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# Joints, Fissures, and Voids in Rhyolite Welded Ash-flow Tuff at Teton Damsite, Idaho

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# JOINTS, FISSURES, AND VOIDS IN RHYOLITE WELDED ASH-FLOW TUFF AT TETON DAMSITE, IDAHO

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## Abstract

Several kinds of joints, fissures, and voids are present in densely welded rhyolite ash-flow tuff at Teton damsite. Older fissures and voids probably were formed in the ash-flow sheet during secondary flowage, which probably was caused by differential compaction or settling over irregular topography. The younger, more abundant fissures are mostly steep cooling joints that probably have been opened farther by horizontal tectonic extension and gravitational creep, perhaps aided by lateral stress relief.


## Introduction

This report briefly describes and examines the origin of some aspects of the joints, fissures, and irregularly shaped voids that are present in the rhyolite welded ash-flow tuff of the right (northwest) abutment of Teton Dam, Idaho. Visits to the canyon and damsite were made over a period of several years during the course of regional mapping (Prostka and Hackman, 1974). After failure of the dam on June 5, 1976, the damsite was revisited at the request of the Department of Interior Teton Dam Failure Review Group. The right abutment was carefully examined alone and with members of the Review Group and, on one occasion, with Donald A. Swanson, U.S. Geological Survey, who provided additional insights and discussion on the origin and significance of the volcanic features exposed there. The terminology and concepts pertaining to ash-flow tuffs that are used here are those developed and summarized in several definitive papers by Smith (1960a, b) and Ross and Smith (1961), in which the processes of deposition, compaction, welding, and cooling of ash-flow tuffs are described.

The rhyolite that forms the walls of the canyon of Teton River and the abutments of Teton Dam has been correlated with the Huckleberry Ridge Tuff, a densely welded ash-flow tuff that has been radiometrically dated at 1.9 million years (Christiansen and Blank, 1972) in Yellowstone National Park.

On Bureau of Reclamation post-failure geologic maps of the right abutment of Teton Dam, the welded tuff has been subdivided into three informal units that are distinguished primarily by variations in prominence or degree of development of foliation and related platy joints, variations in dip of foliation and variations in dip and spacing of joints (figs. 1, 2, 3). The contact between unit 1 (the upper unit) and unit 2 (the middle unit) is gradational over a few inches; the contact between unit 2 and unit 3 is a breccia zone that is mostly about


Figure 1.--Oblique aerial view of right abutment, Teton Dam, showing overall appearance of rhyolite welded ash-flow sheet. Note threefold subdivision of sheet upstream (to the right) of the embankment remnant in the key trench. Height of exposed canyon wall is approximately 230 feet. View to west taken June 1976.

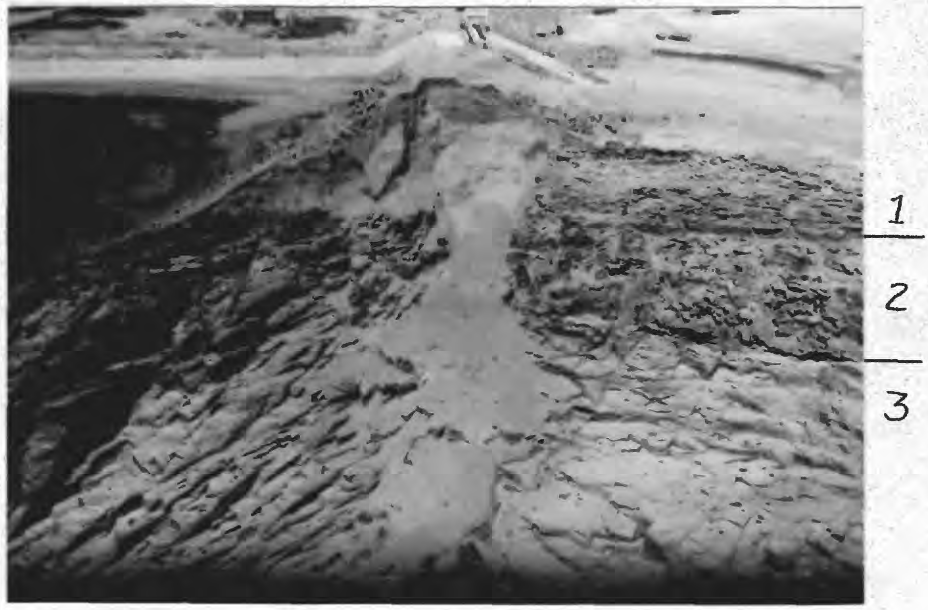


Figure 2.--Aerial view of right abutment, Teton Dam, nearly perpendicular to the canyon wall. Note abrupt termination of unit 2 just downstream from the embankment remnant. Thickness of unit 2 is about 61 feet. View to northwest taken June 1976.

