PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2013
Pomona College, Claremont, CA

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INVESTIGATING LATE PLEISTOCENE AND ANTHROPOCENE FLOOD DEPOSITS ALONG CARIBOU AND NORTH BOULDER CREEK, COLORADO FRONT RANGE

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Research Advisor: Sue Swanson

INTRODUCTION

Mountainous landscapes are the product of tectonic uplift balanced by erosive geomorphic processes such as mass wasting, fluvial and glacial processes. These alpine landscapes can also be altered by high-energy processes such as floods, rock falls, and debris flows. Although these events are temporally and spatially isolated they impact the landscape due to the magnitude of the sediment eroded and deposited during such processes. The failure of moraine-dammed Lake Devlin in the Rocky Mountain Front Range during the Pleistocene is an example of the impact one such event can have on the landscape. Previous studies of Lake Devlin have concentrated on dating lacustrine deposits in order to determine the Pinedale last glacial maximum (Madole, 1980, 2010; Leopold et al., 2008). This study maps the Lake Devlin flood deposits, as well the surrounding materials, and estimates the peak discharge for the Lake Devlin flood and a flood that occurred during the Anthropocene, referred to as the Caribou Creek flood.

BACKGROUND

Lake Devlin last existed during the Pinedale Glaciation of the Front Range, which began sometime before 30 ka and lasted until 12 ka (Madole, 2010). Radiocarbon and optically stimulated luminescence dating (OSL) of lacustrine sediments has determined that Lake Devlin last existed from 31 – 14 ka (Madole, 1980, 2010; Leopold et al., 2008). Cosmogenic dating of boulders deposited by the Green Lakes Valley Glacier in North Boulder Creek Valley indicate that the Pinedale last glacial maximum was reached by 21 ka and that deglaciation began around 18 ka (Dühnforth and Anderson, 2011; Pierce, 2003).

During the Pinedale, the Green Lakes Valley and Arapahoe Glaciers converged and advanced down North Boulder Creek Valley. The combined glaciers built a lateral moraine that dammed meltwater from the Horseshoe Creek and Rainbow Lakes cirques. It also dammed meltwater from a portion of the Middle Boulder Creek Glacier that overtopped the bounding mountain ridge, forming Lake Devlin. It has been estimated that Lake Devlin held somewhere between 12,000,000 – 55,200,000 m^3 of water (Madole, 1980). During its existence Lake Devlin developed a spillway to North Boulder Creek to accommodate excess input, but around 14 ka the moraine dam failed, and Lake Devlin drained into North Boulder Creek Valley (Fig. 1). The failure eroded a new channel through the moraine and deposited eroded moraine material near the confluence of North Boulder Creek and Caribou Creek, the latter of which currently flows through the failure channel.

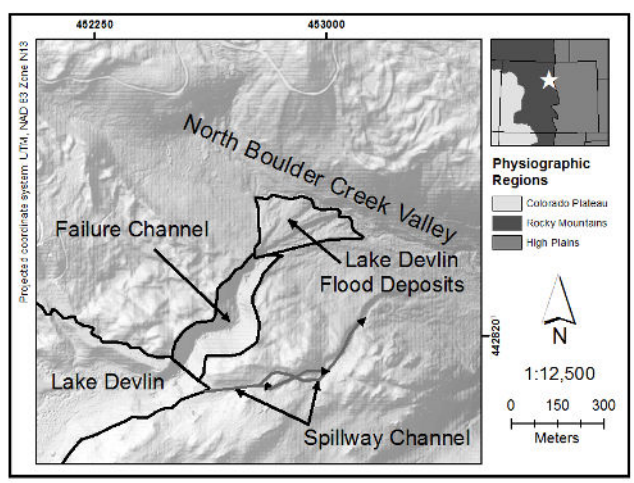

Figure 1: Locations of Lake Devlin flood deposits, the Lake Devlin spillway, the failure channel, and a portion of Lake Devlin.

