Late Cenozoic volcanic stratigraphy and geochronology of the Mount Bennett Hills, central Snake River Plain, Idaho

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LATE CENOZOIC VOLCANIC STRATIGRAPHY AND GEOCHRONOLOGY OF THE MOUNT BENNETT HILLS, CENTRAL SNAKE RIVER PLAIN, IDAHO

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Previous mapping and geochemical analyses have defined the relative and paleomagnetic stratigraphy as well as constrained the petrogenesis of the late Tertiary volcanic rocks comprising the Mount Bennett Hills, located on the margin of the central Snake River Plain in south-central Idaho (Wood and Gardner, 1983, 1984; Wood, 1989; Honjo, 1990; Honjo and others, 1992). Two new K-Ar ages and useful geochemical parameters for the volcanic rocks exposed in the western Mount Bennett Hills are presented in this paper. These ages provide a chronology of late Miocene silicic volcanism, constraints on the timing of graben faulting related to the western Snake River Plain and additional insight on the track of the Yellowstone hotspot through southern Idaho. The stratigraphic nomenclature previously assigned to these units has been modified to reflect the stratigraphic framework established for the Snake River Plain by Malde and Powers (1962) and the standards published in the North American Commission on Stratigraphic Nomenclature (1983).

REGIONAL GEOLOGY

Although the Snake River Plain is a continuous physiographic lowland traversing southern Idaho (fig. 1a), the western and eastern plains differ markedly in styles of volcanism and tectonic origin. The Mount Bennett Hills, consisting of Tertiary volcanics, are at the intersection of the eastern and western plains. Normal boundary faults of the western plain are steeply dipping, trend N40°W, truncate north-south trending faults of the western Idaho Fault Belt (Hamilton, 1962), and down-drop the valley floor 320 to 3,400+ m (Wood, 1983; Wood and Burnham, 1987; Wood, 1989). The boundaries of the eastern plain are defined not by prominent faults with large amounts of vertical displacement, but by late Cenozoic deposits dipping or down-warped into the eastern plain itself (Allmendinger, 1982; Leeman, 1982, 1989; Malde, 1991). Gravity and magnetic surveys (Mabey, 1982), deep (4,200 m) borehole data (Clemens, 1993) and seismic surveys (Wood and others, 1980) indicate that up to 1.8 km of Idaho Group sediments in the western plain are further underlain by at least 2.1 km of interbedded basalts and tuffaceous sediments (Wood and others, 1980) and 0.9 km of basalt, whereas the Neogene sequences of the eastern plain are thought to be underlain by a much thinner, and perhaps unrelated sequence of younger basalts and sediments (Mabey, 1982; Leeman, 1982, 1989; Malde, 1991). Bonnichsen and Godchaux (1989), Bonnichsen and others (1991), and Godchaux and others (1992) suggest that the two geomorphic regions also differ in their patterns of Neogene volcanism and products: western plain volcanism began with extrusion of rhyolitic lavas followed by the eruption of ash flow tuffs, although large caldera systems have not been identified (Ekren and others, 1984). Western plain silicic volcanism was followed within a few million years by the eruption of compositionally-evolved basalts from phreatomagmatic shield volcanos typically erupting through the lake which covered the western plain (Bonnichsen and Godchaux, 1989; Godchaux and others, 1991; Godchaux and others, 1992). Eastern plain volcanism began with the eruption of aerially extensive ash flow tuffs from large caldera complexes, which were later filled to varying degrees with rhyolite lavas and basaltic lavas from shield volcanos.

Malde and Powers (1962) and Armstrong and others (1975, 1980) divided the Neogene rhyolite stratigraphy of southwestern Idaho into two groups based on age and lithology: (1) the 15–16.4 Ma precious-metal mineralized, primary-hydrous mafic mineral-bearing tuffs and flows (2–3% biotite ± hornblende ± pyroxene), which include the Silver City, Wall Creek, and Jarbidge rhyolites (southwest Idaho); and (2) the 9–14 Ma relatively non-precious metal bearing, relatively anhydrous (sanidine, plagioclase ± pyroxene) Idavada Group volcanics (southwest - south-central Idaho). The silicic volcanics decrease in age from northeastern Nevada through southwestern Idaho toward the Mount Bennett Hills and Twin Falls in the east (fig. 1a), and are related at least in time to the Neogene track of the Yellowstone Hotspot (Armstrong and others, 1975, 1980; Leeman, 1982; Norman and Leeman, 1989; Pierce and Morgan, 1990). The change in time and space from hydrous to anhydrous silicic volcanism may be due to

