



Geologic Hazards Evaluation of the Lower Falls Section of the Rio de los Frijoles Canyon Trail, Bandelier National Monument

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Introduction and Background

The June 2011 Las Conchas fire had a tremendous effect on the landscape at Bandelier National Monument (BAND). The loss of vegetation and the development of hydrophobic soil conditions in the Canyon de los Frijoles watershed created extremely high potential runoff conditions. This potential was realized during a moderate rain event in August 2011 which resulted in a flood event that was roughly twice the largest previously recorded flood. So much water and coarse debris flowed down the canyon that it scoured the bedrock slope and caused it to collapse along the Lower Falls section of the Lower Falls Trail through Frijoles Canyon. The trail had to be closed, because one entire section failed into the stream channel, and at another section the trail was left perched immediately adjacent to a precarious 30+-foot high vertical bedrock slope. The trail's subsequent closure has created significant access issues for both administrative and public use.

BAND resource staff requested assistance from the Natural Resource Stewardship and Science (NRSS) directorate. In particular, park staff asked the Geologic Resources Division (GRD) for a professional assessment of risks in order to assist park management in prioritizing recovery efforts and to inform area access closures and infrastructure repairs. BAND staff asked for a risk assessment and evaluation of geologic hazards and for recommendations as to whether the trail should be abandoned, rerouted, or reconstructed in place.

On April 11, 2012, Hal Pranger of NRSS-GRD conducted a day visit to the site, and this report summarizes the observations and broad recommendations to address the park's request. Considerable additional analysis of the site and associated issues could be provided with additional time and resources, but park staffs have asked that this report be expedited with general recommendations.

Park Setting

BAND is located on the eastern flank of Valles Caldera, a very interesting 'supervolcano.' There are many varied volcanic features located at the park, and they are discussed in volumes of technical literature. For this report no discussion of detailed site-specific volcanic characteristics is warranted due to the short time of the visit and the park's desire for only general recommendations.

However, there are several active geologic features, processes and principles applicable to the Lower Falls Trail near the actual Lower Falls of the Rio de los Frijoles that deserve mention and short description. First, the Rio de los Frijoles stream channel interacts closely and actively with the canyon slopes; the flood/ debris flow event of August 2011 undercut and scoured the slopes in the reach of concern and caused them to fail. Second, this stretch of canyon has active rockfalls and occasionally experiences landslides. Finally, intrinsic geomorphic

thresholds control a great deal of the stream channel, rockfall and landslide activity, i.e., this landscape can change suddenly and dramatically with even a very small change in physical conditions.

National Park Service Management Policies 2006

The following are excerpts from the National Park Service Management Policies 2006, included here to encapsulate the most relevant policy related to the situation at this trail:

Protection of Geologic Processes. The Service will allow natural geologic processes to proceed unimpeded. Geologic processes will be addressed during planning and other management activities in an effort to reduce hazards that can threaten the safety of park visitors and staff and the long-term viability of the park infrastructure. Intervention in natural geologic processes will be permitted only when directed by Congress; necessary in emergencies that threaten human life and property; there is no other feasible way to protect natural resources, park facilities, or historic properties; or intervention is necessary to restore impacted conditions and processes, such as restoring habitat for threatened or endangered species (sec. 4.8.1).

Geologic Hazards. Naturally occurring geologic processes, which the Park Service is charged to preserve unimpaired, can be hazardous to humans and park infrastructure. The Service will devise effective geologic hazard identification and management strategies. Although the magnitude and timing of future geologic hazards are difficult to forecast, park managers will strive to understand future hazards and, once the hazards are understood, minimize their potential impact on visitors, staff, and developed areas. Before interfering with natural processes that are potentially hazardous, superintendents will consider other alternatives. The Service will try to avoid placing new visitor and other facilities in geologically hazardous areas. Superintendents will examine the feasibility of phasing out, relocating, or providing alternative facilities for park developments subject to hazardous processes (sec. 4.8.1.3).

Visitor Safety. While recognizing that there are limitations on its capability to totally eliminate all hazards, the NPS will seek to provide a safe and healthful environment for visitors and employees. The NPS will strive to identify recognizable threats to the safety and health of persons. When practicable, and consistent with congressionally designated purposes and mandates, the NPS will reduce or remove known hazards and apply other appropriate measures, including closures, guarding, signing, or other forms of education. In doing so, the NPS's preferred actions will be those that have the least impact on park resources and values (sec. 8.2.5.1).

