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# *Geologic map of the Pliocene Hannegan caldera, North Cascades, Washington*

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## INTRODUCTION

The 8 × 3.5 km Pliocene Hannegan caldera (Tucker, 2004; Tucker et al., 2007) lies in deeply dissected terrain of the North Cascades, 15 km south of the Washington–British Columbia border, and 25 km northeast of the Holocene Mount Baker volcano. Geologic units of the caldera were mapped at 1:24,000 scale. For a detailed discussion of the Hannegan caldera, chemical analyses, and geochronology data, see Tucker et al. (2007).

Caldera collapse occurred in two phases. The first collapse, probably trap-door style, followed eruption of the ≥900-m-thick *ignimbrite of Hannegan Peak* (map unit *Thh*) at 3.722 ± 0.020 Ma (Hildreth et al., 2003). This single cooling unit, generally welded, has an uppermost facies of non-welded ignimbrite and fine co-ignimbrite ash. No base is exposed. Eruption of the *ignimbrite of Ruth Mountain* (map unit *Thr*) led to a second collapse, likely also trap-door, as the first-phase partial ring fault propagated to the south and closed. Ruth Mountain ignimbrite, also ≥900-m thick but nonwelded, was deposited on top of the Hannegan Peak ignimbrite. The two rhyolitic (72.3%–75.2% $SiO_2$) intracaldera ash-flow tuffs have a combined volume of ~125 $km^3$ and are entirely bounded by a continuous ring fault. No ignimbrite outflow sheets are preserved. Precaldera basement rocks are schists of the Cretaceous Darrington phyllite member of the Easton Metamorphic Suite (Tabor et al., 2003; map unit *Ked*) and Tertiary arc plutons of the Chilliwack composite batholith (Tabor et al., 2003). Wall-rock breccias are intercalated as lenses and isolated megabreccia blocks in both ignimbrites. Volcaniclastic sedimentary rocks, nowhere more than 30 m thick, locally separate the two ignimbrites. Rhyolite intruded the ring fault and caldera fill. One of these, the *rhyolite of Hells Gorge* (map unit *rhg*), yielded a $^{40}Ar/^{39}Ar$ age of 3.72 ± 0.34 Ma. Dacite-andesite domes and lava flows followed. The *andesite lava of Chilliwack Pass* (map unit *acp*) yielded a $^{40}Ar/^{39}Ar$ age of 2.96 ± 0.20 Ma. Nearly all of the intracaldera units are cut by generally northwest-to-northeast–striking dikes, which have compositions ranging from basaltic andesite to dacite. Only representatives of the hundreds of dikes observed are shown on the geologic map.

Two plutons intruded the intracaldera fill and adjoining basement in the southwest quadrant of the caldera. First described by Tabor et al. (2003), these are the *quartz diorite of Icy Peak* (map unit *Tcid*) and the *granite of Nooksack Cirque* (map unit *Tcnm*). Zircons from these plutons yielded $^{206}Pb/^{238}U$ ages of 3.42 ± 0.1 Ma and 3.36 ± 0.2 Ma, respectively. The plutons are now exposed on high, glacially sculpted peaks within the caldera. Based on the medium grained texture of these plutons, it is estimated that at least 1 km of the intracaldera fill, including some of the two plutons, has been stripped. This estimate does not include the 1000 m of relief imposed by erosion on the modern landscape surrounding Hannegan caldera.

## DESCRIPTION OF MAP UNITS

Surficial units were generally not mapped, although an extensive cover of talus, glacial deposits and alluvium is present. Vegetation, ranging from old growth coniferous forests to subalpine meadows, covers much of the map area.

Major element geochemical analyses were obtained by X-ray fluorescence (XRF). Data tables for geochemistry and age determinations are in Tucker et al. (2007). Yellow stars indicate locations of dated samples on the map. Plateau ages are given when $^{40}Ar/^{39}Ar$ ages are stated.

### Surficial Deposits (Quaternary)

Ql **Landslide deposit—**prominent forested deposit in the Chilliwack River at the mouth of Copper Creek.