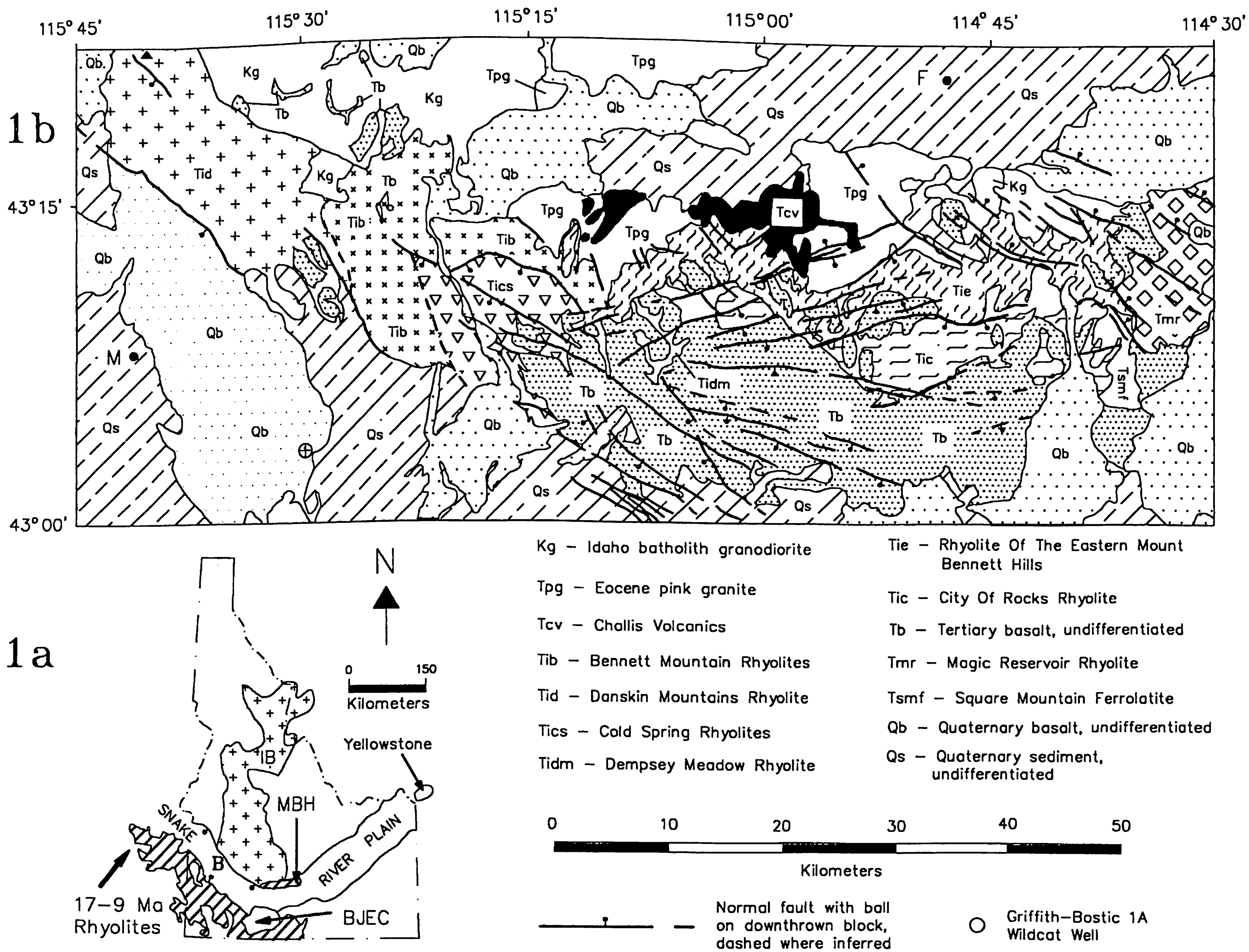

FIGURE 1. ***a.*** **Generalized geologic map of Idaho. B = Boise; MBH = Mount Bennett Hills; BJEC = Bruneau-Jarbidge Eruptive Center (Bonnichsen and Kauffman, 1987).** ***b.*** **Generalized geologic map of the Mount Bennett Hills in south-central Idaho shown in figure 1a (after Lewis and Kiilsgaard 1991; Honjo 1990; and Wood and Gardner, 1984). ▲ = Danskin Peak, M ● = Mountain Home; F ● = Fairfield, O = Griffith-Bostic 1A wildcat well.**

the hotspot crossing the boundary between accreted terranes to the west and pre-Mesozoic, relatively anhydrous cratonic crust to the east as defined by the Sr 0.706 isopleth (Leeman, 1982b; Leeman and others, 1991, 1992).

Overlying the silicic volcanic rocks is a sequence of basalt flows and basaltic tuffs with silicic ash interbeds called the Banbury Basalt by earlier workers (Armstrong and others, 1975; Malde and Powers, 1962), for which K-Ar age dates have been conflicting. The somewhat erratic radiometric dates (weighted mean age of selected rocks is 9.4 ± 0.6 Ma [Armstrong and others, 1980]) and lack of a dominant lacustrine facies in the Banbury Basalt led Wood and Anderson (1981) and Hart and others (1984) to question the placement of the Banbury Basalt within the Idaho Group. The Idavada Group and Banbury Basalt are overlain by the Neogene Idaho Group sediments, consisting of 3 major units: 1) the Poison Creek Formation, comprised of silicic ash and tuffaceous material in massive beds with some beds of cemented arkosic sands, gravel, and basalt volcaniclastics; 2) the Chalk Hills Formation, which is composed of a silt and sand unit with numerous thin layers of fine silicic ash; and 3) the Glenns Ferry Formation, which consists of fluviolacustrine sediments with minor basalt flows. The Neogene units are in turn overlain by the Quaternary basalt flows and lacustrine sediments of the Bruneau Formation and Snake River Group (Kimmel, 1982; Malde, 1962, 1991; Wood, in press).

METHODS

Contacts between cooling units within the Idavada Group volcanics are typically exposed only locally or at the distal ends of the rhyolites, where the units are separated by weathered zones or layers of ash, block and ash, and/or sediments. Criteria used by Wood and Gardner (1984) and Honjo (1990) to distinguish one sequence of cooling units from another include: presence of upper and/or basal vitrophyres; abrupt changes in the character and inclination of flow banding, jointing and flow banding parallel to lithologic contacts; changes in phenocryst size and abundance, and composition; and paleomagnetic polarity. The lack of well exposed contacts between widespread units within the Idavada Group has lead to these silicic volcanic rocks being interpreted by some workers as both rheomorphic ash flow tuffs and lava flows based on the presence of chaotic flow-banding, lack of pyroclastic textures and/or the assumption that silicic lava flows travel only short distances (Ekren and others, 1984; Wood and Gardner, 1984; Wood, 1989; Honjo, 1990). It has been shown by Henry and Wolff (1992) and Bonnichsen and Kauffman (1987) that the best criteria for distinguishing silicic lava flows from rheomorphic ash flow tuffs is the presence or absence of a basal crumble breccia. These crumble breccias form as the chilled outer crust of the lava flow shatters, falls to the base of the flow front, and is overlain by the advancing flow. Rheomorphic tuffs may flow short distances *after* emplacement, but in the great majority of these densely welded tuffs the basal layer will contain ash and surge deposits, ***not*** crumble breccia. In this study, if a unit is named a tuff, it denotes overwhelming evidence of a pyroclastic origin. A unit is called a rhyolite if the origin is unclear, and called a rhyolite lava where the origin is clearly a lava flow (basal breccia present).

