Stream Terrace Genesis Along Bunte Creek in the Elkhorn Plain, CA

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Abstract

There are several factors influencing terrace genesis and terrace types in Bunte Creek. Strath terraces exist at upper Bunte Creek, whereas thick fill terraces exist at lower Bunte Creek. Analysis of these terraces leads to insight on what specific factors lead to their formation. Terraces were mapped along the extent of Bunte Creek. Sediment data and terrace-height data were collected for in order to make a complete analysis of the terraces. Tectonic uplift led to incision and strath terrace genesis at upper Bunte Creek. Climatic forcing and base-level rise caused alluvial aggradation behind a shutter ridge that intersects lower Bunte Creek. Once the alluvial fill reached the elevation of the shutter ridge, a new, lower base level at Bunte Creek was established. This led to incision and fill terrace genesis in lower Bunte Creek.

Introduction

This paper identifies different factors that influenced stream terrace morphology along Bunte Creek, located in the Elkhorn and Carrizo Plains (Figure 1). The upper reaches of Bunte Creek are dominated by strath terraces, whereas the lower reaches of Bunte Creek are dominated by fill terraces. In this paper, a model is proposed for how these terraces formed.

Stream Power

Whether a stream aggrades or incises into its stream bed depends on the threshold of available stream power and critical power (Bull, 1979). Critical power is the amount of power required to transport sediment in the stream (Bull, 1979). When the stream power divided by the critical power equals one, the stream is at the threshold of critical power (Bull, 1979). If the ratio of stream power to critical power is less than one, the stream will aggrade (Bull, 1979). If the ratio is more than one, the stream will incise into the stream bed and form a terrace (Bull, 1979).

Fill terraces form when the critical stream power threshold is crossed, switching the stream from aggradation dominant to incision dominant (Bull 1990). The tread of a terrace represents this switch (Bull 1990). Base-level fall can also lead to terrace genesis, because it causes stream incision. In many instances incision processes propagate from downstream to upstream (Garcia, 2004). Currently, there are thick fill terraces present in lower Bunte Creek.

Holocene Paleoclimate

Climate forcing is one factor that caused changes in stream power at Bunte Creek Creek. Significant climate changes marked by the transition from the Pleistocene to the Holocene and altered the ratio of stream power and critical stream power throughout the American Southwest (Bull, 1979). During the Holocene in the American Southwest, there was either a drop in precipitation or increase in temperature, or both (Bull 1979). These climatic developments decreased soil-water infiltration and vegetation density (Bull, 1979). During this time, regional soils grew increasingly prone to erosion (Bull, 1979). This climate forced soil erosion could have led to increasing amounts of sediment runoff into rivers and thereby increased critical stream power (Bull, 1979). Additionally, drier climate led to lower discharge and decreased stream power in those same channels.

Paleoclimate Influence on Stream Terraces

Based on paleoclimate inferred from the model of Bull (1979), little vegetation has been present in the Elkhorn Plain during the Holocene, due to the semi-arid conditions. The lack of vegetation in this area could have led to an increased rate of erosion, based on the composition of the unconsolidated sediments that underlies most of the landscape of the Bunte Creek drainage basin (Dibblee and Minch 2005). These sediments are largely composed of poorly-cemented sandstone and clayey shale (Dibblee and Minch 2005) that are susceptible to climate forcing. Over a few thousand years, the prevailing climate of the Holocene would lead to transport of large amounts of sediment from hillslopes into the channel of Bunte Creek.

Tectonic Influence on Aggradation and Incision

Another possible factor contributing to stream terrace formation is regional tectonism. The horizontal shortening component of plate motion along an oblique margin may be transformed into crustal thickening, which can create a visible vertical strain across the topography (Spotila, 2007). Crustal thickening forms elongate ridges and ridge spurs, which can develop shutters across drainage channels (Wallace, 1990). After intersecting these drainage systems, the shutter ridges can create a internally drained basin, leading to aggradation of sediment .

