Large-Scale Rheomorphic Structures and Basalt Stratigraphy of the Newdale and Linderman Dam 7.5-minute Quadrangles, Eastern Snake River Plain, Idaho

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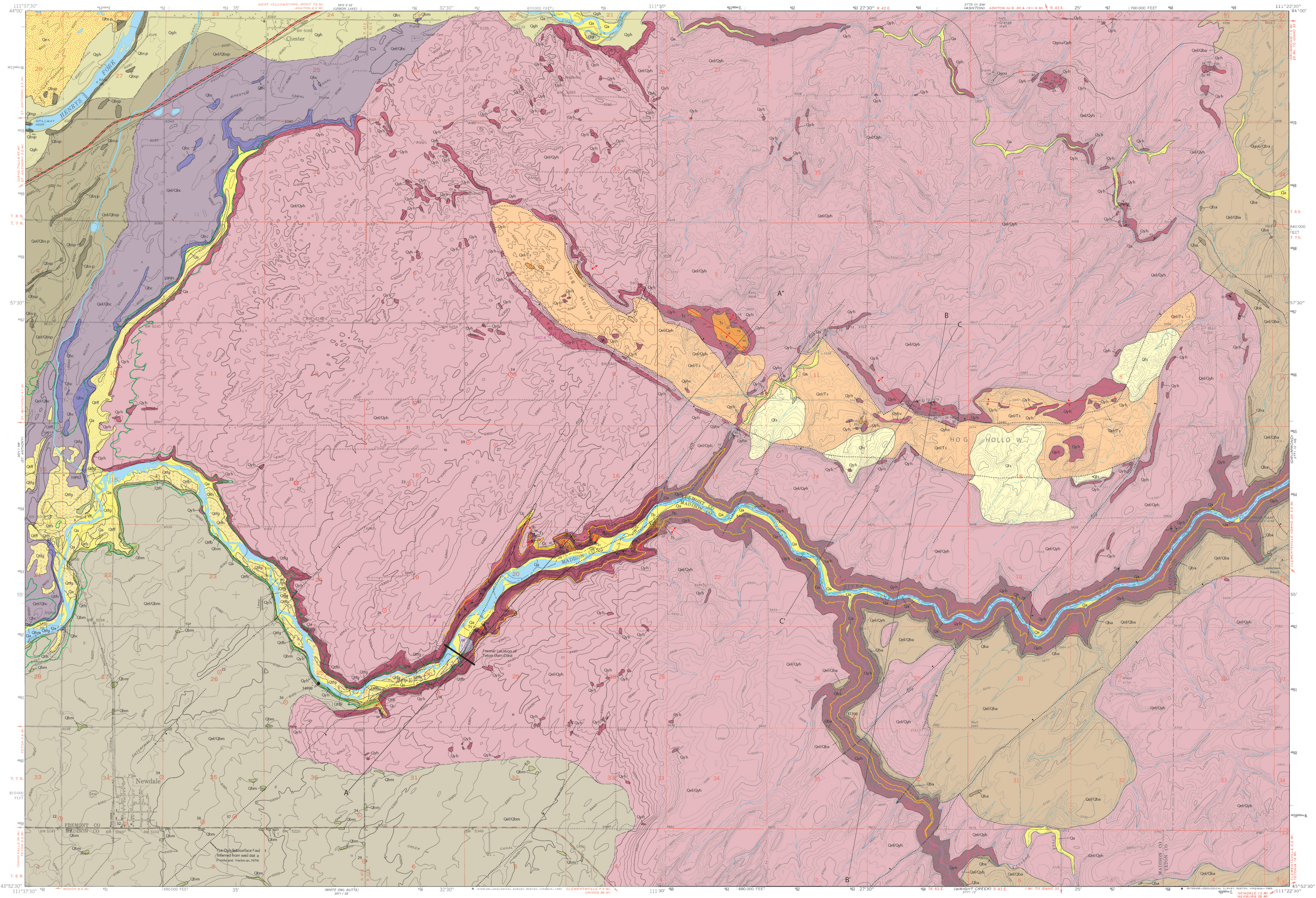
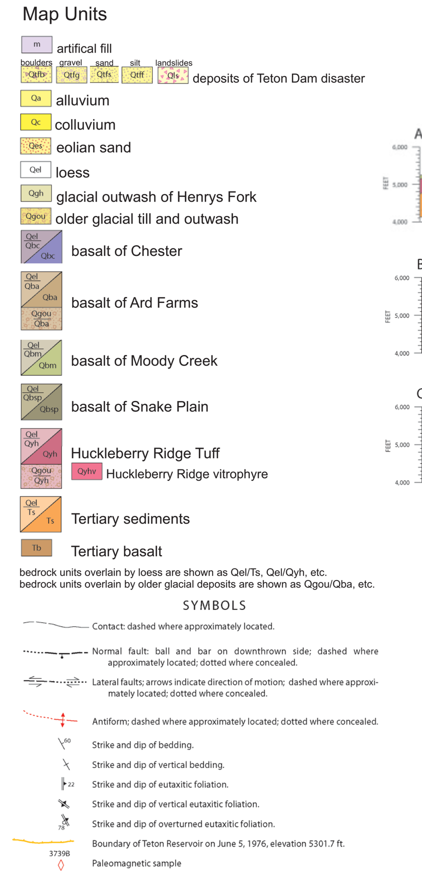
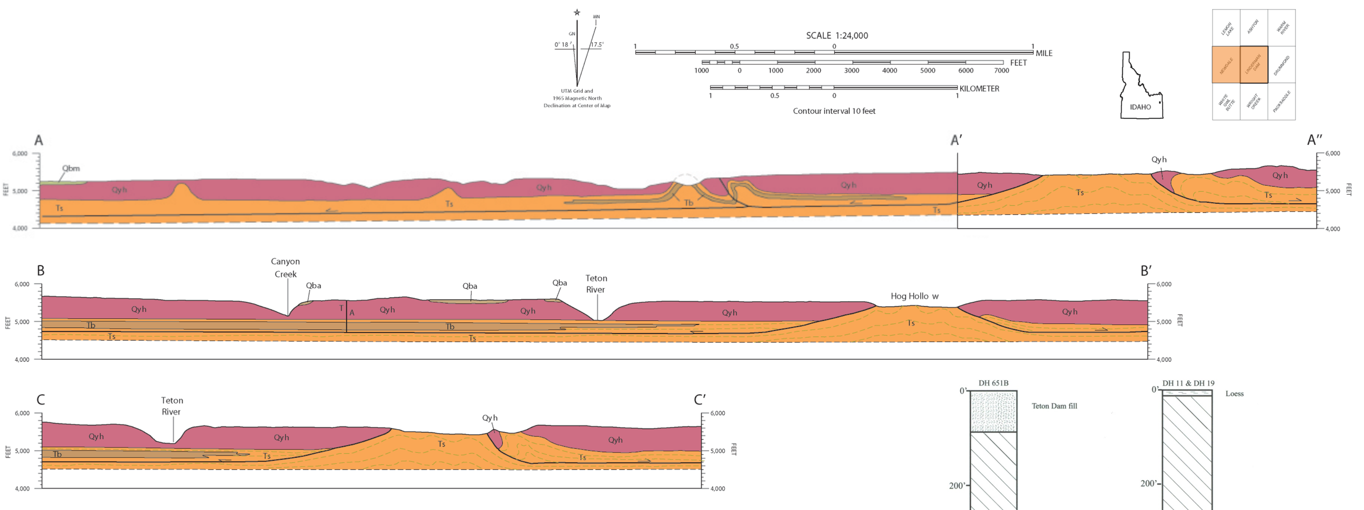
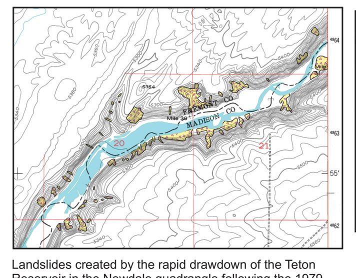
Newdale Quadrangle / Linderman Dam Quadrangle

