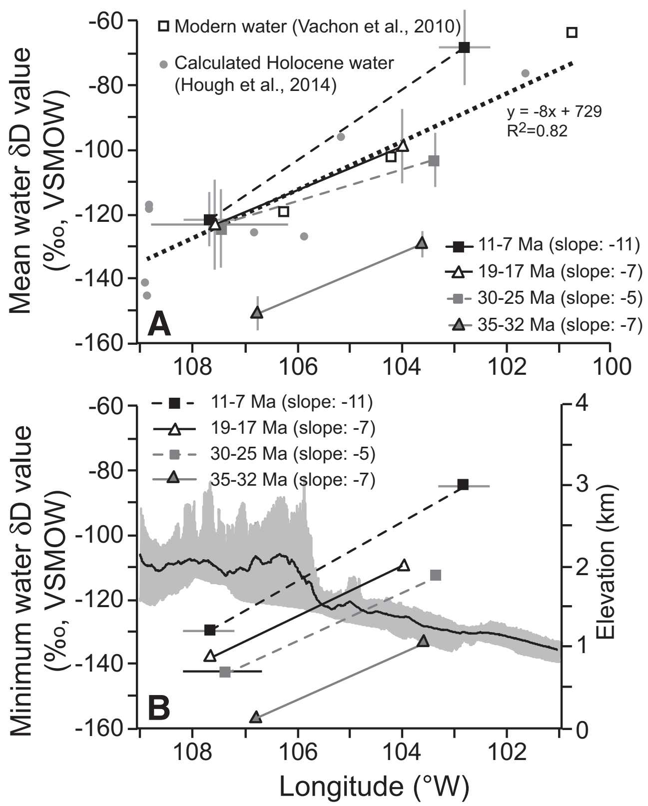

Figure 3. A: Calculated mean latest Eocene–Miocene surface-water δD gradient and Holocene precipitation δD values in central Rocky Mountains and western Great Plains (VSMOW—Vienna standard mean ocean water). Holocene precipitation δD values (regression in thick dashed line) are calculated from modern precipitation $\delta^{18}O$ values of Vachon et al. (2010), and reconstructed Holocene precipitation $\delta^{18}O$ values using soil carbonate $\delta^{18}O$ values and clumped isotope temperature of Hough et al. (2014). B: Calculated minimum latest Eocene–Miocene surface-water δD gradient, and mean (black line) and variation (gray zone) of elevation along 10-km-wide swath at 42.5°N.

[1]GSA Data Repository item 2014191, sample processing and analysis method, discussion of other factors on isotope record, and Table DR1, is available online at www.geosociety.org/pubs/ft2014.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

ies and western Nebraska from late Eocene to Miocene time. Three lines of evidence suggest that our documented trends did not result from secondary alteration of volcanic glass. First, the mechanisms of volcanic glass hydration suggest that secondary hydration of glass is very unlikely. A depolymerized gel surface layer <0.1 μm thick is formed by hydrolysis and condensation reactions as water molecules diffuse into glass, and the layer becomes denser during hydrolysis and behaves as a diffusion barrier to prohibit secondary water exchange at near surface temperature (Cailleteau et al., 2008; Valle et al., 2010). Second, volcanic glasses formed during the Pleistocene yield very distinctive δD_{sw} values compared to present local precipitation δD values (Friedman et al., 1993b). Third, the large variation of δD_{vg} values in our studied stratigraphic units argues against secondary hydration, because such alteration should reset the δD_{vg} values to be identical to each other.

We interpret the gradual increase of the δD_{vg} values during the latest Eocene–Miocene time to be the result of regional drying in the central Rockies and western Great Plains. A decrease in precipitation led to low relative humidity, which increases precipitation values by enhancing sub-cloud evaporation and recycling of continental vapor into atmosphere (Gat, 1996). Such a drying effect is typically a result of high local elevation, such as found in the northern Tibetan Plateau (Bershaw et al., 2012). The latest Eocene–Miocene drying trend may have been initiated by high local elevations in the central Rockies and adjacent Great Plains, as well as high elevation in the Cordilleran hinterland to the west (to 3.4 km) during latest Eocene–Oligocene time (Mix et al., 2011).