Siting Facilities to Avoid Natural Hazards. The Service will strive to site facilities where they will not be damaged or destroyed by natural physical processes. Natural hazard areas include sites with unstable soils and geologic conditions. Park development that is damaged or destroyed by a hazardous or catastrophic natural event will be thoroughly evaluated for relocation or replacement by new construction at a different location. If a decision is made to relocate or replace a severely damaged or destroyed facility, it will be placed, if practicable, in an area that is believed to be free from natural hazards. In areas where dynamic natural processes cannot be avoided, developed facilities should be sustainably designed (e.g., removable in advance of hazardous storms or other conditions). When it has been determined that facilities must be located in such areas, their design and siting will be based on a thorough understanding of the nature of the physical processes; and avoiding or mitigating (1) the risks to human life and property, and (2) the effect of the facility on natural physical processes and the ecosystem (sec. 9.1.1.5).

Hiking Trails. Trail design will vary to accommodate a wide range of users and will be appropriate to user patterns and site conditions (sec. 9.2.2.2).

Discussion

Observations of the hazards and issues

The section of the Lower Falls Trail near the Lower Falls of Canyon de los Frijoles has several moderate to considerable geological hazards. Historically, the site experienced a major landslide and rockfalls. During the August, 2011 event, the toe of the slope was scoured by the stream channel, and thin vertical bedrock blocks fell

into and broke up in the stream channel. The site also is poised to experience another major landslide and/or rock slope failure that could very easily obliterate the remaining trail remnants in this area.

Observation of Landscape Changes During the 20th Century

Photos of Lower Falls from 1920 and 1995 show landscape changes that occurred in the 20th century (Figure 1 - the circles labeled '1,' '2,' and '3' show common reference points (rocks) that are found on both photographs. Blue line on 1995 photograph shows trail). First, according to park staff a large landslide occurred in the 1930's that created a multi-hundred thousand-ton debris fan (area "A" on the 1995 photograph). Second, an older vegetated and currently inactive coarse debris fan is on the opposite side of the canyon (labeled 'B' on both photographs). Third, large fractures (small arrows) exist just below a portion of debris fan 'B.' Fourth, one can see that many very large (several ton) rocks near and surrounding reference rocks '2' and '3' in the 1920 photograph but not the 1995 photograph; they might have been removed by the trail construction staff of the 1930's, subsequent maintenance staffs, or they could have fallen into the Rio de los Frijoles stream channel. Fifth and finally, the large arrow in the 1920 photograph shows a large Ponderosa Pine tree that is not there in 1995; while it could have died and fell over and was washed away, it very well could have been removed when the trail was being constructed or was destroyed by a slope failure, landslide or by a flood event. A quick evaluation indicates that the bedrock immediately uphill of the tree may have failed during the time between the two photographs, and a small new debris fan appears to occupy the spot where the former tree used to stand. Construction of the trail also could have involved scaling the base of this slope and allowing already fractured bedrock to collapse into the stream channel as well. Cracks in the bedrock still remain in this area (see below).

Landscape Changes Resulting from the August, 2011 Flood Event

Many interesting landscape changes occurred during and after the August, 2011 flood event, including:

- The rock labeled '1' on both photographs of Figure 1 was mobilized during and likely disintegrated after the August, 2011 flood (compare Figure 1 to Figures 2, 3 and 4);
- Regarding the slope immediately below the trail (Figures 3 and 4), the channel scoured and caused slabs of rock to fail and disintegrate immediately below the trail. The trail itself had failure cracks along several sections, and park staff report that more have developed and other small sections of trail have failed;
- There is an approximately 50-foot length of bedrock and trail that collapsed and disintegrated into rubble when the slope failed;
- Regarding debris Fan 'B,' 1) it has a very steep gradient - over 100%, 2) large multi-ton boulders could possibly slide or roll onto the trail (and likely have in the past), and 3) with the erosion and failure of the lower ('toe' of the) slope there is an increased chance that the entire fan could move as a large landslide; such a slide is envisioned to be similar to the landslide labeled 'A' on Figure 1;
- Regarding the large wedge of bedrock (labeled 'C' on Figures 4 and 5), several large open fractures and the failure at its base during the August, 2011 flood event suggest that a much larger mass will collapse onto the trail, perhaps very soon.
- The stream channel, 1930's debris fan, and the vertical slope immediately adjacent to the trail all still are interacting and changing rapidly. This area will experience additional changes as the area floods, mobilizes more channel and fan material, scours more bedrock and more material fails from the bedrock slopes;

In summary, the Lower Falls portion of the trail passes through a section of the canyon that has numerous kinds and types of geological hazards. While extremely large hazards do not occur on a daily basis, the evidence of one massive landslide from the 1930s, of moderate-sized rock slope failures and the mobilization of a multi-ton boulder during the event, the imminent failure of a very large wedge of bedrock, and the obvious potential for a substantial landslide like that which occurred in the 1930's indicate that considerable caution should be exercised if the park is contemplating allowing people to continue to pass through this section of the canyon.

