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A stable isotope record of late Cenozoic surface uplift of southern Alaska

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ABSTRACT

Although the timing of an acceleration in late-Cenozoic exhumation of southern Alaska is reasonably well constrained as beginning ∼5–∼6 Ma, the surface uplift history of this region remains poorly understood. To assess the extent of surface uplift relative to rapid exhumation, we developed a stable isotope record using the hydrogen isotope composition (δD) of paleo-meteoric water over the last ∼7 Ma from interior basins of Alaska and Yukon Territory. Our record, which is derived from authigenic clays (δD_{clay}) in silicic tephras, documents a ∼50–60‰ increase in δD values from the late Miocene (∼6–∼7 Ma) through the Plio-Pleistocene transition (∼2–∼3 Ma), followed by near-constant values over at least the last ∼2 Ma. Although this enrichment trend is opposite that of a Rayleigh distillation model typically associated with surface uplift, we suggest that it is consistent with indirect effects of surface uplift on interior Alaska, including changes in aridity, moisture source, and seasonality of moisture. We conclude that the δD_{clay} record documents the creation of a topographic barrier and the associated changes to the climate of interior Alaska and Yukon Territory.

1. Introduction

Earth's topography reflects the dynamic balance of the feedbacks among tectonic and Earth-surface processes and climate (England and Molnar, 1990). As such, determining paleo-elevation and paleoclimate histories of mountain belts provides insight into interactions of these processes and their contribution to the evolution of surface topography (Chamberlain et al., 2012; Chase et al., 1998; Feng et al., 2016, 2013; Feng and Poulsen, 2016; Insel et al., 2012; Mix et al., 2011; Mulch and Chamberlain, 2007; Pavlis et al., 1997; Poulsen et al., 2010; Rowley and Garzione, 2007).

Southern Alaska is one of the most tectonically active region's in the world, as evidenced by dramatic topographic relief that forms the Earth's highest coastal mountain range, with peaks rising from sea level to over 6-km elevation over relatively short distances (O'Sullivan et al., 1997). Recent work has provided clear evidence that feedbacks between tectonics and erosion associated with collision of the Yakutat terrane have contributed directly to rapid exhumation of this region over the last few million years (Berger et al., 2008; Enkelmann et al., 2010; McAleer et al., 2009; Meigs et al., 2008). Active tectonics is expressed by high seismicity and continental convergence rates of 40–55 $mm\,yr^{-1}$ (Savage and Plafker, 1991). Precipitation rates of up to 7 $m\,yr^{-1}$ in the coastal mountains support widespread coverage of the mountains by glaciers and ice fields with corresponding high mass fluxes, resulting in some of the highest rates of glacial erosion on Earth (Hallet et al., 1996; Sheaf et al., 2003). Finally, thermochronology reveals rapid exhumation and rock uplift of coastal (St. Elias–Chugach Mountain Range) and interior (Wrangell Mountains, Alaska Range) mountain ranges during the late Cenozoic (Benowitz et al., 2013, 2012, 2011; Berger et al., 2008; Enkelmann et al., 2010; Fitzgerald et al., 1995, 1993; McAleer et al., 2009; Meigs et al., 2008; Plafker et al., 1992; Riccio et al., 2014) (Fig. 1).

Collision and subduction of the Yakutat terrane began ∼30 Ma, but an acceleration in rates of exhumation and rock uplift ∼5–∼6 Ma (Fig. 1) is generally attributed to a change in the direc-

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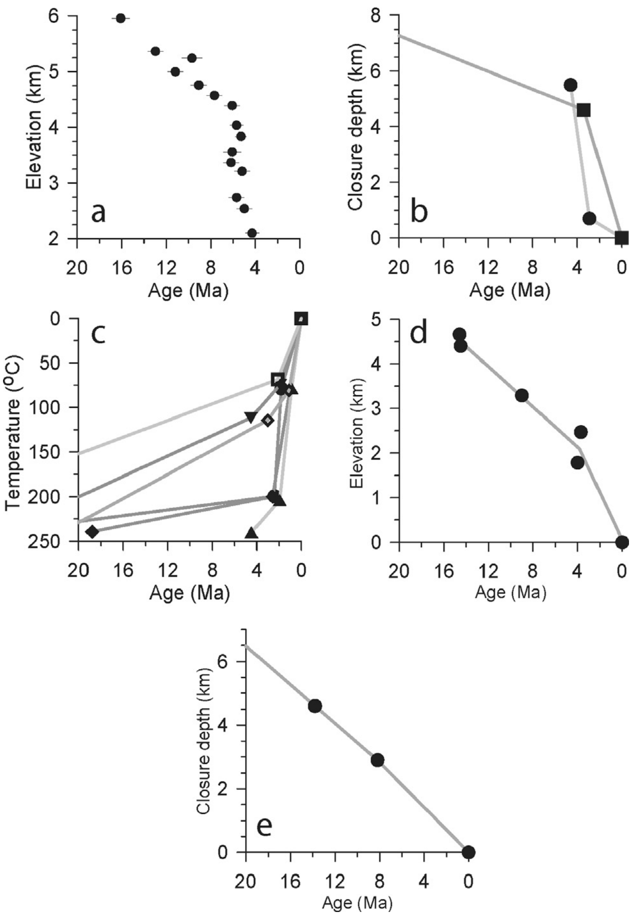

