Earth and Planetary Science Letters 479 (2017) 156–169

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Hinterland drainage closure and lake formation in response to middle Eocene Farallon slab removal, Nevada, U.S.A.

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A R T I C L E I N F O

Article history:
Received 21 June 2017
Received in revised form 29 July 2017
Accepted 7 September 2017
Available online xxxx
Editor: A. Yin

Keywords:
Farallon slab rollback
Elko Formation
lacustrine
Eocene
δD values
evaporation

A B S T R A C T

Hinterland basins can accumulate high resolution archives of orogenic processes and continental climate, but are challenging to reconstruct due to tectonic overprinting and the inherent complexity of their lithofacies assemblages. The Cordilleran hinterland of northeast Nevada has been interpreted to have overlain a flattened Farallon slab from the Late Cretaceous to Eocene. Slab removal and advection of asthenospheric mantle beneath Nevada have been invoked to explain a southwestward migrating wave of Eocene to Oligocene volcanism and proposed as a driver for topographic uplift. However, the timing of slab removal and possible subsequent delamination of North American lithospheric mantle can only ambiguously be related to the surface record. Subsequent Neogene extension and basin filling has complicated the correlation and interpretation of strata that record these events. Here we apply single crystal sanidine ^{40}Ar/^{39}Ar geochronology to 26 ash beds in northeast Nevada to reconstruct Paleogene geographic and hydrologic evolution. We use these ages and legacy geochronology to compare lithofacies and isotope proxy records of meteoric waters to regional tectonics and global climate, and assess competing tectonic interpretations for lake basin formation. Lakes formed locally prior to ca. 48.7 Ma in northeast Nevada, coeval with foreland lakes of the Green River Formation. The most expansive phase of lacustrine deposition resulted in onlap onto locally derived fluvial deposits and folded Paleozoic bedrock, and occurred between ca. 43.4 and ca. 40.8 Ma. Elko Formation strata exhibit a basin-wide transition from fluvial-lacustrine to fluctuating profundal lithofacies at ca. 42.7 Ma, suggesting a shift towards regional hydrologic closure. The stromatolitic upper Elko Formation is intercalated with ash fall tuffs and several partially welded to unwelded ignimbrites from increasingly proximal volcanism. Elko Formation deposition ended by ca. 40.4 Ma. ^{40}Ar/^{39}Ar ages for seven ash beds in the Dead Horse Formation at Copper Basin in northern Elko County indicate intermittent ash bed deposition between 45.2 Ma and 38.6 Ma, and an episode of lacustrine deposition between 39.8 Ma and 38.6 Ma that post-dates the main phase of Lake Elko. δD values of volcanic glass sampled from dated ash beds reflect changes in the hydrogen isotope compositions of local Eocene waters, and systematically vary by 80–102‰ according to their depositional environment. The Elko Formation and overlying volcanic strata are overlain regionally by a pronounced unconformity of ~20 m.y. In the Copper Basin area, deposition continued locally into the Oligocene in the hanging wall of a ductile detachment. The geochronologic and isotopic framework presented here permits reanalysis of the Piñon Range carbonate proxy record that was previously interpreted to record both regional uplift and the middle Eocene climatic optimum. New data suggest instead that isotope values of hydration waters within the Elko Formation were strongly influenced by evaporation, and a change from lacustrine to non-lacustrine conditions can account for the δ^{18}O shift that was interpreted to reflect regional uplift. Moreover, the end of Elko Formation deposition predated the middle Eocene climatic optimum. We interpret the overall record of drainage ponding and paleovalley inundation, progressively more evaporative lacustrine conditions, increasingly proximal

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http://dx.doi.org/10.1016/j.epsl.2017.09.023

volcanism, and subsequent prolonged unconformity to reflect the surface effects of progressive NE to SW removal of the Farallon slab.

1. Introduction

Hinterland lakes can accumulate archives of orogenic landscapes that are otherwise largely erosional and thus rarely preserved in the geologic record. Lacustrine lithofacies in particular can be sensitive indicators of local and regional basin hydrology, and can record subtle deformation caused by dynamic or isostatic processes (Carroll and Bohacs, 1999; Smith et al., 2014; DeCelles et al., 2015). Due to structural deformation in orogenic belts and the often dynamic paleogeography of terrestrial depositional environments, hinterland lake strata are often difficult to reconstruct using traditional stratigraphic correlation (i.e., Umhoefer et al., 2010). The hinterland of the North American Cordillera underwent contraction from the Triassic through Late Cretaceous due to viscous coupling between the subducting Farallon plate and North American lithosphere (DeCelles, 2004). Beginning at approximately 80 Ma, volcanism in the Sierra Nevada ceased due to flattening of the slab, and deep-seated contractile deformation occurred across the Laramide foreland (Erslev, 1993; Copeland et al., 2017). The stratigraphic record after 80 Ma of the Cordilleran hinterland is much less complete than the record of the foreland to the east. Isolated exposures suggest surface deformation and the incision of paleovalleys from the Late Cretaceous through early Eocene (Smith and Ketner, 1976; Druschke et al., 2009; Long, 2012; Henry, 2008), but provide scant regional kinematic or paleogeographic details. In contrast, a robust collection of middle Eocene terrestrial strata occur across a 30,000 km^2 region of the central hinterland of the North American Cordillera in northeast Nevada (Fig. 1), between the Cordilleran divide and the Sevier fold-thrust belt (Fig. 1). This hinterland is interpreted to have been an orogenic plateau during the Paleogene that sustained elevations of at least 2–3 km (Best et al., 2009; Cassel et al., 2014; Snell et al., 2014). Pre-Eocene structural relief and orogenic exhumation in the study area of northeast Nevada is relatively modest compared to the Luning-Fencemaker, central Nevada, and Sevier fold and thrust belts (DeCelles, 2004; Long, 2012). Paleovalleys filled with Paleogene strata are cut into gently folded late Paleozoic carbonates (Henry, 2008; Henry et al., 2012). The lacustrine Elko Formation and related terrestrial strata onlap this paleotopography and record a major long-lived lake system. These deposits provide an important record of the presumed regional transition from Triassic through Paleogene contraction to the Neogene extension that dominates the region's kinematics and topography today.

