ABSTRACT

The Green River's turn south from Browns Park to cut Canyon of Lodore and cross the eastern Uinta uplift is one of the most famous and long-debated drainage anomalies. For the river to flow towards and then cross the Laramide uplift, some combination of antecedence, superposition, or stream capture must have occurred in later Cenozoic time. This review of the history of ideas on how and when this happened, especially the extensive work of Wally Hansen, provides a new hypothetical scenario of events that combines previous ideas.

INTRODUCTION

The Uinta Mountain region contains a relatively complete geologic record of Cenozoic landscape evolution. This includes the Laramide uplift and erosion of the range, the slow development of a low relief landscape during middle Cenozoic quiescence, and later Cenozoic extension as well as the major drainage reversal that resulted in the Green River traversing and incising the Uinta uplift. This regional drainage change is important because it integrated the upper Green River into the greater Colorado River drainage, lowering baselevel and setting the stage for the late Cenozoic erosion that defines the modern landscape. It has also inspired a long debate about the timing and mechanisms for how the change came about.

It was in the northeast Uinta Mountains that John Wesley Powell, near the beginning of his first voyage through the canyons of the region, viewed the Gates of Lodore and first recognized the classic conundrum of rivers that punch through mountain ranges (Powell, 1876). The Green River turns abruptly south from its route along the broad Browns Park graben here and carves a path through the Uinta uplift, forming Canyon of Lodore (figure 1). Powell coined the term ‘antecedent’ to relate his hypothesis about how this happened. In this paper, we review the long history of ideas by Uinta Mountain researchers on how this regional river came to defy gravity and gradient and cross a mountain range. Though a thorough set of reasonable hypotheses was provided long ago, a fresh look back provides a new synthesis of ideas that, together, form the most likely scenario for how the Green River got across the Uinta Mountains.

LANDSCAPE HISTORY

AND HISTORY OF IDEAS

Powell's original idea of antecedence, that the river path is older than the young orogen lifting up through it, was short lived. It was recognized early on that the major faulting and uplift of the range was not recent and that the uplifting range was surrounded by large lake basins, not crossed by an older river (Emmons, 1897). Subsequent mapping established the relative timing of the Laramide orogeny in the area (Sears, 1924; Bradley, 1936; Hansen, 1969). Once Laramide uplift ceased, there was a period of tectonic stability that was of sufficient duration for significant pedimentation,
as seen in the landscape throughout the Rocky Mountains (Epis and Chapin, 1975; Mears, 1993). In the case of the Uinta Mountains, the extensive Gilbert Peak erosion surface developed around its flanks (Sears, 1924; Bradley, 1936; Hansen 1986).

Two Tertiary deposits, the Bishop Conglomerate that buries part of the Gilbert Peak surface and the Browns Park Formation, have provided researchers with a framework for understanding post-Laramide structural deformation, drainage development, and subsequent erosion of the eastern Uintas. The poorly understood Bishop Conglomerate was deposited basinward of and atop the Gilbert Peak surface as pedimentation continued at the retreating mountain front in late Eocene and Oligocene time (Hansen, 1986; Kowallis and others, this volume). The Browns Park Formation is younger basin fill of Browns Park, and is more directly related to the history of the Green River. It is primarily tan to light gray, tuffaceous sandstone and mudstone interbedded with volcanic ash, though there are some locally derived gravels near basin margins (Hansen, 1986). K-Ar and fission-track dates from Browns Park tephras range from ~25 to 7 Ma in general agreement with ages reported for fossil assemblages (Winkler, 1970, Luft, 1985; Honey and Izett, 1988).

All workers since Powell seemed to agree on the evidence in the Gilbert Peak erosion surface and Bishop Conglomerate that, during middle Cenozoic time, drainages were consequent off the uplift and flowed into the surrounding basins. No trunk stream passed through the range as the Green River does today. To the extent that an upper Green River north of the Uintas existed at all in the middle Cenozoic, Bradley (1936) and Hansen (1969) suggested that it flowed east into the Platte River drainage. Hansen (1986) cites evidence that this uppermost Green River was the last reach to be integrated into the existing system in the Pleistocene.