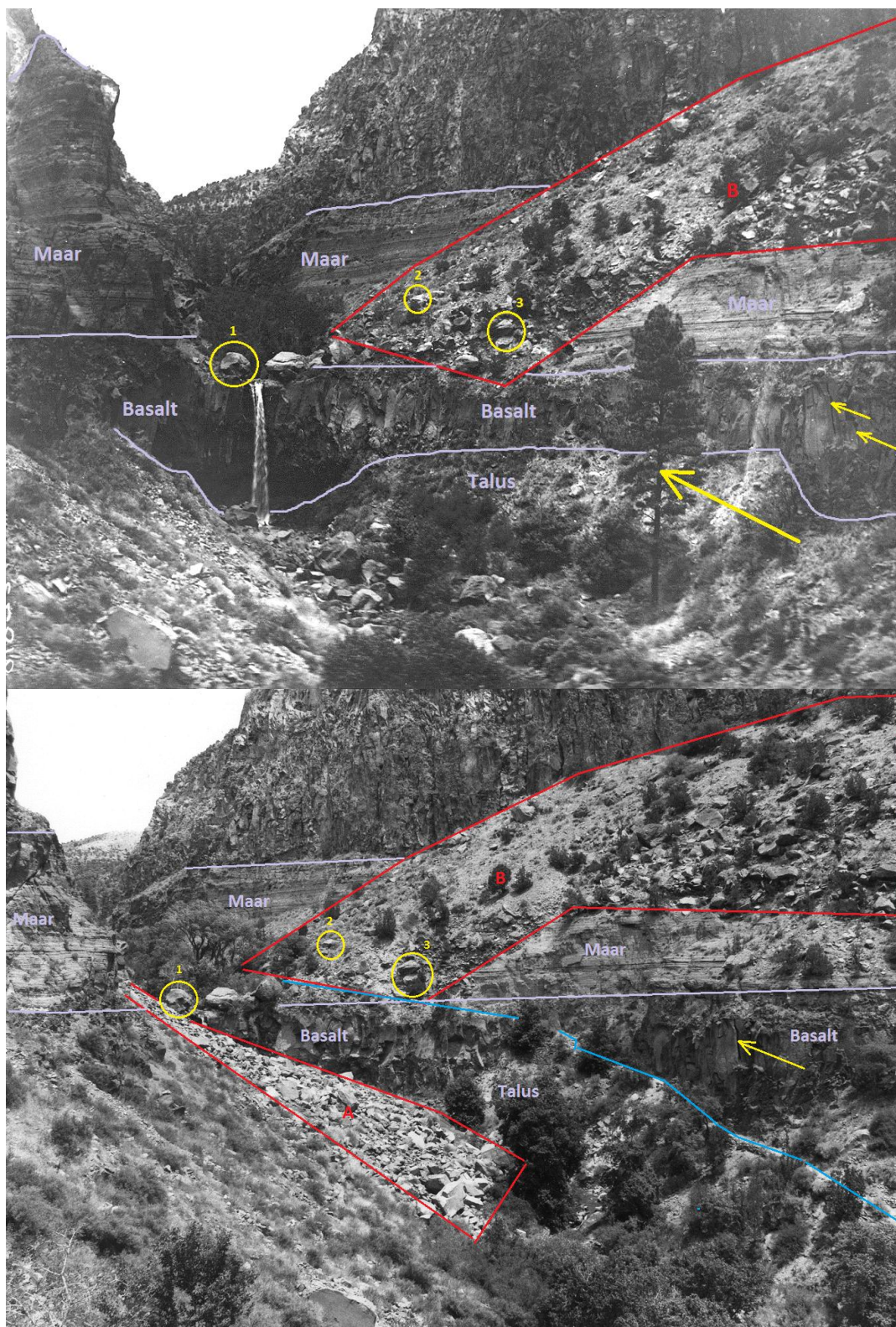


Figure 1 - View, looking upstream, of the Lower Falls Section of Frijoles Canyon – 1920 (top), and 1995 (bottom). See text for explanation. (NOTE: views were taken from somewhat different positions).