The eastward increases of the δD_{vg} and calculated δD_{sw} values are similar to the δD gradients of both modern and reconstructed Holocene precipitation in the area (Vachon et al., 2010; Hough et al., 2014; Fig. 3). The lapse rate of 8‰ ± 3‰ per degree of longitude (Fig. 3) is higher than the expected effects of continentality, which is typically in the range of 1‰–3‰ per 100 km for δD values (Sharp, 2007). Any climate change that took place should have affected the precipitation δD values in both the central Rockies and in the adjacent Great Plains, as seen in the similar drying trends in both areas over the past 35 m.y. (Fig. 2). Thus climate change did not have an impact on the observed isotopic gradients. It is possible that different-from-present atmospheric circulation caused high summer:winter precipitation ratios in the western Great Plains and low summer:winter precipitation ratios in the central Rockies during the studied periods, which led to the same isotopic gradient as the current gradient. However, given that atmospheric circulation is often modified by topography (Roe, 2005), and Paleogene large-scale atmosphere circulation models for the western U.S. are not significantly different from that of today (Sewall and Sloan, 2006), it seems unlikely that any change of atmospheric circulation by factors other than uplift of the Rockies is responsible for the observed conformity of isotopic gradient. Instead, we interpret the eastward increase of δD_{sw} values as a result of progressive rainout of air masses derived from the Gulf of Mexico and Atlantic as they lifted over the central Rockies.

In addition to reflecting regional elevation contrasts, the large variation of δD_{sw} values locally within the central Rockies reflects local relief during Oligocene time. The isotopic variation is as much as 32‰ during the period 30–25 Ma, with the lowest δD values in the highlands of the Bighorn and Granite Mountains and the highest δD values in the lowlands. This large isotopic variation is similar to the variation of Holocene precipitation δD values in the central Rockies (Fig. 3). The estimated paleorelief between the Laramide peaks in Wyoming and adjacent basin floors was <1 km when the modern precipitation δD lapse rate is assumed; this value is similar to the modern relief in the area (Fig. 3B). This magnitude of paleorelief is small compared to the 3–4 km of total relief in the Rockies during early Eocene time (Fan and Dettman, 2009; Fan et al., 2011). The magnitude of relief was reduced during middle-late Eocene time by some combination of factors, such as erosion or extensional collapse of range crests, and/or infilling or uplift of the basins.

DISCUSSION AND CONCLUSIONS

The volcanic glass hydrogen isotope data presented here support a hypothesis that the steep elevation gradient between the central Rockies and the western Great Plains has existed as a major topographic feature since at least earliest Oligocene time with mean elevation contrast comparable to the modern topography. This result is in agreement with previously published oxygen isotope results for similar units in the same study area (Fig. 1; Sjostrom et al., 2006). These results, in combination with evidence that Laramide intermontane basins were near sea level during early Eocene time (Fan et al., 2011), suggest that the entire central Rockies and adjacent parts of the Great Plains gained much of their present elevation concurrently during middle-late Eocene time and regional drying was initiated in response to this surface uplift. This is coincident with the development of a widespread depositional hiatus or erosion event that took place during the late Uintan–Duchesnean land mammal stages (42–37 Ma) in Wyoming (Lillegraven, 1993). A similar unconformity separating Late Cretaceous and latest Eocene–Oligocene strata is found in Nebraska and South Dakota (Terry and LaGarry, 1998). The mechanism of uplift may be attributed to lithospheric rebound induced by the foundering of the Farallon slab or lower mantle lithosphere (Liu and Gurnis, 2010; Roberts et al., 2012), dynamic or isostatic topography induced by mantle and crustal anomalies (Lowry et al., 2000), and/or surface erosion (Champagnac et al., 2007). The uplift in our study area may be part of a more regional uplift pattern in the Cordilleran during middle Cenozoic time (Mix et al., 2011; Chamberlain et al., 2012).

Although the isotopic gradient mainly reflects topographic differences, there are some uncertainties due to not knowing well the relative contributions of different vapor sources, vapor condensation temperature, and degree of evaporation. As such, our results have an overall uncertainty of ±500 m, based on the calibration of Hough et al. (2014). Furthermore, our data set is limited; more data would refine the results. Our results are not counter to the proposed differential uplift of the region during latest Cenozoic time determined from incisional and tilting histories (McMillan et al., 2002, 2006; Duller et al., 2012), and suggest that such differential uplift was of small magnitude (<500 m) compared to the middle Cenozoic event described here. Therefore we suggest that the modern landscape of the central Rockies in Wyoming and adjacent Great Plains of Nebraska was established by earliest Oligocene time, and may have been modified by a few hundreds of meters during Neogene time. The uplift of the region initiated regional drying, and caused a concomitant positive shift of surface-water δD values in the past ~35 m.y.

