Geomorphology 278 (2017) 43–59

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Geomorphology of the Burnt River, eastern Oregon, USA: Topographic adjustments to tectonic and dynamic deformation

Matthew Connor Morriss [a,b,*], Karl W. Wegmann [a]

[a] Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Campus Box 8208, Raleigh, NC 27695-8208, United States
[b] Department of Geological Sciences, University of Oregon, 100 Cascade, 1275 E 13th Avenue, Eugene, OR 97403-1272, United States

ARTICLE INFO

Article history:
Received 5 December 2015
Received in revised form 25 August 2016
Accepted 6 September 2016
Available online 24 October 2016

Keywords:
Strath terrace
Fluvial incision
Optically stimulated luminescence (OSL)
Tephrochronology
Quaternary stratigraphy
Inland Northwest

ABSTRACT

Eastern Oregon contains the deepest gorge in North America, where the Snake River cuts vertically down 2300 m. This deep gorge is known as Hells Canyon. A landscape containing such a topographic feature is likely undergoing relatively recent deformation. Study of the Burnt River, a tributary to the Snake River at the upstream end of Hells Canyon, yields data on active river incision in eastern Oregon, indicating that Quaternary faults are a first order control on regional landscape development. Through 1:24,000-scale geologic mapping, a 500,000-year record of fluvial incision along the Burnt River was constructed and is chronologically anchored by optically stimulated luminescence dating and tephrochronology analyses. A conceptual model of fluvial terrace formation was developed using these ages and likely applies to other non-glaciated catchments in eastern Oregon. Mapped terraces, inferred to have formed during glacial-interglacial cycles, provide constraints on rates of incision of the Burnt River. Incision through these terraces indicates that the Burnt River is down-cutting at 0.15 to 0.57 m kyr^{-1}. This incision appears to reflect a combination of local base-level adjustments tied to movement along the newly mapped Durkee fault and regional base-level control imposed by the downcutting of the Snake River. Deformation of terraces as young as 38.7 ± 5.1 ka indicates Quaternary activity along the Durkee fault, and when combined with topographic metrics (slope, relief, hypsometry, and stream-steepness), reveals a landscape in disequilibrium. Longer wavelength lithospheric dynamics (delamination and crustal foundering) that initiated in the Miocene may also be responsible for continued regional deformation of the Earth's surface.

1. Introduction

The ~2850 km^2 Burnt River catchment contains normal faults, Neogene volcanics and Quaternary fluvial terraces, all of which indicate a dynamic late Cenozoic landscape. The Burnt River drains into the Snake River at the upstream end of Hells Canyon. The Snake River sets the regional base level; any fluvial signal of the carving of Hells Canyon may have been communicated to tributary systems such as the Burnt River. The goal of this investigation is to improve our understanding of Neogene surface deformation in eastern Oregon through the development of a geo-chronologically-anchored model of fluvial dynamics and terrace development for the Inland Northwest (Fig. 1).

Detailed mapping of Quaternary deposits along the Burnt River constrains the rate and timing of fluvial incision in this catchment and reveals a ~500 ka record of incision in the lower and upper Burnt River canyons (Fig. 2A). Our mapping indicates that the Durkee fault, an active normal fault defining the Durkee Basin (Fig. 2A), controls the base level for the upper Burnt River catchment. Local faulting is believed to drive much of the fluvial incision through this high-relief landscape.

Neogene incision in the lower Burnt River canyon is interpreted as a combination of base-level adjustments tied to the Snake River and footwall uplift along the Durkee fault where the Burnt River exits the Durkee Basin (Fig. 2). The trend and size of this fault is inconsistent with Neogene extensional tectonics (i.e. Basin & Range) in the western U.S (McCaffrey et al., 2013). It is possible that the Durkee fault formed due to a combination of rotational extension and long wavelength lithospheric flexure of in the Inland Northwest (McCaffrey et al., 2013). Geomorphic research of the Salmon River catchment indicates that this fluvial system is adjusting to 1 to 1.5 km of base-level drop that initiated between 8 and 10 Ma (Vogl et al., 2014; Larimer, 2015). Fluvial knickzones have migrated 250 km upstream from the Snake-Salmon confluence and have likely propagated through Hells Canyon into other tributaries of the Snake River, including the Burnt River.

