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# CLARON BASIN PROVENANCE SHIFT FROM SEVIER-LARAMIDE COMPRESSION TO BASIN AND RANGE EXTENSION—DETRITAL ZIRCON GEOCHRONOLOGY FROM THE EOCENE-OLIGOCENE BRIAN HEAD FORMATION, UTAH

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Cover

Volcaniclastic sandstone and mudstone of the Eocene Brian Head Formation at the south end of the Sevier Plateau. Dixie National Forest, Garfield County, Utah.



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# Claron Basin Provenance Shift from Sevier-Laramide Compression to Basin and Range Extension—Detrital Zircon Geochronology from the Eocene-Oligocene Brian Head Formation, Utah

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## ABSTRACT

The Eocene-Oligocene Brian Head Formation is the basal volcanic unit throughout much of the southern Marysvale volcanic field but rests atop Sevier-Laramide synorogenic strata of the Claron foreland basin in southern Utah. The Brian Head Formation reaches 300 m in thickness and consists of light-colored volcaniclastic sandstone, siltstone, mudstone, and minor conglomerate and airfall tuff; in northern exposures, the upper part locally contains a volcanic section of lava flows, ash-flow tuff, and volcanic mudflow breccia. These rocks were deposited in a slowly aggrading fluvial to lacustrine depositional environment distal to the Indian Peak caldera complex to the west. We sampled three volcaniclastic sandstone units near the top of the formation, specifically near Haycock Mountain and along the southern and western flanks of the Sevier Plateau near Casto Butte and Blind Spring Mountain. The sandstone beds are compositionally and texturally immature and classify as lithic and arkosic wacke. U-Pb geochronological data for samples from the three sites were obtained on zircon by inductively coupled plasma mass spectrometry (ICP-MS) at the University of Arizona Laserchron Center. A total of 370 zircon crystals were analyzed. Most zircons were pale, translucent, and euhedral. The detrital zircon age spectra of the three sites are statistically indistinguishable. Each sample contained greater than 80% Paleogene zircons and had prominent age peaks of about 34.5 Ma. We interpret that the maximum depositional age is about 33.4 Ma. Older zircons range from Mesozoic to Archean in age. We suggest that the Brian Head Formation was sourced from the Indian Peak caldera and its environs, which are greater than 150 km to the west. Thus, Brian Head deposition in the Claron basin represents the transition from a Sevier-Laramide foreland basin characterized by the synorogenic Claron Formation to a system dominated by more distally derived sediments from the Indian Peak caldera complex, which is probably the most prominent eruptive center on the Nevadaplano uplift.

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## INTRODUCTION

The tectonic regime of the North American Cordillera transitioned from Mesozoic-Paleogene Sevier-Laramide crustal shortening to Paleogene-Neogene crustal extension accompanied by the "great ignimbrite flare-up." The conventional view is that Mesozoic crustal thickening in the Sevier-Laramide belt produced the Nevadaplano uplift, a high plateau in the region that is now the Great Basin (DeCelles, 2004; Lund Snee and Miller, 2022). However, there is disagreement regarding the timing of the Nevadaplano uplift, the nature of its topography, its maximum elevation, and its time and duration of collapse (Parsons et al., 1994; Best et al., 2009; Mix et al., 2011; Cassel et al., 2012; Chamberlain et al., 2012; Lee et al., 2017; Bahadori et al., 2018).

Based on the configuration of regional Cenozoic ash-flow deposits filling broad paleovalleys (Best et al., 2013; Henry and John, 2013; Biek et al., 2019), a north-trending Eocene drainage divide passed through central Nevada in the Sevier-Laramide hinterland, east of the Mesozoic arc and west of the foreland fold and thrust belt (Lund Snee et al., 2016, 2022). The Claron basin is a Sevier-Laramide foreland basin that subsided during Eocene time, accumulating more than 400 m of synorogenic strata of the Paleocene-Eocene Claron Formation (Eaton, 1995). The Marysvale volcanic field consists of calc-alkaline and bimodal volcanic rocks and their intrusive equivalents resulting in thick successions of volcaniclastic strata (Cunningham and Steven, 1979; Rowley et al., 1979, 1994, 2005, 2019, 2020; Cunningham et al., 1998, 2007; Figure 1). The field covers parts of the Colorado Plateau and Basin and Range physiographic provinces. The main activity occurred during the Oligocene and early Miocene, from about 32 to 14 Ma (Cunningham et al., 1998), which is partly coeval with Basin and Range extension that began here at about 20 Ma. The Eocene-Oligocene Brian Head Formation is the oldest volcanogenic stratigraphic unit in the southern Marysvale volcanic field and the youngest unit in the Laramide Claron basin (Davis et al., 2009). The Marysvale volcanic field includes a complex array of locally derived volcanic and volcaniclastic rocks that intertongue with volcanic rocks sourced from calderas in the Basin and Range physiographic province. Isotopic dating is one of the best tools for understanding the resulting complex stratigraphic succession (Best et al., 2013).

Here we present detrital zircon U-Pb data from three sandstone units in the uppermost Brian Head Formation (Oligocene). Our goal is to determine the age and provenance of these rocks to further understand the development of the Marysvale volcanic field and the coeval transition from terrestrial sedimentation in a Laramide foreland basin to volcaniclastic sedimentation. This transition corresponds to the collapse of the Sevier fold and thrust belt, as Claron basin sedimentation shifted from recycling of Paleozoic-Precambrian strata to new source areas dominated in a new volcanic highland that developed in Nevada more than 150 km to the west (Dickinson and Gehrels, 2003, Dickinson and Gehrels, 2009; Best et al., 2013; Biek et al., 2019; Foreman et al., 2022; Malone et al., 2022).