Wood and Gardner (1984) determined the paleomagnetic polarity of the western Mount Bennett Hills volcanic units by measuring fresh, oriented samples with a field fluxgate magnetometer. Four out of five consistent polarities was accepted as an accurate measurement for an outcrop, and anywhere from five to ten outcrops were measured in a given unit to verify the unit's magnetic polarity. Honjo (1990, p. 47) used 1–3 measurements of one or two outcrops to determine a unit's magnetic polarity.

All samples used for K-Ar dating in this study were taken from fresh-appearing rock and were selected from bedrock outcrops of the type sections. These samples were initially reduced using a hydraulic rock splitter to remove all weathered material. The resulting fresh samples were crushed, sieved, and analyzed at the Geochron Laboratories Division of Krueger Enterprises, Inc. Mineral separates were obtained using heavy liquid separation techniques, and treated with dilute HF and HNO_3. The constants and formulas used for the age determination were those of Steiger and Jaeger (1977). X-ray fluorescence (XRF) analyses for this study were conducted at the Geo-analytical Lab in the Department of Geology at Washington State University.

SAMPLE DESCRIPTIONS

1. *F-9409* K-Ar
Rhyolite of High Springs, Danskin Mountains Rhyolites (43°10′29E″, 115°31′02N″; NW¼ SW¼, S9,T3S,R7E, Teapot Dome 7.5′ quad.) of Teapot Dome. Phyric upper vitrophyre from the uppermost exposed flow collected ⅛ mile west of CROWN 4713 on the summit of Tea Pot Dome. *Analytical data:* ave. K (wt. %) = 7.410, ave. ^{40*}Ar (ppm) = 0.005133. *Collected by:* D. Clemens and T. Morgan.
(sanidine) 10.0 ± 0.3 m.y.

2. *F-9410* K-Ar
Rhyolite of Willow Creek, Bennett Mountain Rhyolites (43°02′43N″, 115°27′13E″; SE¼ NW¼, S36,T2S,R8E, Bennett Mountain 15′ quad.). Phyric upper vitrophyre sample collected from the lowermost exposed unit near on-lapping contact with basal unit of the Danskin Mountains Rhyolites of

the Idavada Group volcanics. *Analytical data:* ave. K (wt. %) = 0.960, ave. $^{40*}Ar$ (ppm) = 0.000734. *Collected by:* D. Clemens and S. Wood.

(andesine plagioclase) 11.0 ± 0.5 m.y.

GEOLOGIC SETTING OF THE MOUNT BENNETT HILLS

Idaho batholith (Kg)

The mountains to the north of the Mount Bennett Hills and the exposed basement rock within the range consist of the Cretaceous Atlanta Lobe of the Idaho batholith which is mostly granite or granodiorite. This part of the batholith contains numerous aplite-alaskite dikes as well as pods of gneiss and gneissic quartzite of amphibolite grade, with outcrop areas ≤200 m^2 (Wood and Gardner, 1984). Criss and others (1982) describe this portion of the Atlanta Lobe as having undergone Ar loss due to meteoric/hydrothermal fluids and regional uplift events associated with Eocene intrusions north of the map area. This Ar loss produces anomalously young K-Ar dates for biotite separates from the region (Criss and others, 1982), such as the 44.1 Ma K-Ar date derived from a section of the batholith (43°10.5E′, 115°17N′, fig. 1b) recalculated from an age originally reported by McDowell and Kulp (1969). The age of emplacement for the granite in this region is thought to be between 75 and 85 Ma (Johnson and others, 1988).

Challis-Age Intrusives (Tpg) and Volcanics (Tcv)

Dikes and stocks of wide variations in composition locally intrude the Idaho batholith north of the Mount Bennett Hills and are thought to be Eocene in age. Lewis and Kiilsgaard (1991) subdivided the intrusive rocks into the pink granite (Tpg) and the quartz monzodiorite suites, of which the pink granite suite is present in the map area (fig. 1b) as the Hall Gulch stock (Bennett and Knowles, 1985). Nonconformably overlying the Idaho batholith in the western Mount Bennett Hills are andesitic flows and rhyolite tuffs, which locally consist of erosional remnants of biotite and hornblende-bearing lavas and ash flow tuffs ≤100 m thick (Wood and Gardner, 1984). Malde, Powers, and Marshall (1963) describe a similar sequence of rhyolitic (quartz, sanidine, and biotite) and andesitic (plagioclase and hornblende) rocks on the northern side of the eastern Mount Bennett Hills which has been tilted and faulted. The sequences of hydrous mafic-mineral-bearing rhyolitic-andesitic volcanic rocks may be related to the petrographically similar lower portion of the southern Challis volcanic field as mapped and described by Moye and others (1988), though detailed mapping and sampling will be necessary to verify this relationship.

Miocene Idavada Group Volcanics

Bennett Mountain Rhyolites (Tib)

The Bennett Mountain Rhyolites in the western Mount Bennett Hills (fig. 1b) consist of a 660+ m-thick sequence of six mappable silicic volcanic units (fig. 2) containing 5–15% 2- to 4-mm plagioclase ± quartz, all exposed in the type section at Willow Creek (43°11N′, 115°32E′, fig. 1b) as an upthrown fault block trending ~N20°W (Wood and Gardner, 1984). Some units, where exposed, are separated by ash layers or a weathered contact. The rhyolite layers pinch out to the north and east, and have been tectonically tilted 12°–25° to the northeast. The sequence of six units informally named by Wood and Gardner (1984) is shown in figure 2. The oldest exposed unit is the rhyolite of Willow Creek, which does not have an exposed base. Honjo (1990) observed a basal breccia in the overlying rhyolite of normal polarity (polarity meaning paleomagnetic polarity as determined in the field), but did not state a specific outcrop locality, so we are unsure of the unit's volcanic origin. The rhyolite of Bennett Mountain informally named by Wood and Gardner (1984) has a planar lower contact with the rhyolite of Windy Gap and thins considerably to the north, which may suggest a pyroclastic origin (Honjo, 1990). The lower section of the Bennett Mountain Rhyolites consists of mostly reverse polarity flows capped by the normal polarity rhyolite of Bennett Mountain and the Henley Rhyolite (not the Henry Rhyolite as reported by Honjo, 1990). Honjo (1990) indicated that the rhyolite of Bennett Mountain (tuff of Bennett Mountain from Honjo, 1990) could be traced as far east as the central Mount Bennett Hills (fig. 2).