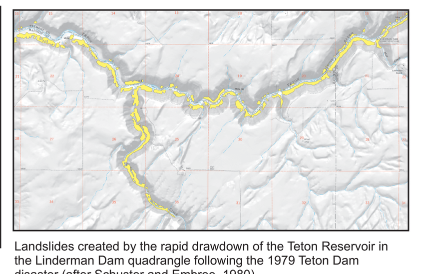




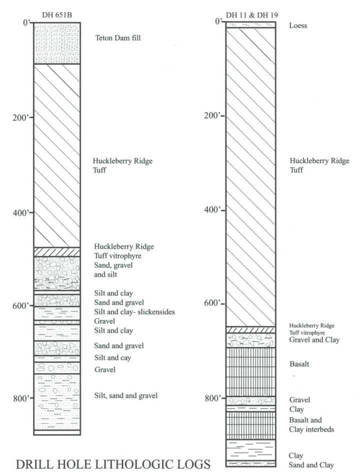




Landslides created by the rapid drawdown of the Teton Reservoir in the Newdale quadrangle following the 1976 Teton Dam disaster (after Schuster and Embree, 1980).

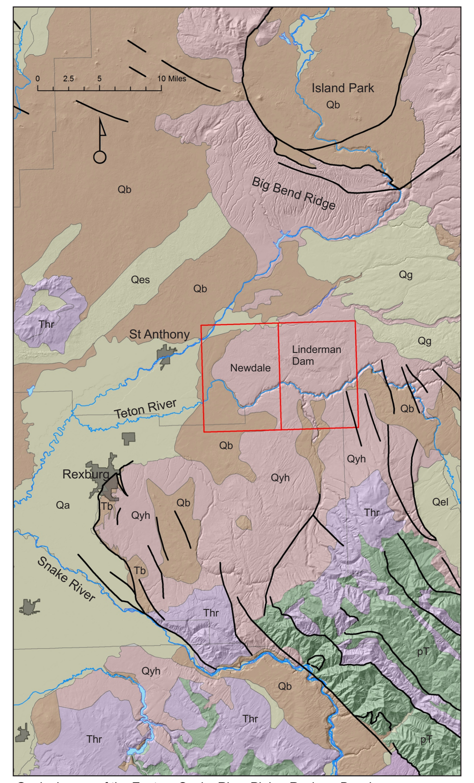


Landslides created by the rapid drawdown of the Teton Reservoir in the Linderman Dam quadrangle following the 1976 Teton Dam disaster (after Schuster and Embree, 1980).

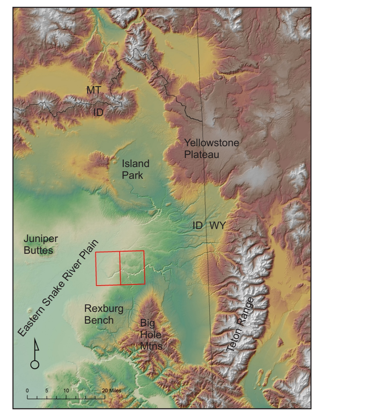


DRILL HOLE LITHOLOGIC LOGS

Drill logs from the Newdale quadrangle showing stratigraphic features of pre-Qyh deposits.



Geologic map of the Eastern Snake River Plain - Rexburg Bench area. Quaternary units--Qa: alluvium; Qel: loess; Qes: sand dunes; Qb: basalt; Qyh: Huckleberry Ridge Tuff. Tertiary units: Tb: Rexburg basalt; Thr: Heise Volcanic Field rhyolites. Pre-Tertiary units: pT



Location map of the study area showing major topographic features.

Abstract

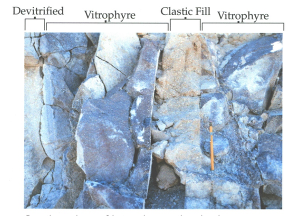
Detailed geologic mapping of the Newdale and Linderman Dam 7.5 minute quadrangles supported by paleomagnetic and geochemical data: document the distribution of large- scale gravity sliding and secondary deformation structures within the 2.06 Ma Huckleberry Ridge Tuff (Qyh) and underlying sediments, basalts and rhyolites; document geologic causes and effects of the Teton Dam failure; and refine the post Qyh basalt stratigraphy.

A sheet consisting of ~130 m of Qyh and at least 30 m of underlying units has moved ~1 km horizontally. Large scale structures in the detached sheet include diapiric antiforms >100 m in amplitude, strike slip faults with up to 1 km of displacement, and an arcuate 1 km by 12 km tectonically denuded valley. Detachment and deformation apparently occurred within the underlying sediments as a result of overloading by the rapid emplacement of the Qyh. Movement occurred after compaction and welding but before devitrification of the tuff. Paleomagnetic data confirm that folding of the Qyh took place above the maximum blocking temperature of magnetite (~580°C). Infiltration of water along numerous open joints and shear zones produced during this deformation of the tuff contributed to the failure of the Teton Dam in 1976. Numerous landslides resulted from rapid drawdown of the reservoir when the dam failed. These slides involve ~500 acres or 34% of the submerged canyon slopes.

