Badger Mountain - Supporting Information

DESCRIPTION OF MAP UNITS

SURFICIAL QUATERNARY UNITS

Qa — ALLUVIUM/GULLY FACIES (Holocene to Pleistocene) - Channel-fill debris and associated entrenched gullies on ridge slopes, and the valley fill in the Goose Ridge and Keen Road synclines; alluvium on ridges is unconsolidated poorly-sorted rock debris that is in-filled with eolian sandy silt in mid-to-lower reaches; includes remnants of older alluvium commonly capped by a petrogenic carbonate horizon; alluvium in valley-fill is composed of unconsolidated, moderately well sorted silty sand with occasional sandy gravel lenses.

Qaf — ALLUVIAL FAN DEPOSITS (Holocene) - Mainly unconsolidated, poorly sorted silty, sandy basaltic gravel; conically shaped landforms at base of the mountain; coalesce NW at Keene Road syncline.

Qc — COLLUVIUM (Holocene) - Largely unconsolidated poorly-sorted rock debris deposited through hill-slope processes; occasional rock stripes on upper backlimb of Big Badger Mountain; interstices locally infilled by eolian sandy silt; includes older colluvium on upper to mid hill slopes.

Qco — OLDER COLLUVIUM (Pleistocene) - Compact rock debris deposited by hill-slope processes; interstices locally infilled with eolian sandy silt; typically capped by pedogenic carbonate horizon, forms a wedge below lower thrust fault on Big Badger and saddle and thins out on to the Keene Road Syncline; thick units with multiple pedogenic carbonate horizons occur on limbs of Little Badger.

Qd — DUNE SANDS (Holocene) - Mainly loose moderately well-sorted, medium-to-fine sand; deposited as subdued dune landforms by eolian processes; mainly stabilized dunes; many dunes modified by agrarian and urban development.

Ql — LOESS (Holocene to Pleistocene)- Mainly massive, unconsolidated, homogeneous, moderately well-sorted fine sand to sandy silt; light gray (10YR 7/2) to very pale brown (10YR 7/3); deposited by eolian processes; contains discontinuous horizon of Mount Mazama tephra (~7 thousand years ago (Ka)) (Bacon 1983). Includes remnants of older compact very pale brown (10 YR 7/3) capped by pedogenic carbonate horizon; contains discontinuous horizon of Glacier Peak tephra couplet (~11 Ka) (Porter 1978, Mehringer et. al. 1977 and 1984).

Qls — LANDSLIDE DEPOSITS (Middle to early Late Pleistocene) - Rotational and translational debris slumps and associated debris flows consisting of loose, moderately sorted, generally unstratified, clay, silt, sand and basaltic gravel. Arrows indicate direction of movement. Mass-waste debris is several meters to ten meters deep. Slumps are associated with Ellensburg sediments within the brecciated fault zone on the upper forelimb of Big Badger Mountain. Slumps transition downslope to debris flows that partially fill preexisting gullies before spreading out on to the margin of the valley floor. Toes reaching valley floor are buried beneath Qhz and Qa/Qaf. Landslides likely initiated during or shortly after cataclysmic flooding possibly induced by hydraulic loading or seismicity. Age inferred from geomorphology and stratigraphic position. Mass wasting also occurs in the form of soil creep (Holocene) on steep loess-covered slopes; typically form terracettes with occasional shallow tension cracks and/or small slumps; creep features too limited in size to include as mapping unit.

MISSOULA CATACLYSMIC FLOOD DEPOSITS (Pleistocene) - HANFORD FORMATION

Deposits mainly from Missoula floods, but may include deposits from other Pleistocene floods.

Qhg — GRAVEL-DOMINATED FACIES - Forms a multi-lithologic sandy gravel on the lower NW flank of Goose Gap. Gravel unit is older than the youngest Pleistocene cataclysmic flood deposits in the Badger Mountain area.

Qhz — INTERBEDDED SAND- AND SILT-DOMINATED FACIES - Rhythmically and graded beds of unconsolidated silt and fine-to-coarse sand; mainly plane-laminated and ripple cross laminated; very pale brown (10YR 7/3 to pale brown (10YR 6/3); clastic dikes ubiquitous throughout facies and discontinuous Mount St. Helens Set S tephra couplet (~13 Ka) (Mul-lineaux et. al. 1978) common near top of facies.