Danskin Mountains Rhyolites (Tid)

The Danskin Mountains in the western-most Mount Bennett Hills (fig. 1b) consist of a 340+ m-thick sequence of at least four mappable normal polarity, 10–11 Ma rhyolite units containing 5–20% plagioclase, quartz, and sanidine (fig. 2). The Danskin Mountains Rhyolites appear to lap onto the ~N20°W trending fault block containing the Bennett Mountain Rhyolites (Wood and Gardner, 1984; Honjo, 1990). The section at Danskin Peak (fig. 1b) was examined by Clemens (1993) and found to be about 300-m-thick. The section consists of at least four plagioclase- and sanidine-bearing mappable units. The rhyolites exposed at Danskin Peak are geochemically correlative with those analyzed by Honjo (1990) as shown by Clemens (1993) and are discussed later. Although Honjo (1990) interpreted some of the units defined by Wood and

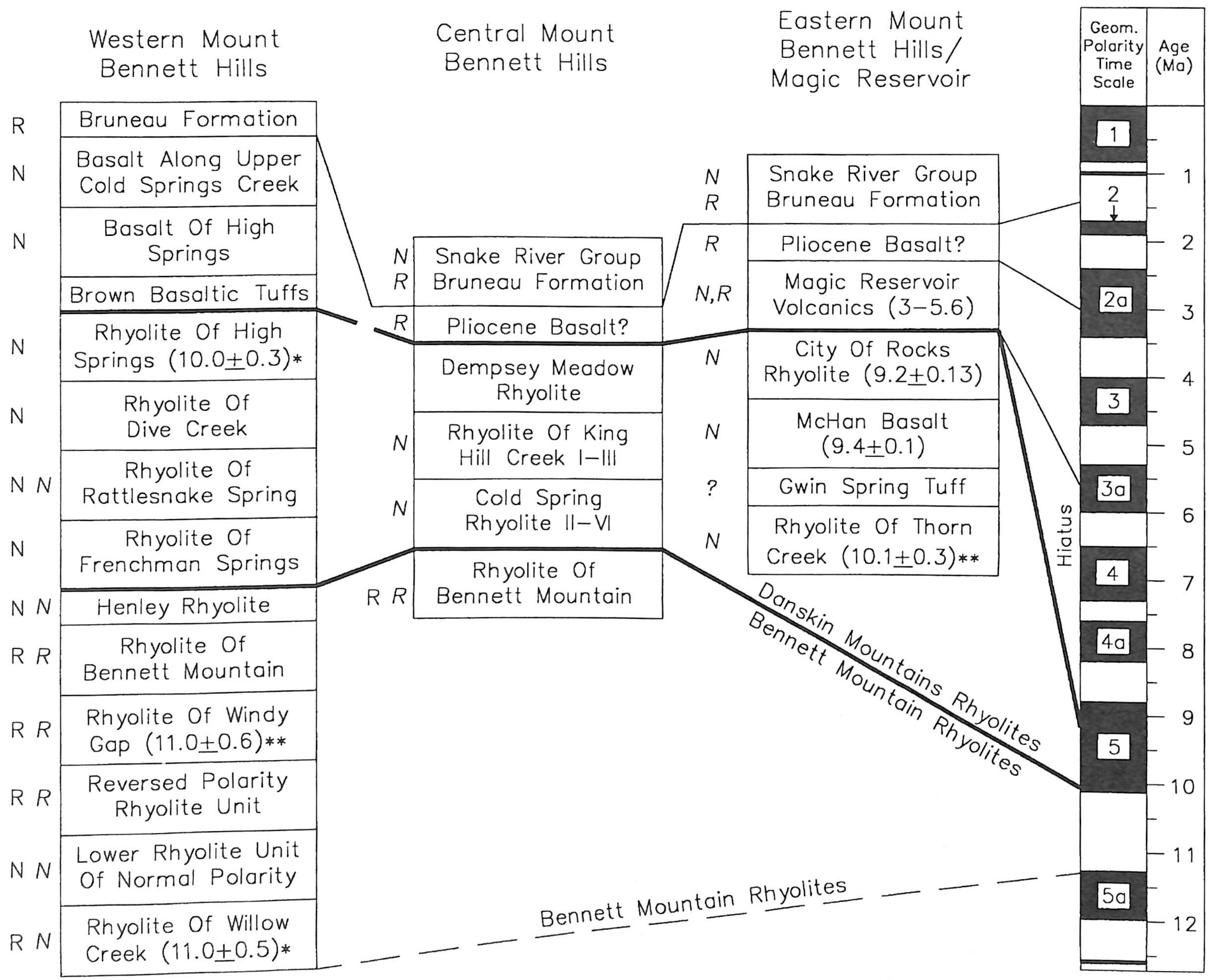

FIGURE 2. Chronostratigraphic correlation of units in the Mount Bennett Hills and Magic Reservoir areas. Stratigraphic and paleomagnetic data for the western Mount Bennett Hills from Wood and Gardner (1984), names in italics from Honjo (1990). Stratigraphic and paleomagnetic data for the eastern Mount Bennett Hills and Magic Reservoir area from Honjo (1990). * are K-Ar ages from this study, ** are K-Ar ages from Armstrong and others (1980), all other age dates are Ar-Ar from Honjo (1986). Geomagnetic polarity time scale (dark bands represent normal polarity) after La Brecque and others (1977).

Gardner (1984) as tuffs, we feel that the field evidence cited is not sufficient to determine if these units are rheomorphic tuffs or lavas. Like the Bennett Mountain Rhyolites, some of the Danskin Mountains Rhyolites are separated by ash layers or a weathered upper contact. The units within the Danskin Mountains Rhyolites also dip 12°–20° to the northeast.