Basalt units in the area are compositionally diverse, consistent with having formed near the edge of the Snake River Plain during active caldera formation in the area. Compositional and paleomagnetic data are used to distinguish units and correlate isolated outcrops and vents. Field relations indicate that at least three lava flows of the Pleistocene basalt of Moody entered the Teton Canyon in rapid succession from the south and dammed the river at progressively higher levels. Pillow lavas and hyaloclastite deposits at the base of each flow indicate that the reservoir level reached the top of each lava dam, before subsequent flows were emplaced. The river finally breached and cut completely through all three flows (Jordan and others, 2008).

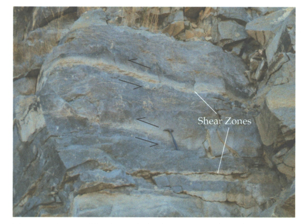
Secondary Deformation

Open vertical to steeply-dipping cooling fractures offset by horizontal shear zones in the upper zone of the Qyh. Arrows indicate relative motion along shear zones. Left is southwest.



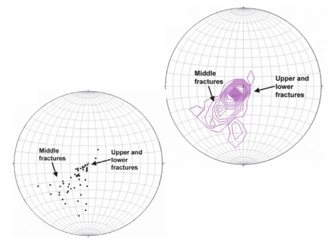
Section view of lateral zonation in de-vitrification adjacent to an open joint which was filled with reworked ash from above.

En echelon tension fractures in the devitrified middle zone of the Qyh. These fractures were filled with vapor phase crystals during subsequent cooling of the tuff. Most of these fractures dip gently to the northeast (left), indicating that the lower part of the unit moved to the southwest.



Vapor-phase-filled en echelon extensional fractures in massive gray tuff are separated by white, vapor-phase-filled, open shear zones. Arrows indicate relative motion, right is to the southwest.

Photo showing multiple sets of horizontal brecciated shear zones and curved extensional cooling fractures. Rock hammer for scale. Photo from Millard and others (2005).



Equal area plots showing poles of 52 measurements taken from 17 curved fractures. Note the sub-horizontal dip of the upper and lower fractures and the moderately dipping middle fractures. Image from Millard and others (2005).

Unusual structural and lithologic zonation in the Huckleberry Ridge Tuff is evident along the walls of Teton Canyon. The basal vitrophyre exhibits a strong eutaxitic foliation which locally shows small-scale (~1 m) isoclinal flow folds, indicating that viscous flow occurred after compaction produced the eutaxitic fabric.

In the central, devitrified part of the unit, the welded tuff contains a large number of sub-horizontal joint sets and closely spaced en echelon tension fractures filled with vapor-phase crystals. Many of the horizontal joints are produced by dense concentrations of these tension fractures.

The uppermost part of the tuff contains vertical cooling joints separated by zones of sub-horizontal platy joints. Separation between the joint walls is a few centimeters to more than a meter wide. Many of the vertical cooling joints are open, forming fissures filled with non-welded, reworked ash from above. In some cases the vertical fissures are offset by horizontal fractures, with the width of the fissures varying across the horizontal breaks. This suggests that many of the horizontal fractures are small scale shear zones that accommodated horizontal slippage (Prostka, 1977). In addition to the normal vertical zonation in welding and devitrification, the Huckleberry Ridge Tuff in this area exhibits lateral zonation adjacent to the open cooling joints. The tuff on either side of the joints is commonly vitrophyric and grades outward into the devitrified tuff more typically found at this level within the ignimbrite sheet. This indicates that extension occurred after welding but before devitrification (Embree and others, 2008).

A larger-scale version of this lateral zonation is seen at the margins of the Hog Hollow depression. On either side of the depression, the walls exhibit vitrophyres several meters in width, grading laterally into devitrified Huckleberry Ridge Tuff.

Teton Dam Disaster

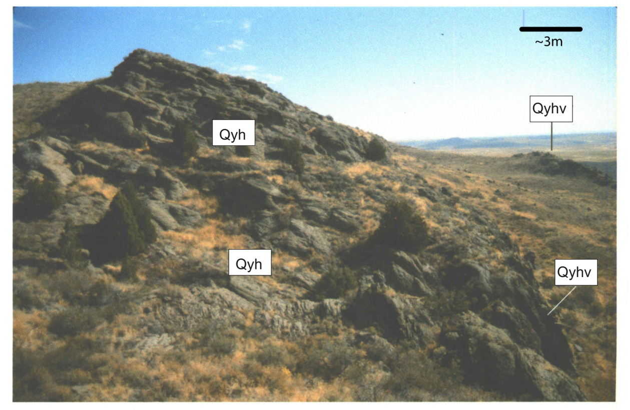
Sequence of photos taken during the failure of the 90 m high Teton Dam. These three photos were taken at 11:20a.m., and the early afternoon of June 5, 1976 (from Chadwick, 1976). Over a period of hours, piping through joints in the key trench area eroded the core material from within, undermining the north side of the dam.