RINGOLD FORMATION (Mio-Pliocene)

Tru — RINGOLD FORMATION (UNDIFFERENTIATED) - Formed of intercalated lenses of clay (gray, yellow, blue-green), quartzofeldspathic sand, and sandy multilithologic gravel; mainly deposited in low-energy overbank and lacustrine environments with occasional higher energy floods. Petrified wood common. Mainly quivalent to upper units of Lindsey (1995, 1996).

COLUMBIA RIVER BASALT GROUP - SADDLE MOUNTAINS BASALT (Miocene)

Tim — ICE HARBOR MEMBER - Martindale basalt flow - single flow, black to gray, weathers reddish brown; fine-to-medium grained, coarsely phyric with abundant plagioclase crystals and scattered glomerocrysts of clinopyroxene, plagioclase and olivine; entablature mostly eroded where present it's highly weathered (grussy), basal colonnade with large dense col-umns [1 to 1.2 m (3 to 4 feet) in diameter]; reversed magnetic polarity (Choiniere and Swanson 1979); K-Ar age ~8.5 million years ago (Ma) (McKee et. al. 1977).

Tem — ELEPHANT MOUNTAIN MEMBER (Undifferentiated) - Two aphyric flows; fine-to-coarse grained; abundant microphenocrysts of plagioclase; normal to transitional magnetic polarity (Rietman 1966, Choiniere and Swanson 1979, Reidel and Fecht 1981); K-Ar age ~10.5 Ma (McKee et. al. 1977).
Temw WARD GAP FLOW - Black, weathers reddish brown; upper blocky flow top, thick lower colonnade with large columns [45 to 60 cm (18 to 24 in) in diameter], thin glassy selvage flow bottom.
Teme ELEPHANT MOUNTAIN FLOW - Black, weathers dark gray to brownish gray; upper rubbly flow top breccia, dense columnar entablature, thin basal colonnade with small columns [15 to 30 cm (6 to12 in) in diameter].

Tp — POMONA MEMBER - One or more flows/flow units; black to gray black, weathers gray to locally black; fine-to-medium grained; phyric with small plagioclase phenocrysts; thin upper crude colonnade, thick hackly entablature, basal colonnade not exposed; reversed magnetic polarity (Choiniere and Swanson 1979, Reidel and others 1984); K-Ar age 12 Ma (McKee et. al. 1977) and 40Ar-39Ar 12 Ma (S.P. Reidel, Washington State Univ. unpub. data, 1991).

Te — ESQUATZEL MEMBER - Single flow; blue-black, weathers brown; fine-to-medium grained; aphyric with rare sparse phenocrysts; well developed hackly entablature , basal colonnade not exposed; normal magnetic polarity (Choiniere and Swanson 1979, Reidel and Fecht 1981).

Tu — UMATILLA MEMBER (Undifferentiated) - Single cooling unit; black, weathers yellow orange; glassy to very fine grained; sparsely phyric; thick hackly entablature and thin basal colonnade not exposed; normal magnetic polarity (Reitman 1966).

COLUMBIA RIVER BASALT GROUP - WANAPUM BASALT (Miocene)

Wanapum Basalts - Only the Roza member (Tr) crops out on Badger Mountain at the base of brecciated fault zone in the upper thrust fault on Big Badger. Other Wanapum members (Tpr - Priest Rapids Member, and Tf - Frenchman Springs Member) are not exposed, but are depicted on Badger Mountain cross sections.

Tr — ROZA MEMBER - Single flow; gray black, weathers reddish brown, fine-to-medium grained; discrete and clotted plagioclase phenocrysts; transitional to reversed polarity (Choiniere and Swanson 1979).

ELLENSBURG FORMATION (Miocene)

Tel — LEVEY INTERBED - Mainly three overbank units: a capping red (10YR 5/6) blocky sandy siltstone unit, a middle multistory unit of pale yellow (10Y 7/4) normally-graded, siltstone-sandstone beds, and a basal light gray (10YR 7/2) massive sandstone unit; thermally bake on top, pedogenically altered, and locally tuffaceous with occasional discrete tephra horizons.

Trr — RATTLESNAKE RIDGE INTERBED - Overbank sediments that commonly include a thin capping red (10R 6/6) to olive yellow (2.5Y 6/6) baked siltstone, a light gray (10YR 7/2) reworked airfall tuffite, and basal section of epiclastic and volcaniclastic siltstone-sandstone beds that are normally graded yellow (5Y 7/3) to olive yellow (2.5Y 6/6); locally well-developed paleosols (dark gray 5Y 4/1).

