View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Caltech Authors - Main

GSA Data Repository Item 2017320
Malatesta, L.C., and Lamb, M.P., 2017, Formation of waterfalls by intermittent burial of active faults: GSA Bulletin, https://doi.org/10.1130/B31743.1.

DATA REPOSITORY

Selection of unexplained waterfalls

We detail here how we selected 15 waterfalls out of a total of 62 surveyed waterfalls (Supplementary Table 1, last two columns). To be selected, waterfalls needed to have no explained origin and to be in a setting where equations for fluvial dynamics are valid. The specific reasons they did not meet the criteria are as follows. Eight waterfalls are pinned on lithological contacts and likely to have developed on site. Most of them were due to granite intruding fractured marble in Saline Valley. In Panamint Valley, a total of 14 small waterfalls (between one and five meters) in groups of two to four successive steps are interpreted to be likely due to the development of step-pools. In Panamint Valley as well, four waterfalls coincided with inactive faults where the hanging wall is significantly more fractured than the footwall. In the same valley one waterfall was on the contrary located on an active fault where recent seismic activity caused a co-seismic throw of ~2 m (North Fork of South Middle Park Canyon 2). In Happy Canyon of Panamint Valley, two waterfalls have no obvious origins but lie along a river reach where we observed many waterfalls formed in step-pools and at lithological contacts. We ignore them on the ground that they could be derived from similar causes. In Happy Canyon the local fault has multiple active splay faults that discard the waterfall measured in the canyon because the assumption of accumulated slip on a single fault is violated. The first waterfall of South Badwater 4 lies at the apex of the fan and the base of the waterfall is buried in alluvium so that we could not measure the total height of the bedrock waterfall. In the same catchment, waterfalls 3a and 3b lie next to each other in a section where the channel is split in two. The height of the second waterfall of South Badwater 5 could not be measured because we could not get access to a viewpoint overlooking the entire waterfall. In South Badwater 3 and 4, the fourth waterfall counting from the apex is at least twice as high as the downstream ones: 26 m and >20 m respectively. They are the likely result of several waterfalls that merged during their upstream migration. In Copper Canyon several waterfalls were identified in the tributaries of the main canyon but they were all cut in Quaternary conglomerate recently uplifted after the normal fault migrated basinward. We ignore this catchment as we lack information about the former geometry of the alluvial fan. In the end there remains 25 unexplained waterfalls that could correspond to the shielding mechanism. However, for seven of them, debris flows dominate the alluvial fan and its channel and we cannot apply Equation 13. Finally, there are 18 individual steps that come down to 15 waterfalls after merging small steps in close succession in South Badwater 3 and 4. All the surveyed waterfalls are listed in supplementary Table 1, the selected waterfalls are detailed in Table 2, and three examples showed in Figure 1.

Appendix. Name and symbols of variables used in the main text.

Table DR1. List of the surveyed waterfalls in Saline (SV), Panamint (PV) and Death Valley (DV) with their location and the main characteristics of each site that determine their selection for the demonstration. The precision of the UTM coordinates is oftentimes limited by the high walls of the canyons blocking the acquisition of the GPS signal.

Symbol	Variable
A	Upstream drained area [L^2]
D	Grain size (using D_{50} measured in the field) [L]
ΔS	Difference between steep and gentle equilibrium slopes [1]
E	Erosion rate in catchment [L/T]
f_{coarse}	Coarse fraction of total sediment flux [1]
f_{skin}	Proportion of skin friction in total Shields stress [1]
f_{radius}	Ratio of hydraulic radius and bankfull depth [1]
g	Gravitational acceleration [L/T^2]
h_{bf}	Bankfull depth [L]
h_c	Critical water depth to entrain sediment grains [L]
h_{max}	Maximum waterfall height [L]
h_{sed}	Waterfall height limited by sediment aggradation rate [L]
h_{up}	Waterfall height limited by uplift rate [L]
k_s	Bed roughness ($2D_{84}$) [L]
L_{fan}	Length of the alluvial fan [L]
Q_s	Sediment flux [L^3/T]
Q_w	Water discharge [L^3/T]
R	Submerged density of sediment [1]
R_h	Hydraulic radius [L]
ρ	Density [M/L^3]
S	Slope [1]
S_{gentle}	Gentle gradient equilibium slope [1]
S_{steep}	Steep gradient equilibrium slope [1]
t_f	Forcing timescale [T]
t_s	Sedimentary timescale [T]
t_u	Uplift timescale [T]
$\tau_{*_c}(S)$	Critical Shields stress [1]
τ_{*m}	Morphological drag component of the Shields stress [1]
τ_{*sf}	Skin friction component of the Shields stress [1]
τ_{*T}	Total Shields stress [1]
u	Flow velocity [L/T]
u_*	Shear velocity ($(\tau/\rho)^{1/2}$) [L/T]
U	Uplift rate [L/T]
V	Volume to fill to reach S_{steep} from S_{gentle}
W	Channel width [L]
w_r	Reconstructed rectangular channel width [L]
z_{bar}	Height of bar above thalweg [L]

