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# Geochronology of the Late Cenozoic Volcanism of Yellowstone National Park and adjoining areas, Wyoming and Idaho

by

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# INTRODUCTION

Yellowstone National Park and surrounding regions were the scene of two major episodes of volcanism in the early and latter parts of the Cenozoic. The geochronology of the earliest of these volcanic episodes (the Absaroka Volcanic Supergroup) will be dealt with elsewhere. It is the purpose of this report to document the chronology of the volcanism of the three major eruptive phases of the Yellowstone Volcanic Province. This has been an ongoing study and often the geologic relationships as mapped and the geochronology have been at variance. Only through additional studies both in the field and in the laboratory have most of these differences been resolved. The evolution in methodology employed is detailed in Appendix I but it is sufficient to note that the isotopic analyses showing the smallest analytical uncertainty generally reflect the more recent analyses and the more advanced technologies of the time. In the course of this study more than 200 age determinations were made and 170 of these are reported here.

The Yellowstone Rhyolite Province sits at the eastern end of the Snake River Plain Volcanic Province (Figure 1). The age relations of the volcanic units of the Snake River Plain become younger from SW to NE (from mid Miocene to Late Pliocene-Pleistocene). This NE migration is thought to reflect the SW movement of the North American plate over a mantle hot spot (appropriately named the North American Hot Spot).

Geologic mapping by Christiansen and Blank (1972) reveals that three major ash flow tuffs constitute the bulk of the Yellowstone Plateau rhyolites in which single or multiple cooling units are separated from the others by unconformities. These have been termed, from oldest to youngest, the Huckleberry Ridge, Mesa Falls, and Lava Creek Tuffs. As a certain amount of paleomagnetic data exists for these tuffs and other volcanic units within the park it is necessary to summarize the paleomagnetic chronology established elsewhere. The most recent major review, that of Mankinen and Dalrymple (1979) summarizes the ages for the boundaries of the magnetic polarity chrons and subchrons (see Table 1). However, this time scale has recently been challenged by one derived from astronomical studies employing Milankovitch cyclicities. this new time scale, displayed as a composite of the works of Shackleton et al. (1990), Hilgen (1991), and Langereis and Hilgen (1991) is compared to that of Mankinen and Dalrymple in Figure 1. The astronomical time scale is some 5-7% older than the isotopically derived scale over the past 5 m.y. This difference is difficult to accept but unfortunately has proved to be true for the Brunhes/Matuyama boundary (Izett and Obradovich, 1991 and Baksi et al., 1991a) and may well be true for the Reunion subchron(s) (Izett and Obradovich, unpublished data; Baksi et al., 1991b). The question that comes to mind is why the significant difference in time scales? The reason for the prior minimum value for the age of the Brunhes/Matuyama boundary is that sanidine for the normally magnetized Bishop Tuff (the constraining data point) was not totally degassed when the argon was extracted from the sample (Izett and Obradovich, 1991). This same phenomenon is now becoming to be widely recognized when $^{40}Ar/^{39}Ar$ results are compared to conventional K-Ar results for the same sample (Deino et al., 1989). The degree to which sanidines may or may not be totally degassed varies from sample to sample so that no generalization can be made except to say that the values cited may be too young. Despite the efforts made in this study to insure that all samples were adequately degassed this admonition may apply to the Yellowstone data. The generalized age sequences described here are valid but the accuracy of the ages presented may, in some instances, be in question.

The reason why the sanidine ages are too young, however, will not suffice for the whole rock basalt results which form the bulk of the data base for the past 5 m.y. or so. Here we would have to invoke an explanation that all basalts in general suffer diffusive loss of $^{40}Ar^*$ (radiogenic $^{40}Ar$) to the same degree regardless of age or that there is an imperceptible degree of alteration to the main K bearing phase (groundmass glass) resulting in the same degree of discordancy. Considering the contrasting data $^{40}Ar/^{39}Ar$ vs conventional K-Ar) now becoming available for sanidines it is easy, but none the less disconcerting, to accept the rationalization that all whole rock basalt data are too young despite the considerable efforts made to establish the working criteria for acceptable samples (see Dalrymple and Lanphere, 1969 and McDougall, 1964). Based on the results for the Bishop Tuff and the preliminary results relating to the Reunion subchron (if there is but a single event), and the age for the Wapiti Lake flow (see Third Volcanic Cycle), I am forced to accept, at least in part, the composite time scale of Shackleton et al. (1990), Hilgen (1991), and Langereis and Hilgen 1991) for the past 2.2 Ma.