Tes — SELAH INTERBED* - Mainly thin massive overbank mudstone with occasional fine sand-stone stringers. The unit has been pedogentically altered. A capping tuffite commonly found throughout much of the Pasco Basin has not been observed in the map area.

Tcc — COLD CREEK INTERBED* - Mainly a thin massive mudstone that outside the map area is known to be pedogentically altered; occurs along the distal margin of the sandstone-siltstone overbank facies of an ancient fluvial system (Fecht et al. 1987).

Tmb — MABTON INTERBED* - Typically a massive mudstone that is pedogentically altered.

**Geologic units not exposed on earth surface in Preserve and vicinity; depicted on cross section(s); descriptions based on borehole logs and drill cutting descriptions.*

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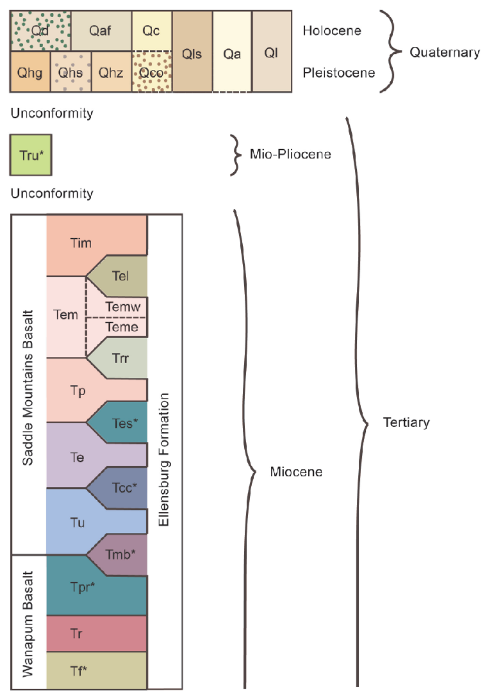
BFZ — BRECCIATED FAULT ZONE - Zone of cohesive to noncohesive fault breccia with varying bedrock clast sizes; commonly includes secondary faults, shears, shatter breccia, rotated clasts and rotated bedrock blocks; locally includes Pleistocene clastic injection dikes and secondary opaline or carbonate minerals.

OTHER CATACLYSMIC FLOOD FEATURES

Ice Rafted Debris - clastic material transported within icebergs caught up in cataclysmic flooding and then deposited as dropstones or grounded bergs melted (Bretz 1919). Occur as isolated erratics, erratic clusters, or mounds of diamicton (Fecht and Tallman 1978, Chamness 1994, Bjornstad 2014). Found below 380 m (1250 feet) elevation [maximum stand of Lake Lewis (Baker et. al. 1991)]; mainly strewn across top of Qhz on backslope of Badger Mountain and the Goose Ridge syncline, and scattered atop Qhs in the Keene Road syncline valley. Selected erratics/erratic clusters depicted on geologic map.

Clastic Dikes - Tabular vertical to sub-vertical fractures filled by fluidized injection of clastic sediments. Formed during or soon after cataclysmic flooding and possibly induced by seismicity (Fecht et al. 1999). Common features in Qhz and Qhs deposits found in the valley fill; less common in Tru, Qco and older Ql on the lower ridge slopes; occasionally present within cooling joints in underformed basalt (mainly Tim) and notably occur in rubbly basalt and Ellensburg sediments in fault zones in Goose Gap and on Little Badger. Found up to an elevation of 324 m (1062 feet).

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

BEDDING

Strike and dip of unit, dip in degrees

Overturned Bed

Horizontal Bed

Ash Horizons (Selected)

Agp - Glacier Peak Ash

Am - Mount Mazama Ash

Ash - Mount Saint Helens Ash

Erratics (Selected)

Eg - Granitic Erratic

Shatter Breccia

SB - Isolated Shatter Breccia

Badger Mountain Centennial Preserve

FOLDS

Doubly Plunging Anticline - Showing Crestline; arrowhead on crestline indicates direction of plunge

Syncline - Showing Troughline; arrowhead on troughline indicates direction of plunge