METHODS

MAPPING

To determine the impact of the Lake Devlin flood on the landscape, geological materials near the location of the outburst flood were mapped. Topographic characteristics of the landscape observed on LIDAR images provided the initial insight for where to expect different materials. For example, ice contact stratified deposits (ICSD) appeared as hummocky terrain with a few kettles present. Field mapping verified or dismissed these initial interpretations. In addition to insight provided by LIDAR images, field mapping considered relative ages of materials based on weathering and lichen cover of boulders, as well as landforms such as lobes. For example, till has the same degree of weathering and lichen cover as the Lake Devlin flood deposits, but it does not have lobes or imbricated boulders. Deposits that show alluvial characteristics, but do not display weathering and lichen cover, are interpreted as post-Lake Devlin flood deposits, and are likely the deposits of the Caribou Creek flood.

To assist the mapping of materials, sediment samples were collected at selected sites to examine the sorting of unknown materials by sieve analysis and then compared to samples representative of other material in the area. Samples were collected at least 0.5 m below the surface to obtain minimally weathered sediment representative of the original deposits. Three grain size samples were collected as representative of Lake Devlin deposits. Two came from site 030 and one came from site 157 (Fig. 2). Two samples were collected at site 030 at different depths to examine any change in sorting with depth. A representative till sample was also collected, which is labeled as 149. The other samples were collected to determine whether the deposits on the north side of North Boulder Creek resemble the Lake Devlin flood deposits. If so, this may suggest that deposits from the Lake Devlin flood extended across the North Boulder Creek valley floor, temporarily damming North Boulder Creek after the Lake Devlin flood. These samples were collected from sites 128, 161, and 175 (Fig. 2).