The formation of open horizontal detachments and open vertical cooling joint sets within the Huckleberry Ridge Tuff contributed to the 1976 failure of the Teton Dam. During initial filling of the reservoir, flow of water through the open joint systems in the north abutment eroded the core of the earth-filled dam causing its collapse. The peak flow during this failure was roughly equivalent to that of the Mississippi River in flood stage (Elkenberry et al., 1977). Eleven people lost their lives, 25,000 were left homeless, ~ 780 km2 of land was inundated, and $1 billion in damage resulted from the failure.

Rheomorphic Structures in Huckleberry Ridge Tuff

Hog Hollow

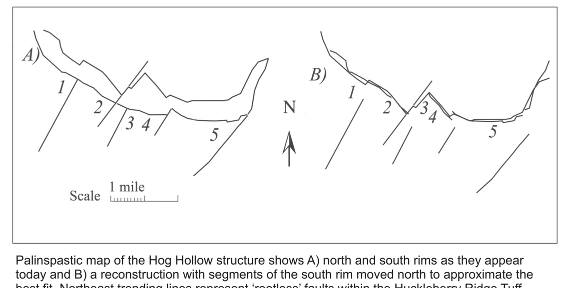
Aerial photo of the Hog Hollow and Teton Canyon area. Boundary faults, 'rootless' lateral faults, and major monoclinal and antiformal structures associated with Hog Hollow are delineated.



Monoclinal flexure on the north rim of Hog Hollow is defined by a change in the attitudes of foliation in the Huckleberry Ridge Tuff (Qyh). Foliation at the hilltop dips 20° to the south (right). Dips in the lower right corner of the photo are 80° south. The rock at the extreme right edge of the exposure is vitrophyric (Qyhv).

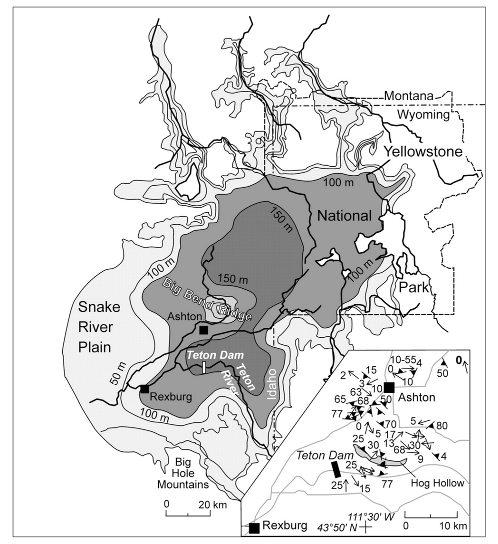
An anomalous 0.5-1.8 km wide by 12 km long arcuate depression called Hog Hollow lies ~1-5 km north of Teton Canyon. This depression has pre-Qyh sediments exposed in its floor. The north rim consists of a long monoclinal flexure and some smaller antiforms in Qyh. Erosionally resistant vitrophyre is common along both edges of the basin. Landslides are also common along both sides of the Hog Hollow depression, and are due to the incompetence of the pre-Qyh sediments.

Several northeast-trending lineaments interpreted as 'rootless lateral faults' transect Hog Hollow and extend south to Teton Canyon. These faults are 'rootless' in the sense that they involve only the Qyh and some underlying units, but probably do not extend down more than a few hundred meters. Along these lineaments, both rims of Hog Hollow have been offset from 0.3-1 km in numerous places. Between Hog Hollow, and Teton Canyon these lineaments are commonly marked by straight gullies forming tributaries of the Teton River. Vertical slickensided faces with horizontal striations can be seen in the Qyh within one of these gullies. A pair of large amplitude antiforms, exposed on opposite rims of Teton canyon, are offset by ~0.7 km along one left lateral fault.

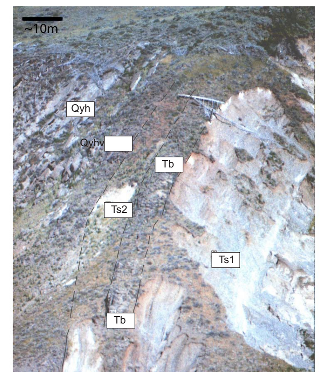


Palinspastic map of the Hog Hollow structure shows A) north and south rims as they appear today and B) a reconstruction with segments of the south rim moved north to approximate the best fit. Northeast trending lines represent 'rootless' faults within the Huckleberry Ridge Tuff.

