# Geological Field Trips in Southern Idaho, Eastern Oregon, and Northern Nevada

Edited by Kathleen M. Haller and Spencer H. Wood



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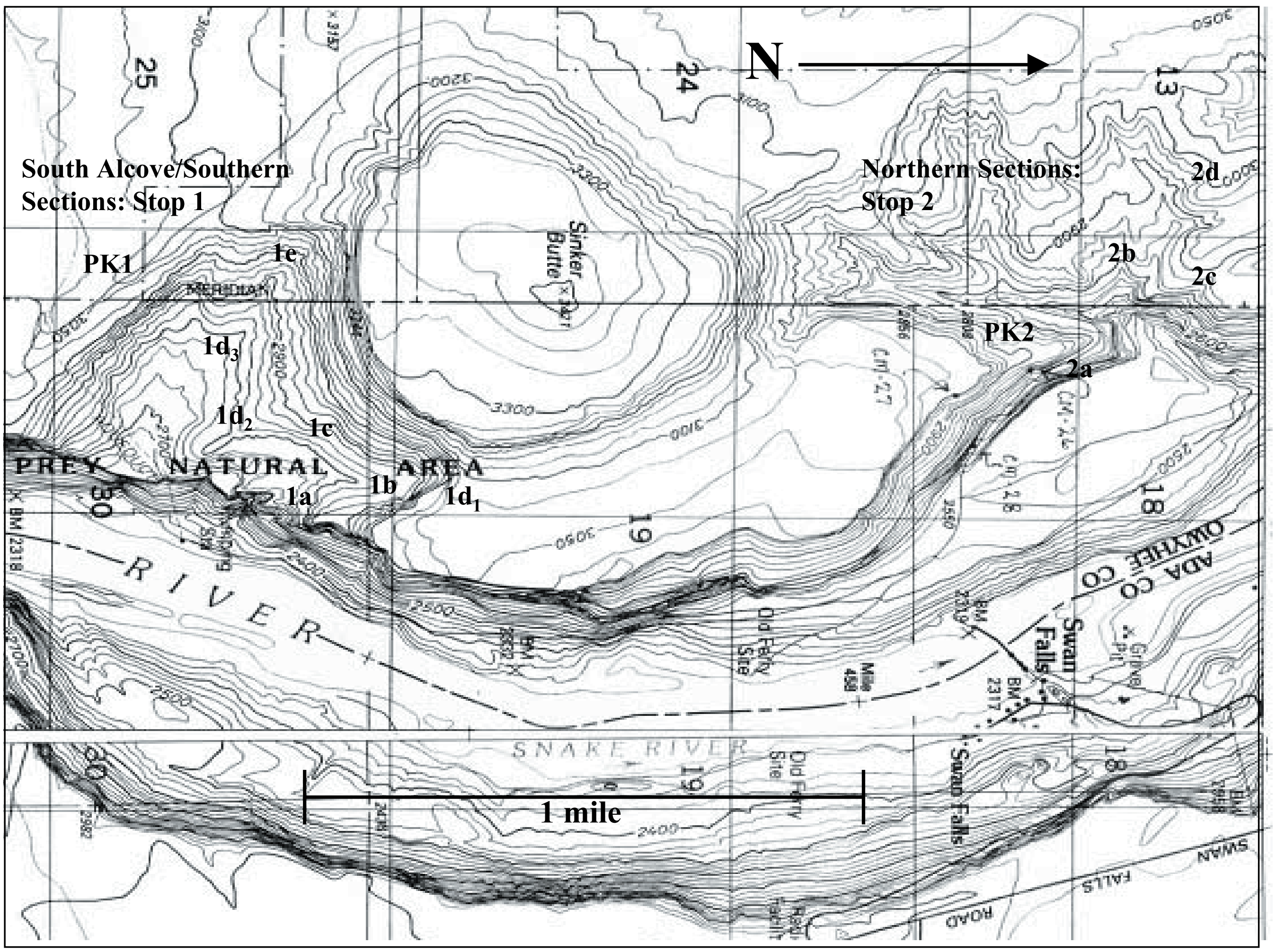


Figure 1. Topographic map of Sinker Butte showing the southern and northern sections with each stop (1a-1e, and 2a-2c) labeled.

# Basalt Emergent Volcanoes and Maars, Sinker Butte-Snake River Canyon, Idaho

By Brittany Brand

## Introduction

This field trip (fig. 1) offers the opportunity to explore the spectacular, well-exposed, hydrovolcanic tuff beds at Sinker Butte, a Pleistocene volcano that erupted underneath a freshwater lake in the western Snake River Plain (WSRP). The products of basaltic hydrovolcanism (maars, tuff rings, and tuff cones) are second only to scoria cones as the most abundant volcanic landforms on Earth (Cas and Wright, 1988); however, the mechanics of emplacement of these deposits remain poorly understood.

The volcanic stratigraphy at Sinker Butte has been subdivided into three main stages (fig. 2). The first stage of this eruption included deposition of a series of subaqueous tuff deposits as a volcanic-sedimentary platform grew toward the surface of the lake. Within these subaqueous deposits are many forms of cross stratification including channel scour and fill, dune bedding, trough cross bedding, and Bouma-turbidite sequences.

As the eruption progressed, the platform built above the water level, which represents the subaerial stage of the eruption (fig. 2). During this stage, the magma/water interaction was still significant, and caused a pulsatory type of eruption creating many thin interbedded-pyroclastic surge and fall deposits. Near the vent, large-scale, regressive, low-angle cross strata (wavelength 1–2 m) are found interbedded with thin planar beds. Regressive cross strata are analogous to antidunes, the crests of the strata migrate upstream with the coarser fragments deposited on the upstream side. The presence of accretionary and (or) armored lapilli, as well as vesicles due to trapped volatiles in wet ash, suggest emplacement by wet surges. Cross strata in deposits farther from the vent are generally thinly bedded and have gentler dip angles and shorter wavelengths. Other types of cross stratification found at Sinker Butte are wavy-planar beds, which are a mixture of fall and surge deposits, and deformed low-angle cross-stratified beds (0.5- to 1-m wavelength) containing abundant soft sediment deformation and sag structures. High in some sections are large-scale progressive cross strata (1- to 2-m wavelength) possibly deposited during a late-stage dry surge towards the end of eruption, just before the volcano isolated itself from all external water.