## THE ERUPTIVE HISTORY OF YELLOWSTONE NATIONAL PARK

### First Volcanic cycle

The Huckleberry Ridge Tuff [2], the first of the three major rhyolitic eruptions (Figure 2), is represented by a thin (2 meter) airfall deposit and three welded tuffs (members A, B, and C) with a composite thickness of approximately 170 meters. The total eruptive volume of the members of the Huckleberry Ridge Tuff exceed 2,500 $km^3$ As all three members of the Huckleberry Ridge Tuff have a transitional magnetic polarity (Reynolds, 1977) the separate caldera forming

[2] The reader is advised to have MAP I-711 and GQ-1189, 1190, 1191, and 1193 on hand to assist in the following presentation.

eruptions were emplaced in a very brief period of time (possibly on the order of 10,000 years). During the First Cycle the eruptions of the Huckleberry Ridge Tuff were preceded by flows of the Junction Butte Basalt currently exposed in the valley of the Yellowstone River and on Mount Everts and the Rhyolite of Snake River Butte. Paleomagnetic properties summarized by Christiansen (per. comm.) indicate that the basalt flows have both a reversed and and normal polarity while that of the rhyolite is normal. Considering these polarities and their stratigraphic positions and assuming a single Reunion subchron I can only conclude, using Table 1, that the Junction Butte Basalt is both pre Reunion and Reunion in age. The Rhyolite of Snake River Butte is within the Reunion subchron while the Huckleberry Ridge Tuff is at the younger transition boundary of the subchron. Looking at Table 2a for the age data covering these flows one sees that the age for for the Junction Butte Basalts are acceptable while the age for the sanidine from the Rhyolite of Snake River Butte is clearly too young for the scenario outlined.

Before passing on to the age of the Huckleberry Ridge Tuff it should be noted that the Rhyolite of Broad Creek, which Christiansen and Blank (1972) placed in the First Volcanic Cycle, has now been removed from this cycle and placed in the the Mount Jackson Rhyolite of the Third Volcanic Cycle by Hildreth et al. (1984) without explanation for this change. Although Christiansen and Blank (1972) state that the Rhyolite of Broad Creek "appears to be conformable beneath the overlying welded tuff" and also that it "underlies the Huckleberry Ridge Tuff" it would appear that the significantly different $\delta^{18}O$ value for quartz from the Rhyolite of Broad Creek when compared to that of the Huckleberry Ridge Tuff prompted Hildreth et al. (1984) to reassess its field relationship to the Huckleberry Ridge Tuff members A and B at the Broad Creek locality (see Christiansen and Blank, GQ-1192, 1975). It may well be that a preliminary K-Ar age of 1.15 Ma for the Rhyolite at Broad Creek helped influence their decision (see Table 2c).

Table 2a provides a tabulation of all K-Ar data for the Huckleberry Ridge Tuff. A straightforward weighted mean results in an age of 2.018 ± 0.0079 Ma (one sigma). These data are also plotted on an $^{40}Ar_{(total)}/^{36}Ar$ vs $^{40}K/^{39}Ar$ isochron diagram (Figure 3) and the data regressed according to York (1969). This type of plot has the advantage of not assuming any predetermined value for the isotopic composition of atmospheric argon (295.5; Neir, 1950). The result in this case is an age of 1.99 ± 0.0093 Ma with an intercept of of $(^{40}Ar/^{39}Ar)_i = 304.4 \pm 46.1$. An MSWD (Mean Square Weighted Deviate) of 10.8 indicates scatter in the data which far exceeds that attributable to analytical uncertainty alone. Recalling the quantifier mentioned earlier it may well be that much of the data for the Huckleberry Ridge Tuff is strictly minimal and that the true age may be older than the age of 1.99 Ma arrived at. A second regression of selected data (i.e., the more precise and oldest ages) results in an age of 2.11 Ma ± 0.008 Ma with an MSWD of 4.46. There is still an indication of excess scatter in the data but the age of 2.11 Ma is in agreement with the preliminary $^{40}Ar/^{39}Ar$ unpublished results for the Huckleberry Ridge Tuff of 2.09 - 2.11 Ma. This result would be more in keeping with the age of the single Reunion subchron of the Shackleton et al. (1990) time scale.

Four post-Huckleberry Ridge Tuff and pre(?)-Mesa Falls rhyolitic lavas and one tuff have been designated the Big Bend Ridge Rhyolite (Christiansen, 1982). It was unclear then to Christiansen whether these flows and tuff should be considered as comprising post-collapse flows of the first cycle, pre-collapse flows of the second cycle, or a combination of both. The Blue Creek and Headquarters flows have normal paleomagnetic polarities. This along with petrographic and geochemical studies suggests a relationship to the first magmatic cycle. Dating of sanidine from these flows (Table 2a) reveals that this indeed the case, With the limited data these flows clearly belong to the Olduvai subchron although the mean ages do not fit the stratigraphic order (i.e., the headquarters flow overlies the Blue Creek flow).