Tucker, D.S., 2006, Geologic map of the Pliocene Hannegan caldera, North Cascades, Washington: Geological Society of America Digital map and Chart Series 3 (accompanying text), 3 p., doi: 10.1130/2006.DMCH003.TXT. 

**Postcaldera igneous rocks (Pliocene)**

acp **Andesite lava of Chilliwack Pass**—At least three flow-banded, hornblende-bearing, two-pyroxene andesite lava flows (62.3% $SiO_2$) on the ridge west of Chilliwack Pass. The flows dip very gently to the northeast. No vent is recognized. Sample HC 88 from the center of the stack yielded a $^{40}Ar/^{39}Ar$ age of 2.96 ± 0.20 Ma. A dike that cuts all the way to the top of the lava exposure indicates that later eruptive products or other overlying intracaldera fill has been stripped.

Tcnm **Quartz monzonite and granite of Nooksack Cirque—** (Tabor et al., 2003) Equigranular, medium-grained (2 mm), pale pink granite and quartz monzonite (67.9% $SiO_2$) intruded intracaldera and basement rocks on the walls of Nooksack Cirque. Dikes intrude the Icy Peak pluton. K-feldspar is subequal in abundance to plagioclase; quartz makes up 14 vol%. Mafic phases are uralitic hornblende, biotite, and sparse clinopyroxene. Zircon separates yielded a $^{206}Pb/^{238}U$ age of 3.36 ± 0.2 Ma; biotite from the same sample gave a $^{40}Ar/^{39}Ar$ age of 3.164 ± 0.074 Ma

Tcid **Quartz diorite and quartz monzodiorite of Icy Peak—** (Tabor et al., 2003) Medium grained (2–3 mm), plagioclase and potassium feldspar-porphyritic, biotite and clinopyroxene-bearing quartz monzonite, granite, and subordinate granodiorite. This pluton (59.9% $SiO_2$) intrudes intracaldera and basement rocks in the southwest corner of the caldera. Epidote-filled miarolitic cavities (2–10 cm) and swarms of 2–10 cm rounded, fine-grained pyroxene-plagioclase enclaves were noted on the ridge near Ruth Mountain. Zircon separates yielded a $^{206}Pb/^{238}U$ age of 3.42 ± 0.1 Ma; biotite from the same sample gave a $^{40}Ar/^{39}Ar$ age of 2.96 ± 0.16 Ma.

rdr **Rhyodacite of Ruth Mountain—**Hornblende-bearing (<1%), plagioclase-porphyritic (10%), fine-grained gray rhyodacite (68.0% $SiO_2$) intrusion cutting ignimbrite on the southwest shoulder of Ruth Mountain. This sizable intrusive pod is ~500 m across and is ≥250 m thick. This unit is cut by dikes of Icy Peak diorite but is chemically nearly identical to Nooksack Cirque quartz monzonite.

rhg **Rhyolite of Hells Gorge—**Plagioclase-porphyritic (11 vol%), hornblende (3 vol%) and sparse biotite-bearing, glassy, flow-banded rhyolite (75.5% $SiO_2$) pod intruding Hannegan Peak ignimbrite. Contacts are sharp and glassy; dikes radiate outward into the ignimbrite. Units *Thh* and *rhg* are chemically nearly indistinguishable. Biotite gave a $^{40}Ar/^{39}Ar$ correlation age of 3.70 ± 0.38 Ma. The plateau age, 3.95 ± 0.30 Ma, although within error of a reasonable value given the stratigraphic position, is invalid due to excess Ar in the sample.

acd **Andesite of Cassiope Dome—**Plagioclase-porphyritic (10 vol%), two-pyroxene, glassy, nonvesicular andesite (59.2% $SiO_2$) dome forms the crest of "Cassiope Dome." The sediments (map unit *Ths*) interbedded between the two ignimbrites appear to be displaced outward by the intrusion of this dome. In places, jigsaw-jointed breccia veneers the upper surface of this unit. Plagioclase held too little K to give a meaningful $^{40}Ar/^{39}Ar$ date; ages obtained were 3.4 ± 1.5 and 2.8 ± 1.1 Ma.