The low-angle cross stratification and irregular truncations reflect the highly pulsatory nature of surges during deposition. Cross-stratified bed thickness and average wavelengths decrease away from the vent. The fine cross stratification may be result of the same type of surges that formed the larger regressive cross strata, but may represent a loss in momentum,

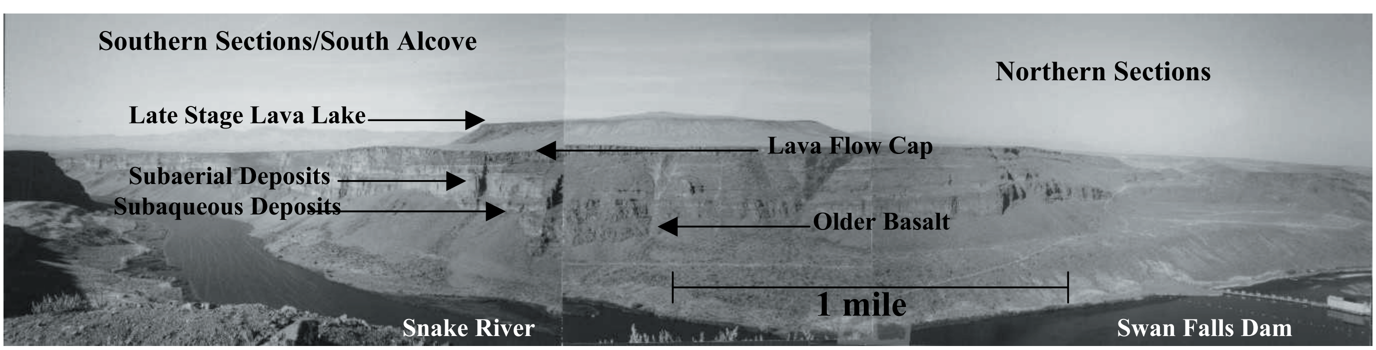


Figure 2. Sinker Butte as viewed from Swan Falls Road on the east side of the Snake River canyon. In this photo you can see the underlying older Swan Falls basalt deposits, the subaqueous deposits, the subaerial deposits, the lava flow cap, and the late-stage lava lake. Also identified are the southern and northern sections, as well as Swan Falls Dam.

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sediment load, and heat as the surge travels farther from its source.

During the third and final stage of the eruption, the volcano effectively sealed itself off from external water and ended with a Strombolian lava flow that caps older deposits (fig. 2).

## Geologic Setting of the Western Snake River Plain

The Snake River Plain extends across southern Idaho in a continuous arc. It is distinguished by its lower topography, and it contains several thousand feet of late Tertiary and Quaternary volcanics and sediments (Smith and Wilkinson, 1991). Mabey (1982) divided the plain into three parts: the northwest-trending western Snake River plain, the northeast-trending eastern Snake River Plain, and the central Snake River Plain between them. The eastern Snake River Plain (ESRP) is thought to have formed from the interplay of magmatism and extension associated with the Yellowstone hot spot (Parsons and others, 1998). The western Snake River Plain (WSRP) is a basin-and-range structure whose formation was triggered by the magmatism of the migrating Yellowstone hot spot (Clemens, 1993). Each of these parts of the plain has significant tectonic differences, but for the purposes of this study we will only focus on those in the western Snake River Plain.

The WSRP trends northwest and is the site of an extensive rift zone that widened perpendicular to the Yellowstone hot spot path. It is a depression with normal faults on both edges (Malde, 1965). The popular model for the formation of the WSRP is that a system of symmetrically-disposed half-grabens formed beyond the parabolic-shaped “wake” as the hot spot passed by (Anders and others, 1989; Pierce and Morgan, 1992). A problem with this model is there is no similar graben structure south of the path of the Yellowstone hot spot (Wood and Clemens, 2002).

Most of the northwestern portion of the WSRP is covered with Quaternary alluvium, whereas in the southeastern portion the dominant rocks are Tertiary and Quaternary lacustrine sediments and basalt flows. The plain is thought to have started extending around 11.6 to 10 m.y. ago (Bonnichsen and others, 1997), resulting in bimodal volcanism.

The volcanism in the WSRP region began with extrusion of rhyolitic lavas followed by the eruption of basalt and ash-flow tuffs. As the plain pulled apart and subsided, a lake, or succession of lakes, known as Lake Idaho formed (Godchaux and others, 1992). Volcanic activity occurring when the lake was present resulted in many spectacular examples of three major types of phreatomagmatic volcanoes: emergent, subaqueous, and subaerial. Emergent volcanoes, like Sinker Butte, began erupting under water and eventually build a volcanic edifice above the lake level. Subaqueous volcanoes erupt under water and never build above the lake level. Finally, subaerial volcanoes erupt through a buried aquifer system and produce classic maar volcanic features. All of these volcanic systems contain a significant amount of water, causing a high magma/water interaction. Emergent and subaqueous volcanoes usually form gently sloping tuff cones, whereas subaerial volcanoes form maars or tuff rings (Godchaux and others, 1992).

The WSRP is an excellent area to study phreatomagmatic eruptions and hydrovolcanism. Godchaux and others (1992) put it best when they stated, “This field has great potential for advancing our understanding of eruption mechanisms resulting from magma/water interactions across the entire magma/water-ratio spectrum.”

# ROAD LOG

| Mileage Cum. | Inc. | |
|---|---|---|
| 0.0 | 0.0 | Trip starts from Bank of America Center on the corner of 9th and Front Streets. |
| 1.68 | 1.53 | Turn RIGHT onto W. FRONT STREET/US-20 W/ US-26 W. Continue to follow US-20 W/ US-26 W. |
| 4.39 | 2.71 | Stay straight to go onto I-184 W. |
| 18.14 | 13.75 | Merge onto I-84 W/ US-30 W via the exit- on the left. |
| 18.41 | 0.27 | Take the FRANKLIN BOULEVARD exit—exit number 36. |
| 19.35 | 0.94 | Turn LEFT onto FRANKLIN BOULEVARD. |
| 20.16 | 0.81 | Turn RIGHT onto 11TH AVENUE N/ I-84 BOULEVARD. |
| 20.23 | 0.07 | Turn LEFT onto E. 3RD STREET S/ ID-45 S. |
| 38.0 | 17.77 | Turn RIGHT onto 12TH AVE S/ ID-45. Continue to follow ID-45. |
| 52.7 | 14.70 | ID-45 becomes ID-78. |
| 57.3 | 4.6 | Turn left on first road past Murphy (road name is Murphy Flat Road, but there is no road sign). |
| 60.3 | 3.0 | Turn Left on Sinker Butte Road. |
| 62.22 | 1.92 | Turn Right on farm road just before barn (you will drive through the farm, between the agricultural fields). Continue straight through fence towards Butte. Park on south side of Butte. |