Although the Bishop Mountain and Green Canyon flows have reversed paleomagnetic directions and differ petrographically and geochemically from the Headquarters and Blue Creek flows they, along with the tuff of Lyle Spring, have been included in the Big Bend Ridge Rhyolite. The ages determined for the Bishop Mountain and Green Canyon flows and the Tuff of Lyle Spring (see Table 2b) of approximately 1.2 - 1.3 Ma indicated that they are indeed part of the Second Volcanic Cycle. It would seem more appropriate and less confusing to restrict the term Big Bend Ridge Rhyolite to only the Headquarters and Blue Canyon flows and to place the Bishop Mountain, Green Canyon flows along with the Tuff of Lyle Spring into a newly designated unit. These results will be discussed more fully in a latter section.

The last units previously considered to be part of the First Volcanic Cycle have been the Basalts and Sediments of the Narrows. A series of ages determined on sanidine from ashes interbedded with the sediments have grouped around 1.5 Ma (see Table 2b). Attempts to date the Basalts of the narrows have not been successful in that the samples have very large analytical uncertainties. There has been a long standing disagreement regarding the age of the ashes of the Narrows. G. Izett (per. comm.) has always insisted that the geochemistry of the glass shards of these ashes showed affinities to the Mesa Falls Tuff and therefore the ashes should be younger in age or nearer to 1.3 Ma. Recent preliminary $^{40}Ar/^{39}Ar$ results on selected hand-picked sanidine crystals resulted in an age of 1.29 Ma. Taken at face value I would have to conclude that the prior sanidine concentrates were simply mixtures of sanidine from the Huckleberry Ridge and Mesa Falls Tuffs. There was one determination (DKA 2100) that was simply ignored as being too young because of suspected partial degassing of the sanidine melt. However, this younger age may be tending toward the correct age because of a smaller level of contamination of Huckleberry Ridge sanidine.

In summary the only definite post-collapse volcanism recognized are the two flows of the Big Bend Ridge Rhyolite having normal paleomagnetic polarities and which are assigned to the Olduvai subchron. The First Cycle Volcanism as currently recognized spanned an interval of approximately 400,000 years from 2.2 to 1.8 Ma.

## Second Volcanic Cycle

The Second Volcanic Cycle was the smallest of the three and as we shall see, the existing record is the briefest of the three. The second volcanic cycle was centered in an area nestled within the first cycle caldera (see Figure 2) and rhyolites of this cycle are exposed only within the Island Park area. The main eruptive phase, the Mesa Falls Tuff, had a volume of more than 280 $km^3$. The Mesa Falls Tuff varies greatly in thickness but has a maximum thickness of about 150 meters where exposed on Thurmon Ridge, the northern rim of Island Park. The Mesa Falls Tuff is lithologically the most distinctive of the three ash flow sheets of the Yellowstone Group having abundant, very large phenocrysts, especially the unbroken sanidines which often are as large as 2-3 cm. The Mesa Falls Tuff represents a single cooling unit in contrast to the compound cooling units of the Huckleberry Ridge and Lava Creek Tuffs.

The K-Ar results on sanidine from the basal air fall and from distal pumice yield an unweighed mean age of 1.27 ± 0.013 Ma. An $^{40}Ar_{(t)}/^{36}Ar$ vs. $^{40}Ar/^{39}Ar$ isochron plot yields an age of 1.25 ± 0.003 Ma with an MSWD of 0.84. These results are in good agreement with the preliminary $^{40}Ar/^{39}Ar$ age of 1.29 Ma on ashes from the Narrows indicating that here at least the sanidine melts were essentially completely degassed.

According to Christiansen (1982) the Bishop Mountain and Green Canyon Flows are pre-collapse rhyolites and so should have ages older than or near to the age of the Mesa Falls Tuff. The oldest results for the Bishop Mountain and Green Canyon Flows have means that are near 1.22 Ma. It must be admitted though that these results may simply be a minimum because of incomplete degassing of the sanidines and that they should be closer in age to the tuff of Lyle Spring(1.32 Ma). This interpretation would be given added weight in view of the fact that a post collapse rhyolite (the Moonshine Mountain Flow of the Island Park Rhyolite (Hildreth et al., 1984)) is now correlated chemically and mineralogically with the Bishop Mountain Flow and is probably its down faulted vent dome. The Moonshine Mountain Flow has been dated at 1.26 ± 0.02 Ma. (DKA 4590; Table 2b). However, statistically this result is indistinguishable from the result of 1.21 ± 1.22 Ma or for that matter from 1.32 Ma.

What is disconcerting about all of this is the fact that Christiansen (1982; Figure 2, explanation) indicates that the Moonshine Mountain dome is younger than the Silver Lake dome. Clearly there must be some geologic feature to establish this relationship. However, if Moonshine Mountain is now pre Mesa Falls Tuff in age then Silver Lake dome should also be older. Yet in Figure 1 of Christiansen and Embree (1987) Silver Lake dome is shown as being the same age as all of the domes of the Island Park Rhyolites. The geologic map of the Island Park area (Christiansen (1982; Figure 2) is shown as Figure 5 with the explanation 5a taken from Christiansen (1982) and explanation 5b taken from Christiansen and Embree (1987).