Cold Spring Rhyolites (Tics)

In the central Mount Bennett Hills, Honjo (1990) described two normal polarity sequences of possibly related rhyolitic units containing 7–20% plagioclase: the Cold Spring sequence of rhyolites (43°11′N, 115°25′E, fig. 1b) and rhyolites of the King Hill area (43°10′N, 115°15′E, fig. 1b). The Cold Spring sequence consists of at least four cooling units ranging in total thickness from 310 to 370 m, and overlying an ash flow tuff. According to Honjo (1990, p. 9, and fig. 1–3, p. 19), this sequence, collectively called the Cold Spring Rhyolites, and an underlying tuffaceous layer lap onto an E-W to NW-SE arcuate fault block consisting of the rhyolite of Bennett Mountain (fig. 2). Based on the continuation of the E-W portion of the arcuate fault from Cold Spring to King Hill, where the rhyolites overly the rhyolite of Bennett Mountain, Honjo (1990, p. 9) felt the Cold Spring and King Hill sequences were correlative. These relationships also suggest that the Cold Spring Rhyolites are similar in age to the Danskin Mountains Rhyolites.

Dempsey Meadow Rhyolite (Tidm)

The Dempsey Meadow Rhyolite occurs east of the Cold Spring Rhyolites in the south-central portion of the Mount Bennett Hills (43°8N′, 115°6E′, fig. 1b). The unit is characterized by 15% plagioclase phenocrysts. Magnetic polarity is not reported by Honjo (1990). Because its base is not exposed and the majority of the unit is covered by late Neogene(?) basalts, its stratigraphic relationship to other units in the Mount Bennett Hills is uncertain (Honjo, 1990).

Eastern Mount Bennett Hills Rhyolites (Tie)

The 9–10 Ma Eastern Mount Bennett Hills Rhyolites (fig. 1b, 2) as defined by Honjo (1990) consist of several units: the Tuff of Knob with 15–20% plagioclase and an unwelded basal layer; Deer Creek Rhyolite with 10% plagioclase, sanidine, and quartz; the Gwin Spring Tuff (Smith, 1966) with 5–10% plagioclase; and the Rhyolite of Thorn Creek with 15% plagioclase (Older Welded Tuff of Smith, 1966); with a combined thickness of about 140 m. Although the Tuff of Knob overlies the rhyolite of Bennett Mountain (separated by a gravel layer according to Honjo [1990]), the stratigraphic relationships among the eastern Mount Bennett Hills Rhyolites and surrounding units are not clear due to uncertain field relationships and contradictory paleomagnetic readings for the Tuff of Knob and Gwin Spring Tuff (see fig. 2). The Gwin Spring Tuff is overlain by a local basalt flow called the McHan Basalt (Honjo and others, 1986; Honjo, 1990). Honjo's descriptions of the Gwin Spring unit which Smith (1966) called a tuff does not convincingly support the conclusion that this unit can be reinterpreted as a lava flow.

City of Rocks Rhyolite (Tic)

The City of Rocks Rhyolite, originally mapped by Smith (1966) as the City of Rocks tuff, was called both a tuff and a rhyolite by Honjo (1990), so we will use the generic term rhyolite for this unit until the origin can be constrained. The unit has a normal polarity, occurs in the southeastern-most portion of the Mount Bennett Hills (fig. 1b), contains 20% plagioclase, and overlies the McHan Basalt (Honjo, 1986, 1990). Honjo assigned the McHan Basalt to the problematic Banbury Basalt, which overlies the Idavada Group and was initially defined by Malde and Powers (1962). Analysis of drill cuttings (Arney and Goff, 1982; Campbell, 1974) and geophysical logs (Clemens, 1993) from the Griffith-Bostic 1A well (see fig. 1a) indicate that basaltic rocks are intercalated with rhyolite in the upper portion of the Idavada Group. Because the basalt units are 25- to 75-m-thick, we cannot discount the possibility that they are dikes. Because of the relationships presented here, we would place the McHan basalt within the Idavada Group. Problems with the Banbury basalt designation are discussed below. The McHan Basalt and the basalts within the rhyolite section penetrated by the Griffith-Bostic 1A well suggest that basalt eruptions occurred during periods of silicic volcanism in this region.

Neogene Basalts (Tb) and Idaho Group Sediments

In the western Mount Bennett Hills, Wood and Gardner (1984) mapped a 50 m-thick sequence of brown basaltic tuffs or volcaniclastic units containing layers of silicic white ash and blocks of vitrophyre. Because this unit contains lithologies similar to the Banbury Basalt and the Idavada Group silicic volcanics, Wood and Gardner felt that this unit should eventually be assigned a formation status. Overlying the volcaniclastic sequence are the Basalt of High Springs and the basalt along upper Cold Springs Creek, a series of at least four normal polarity, porphyritic-diktytaxitic (plagioclase ± olivine) basalt flows, the latter of which occurs as an intracanyon flow near Cold Springs Creek (Wood and Gardner, 1984).

A 700-m-thick section of similar volcaniclastic rocks and flows occurs in the Griffith-Bostic 1A well south of the western Mount Bennett Hills (see fig. 1a). The stratigraphic setting of this section of mostly basaltic rocks is similar to the Banbury Basalt mapped along the northern side of the central Snake River Plain by Malde and Powers (1962) and Malde and others (1963) .

Neogene fluvio-lacustrine sequences are rarely exposed in the map area. However, a 770-m-thick section of sediment overlying the basalt volcaniclastics and flows and similar to the Idaho Group was penetrated by the Griffith-Bostic 1A well (Arney and Goff, 1982; Campbell, 1974).

Late Pliocene Magic Reservoir Volcanics (Tmr & Tsmf)

The 3–5.6 Ma Magic Reservoir sequence of lavas, domes, and tephra units unconformably overly Pliocene basalt and Miocene-Pliocene Idavada Group volcanics in the eastern-most portion of the map area (fig. 1b, 2). The Magic Reservoir Rhyolite (Tmr), actually a quartz latite (Honjo, 1986; Honjo and others, 1986), is the oldest exposed unit in the eruptive center described by Leeman (1982). This quartz latite was dated by Honjo (1986) using Ar/Ar at 4.15 ± 0.05 Ma and 5.81 ± 0.69 Ma, contains multiple flow units and covers at least half of the eruptive center (fig. 1b). Overlying the Magic Reservoir Rhyolite is the Square Mountain Ferrolatite (Tsmf) sequence of hybrid lavas. Both of these units are locally overlain by ash flow tuffs mapped informally as the Moonstone rhyolite (Smith, 1966), Tuff Numbers 1–3 by Struhsacker and others (1982) and as the Young Tuff by Honjo (1990, 1986). Small, 3–4 Ma porphyritic rhyolite domes are present in the center and on the margins of the eruptive center (Honjo, 1990; Struhsacker and others, 1982). Honjo (1986) obtained 5 Ar/Ar ages for these young domes ranging from 3.88 ± 0.6 Ma to 2.92 ± 0.4 Ma, which brackets a K-Ar age of 3.06 ± 0.4 Ma obtained by Armstrong and others (1975). The age dates on the silicic rocks of this eruptive center are considerably younger than expected for a rhyolite along the hot spot track as discussed by Armstrong and others (1975, 1980) and Pierce and Morgan (1990).