## Stop 1. South Alcove-Proximal Deposits

The South Alcove (fig. 2) contains the deposits nearest the vent. We will spend the first half of the day here, exploring and examining many of the exposed sections within the canyon walls. We will begin by observing deposits that mark the beginning of the eruptive sequence (fig. 1, Stop 1a). These are the units deposited subaqueously (fig. 3). Notice that the sequence begins with a massive, fine, white unit, which occurs around the entire volcanic edifice. This white unit is reworked lake sediment with incorporated juvenile and accidental fragments. The accidental fragments are pieces of older basalt or rip-up clasts of underlying siltstone and lake deposits. Above the white unit is a massive orange block lapilli tuff unit. Within this massive unit are many accidental blocks and clasts, as well as some juvenile clasts. In some areas, the deposits are massive, in other areas cross stratification and channel scours occur. The variations are indicative of a volcanic platform growing closer to the surface of the water causing turbidite sequences, channelization, and wave-base affects.

An extremely sharp contact occurs between the lower subaqueously deposited tuffs and the subaerial tuffs (fig. 3). The subaerial units are planar, fine-grained, well sorted, even thickness, laterally continuous, orange, palagonitic tuffs that contain a mixture of accidental and juvenile fragments. The accidental fragments are older basalts and siltstones. These are interpreted to be subaerial due to the presence of accretionary and armored lapilli, which indicates that there was enough condensing steam and heat to cause fine ash to adhesively clump together or plaster onto other grains. The presence of palagonite also indicates that there were significant amounts of heat and steam present. Vesiculated tuffs are present and form when volatiles get trapped within fine wet ash. Had these deposits been subaqueous, there would have been too much water and not enough heat to cause these depositional processes to occur.

We will walk up section examining these planar tuff beds. They continue for many tens of meters, and are interpreted to be a combination of fallout and low-density pyroclastic surge deposits. They vary slightly in thickness (4–10 cm) and grain size (alternating fine and coarse ash). These differences can be attributed to the pulsating nature of emergent volcanoes, each pulse of eruption being slightly different in force, sediment load, heat, water, and water vapor.

Stop 1b (fig. 1) is located just up section and west-southwest of the deposits we have observed. Here we see one of the most interesting things in the South Alcove: large, low-angle regressive cross strata (wavelength ~1–2 m, height ~1 m, fig. 4). These beds occur at several horizons throughout the subaerial tuffs and can be traced across the entire South Alcove. Wet pyroclastic surges are 3-phase flows that include gas, water, and particles (unlike dry surges which are 2-phase, containing gas and particles). The water causes the particles to plaster against the stoss side of the dune forms, causing the crests of regressive cross strata to migrate upstream and the coarser fragments to fall on the upstream side of the crest (Cas and Wright, 1988). These deposits also contain accretionary and armored lapilli, as well as vesicles in the fine ash, which supplies more evidence for a wet surge.

Stop 1c is farther northwestward in the alcove (fig. 1). High in this section is a light-colored unit that contains abundant cross stratification, block sags, and soft-sediment deformation (fig. 5). This unit is overlain by a planar/wavy bedded, orange, palagonitic tuff that also contains soft-sediment deformation. The abundant block sags and soft-sediment structures indicate that these tuffs were quite wet when deposited, suggesting a renewed source or influx of external water during the eruption.

As we make our way westward, toward the back of the South Alcove, we find many impressive radial dikes that cut the deposits (fig. 1, Stop 1d). The dikes broke out through the tuff cone during the later stages of the eruption and may have been the source of the lava flow that caps the deposits (fig. 6).

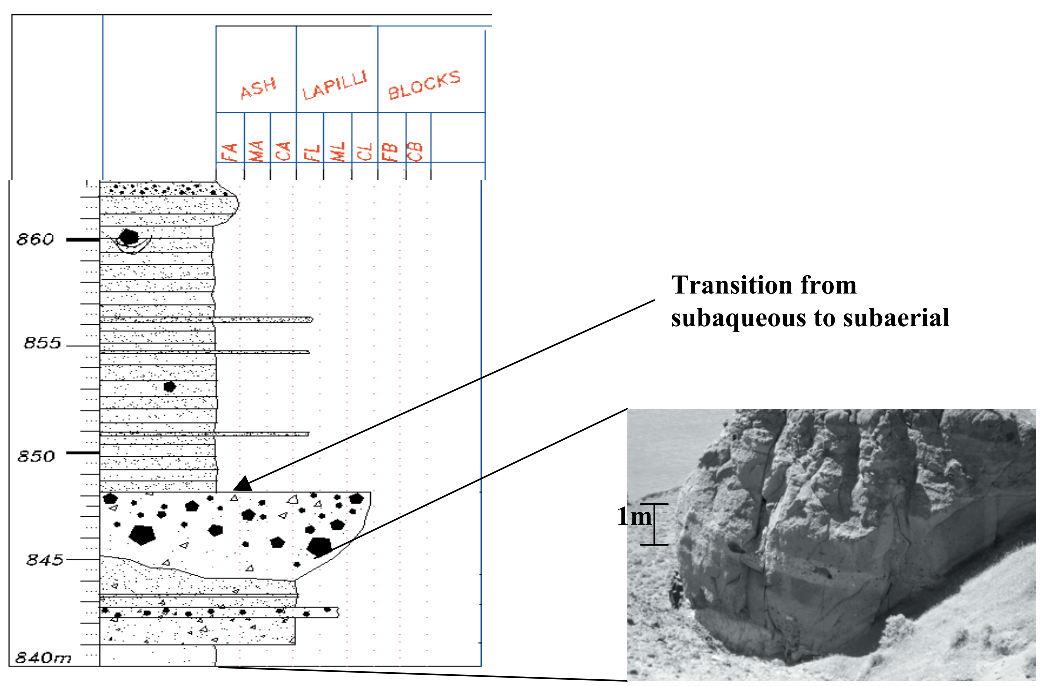


Figure 3. Stop 1a—Subaqueous deposits found within the canyon walls of the South Alcove.