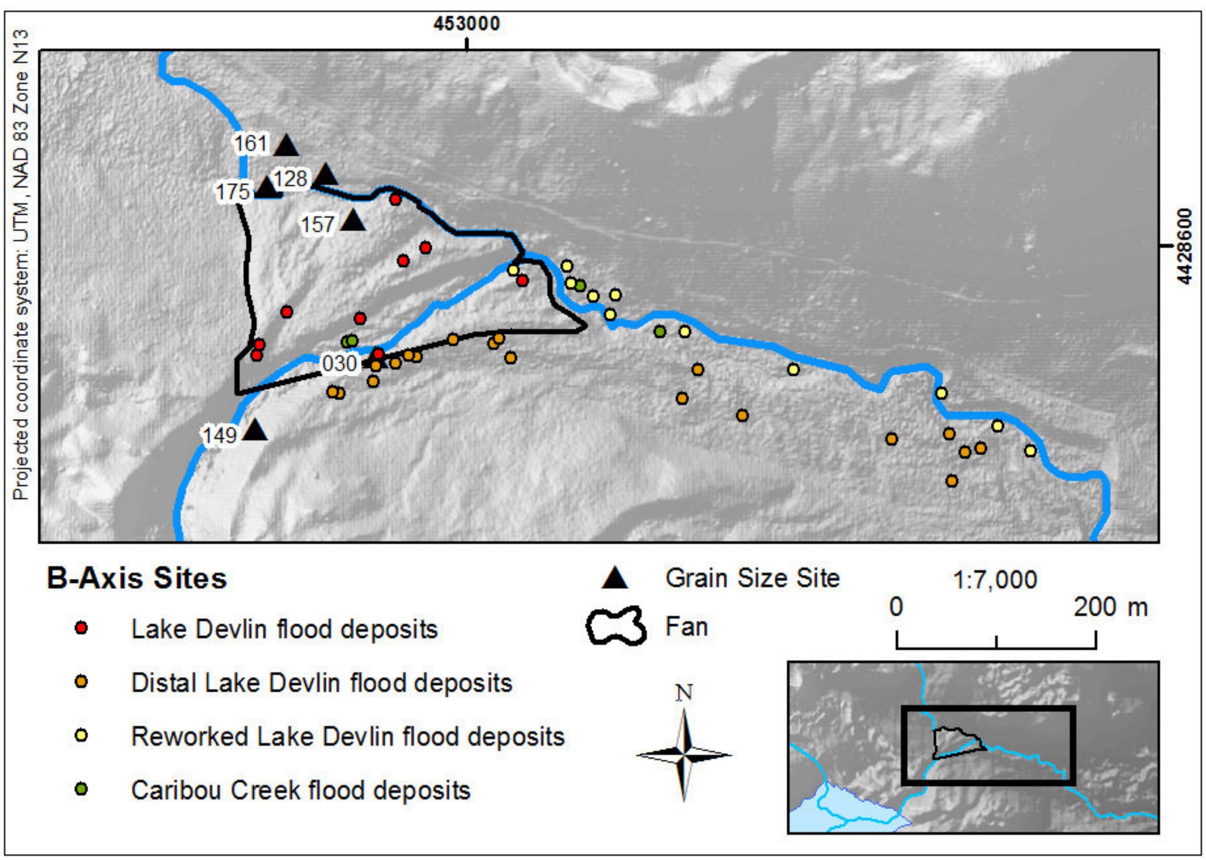

Figure 2: Locations of grain size sample and imbricated boulder B-axis measurements. Boulder DI measurements are categorized by flood event and likelihood of post flood event transport.

DISCHARGE

With an understanding of where flood deposits of both the Lake Devlin flood and Caribou Creek flood are located, B-axes of boulders were measured to estimate velocity and thus the peak discharge of each flood. B-axes were measured on boulders displaying imbrication due to fluvial transportation and categorized according to age of deposit, location and likelihood of post-flood reworking. Lichen cover and weathering of imbricated boulders allowed for classification of deposits as Lake Devlin or Caribou Creek flood deposits. Lake Devlin flood boulders exhibit moderate lichen cover and weathering, whereas the Caribou Creek flood deposits do not. Measurements of Lake Devlin flood materials were divided further by location, ultimately producing a total of four categories of B-axis measurements: (1) Lake Devlin flood deposits; (2) Distal Lake Devlin flood deposits; (3) Reworked Lake Devlin flood deposits; (4) Caribou Creek flood deposits. The Lake Devlin flood deposits are located in the fan-like landform outlined in Figure 2; these boulders were likely unaltered since deposition. The distal Lake Devlin flood deposits are found outside the main area of flood deposits. These boulders likely have not been remobilized since the Lake Devlin flood, but since these materials were deposited once the flood started flowing down North Boulder Creek, it is possible that these boulders were deposited under slightly different conditions than the axial deposits. Reworked Lake Devlin flood deposits are of Lake Devlin flood age, but are intermingled with material of Caribou Creek flood age and at locations that suggest reworking since the Lake Devlin flood. Caribou Creek flood deposits are boulders deposited by the Caribou Creek flood based on lichen cover and weathering. The first two categories represent boulders deposited during the Lake Devlin flood, whereas the last two categories represent boulders last deposited during the Caribou Creek flood.

A velocity estimate based on the mean of the five largest B-axis measurements was combined with a depth based on the Manning Equation and an average channel width measured from the LIDAR digital elevation model to determine peak discharge. Velocities for flood events in mountainous channels can be estimated using Equation 1, where velocity is a function of B-axis length. Equation 1 was estimated using the average results of four velocity estimate methods: the balancing forces turning moment equation; the US Bureau of Reclamation estimate; a basic data regression estimate; and the theoretical relationship between fluid drag, fluid lift, and gravitational friction (Costa, 1983).

Equation 1: $v = 0.18\ D_I^{0.487}$

Where: v = velocity (m/s)

D_I = B-axis length (mm)

Velocity estimates were applied to the mean B-axis length of the five largest boulders in each of the four categories of measurements. The Manning equation (Equation 2), where v is velocity, n is the roughness coefficient and s is the channel slope, was used to estimate depth.

Equation 2: $D = \left[v\ n/\sqrt{s}\right]^{1.5}$

Slope along the failure channel was calculated to be 0.117. A roughness coefficient of 0.124 was utilized because it represents an estimate of channel roughness in mountainous channels with slopes of 0.10 (Costa, 1983). The final part needed to calculate channel area is width. The calculation assumes that the flood events produced flows of bank-full conditions. Six channel widths were measured in ArcGIS from the LIDAR image and averaged to produce channel width. The channel area is the product of the width and depth, divided by two.