Antiforms

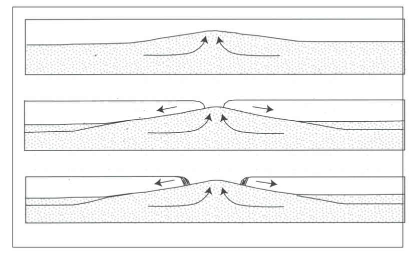


Extent and thickness of the Huckleberry Ridge Tuff member B. Inset shows fold axes with plunges and eutaxitic foliation (Geissman and others, 2010).

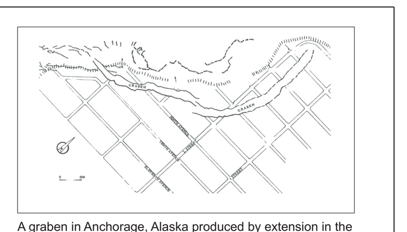


Pliocene gravels (Ts) and basalt (Tb) beneath the Huckleberry Ridge Tuff (Qyh) and vitrophyre (Qyhv) exposed in the core of an antiform in the Teton River canyon, Newdale quadrangle.

Northwest-trending overturned fold in Huckleberry Ridge Tuff. View is northwest across Teton River. Numbered localities identify paleomagnetic and/or anisotropy of magnetic susceptibility sampling sites. Vertical distance from valley floor to potato fields (subhorizontal surface) is ~100 m (from Geissman and others, 2010).



Stylized sketch showing the development of the Hog Hollow depression by diapiric uplift within the pre-Qyh sediments (stippled) and lateral spreading of the Huckleberry Ridge Tuff (white) and sediment slab above.

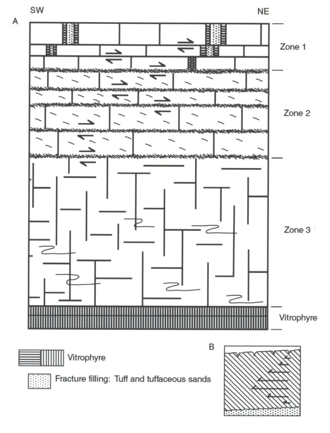


A graben in Anchorage, Alaska produced by extension in the surface layers as liquified clays beneath flowed to the NE during the 1965 Prince William Sound Earthquake (Wilson, 1967).

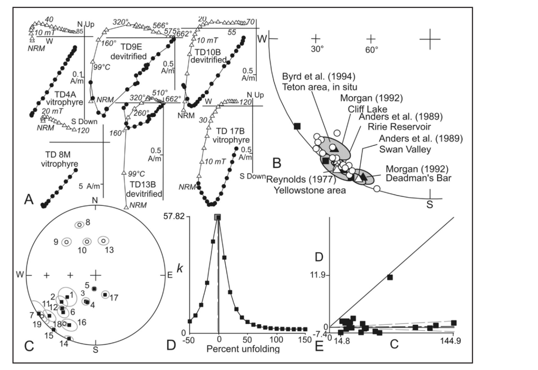
Throughout the area between Big Bend Ridge and the Teton Canyon are numerous scattered exposures of Qyh with steeply dipping foliation. In many cases these outcrops expose the basal vitrophyre and pre-Qyh sediments. The best exposures of these fold-like features are seen in Teton Canyon where large-scale antiforms were dissected by the river. Several of these antiforms have amplitudes of ~100 m and widths of ~200 m. The style of deformation ranges from broad open symmetrical antiforms to asymmetrical or even overturned structures which verge to the south. Although antiforms are abundant in the area, there is a conspicuous absence of synforms. Generally the foliation within the Qyh grades laterally from essentially horizontal into arch or dome-shaped structures. The tuff thins over the crests of antiforms, in many cases leaving only a vitrophyric zone <10 m thick. The result is that the top of the tuff along the canyon rim is essentially flat, with the base of the unit rising and falling to produce the structures.

Although the Huckleberry Ridge Tuff is the main unit in which this deformation is seen, several of the large-amplitude antiforms have exposed pre-Qyh units in their cores. These units, including sediment and basalts are concordant with the base of the tuff.