Variables such as local uplift, regional uplift, stream discharge, stream gradient, and even resistance of earth materials to degradation all contribute to determining incision rates. After periods of uplift, stream erosion induces incision due to the critical-power threshold being exceeded along the drainage network (Bull, 1979). This can be indicated by lack of net alluviation in narrow V-shaped valleys and steeper slopes in the active stream channel (Bull, 1979).

Goals of Paper

The goal of this paper is to identify the causes of terrace genesis in Bunte Creek, and to understand why terraces in the upper portion of Bunte Creek are different than the terraces in the lower portion of Bunte Creek. Compositional analysis of the terraces in lower and upper portions of the creek provides insight into the factors that led to the development of terraces.

Regional Setting

Elkhorn Plain and San Andreas Fault Zone

Bunte Creek cuts perpendicularly across The Temblor Range, the Elkhorn Plain and the San Andreas fault. The coordinates of Bunte Creek are 35.161360, -119.708051 at its intersection with the San Andreas Fault (Figure 1).

The Elkhorn Plain is raised above the Carrizo Plain due to convergence across the primarily dextral transform plate boundary at the San Andreas fault (Jahns and Sieh, 1984). The San Andreas fault is currently moving the Elkhorn Plain closer to a right lateral step, causing the Elkhorn Plain uplift (Jahns and Sieh, 1984). Currently, the slip rate along the San Andreas Fault is 33.9 +/- 2.9 mm/yr (Jahns and Sieh, 1984). When the slip along a fault is faster than the erosion in dry climates, the evidence that fault slip occurred is preserved in the geologic record and can be exposed by subsequent stream cutting (Wallace, 1990).

Other features that occur within the lateral and vertical shuffling of the strike slip fault zone include offset streams, deflected streams, shutter ridges, sag ponds, pressure ridges, stream terraces, sinusoidal streams and deranged streams (Wallace, 1990). Along its entire length, the fault zone exhibits anomalous drainage patterns (Wallace, 1990). When drainage flowing from the Elkhorn Plain meets the San Andreas fault, it is diverted parallel or subparallel to the strike of the active fault zone(Wallace, 1990). In most landscapes, erosion is the dominant factor in carving geomorphic forms, but displacements are so rapid within San Andreas fault zone that tectonic movements outpace erosion, and so the geomorphic features directly express fault movement (Wallace, 1990).

Geology of the Area

The canyon of upper Bunte Creek is formed in relatively weak claystone, shale and sandstone of the Temblor Formation, Monterey Shale, and Santa Margarita Formation (Dibblee and Minch, 2005) that compose the Temblor Range. The hinges of the folds in these sedimentary rocks trend perpendicular to the flow direction of Bunte Creek,and the dips of the beds in the folds range between 12 and 88 degrees. Faults that strike perpendicular to the direction of streamflow are present along the entirety of Bunte Creek.

The canyon of lower Bunte Creek is formed in sandstone (Tuss) of the Morales Formation, and alluvial sand as well as clay sediments (Tmo and QTp) of the Morales and Paso Robles Formation (Dibblee and Minch, 2005). The headwaters of the three main tributaries pf Bunte Creek that converge in the Elkhorn Hills (Figure 2) also flow through this geology.The San Andreas cuts across the lowest portion of Lower Bunte Creek, where a shutter ridge denotes the surface trace of the fault (Figure 2).

Climate and Vegetation of the Study Site

Bunte Creek is in the Carrizo Plain National Monument in eastern San Luis Obispo and western Kern counties (Stout, 2013). Summers are usually warm and dry, while winters are mostly cool and wet (CPNMRG, 2012). Average summer temperatures range from a low of 10 degrees celsius at night to a high of 32 degrees celsius during the day (CPNMRG, 2012). Average winter temperatures range from a low of 0 degrees C at night to a high of 15 degrees C during the day (CPNMRG, 2012). The area receives around 17.5 to 25 centimeters of precipitation annually (CPNMRG, 2012).