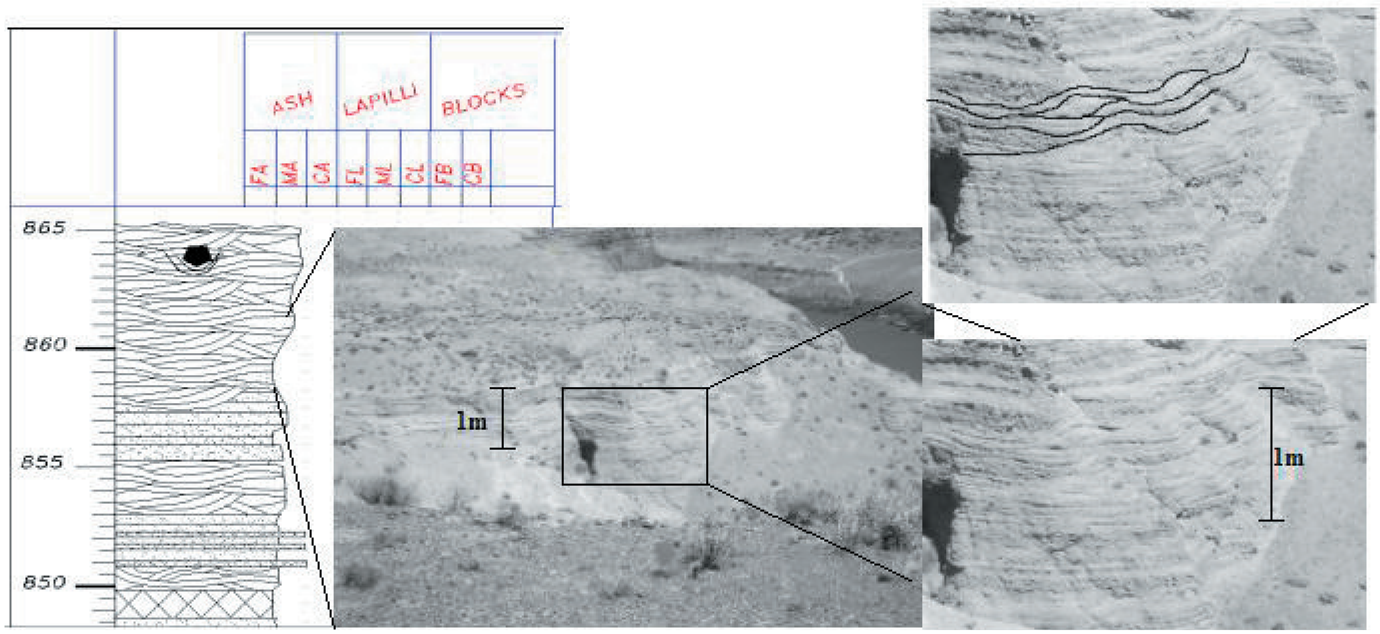


Figure 4. Stop 1b in South Alcove. These are the regressive dune beds found within the southern section. The sediment builds up on the stoss-side of the dune forming “anti-dunes”.

Finally we walk up towards the back of the South Alcove (fig. 1, Stop 1e), high in the eruptive sequence, to observe some brecciated tuff beds that are part of the inner and outer crater walls dipping away from the vent at 20° SE. and into the vent at 35° NW. (fig. 7). The beds that dip into the vent truncate each other at steep angles, indicating that some of the accumulated sediment had avalanched back into the vent.

| Mileage Cum. | Inc. | |
|---|---|---|
| 64.1 | 1.88 | Drive to the north side of the Butte. |

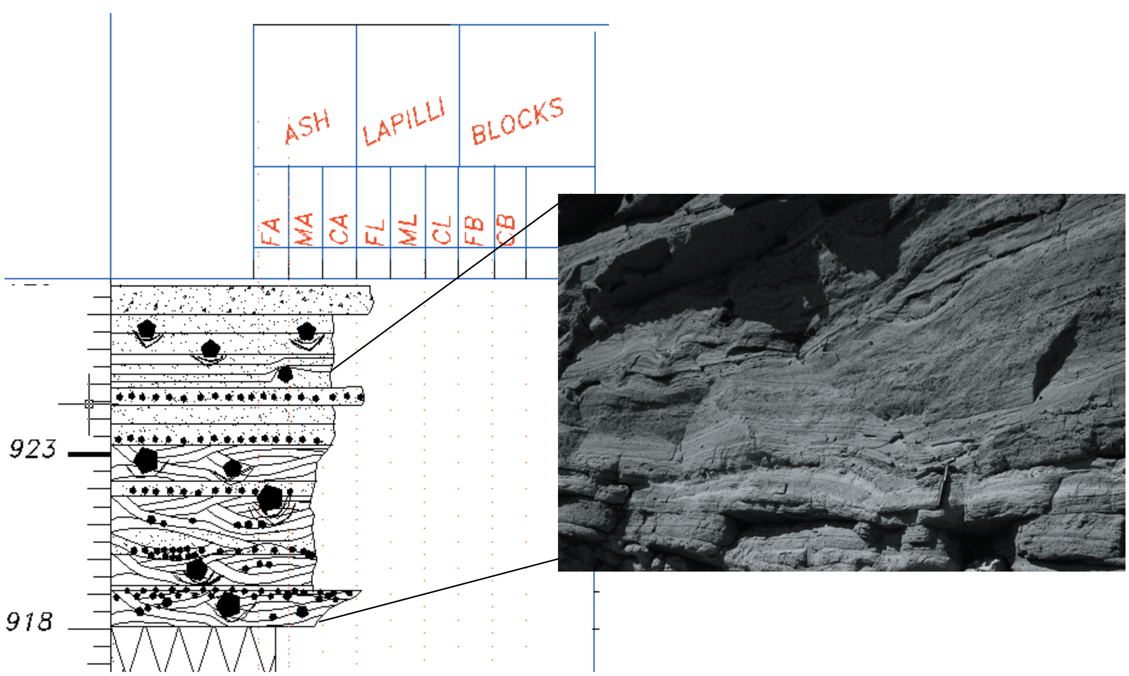


Figure 5. Stop 1c in South Alcove. This unit contains abundant bombs with bomb sags and soft-sediment deformation. These sediments show that during the eruption the water/magma ratio increased. Hammer for scale.