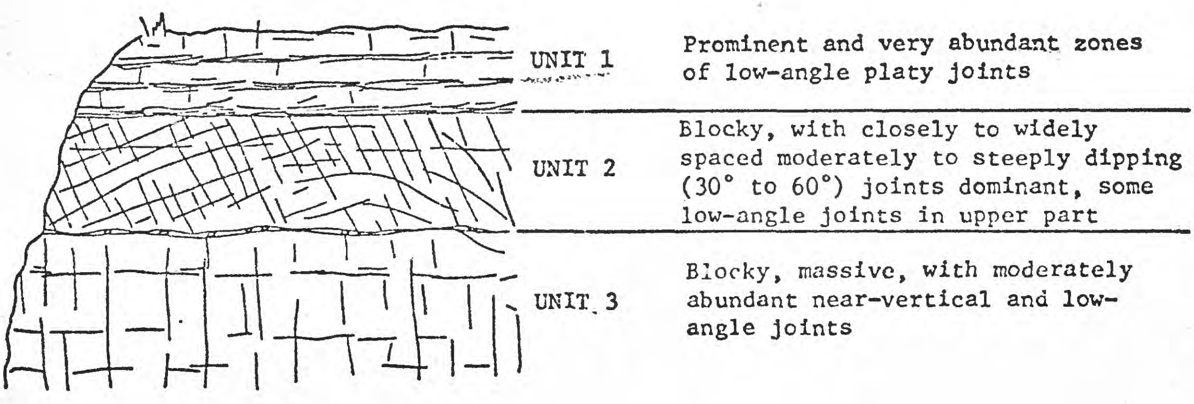


Figure 3.--Schematic section of welded rhyolite ash-flow tuff in right abutment, Teton Dam, as exposed after failure just upstream from the embankment remnant, showing principal joint features of the three informal units distinguished on Bureau of Reclamation post-failure geologic maps.

2 inches thick, but which laterally grades into an interval about 10 feet thick containing several thin discontinuous breccia zones.

## Low-angle foliation and platy joints

Low-angle foliation and related platy joints appear to have resulted primarily from depositional layering and from flattening and collapse of the ash-flow sheet. Zones of prominently developed platy joints are layers that probably had, in addition, more abundant entrapped gases either because of an initial higher concentration of pumice in these layers or because they represent gas-rich pulses of the eruption that formed vesicle-rich or lithophysal layers which subsequently collapsed during cooling and degassing of the sheet. These platy collapsed zones apparently were mechanically weaker than the more massive layers of the ash-flow sheet. During secondary flowage, they formed horizontal zones a few inches to about 1 foot thick of short (less than 6 inches), closely spaced, gently dipping imbricate joints (fig. 4). These zones occur between thicker, more blocky layers of the rhyolite and are best developed in unit 1. The layered appearance of the sheet, as seen from a distance (figs. 1, 2), is due to the presence of these platy zones as well as to the foliation. Elongate pumice fragments in the tuff at the damsite do not everywhere display a strongly preferred orientation; instead, many are randomly oriented, especially in unit 2. This may reflect exceptionally high turbulence within the ash flow during emplacement.

## Steeply dipping foliation and joints in unit 2

Foliation that dips 70$^{\circ}$ north-northeast to vertical is shown throughout the lower three-fourths of unit 2 on Bureau of Reclamation post-failure geologic maps. Locally, closely spaced joints have developed parallel to the foliation; many of them are slightly open and lined with coatings of silica and alkali feldspar. The steep foliation may be due to a steep primary depositional fabric that has been called ramp structure (Schmincke and Swanson, 1967), although the apparently random orientation of elongate pumice fragments does not lend support to this interpretation.