Fig. 1. Thermochronology data constraining rock uplift and exhumation over last 20 Myr for several areas of Alaska. Panels a–d show an acceleration over last 5–6 Myr from several Alaska ranges, whereas panel e shows constant values from the Chugach terrane, which is representative of the stable North American upper plate in more interior Alaska. **(a)** Variation of apatite fission-track age with elevation from central Alaskan Range (Fitzgerald et al., 1995). **(b)** Apatite and zircon thermochronology data constraining closure depth from the Yakutat terrane (Meigs et al., 2008). **(c)** Apatite and zircon helium and fission track ages constraining time–temperature paths for Mt. Fairweather region (McAleer et al., 2009). **(d)** Variation of apatite fission-track age with elevation from Mt. Logan (O'Sullivan and Currie, 1996). **(e)** Apatite and zircon thermochronology data constraining closure depth from the Chugach terrane (North American upper plate) (Meigs et al., 2008).

tion of plate movement from NW to NNW accompanied by an increase in the rate of plate convergence (Benowitz et al., 2013; Fitzgerald et al., 1995; Lease et al., 2016; Plafker et al., 1992; Trop and Ridgway, 2007). The resulting increase in oblique collision and in the rate of underthrusting led to an increase in sedimentation rates in regional basins as well as increased exhumation and rock uplift of the Saint Elias and Chugach Mountains, the Alaska Range, and adjacent regions (Bruhn et al., 2004; Enkelmann et al., 2010; Fitzgerald et al., 1995, 1993; Little and Naeser, 1989; Pavlis et al., 2012, 2004; Plafker et al., 1994; Ridgway et al., 2007).

While records of increased exhumation and sedimentation provide clear signals of increased rock uplift and erosion of the Alaskan ranges ∼5–6 Ma, evidence for the lateral extent of surface uplift and its timing to produce the present-day orography remains uncertain, requiring additional constraints to establish the temporal relation between collision, exhumation, and surface uplift. Here we develop a ∼7 Ma stable isotope record of paleo-precipitation from sites that are leeward of coastal and interior Alaskan mountain ranges to evaluate whether there is a signal of increasing surface uplift that accompanied the acceleration in exhumation beginning ∼5–∼6 Ma.

Stable isotope records provide one of the few methods of reconstructing the surface-uplift history of the world's mountains by exploiting systematic changes in the δD or δ^{18}O values of meteoric water that ultimately can be related to changes in paleoenvironment and paleoelevation (Blisniuk and Stern, 2005; Feng et al., 2016, 2013; Galewsky et al., 2016; Mulch, 2016; Rowley and Garzione, 2007; Stern et al., 1997). This technique has been used to reconstruct past elevation histories of the Himalayas and Tibetan Plateau (Garzione et al., 2000; Gebelin et al., 2013; Rowley et al., 2001; Rowley and Currie, 2006), the Andes (Canavan et al., 2014; Garzione et al., 2008; Ghosh et al., 2006; Mulch et al., 2010; Stern and Blisniuk, 2002), the New Zealand Southern Alps (Chamberlain et al., 1999), the European Alps (Campani et al., 2012) and western North America (Poage and Chamberlain, 2002; Takeuchi and Larson, 2005; Sjostrom et al., 2006; Mulch and Chamberlain, 2007; Mix et al., 2011; Chamberlain et al., 2012). As the coastal and interior mountain ranges in Alaska provide a strong orographic barrier to onshore moisture transport today (Fig. 2), we expect the dominant control on water isotope ratios of modern precipitation in interior Alaska to be continentality. We thus expect that changes in the δD of paleo-precipitation from interior Alaska would be strongly influenced by surface uplift-dependent changes in continentality and the hydrologic cycle.

2. Existing evidence of regional surface uplift

Several lines of evidence suggest that the regional extent of surface uplift of the Alaskan ranges increased during the late Miocene and Pliocene, and thus may have accompanied the acceleration in exhumation and rock uplift beginning ∼5–∼6 Ma. We note where uncertainties in understanding exist, specifically, that direct elevation estimates are absent. What we outline below are changes in surficial geological features that can oftentimes be explained by processes other than surface uplift. In many cases, the resolution of the dating constraints is too low to resolve whether the surface uplift was contemporaneous with the acceleration in exhumation over the last ∼5–∼6 Ma.

2.1. Paleogeographic reconstructions

There has been recent work using detrital geochronology to constrain the Miocene paleo-drainage reorganization history across interior Alaska. Brennan and Ridgway (2015) applied detrital U–Pb zircon source to sink analysis to the paleo-Tanana Basin as a proxy for major changes in sediment source with time. They constrained a change from dominantly north of the Alaska Range sediment sourcing changing to dominantly intra-Alaska Range and south of the Alaska Range by ∼15 Ma and inferred surface uplift was underway by this time. Davis et al. (2015) applied detrital ^{40}Ar/^{39}Ar source to sink analysis to the same paleo-Tanana Basin strata as a proxy for major changes in sediment source with time. They constrained a change from dominantly north of the Alaska Range sediment sourcing changing to dominantly intra-Alaska Range and south of the Alaska Range by ∼20 Ma and inferred surface uplift was underway by this time. Both these studies are in agreement with regional thermochronology studies demonstrating rock uplift in the Alaska Range was underway by ∼30 Ma (Benowitz et al., 2013, 2012, 2011; Burkett et al., 2015; Fitzgerald et al., 2014; Haeussler et al., 2008; Lease et al., 2016; Riccio et al., 2014). None of this previous research studies puts constraints on when the Alaska Range was laterally extensive enough to be an orographic barrier.

North of the central Alaska Range, the Neogene (∼23–∼2.6 Ma) Tanana basin contains a sedimentary record of the collision of the Yakutat terrane. Based on paleocurrents and clast composition of conglomerates, Wahrhaftig et al. (1969) showed that