Cenozoic crustal extension across the hinterland has been broadly attributed to gravitational instability due to orogenically thickened lithosphere. Extensional structures fall into three general classes: enigmatic isolated Cretaceous–Paleogene faults with normal displacement (Drushke et al., 2009), detachment faults related to middle Cenozoic metamorphic core complexes (McFadden et al., 2015), and high-angle Neogene normal faults that bound modern basins (Colgan et al., 2010). Metamorphic core complexes are areas of crystalline rocks that were uplifted along detachment faults with a net normal sense of displacement (Dickinson, 2009; McFadden et al., 2015). Ductile deformation along detachment faults exposed above metamorphic core complexes in northeast Nevada is typically cut by steeper, brittle faults that also offset Oligocene ignimbrites and coincide with modern Basin and Range topography (Colgan et al., 2010; Henry et al., 2011).

Geochronology, thermochronology, paleobarometry, and provenance indicators collectively indicate that metamorphic core complex footwall rocks in northeast Nevada underwent considerable post-Cretaceous vertical advection from middle crustal levels (McGrew et al., 2000; Hallett and Spear, 2015), presumably along deeply-rooted detachment faults. These features occur in a north–south-trending line along the center of the hinterland, and Eocene lake strata occur near several of them (Fig. 1A). The most deeply exhumed rocks in northeast Nevada occur in the greater Ruby Mountains–East Humboldt Range–Wood Hills–Pequop Mountains (R–EH–W–P) metamorphic core complex, and have interpreted peak paleodepths of 35–40 km (Hodges et al., 1992; Hallett and Spear, 2014). Zircon and monazite yield U–Pb ages for associated peak metamorphism of 97–77 Ma (Camilleri and Chamberlain, 1997; Hallett and Spear, 2015). Zircon U–Pb ages from a pluton exposed in the southern Ruby Mountains suggest at least 10 km of exhumation since its emplacement from 37.3–36.3 Ma, near the end of an episode of intense regional volcanism (Brooks et al., 1995; Henry, 2008; Henry et al., 2012; Lund Snee et al., 2016). Multi-crystal biotite and muscovite $^{40}Ar/^{39}Ar$ cooling ages (350–400 °C) range between 50 Ma and 17 Ma, with the majority 33–21 Ma, generally younger to the west (McGrew and Snee, 1994; Henry et al., 2011). Apatite (U–Th)/He and fission track ages of 17–10 Ma from the southern Ruby Mountains indicate Miocene exhumation from temperatures above 60 °C along a west-dipping detachment that bounds the western edge of the R–EH–W–P metamorphic core complex (Colgan et al., 2010). Clasts of lower plate crystalline rocks also first appear in basins adjacent to the R–EH–W–P structure during Miocene deposition of the Humboldt Formation (Colgan et al., 2010), although there is no depositional record from the Oligocene. The oldest evidence for exumation of lower plate crystalline rocks occurs at Copper Basin, 50 km north of the R–EH–W–P structure. There, a detachment fault has exhumed Cretaceous-aged plutonic rocks along a ductile shear zone, and sediments sourced from the structure are Oligocene, based on multi-crystal biotite $^{40}Ar/^{39}Ar$ ages of 32.7 ± 0.4 Ma and 29.5 ± 0.8 Ma for ashes interbedded with the Meadow Fork Formation (Rahl et al., 2002; Henry et al., 2011).

Several lines of evidence suggest high average surface elevations in the Cordilleran hinterland during the Paleogene: plant fossils of upland conifers (Axelrod, 1968; Wolfe et al., 1998); low $\delta^{18}O$ values in hydrothermal fluorite (Seal and Rye, 1993); low $\delta^{18}O$ values in hinterland proxies relative to those from the Great Plains (Chamberlain et al., 2012); low $\delta^{18}O$ values in lacustrine carbonates from waters delivered to foreland lakes from hinterland-sourced streams (Carroll et al., 2008); and low clumped-isotope-derived temperatures in the Utah hinterland (Snell et al., 2014). Recently obtained hydrogen isotope values from hydrated volcanic glass (δD_{glass}) indicate elevations in central to eastern Nevada of at least 2.6 km during the Eocene, increasing to 3.5 km during the Oligocene (Cassel et al., 2014). These studies have identified two primary potential mechanisms for the generation and evolution of hinterland high topography, including 1) Late Cretaceous surface uplift due to contractile thickening (Ernst, 2010; Snell et al., 2014), and 2) a mid-Cenozoic north-to-south progression of uplift due to dynamic topography driven by asthenospheric upwelling (Chamberlain et al., 2012) or delamination of the mantle lithosphere of North America (Porter et al., 2016). Despite regional elevation constraints suggesting high topography, a lack of systematic geochronology for Paleogene strata in northeast Nevada introduces substantial uncertainty concerning the relative timing of basin development and metamorphic core complex formation,