Valley	Catchment	Water-fall #	Height, m	UTM Quad	UTM E	UTM N	Channel Type	Fault trace	Waterfall origin	selection
DV	Gower Gulch	WTF 1	6.75	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	Badwater Canyon	WTF 1	9.44	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 3	WTF 1	12.6	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 3	WTF 2	2.03	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 3	WTF 3	4.16	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 3	WTF 4	25.98	11S	5E+05	4E+06	fluvial	unique	merged?	no
DV	South Badwater 4 north	WTF 1	4.39	11S	5E+05	4E+06	debris flow	unique	shield	no
DV	South Badwater 4	WTF 1	4.74	11S	5E+05	4E+06	fluvial	unique	shield	no
DV	South Badwater 4	WTF 2a	4.56	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 4	WTF 2b	5.55	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 4	WTF 2c	5.53	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 4	WTF 3a	2.97	11S	5E+05	4E+06	fluvial	unique	shield	no
DV	South Badwater 4	WTF 3b	3.34	11S	5E+05	4E+06	fluvial	unique	shield	no
DV	South Badwater 4	WTF 4	10.69	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 4	WTF 5	>20	11S	5E+05	4E+06	fluvial	unique	shield	no
DV	South Badwater 5 north	WTF 1	7.03	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 5 south	WTF 1	10.01	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	South Badwater 5 south	WTF 2	?	11S	5E+05	4E+06	fluvial	unique	shield	no
DV	South Badwater 5 south	WTF 3	5.43	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	Coffin Canyon	WTF 1	18.6	11S	5E+05	4E+06	fluvial	unique	shield	yes
DV	Copper Canyon	WTF 1	-	-	-	-	fluvial	migrated	-	no
PV	Surprise Canyon	WTF 1	2.36	11S	5E+05	4E+06	fluvial	multiple	fault	no
PV	Surprise Canyon	WTF 2	3.38	11S	5E+05	4E+06	fluvial	multiple	fault	no
PV	Surprise Canyon	WTF 3	~2.5	11S	5E+05	4E+06	fluvial	multiple	fault	no
PV	Happy Canyon main canyon	WTF 1	2.9	11S	5E+05	4E+06	fluvial	multiple	lithology	no
PV	Happy Canyon main canyon	WTF 2	6.92	11S	5E+05	4E+06	fluvial	multiple	?	no
PV	Happy Canyon main canyon	WTF 3	4.09	11S	5E+05	4E+06	fluvial	multiple	?	no
PV	Happy Canyon main canyon	WTF 4	1.62	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	Happy Canyon main canyon	WTF 5	1.94	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	Pleasant Canyon	WTF 1	8.19	11S	5E+05	4E+06	fluvial	multiple	shield	yes
PV	Middle Park Canyon	WTF 1	2.22	11S	5E+05	4E+06	fluvial	multiple	fault	no
PV	Middle Park Canyon	WTF 2	3.23	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	Middle Park Canyon	WTF 3	3.07	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	Middle Park Canyon	WTF 4a	5.5	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	Middle Park Canyon	WTF 4b	3.02	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	Middle Park Canyon	WTF 5	4.96	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 north fork	WTF 1	2.12	11S	5E+05	4E+06	fluvial	multiple	active fault	no
PV	South Middle Park Canyon 2 middle fork	WTF 1	2.29	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 middle fork	WTF 2	2.3	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 middle fork	WTF 3	2.05	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 south fork	WTF 1	1.08	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 south fork	WTF 2	2.03	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 south fork	WTF 3	2.74	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Middle Park Canyon 2 south fork	WTF 4	3.91	11S	5E+05	4E+06	fluvial	multiple	step-pool	no
PV	South Park Canyon	WTF 1	9.11	11S	5E+05	4E+06	fluvial	migrated	shield	yes
PV	South Park Canyon	WTF 2	4.73	11S	5E+05	4E+06	fluvial	migrated	shield	yes
PV	South Park Canyon	WTF 3	6.28	11S	5E+05	4E+06	fluvial	migrated	shield	yes
SV	Pat Keyes	WTF 1	11.66	11S	4E+05	4E+06	fluvial	unique	shield	yes
SV	Pat Keyes	WTF 2	11.6	11S	4E+05	4E+06	fluvial	unique	shield	yes
SV	McEllvoy	WTF 1a	1	11S	4E+05	4E+06	debris flow	unique	shield	no
SV	McEllvoy	WTF 1b	8.31	11S	4E+05	4E+06	debris flow	unique	shield	no
SV	McEllvoy	WTF 2	2.59	11S	4E+05	4E+06	debris flow	unique	shield	no
SV	Beveridge	WTF 1	12.85	11S	4E+05	4E+06	debris flow	unique	shield	no
SV	Beveridge	WTF 2a	8.4	11S	4E+05	4E+06	debris flow	unique	shield	no
SV	Beveridge	WTF 2b	11.26	11S	4E+05	4E+06	debris flow	unique	shield	no
SV	Hunter Canyon	WTF 1	6.12	11S	4E+05	4E+06	debris flow	unique	lithology	no
SV	Hunter Canyon	WTF 2	10.23	11S	4E+05	4E+06	debris flow	unique	lithology	no
SV	Hunter Canyon	WTF 3	~5	11S	4E+05	4E+06	debris flow	unique	lithology	no
SV	Craig Canyon	WTF 1a	3.14	11S	4E+05	4E+06	debris flow	unique	lithology	no
SV	Craig Canyon	WTF 1b	2.97	11S	4E+05	4E+06	debris flow	unique	lithology	no
SV	Craig Canyon	WTF 2	5.91	11S	4E+05	4E+06	debris flow	unique	lithology	no
SV	Craig Canyon	WTF 3	11.29	11S	4E+05	4E+06	debris flow	unique	lithology	no