## BACKGROUND

The Paleogene Claron Formation, which comprises the lower stratigraphic succession of the Claron basin, is notable for its vivid pink, orange, and white mudstone, limestone, sandstone, and conglomerate seen in Bryce Canyon National Park and Cedar Breaks National Monument (Biek et al., 2019, 2024). These strata were deposited in fluvial and lacustrine environments and were shed from the Sevier-Laramide fold and thrust belt to the west and south. The Claron Formation is mostly flat lying, and unconformably overlies deformed Cretaceous strata. A poorly understood conglomerate at Boat Mesa in Bryce Canyon National Park (as much as 30 m thick) rests in slight unconformity above the Claron Formation (Biek et al., 2019; Cull et al., 2024).

The Brian Head Formation rests unconformably above the conglomerate at Boat Mesa, which is notably devoid of volcanic clasts. Thus, the Brian Head reflects the first volcanic influx into the Claron basin during latest Eocene-Oligocene time. It also reflects the first volcanic-sourced strata in the Marysvale volcanic field. Gregory (1944) first named the Brian Head Formation for the light-colored tuffaceous and volcanic rocks that

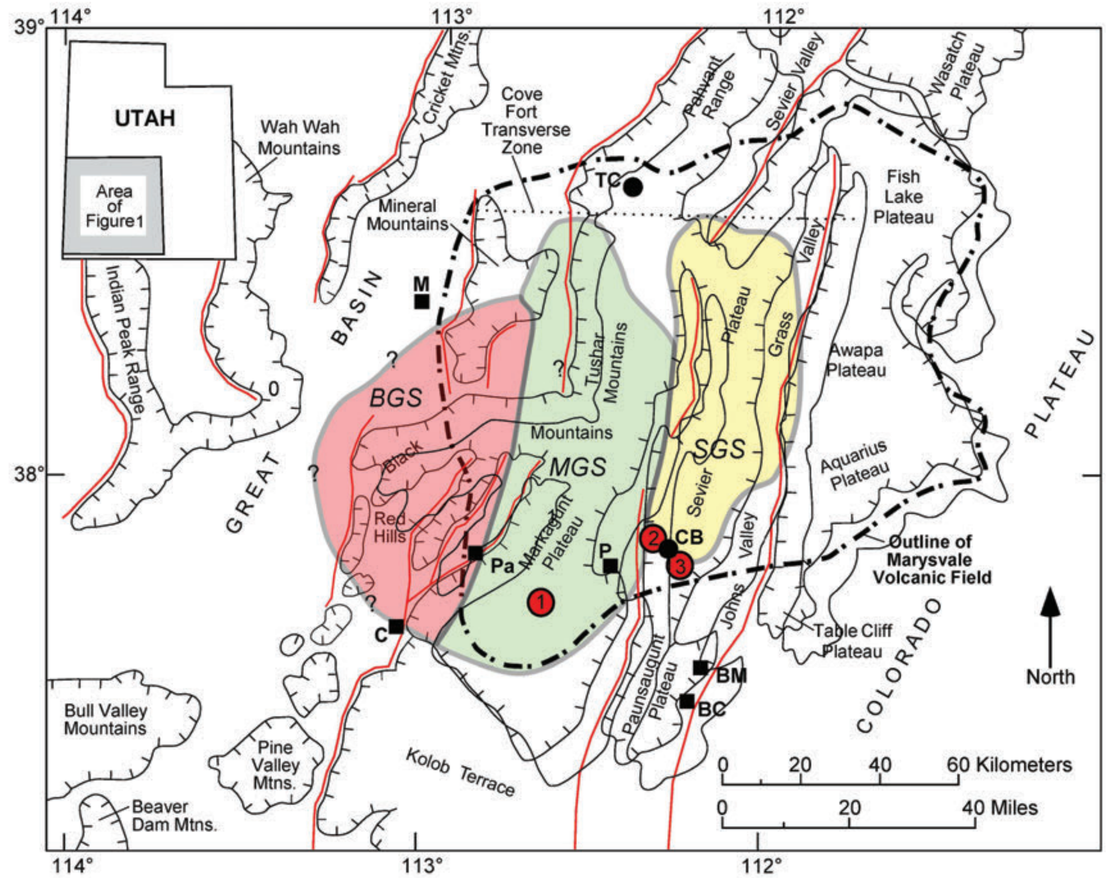


Figure 1. Map of the Marysvale volcanic field showing the location of the three gravity slides. Hachures enclose the various mountain ranges in the regions. Red lines = Tertiary normal faults, BGS = Black Mountains gravity slide, MGS = Markagunt gravity slide, SGS = Sevier gravity slide. Large black dots show central part of calderas (CB = Casto Butte, TC = Three Creeks). BC = Bryce Canyon, BM = Boat Mesa, C = Cedar City, M = Milford, P = Panguitch, Pa = Parowan. Modified from Rowley et al. (1994) and Biek et al. (2019). Sample locations are indicated by the red dots: 1 = Haycock Mountain, 2 = Blind Spring Mountain, 3 = Casto Butte. We collected the Casto Butte and Blind Spring Mountain samples in the autochthonous lower plate of the Sevier gravity slide. We collected the Haycock Mountain sample from the allocthonous upper plate of the Markagunt gravity slide.