In addition to the steep joints there are many low to moderately dipping joints, many of which are curved and which define a broad archlike structure in unit 2 (fig. 5). The origin of these curved joints is not clear and no explanation for them is offered here.

## Steep irregular-shaped fissures

Steeply dipping fissures of lenticular to highly irregular shape, a few inches to several feet in length (fig. 6), are rare but are present in a few places in unit 1. These fissures generally dip northeastward

Figure 4.--Zone of closely spaced, short imbricate joints in unit 1 exposed along a haul road a short distance upstream from the right abutment. Hammer head is at the contact between the imbricate zone and underlying blocky welded tuff.


Figure 5.--Right abutment just upstream from key trench, showing subhorizontal platy joints of unit 1, archlike form of curved joints superimposed on steep foliation and related joints dipping to the right (north-northeast) in unit 2 (see also fig. 3), and widely spaced joints in unit 3. Prominent white lines are engineering reference lines painted on the rocks. The parallel lines are at 50-foot intervals upstream from the dam centerline.

Figure 6.-- Steeply dipping irregularly shaped fissure about 2 feet wide that probably formed as a viscous pull-apart structure during secondary flowage of the rhyolite. Note small steeply dipping tension cracks along the left side of the large void. This fissure is exposed in unit 1 along a haul road a short distance upstream from the right abutment.

like the small imbricate joints in the platy zones of unit 1 (fig. 4) and many of the steep foliation joints in unit 2 (fig. 5). Voids along all three kinds of features are lined with coatings and replacements of silica and alkali feldspar that were deposited by gases escaping upward through the ash-flow sheet during compaction, cooling, and welding. The similar direction of dip of all three kinds of features and the presence of vapor-deposited coatings in voids along them suggest that they all probably formed at about the same time in response to tensional and shear stresses that developed during differential compaction and secondary flowage of the ash-flow sheet. These fissures and joints generally strike northwest, as do the axes of folds in the lower part of the sheet (fig. 7) in the vicinity of the damsite, and the predominantly northeast dips suggest that the upper part of the sheet may have slid northeastward over the lower part as a result of secondary flowage that may have been caused by differential compaction of the ash-flow sheet over irregular topography.

## Very steep to vertical columnar joints and fissures

The most abundant steep to vertical joints have smooth planar surfaces. Most of them are columnar-type joints that formed by thermal contraction during final cooling and consolidation of the ash-flow sheet. At the damsite the northwest-trending joint set is more prominently developed than the northeast-trending set. Because the amount of separation along joints in volcanic rock that is due to thermal contraction alone is typically much less than 1 inch, the separations of as much as several feet that are found along some joints at Teton damsite must be due to later additional widening of some kind. The amount of separation along these steep joints varies vertically, commonly quite abruptly at intersections with low-angle joints (fig. 8); this abrupt variation requires some slippage along the low-angle joints, as indicated in figure 9. This relationship between high-angle and low-angle joints is best seen in unit 1 along the upper haul road upstream from the right abutment.

## Brecciated contact between unit 2 and unit 3

Small amounts of lateral slippage have occurred along many minor low-angle joints. Locally, however, some major low-angle joints appear to have individually accommodated the aggregate lateral slippage due to widening of several steep joints, a process which may have formed the brecciated contact between unit 2 and unit 3. This contact is a prominent discontinuity (figs. 1, 2) that can be traced from the dam centerline, to the left of the key trench, upstream along the right abutment for at least 400 feet. Sharp angular fragments of brecciated rhyolite occur discontinuously in voids along this zone, which is undulatory or wavy in detail (figs. 5, 10). Matching of details of the fit between the upper and lower surfaces suggests that lateral displacement of not more than a few inches could have occurred along the zone. Upstream, the zone splits into several gently curved branches which die out laterally. Downstream, the zone ends abruptly about

Figure 7.--Fold in lower part of ash-flow sheet exposed in right canyon wall less than 1/2 mile upstream from the dam. The axis of this fold is about in line with the arching of foliation over a pre-rhyolite topographic high exposed in the left side of the canyon just upstream from the intake tower.

Figure 8.--Large vertical fissure apparently offset along several low-angle joints in unit 3.