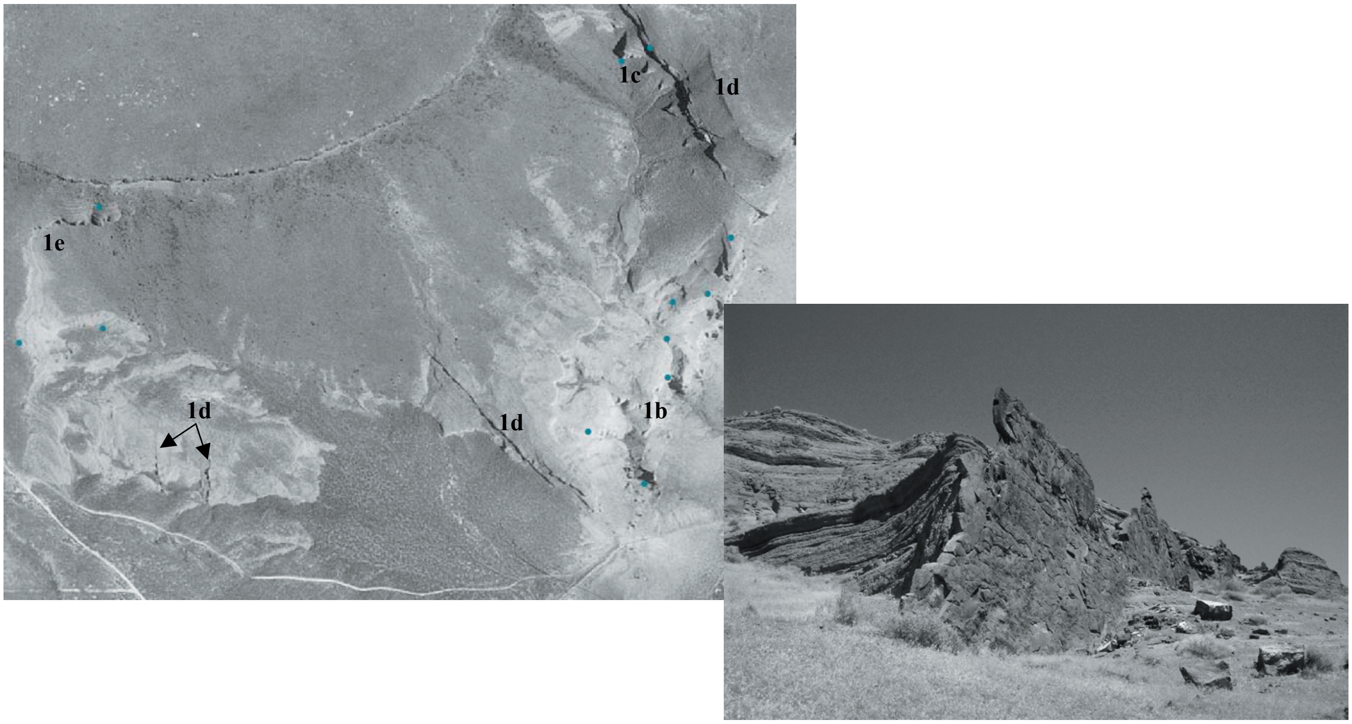


Figure 6. Ortho-photo quad (left) of the northwest corner of the southern alcove (Stop 1d). I also have identified some of the other stops. Notice the dark radial dikes that run through the deposits. Dike cutting through subaerial tuff deposits (right).

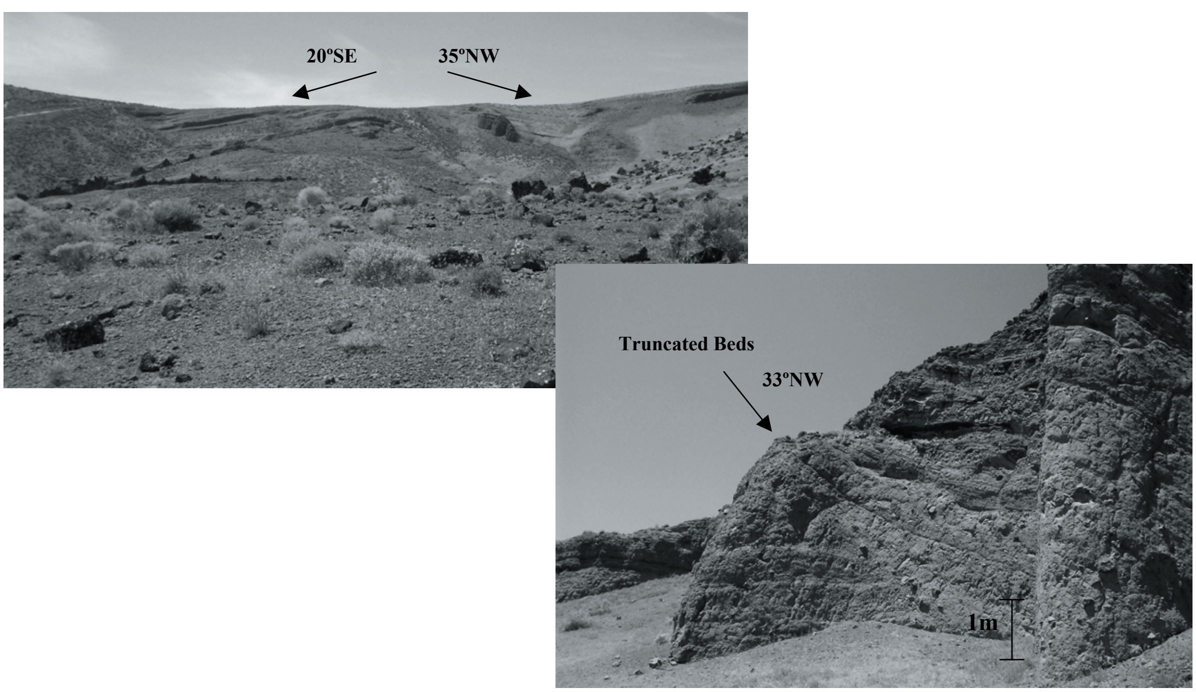


Figure 7. Final stop (Stop 1e) within the South Alcove. Here we are looking at the crater-wall deposits. View of the inner and outer crater walls (left). Note the opposing dip angles. Picture of the deposits that dip into the crater truncating one another. Truncation indicates avalanching into the crater after deposition.