FAULTS

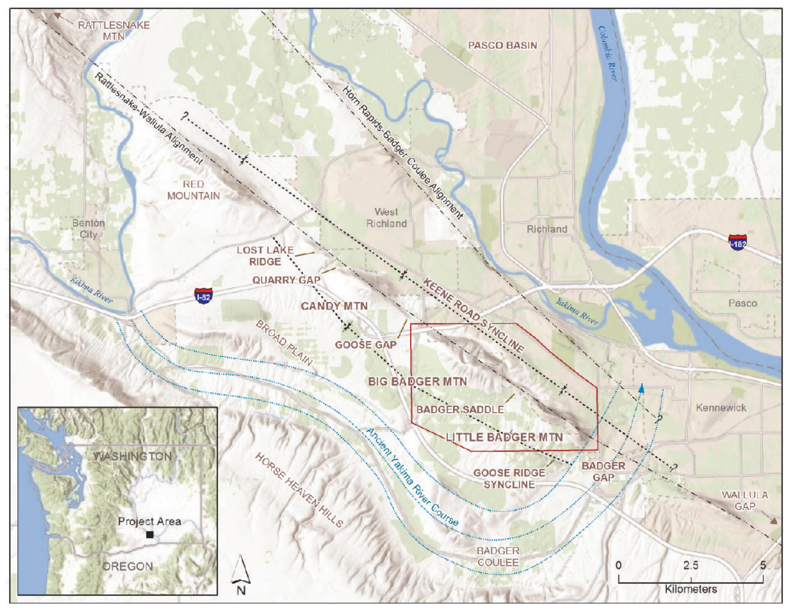
Extensional Fault - Ball and bar on downthrown side; dotted where concealed; queried where probable or unknown

Thrust Fault - Sawteeth on upper plate; dashed where inferred, dotted where concealed, queried where probable

Upper limit of brecciated fault zone

Shear Zone

LOCATION MAP



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INTRODUCTION

The geologic map of the Badger Mountain Centennial Preserve and surrounding terrain has been updated to incorporate information collected since previous published mapping. The map includes details discovered during surface mapping and from the examination of excavations created during urban development. The field investigations have resulted in new insights into the stratigraphy, structures and landforms of the Badger Mountain and the processes involved in the evolution of the ridge landscape.

The basic geologic processes involved in development of the Badger Mountain landscape include: 1) Eruption of flood basalts with quiescent periods between volcanic eruptions mainly marked by alluviation and pedogenesis; 2) Orogenic activity of ridge uplift with bedrock folding, faulting, and shearing; 3) Ridge slope denudation by gully erosion, landslide activity, and colluvial creep; 4) Scouring and subsequent sediment deposition in the lower terrain by cataclysmic ice-age floods, and; 5) Eolian deposition of a veneer of loess and local sand dunes that attest to an arid climate since the ice-age floods.

The geologic mapping was produced in cooperation with the Benton County Parks Department. The objective of the mapping project was to provide the Parks Department and visitors a basic understanding of the geology of Badger Mountain and the surrounding terrain. The nature of the geology is an important component of protecting the natural habitat of Badger Mountain since rocks and sediments have a direct influence on the native ecosystem. The characteristics and extent of rocks and sediments and associated structures and landforms are key components that control the distribution of habitat and species in the Preserve area.

FIELD INVESTIGATIONS

The field investigation phase of the Badger Mountain mapping project was conducted over decades as the authors inspected excavations in and around the mountain. The mapping project incorporates results from previous geologic investigations. Early investigations included reconnaissance resource mapping (Shedd 1925) and a regional stratigraphic and structural geology study (Laval 1956). Interest in neotectonics to support nearby nuclear facility activities resulted in numerous studies of the area (Jones and Deacon 1966, Brown 1968, Farooqui 1977, GRC 1978, Meyers/Price et. al. 1979, WWC 1981, WPPSS 1981). In 1994 the geologic map of the Badger Mountain area was revised as part of the Washington State geologic mapping project at 1:100,000 scale (Reidel and Fecht 1994).

GEOLOGIC SUMMARY

Geographic Setting - Badger Mountain is located along the SW boundary of the Pasco Basin in the southern part of the Yakima fold and thrust belt. The mountain is dominated by two nearly aligned ridges, Big Badger and Little Badger. The ridges are separated along trend by a broad low saddle. The Badger Mountain Centennial Preserve encompasses most of Big Badger and a portion of the saddle. The ridges and Preserve overlook a broad thin sediment-mantled Goose Ridge syncline to the SW and a sediment-filled valley of the Keene Road syncline to the NE. Badger Mountain terminates along the ridge trend at Goose Gap (NW) and Badger Coulee (SE).

