Surficial Geologic Map of Kings Canyon:

Implications for Relatively Slow Stream Incision Rates

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Andrew Farris

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Authors: Andrew Farris

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Dr. Antonio F. Garcia ____________________
Senior Project Advisor Dr. Antonio F. Garcia

Dr. Doug Piirto_ ____________________
Department Head Dr. Doug Piirto

NRES Department

Abstract

Most of the Kings River in the Sierra Nevada Mountains of California has responded to regional uplift with rapid incision, creating the deepest canyon in the United States. However, Kings Canyon near Cedar Grove is still a mountainous relict landscape with little evidence of fluvial incision. Mapping took place in the Cedar Grove area of Kings Canyon to assess factors and/or processes causing relatively low stream incision rates in the region during Holocene time. A surficial geologic map was created in the field, along with visual observations of the South Fork of the Kings River and characterization of geologic map units. The surficial map showed no evidence of knickpoint retreat and little subsequent vertical erosion near Cedar Grove. The field area has a large amount of young alluvium (unit *Qa*) and a significant amount of young colluvium (unit *Qc*). Tioga and Tahoe Stade moraines (unit *Qm*) are present, but only as far west as Cedar Gove village. Stream terraces (unit *Qoa*) exist in close proximity to the South Fork of the Kings River, but they postdate the last glaciation and are less than 10,000 years old. Minimal Holocene time fluvial incision near Cedar Grove appears to be a consequence of glaciation. Glacition lowered channel gradient and vertically denuded the valley bottom of Kings Canyon at Cedar Grove far greater than fluvial erosion would have in a comparable time scale. The Wisconsinan Glaciation also proved to be a major erosional agent and originator of sediment in the upper Kings drainage. This glaciation significantly lowered stream gradient and, consequently, stream power, and produced sufficient sediment (alluvium and till) to partially fill the scoured Kings Canyon glacial trough. Relatively fast and large magnitude Holocene time stream incision rates in areas not affected by glaciation (5 km west of Cedar Grove) support the case that Wisconsinan glaciations have proven to be a "system wrecking ball" for the Kings drainage near Cedar Grove.

Key Words

Knickpoint, Incision, Geologic Map, Tectonics, Wisconsinan Glaciation.

TABLE OF CONTENTS

Introduction

Kings Canyon National Park Geographic Location and History

Kings Canyon National Park is located in the Southern Sierra Nevada, approximately 80 kilometers east of Fresno, California (Figure 1). The geology and geomorphology of Kings Canyon National Park includes rugged granitic peaks, metamorphic roof pendants, and arguably the deepest river canyon in the United States (National Park Service, 2013). Kings Canyon has recently experienced significant landscape evolution because of rapid incision of the Kings River. Downcutting in the Kings' drainage has been a response to either uplift or climate of the region (Figueroa and Knott, 2010; Brocklehurst and Whipple, 2000). Vertical incision in the Kings River can be expected to continue, because the Sierra Nevada is continuing to grow upward in elevation. It is not completely agreed upon by geologists why the Sierra Nevada continues to grow. The causes may include westward encroachment of the Walker Lane Dextral Deformation Belt into the Eastern Sierra Nevada (similar to tectonism the Basin and Range), isostatic response to sedimentation in the Central Valley (the mechanism is flexural rift flank uplift), or mantle delamination of an eclogititic root under the Sierra Nevada. (Wakabayashi and Sawyer, 2001; Saleeby et al., 2003).

Cedar Grove and Mapping Area

The Cedar Grove part of Kings Canyon is at an elevation of 4000 feet and is a classical "U" shaped valley, most recently carved by Wisconsonian-time glaciations (Figure 2). The South Fork of the Kings River, which is a meandering river, flows through this part of Kings Canyon (Figure 4). The presence of large floodplains and point bars (unit *Qa*) that do not exist in much of the vertically incising Kings River are a testament to the atypical character of the Kings River in the Cedar Grove area relative to the Kings River in the rest of the Canyon. The area mapped near Cedar Grove is approximately 1 km in width and 7 km in length (Figure 3). The field area for this research extends from the Kings Canyon National Park/ Sequoia National Forest border to the west and near the "roads end" of Highway 180 to the east.