occur at the base of the Marysvale volcanic field. The Brian Head name was later abandoned because of erroneous correlations, inconsistent boundary definitions, and the designation of new units such as the Bear Valley Formation (Anderson, 1971; Anderson and Rowley, 1975). However, the name was later reinstated to indicate rocks between the Claron Formation and Needles Range Group (Anderson, 1993; Sable and Maldonado, 1997; Biek, et al., in press). The type section is a poorly exposed, 150-m-thick section near the North View overlook at Cedar Breaks National Monument (Brian Head is a prominent peak about 3 km to the north), where a thin, 35.77 ± 0.28 Ma ash bed in the lower Brian Head Formation overlies the conglomerate at Boat Mesa (Biek et al., 2019, in press). This is similar to other isotopic ages for ash beds in the Brian Head Formation, which are late Eocene to early Oligocene in age, ranging from about 37 to 33 Ma (Biek et al., 2019).

The Brian Head Formation consists of light-colored, poorly exposed volcaniclastic mudstone, siltstone, silty sandstone, sandstone, volcanic ash, micritic limestone, and minor conglomerate. Quartzite clasts are abundant in many conglomerate layers. These facies were deposited in low-relief fluvial, floodplain, and lacustrine environments rich in volcanic ash (Sable and Maldonado, 1997). At the southern end of the Sevier Plateau, the Brian Head is well exposed and is about 150 m thick. Here it rests disconformably over the conglomerate at Boat Mesa, and is overlain in turn by allochthonous volcanic rocks of the Sevier gravity slide (SGS), described below. The lower Brian Head consists of evenly stratified variegated mudstone, siltstone, and sandstone. The upper Brian Head is coarser grained, and consists of lithic wacke and arenite, conglomerate, and some limestone.

The southern part of the Marysvale volcanic field experienced three sequential mega-scale collapse events referred to collectively as the Marysvale gravity slide complex (MGSC) (Figure 1). The MGSC comprises, from east to west, the about 25 Ma Sevier (SGS), about 23 Ma Markagunt (MGS), and about 21 Ma Black Mountains (BGS) gravity slides. Each is differentiated by geological mapping and isotopic dating of deformed and undeformed volcanic rocks, which indicate gravitational collapse occurred during the growth of the Marysvale volcanic field from the late Oligocene to early Miocene (Hacker et al., 2014; Biek et al., 2019, 2022; Mayback et al., 2022; Braunagel et al., 2023, 2025; Holliday et al., 2022; Rivera et al., 2025; Figures 2 through 4). The uppermost Brian Head Formation was deformed by the emplacement of the SGS, some of it being incorporated into the slide basal layer (Biek, et al., 2019; Braunagel et al., 2025).

## METHODOLOGY

We collected three samples of Brian Head Formation sandstone from different localities across the MGSC. We collected one sample north of Haycock Mountain (37.743205° -112.589376°) in the upper (i.e., allochthonous) plate of the MGS. We collected two samples of autochthonous (uppermost lower plate) Brian Head sandstone in the lower plate of the SGS. We collected one of these two samples east of Blind Spring Mountain (37.853823° -112.317677°) and the other from east of Casto Butte (37.806674°-112.202501°). For the SGS lower plate Casto and Blind Spring samples, the uppermost Brian Head sandstone was collected. For the MGS upper plate Haycock sample, the collection horizon is less certain, but probably near the top of the formation.

U-Pb geochronologic analyses were conducted by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) at the Arizona LaserChron Center. Please refer to the Appendix (Element2) methodology at www.laserchron.org for the details of our analytical techniques. These U-Pb geochronology methods also have been described by Gehrels et al. (2008), Gehrels and Pecha (2014), and Sundell et al. (2021). The details of the zircon U-Pb data and analytical methodology are also provided in the supplementary files. The ages are presented as a probability density plot using Isoplot (Ludwig, 2008). Ranked age diagrams display the weighted mean (weighted according to the square of the internal uncertainties), its internal uncertainty, external systematic uncertainty, final age uncertainty, and mean squared weighted deviation (MSWD). Figure 5 shows the maximum depositional ages (MDAs) for the three Brian Head Formation samples, probability density plots for the Tertiary zircon fractions, and a combined plot for Precambrian zircon ages (n = 82). The maximum depositional age (MDA) was calculated by taking the weighted mean average of the youngest zircon populations (e.g., Malone et al., 2016a).