Stratigraphy - Bedrock in the mapped area consists of basalt flows of the Miocene Saddle Mountains and Wanapum Basalts of the Columbia River Basalt Group and intercalated sediments of the Ellensburg Formation. The basalt flows and sedimentary interbeds crop out on the anticlinal ridges, in the saddle, at Goose Gap and locally in the Goose Ridge syncline. Bedrock is capped mainly by Pleistocene loess and colluvium that form a sedimentary apron from near mid ridge downslope to the base of the mountain. Gullies partially filled with alluvial debris (mainly Holocene) are entrenched into the bedrock on the side slopes of Badger Mountain as well as into the sediment cover of the Goose Ridge and Keene Road synclines. Landslide slumps are common near the upper forelimb thrust of Big Badger with several debris flows extending down slope and onto the margins of the alluvial plain. Overlying the bedrock in the Keene Road syncline and lapping on to the ridge side slopes are: 1) valley-filling fluvial and lacustrine deposits of the Mio-Pliocene Ringold Formation, 2) colluvium shed from the ridges (mainly Pleistocene), 3) deposits from Pleistocene Missoula catacylsmic floods of the Hanford Formation, and (4) local accumulations of Holocene alluvium and alluvial fan debris. The Goose Ridge syncline is mainly formed of basaltic bedrock that is mantled by fine-grained Missoula cataclysmic flood deposits. Surficial sediments and landforms in portions of the mapped area have been significantly disturbed and in places destroyed by urban and agrarian development.

Structural Geology - Badger Mountain consists of two narrow doubly-plunging, open, non-cylindrical anticlinal folds, Big Badger and Little Badger that separated by a structural saddle. The three segments have a north-vergent asymmetrical shape. The Badger Mountain structure is elongated NW-SE and is one in series of anticlinal structures that lies along the NW-SE trending Rattlesnake-Walla Walla River alignment (RAW) (Reidel et. al.

Big Badger is the larger of the two anticlinal folds. Big Badger has a steep and faulted forelimb, a relatively undeformed moderate-to-gently dipping back slope, and gently plunging limbs. Forelimb faults are dominated by thrusts that commonly extend into other Badger Mountain segments. The upper thrust fault located along the upper-central ridge forms a broad brecciated fault zone with maximum stratigraphic displacement of Roza Member (Tr) thrust over Pomona Member (Tp). The lower thrust fault is buried at the base of the ridge and forms the Badger Mountain fault of GRC (1978) The fault extends the length of Badger Mountain. The upper and lower thrusts narrow with smaller displacement as they converge toward the plunging limbs. An additional thrust occurs on the forelimb near mid ridge. The mid-ridge thrust is narrow in width with little displacement. The mid-ridge thrust truncates to the SE at a transverse tear fault and dies out to the NW.

The saddle segment forms a broad structural and topographic low between the Big Badger and the Little Badger anticlines. The saddle is faulted with a single thrust (Badger Mountain fault) as the major upper and lower thrusts of Big Badger and Little Badger converge on the forelimb of the saddle to form a single fault. The fault zone is narrow with minor displacement. The backlimb of the saddle segment slopes gently into Goose Ridge syncline with only minor bedrock warping.

Little Badger is a tight anticlinal fold that is intensely faulted. Three thrust faults have been mapped on the forelimb. The upper thrust forms a broad brecciated fault zone with moderate displacement. The faulted bedrock is highly deformed with extensive brecciation, faults, shears, and rotation including localized areas of overturned bedrock units [e.g., involving Elephant Mountain Member (Tem), Rattlesnake Ridge Interbed (Trr), and Pomona Member (Tp)]. The brecciated fault zone decreases in width and displacement down the plunging limbs. At the base of Little Badger forelimb are two thrust faults. One thrust is the continuation of the Badger Mountain fault of GRC (1978) and includes overturned bedrock units (e.g., involving Elephant Mountain Member (Tem), Levey Interbed (Tel), and Ice Harbor Member Martindale flow (Tim)] (Farooqui 1977; this study). The second basal thrust occurs in front of the Badger Mountain fault and is mainly obscured beneath sediments. The second basal thrust is interpreted as a splay of the Badger Mountain fault. On the backlimb of Little Badger, two near-vertical faults are exposed at mid ridge that trend parallel to the crestal axis. One fault displaces Tem against Qco. At the ridge crest, the bedrock is faulted, sheared, and rotated as a result of intense compressional stresses imposed between the forelimb and backlimb thrust faults that forced the ridge crest upward, possibly creating a 'pop up' structure.