Quaternary Bruneau Formation (Qb) and Snake River Group (Qs)

Along the northern and southern flanks of the Mount Bennett Hills (fig. 1b), the reverse-polarity basalts of the Bruneau Formation (Qb), and basalt and sediments of the Snake River Group, lap onto the Idavada Group silicic volcanics (Wood and Gardner, 1984). These basalt flows south of the Mount Bennett Hills probably originated from the Quaternary shield volcanos a few kilometers south from the Mount Bennett Hills (Wood, 1989), whereas those Quaternary basalts north of the Mount Bennett Hills originated mostly from vents 10 km north of the central Mount Bennett Hills mapped by Howard and others (1982). The Quaternary Snake River Group (Qs) consist of fluvial sediments and alluvial fan deposits interbedded with basalt flows (Bonnichsen and others, 1988). Though these sediments and lava flows are not well exposed in the Mount Bennett Hills, they attain considerable thickness south of the range. Arney and Goff, 1982; Campbell (1974) report that the Griffith-Bostic 1A wildcat well penetrated 620 m of Bruneau Formation-type sediments and basaltic lava flows based on field examination of cuttings, but this has not been confirmed by well logs.

DISCUSSION

Geochemical Correlations

Chemical analysis of rhyolites obtained by Honjo (1990) in the western Mount Bennett Hills and analysis obtained by Clemens (1993) from the upper and lower cooling units exposed at Danskin Peak have been compared to find geochemical discriminants between the Danskin Mountains and Bennett Mountain rhyolites. As shown in figure 3, plotting K_2O (wt. %) versus Sr (ppm) was a useful way to discriminate between these units. The Danskin Mountains Rhyolites including Danskin Peak define a field of high Sr and relatively lower K_2O. The Frenchman Spring unit is the exception with anomalously low Sr - more like some flows of the Bennett Mountain Rhyolites. The Bennett Mountain Rhyolites are somewhat lower in Sr while some flows have K_2O concentrations approaching 6%.

Ekren and others (1984) hypothesized that many of the Idavada Group rocks in the Mount Bennett Hills may be the distal ends of large ash flow tuff sheets erupted from the Bruneau-Jarbidge Eruptive Center at the southern margin of the central Snake River Plain (fig. 1a). This has been difficult to verify due to the extensive amount of graben faulting and basin fill within the central Snake River Plain. Honjo (1990) used mineralogy, bulk and phenocryst chemistry to try to correlate the rheomorphic tuffs found in the Mount Bennett Hills with the Cougar Point tuffs of Bonnichsen and Citron (1982). Based on the phenocryst chemistry of suspected rheomorphic tuff units in the Mount Bennett Hills and those within the Cougar Point tuffs, Honjo (1990) concluded that the volcanics in the two regions erupted from chemically different eruptive centers.

Geochronology and Field Magnetic Polarity Determinations

In the western Mount Bennett Hills, Armstrong and others (1980) dated a rhyolite unit that was subsequently called the rhyolite of Windy Gap by Wood and Gardner (1984) at 11.0 ± 0.6 Ma (K-Ar). The 11.0 ± 0.5 Ma (K-Ar) age for the rhyolite of Willow Creek and the 10.0 ± 0.3 Ma (K-Ar) age for the Rhyolite of High Springs reported here (fig. 2) all indicate that the units comprising the Bennett Mountain Rhyolites in the western Mount Bennett Hills geochronologically correlate to the 9–14 Ma range of ages for the Idavada Group volcanics in southwestern Idaho as shown by Armstrong and others (1980) and Leeman (1982, 1989). Magnetic polarity of oriented samples indicates that the Bennett Mountain Rhyolites mostly have a reverse polarity while the Danskin Mountains Rhyolites have a normal magnetic polarity, as shown in figure 2. The combination of the K-Ar dates and the magnetic polarity data constrains the emplacement of the Danskin Mountains and Bennett Mountain rhyolites to between 10 and 11.3 Ma as shown in the global geomagnetic time scale of La Brecque and others (1977) in figure 2.

The silicic units in the eastern Mount Bennett Hills/Magic Reservoir area dated by Armstrong and others (1980) and Honjo (1990) yield a similar series of relationships. The oldest exposed Miocene unit in the eastern Mount Bennett Hills is a silicic lava flow renamed by Honjo (1990) the Rhyolite of Thorn Creek (Older Welded Tuff of Smith [1966]). Armstrong and others (1980) dated this rhyolite at 10.1 ± 0.3 Ma. This unit is in turn overlain by the Gwin Spring Tuff, McHan Basalt, and the City of Rocks Rhyolite, respectively (fig. 2). The McHan Basalt and City of Rocks Rhyolite were dated by Honjo (1990) at 9.4 ± 0.1 Ma and 9.2 ± 0.13 Ma, respectively, using the Ar-Ar method. These ages all indicate that the silicic *and* intercalated basaltic volcanic units in the eastern Mount Bennett Hills geochronologically correlate to the 9–14 Ma range of ages for the Idavada Group volcanics in southwestern Idaho as shown by Armstrong and others (1980) and Leeman (1982, 1989). The normal magnetic polarity of these units support the Ar-Ar and K-Ar dates in constraining the initial episode of silicic volcanism in the eastern Mount Bennett Hills to between 9 and 10.1 Ma (fig. 3), significantly younger than the oldest Idavada Group volcanic unit in the western Mount Bennett Hills dated at 11.0 + 0.5 Ma (this paper). It is significant that the lower rhyolites are without intercalated basalt flows, which appears only among the youngest rhyolite units of the Idavada Group in the area.