The primary vegetation of upper Bunte Creek is low density California Annual and Perennial Grassland and unvegetated cliffs and rock outcrops (Stout et al, 2013). The California Annual and Perennial Grasslands grow in higher densities in lower Bunte Creek (Stout ect. 2013). Low densities of Desert Scrubs exist throughout the drainage basin of Bunte Creek and in the lower portion of lower Bunte Creek there is a very low density of Arroyo Wash Scrubs.

Materials and Methods

Field maps were created by enlarging 1;24,000 scale U.S. Geological Survey topographic maps to 1:11,765 and 1:9,804 scales. A 30 meter tape measure was used to measure the height of the different terraces and a knickpoint in Bunte Creek. A digital planimeter was used on the topographic maps to create a longitudinal stream profile (Figures 3a and 3b). Slopes within

Bunte Creek were calculated using Excel software to analyze planimeter results. ArcMap was used to digitize field maps.

An initial survey of Bunte Creek was completed to determine the extent of the terraces. After the initial survey was complete, mapping was completed in the field (Figure 2). Stratigraphic sections were measured and described where suitable outcrops in the terraces were present. A grain size comparator was used to determine grain size in the field. Not all terraces permitted this due to colluvial or vegetative cover. The height of terrace treads were recorded and compared to distinguish terrace units.

Results

Longitudinal profile of Bunte Creek

The longitudinal profile of Bunte Creek is relatively linear, with the exception of a 10.2m tall knickpoint upstream from the shutter ridge (Figure 3.b). The average slope of lower Bunte Creek is 0.0269 and the slope of upper Bunte Creek is 0.0354 (Figure 3.b).

Spatial Distribution of Stream Terraces

Map unit Qtf consists of stream terraces that are directly upstream of the shutter ridge (Figure 2) and have surfaces that are between 14 and 15 meters above the channel bed. Map unit Qt1 represents the active floodplains within the incised channel. These floodplains are 1.2 to 1.7 meters above the channel bed and are inset into sections Qtf and Qt3 terraces along their entire extents (Figure 2). Map unit Qt2 is the active floodplain downstream of shutter ridge (Figure 2).

The QT2 are 1.5 to 2 meters above the channel bed and are not within an incised channel. Map unit Qt3 consists of stream terraces upstream of the Qtf terraces. They are concentrated in the midsection of Bunte Creek and have surfaces that are 3 to 7 meters above the stream bed. Map unit Qt4 represents the stream terraces located upstream of the Qt3 terraces. These are concentrated in the upper section of Bunte Creek and their surfaces are greater than 30 meters above the stream bed. The sedimentology of all terraces is described in Appendix 1.

Discussion

Terrace Formation in Upper Bunte Creek

The relatively great height of the strath terraces (Qt4 in Figure 2)above the channel of upper Bunte Creek is a result of tectonic uplift (e.g. Bull, 1990). Uplift of the Temblor Range was a result of oblique, right-lateral movement the San Andreas fault. Alternating periods of uplift and quiescence caused intermittent down cutting periods into the valley floor indicated by steep v-shaped valleys and erosional scarps (Bull, 1990).

Lower Bunte Creek Terrace Formation

Assuming that the Holocene paleoclimate provided dry enough times to decrease stabilizing vegetation around Bunte Creek, intermittent storms during this time created large bed loads (e.g. Bull 1979; Bull, 1990). Additionally, bedload was blocked from deposition into the Carrizo Plain by the shutter ridge. Deposition of alluvium resulted in 14 to 15 meter backfill deposits. After the alluvial fill reached the same elevation of the shutter ridge, the new base level became the elevation of the Carrizo Plain. Once this new, lower base level was established, the stream incised into the bacc, creating the alluvial fill terraces (Qtf in Figure 2). Terrace genesis occurred along most of the length of Bunte Creek because the base-level fall that occurred when the channel of Bunte Creek breached the shutter ridge propagated upstream through the back-filled valley as an incision wave (e.g. Safran, 1998; Garcia et al, 2004). The ongoing incision is enhanced by Bunte Creek's steep channel slopes (Figure 3.a and Figure 3.b). Oversteepened channel slopes and base-level fall both contributed to incision and abandonment of terrace surfaces and resultant terrace genesis.