Hansen (1984, 1986) used evidence for the regional tilting of the Bishop Conglomerate-Gilbert Peak surface to reconstruct the former profile of the range. He concluded that the northeastern part of the Uinta fault was reactivated with normal dip-slip motion in Neogene time. This, and faulting associated with the formation of the Browns Park graben, represent the gravitational collapse of the high, eastern Uinta anticline (Bradley, 1936; Hansen, 1984, 1986). This event is crucial to understanding drainage development in the area.

Additional evidence for late Cenozoic deformation in the eastern Uinta Mountains includes the courses of numerous streams that have been altered and reversed (1984, 1986). Hansen recognized relict drainage patterns indicating that streams originally flowed southward from the crest of the highest, eastern part of the Laramide uplift over what is today Browns Park—the lowest area (figure 2A). The courses of many of these drainages have now been reversed, as evidenced by relict drainage divides and broad, relict valleys as well as the barbed pattern headwater streams that make nearly 180° turns before joining tributaries exiting into Browns Park. For example, the tilting and subsidence of Browns Park developed steep drainages off the adjoining Diamond Mountain highlands that continue to slowly headwardly erode and capture south-flowing drainages, thus displacing the drainage divide southward (figure 2B).

Getting back to drainage integration of the Green River across the Uinta uplift—workers after Powell provided two main hypothetical mechanisms: (a) headward erosion of a small, south-flank stream through the uplift and capture of the upper Green River (Bradley, 1936; Hansen, 1969), and (b) superposition of the Green River over the eastern Uintas as it flowed along the depositional top of the Browns Park Formation (Sears, 1924; Hansen, 1969). Hunt (1969) also hypothesized that the canyons in the Uintas were in part antecedent and
Figure 2. Illustration of hypothetical eastern Uinta Mountains drainage-integration history set on a background of modern topography. A) post-Laramide (Oligocene) drainage pattern with the original drainage divide along structural and topographic axis of range indicated by dashed line. Consequent streams drained away from the divide into the basins (examples shown are schematic), though the paleo-Yampa River must have flowed on the low-relief flanks of the range along its present path to become superimposed and entrenched. B) During or just after Miocene subsidence of the Browns Park graben and collapse of the highest, eastern part of the uplift, streams of the Green River Basin were diverted south, including the upper Green River into Browns Park. The drainage divide shifted south due to subsidence and tilting of headwater catchments and due to the new baselevel in Browns Park driving stream capture. A key example is a likely tributary drainage (in white) of the paleo-Yampa coincident with where Canyon of Lodore now lies. C) In post-Browns Park time (Pliocene?), the Green River was captured or diverted across the subsided drainage divide and through the paleo-Yampa tributary. Increased rates of incision in the late Cenozoic, partly driven by the drainage capture itself, subsequently deepened Canyon of Lodore and other canyons in the region.
that Quaternary uplift of the range was responsible for a significant portion of their depth. But this does not match the pattern of region-wide erosion (Hansen, 1986), nor is their evidence for the recent faulting this requires. The most extensive research in the region was done by Hansen, who debated the problem at length, and finally concluded that the Green River's path over the Uinta Mountains is essentially the result of superposition when the Browns Park Formation, fed by the Green River, completely filled its basin and spilled to the south at the location of Canyon of Lodore (Hansen, 1969). Each of these hypotheses has problems when simplified and taken individually. Headward erosion of a first-order stream and migration of a drainage divide through resistant sandstone is difficult in most circumstances because of the absence of discharge to do the work of erosion. In the case of superposition of the Green River along the depositional top of the Browns Park Formation, this requires that a missing, upper section of the Browns Park Formation was fed by the proto-Green River. Though this is possible, there is no known evidence in the Browns Park Formation for sediment of a proto-Green River (Winkler, 1970). Also evidence that the Browns Park graben was once filled with enough sediment to accomplish pure superposition of the river on the surface of the Bishop Conglomerate is equivocal (Sears, 1924; Hansen, 1986). Alternatively, significant post-integration subsidence of the Browns Park graben at the Gates of Lodore could have deceptively lowered the Browns Park Formation, but again, there is no evidence of such faulting.