Armstrong and other's (1980) revised ages on the Banbury Basalt (average mean age of 9.4 ± 0.6 Ma) constrain its age in the Twin Falls type section south of the Mount Bennett Hills, where basalt flows and tuffaceous sediments overlie Idavada Group volcanics and underlie the fluvio-lacustrine rocks of the Idaho Group. Past confusion regarding the Banbury Basalt resulted from correlating any basalt within the lacustrine sequence with the Banbury Basalt (see Wood and others, 1981; Hart and others, 1984). In the Mount

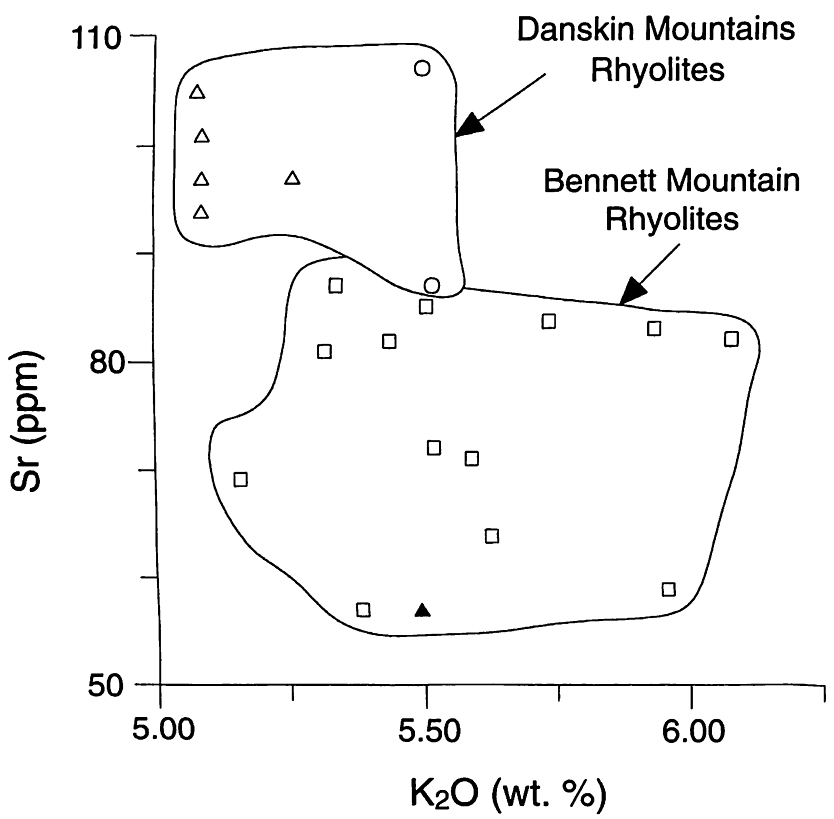

FIGURE 3. Plot of K2O (wt. %) vs. Sr (ppm) for silicic volcanic rocks in the western Mount Bennett Hills showing the distinct grouping of the Bennett Mountain Rhyolites and the Danskin Mountains Rhyolites. O are data from Clemens (1993), □ and Δ are data from Honjo (1990). ▲ is the rhyolite of Frenchman Springs, part of the Danskin Mountains Rhyolites, but geochemically different from all of the other units.

Bennett Hills, Wood and Gardner (1984) and Honjo (1990) define a small thickness of basalt flows and volcaniclastics similar to those found near Boise which have been correlated in time to the Banbury Basalt based on lithology and bracketing K-Ar ages (Clemens and Wood, 1993). The 9.4 ± 0.1 Ma (Ar-Ar) McHan Basalt, a local basalt flow in the eastern Mount Bennett Hills (Honjo, 1990), may be correlative to the Banbury Basalt at least in time, but the overlying 9.2 ± 0.13 Ma (Ar-Ar) City of Rocks Rhyolite (Honjo, 1990) makes it an anomalous basalt unit. Unfortunately, the lack of dated basalt flows, rock chemistry, and the inconsistent definition of individual map units throughout the study area between Wood and Gardner (1984) and Honjo (1990) make it difficult to correlate the Mount Bennett Hills basalt flows and subsurface basalt units to the Banbury Basalt or to the 4–5 Ma basalts associated with the overlying Glenns Ferry Formation of the Idaho Group (Armstrong and others, 1980).

Style and Timing of Faulting

Based on field relationships, the oldest pattern of faulting in the study area occurs in the western Mount Bennett Hills and consists of a few prominent ~N15°W-trending, down to the west fault-line scarps within the Bennett Mountain Rhyolites, onto which lap the Danskin Mountains Rhyolites (43°11′,115°32′, fig. 1b). It has been suggested by Wood and Gardner (1984) that this N15°W trend may be related to early Basin and Range extension between 10 and 15 m (Anderson, 1989). If so, this would indicate that Basin and Range extension ceased before the 10 Ma Danskin Mountains Rhyolites lapped onto the Bennett Mountain Rhyolites fault block. It is also possible that these N15°W trending faults represent Mesozoic or early Cenozoic structures similar to those mapped in the Challis 1° × 2° Quadrangle north of the Mount Bennett Hills by Hobbs (1983) which were reactivated by Miocene uplift and volcanism related to passage of the Yellowstone hotspot, or minor transform/transverse faults related to different orientations of extension and deformation as proposed by Chorowicz and Sorlien (1992) for the African Malawi rift and noted by Wood (1989b) between the western and eastern plains. These N15°W faults may also be splays from the N50°W trending graben faults of the western Snake River Plain, similar to those associated with major faults within continental rifts such as the East African Rift (Eibinger, 1989; Chorowicz and Sorlien, 1992). Further mapping of these structures in the northern portion of the Hailey 1° × 2° Quadrangle will be necessary before the origin of these faults can be further constrained.