Figure 2 – View, looking downstream, at Lower Falls. Circle labeled ‘1’ shows location where reference rock shown in Figure 1 used to rest. ‘A’ shows landslide debris fan that occurred in the 1930’s (see Figure 1).

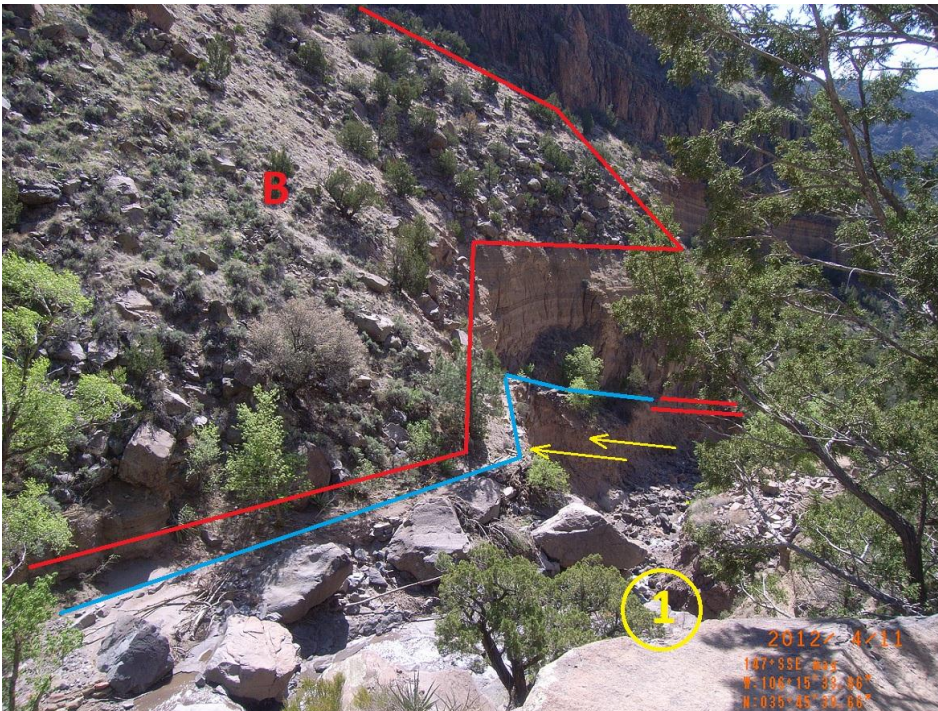


Figure 3 – View, looking downstream, of primarily the left side of Canyon de los Frijoles and Lower Falls Trail at the Lower Falls. Blue line is existing trail. B is coarse debris fan. Two parallel red lines show destroyed section of trail. Yellow circle labeled ‘1’ shows location of missing reference rock shown in figure 1 at the falls. Two parallel yellow arrows show vertical eroded and failed slope immediately below trail.