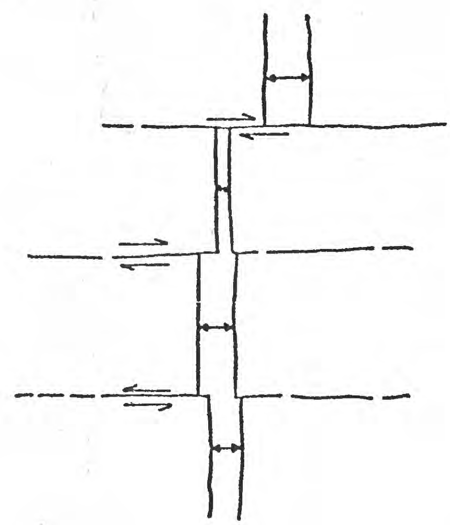

Figure 9.--Diagram of vertical fissure; horizontal offsets show how differential separation (⟷) along a vertical joint is accomodated by slippage (⇋) along low-angle joints in rhyolite at damsite.

Figure 10.--View of prominent contact between unit 2 and unit 3 just upstream from embankment remnant. Arrows indicate location of contact.

50 feet downstream from the grout cap, which is in the middle of the key trench.

Because the breccia fragments are all sharply angular and devoid of vapor-deposited coatings, the breccia must have formed when the rhyolite was relatively cold and brittle, sometime later than the episode of secondary flowage. Deposits of calcite on and between breccia fragments are not brecciated or fractured, indicating that no additional displacement has occurred along this zone since it was formed.

## Causes of enlargement or widening of steep joints at the damsite

There are several possible causes of additional widening or enlargement of steep joints since their original formation by contraction during cooling. They fall into two general classes: those related to horizontal extension, or pulling apart, and those related to erosion, or removal of rock material.

Processes of widening related to horizontal extension include (1) tectonic crustal extension; (2) gravitational creep, aided by weathering, especially frost action; (3) movement of rock toward the canyon because of lateral stress relief, or unloading; and (4) movement caused by differential settlement due to subsurface erosional sapping of fine-grained sediments beneath the rhyolite.

Evidence for (1) tectonic crustal extension includes the following: (a) the Snake River Plain and surrounding Basin-Range provinces of eastern Idaho have been undergoing regional tectonic extension from at least late Miocene time to the present; (b) tectonic extension in the Teton-Rexburg Bench area, in particular, has been most active since late Pliocene time, or since emplacement of the Huckleberry Ridge Tuff less than 2 million years ago; and (c) the predominant northwest trend of fissures at the damsite is consistent with the predominant northwest trend of Quaternary fissure zones, such as the Great Rift on the Snake River Plain, and with the dominant trend of late Cenozoic, possibly active, normal faults adjacent to the plain.

(2) Gravitational creep has been the demonstrable cause of block movement with attendant joint widening at a number of places along the canyon, but because most of the prominent wide fissures at the damsite trend at high angles to the canyon walls it does not seem likely that creep could have been the principal cause of joint widening. Intersecting joints conceivably might have blocked out large rock masses that migrated canyonward, perhaps influenced by the character of the underlying sediments, especially claystone; however, the relative sparsity of wide fissures oriented parallel to the canyon walls argues against this process being the most important one.

(3) Stress relief due to erosion of the present canyon may account

for some widening of joints, particularly in the lower part of the canyon; it probably is not an especially important cause, however, and its effects would be difficult to distinguish from widening due to gravitational creep.

Little evidence supports (4) differential settlement caused by subsurface erosional sapping. However, because the rhyolite is underlain by variably indurated fine-grained sediments interlayered with gravels, some of which may be ground-water aquifers, this process cannot be entirely discounted.

Erosional processes include spalling or slabbing of fractured rock along joints and enlargement by hydrothermal leaching. Spalling has contributed to the further enlargement of already opened joints, but it cannot be the primary process of widening because there is no effective way of removing the coarse rubble from the fissure. Hydrothermal leaching probably is not important except very locally, because nearly all of the exposed fissures have surfaces that are smooth and planar, not irregular and corroded.

On the basis of the available evidence, most of the high-angle fissures at Teton damsite seem to be cooling joints that subsequently have been further opened mainly by horizontal tectonic extension and locally by gravitational creep, perhaps aided to some extent by lateral stress relief. Other fissures, formed earlier during differential compaction and secondary flowage of the ash-flow sheet, are not as numerous or as extensive as the later ones. The rate of extension and its recency have not adequately been established.

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