RESULTS

MAPPING

Figure 3 shows the distribution of deposits near the failure channel of the Lake Devlin and Caribou Creek flood events. Several units existed prior to the Lake Devlin flood and remain undisturbed. ICSD is found on lateral moraine ridges of North Boulder Creek Valley. Characteristics of the ICSD include rolling surfaces, kettles, and scattered boulders ranging from <1 m to >3 m in diameter. Till is exposed along the North Boulder Creek Valley, near the southern lateral moraine. The topography of the till is much smoother than the ICSD, and pronounced relief is due to incision

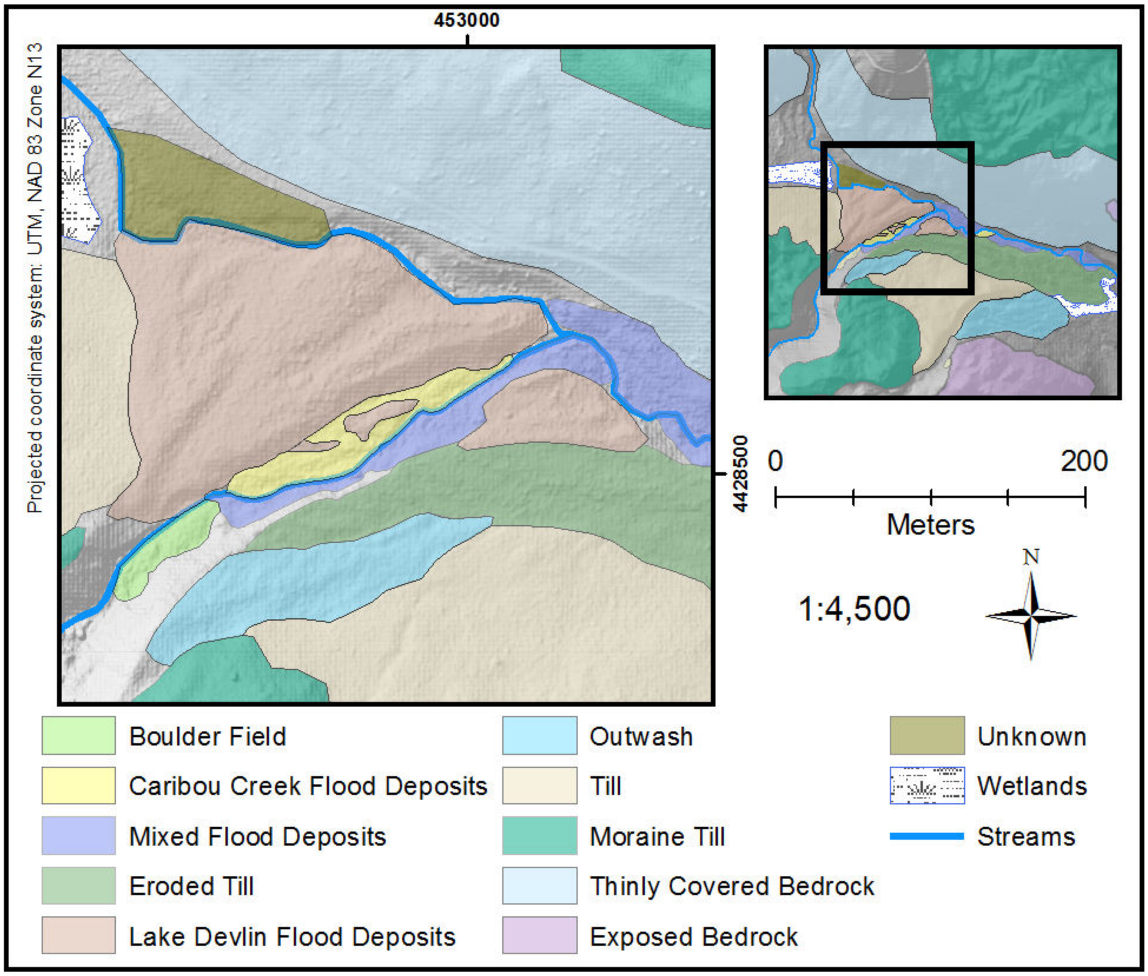

Figure 3: Map showing surficial materials mapped along Caribou Creek and North Boulder Creek near the Lake Devlin flood fan deposits.

by ephemeral streams. Outwash deposited during the retreat of the combined Arapahoe and Green Lakes Valley glaciers is exposed at two locations south of North Boulder Creek. The valley wall on the north side of North Boulder Creek is bedrock thinly covered by colluvium. Exposed bedrock is observable at one location within the thinly covered bedrock on the northern valley wall. A more extensive bedrock exposure exists on the south valley wall near the spillway shown in Figure 1.