Another effect of breaching of the shutter ridge was that an upstream-migrating knickpoint developed as Bunte Creek incised into the channel. The knickpoint has migrated upstream to its present location, north east of the shutter ridge, and currently has a height of 10.2 meters (Figure 2). The tight curve in Bunte Creek where the knickpoint is located is a result of the ongoing movement of the San Andreas fault.

Similar Case Studies

At Wallace Creek, a nearby stream channel to Bunte Creek, there are numerous remnants of a terrace above the modern stream bed. The terrace underlain by sand and gravel beds, and is characterized by scour-and-fill structures (Jahns and Sieh, 1984). The massive and poorly sorted nature of some of these beds indicates that they are debris-flow deposits (Sieh and Jahns 1984). Other beds that are well sorted and stratified must have been transported as bedload in the waters of Wallace Creek (Sieh and Jahns 1984). Due to their proximity, it is possible that the terraces and sediments at Wallace Creek are temporally correlative to those at Bunte Creek. In comparison, Wallace Creek, which does not have a shutter ridge in front of its lower reach, was able to carry its suspended load to base level, and is why it has formed an alluvial fan and complex stratigraphy southwest of the San Andreas fault (Sieh and Jahns 1984, 887).

Conclusion

Upper Bunte Creek contains strath terraces that were formed from tectonic induced incision. Climatic forcing caused alluvial fill to aggrade in lower Bunte Creek. When the alluvial fill reached the elevation of the shutter ridge, a new base level was achieved and incision propagated upstream. This incision cut through the alluvial fill and created the fill terraces.

Appendix

Figure 1. Gray, centered pin is located at Bunte Creek in the Carrizo Plain National Monument. Image taken from Google Maps.

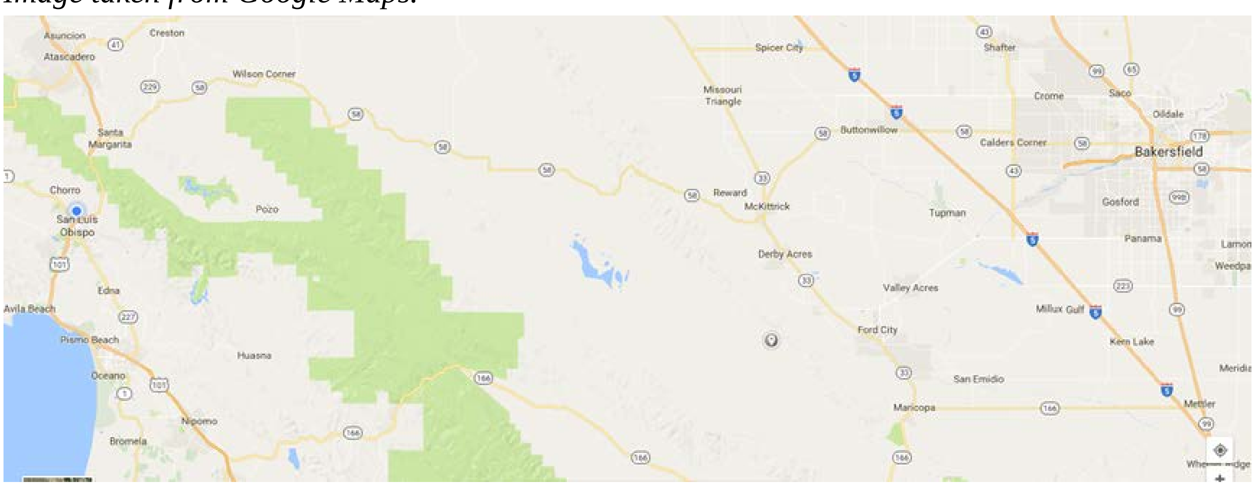


Figure 2. Surficial geologic map of Bunte Creek done on ArcGIS.