Methods

The Kings Canyon Surficial Geologic Map is based on field mapping in Kings Canyon National Park, California. In the field, an initial assessment of the potential map units was made, with characteristics recorded. After an initial assessment, a field survey of the mapping area took place. This included following contacts between units and assessing various characteristics of the units, such as the nature and type of rocks, development of soils, and landscape morphology. All contacts were mapped on a 200% enlarged United States Geological Survey (USGS) 7.5' topographic maps. The Sphinx and Cedar Grove quadrangles were spliced to create the base map. The field map was digitized using ESRI ArcMap. A new file geodatabase was created for the project, and for each map unit a new feature class was made (i.e. *Qa* feature class, *Qhd* feature class). The units and their respective contacts were then placed over an ESRI topographic basemap. The longitudinal profile of the Kings River was made using a 10 m National Elevation Dataset (NED) Digital Elevation Model (DEM) from USGS. This imagery was imported as a .tiff to ESRI ArcMap and reprojected into the UTM (Universal Transverse Mercator) Zone 11 N projection for accuracy and unit purposes. The ArcMap 3d Analyst tool called "interpolate line" was used to make a line outlining the stream length of interest, and a graph of distance over elevation was created.

Results

Geologic Map Units

Qa: Quaternary Alluvium is associated with fluvial processes, typically in close proximity to the South Fork of the Kings River or its tributaries. It is characterized by tan/light colored sandy sediment that has well rounded boulders, cobbles, and pebbles that are composed of Cretaceous granite and granodiorite. The contacts of this unit are gradational to extremely diffuse. This unit is becoming increasingly covered by *Qc* from rockfalls or rockslides from the Kings Canyon walls. This unit is poorly consolidated and has weakly developed soils.

Qoa: Quaternary Alluvium is older than *Qa* but is associated with the existing fluvial system. This unit is primarily tan and light colored and has oxidized sandy sediment that is friable. The unit has fewer well rounded cobbles and pebbles than unit *Qa*. This unit is 5 to 10 meters above the present-day Kings River channel. Most *Qoa* units are interpreted as terraces or rarely flooded (100-500 year floods) floodplains. The majority of the contacts of this unit are abrupt, but some contacts with *Qc* are gradational.

Qc**:** Undifferentiated Quaternary colluvium and Mesozoic granodiorite: The unit is extremely rocky and has primarily pebble to boulder sized rocks derived from the Kings Canyon walls. Soils formed in *Qc* are rare, and when soils do exist they are sandy and weakly developed. *Qc* is primarily composed of talus piles consisting exclusively of gravel and larger size clasts. Many of the rocks are more than 20 meters large in diameter and are composed of approximately 25% quartz, 35% plagioclase, and 40% biotite. Contacts with this unit are typically gradational.

Qm: Quaternary Moraines are either from the Tioga or Tahoe Stade of the Wisconsonian glaciation. The moraines are composed of sand and silt, with 1-15 cm rocks that range from subrounded to angular. *Qm* clast lithology is the same as that of the *Qc* unit. These moraines have distinctive crests that are linear from 100m to 400m. The sediments of some moraines are significantly oxidized. Contacts with other units are distinctively abrupt.

Qhd: Quaternary Human Dumps/Mines are associated with human processes that have significantly altered the geomorphic surfaces. Most soils are disturbed in this region. It is common to find metal, trash, old construction materials, and small tunnels in this area. No natural surficial unit could be interpreted from *Qhd* regions. It has a gradational contact with other map units and is likely overlying *Qa*.