## RESULTS

A total of 370 zircons were analyzed among the Blind Springs Mountain, Castro Butte, and Haycock Mountain samples. Most zircons were pale, translucent, and euhedral. For the Blind Spring Mountain sample 122 zircons were analyzed, ranging in age from 32880 to 3.8 Ma. All but 25 are Paleogene in age. The principal age peak for Paleogene zircons in this sample is 34.81 Ma, and the maximum depositional age is 34.28 ± 0.16 Ma. For the Casto Butte sample, 125 zircons were analyzed, ranging in age from 1840 to 30.8 Ma. All but 15 are Paleogene in age, and the principal Paleogene age peak is 34.20 Ma. The maximum depositional age is 33.40 ± 0.19 Ma. For the Haycock Mountain sample, 123 zircons were analyzed, ranging from 2996 to 32.6 Ma. All but 17 were Paleogene in age. The principal age

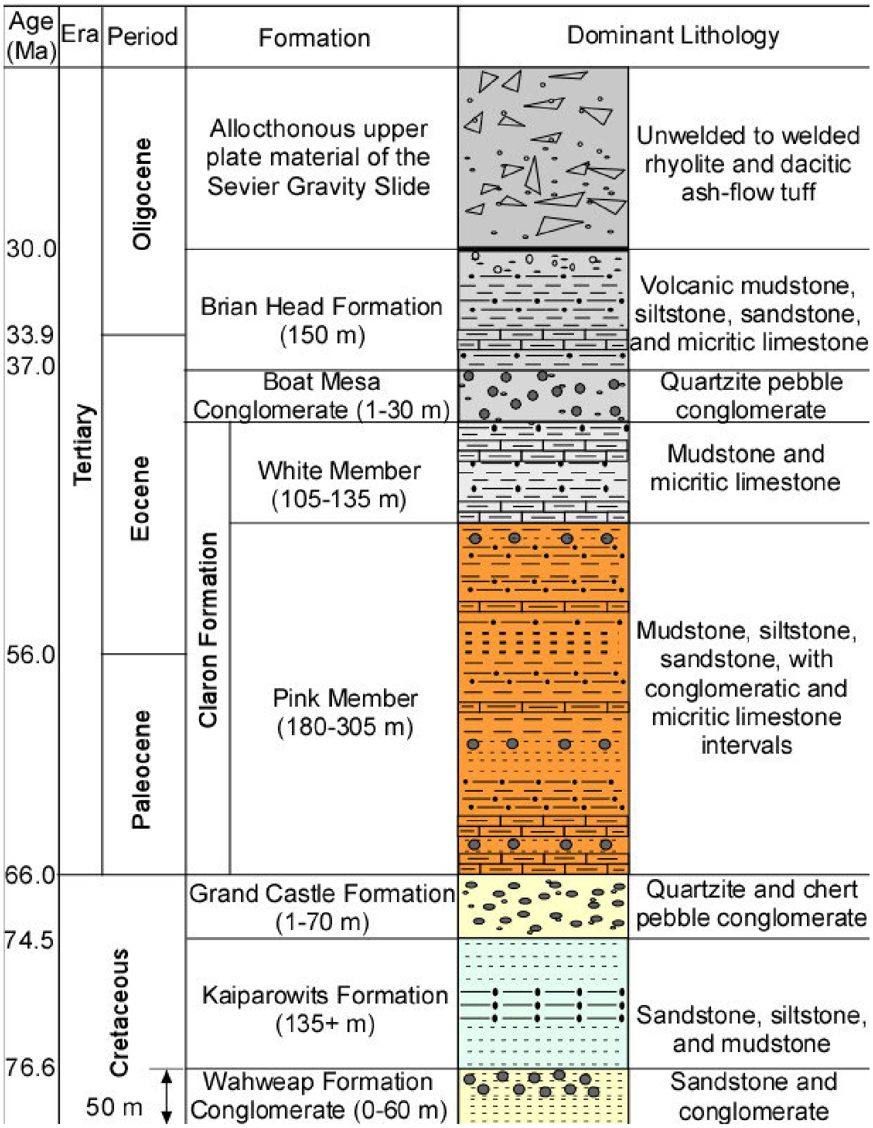


Figure 2. Stratigraphic column of principal rocks associated with the Markagunt and Sevier gravity slides modified from Biek et al. (2019). The Claron Formation rests beneath the Oligocene and Miocene volcanic rocks. The Brian Head Formation is principally in the lower plate of the Sevier gravity slide at the top of the former land surface. It is in both the upper and lower plates of the Markagunt gravity slide.

peak for Paleogene zircons is 34.28 Ma. The maximum depositional age is 33.49 ± 0.12 Ma. We combined the Precambrian-Paleozoic (pre-volcanic and pre-Sevier Laramide) zircons from the three samples (n = 50). The most prominent age peaks are 2874 and 1104 Ma, with the spectrum ranging from 2996 to 376 Ma.

## DISCUSSION

Radio-isotopic dating using multiple systems constrains the age of the Brian Head Formation from about 38 to 33 Ma (Maldonado and Moore, 1995; Davis et al., 2009; Biek et al., 2019). Our MDA of about 33.4 Ma fits well in this framework, with Brian Head sedimentation concluding after this time. The Paleogene zircons were likely derived from the Indian Peak caldera complex, which was active from 36 to 29 Ma (Best et al., 1989). Unfortunately, the available geochronology for units associated with the Indian Peak caldera is insufficient to reveal a single eruptive event at this time. As more than 80% of these detrital zircon ages are early Oligocene, and the Indian Peak caldera complex is the nearest to the Claron basin, we interpret that Brian Head sediment derived from there was transferred east greater than 150 km to the Claron basin through a variety of fluvial, eolian, and eruptive processes (Figure 6).