Goose Gap is a structural and topographic depression at the NW terminus of Badger Mountain. The gap forms the convergence zone between the Badger Mountain and Candy Mountain doubly-plunging anticlines. The land surface through the gap forms a gentle-to-moderate dipping slope from the Goose Ridge syncline into the valley of the Keene Road syncline. Bedrock in the gap area is faulted. An upper forelimb low-angle thrust fault is exposed in an I-182 road cut. This thrust is an extension of the upper Big Badger thrust. A lower thrust fault, the Badger Mountain fault, is buried immediately east of the roadcut. A north-trending tranverse tear fault is buried west of the roadcut.

Badger Gap forms the SE terminus of Badger Mountain. The Little Badger anticline plunges into the structural and topographic low of Badger Gap. Bedrock in Badger Gap was incised by an ancestral Yakima River (prior to the river diversion to its present-day course) and subsequently widened by Pleistocene Missoula floods. Today the gap forms the mouth of Badger Coulee and is partially buried by Pleistocene flood deposits.

The Goose Ridge syncline is broad, shallow, and relatively undeformed with an axis that parallels the Badger Mountain structure. The NE limb of the syncline dips gently away from the Badger Mountain structure in a radial pattern.

The Keene Road syncline is a broad shallow topographic and structural low that formed as the Badger Mountain structure was thrust up and onto the SW-dipping limb of an anticlinal ridge located along the NW-SE trending Horn Rapids-Badger Coulee alignment (Reidel et. al. 2019). The syncline shows little evidence of deformation on the gentle SW-dipping limb with the exception of an elongated linear depression bounded by escarpments that is located along the juncture of the syncline and Badger Mountain. The landform is interpreted as tectonic and displays characteristics of a graben. The graben feature forms a narrow, laterally extensive depression that is bounded by the Badger Mountain fault to the SW and an interpreted buried extensional fault along the NE escarpment. The central depression is capped by Missoula fine-grained deposits (Qhz), alluvium (Qa), alluvial fan deposits (Qaf), loess (Ql), colluvium (Qc) and landslide deposits (Qld) are also buried within the depression. The surface sediments partially fill or completely fill portions of the graben landform.

Badger Mountain anticlinal growth since the middle Miocene was mainly created horizontal compressional stresses. The stresses resulted in crustal shortening and bedrock being thrusted up and rotated onto adjacent bedrock. Continued rotation on the tightly folded Little Badger segment resulted in more intense internal deformation manifested by (1) an additional thrust splayed out from the Badger Mountain fault and (2) the synchronized deformation on both forelimb and backlimb that potentially created a 'pop up' structure at the ridge crest. This high degree of rotational deformation was not observed in the broader more open fold of the Big Badger segment or in the low structural relief of the saddle segment. The graben at the

The emergence of the Badger Mountain anticlinal structure began prior to emplacement of the Saddle Mountains Basalt (~13 Ma) based on the thinning of basalt flows as well as interbedded sediments on to and over the structures. The anticlinal structure continued to emerge following cessation in volcanism with much of present structural relief occurring post basalt (8.5 Ma).

Faulting on Badger Mountain influenced the geometry of the anticline structure. The lower thrust fault(s) aligns along the NW-SE trending RAW and primarily influenced the anticlinal elongated shape, north vergence, and NW-SE trend. Whereas, the upper thrust faults on Big Badger and Little Badger are responsible for much of the topographic and structural relief of the ridge.

The Badger Mountain anticlinal structure is continuing to emerge, but little evidence was found for ridge growth or fault displacement since fault movement during the Pleistocene. Fault movement in the Pleistocene is associated with the emplacement of clastic dikes and cataclysmic flooding. Clastic dikes are present within several thrust fault zones on Little Badger and in Goose Gap. A landform analysis of the graben depression and bordering escarpments did not reveal definitive evidence of tectonic disruption of late Pleistocene or Holocene age sediments or associated landforms.

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