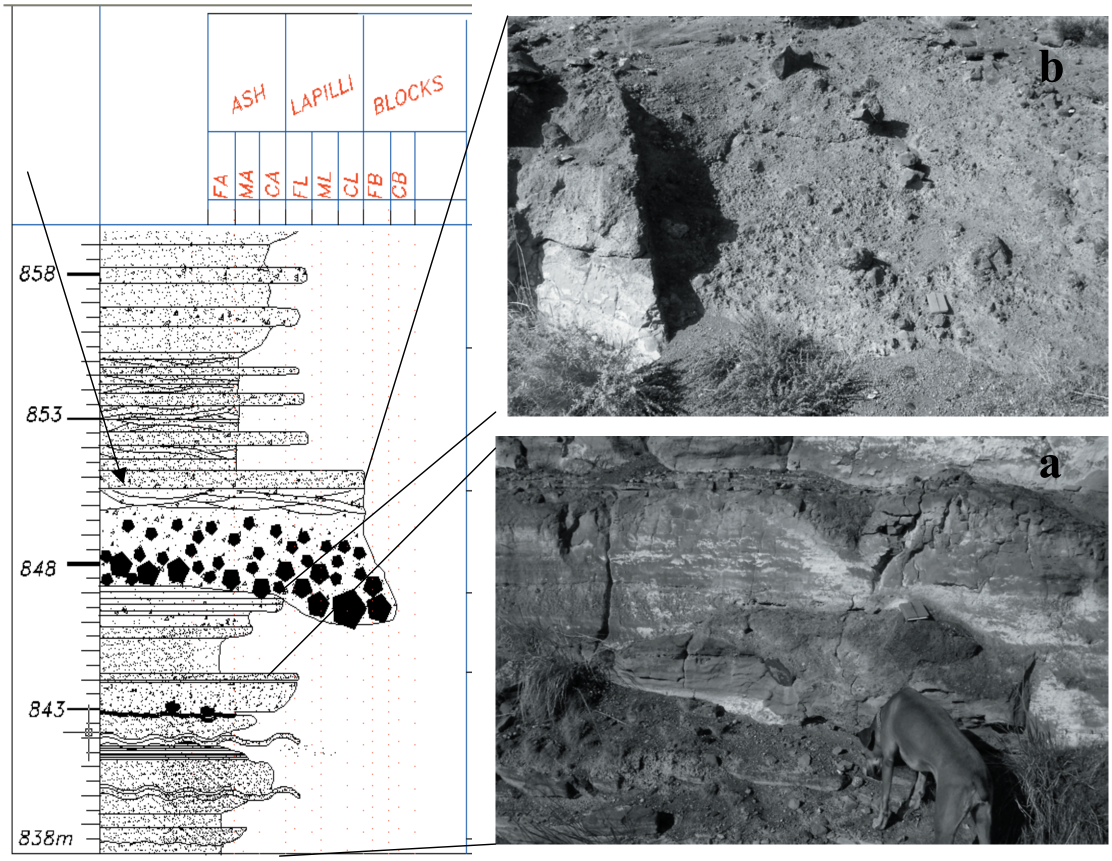


Figure 8. First stop in the northern sections (Stop 2a). We begin here by observing the subaqueous deposits up through to the transition into subaerial deposits. (a.) A Bouma sequence can be identified in the lower subaqueous deposits (dog for scale). (b.) This grades up into massive debris flow deposits (field book 19 x 12 cm for scale). The contact between the subaerial and subaqueus deposits is quite sharp. Notice the finely cross-stratified planar beds.

## Stop 2. North Sections—Medial and Distal Deposits

Our second set of stops will be in the medial to distal portions of the deposits, which differ from those proximal to the vent. We will walk down the canyon along a gravel road examining the subaqueously deposited tuffs (fig. 1, Stop 2a) and then work our way up through the subaerial tuffs. The first unit in the sequence is much like the first one in the South Alcove. It consists of a fine-grained, massive, white tuff that is interpreted to be reworked lake sediment with accidental and juvenile clasts (similar to the white unit found in the south). Above this unit are cyclic beds that are analogous to a Bouma sequence (fig. 8a). Continuing up through the section, we encounter large erosive debris flows as well as large-scale cross stratification and channel scour and fills (fig. 9b). All of these units were deposited subaqueously and are a consequence of the volcanic platform growing progressively closer to the surface of the lake.

Above the subaqueous tuffs with again an extremely sharp contact are the subaerial tuff deposits (fig. 9a). These tuffs, like the proximal tuffs, contain accretionary and armored lapilli, as well as abundant amounts of palagonite. They differ from the proximal tuffs as follows: (1) beds alternate from planar to low-angle cross-stratified beds with an average wavelength of less than 10 cm (fig. 9b), (2) the tuffs alternate from fine ash to coarse ash, (3) contain a mix of accidental (older basalt and siltstone) and juvenile clasts, and (4) the overall wavelength of the cross stratification increases higher in the section. Cas and Wright (1988) interpreted such cross-stratified sedimentary features to be due to high velocity, current driven grain layers being sheared over an irregular, surface of low relief due to high bed-shear stress. The deposits at Sinker Butte suggest the same type of emplacement as turbulent, wet, low-density pyroclastic surges were codeposited with airfall deposits.

Coarse interbeds (up to 1-m thick) of ash- to lapilli-sized, juvenile, cinder-like layers are found within the orange tuffs. The beds increase in grain size, thickness, and abundance up section until they dominate the deposits. These juvenile beds become more abundant up section which suggests that the eruption was “drying out”, or the influx of external water was being depleted and no longer having as much effect on the magma.