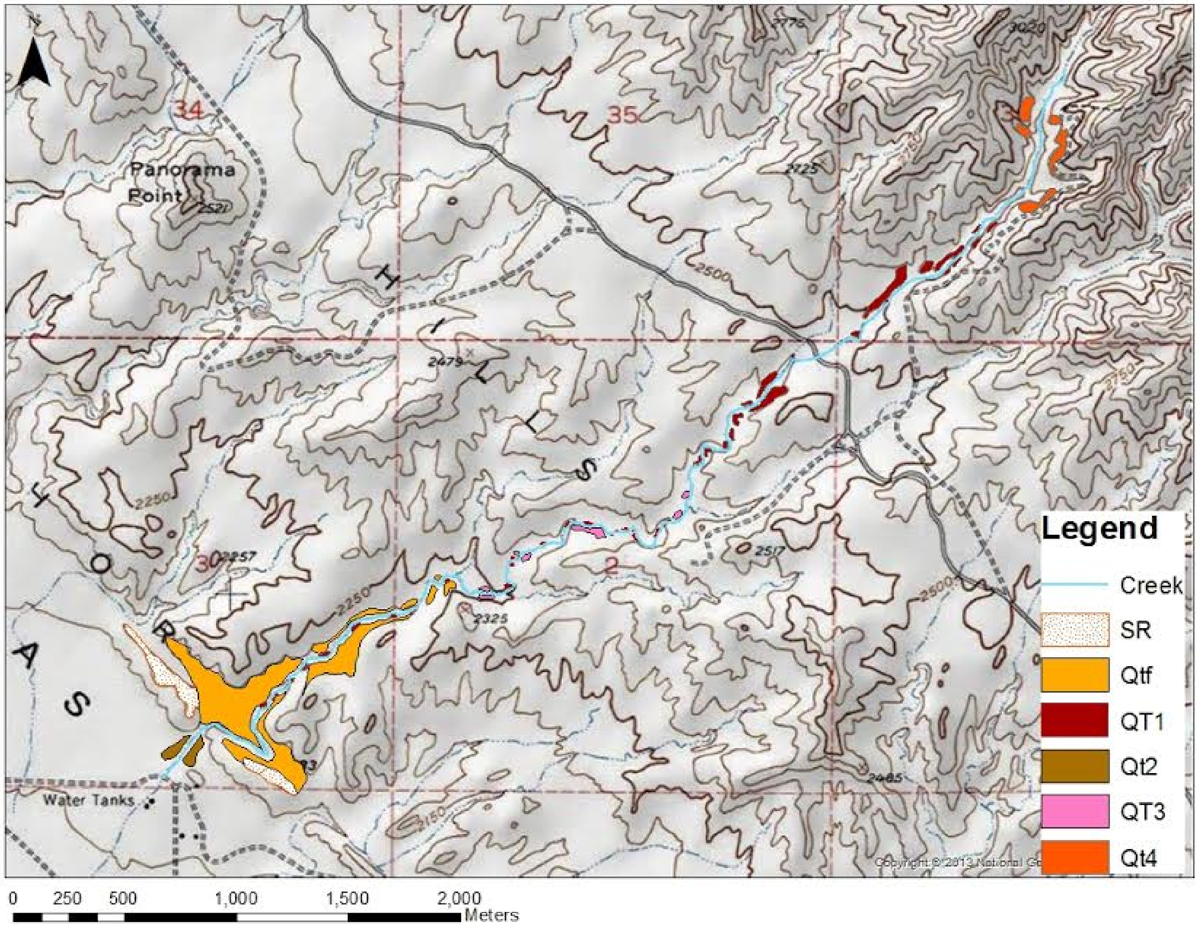


Figure 3.a Stream Profile of the entirety of Bunte Creek study area.