Six small domes crop out within or adjacent to the Henry's Fork Caldera and are termed the Island Park Rhyolite (Christiansen (1982). These six are the Moonshine Mountain (now correlated with the Bishop Mountain Flow and considered as its downfaulted vent dome), Silver Lake, Osborne Butte, Elk Butte, Lookout Butte, and Warm River Butte domes (Figure 5). Because the remaining five domes stand above the floor of the second cycle Henry's Fork caldera they must post date the Mesa Falls Tuff and the penecorntemporaneous caldera collapse. The Lava Creek Tuff that was later emplaced into the Henry's Fork caldera has normal magnetic polarity (i.e., < 0.78 Ma) but the domes of the Island Park Rhyolite have reversed polarities (> 0.78 Ma) and must be older than 0.78 Ma and predate the Lava Creek Tuff.

The Island Park Rhyolite is lithologically distinctive consisting of extremely phenocryst-rich rhyolite. The phenocrysts generally constituent more than half the rock and petrographically are similar to the Mesa Falls Tuff.

Only the Osborne Butte and Warm River Butte domes have been dated at 1.28 ± 0.01 Ma (DKA 3114) and 1.27 ± 0.02 Ma (DKA 4588), respectively (Table 2b). Clearly these results are extremely close to that for the Mesa Falls Tuff and provides a constraint on the timing of caldera collapse after the eruption of the Mesa Falls Tuff.

In contrast to the time span of approximately 400,000 years for the pre and post collapse volcanism of the First Volcanic Cycle the Second Volcanic Cycle as currently recognized was extremely brief lasting perhaps 50,000 years if one discounts the ages for the Bishop Mountain and Green Canyon Flows. In this regard it is somewhat disturbing to have the results for the Island Park Rhyolite domes fall so close to that for the Mesa Falls Tuff (and the Tuff of Lyle Spring) but to have the ages for the supposed precollapse rhyolites turn out to be younger than the postcollapse Island Park domes!

## Third Volcanic Cycle

Volcanic activity of the Third Cycle began shortly after the cessation of volcanism of the Second Cycle. The locus of activity, however, shifted away from the Island Park area to the Yellowstone Plateau (Figure 2 and Figure 6).

The Mount Jackson Rhyolite (one of the two pre Lava Creek units) was defined by Christiansen and Blank (1972) to include rhyolitic lava flows essentially conformable beneath the Lava Creek Tuff of the Yellowstone Group in areas near the wall of the Yellowstone Caldera. The seven flows of the Mount Jackson Rhyolite along with the Lewis Canyon Rhyolite that constitute the pre caldera flows are:

| | |
|---|---|
| Flat Mountain | 0.926 Ma |
| Wapiti Lake | 1.17 Ma |
| Moose Creek Butte | 1.23 Ma |

| | | |
|---|---|---|
| Jackson Rhyolite | Harlequin Lake | 0.822 Ma |
| | Broad Creek Rhyolite | 1.06 Ma |
| | Mount Haynes Flow | 0.626 Ma |
| | Big Bear Lake | |
| Lewis Canyon Rhyolite | | 0.93-0.97 Ma |

Of the eight flows just listed seven have been dated and the ages reveal an interesting time span with the Moose Creek Butte flow close in age to the Island Park Rhyolites (Table 2c). This activity (see Figure 6) is on the southwest part of the Yellowstone Caldera and on the southeastern margin of the Henry's Fork Caldera. Volcanism then shifted to the extreme northeastern margin of the Yellowstone Caldera with the eruption of the Wapiti Lake and Broad Creek Rhyolites in the interval around 1.15 - 1.17 Ma.

The Wapiti Lake flow has a horizontal paleomagnetic direction and with its age of 1.17 Ma may correlate with the Cobb Mountain subchron (Mankinen and Dalrymple, 1979).

There is a set of data for the Tuff of Sulphur Creek (early postcaldera rhyolite of the Third Volcanic Cycle) at the Broad Creek locality (see Table 2d) that merits mention. Sample 9YC492 (locality at 110° 16.82' and 44° 43.61') from a crescent or C shaped flow yielded results for sanidine and plagioclase of 0.948 Ma (s), 1.11 Ma (pl) and 1.04 Ma (pl). Either this lobe of the Tuff of Sulphur Spring contains a portion of older rhyolite and thus the results have no meaning regarding the actual age of the flow or this crescent shaped outcrop is really not part of the Tuff of Sulphur Creek. Note that on GQ-1192 (Christiansen and Blank, 1975) this C shaped segment is actually mapped as a separate unit. Could it instead belong to the Wapiti Lake-Broad Creek Rhyolite complex?