The next unit upward consists of thick, massive, tuff breccias containing abundant accidental and some juvenile clasts within a medium- to coarse- ash matrix (fig. 10). These massive beds introduce new accidental clasts consisting of rounded river gravel and siltstone, which is evidence for downward coring of the volcano. This massive unit almost certainly indicates a new stage in the eruptive sequence involving more water. The rounded river gravels and the water-affected deposits suggest that as the volcano cored

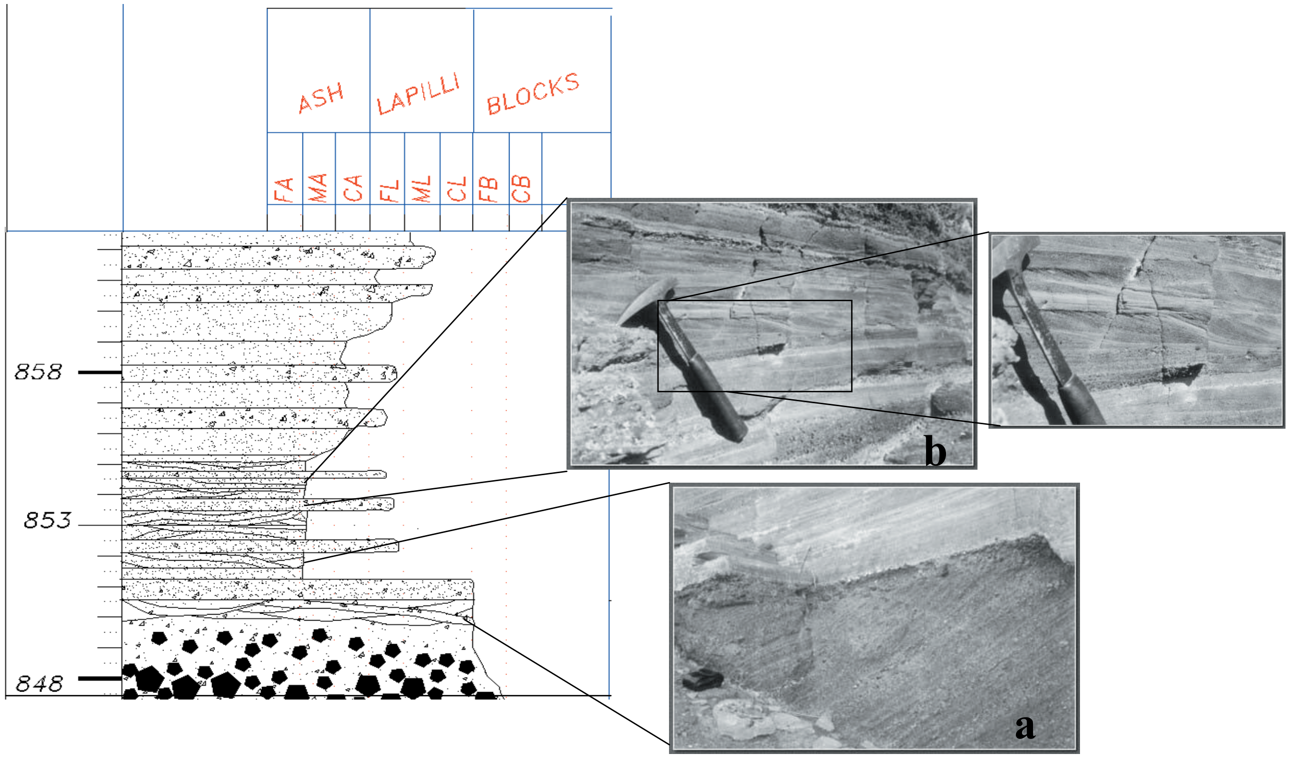


Figure 9. Column located high in the section at Stop 2a. (a.) The abrupt transition from the subaqueous deposits into the subaerial deposits. (b.) The fine cross-stratification in this section. (Camera case for scale in a; hammer for scale in b.)

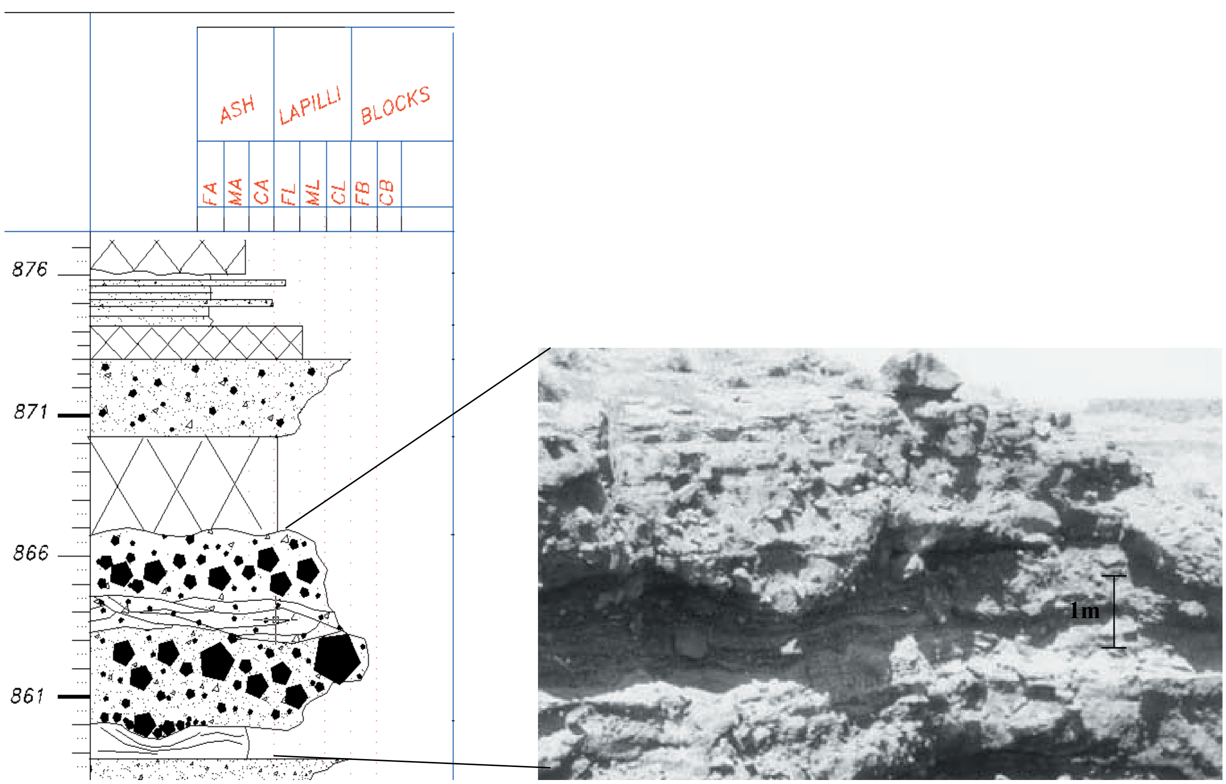


Figure 10. Deposit found just above the previous subaerial deposits (Stop 2a). These massive deposits represent an eruptive event involving additional water. Notice that the blocks have reverse grading.