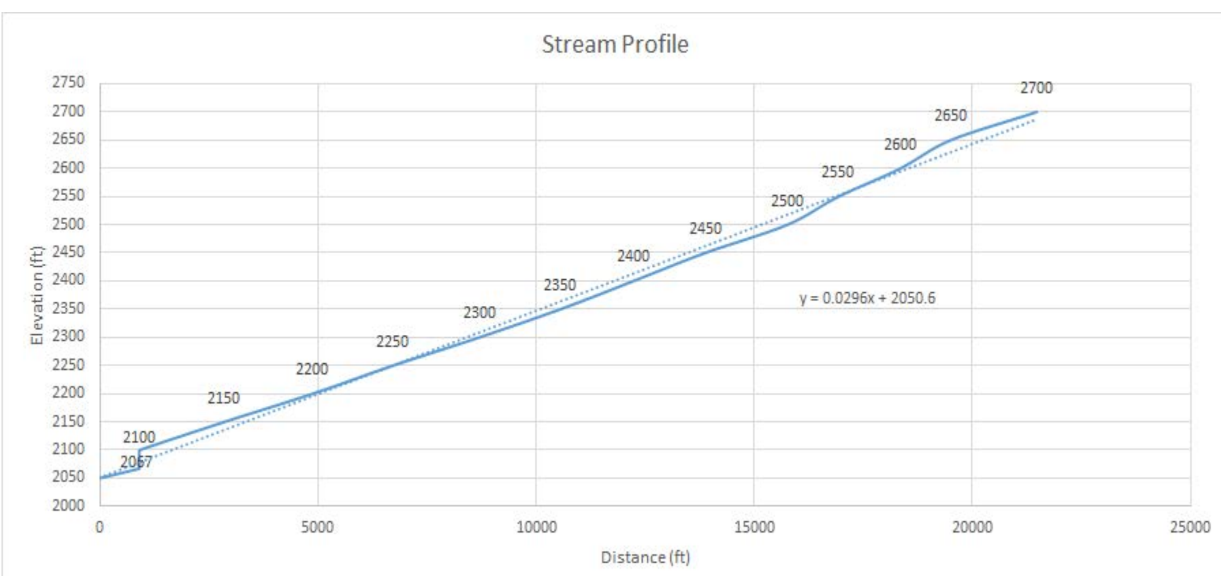
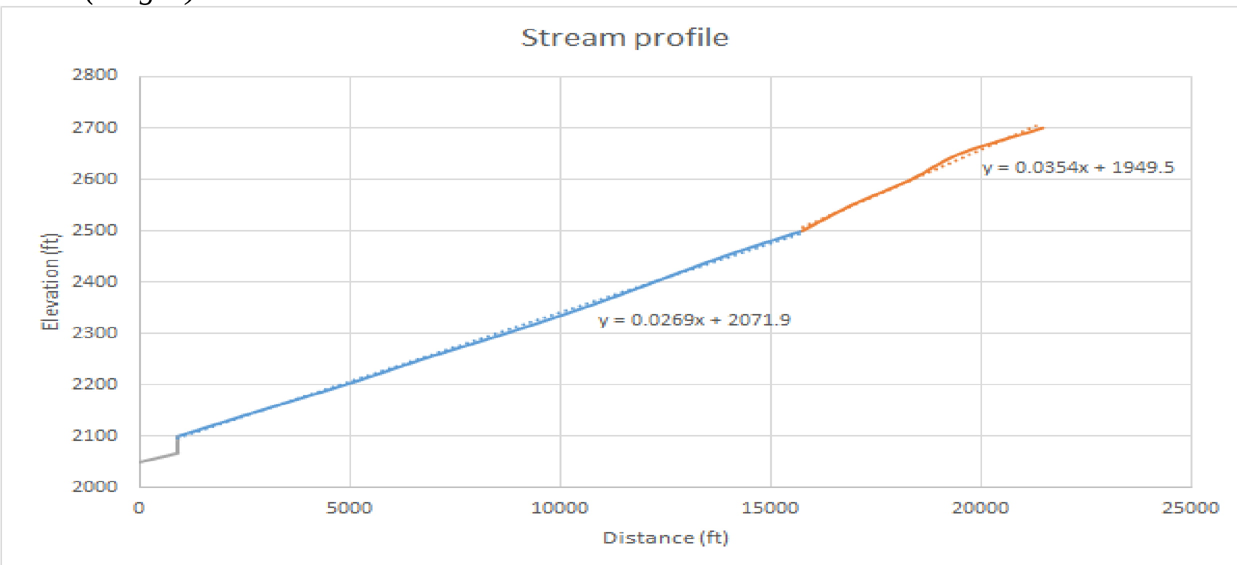


Figure 3.b Stream profiles and slopes separated by lower Bunte Creek (blue) and Upper Bunte Creek (oragne).