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REFERENCES CITED

Bershaw, J., Penny, S.M., and Garzione, C.N., 2012, Stable isotopes of modern water across the Himalaya and eastern Tibetan Plateau: Implications for estimates of paleoelevation and paleoclimate: Journal of Geophysical Research, v. 177, D02110, doi:10.1029/2011JD016132.

Best, M.G., Christiansen, E.H., and Gromme, S., 2013, The 36–18 Ma southern Great Basin, USA, ignimbrite province and flareup: Swarms of subduction-related supervolcanoes: Geosphere, v. 9, p. 260–274, doi:10.1130/GES00870.1.

Cailleteau, C., Angeli, F., Devreux, F., Gin, S., Jestin, J., Jollivet, P., and Spalla, O., 2008, Insight into silicate-glass corrosion mechanisms: Nature Materials, v. 7, p. 978–983, doi:10.1038/nmat2301.

Chamberlain, C.P., Mix, H.T., Mulch, A., Hren, M.T., Kent-Corson, ML., Davis, S.J., Horton, T.W., and Graham, S.A., 2012, The Cenozoic climatic and topographic evolution of the western North American Cordillera, Journal of Science, v. 312, p. 213–262, doi:10.2475/02.2012.05.

Champagnac, J.D., Molnar, P., Anderson, R.S., Sue, C., and Delacou, B., 2007, Quaternary erosion-induced isostatic rebound in the western

Alps: Geology, v. 35, p. 195–198, doi:10.1130/G23053A.1.

Dickinson, W.R., Klute, M.A., Hayes, M.J., Janecke, S.U., Lundin, E.R., McKittrick, M.A., and Olivares, M.D., 1988, Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region: Geological Society of America Bulletin, v. 100, p. 1023–1039, doi:10.1130/0016-7606(1988)100<1023:PAPSOL>2.3.CO;2.

Duller, R.A., Whittaker, A.C., Swinehart, J.B., Armitage, J.J., Sinclair, H.D., Bair, A., and Allen, P.A., 2012, Abrupt landscape change post–6 Ma on the central Great Plains, USA: Geology, v. 40, p. 871–874, doi:10.1130/G32919.1.

Fan, M., and Dettman, D.L., 2009, Late Paleocene high Laramide ranges in northeast Wyoming: Oxygen isotope study of ancient river water: Earth and Planetary Science Letters, v. 286, p. 110–121, doi:10.1016/j.epsl.2009.06.024.

Fan, M., DeCelles, P.G., Gehrels, G.E., Dettman, D.L., and Peyton, S.L., 2011, Sedimentology, detrital zircon geochronology, and stable isotope geochemistry of the lower Eocene strata in the Wind River Basin, central Wyoming: Geological Society of America Bulletin, v. 123, p. 979–996, doi:10.1130/B30235.1.

Friedman, I., Gleason, J., Sheppard, P.A., and Gude, A.J., 1993a, Deuterium fractionation as water diffuse into silicic volcanic ash, *in* Swart, P.K., et al., eds., Climate change in continental isotopic records: American Geophysical Union Geophysical Monograph 78, p. 321–323.

Friedman, I., Gleason, J., and Warden, A., 1993b, Ancient climate from deuterium content of water in volcanic glass, *in* Swart, P.K., et al., eds., Climate change in continental isotopic records: American Geophysical Union Geophysical Monograph 78, p. 309–319.

Gat, J.R., 1996, Oxygen and hydrogen isotopes in the hydrologic cycle: Annual Review of Earth and Planetary Sciences, v. 24, p. 225–262, doi:10.1146/annurev.earth.24.1.225.

Hembree, D.I., and Hasiotis, S.T., 2007, Paleosols and ichnofossils of the White River Formation of Colorado: Insight into soil ecosystems of the North American Midcontinent during the Eocene-Oligocene transition: Palaios, v. 22, p. 123–142, doi:10.2110/palo.2005.p05-119r.

Hough, B.G., Fan, M., and Passey, B., 2014, Calibration of clumped isotope geothermometer in soil carbonate in Wyoming and Nebraska, US: Implications for paleoelevation and paleoclimate reconstruction: Earth and Planetary Science Letters, v. 391, p. 110–120, doi:10.1016/j.epsl.2014.01.008.

Lillegraven, J.A., 1993, Correlation of Paleogene strata across Wyoming—A user's guide, *in* Snoke, A.W., et al., eds., Geology of Wyoming: Geological Survey of Wyoming Memoir 5, p. 414–477.

