

Field observations of bedrock channels scoured by debris flows

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Summary

Bedrock channels recently scoured by debris flows exhibit a wide range of surface roughness, joint spacing, wear marks, and cohesion. The mechanisms of bedrock lowering by debris flows depend both of the flow and the initial properties of the eroding substrate. To document the variety of bedrock channel form after debris flows, I visited several sites in the southwestern United States and Switzerland between one week and nine months after debris flow events. One of the most dominant differences between sites was the roughness scale and frequency, ranging from very smooth to jagged, blocky topography. Another difference was the coherence of the exposed surface, ranging from massive bedrock to extremely incohesive saprolite-like material. For a more controlled erosion study in nature, we also installed two rock slabs, one granite and one marble, on the upstream side of a check dam in the Illgraben torrent, Switzerland. Photo documentation over three debris flow seasons showed both long mm-depth grooves and circular impact marks on the weaker marble sample, and scratches and preferential wearing of the weaker mineral on the granite sample. The initial grooves on the marble were worn away after two debris flow seasons, erasing any evidence of the significant sliding wear. The observations at these sites support the view that (1) debris flows are necessary to clear the channel of soil cover and vegetation and expose the bedrock channel, and (2) joint spacing and other existing structure are important variables influencing the rate of bedrock lowering by debris flows.

Introduction

Field observations of bedrock channels scoured by debris flows have motivated studies on erosion mechanisms by debris flows (e.g., Stock et al., 2005). Unlike the well established and documented field of fluvial bedrock channels (e.g., Whipple, 2000; Richardson and Carling, 2005), there are fewer comparative studies of debris flow channels. Such field observations would complement experimental results and guide their application to nature. They would also help to distinguish different mechanisms of wear in fluvial and debris flow processes.

In this document, we report observations at sites with channels that are freshly scoured by debris-flows in the southwestern United States and Switzerland. Field observations will help to translate laboratory-derived erosion mechanisms to the more heterogeneous natural landscape. For example, the laboratory erodible samples in Hsu (2010) are homogeneous sand-cement mixtures, but in the field we have a chance to observe the erosion of jointed and otherwise heterogeneous substrate. Field observations may also inform the relative importance of impact wear versus sliding wear, or, roughening versus smoothing styles of erosion in natural channels. We hypothesize that this depends on the relative strength of the erodible material and the eroding particles, in addition to pre-existing structure in the bedrock substrate.

First I describe the bedrock channels observed at the sites, with accompanying photographs and satellite imagery before and after the debris flow event from Google Earth. Next I describe the project where we fixed two rock samples to the upstream side of a dam in the debris-flow rich Illgraben torrent in Switzerland.

Site descriptions and observations of wear

Between 2004-2007, I visited sites where debris flows scoured to the bedrock channel, leaving it freshly exposed. I documented the form of the channel and any wear marks, if present. Five sites are in southern Arizona, all triggered by a large precipitation event in July 2006 (Youberg et al., 2008). Two sites are in southern California and failed during heavy precipitation in January 2005, after being burned the previous summer (**Figure 1**). Finally, one site is in southern Switzerland, and is monitored by the Swiss Federal Institute for Forest, Snow, and Landscape (WSL) because of its high frequency of debris flow events (**Figure 2**). The sites and their detailed locations, date of failure, and date of visit are listed in **Table 1**.

Arizona

6200 Curve

(**Figures 3a-d**) Huachuca Mountains, Arizona. This channel had the roughest surface observed, with decimeter-scale protrusions lining the walls and bed. The basin had been burned prior to the triggering precipitation event. The satellite images before and after show that neighboring channels were also scoured (Figures 3a-b). Figures 3c and 3d show the extremely rough surface of the bedrock channel, presumably due to pre-existing jointing, and the soil mantle that had been stripped from the bottom of the channel remains on the sides.

Bab Wash

(**Figures 4a-i**) Chiricahua Mountains, Arizona. Granodiorite. The satellite images before and after show that the homogeneously-soil-mantled and vegetated swale was deeply gouged by a wide flow (Figures 4a-b). In the channel, the most notable characteristic is the low cohesion of the bedrock, which could be dug with one's boot

(Figure 4e,f). The consistency was like that of saprolite. Also notable was the variable width in the channel (Figures 4c,d,g). In more coherent areas there was evidence of plucking of decimeter-scale blocks. Boulder size reached several meters in diameter, many sourced from the initial rock fall area (Figure 4h).

Bear Canyon

(Figures 5a-d) Santa Catalina Mountains, Arizona. Here, the flow left a very smooth massive bedrock surface with a parabolic cross-section, cutting across dikes (Figure 5d). The pre-event thin soil and vegetation mantle was stripped away in many channels across this area (Figures 5a-b). The natural hazards potential in this area is discussed in Youberg et al. 2008.

Giftshop Channel

(Figures 6a-f) Santa Rita Mountains, Arizona. Decimeter-scale jointing appeared to be the dominant control on the bedrock lowering, with empty spaces where blocks were plucked very noticeable (Figure 6c,d). The surface between the joints was smooth with subtle flow-parallel grooves (Figure 6e). Downstream in the deposit, the plucked blocks were clearly visible mixed in with a different lithology rock from closer to the source (Figure 6f).

