Earth and Planetary Science Letters ••• (••••) •••–•••

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Prolonged high relief in the northern Cordilleran orogenic front during middle and late Eocene extension based on stable isotope paleoaltimetry

Majie Fan [a,*], Kurt N. Constenius [b], David L. Dettman [b]

[a] Department of Earth and Environmental Sciences, University of Texas at Arlington, United States
[b] Department of Geosciences, University of Arizona, United States

ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form 17 October 2016
Accepted 18 October 2016
Available online xxxx
Editor: A. Yin

Keywords:
Cordillera
paleorelief
paleoelevation
paleoaltimetry
extension
mollusk

ABSTRACT

The paleoelevation and size of the North America Cordilleran orogen during the late Cretaceous–Paleogene contractional and subsequent extensional tectonics remain enigmatic. We present new estimates of paleorelief of the northern Cordilleran orogenic front during the middle and late Eocene using oxygen isotope compositions of unaltered molluscan fossils and paleosol carbonates in the Kishenehn basin. Bounded by several mountains ranges to the east, the Kishenehn basin was a half graben developed during middle Eocene to early Miocene collapse of the Cordilleran orogen. These mollusk taxa include three sympatric groups with affinities to wet tropical, semi-arid subtropical, and temperate environments. Our reconstructed surface water $\delta^{18}O$ values vary between −19.8‰ and −6.3‰ (VSMOW) during the middle and late Eocene. The large differences in paleoenvironments and surface water $\delta^{18}O$ values suggest that the catchment of the Kishenehn basin was at variable elevation. The estimated paleorelief between the basin and the surrounding mountains, based on both Rayleigh condensation model and predictions of Eocene precipitation isotope values using an isotope-enabled global climate model, is ~4 km, and the basin floor was <1.5 km high. This high topography and high relief paleogeography suggest that the Cordilleran orogenic front reached an elevation of at least 4 km, and the crust thickness may have reached more than 55 km before Eocene gravitational collapse. We attribute the maintenance of high Eocene topography to the combination of an inherited thick crust, thermal uplift caused by mantle upwelling, and isostatic uplift caused by removing lower lithosphere or oceanic slab.

1. Introduction

The construction and collapse of the North America Cordilleran orogen reflect changes of lithosphere structure, plate tectonics, and mantle dynamic process. Although the tectonic history of the orogen has been extensively studied, little is known about the paleoelevation and size of the Cordilleran orogenic plateau during the Late Cretaceous–early Paleogene contractional and subsequent late Paleogene–recent extensional tectonics (e.g., Wernicke et al., 1987; Constenius, 1996; Sonder and Jones, 1999; DeCelles, 2004; Fuentes et al., 2011; Chamberlain et al., 2012; Fuentes et al., 2012; Lechler et al., 2013). In northwestern Montana and adjacent parts of Canada, crustal shortening during the Late Cretaceous and early Eocene associated with eastward progressive displacements of multiple thrust sheets, including the immense Lewis thrust, constructed an edifice of highly deformed Proterozoic–Mesozoic strata (e.g., Fuentes et al., 2011, 2012). After large-magnitude post-early Eocene extension, modern crustal thickness in the area remains high (~40 km, Constenius, 1996; Perry et al., 2002), suggesting that the pre-extensional crustal thickness was very high (>50 km). If limited addition of high-density material occurred to the lithosphere during the compressional tectonics, isostatic compensation of such thick crust would have resulted in high pre-extensional paleoelevation (>3 km) in the Cordilleran orogen (Lachenbruch and Morgan, 1990). Currently, the lack of accurate quantitative paleoelevation estimates for the Cordilleran orogenic front limits our ability to understand the geodynamic process that changed lithosphere structure.

Extensional collapse of the Cordilleran orogen in British Columbia and northwestern Montana initiated during the early middle Eocene (ca. 53–48 Ma; e.g., Constenius, 1996; Mulch et al., 2004, 2007; Foster et al., 2007), associated with the rapid drop in North

* Corresponding author.
E-mail address: mfan@uta.edu (M. Fan).

http://dx.doi.org/10.1016/j.epsl.2016.10.038
0012-821X/© 2016 Published by Elsevier B.V.