Regional Geomorphology

The surficial geology of Cedar Grove as mapped for this research provides valuable information in differentiating the type and timing of incision in different parts of the Kings Canyon. The stream profile of the Kings River in the Sierra Nevada foothills is markedly different than the Kings River stream profile in the Cedar Grove part of Kings Canyon (Figure 5). In the westward, foothills part of the Kings River (greater than 18,000 meters from "roads end" on Figure 5), the river channel has been affected by and has responded to base level fall, and has a markedly greater slope than it does farther upstream (Stock et al., 2004). In the eastern, Cedar Grove section of the Kings River, the river channel has not responded to base level fall and retains a low slope (Figure 5, from 0-10,000 meters) and alluviated channel. The stream profile of the entire Kings River does not fit the classical "steady state" stream profile, which is concave up and smooth (Pazzaglia and Brandon 2001; Stock et al., 2004). It is unusual that this old drainage system hasn't achieved a steady state: *most* of this drainage has *not* been subject to "system wrecking balls" such as glaciation or stream piracy, and has been incising for at least 80 m.y at a steady rate of 0.04 mm/yr (Clark et al.,2005;). The westward, foothills part of the Kings Canyon has responded to base-level fall, but base-level fall has not propagated very far upstream in the North Fork of the Kings River (which is downstream and approximately 18 km west of Cedar Grove; Clark et al., 2005; Figure 4). Steep knickpoints in the North Fork of the Kings River are a result of the resistant metamorphic rocks in the area that are difficult to erode (Miller, 1991).

The South Fork of the Kings River does not have any clear knickpoints below Grizzly Falls, approximately 8 km west of Cedar Grove Village (Figure 5, at 18,000 meters). This suggests that base-level fall has not affected Cedar Grove, and therefore, little vertical stream incision has occurred in Cedar Grove. There is so little vertical stream incision that Cedar Grove fits the requirements for a Sothern Sierra Nevada relict landscape (Clark et al., 2005). A relict landscape is defined as an area having relatively low slopes, a uniform planar shape, and extremely limited alluvial stream transportation, but is surrounded by relatively steep hillslopes and channels having relatively steep channels (Clark et al., 2005). Kings Canyon near Cedar Grove, hypothetically, should not be a pre- uplift, relict landscape. As the rest of the Kings River continues to respond to base level fall because of tectonic processes (e.g., Wakabayashi and Sawyer, 2001; Saleeby et al., 2003, Stock et al.,2004), Kings Canyon near Cedar Grove remains unaffected by base-level fall

Implications of Surficial Mapping Results: Explanation for Slow Incision Rates

The Cedar Grove field area is resistant to vertical incision for a variety of reasons. The basement rock in the region is granodiorite, a plutonic rock that can be considered as a strong non-fluvial control on incision (Miller, 1991; Moore, 1978). The regional glacial history, however, is likely the most significant factor inhibiting response to base-level fall.

The relative abundance of young Kings River alluvium (*Qa*) supports the hypothesis that the Kings River in Cedar Grove is not a bedrock-eroding stream, and lacks sufficient available stream power to denude its valley bottom's bedrock. The Kings River in Cedar Grove lacks sufficient available stream power to develop a bedrock-eroding channel because of its relatively low slope and the large sediment load imposed by the upper Kings drainage. A low slope significantly reduces a streams ability to transport sediment because it lowers available stream power (Bull, 1990). The relatively low slope of the Kings River in Cedar Grove is due to repeated Wisconsonian glaciations, which scoured the Kings Canyon. Wisconsonian glaciations may have caused valley-bottom lowering rates as fast as 8 mm/yr in Kings Canyon, which is 200 times faster than the current rate of fluvial incision in the Kings River, 0.04 mm/yr (e.g., Harbor, 1992; Brook et al, 2006). With these low channel slopes created by intense glacial scouring of Kings Canyon, stream power in post-glacial times was destined to be very low and therefore, basin filling is expected.

Critical stream power (the stream power threshold that must be exceeded for vertical incision to take place) is extremely high as of present, and is unlikely to become lower in the near future. The reason that it is unlikely to change is the continued sediment transport from the upper Kings drainage into the Cedar Grove area (see surficial geologic map). A large amount of material was eroded and transported by glaciations from 2 Ma to the present and subsequently choked the upper Kings River with sediment (Amantov et al., 2011). The glacially derived sediment is difficult to entrain and has a large Shields criterion, according to the Shields equation: $\tau^* = \frac{\tau_b}{\rho RgD}$, where τ^* is shear traction, τ_b is shear stress, ρ is density of fluid, R is density of the sediment, *g* is gravitational constant, *D* is mean sediment particle diameter (Parker, 2004). The reason the sediment in Cedar Grove is difficult to entrain is because of the large mean particle diameter (*D*) of the sediment near the Kings River (see surficial map unit descriptions). Colluvium (unit *Qc*) is providing the largest diameter rocks (*D*) that require relatively high shear traction to move, and glacial/fluvial processes are providing the large amount of sediment and rocks to the Kings River that require high available stream power to transport downstream (Bull, 1990; Zgheib, 1990;Wouda. 1977).