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Appendix 1: Bunte Creek Map Unit Descriptions of *Figure 2* Map

*Composition of gravel-sized clasts: Granite, schist, quartz, and gypsum.

Qtf: Quaternary terrace fill. This map unit consists of fill terraces composed of alluvial sediment. The base of the terraces are not exposed and the thickness of the terrace alluvium is between 14 and 15 meters thick. The fill terraces extend from the shutter ridge to the first confluence upstream of the shutter ridge (Figure 2). The sediment is weakly cemented and matrix supported. Clasts range between gravels and cobbles with a median clast size of 1 cm and a grain size of medium to very coarse sand. Within the fill, there are clast supported lenses typically 1 to 4 meters wide and 20 to 40cm thick. There is a knickpoint formed in the alluvium that is inset into the shutter ridge that is 10.7 meters tall.

Qt1: Quaternary terrace 1. Where present, this map unit represents the lowermost terraces of Bunte Creek. This unit extends upstream from the shutter ridge. The base of the terrace is not exposed and the surface of the terrace is 1.2 to 1.7 meters above the channel of Bunte Creek. The terraces are inset into the Tertiary and Quaternary sedimentary unit mapped by Diblee and Minch (2005). Qt1 terraces are within the incised channel and areas mapped as Qt1 include the active channel. The terraces are composed of matrix supported and locally clast supported gravel and sand. Clasts range between gravels and cobbles with a median clast size of 1cm and a grain size of medium to very coarse sand.

Qt2: Quaternary terrace 2. This map unit is an alluvial fan lobe incised into by Bunte Creek. The base of the lobe is not exposed and the surface of the fan lobe is 1.5 to 2 meters above the channel of Bunte Creek. The fan lobe is matrix supported and locally clast supported. Clasts range between gravels and cobbles with a median clast size of 1cm and a grain size of medium to very coarse sand.

Qt3: Quaternary terrace 3. This map unit is inset into the Tertiary and Quaternary sedimentary units mapped by Dibblee and Minch (2005). The base of the terraces are not exposed, and the surface of the terraces are 3 to 7 meters above the channel of Bunte Creek. The height of these terraces above the stream channel increases upstream. Qt3 terrace remnants extend upstream from the Qf alluvial fill to midway up the Bunte Creek study area (Figure 2). The terraces are clast supported and locally matrix supported. They contain beds of interlayered sand and gravel. Clasts range between gravels and boulders with median clast size is 1cm and the grain size of lower to coarse upper sand.

Qt4: Quaternary terrace 4. This map unit consists of terraces that are inset into the Tertiary units mapped by Dibblee and Minch (2005) in upper Bunte Creek. The height of the terrace surface is greater than 30 meters above the channel of Bunte Creek. Remnants of these terraces extend from Elkhorn Road to the end of the unnamed road (Figure 2). The terraces are composed of alluvial sediment that is coarser than the lower terraces of Bunte Creek. The risers of the terraces are subvertical and are prone to landslides.

Observations of Hillslopes and Valley Form

Upper Bunte Creek is contained in a V-shaped canyon that has dramatically steep walls. The canyon walls show ample evidence of landslide scars, which locally expose sedimentary rock outcroppings. The Qt4 terraces formed here also maintain steep walls that also show evidence of landslide scars (Figure 2). Lower Bunte Creek is surrounded by narrow to wide valleys and gently sloping hillsopes. At the lowest portion of Bunte Creek, upstream and within approximately 1 km of the shutter ridge, the the valley that composes the QTf terrace and surrounds the creek is at its widest (Figure 2).