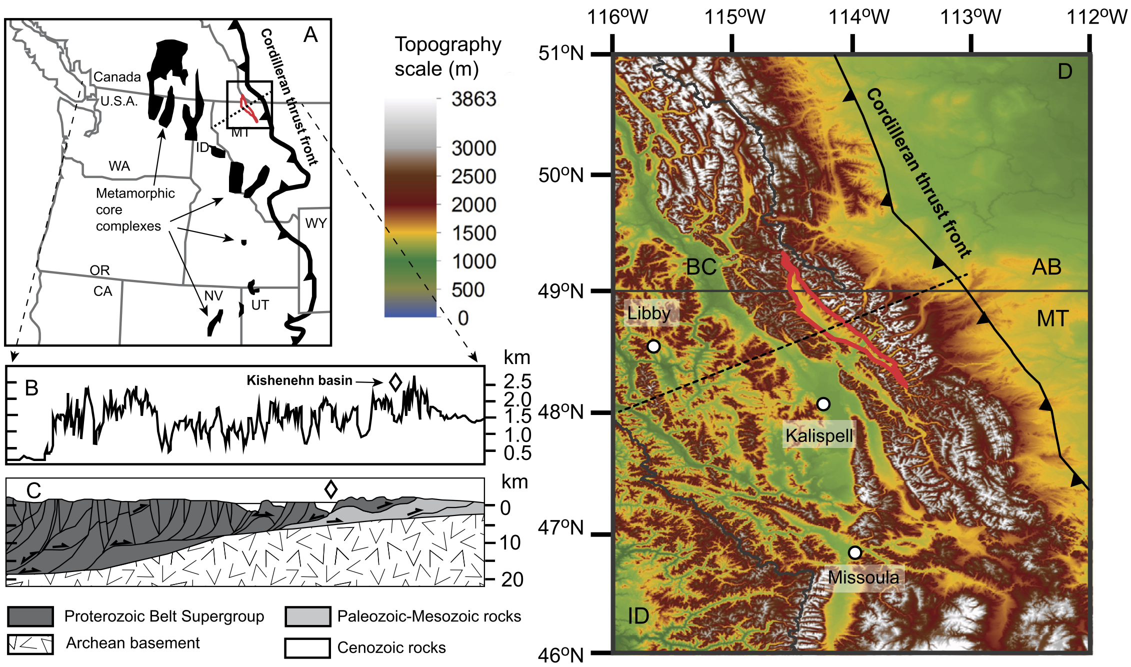

Fig. 1. A. Location of the Kishenehn basin (red polygon) with respect to the Cordillera thrust front and Eocene extensional metamorphic core complex in the western United States (modified from Constenius, 1996, and Foster et al., 2007). B. W–E elevation profile along the U.S. and Canada border. C. Cross section along the dashed line in A (modified from Fuentes et al., 2012). D. Relief map of the Kishenehn basin in relation to the nearby mountain ranges. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

America–Pacific plate convergence rate (Engebretson et al., 1985). The extension formed a network of half grabens (Constenius, 1996), and metamorphic core complexes (Wernicke et al., 1987; Sonder and Jones, 1999). The mechanism of extension has been attributed to the relaxation of horizontal stresses on the Cordillera that had high gravitation potential following a protracted episode of crustal shortening (e.g., Wernicke et al., 1987). Weakening of lithosphere by asthenosphere upwelling induced by lower crust delamination (e.g., Sonder and Jones, 1999; Liu, 2001), or removal of Farallon slab (Dewey, 1988; Humphreys, 1995), or a slab window (e.g., Breitsprecher et al., 2003; Haeussler et al., 2003) are other elements that potentially facilitated crustal spreading. Crustal extensional was partly concurrent with the southward migration of arc magmatism in the Cordillera hinterland (Humphreys, 1995), in particular the Absoroka–Challis–Kamloops volcanic field (Schmandt and Humphreys, 2011), thus may be associated with the southward removal of the subducting Farallon plate (Mix et al., 2011; Chamberlain et al., 2012). However, in the Cordillera foreland, it is suggested that magmatism occurred during the early and middle Eocene following a westward trend, in association with westward rollback of the Farallon plate (Coney and Reynolds, 1977; Constenius, 1996). In northwestern North America, extensional tectonics were associated with mafic magmatism in the Coast Mountains and Cascades, which was attributed to slab window opening related to the breakup of the Resurrection plate, or the Kula–Farallon slab window (e.g., Breitsprecher et al., 2003; Haeussler et al., 2003). Accurate quantitative paleoelevation histories during the extensional collapse of this orogen are critical to evaluate the geodynamic models of the extension.

Recent stable isotope paleoaltimetry studies have brought new understanding to the development of topography in the northern Cordillera during the latest Cretaceous and early Eocene, yet a clear picture of the paleotopography of the entire northern Cordillera during the Late Cretaceous–Paleogene contractional and subsequent extensional tectonics can not be depicted from a few scattered sites over a broad region. In Alberta, oxygen isotope compositions of freshwater invertebrate fossils suggest that the front of the Canadian Cordillera may have been as high as 4.5 km during the latest Cretaceous (Dettman and Lohmann, 2000; Fan and Dettman, 2009). In British Columbia, hydrogen isotope compositions of muscovite formed in detachment faults of metamorphic core complexes suggest a paleoelevation of ∼4 km soon after the initiation of extensional tectonism during the early middle Eocene (Mulch et al., 2004, 2007). This reconstruction is consistent with the high late early Eocene elevation estimated by a fossil floral physiognomy study in northern Washington (Wolfe et al., 1998). The attainment of high elevation in northern Cordillera during the early middle Eocene may represent the initiation of a renewed topographic gain in the North America Cordillera, which migrated southward and reached southern Idaho during the latest Eocene, and Nevada during the Oligocene (Mix et al., 2011; Chamberlain et al., 2012; McFadden et al., 2015). Nevertheless, most of the studies focus on the Cordilleran hinterland, and no study has constrained the paleotopography of the Cordilleran front during the late Paleogene.

Here we present new oxygen isotope data from middle and late Eocene terrestrial and aquatic mollusk fossils and paleosol carbonates in the Kishenehn basin in northwestern Montana and southeastern British Columbia, in combination with previously published stable isotope results, to reconstruct the elevation history of the Cordilleran orogenic front in that region (Fig. 1). The coexistence of three disparate types of fossil mollusks possessing distinct paleoenvironmental affinities, wet tropical, semi-arid subtropical and temperate, suggests a broad range of paleoclimate and paleoelevation existed in the catchment of the Kishenehn basin during the Eocene. The differences of $\delta^{18}O$ values between the alpine snowmelt and basinal precipitation further show that relief of the Cordilleran orogenic front was more than 4 km during the middle and late Eocene extension. We suggest that the persistence of high elevation and high relief during this episode of extension in the Cordilleran orogenic front was the result of mantle upwelling combined with the support of an inherited thick crust and associated isostatic uplift concomitant with changes in the geometry of the subducted Farallon plate.

Please cite this article in press as: Fan, M., et al. Prolonged high relief in the northern Cordilleran orogenic front during middle and late Eocene extension based on stable isotope paleoaltimetry. Earth Planet. Sci. Lett. (2016), http://dx.doi.org/10.1016/j.epsl.2016.10.038