The Paleozoic-Precambrian zircons were likely de-

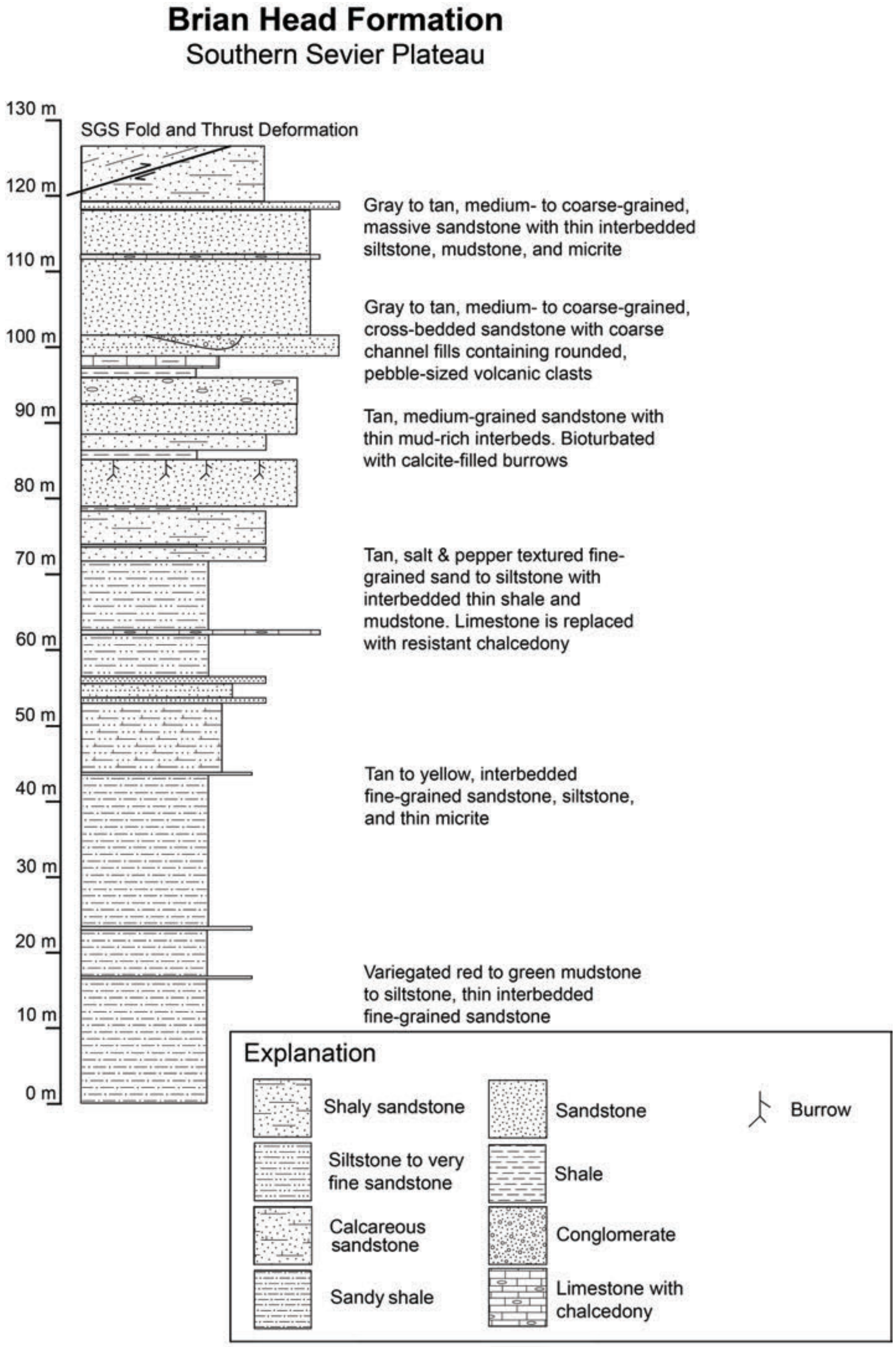


Figure 3. Stratigraphic column of the Brian Head Formation at the base of Casto Butte. Here the Brian Head is well exposed and approximately 125 m thick. The Brian Head Formation here rests disconformably over the Claron Formation, and it is overlain by allochthonous volcanic rocks of the Sevier gravity slide (SGS). The lower Brian Head consists of evenly stratified variegated mudstone, siltstone, and sandstone. The upper Brian Head is coarser grained, and consists of lithic wacke and arenite, conglomerate, and some limestone. The uppermost Brian Head was deformed by the emplacement of the SGS, some of it being incorporated into the slide basal layer (Mayback et al., 2022; Braunagel et al., 2025). We collected samples for the lower plate Casto and Blind Springs, and the uppermost Brian Head sandstone. For the upper plate Haycock sample, the collection horizon is uncertain.