**Intracaldera Ash Flow Tuffs, Intercalated Breccias, and Interbedded Sedimentary Rocks (Pliocene)**

Thr **Ignimbrite of Ruth Mountain—**Poorly sorted, massive, lithic-rich, rhyolite intracaldera ash-flow tuff, over 900 m thick. Whole rock XRF analysis of pumice gave 72.3% $SiO_2$. This value may be inflated due to pervasive propylitic alteration. The matrix is devitrified and pale green to gray. The tuff was indurated by groundwater and hydrothermal fluids. The crystal fraction, generally ≤2 vol%, is broken plagioclase, K-feldspar, and rare hornblende. Lapilli pumice clasts locally compose as much as 18 vol% and consist of ~16 vol% phenocrysts (plagioclase >> orthopyroxene > k-feldspar ≈hornblende). Wall-rock breccia lenses and megaclasts are abundant. Dozens of andesite to rhyodacite dikes intrude the tuff, though none are known to extend beyond the caldera structural margin. Alteration precluded dating of samples.

Ths **Sedimentary rocks—**Laminated to thin-bedded ashy shale, fine-to-medium-grained sandstone, and pebble conglomerate (pumiceous and lithic clasts). Colors range from pale gray to very pale green and tan. These rocks were probably deposited in one or more lakes developed in local depressions on the surface of the Hannegan Peak ignimbrite. The two surviving exposures have a maximum observed thickness of 30 m; mud cracks in some shales suggest shallow water. Beds dip 28–48° away from the intrusive Cassiope dome. Both outcrops are intruded by dikes and sills.

Thh **Ignimbrite of Hannegan Peak—**Poorly sorted, massive, lithic-rich, rhyolite intracaldera ash-flow tuff, at least 900 m thick, with no base exposed. Whole-rock analysis of nearly pure vitrophyre gave 74.3%–75.2% $SiO_2$. The tuff is generally welded and rich in fiamme, with the exception of nonwelded, devitrified and altered, crystal- and lithic-poor white tuff at the top of the unit, probably deposited from coignimbrite ash clouds. The matrix is devitrified and purple to tan. The crystal fraction, ~4 vol%, is composed of broken plagioclase > K-feldspar > quartz ≥ orthopyroxene ≥ opaques ± biotite. Pumice clasts (5–20 vol%) consist of sparse plagioclase, K-feldspar and quartz phenocrysts. Wall-rock lithic fraction varies from >>40 vol% near caldera walls to < 10 vol% away from the walls. Clast-supported breccia forms thick lenses near caldera walls. Biotite gave a $^{40}Ar/^{39}Ar$ age of 3.722 ± 0.020 Ma (Hildreth et al., 2003). As many as 100 basaltic andesite to rhyodacite dikes intrude the tuff. None is known to extend beyond the caldera structural margin.

Thb **Caldera-collapse breccia—**Lenses of angular, largely clast-supported, monolithologic breccia and megablocks intercalated in intracaldera ignimbrite, derived from avalanching of oversteepened caldera walls during caldera subsidence. Clast sizes range from a few mm to hundreds of meters. Subdivided into:
Δc Breccia, derived from Chilliwack batholith
Δmm Breccia, derived from Darrington phyllite

Δv Breccia, derived from precaldera volcanic rocks
Δu Breccia, undifferentiated

**Precaldera Basement Rocks**

Tc **Rocks of the Chilliwack composite batholith (Oligocene to Pliocene)—**Plutons with compositions from gabbro to alaskite. Plutons adjacent to Hannegan volcanic rocks are subdivided and labeled on the map as described in Tabor et al. (2003).

Ked **Darrington phyllite of the Easton Metamorphic Suite (Jura-Cretaceous)—**Muscovite-chlorite-albite-quartz schist facies of metamorphosed marine protolith (Tabor et al., 2003).

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