Extent of Glaciation: A Knickpoint Control Mechanism

It is clear that glaciation has affected Cedar Grove, due to the presence of Tioga and Tahoe Stade moraines still existing in the valley (see *Qm* units). Westward of the Cedar Grove field area, however, Tioga and Tahoe Stade moraines were found as far westward as Grizzly Falls (at 18,000 meters downstream of "roads end" in Figure 5; Moore and Mack, 2005). The knickpoint, which is the downstream limit of the relict or relict-like landscape, is at the exact location as the extent of the most recent glaciations (Tioga/Tahoe Stade) in the Kings Canyon (Figure 5). This suggests that some mechanism(s) associated with glaciations inhibit stream incision in post-glacial times.

Conclusions

Glaciation has truly been the "wrecking ball" mechanism that has prevented incision into bedrock in the Cedar Grove section of Kings Canyon. Large magnitude incision into bedrock is taking place in much of the Kings Canyon, but a knickpoint is present at the extent of the recent Tioga and Tahoe Stade glaciations in the Canyon (Figure 5). This suggests that glaciation is inhibiting upstream propagation of base-level fall. The stalling of the knickpoint near Grizzly Falls is likely due to relatively low available stream power and the vast discharge of sediment from the upper Kings Drainage. Wisconsonian glaciations were a much more effective erosional agent than fluvial erosion would have been in the same time period. Erosion from this glaciation scoured the Kings Canyon, and lowered the valley bottom gradient sufficiently to result in a post-glacial axial drainage having relatively low stream power. In the upper Kings drainage, much sediment was produced by the Wisconsonian glaciations. The low slope and abundance of sediment associated with glacial processes have prevented the Kings River in the Cedar Grove area from incising into bedrock in Holocene time.