The next younger flows, Flat Mountain and Harlequin Lake, of the Mount Jackson Rhyolite and the Lewis Canyon Rhyolite are dated at 0.92 Ma, 0.84 Ma, and 0.93 - 0.97 Ma respectively. The undated Big Bear Lake flow with its normal magnetic polarity can only fall in the interval of 0.61 - 0.78 Ma (i.e., older than the Lava Creek Tuff and pre Brunhes/Matuyama boundary) or within the Jaramillo subchron (0.99 - 1.07 Ma).

The youngest flow of the Mount Jackson Rhyolite, the Mount Haynes flow, is essentially penecorntemporaneous with the eruption of the Lava Creek Tuff having an age of 0.609 ± 0.009Ma.

The Mount Jackson Rhyolites share a characteristic abundance of phenocrysts (30-50% by volume) and large size (1-4mm). Quartz, sanidine, and minor plagioclase are the principal phenocrysts. By contrast, the Lewis Canyon Rhyolite, while falling in the same general time framework, is petrographically different from the Mount Jackson Rhyolite. It contains quartz, abundant embayed plagioclase, but sparse sanidine.

Figure 7 shows that all flows of the Mount Jackson Rhyolite and the Lewis Canyon Rhyolite lie near the margin of the Yellowstone Caldera and that all had their vent areas in or near what was subsequently to become the compound ring-fracture zone of the caldera. Whereas the known precaldera eruptive phase of the First and Second Volcanic Cycles was on the order of 100,000 years or less the precaldera eruptive phase for the Third Volcanic Cycle took place over a period of some 600,000 years; this magmatic insurgence, ring-fracturing, and eruption correspond to stage I of the resurgent cauldron cycle of Smith and Bailey (1968), encompassing regional tumescence and generation of ring-fractures, with occasional outpouring of rhyolitic magma.

Relatively minor basalt was erupted during this precaldera phase. The Warm River Basalt which lies between the Mesa Falls and Lava Creek Tuffs has an age of 0.752 ± 0.052 Ma. The fact that it has a reversed magnetic polarity implies that it should be older than 0.78 Ma; the low radiogenic $^{40}Ar$ content and the rather large analytical uncertainty would certainly allow for this basalt to be within the latest Matuyama polarity chron.

The only other basalt belonging to the precaldera phase is the Undine Falls Basalt which has an age of 0.585 ± 0.026 Ma. The fact that it is pre Lava Creek in age and has a normal magnetic polarity means that its age should fall in the interval of 0.78 - 0.61 Ma. Statistically the Undine Falls Basalt is just pre-Lava Creek in age.

The Lava Creek Tuff was emplaced about 0.62 Ma (see Table 2c). Just four of the eleven analyses are thought to represent valid results and a weighted mean results in an age of 0.617 ± 0.004 Ma. The analysis for Notch Mountain was based on a very limited amount of material with probe analysis for potassium.

Some 1000 $km^3$ of rhyolitic pumice and ash were erupted from vents within the area of magmatic insurgence outlined by the Mount Jackson Rhyolite which surround the Yellowstone Caldera. The Lava Creek Tuff is composed of two ash flows, Members A and B. Member A is exposed mainly in western and north central Yellowstone Park while ash flow tuff of Member B is exposed widely in and around the Yellowstone Rhyolite Plateau and southwest to the margin of the Snake River Plain. In several areas the Lava Creek Tuff is more than 300 meters thick. All parts of the Lava Creek Tuff have phenocrysts of quartz, sanidine, and subordinate plagioclase. Hornblende is the dominant mafic constituent in glassy portions of Member A, the only rhyolite of the volcanic field of which this is true while it is rare in Member B. Christiansen (in press) indicates that the source areas for members A and B within the Yellowstone caldera were slightly different. Although the Yellowstone caldera forms a single topographic basin it comprises two distinct structural entities as shown by its two resurgent domes, the Mallard Lake and Sour Creek domes (Figure 6). These domes lie near the centers of two approximately circular overlapping segments which together give \the compound Yellowstone caldera an elliptical shape. Eruption of the Lava Creek Tuff represents stage II of the resurgent cauldron cycle of Smith and Bailey (1968).

Smith and Bailey (1968) describe caldera collapse as stage III of the resurgent cauldron cycle, indicating that it shortly follows (by perhaps a few years) the ash flow eruptions of stage II. Using the Valles Caldera as an example Smith and Bailey hypothesize that stage IV (minor pyroclastic eruptions) and stage V (resurgent doming; Figure 6) take place in less than 100,000 years. In the Yellowstone Caldera stages IV and V are beyond the resolution of the dating method. The Canyon Flow which overlaps the Sour Creek dome has an age of 0.623 ± 0.011 Ma based on a single analysis of plagioclase. This would place resurgent doming of the Sour Creek structure within an extremely brief period after the eruption of the Lava Creek Rhyolite, possibly less than 10,000 years.