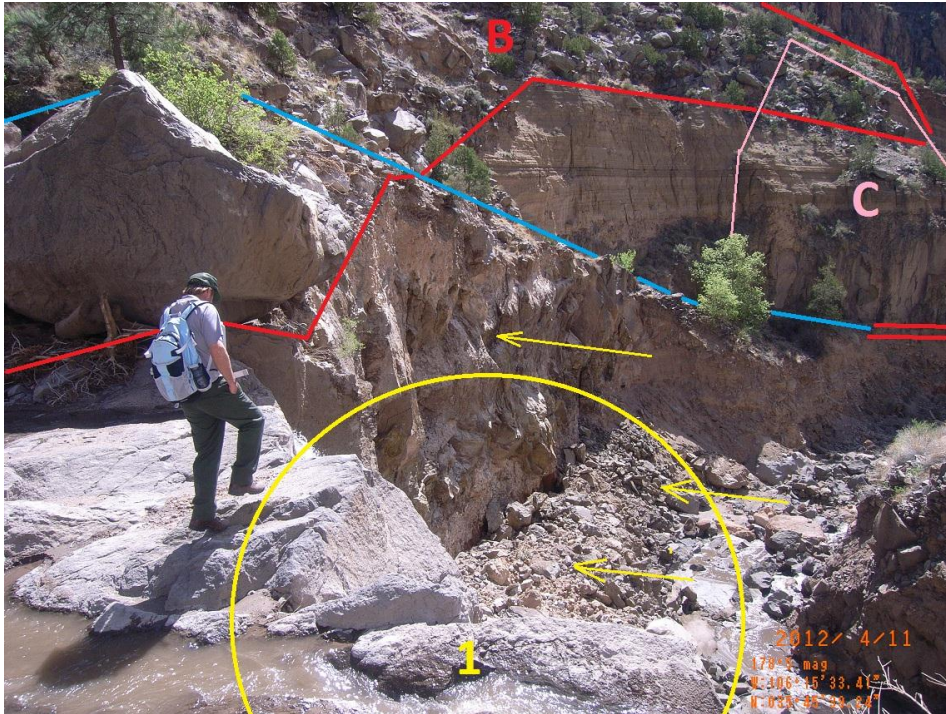


Figure 4 – View, looking downstream, at Lower. Blue line is existing trail. B is coarse debris fan. C is rock wedge that could fail at any time. Two parallel red lines show destroyed section of trail. Yellow circle labeled '1' shows location of missing reference rock (see Figure 1). Yellow arrows show failed bedrock and debris.



Figure 5 – View, looking downstream, from center of coarse debris fan 'B.' Blue line is existing trail. Two parallel red lines show destroyed section of trail. Parallel yellow arrows show vertical cracks on slope immediately above trail. Pink zone labeled 'C' shows wedge of Maar bedrock that could fail at any time.

Summary of the Site Conditions, and Additional Considerations

Currently it is very hazardous for people to walk along this section of trail. The vertical bedrock stream bank immediately adjacent to the trail is over 30 feet, and tripping and falling over this ledge easily could be fatal but at least would cause very serious injury. Great caution should be required if any further field investigations take place at and near this site. In addition to this acute falling hazard potential, the geological hazards mentioned above also create a chronic but lower risk of major mass-moving events.

For the next two to five years, or so, the risk for additional flooding, debris flow and mass-wasting events will be elevated. This is because slopes near this section of trail haven't failed completely and because additional runoff events are more likely to occur because of the continued hydrophobic and defoliated watershed conditions. The debris in fan 'B' will move eventually; it is not possible to predict when this will occur or whether it will gradually ravel or fail catastrophically as a large landslide. Rock wedge 'C' appears to be more likely to fail sooner than the material in debris fan 'B.' Also, the failure of the vertical bedrock channel bank immediately adjacent to the trail likely has not yet finished. Additional rock slabs could fall into the stream channel and could further damage the trail and destabilize debris fan 'B' and bedrock wedge 'C.'

Park staff asked for thoughts regarding how and if it should reconstruct, relocate or abandon this section of the trail. Strong considerations for any alternative are that this trail follows a very important recent, historic and ancient route and that more visitors hike along this trail than anywhere else at BAND. Considerations are:

- Rather than just cover this section of trail with brush as a deterrent to access, one BAND staff member suggested that blasting should be considered to physically and completely remove the trail remnants; considering the precarious nature of the failing bedrock slabs, the perched debris fan and the always-changing landforms, setting off a charge with its dynamic load would acutely raise the risk of triggering large mass movements of these unstable features.
- Regarding stabilizing and reconstructing the trail in its current alignment, it is conceivable that an engineering solution could be developed to accomplish this goal, but considered speculation suggests that the costs would be extraordinarily high to design and build such structural fix to the problem, and this would run contrary to many aspects of Management Policies 2006 cited above.
- Regarding locating an alternative route for the trail, the site visit did not allow time to explore any more than one potential alternative route, which, when, looking at Figure 5, would pass through the middle of what may be a very unstable debris fan 'B' and go above and then around failing bedrock wedge 'C.' Other potential routes would need to be explored in much more detail by trail design experts. NPS contacts for such trail advice are Ken Hornback, Acting Facility Lead, IMR-Santa Fe, and Hugh Duffy, PLA, ASLA, PMP, LEED® Green Associate, DSC Project Manager - Design & Construction East (see Hugh's information at [http://workflow.den.nps.gov/8 Transportation/docs and studies transplan.htm](http://workflow.den.nps.gov/8%20Transportation/docs%20and%20studies%20transplan.htm)).

Recommendations

1. Continue to discourage or prevent visitor access;
2. Develop a safety plan for anyone accessing the Lower Falls section of the Canyon de los Frijoles trail for further site analysis or work;
3. Don't blast to remove precarious trail segments;
4. Permanently abandon the current trail alignment and don't consider an engineering solution to 'stabilize' the many dynamic and developing aspects of this terrain;
5. Allow two to five years for this landscape to naturally develop further at its current accelerated pace, with possible additional mass movements, floods and debris flows;
6. Photographically document landscape changes in this area during that time frame; and
7. Use the aforementioned contacts to seek out and develop potential designs for alternative routes through this section of the canyon.