Two types of deposits are interpreted to contain original material from the Lake Devlin flood – Lake Devlin flood deposits and eroded till. The Lake Devlin flood deposit geometry generally resembles a fan. The surface of the Lake Devlin flood deposits forms terraces that include imbricated boulders throughout and terminate in large lobes. Part of the Lake Devlin flood deposits has since been incised by Caribou Creek. Lake Devlin flood deposits consist of eroded moraine material that occupied the failure channel before the flood. The eroded till has boulders with the same degree of weathering and lichen cover as Lake Devlin flood deposits. The materials are differentiated from other till deposits by the presence of imbricated boulder lobes that are parallel to North Boulder Creek. The eroded till consists of till that is covered by deposits that were reworked after water from the Lake Devlin outburst began flowing down North Boulder Creek Valley.

Four additional materials are also displayed in Figure 3. Caribou Creek flood deposits are characterized by imbricated boulders on terraces slightly above current river stage. They are differentiated from older flood deposits by weathering and lichen cover. Areas determined as mixed flood deposits display imbricated boulders of both Lake Devlin flood age and Caribou Creek flood age and are found on Caribou and North Boulder Creek flood plains. Figure 3 also displays areas of unknown material, wetlands, and boulder fields, the latter of which is the result of rock fall.

GRAIN SIZE ANALYSIS

To help constrain the origin of terrace material north of the confluence of North Boulder Creek and Caribou Creek referred to as unknown deposits in Figure 3, three sediment samples were collected for sieve analysis and compared to the representative till and Lake Devlin flood deposit samples. The sorting of each sample was quantified using uniformity coefficients (Equation 3).

Equation 3: $\frac{D_{60}}{D_{10}}$

The sample from site 175 was collected from a terrace ~ 1 m above the current river level. Sample sites 128 and 161 are from a terrace ~ 4 m above the current river level. The results from grain size analyses (Fig. 4) found that Lake Devlin flood deposits have uniformity coefficients within a range of 14 – 25, whereas the representative till sample has a uniformity coefficient that is much greater than 50. The three samples collected from sites 128 and 161 have nearly identical sorting to the till sample, whereas the sample from site 175 resembles fluvial deposition with a uniformity coefficient of 5. Since the sample from 175 is better sorted than the other Lake Devlin flood samples, the deposits on the terrace ~ 1 m above current river stage are likely floodplain deposits of North Boulder Creek.

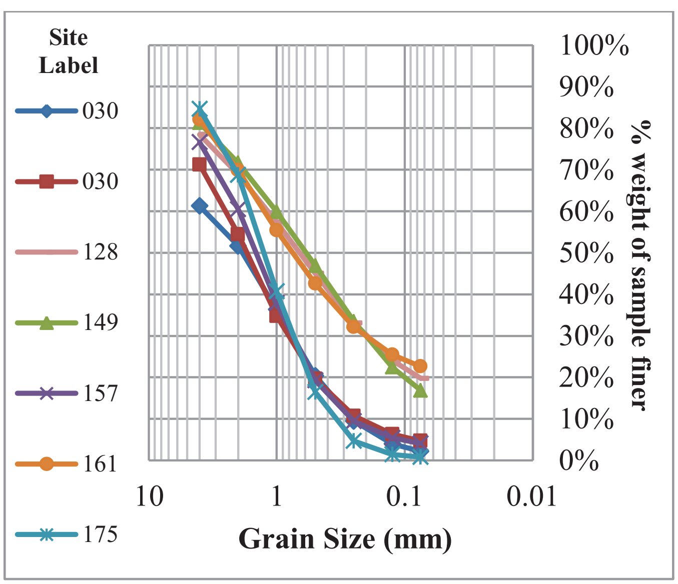

Figure 4: Cumulative distribution curves produced from grain size sieve analysis. Site locations are shown in Figure 1.

DISCHARGE

Table 1 shows velocity estimates determined using Equation 1 based on the mean B-axis length of the five largest boulders in each deposit category. The two rows representing boulders transported during the Lake Devlin flood have similar velocity estimates of 8.9 and 8.4 m/s. Likewise, the two rows representing material last transported during the Caribou Creek flood had similar velocity estimates of 5.9 and 5.6 m/s.