The Mallard Lake Dome, while originally thought by Christiansen and Blank (1972) to be similar in age to the Sour Creek dome , has proved to be markedly younger (circa 150-160,000 years) and will be discussed later.

## Plateau Rhyolitic Volcanism

The post collapse rhyolites of the Third Volcanic Cycle were named the Plateau Rhyolite by Christiansen and Blank (1972) and were divided into the following members:

| | |
|---|---|
| | Upper Basin Member |
| Intracaldera Members | Mallard Lake Member |
| | Central Plateau Member |
| Extracaldera Members | Obsidian Creek member |
| | Roaring Mountain Member |

All have similar mineralogies, distributions, and age relations to various caldera events. Volcanic eruptions have taken place intermittently following resurgent doming (see Canyon Flow) to about 70-80,000 years ago. It is questionable as to whether or not volcanism of the Third Volcanic Cycle is complete.

## Upper Basin Member (Intercaldera)

Flows of the Upper Basin Member occur low in the caldera and have a distribution and lithology different from younger rhyolites within the caldera. In particular they are plagioclase rich and are exposed in two areas, each adjacent to one of the resurgent domes.

Two flows of the Upper Basin member occur west and southwest of the Mallard Lake dome. The older of these, the Biscuit Basin flow, has an age of 0.542 ± 0.042 Ma (DKA 1867) and possibly post dates the initial uplift of the Mallard Lake dome. The Biscuit Basin flow is overlain by another plagioclase-rich rhyolite, The Scaup Lake flow, that is dated at 0.275 ± 0.011 Ma (DKA 2442).

A somewhat more complex sequence occupies a corresponding position on the northern and northeastern flanks of the Sour Creek dome. In the Grand Canyon of the Yellowstone the base of the exposed post resurgent sections is the welded ash flow tuff of Uncle Tom's Trail. The tuff contains large angular blocks of andesite of Absaroka affinity. Overlying this is a complex of rhyolitic flows and tuffs. The entire sequence is listed below:

| | |
|---|---|
| Scaup Lake flow | 0.275 ± 0.011 Ma |
| Biscuit Basin flow | 0.542 ± 0.042 Ma |
| Dunraven Road flow | imprecise results |
| Canyon flow | 0.613 ± 0.011 Ma |
| Tuff of Sulphur Creek | contaminated |
| Tuff of Uncle Tom's Trail | not dated |
| Lava Creek Tuff | 0.617 ± 0.004 Ma |

Sanidine from the Tuff of Sulphur Creek at the Grand Canyon was analysed but clearly this result is anomalous indicating contamination of the sample by reworking of older pumice into the sequence during airfall deposition. The sample of the Tuff of Sulphur Creek at the Broad Creek locality has been discussed earlier. While the ages of 0.95 - 1.1 Ma are again too old for the strratigraphic sequence outlined above there remains the possibility that this lobate flow may be part of the Mount Jackson Rhyolite. Future work should clarify this issue.

The age of the Dunraven Road flow has proved to be particularly troublesome. All attempts to date the obsidian have resulted in low radiogenic contents (approximately 3%) and as a result imprecise ages. The most precise age (DKA 2497) for the plagioclase sample is, unfortunately, too old for the stratigraphic succession, clearly older than the age of the Lava Creek Tuff.

Except for the result for the Dunraven Road flow all other ages fit the sequence outlined above. Again except for the age of the Scaup Lake flow most of the ages for the other flows of the Upper Basin Member of the Plateau Rhyolite are close in age or are constrained to be close in age to the Lava Creek Tuff and are clearly early in the post resurgent phase of volcanism.

## Obsidian Creek Member (Extracaldera)

Early post-Lava Creek rhyolitic lavas occur outside the caldera forming the Obsidian Creek member of the Plateau Rhyolite. Volcanic edifices that form most of the Obsidian Creek member are the Paintpot Hill, Geyser Creek, Gibbon Hill, Landmark, Appolinaris Spring, and Willow Park domes.

The Obsidian Creek Member generally seems to be conformable on the Lava Creek Tuff outside the Yellowstone caldera All known flows of the Obsidian Creek Member occur in a linear trend within a zone of recurrent faulting that extends from the caldera rim in the vicinity of Norris Geyser Basin northward toward Mammoth Hot Springs. It is also the locus of both early and late post caldera rhyolitic eruptions and of pre and post Lava Creek basaltic vents.