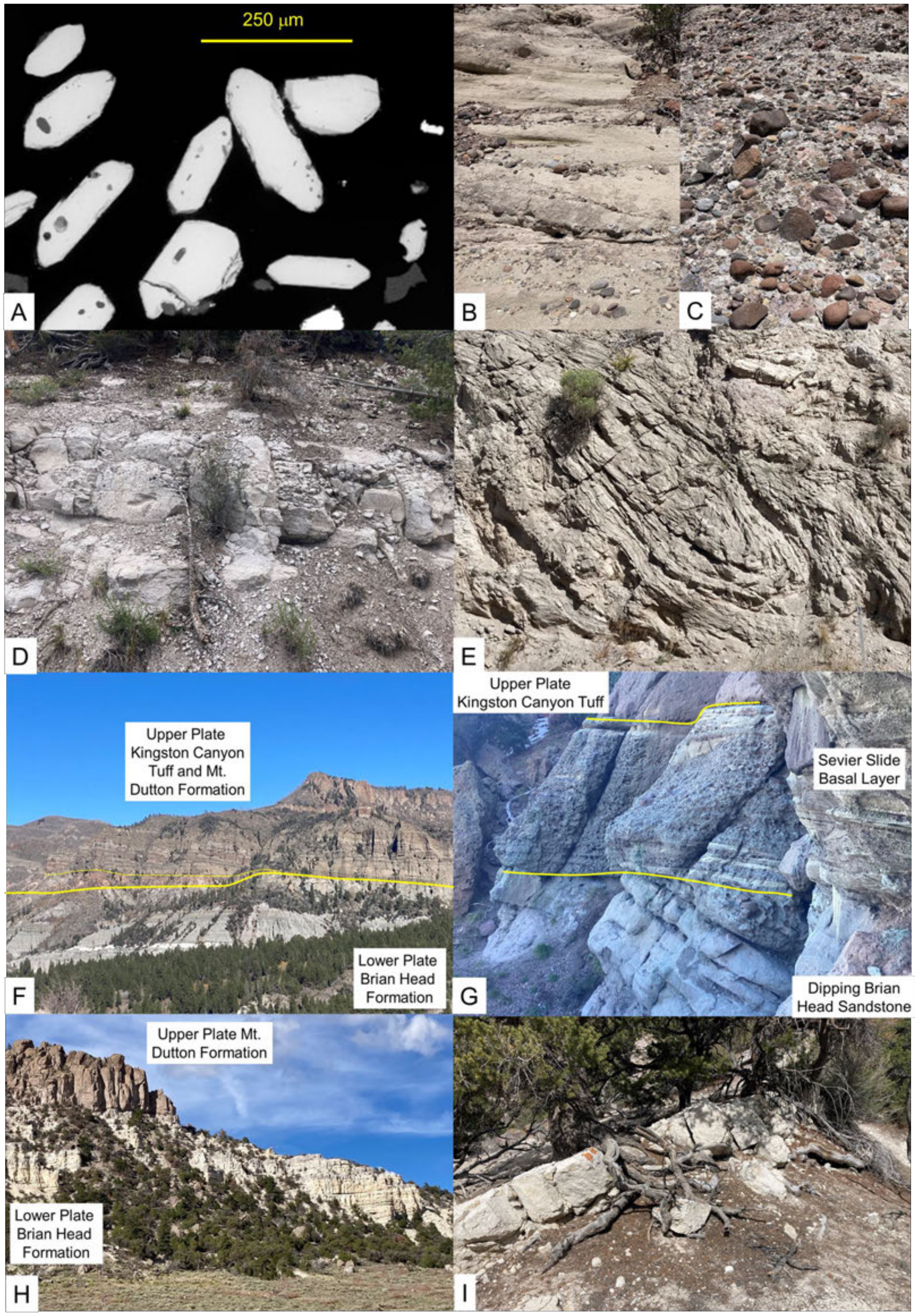


Figure 4. (A) Scanning electron microscope image of Brian Head zircons. (B) Field photograph of interbedded upper Brian Head sandstone and conglomerate. (C) Polymict cobble-boulder conglomerate. (D) Haycock Mountain sampling locality. (E) Barrel fold (Craddock et al., 2015) in allochthonous Brian Head sandstone near Haycock Mountain. (F) East looking view of the Sevier gravity slide upper and lower plates from Blind Spring Mountain (G) Blind Spring Mountain sampling locality. (H) Sevier gravity slide exposure east of Casto Butte. (I) Casto Butte sampling locality.