Table 1: Peak discharge estimates and inputs utilized to estimate discharge organized by flood event and deposit.

Deposit	*n*	Mean of 5 largest D_I (mm)	Velocity (m/s)	Depth (m)	Width (m)	Peak Q (m^3/s)
Lake Devlin flood deposits	41	3020	8.9	5.8	114.17	2900
Distal Lake Devlin flood deposits	53	2680	8.4	5.3	114.17	2600
Reworked Lake Devlin flood deposits	38	1300	5.9	3.1	114.17	1100
Caribou Creek flood deposits	16	1160	5.6	2.9	114.17	920

Notes: D_I = B-axis length; Q = Discharge

Peak discharge estimates are also shown in Table 1. Peak discharge estimates based on the Lake Devlin flood deposits indicate that the Lake Devlin flood had a peak discharge around 2900 m^3/s. Distal Lake Devlin flood deposits give a slightly lower discharge of 2600 m^3/s. Peak discharge for the measurements representing boulders transported during the Caribou Creek flood give a discharge of 920 – 1100 m^3/s.

DISCUSSION AND CONCLUSIONS

MAPPING

One goal of the project was to map the location of the Lake Devlin flood deposits. Although a portion of the material transported during the Lake Devlin flood is present in the fan-like feature near the failure channel, it is unlikely that the volume of material removed from the moraine dam is accounted for in the fan. Some of this material was likely deposited further down North Boulder Creek Valley after the Lake Devlin flood was redirected. Additionally, some material originally deposited in the fan has been eroded by the incision of Caribou Creek and more recent flood events. The grain size analyses performed suggest the unknown area does not contain Lake Devlin flood deposits.

The samples from sites 128 and 161 indicate that the superior terrace largely consists of till material whereas the sample from site 175 indicates fluvial deposition. Lake Devlin flood deposits are found within the fan produced during the flood event, on the eroded till surface, and intermingled with Caribou Creek flood deposits on terraces slightly above current river stage along North Boulder and Caribou Creek.

DISCHARGE

The second goal was to estimate the peak discharge of the two floods. The peak discharge estimates assume that both the Lake Devlin flood and the Caribou Creek flood occupied the entire area of the failure channel. The Lake Devlin flood may have occupied the entire failure channel area but it is highly unlikely the Caribou Creek flood did. This is because field observations found that the dam that failed during the Caribou Creek flood was roughly 4.3 m above lake bottom compared to the 21.1 m high moraine that failed during the Lake Devlin flood. Therefore, the Lake Devlin flood estimates are much more accurate than the Caribou Creek flood estimates.

The Lake Devlin flood deposits located within the fan best represent the flood velocity. It is estimated that the Lake Devlin flood had a peak discharge of 2900 m^3/s. The Lake Devlin flood likely reached peak discharge shortly after the initial outburst. Peak discharge was then followed by a period of waning flow until Lake Devlin drained. The discharge of the 1982 flood resulting from the failure of the Lawn Lake dam in Rocky Mountain National Park provides an appropriate comparison. Lawn Lake was smaller than Lake Devlin is believed to have been, containing 831,000 m^3 of water. The flood following the dam failure caused roughly $31 million in damages and had a peak discharge of 510 m^3/s, which is considerably less than the peak discharge estimates for the Lake Devlin flood (Jarrett and Costa, 1986). Field observations concluded that boulder deposits of the Lawn Lake flood were much larger than those of the Caribou Creek flood, again suggesting that a more accurate channel width is required before the Caribou Creek flood can be accurately estimated.

CONCLUSIONS

This study has shown how the peak discharge of the Lake Devlin flood can be estimated using field measurements of particles transported during the flood and GIS analysis with high-resolution LIDAR images. Investigating the failure channel for evidence of peak flood stage would provide a more accurate estimate of channel area than simply assuming bank full conditions. Field mapping of the geologic deposits around the confluence of North Boulder Creek and Caribou Creek has identified the location of Lake Devlin flood deposits and material affected by the flood. Future work could investigate deposits found further down North Boulder Creek from the confluence to determine the extent of the Lake Devlin flood's impact on the landscape.

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