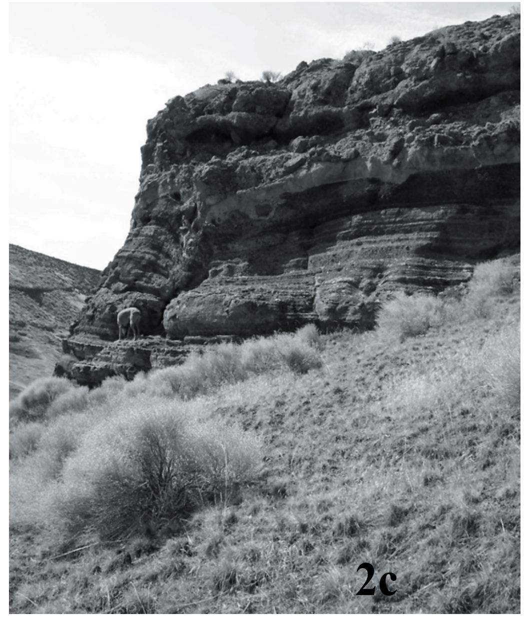


Figure 11. Pictures of the more distal outcrops (Stops 2b, on left, and 2c, on right). Notice the wavy stratification, abundant sags under large clasts, and soft sediment deformation. This may indicate that more water was condensing as the pyroclastic flows cooled and slowed further from the vent, creating these “wetter” looking deposits (tired dog for scale in both, she is nearly 1 m).

downward into the underlying stratigraphy, it may have hit an aquifer exposing a new influx of water. Above these massive units are more orange, planar, and cross-stratified tuffs with interbeds of juvenile layers. These are followed by the lava flow capping the deposits, which indicates that the volcano effectively isolated itself from all external water and became Hawaiian or Strombolian in nature.

Next we will continue hiking northwest around different outcrops throughout the north section until we reach the most distal deposits in the area (fig. 1, Stop 2b and 2c). We will see the same sequence of planar and cross-stratified tuffs transitioning into massive tuff breccias (fig. 11). Notice that as we get more distal from the vent, the deposits tend to look “wetter”. There is a lot of wavy bedding, block sags, and soft sediment deformation. This suggests one of two interpretations. The first is that these deposits either are flowing back down into or towards the body of the lake and being affected by water. The second is that as the surges cool, more water condenses and creates “wetter” deposits.

The last stop of the trip is high in the northern section (fig. 1, Stop 2d). Present here are large, low-angle, cross-stratified beds (fig. 12). Unlike the large regressive cross strata we observed in the Southern Alcove, these are progressive and analogous to normal sedimentary dune beds. The wavelength of the dunes is approximately 2–3 m, and the height is around 1 m. They are internally massive with the juvenile and accidental clasts supported within a fine-ash matrix. There are no apparent accretionary or armored lapilli, and the deposits are much finer grained than the other massive beds closer to the vent.

These cross-stratified beds suggest emplacement by a dry surge and represent a drying out of the eruption in the latest stages before the volcano was completely isolated from external water. The general lack of accretionary/armored lapilli, as well as the progressive cross strata, supports this interpretation.

## Conclusions

On this trip we observe, discuss, and argue about the depositional environments, mechanics of emplacement, and the resulting deposits of an emergent hydrovolcano. Within the unique and diverse volcano-clastic deposits, we observe how the changes in the magma/water ratio affect the evolution of the volcano as the eruption progresses, as well as the many changes that occur from proximal to distal. I hope that this field excursion has peaked your interest, answered questions, and created new arguments and theories regarding these types of eruptions and their subsequent deposits.

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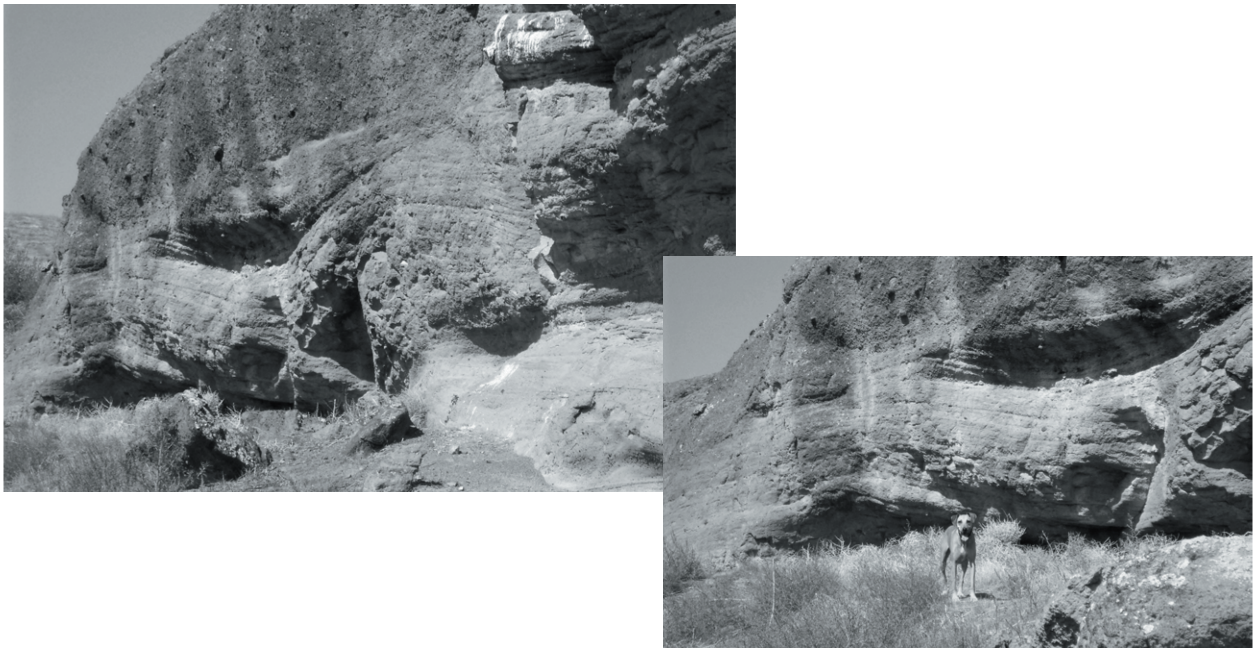

Figure 12. Large-scale cross-stratified progressive dune beds at Stop 2d, which is the last stop of the day. The progressive nature is characteristic of a dryer surge deposit, which suggests that the magma/water ratio during this later stage of the eruption was decreasing (tired dog for scale).

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