2. Regional geologic setting

The Burnt River drains portions of the Blue Mountain and Payette sections of the Columbia Plateau physiographic province (Fenneman and Johnson, 1946). Beginning at 2400 m in the Blue Mountains, the

* Corresponding author at: Department of Geological Sciences, University of Oregon, 100 Cascade, 1275 E 13th Avenue, Eugene, OR 97403-1272, United States.
E-mail addresses: matthew.c.morriss@gmail.com (M.C. Morriss), karl_wegmann@ncsu.edu (K.W. Wegmann).

http://dx.doi.org/10.1016/j.geomorph.2016.09.015

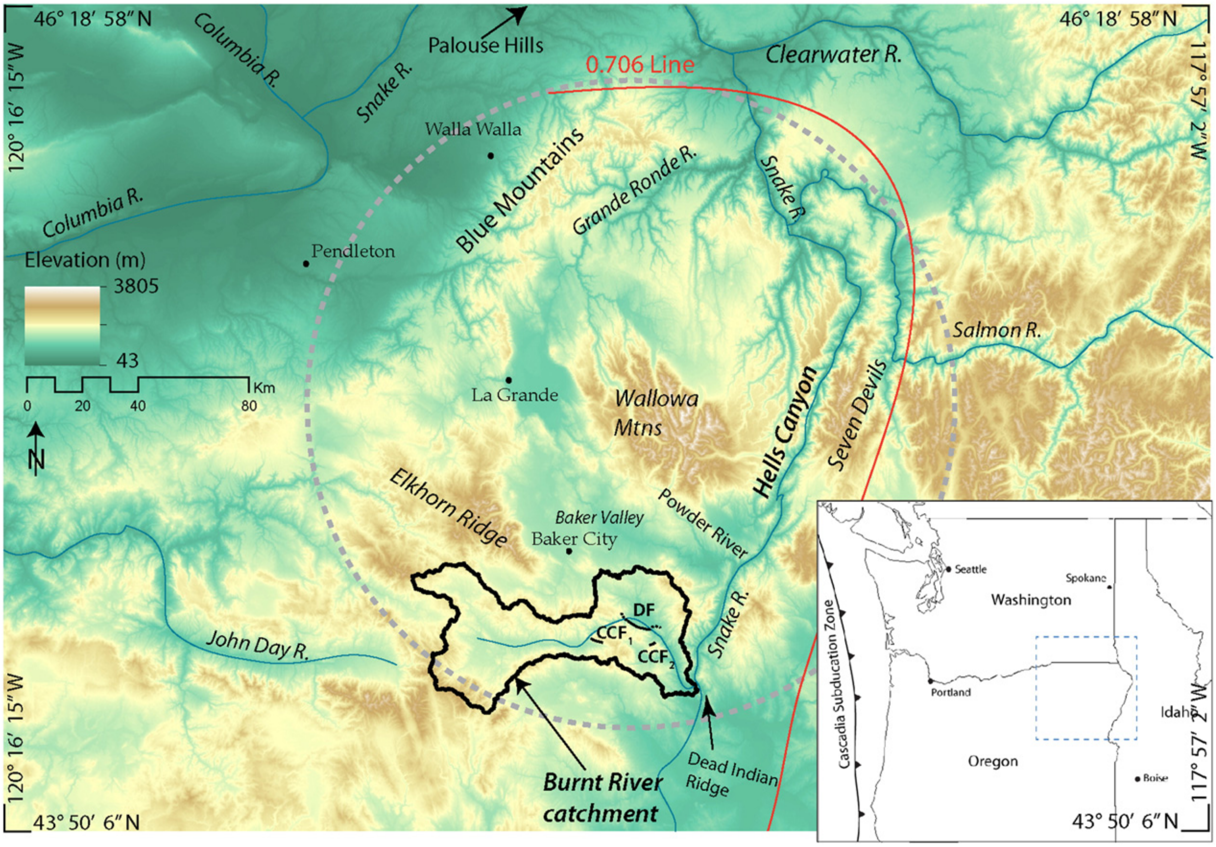

Fig. 1. Inset. Geographic location of the main map in relation to the Cascadia Subduction Zone. Main Map. Burnt River catchment (bold polygon) in the context of regional topography and drainage networks. The thin red line approximates the boundary between the North American craton and accreted terranes demarcated by the $^{87}Sr/^{86}Sr$ 0.706 isopleth (Leeman et al., 1992). The bulls-eye of high-standing topography described in Hales et al. (2005) and by Darold and Humphreys (2013) is outlined by the gray dashed line. Abbreviations used: Durkee fault (DF); Clarks Creek Fault (CCF_1); for the Conner Creek Fault (CCF_2). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