Only two flows of the Obsidian Creek Member were dated. The Willow Park dome was dated at 317 ± 5 Ka[3]. The Gibbon Hill dome (sampled at Hill 8065, GQ-1193)was dated at 116 ± 10 Ka (DKA 4519) and may just be older than the overlying Pitchstone Plateau flow of the Plateau Rhyolite. This age determination was performed at a time when only large spikes were available (see Appendix I) and as a result the analysis was not performed under the most ideal conditions. None the less, it does indicate that eruption of the Obsidian Creek Member took place over some 200 k.y. or possibly more if the Willow Park Dome is not the oldest of the Obsidian Creek domes.

Christiansen and Blank (1972) originally defined a Shoshone Lake Tuff Member of the Plateau Rhyolite but at a later date (see GQ-1192, Christiansen and Blank, 1975) it was found to comprise more than one stratigraphic unit and was abandoned. This tuff member is now designated the Tuff of Bluff Point of the Plateau Rhyolite and was dated at 162 ± 2.2 Ka.

### Roaring Mountain Member (Extracaldera)

Before discussing the other intracaldera members the remaining extracaldera member, the Roaring Mountain Member will be treated. This member consists of four phenocryst free or phenocryst poor rhyolitic lavas, the Crystal Spring, Obsidian Cliff, Cougar Creek, and Riverside flows. Roaring Mountain is in the vicinity of the Crystal Spring and Obsidian Cliff flows which occur in the same belt as the Obsidian Creek Member. All flows contain abundant black obsidian with few or no phenocrysts.

Obsidian from three of the four flows and sanidine from one were dated and yielded the following results (Table 2e):

| | |
|---|---|
| Crystal Spring flow | 80 ± 2 Ka |
| Obsidian Cliff flow | 183 ± 3 ka |
| Cougar Creek flow | 401 ± 4 Ka, 393 ± 7 Ka (s) |

[3] For sake of clarity, ages in the following discussion of the members of the Plateau Rhyolite will be given in Ka.

Although Christiansen and Blank (1972, pg. B15) raised a question about the reliability of obsidian as a chronometer it is clear from the results for the Cougar Creek flow and from Table 2 that the K-Ar ages on obsidian and co-occurring sanidine are generally concordant. Only two of the eleven pairs listed are significantly discordant:

| | | |
|---|---|---|
| Wapiti Lake flow | S | 1.17 ± 0.01 Ma |
| | Ob | 1.22 ± 0.06 Ma |
| West Thumb flow | S | 147 ± 4 Ka |
| | Ob | 158 ± 11 Ka |
| Aster Creek flow | S | 155 ± 3 kA |
| | Ob | 193 ± 3 Ka |
| West Yellowstone flow | S | 120 ± 3 ka |
| | Ob | 108 ± 3 Ka |
| Bechler River flow | S | 112 ± 3 Ka |
| | Ob | 119 ± 3 Ka |
| Summit Lake flow | S | 131 ± 3 Ka |
| | Ob | 103 ± 3 Ka |
| Bechler Meadows flow | S | 106 ± 4 Ka |
| | Ob | 131 ± 8 Ka |
| Grants Pass flow | S | 72 ± 3 Ka |
| | Ob | 82 ± 3 Ka |
| Gibbon River flow | S | 159 ± 51 Ka |
| | Ob | 138 ± 3 Ka |
| Cougar Creek flow | S | 393 ± 7 Ka |
| | Ob | 401 ± 4 Ka |
| Sediments of Hot Springs | S | 170 ± 5 Ka |
| | Ob | 169 ± 5 Ka |

Central Plateau Member (Intracaldera)

The last of the intracaldera members of the Plateau Rhyolite, the Central Plateau Member, consists of twenty one separate flows, tuff and domes, sixteen of which have been dated (Table 2f). In order to discuss the chronology of these units objectively the specific stratigraphic relationships as deduced from GQ's 1189 (Christiansen and Blank, 1974a), 1190 (Christiansen and Blank, 1974b), 1191 (Christiansen, 1974a), and 1193 (Christiansen, 1974b) are displayed graphically in Figure 8. All bodies in a single vertical column are in contact with one another. The most reliable ages (those utilizing metered spikes and the latest in measuring H&circuitry; see Appendix I) are also listed. It seems clear that some units of the Central Plateau member were erupted prior to the late resurgent doming of the Mallard Lake structure despite the comments of Christiansen and Blank (1972) to the contrary. These are the Buffalo Lake flow, Tuff of Bluff Point, Dry Creek flow and the Nez Perce Creek flow (more on this unit later). These flows were emplaced in the interval of 160-165 Ka (Table 2f).

Because the Mallard Lake Member consists of a single flow whose age is similar to the ages of the older flows of the Central Plateau Member it is included in this section. The Mallard Lake flow erupted after the above mentioned flows with subsequent doming and fracturing. Within a time interval too short to be resolved by the K-Ar method the following units were emplaced: West Thumb, Elephant Back, Aster Creek, Spruce Creek, Spring Creek, and the Tuff of Cold Mountain. The later three flows were not dated and are grouped here for convenience. The Tuff of Cold Mountain and Spring Creek flow are older than the Summit Lake flow while the Spruce Creek flow is older than the Nez Perce Creek flow in the vicinity of Mary Mountain.