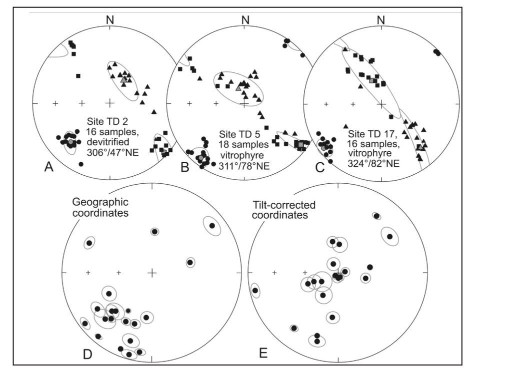
Paleomagnetic Evidence for Rapid, High-Temperature Formation of Large-Scale Rheomorphic Structures



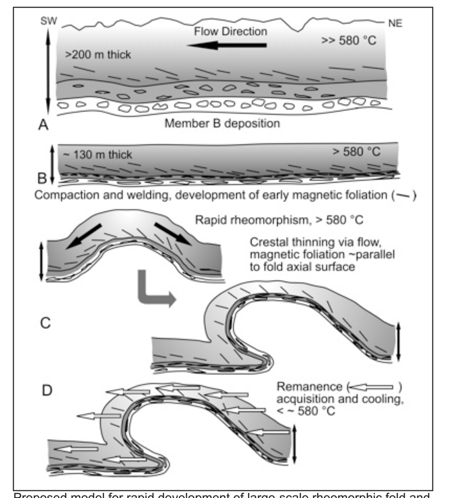
Schematic cross section of the Huckleberry Ridge Tuff in the Teton Canyon area. Secondary movement within the sheet is expressed by different behavior at different levels. The inset schematic section has vectors showing hypothetic relative rates of flow with in the unit. The schematic section below (B) has vectors showing hypothetical relative rates of flow within the unit.



Paleomagnetic data from Huckleberry Ridge Tuff (Qyh). A: Examples of alternating field and thermal demagnetization response. Squares are projections on the horizontal plane; triangles are on east-west and/or vertical projection (in situ coordinates). NRM—natural remanent magnetization. B: Equal-area projection of in situ site mean paleomagnetic data. Circles are upper hemisphere projections of site mean directions; squares are lower hemisphere projections. Triangles show results (tilt corrected) of previous studies of Qyh. C: Equal-area projection of tilt-corrected site mean paleomagnetic data. D: Plot of precision parameter (k) versus percent unfolding for 19 sites in HRT, following approach of Watson and Enkin (1993). E: Direction-correction (DC) plot (Enkin, 2003). Diagram from Geissman et al. (2010).



Anisotropy of magnetic susceptibility (AMS) (K) data from Huckleberry Ridge Tuff. A, B, C: Data from three sites showing well-developed magnetic foliation. Squares—Kmax, triangles—Kint, circles—Kmin; error ellipses are 95% confidence estimates for site mean AMS determinations. D, E: Equal-area plots of Kmin orientations (lower hemisphere) for all 19 sites (circles, with 95% confidence estimates); in situ and tilt-corrected coordinates. Diagram from Geissman et al. 2010.



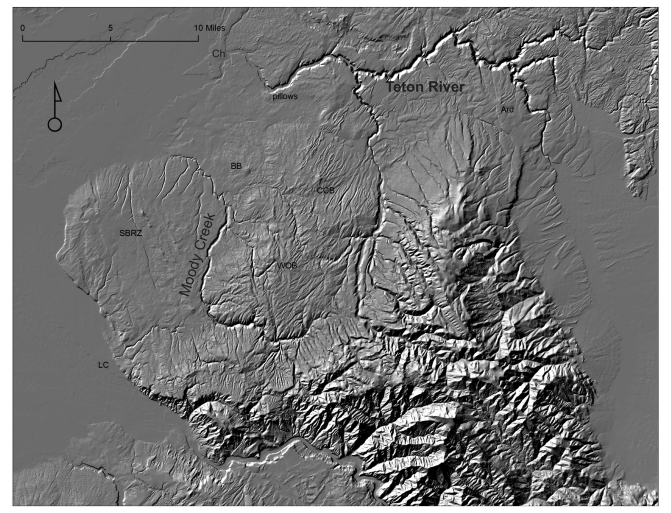
Proposed model for rapid development of large-scale rheomorphic fold and internal structures in Huckleberry Ridge Tuff near Teton Dam (Geissman et al., 2010).