river drops nearly 1800 m over a distance of 160 km before entering the Snake River at the upstream end of Hells Canyon. Two discrete canyon sections, the upper and lower Burnt River canyons, dominate the landscape of the lower 75 km of the river. The upper Burnt River canyon (Fig. 2A) is cut through the Triassic Burnt River Schist of the Baker Terrane (Ashley, 1995). The mouth of the upper canyon is coincident with the footwall trace of the Durkee fault, which defines the structurally-controlled Durkee Basin that is filled with Miocene to Pliocene lake sediments (Van Tassell et al., 2001). The river transits the Durkee Basin, cutting across the Durkee fault for a second time as it enters the lower Burnt River canyon (Fig. 2A). It then encounters the terrane-bounding Connor Creek fault, transitioning from the Baker Terrane into the Jurassic Izee Terrane (Fig. 3A; Dorsey and Lamaskin, 2008). Bedrock in this reach is dominated by steeply dipping shales of the Weatherby Formation (Dorsey and Lamaskin, 2008). The Burnt River crosses into the Permo-Triassic volcanic and volcaniclastic rocks of the Olds Ferry Terrane and Huntington Arc, just before it enters the Snake River at the Brownlee Reservoir (Silberling et al., 1987).

A select series of events in the mid-to-late Cenozoic are intimately connected with the development of topography in eastern Oregon. Both the Sevier and Laramide orogenies resulted in high standing topography to the east and south of Oregon. Between 48 and 39 Ma, areas 50 to 100 km due east of Hells Canyon may have stood at an elevation of 3700 m above sea level, as recorded in the $\delta^{18}O$ of hydrous authigenic minerals in paleosols, whereas present elevations in this region are between 2000 and 2500 m (Mix et al., 2011). Rocks of the Precambrian Belt Supergroup formed the drainage divides between major east and west-flowing Eocene rivers (Allen, 1991; Sears, 2014). Fluvial channel-bed conglomerates composed of Proterozoic quartzite and Eocene Challis volcanic clasts occur at elevations of ~3000 m in eastern Oregon mountain ranges (Allen, 1991). These isolated outcrops are remnants of former west-flowing Eocene channels (Cowan and Reiners, 2004).

Miocene volcanism in southeast Oregon initiated at 16.8 Ma with the eruption of the McDermitt volcanic field and Steens Basalts. Both were associated with the interaction of the Yellowstone mantle plume with the base of continental lithosphere (Hooper et al., 2007; Ferns and McClaughry, 2013). After these initial eruptions, the locus of basaltic volcanism propagated to the north, paralleling the edge of cratonic North America (Hooper et al., 2002; Rodriguez and Sen, 2013; Ferns and McClaughry, 2013).

Extensional basins began opening in eastern Oregon and western Idaho as volcanoes were erupting. Normal faulting initiated on the north-south trending Oregon-Idaho graben (OIG) at 15.3 Ma and continued until 12.6 Ma (Supplementary Figs. 1S, 2S; Cummings et al., 2000). By 11 Ma, an internally-drained basin occupying the western Snake River Plain was present (Wood and Clemens, 2002). Sedimentary deposits associated with Lake Idaho in this basin are herein called Lake Idaho deposits (Wood and Clemens, 2002). Lake Idaho persisted for nearly 8 million years (10 to 1.7 Ma), was the size of modern Lake Huron, and may have had a surface water connection to other basins in northeastern Oregon (Van Tassell et al., 2001). The modern Snake River upstream of Hells Canyon drains the area once inundated by Lake Idaho. Several other extensional basins in northeastern Oregon