Liu, L., and Gurnis, M., 2010, Dynamic subsidence and uplift of the Colorado Plateau: Geology, v. 38, p. 663–666, doi:10.1130/G30624.1.

Lowry, A.R., Ribe, N.M., and Smith, R.B., 2000, Dynamic elevation of the Cordillera, western United States: Journal of Geophysical Research, v. 105, p. 233371–233390, doi:10.1029/2000JB900182.

MacGinitie, H.D., 1969, The Eocene Green River flora of northwestern Colorado and northeastern Utah: University of California Publications in Geological Sciences, v. 83, 202 p.

McMillan, M.E., Angevine, C.L., and Heller, P.L., 2002, Postdepositional tilt of the Miocene–Pliocene Ogallala Group on the western Great Plains: Evidence of late Cenozoic uplift of the Rocky Mountains: Geology, v. 30, p. 63–66, doi:10.1130/0091-7613(2002)030<0063:PTOTMP>2.0.CO;2.

McMillan, M.E., Heller, P.L., and Wing, S.L., 2006, History and causes of post-Laramide relief in the Rocky Mountain orogenic plateau: Geological Society of America Bulletin, v. 118, p. 393–405, doi:10.1130/B25712.1.

Mix, H.T., Mulch, A., Kent-Corson, M.L., and Chamberlain, C.P., 2011, Cenozoic migration of topography in the North American Cordillera: Geology, v. 39, p. 87–90, doi:10.1130/G31450.1.

Roberts, G.G., White, N.J., Martin-Brandis, G.L., and Crosby, A.G., 2012, An uplift history of the Colorado Plateau and its surroundings from inverse modeling of longitudinal river profiles: Tectonics, v. 31, TC4022, doi:10.1029/2012TC003107.

Roe, G.H., 2005, Orographic precipitation: Annual Review of Earth and Planetary Sciences, v. 33, p. 645–671, doi:10.1146/annurev.earth.33.092203.122541.

Retallack, G.J., 2007, Cenozoic paleoclimate on land in North America: Journal of Geology, v. 115, p. 271–294, doi:10.1086/512753.

Sewall, J.O., and Sloan, L.C., 2006, Come a little bit closer: A high-resolution climate study of the early Paleogene Laramide foreland: Geology, v. 34, p. 81–84, doi:10.1130/G22177.1.

Sharp, Z., 2007, Principles of stable isotope geochemistry: Upper Saddle River, New Jersey, Pearson Education, Inc., 360 p.

Sjostrom, D.J., Hren, M.T., Horton, T.W., Waldbauer, J.R., and Chamberlain, C.P., 2006, Stable isotope evidence for a pre-Miocene elevation gradient in the Great Plains–Rocky Mountains region, USA, *in* Willett, S.D., et al., eds., Tectonics, climate, and landscape evolution: Geological Society of America Special Paper 398, p. 309–319, doi:10.1130/2006.2398(19).

Terry, D.O., Jr., and LaGarry, H.E., 1998, The Big Cottonwood Creek Member: A new member of the Chadron Formation in northeastern Nebraska, *in* Terry, D.O., Jr., et al., eds., Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (Late Eocene to Early Miocene, North America): Geological Society of America Special Paper 325, p. 117–141, doi:10.1130/0-8137-2325-6.117.

Vachon, R.W., Welker, J., White, J., and Vaughn, B.H., 2010, Monthly precipitation isoscapes ($\delta^{18}O$) of the United States: Connections with surface temperatures, moisture source conditions, and air mass trajectories: Journal of Geophysical Research, v. 115, D21126, doi:10.1029/2010JD014105.

Valle, N., Verney-Carron, A., Sterpenich, J., Libourel, G., Deloule, E., and Jollivet, P., 2010, Elemental and isotopic (^{29}Si and ^{18}O) tracing of glass alteration mechanisms: Geochimica et Cosmochimica Acta, v. 74, p. 3412–3431, doi:10.1016/j.gca.2010.03.028.

Wolfe, J.A., Forest, C.E., and Molnar, P., 1998, Paleobotanical evidence of Eocene and Oligocene paleoaltitudes in midlatitude western North America: Geological Society of America Bulletin, v. 110, p. 664–678, doi:10.1130/0016-7606(1998)110<0664:PEOEAO>2.3.CO;2.

Zachos, J.C., Pagani, M., Sloan, L., Thomas, E., and Billups, K., 2001, Trends, rhythms, and aberrations in global climate 65 Ma to present: Science, v. 292, p. 686–693, doi:10.1126/science.1059412.

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