**HYBRID HYPOTHESIS**

With that review in mind, and the luxury of a new perspective on the landscape, a hybrid hypothesis for drainage integration seems most likely. Hansen (1969) recognized that the subsidence associated with Miocene extensional faulting of the eastern Uintas must have played a key role in capturing or diverting an upper Green River south into Browns Park. The paleo-Green River, once diverted into the subsided Browns Park, would have found a gentle path continuing along the strike of the graben into northwestern Colorado. In fact, the upper Green may have joined the Yampa as it circumnavigated the east end of the range (Hansen, 1986), solving the issue of the river's fate at the time (figure 2B).

The Laramide (pre-Browns Park) drainage divide would have extended into the heart of Browns Park right in the area of the present Gates of Lodore (Bradley, 1936; Hansen, 1986) (figure 2A). And, in fact, the path of Lodore follows the trend and spacing of the relict, subsided drainage headwaters of the eastern Uinta Mountains. That is, relict Oligocene topography suggests that the headwater drainage divide of a south-flowing tributary of the paleo-Yampa subsided into the Browns Park graben during Miocene faulting (figure 2B). This formed a windgap that was much more easily conquered by either headward erosion or superposition. We speculate that the nascent upper Green River may have simply spilled or diverted through the fallen divide, to some degree riding atop the older Browns Park basin fill (figure 2B,C).

Support for this can be found in the relict-valley landscapes that appear to be preserved along the shoulders of Canyon of Lodore, like those previously recognized in the valleys just to the west (Hansen, 1986). An example is the upper Zenobia Creek catchment along the east side of the present canyon, where wide, flat-bottomed upper valleys trend parallel to Lodore but perpendicular to the modern creek plunging into the canyon (figure 3). Better examples are the wide windgap valleys adjacent to the Gates of Lodore, this includes the southwest-trending paleovalley at the head of Jack Springs Draw and the south-trending windgap valley at the north edge of Buster Basin. In fact, the broader upper cliffs of Canyon of Lodore itself, recognized by Hansen (1984), may be inherited from the old south-flowing valley before drainage capture and subsequent incision of the steep lower gorge.

Wally Hansen first recognized nearly all of the preceding components and processes. But we suggest he did not fully emphasize the important combination of extensional collapse and subsidence of the headwaters of a south-flowing Yampa tributary at the location of Lodore. This side-steps the need for a somewhat older, upper Green River contribution to the Browns Park Formation and also makes headward erosion and capture a much more viable hypothesis.

Subsidence of the Laramide drainage divide beneath Browns Park would have greatly eased the
path for headward erosion of the tributary, with a new, lower drainage divide migrating south along the sunken tributary valley. This subsidence of a partly formed pathway may have also led groundwater gradients more directly from the higher basin of Browns Park to the adjacent, lower topography of the paleo-Yampa and tributaries to the south. If groundwater first breached the subsurface of this new, low divide, groundwater sapping along the headwaters of the paleo-tributary would have effectively driven headward erosion (Pederson, 2001).

The timing of the integration of the Green River is not yet well constrained. The river is, at least, younger than the poorly dated Browns Park Formation (Winkler, 1970). Thus and so it must have arrived after ~7 Ma, the youngest reported age for the unit. To bracket this, a constraining minimum-age estimate is possible from study of the stratigraphy and geochronology of Green River terrace gravels in Browns Park. When the long-term incision rate is better understood through this estimates of the age of the highest and oldest preserved Green River deposits can be made.

In contrast to the obscured and changing path of the Green River on the north side, the major drainage patterns on the southeast flank of the Uinta Mountains seem straightforward, though the upper Yampa may also have a complicated history (e.g. Hunt, 1969, Hansen, 1986). The Yampa River and the Green below its confluence with the Yampa are marked by reaches with entrenched meanders (figure 2). The canyon rims here, the top of the Yampa Plateau and the Split Mountain anticline, are beveled by the Gilbert Peak erosion surface and capped by the Bishop Conglomerate. This low-relief surface is what the paleo-Yampa must have flowed upon between the Sand Wash and Uinta basins after Bishop time, enabling simple superposition of this part of the drainage during subsequent incision.

REFERENCES

Epis, R. C., and Chapin, C. E., 1975, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the southern Rocky Mountains, in Epis, R. C., and Chapin, C. E., editors, Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 45-74.
Flanagan, K.M., and Montague, J., 1993, Neogene stratigraphy and tectonics of Wyoming, in