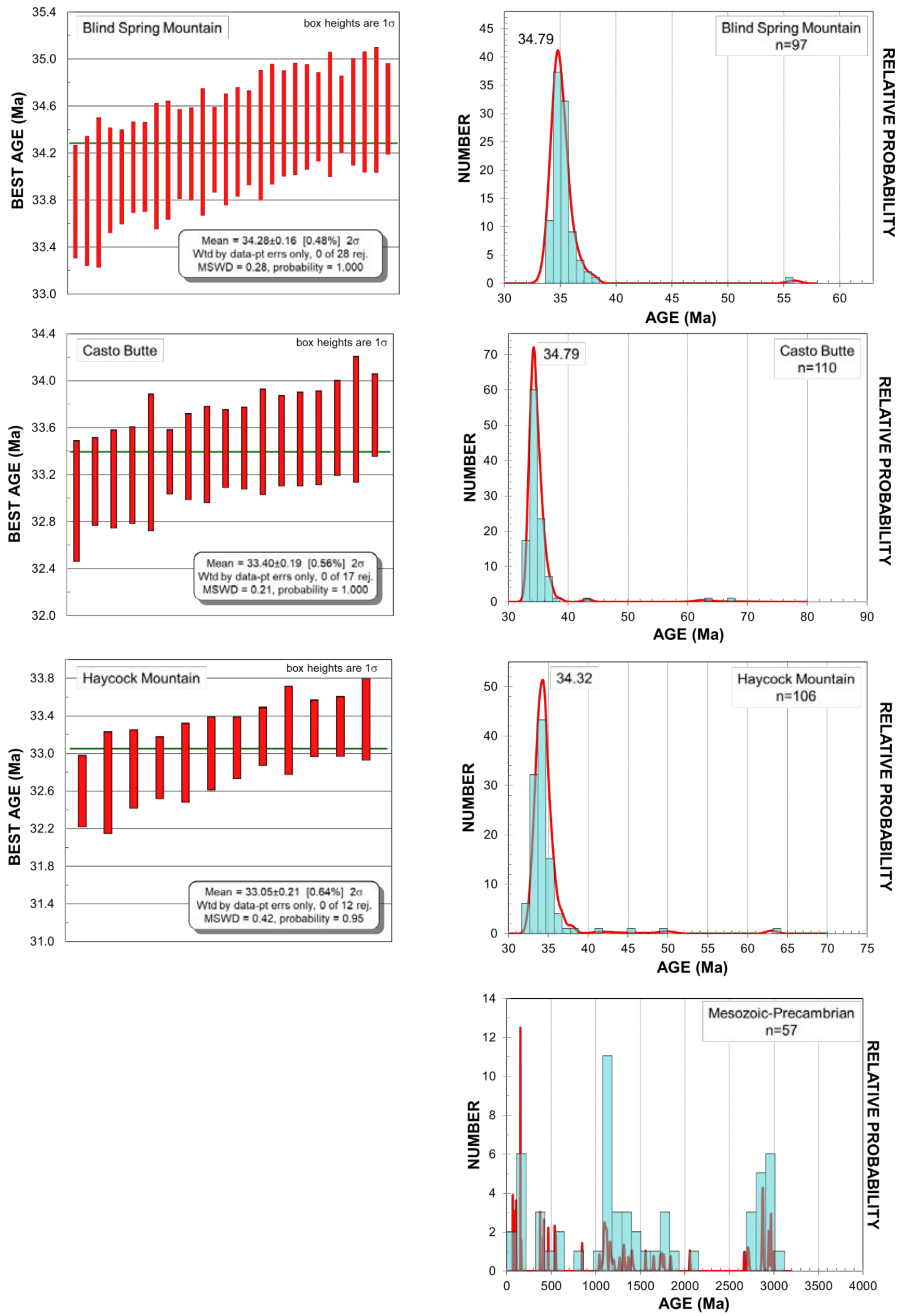


Figure 5. Weighted mean ages (left) and probability density plots/histograms (right) of Tertiary zircons of each of the samples. The aggregate of Paleozoic-Precambrian zircons for each of the three samples is the lowest figure on the right.