The ~N50°W trend of normal faults in the Mount Bennett Hills (fig. 1b) crosscut the N15°W fault trend and offset Quaternary units. These faults are parallel to the boundary faults along the northeastern margin of the western Snake River Plain and are indicative of graben development with a direction of extension of ~N40°E. Wood and Gardner (1984), Wood (1989b), and Clemens (1993) show that between the Griffith Bostic 1A well south of the western Mount Bennett Hills (figure 1b) and the western Mount Bennett Hills, the Idavada Group and Banbury Basalt have been down-dropped over 2 km. Work by Clemens (1993) has shown that the rate of vertical displacement along one of these normal faults had a much higher rate prior to about 9 Ma.

The Neogene basalt flows of the south-central portion of the Mount Bennett Hills contain the majority of the E-W ± 10° faults and offset some of the N50°W faults. Because the N50°W faults do not cross-cut any of the N50°E faults and are rare in Quaternary units, they may be associated with the post-9 Ma development of the western Snake River Plain graben.

The ~N50°E trending normal faults in the eastern Mount Bennett Hills (43°13′, 114°53′, fig. 1b) have not been shown conclusively to offset the N50°W system of faults (Malde and others, 1963; Struhsacker and others, 1982). N50°E faults may be related to the northwest and southeast boundaries of the eastern Snake River Plain (see fig. 1b, 1a). These boundaries are currently thought to be the result of late Cenozoic volcanic and sedimentary units being downwarped as a result of crustal deformation related to the passage of the Yellowstone hotspot (Leeman, 1989; Pierce and Morgan, 1990). However, the downwarped or faulted northwest-southeast boundaries need careful mapping and regional review to ascertain the significance or these northeast-southwest trending faults in the eastern Mount Bennett Hills. Initial work using seismic refraction by Elbring (1985) suggest that parts of the northwest margin of the eastern Snake River Plain may be bounded by normal faults, but more work is needed to expand this hypothesis.

CONCLUSIONS

The oldest Idavada Group silicic volcanic rocks exposed in the western and central Mount Bennett Hills are the Bennett Mountain Rhyolites, a 660+ m-thick sequence of mostly reverse magnetic polarity, plagioclase-bearing tuffs and lava flows. K-Ar dating and mostly reversed magnetic polarities constrain their time of emplacement to between 10.2 and 11.3 Ma. ~N15°W and ~N50°W trending normal fault scarps created topographic barriers onto which lap the Danskin Mountains Rhyolites of the Idavada Group. This on-lapping, 340+ m-thick sequence of normal polarity, sanidine-bearing silicic lavas, tuffs, and minor basalt flows is exposed throughout the Mount Bennett

Hills and consists of all of the upper Idavada Group silicic units with normal magnetic polarities mapped by Honjo (1990) and Wood and Gardner (1983, 1984). The emplacement ages for the Danskin Mountains Rhyolites are constrained by their mostly normal magnetic polarities and K-Ar and Ar-Ar dates be between 10.2 and 9.7 Ma in the west and 10.2 to 9.2 Ma in the east.

Borehole data from the Griffith-Bostic 1A well suggests that the upper portion of the Idavada Group contains interbedded basaltic and rhyolitic units, which suggests that the definition of the upper Idavada Group should be changed to include these basalt flows. Correlation studies (Honjo, 1990) and the lack of field or geophysical (Mabey, 1982) evidence for Miocene regional eruptive centers or calderas within or near the margin of the north central Snake River Plain strongly suggest that the Idavada Group rocks in the Mount Bennett Hills did not originate from large-scale eruptions to the south, but may represent relatively small eruptions of lavas and ash-flow tuffs fed by dikes propagating along faults (e.g., Fink and Pollard, 1983; Henry and Wolff, 1992).

The Idavada Group silicic rocks in the Mount Bennett Hills are overlain by mostly basaltic and minor silicic volcaniclastic units. Basalt flows of both normal and reverse magnetic polarity were mapped in the western Mount Bennett Hills and are about 150 m thick. Borehole data from the Griffith-Bostic 1A wildcat well indicates that these basalt flows and mostly basalt volcaniclastic units thicken greatly to the south over a short distance to about 700 m below the western Snake River Plain (Arney and Goff, 1982; Campbell, 1974). Lack of detailed mapping, complete geophysical logs, and age dates of these basalt lava flows and volcaniclastics prevents them from being assigned to either the 9.4 ± 0.6 Ma Banbury Basalt or the 3–4 Ma Glenns Ferry Formation of the Idaho Group (Armstrong and others, 1980). However, the abrupt thickening indicates that great relief had already developed along this edge of the central Snake River Plain at the time these basalts were emplaced.

The Mount Bennett Hills is a structural horst with four different patterns of normal faults. The oldest fault pattern is series of faults or fault-line scarps oriented ~N15°W and is exposed only in the western Mount Bennett Hills. Based on the fact that the 9–10 Ma Danskin Mountains Rhyolites lap onto a down-to-the-southwest fault scarp composed of the Bennett Mountain Rhyolites, faulting with this orientation appears to have ceased before 10 Ma. Whether these faults are related to early Basin and Range faulting, reactivated older structures, or transverse/transform faults is unclear. Similarly oriented faults have been found in the Owyhee Mountains of the western Snake River Plain, which may suggest that these faults are related to the formation of the western Snake River Plain (Wood and others, 1980; Ekren and others, 1981).

Cross-cutting the N15°W trending faults are a series of down to the southwest ~N50°W normal faults, a trend which offsets Quaternary units and is very similar to those which form the northeastern margin of the western Snake River Plain. In the south-central Mount Bennett Hills, the E-W ± 10° faults crosscut the ~N50°W faults, but rarely offset Quaternary units. The E-W faults may be related to the change in the stress field of the upper crust reflecting the passage of the Yellowstone hotspot. Faulting related to the northwest-trending western Snake River Plain appears to have continued after faulting along the E-W trend had waned, which suggests that the stresses producing the E-W and N50°W fault trends may not be related in time or space.

The ~N50°E trending, down-to-the-southeast normal faults in the eastern Mount Bennett Hills, are parallel to the trend of the eastern Snake River Plain. These N50°E faults do not offset Quaternary units and have not been shown conclusively to offset those of the N50°W or E-W systems of faults. It is unclear from recent studies (Elbring, 1985; Leeman, 1989) whether the margins of the central and eastern Snake River Plain are the result of the downwarping or downfaulting of late Cenozoic volcanic and sedimentary units.

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