Picnic Area

(Figures 7a-g) Huachuca Mountains, Arizona. Bisbee Group Fm, Granodiorites, fanglomerates of volcanics, shales, sandstones, silicious volcanics. Chipping of rock occurred here (Figure 7d), where thin surface-parallel chips of rock were removed. Centimeter-scale blocks which seemed likely units of erosion were also observed (Figure 7e). Decimeter-scale channel steps were common, as at other sites (Figure 7c, f). Figure 7g shows that broadly smooth areas were also present. Here, the steps and topography appeared to be related to base lithology change. We estimated that the soil cover was 20-50 cm in the channel prior to the event.

California

Citrus Farm

(Figures 8a-c) Near Sespe Wilderness, California. This area was burned the summer before the January rains. The debris flow destroyed part of a citrus farm that was built on the debris fan exiting the canyon. Close to the outlet, the channel was steeply incised into bedrock with vertical walls (Figure 6c). The satellite imagery shows that shallow landslides were very common in the area after the fire and precipitation.

Cook Canyon

(Figures 9a-d) San Bernardino Mountains, California. Many decimeter-to-meter knickpoints made up the stepped bedrock channel topography (Figures 7c,d). The satellite imagery shows that many trees were removed from the channel bottom. At this site we walked from deposition to initiation zones, where it appeared that shallow landslides initiated the flow.

Oregon

Hadsall Creek

(**Figures 10a-c**) Oregon Coast Range, Oregon. Sedimentary rock.

Switzerland

Illgraben Upper Reach

(**Figures 11a-d**) Valais, Switzerland. The east side of the Illgraben valley, where tributaries shoot down from the Illhorn, is thought to be the source of most debris flows, as opposed to the open rock face on the west side. Figures 9b-d were taken from the tributary immediately to the left of and level with the Steinschlaghutte placemark in Figure 11a. Knickpoints several meters in height are common. In early June, the channel was occupied with a mixture of snow and debris. We observed a small failure event where a portion of this snow/debris flowed down over the knickpoint. Later in the summer, the amount of debris in the channel was much smaller. The knickpoint was very smooth bedrock with some flow-parallel scratches of insignificant depth.

Summary of observations

At these field sites, there were recurring observations that are useful for describing the role of debris flows in landscape evolution.

(1) At these sites, bedrock in the channel was not exposed until after a debris flow event. Before the event, a soil mantled and vegetated gentle swale existed. During the debris flows, the vegetation and soil was stripped completely from the bottom of the channel. The newly exposed “bedrock” was usually intact, though sometimes smooth, sometimes very jointed, and sometimes extremely crumbly as if it were a saprolite layer on top of the intact bedrock.

(2) During debris flow erosion, the surface can be either smoothed or roughened at the decimeter scale. Plucked blocks may be smoothed between the joints indicating that both types of wear occur, though the plucking removes a much larger volume of rock. At a larger scale, bedrock steps very common in the decimeter to meters-scale. Sometimes lithology differences were responsible for bedrock steps, but sometimes lithology seemed not to matter and the channel smoothness cut across lithologic boundaries.

(3) Different wear mechanisms, such as chipping or grooving, can be highly localized in a channel, and sometimes only observed in one or a few spots in the channel. Evidence of different mechanisms can be widely variable in the same channel.

Previous studies hypothesized that the amount of erosion by removal of jointed blocks was much greater than that removed by abrasive wear by sliding. This is dependent on the material properties of the worn rock and the nature of the channel. At sites like the Giftshop channel it does seem to be the case that both types of wear occur, but the plucking mechanism is dominant.

In steep tributary channels, it seems reasonable to assume that the vegetation and soil will be stripped away by debris flows, at least in arid climates like the U.S. sites reported here. As seen at the Illgraben, at higher altitude and lower temperatures, one must take into account cover by snow as well as just sediment, both which may protect the channel from wear.

Table 1. Sites, dates of debris flows and visits (YYYY-MM), and location.

Location	Date event	Date visited	Latitude	Longitude
6200 Curve, Arizona	2006-07	2007-03	31°21'27.97"N	110°17'9.60"W
Bab Wash, Arizona	2006-07	2007-03	32° 7'52.60"N	109°27'6.76"W
Bear Canyon, Arizona	2006-07	2007-01	32°19'27"N	110°46'37"W
Giftshop Channel, Arizona	2006-07	2007-03	31°43'27.98"N	110°53'4.02"W
Picnic Area Channel, Arizona	2006-07	2007-03	31°20'36.56"N	110°15'8.14"W
Citrus Grove, California	2005-01	2005-01	34°26'31.55"N	118°55'10.02"W
Cook Canyon, California	2005-01	2005-01	34° 8'38.23"N	117°10'2.23"W
Hadsall Creek, Oregon	unknown	2004-07	44°01'15.43" N	123°51'15.39" W
Illgraben Upper Catchment, Switzerland	yearly	2006-07	46°16'38.97"N	7°36'54.48"E

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