Figures

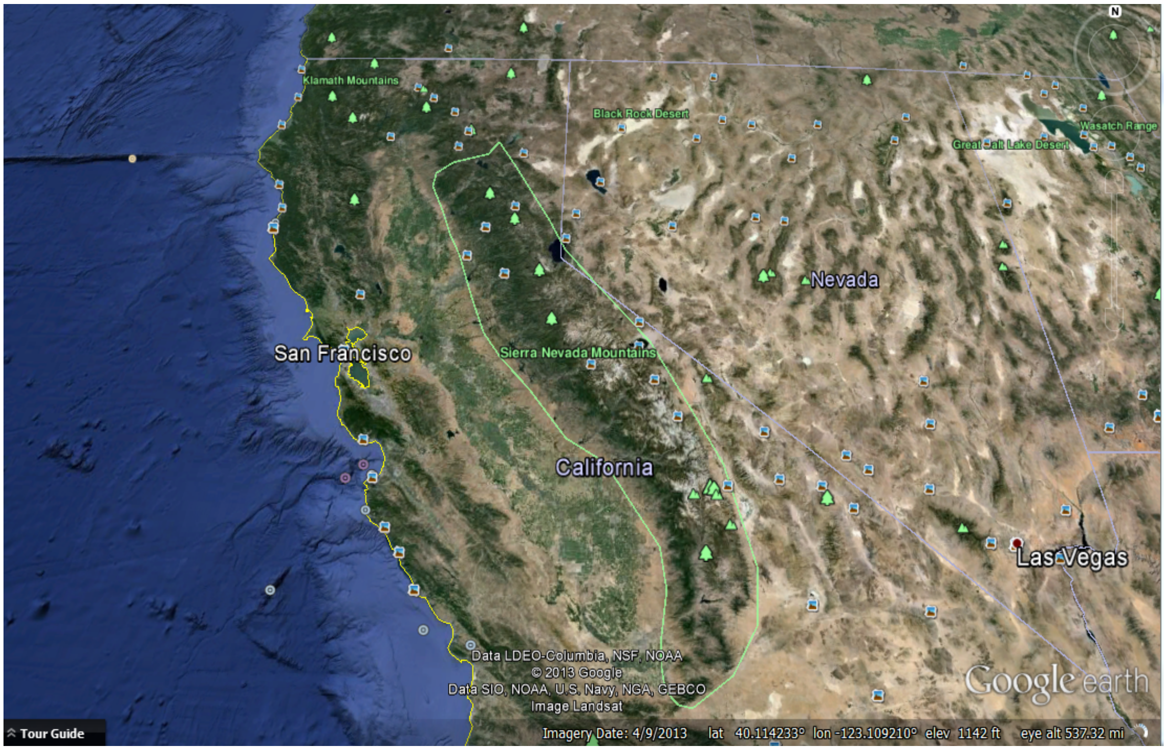

Figure 1. Map of the Sierra Nevada Mountains in California outlined in green. Imagery sourced from Google Earth.

Figure 2. Map of the location of Cedar Grove in Kings Canyon National Park. Imagery sourced from Google Earth.

Figure 3. A map of the extent of the mapping area in Cedar Grove. The mapping area included the entire valley shown. Imagery sourced from Google Earth.

Figure 4. Displays the different drainages of the Kings Rivers. Cedar Grove is in the South Fork Drainage. Imagery sourced from Google Earth.

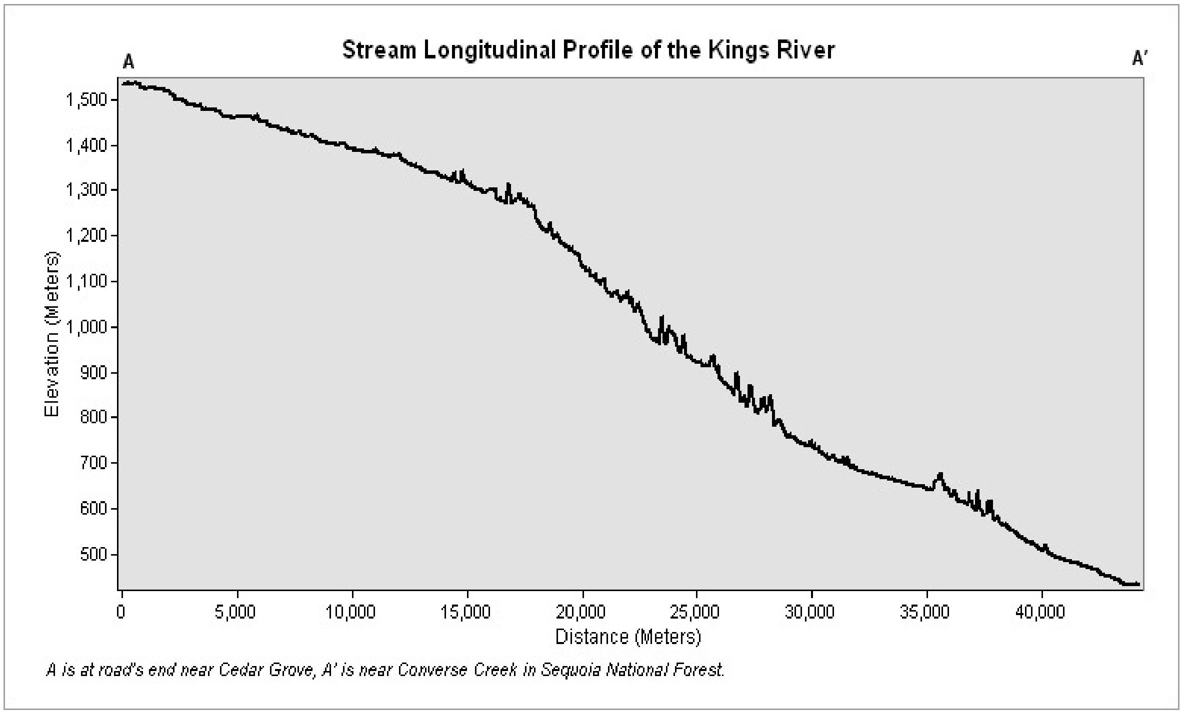

Figure 5. Cedar Grove is from 0-10,000 meters. Grizzly Falls, the knickpoint in the South Fork of the Kings River, is at approximately 18,000 meters. The sharp elevation jumps past 18,000 meters are from error associated with the resolution of the DEM imagery used.

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