Spectacular large-scale rheomorphic features in the >100-m-thick, welded member B of the upper Pliocene Huckleberry Ridge Tuff exposed in the Teton River Canyon formed above 580°C. All deformation features formed prior to Characteristic Remanent Magnetization (ChRM) acquisition. Thermal blocking of the ChRM by the tuff occurred over a short duration, likely on the order of 100–200 years, if not less. The paleomagnetic data from the tuff, in concert with field relations, demonstrate that large-scale rheomorphic features in ash-flow tuffs can develop extremely rapidly. In this case, plastic deformation occurred shortly after compaction and partial welding, but before devitrification, while the Huckleberry Ridge Tuff was still above 580°C. (Geissman and others, 2010).

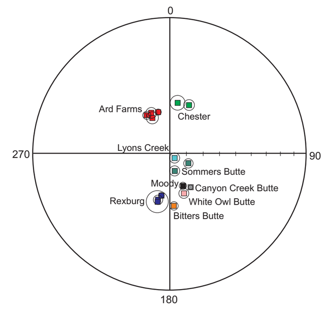
The paleomagnetic results are consistent with observed deformation of the Huckleberry Ridge Tuff including development of shear zones in the lower parts and fissures in the jointed upper parts.

The results also support the interpretation that deformation occurred after compaction and welding but prior to devitrification, when folding, localized uplift, and lateral spreading occurred during extremely rapid loading of poorly compacted water-saturated pre-Qyh sediments (Prostka and Embree, 1978; Embree and Hoggan, 1999).

Basalt Stratigraphy

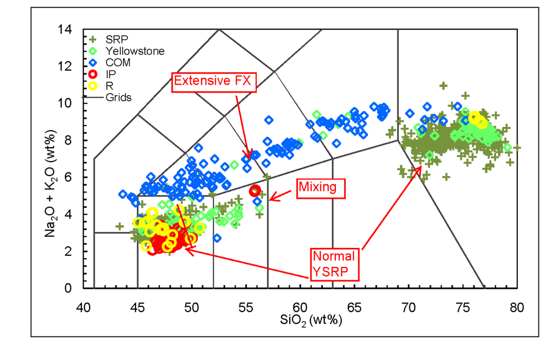


Hillshade DEM of the Rexburg Bench area showing Quaternary basalt vents and other basalt features. BB: Bitters Butte; Ard: Ard Farms Vent; CCB: Canyon Creek Butte; SBRZ: Sommers Butte Rift Zone; LC: Lyons Creek; WOB: White Owl Butte; Ch: basalt of Chester outcrops; Pillows: outcrops of pillow basalt of Moody Creek.

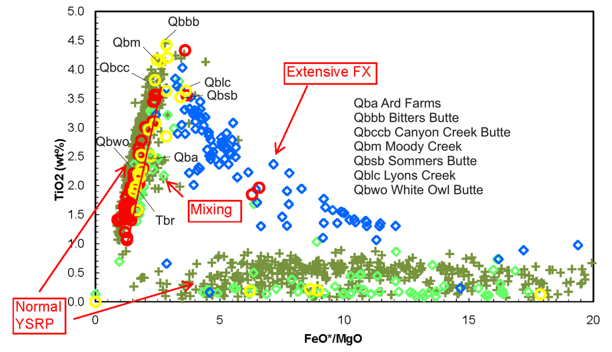


Characteristic-NRM (ChNRM) for basalts on the Rexburg Bench. Sites values are average of 6 to 8 cores. Errors are alpha-95. ChNRM isolated with AF demagnetization of 40-60 mT.

- RESULTS
- Geochemical analyses combined with paleomagnetic data permit correlation of outcrops and identification of vent locations
- Pre-Qyh basalt: basalt of Rexburg; possible correlative to Tb in cores of antiforms
- Post-Qyh basalts: erupted from isolated shields and from aligned vents along rift zone
- Basalts of Rexburg Bench mostly plot within normal YSRP petrogenic series.



Total Alkali-Silica (TAS) diagram showing relationship of Rexburg Bench basalt flows and rhyolitic rocks (yellow R) to the compositional groups of the Yellowstone-Snake River Plain (YSRP) volcanic province (red labels). COM: Craters of the Moon-Cedar Butte-blue; IP: Island Park-red. Modified from Christiansen and McCurry (2008).



Correlation of Rexburg Bench basalts (labeled yellow symbols) on the basis of TiO_2 concentrations and FeO*/MgO ratios. Diagram modified from Christiansen and McCurry (2008).

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