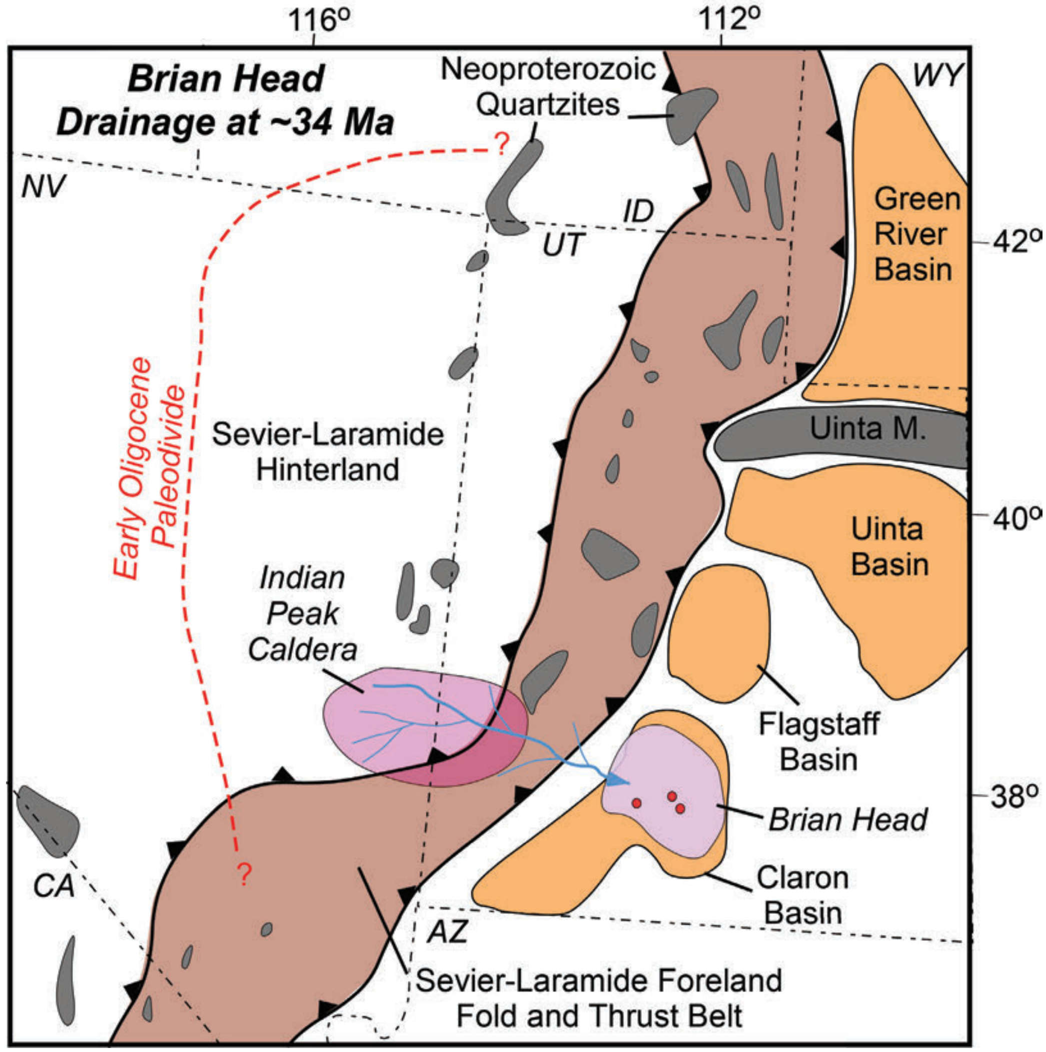


Figure 6. Oligocene reconstruction of the Sevier foreland and hinterland (modified from Davis et al., 2009; Best et al., 2013; Lund Snee and Miller, 2022). The bulk (Paleogene age) Brian Head zircons were derived from the Indian Peak caldera complex 100 to 200 km to the west prior to the 29 Ma eruption of the massive Wah Wah Springs Ignimbrite (not shown). Older zircons were recycled from the underling Sevier-Laramide foreland fold and thrust belt and transported eastward to the vestiges of the Eocene Claron basin. Red circles indicate sample localities.

rived from recycling of Phanerozoic strata in the Sevier-Laramide foreland fold and thrust belt (Malone et al., 2022). Preliminary data indicates that thrust belt sourcing dominated deposition of the underlying Claron Formation (Cull et al., 2024). Because of the preponderance of Archean (greater than 2.5 Ga), Grenville (1.3 to 1.0 Ga), and Taconic-Acadian (450 to 350 Ma) zircons in the Brian Head Formation, it is likely that erosional denudation had not as yet reached the ubiquitous Neoproterozoic quartzites that rest beneath, or the distal thrust sheets that are armored by these rocks were not as yet part of the Brian Head drainage basin (Yonkee et al., 2014; Malone et al., 2016b, 2022). These older detrital zircon age groups are evident in Carboniferous-Cretaceous strata across Laurentia reflecting the development and denudation of the Appalachian highlands during the assembly of Pangea and forming one of the greatest clastic wedges in Earth's history (Dickinson and Gehrels, 2003; Dickinson et al., 2009; Thomas et al., 2020; Foreman et al., 2022). This is in contrast to the 26 to 24 Ma Bear Valley Formation, where the Precambrian subset of zircons has a unimodal age peak of about

1700 Ma, which indicates recycling from Neoproterozoic Brigham Group strata (Yonkee et al., 2014, Malone et al., 2016b), which are in the thrust belt and have prominent coeval age peaks. Abundant quartzite clasts in the Brian Head Formation support this interpretation. The near absence of Mesozoic grains indicates that the volcanic arc in the Sevier hinterland did not contribute sediment to the Claron basin during Brian Head deposition indicating that the arc was west of the presumed late Eocene-early Oligocene drainage divide of the Nevadaplano uplift (Lund Snee and Miller, 2022).

The Oligocene-Miocene volcanism in the Marysvale volcanic field is part of a complex array of magmatic activity that migrated from north to south over time (Best et al., 2013). The ignimbrite flare-up province of Nevada and western Utah records more than 200 massive eruptions from several dozen caldera complexes and involved more than 70,000 km$^3$ of material (Best et al., 2013). Deposition of the Brian Head Formation ceased following the eruption of the Wah Wah Springs ash-flow tuff at about 30.5 Ma, which also originated from the Indian Peak caldera and is one of the most extensive about 22,000 km$^2$) and voluminous (3000 km$^3$) eruptive rocks ever described (Best et al., 1989). The Brian Head Formation represents the distal toe of the volcanic and sedimentary apron derived from the Indian Peak caldera complex as the volcanic highlands became prominent following the erosional denudation of the Sevier-Laramide fold and thrust belt that occurred between this new locus of volcanic activity and the Claron basin. This indicates that the inception of volcanic activity in the Marysvale volcanic field proper had not yet begun.

Following eruption of the Wah Wah Springs Formation at about 30.5 Ma, volcanic activity in the Marysvale volcanic field proper commenced in earnest, with local eruptive centers dominating sourcing (Holliday et al., 2022; Rivera et al., 2025). The calderas to the west remained active during Marysvale volcanism, as the 27.9 Ma Lund Formation, the about 26 Ma Isom Formation, and the about 24 to 22 Ma Quichapa Group ash-flow tuffs are interlayered with the locally derived Marysvale volcanic succession, providing much needed age and stratigraphic control. Zircons derived from the Indian Peak caldera complex also occur more than 1500 km to the northeast in the White River Formation of the central Rocky Mountains and Great Plains, further demonstrating the significance of this caldera complex in particular and the ash-flow tuffs of the Nevadaplano uplift as the most prominent late Paleogene sediment source for many areas to the east (Moll et al., 2024).

## CONCLUSIONS

Our conclusions for this research are:

1. The detrital zircon age spectra for three Brian Head Formation samples in the Claron basin in southern Utah show prominent unimodal zircon age peaks of 35 to 34 Ma.

2. These age peaks represent sediment sourcing from the Indian Peak caldera complex 150 km to the west, and reflect a provenance shift from the Sevier fold and thrust belt and hinterland that dominated the deposition of the underlying Claron Formation.

3. This provenance reflects the rise of the Nevadaplano uplift as the principle sediment source area for this region during the Eocene-Oligocene transition and the collapse of the Sevier fold and thrust belt.

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