In examining the ages and relationships of these two groups it is clear that the only anomalous result is that for the Nez Perce Creek flow. It should be pointed out, however, that all ages were determined on samples from the western end of the flow (Firehole River and Upper Mesa Road; see GQ-1190, Christiansen and Blank, 1974b) while the stratigraphic relationships were established at the eastern vent area around Mary Mountain (see GQ-1193, Christiansen, 1974b). While the Nez Perce Creek flow is inferred to overlie the Elephant Back flow in the area of Nez perce Creek (Christiansen and Blank, 1974b and Christiansen, 1974b) this relationship can not be documented because Quaternary alluvium separates the two flows in this region. It is only in the area of Mary Mountain that the Nez Perce Creek flow (as mapped) overlies the Spruce Creek flow which in turn overlies the Elephant Back flow. If the Nez Perce Creek flow is a single flow unit and the age of approximately 165 Ka is correct then the geochronology for all the underlying units (except for the Tuff of Bluff Point, Dry Creek flow, and Mary Mountain flow) are incorrect and simply too young (ie., incomplete degassing of sanidine). However, it is worthwhile examining GQ-1193 (Christiansen, 1974b) and to observe some very strange relationships of the Nez Perce Creek flow. First of all, the Nez Perce Creek flow nearly wraps itself around the Mary Mountain flow, first going northwest from the vent, then turning and going west and finally going due south while the main body of the flow goes to the west before ending at the Fire Hole River. Secondly, in going across Magpie Creek the Nez Perce Creek flow gains approximately 200 feet (approximately 61 meters) in elevation cresting to the southeast of Canyon Creek before flowing to the northwest and producing the fingers of Qpcn? which crop out under Gibbon River flow. In the absence of any other evidence it is my contention that the Nez Perce Creek flow is a compound flow, the older portion (i.e., 165 Ka) having its source area now hidden by either the Gibbon River or Solfatara flows. The younger part of the Nez Perce Creek flow would have its vent area as now mapped in the Mary Mountain region, would have a flow front somewhere to the southeast of Magpie Creek (perhaps somewhere below the 7800 foot contour level), and would have an age of perhaps 150 Ka. Such a scenario would quite simply resolve the major discrepancy of the current mapping and geochronology. Dating of both the Nez Prece Creek and Spruce Creek flows in the vicinity of Mary Mountain would certainly clarify this issue.

The youngest of the Plateau Rhyolite flows fall into two groups that are readily separated in time. The older of these are comprised of the Summit Lake, West Yellowstone, Bechler River, Hayden Valley, and Solfatara flows. From Table 2e these flows can be seen to fall into the time interval of roughly 110 - 135 Ka.

There is the distinct possibility that what has been mapped as the Gibbon River flow is indeed two flows of widely different age. There is the indication of a domal region in the vicinity of Hill 8065 (GQ-1193; Christiansen, 1974b) and a sample of obsidian from this dome was dated at 138 ± 3 Ka while a sample of obsidian from the vent area (Hill 8540) was dated at 90 ± 2 Ka. If this were a single flow then the older age would be incorrect (for whatever reason) as the Gibbon River flow overlies the Solfatara flow dated at 110 ± 3 Ka.

The results for the Summit Lake flow are conflicting in that sanidine from near the vent region was dated at 131 ± 3 ka while sanidine from what is now mapped as the flow front was dated at 105 Ka and 106 Ka on different samples collected during trips to this area. What was once mapped as Buffalo Lake flow (see Map I-711; U.S. Geological Survey, 1972) is now mapped as the Summit Lake flow (see GQ-1189; Christiansen and Blank, 1974a). It may be possible that these sanidine samples were not completely degassed but it would seem somewhat fortuitous to achieve the same result on two different samples. For the present time these results are considered anomalous awaiting future study to resolve this issue.

The youngest of the Plateau Rhyolites consists of the Pitchstone and Grants Pass flows dated at 70 ± 2 ka and 72 ± 3 Ka respectively. The youngest portion of the Gibbon River flow (90 ± 2 Ka) is also considered part of this eruptive phase.

From the flows dated it appears that we have had quiescence for some 70,000 years although some of the undated basalt flows could be younger than this.

The Third Volcanic Cycle is thus seen to encompass nearly 1.3 m.y. of time, far longer than either the First or Second Volcanic Cycles and the chronology unveiled in this study is perhaps the most detailed for any resurgent cauldron sequence in the sense of Smith and Bailey. The one question that remains though is have we witnessed the last of volcanism in the Yellowstone region? If the same tectonic driving forces remain the same (i.e., migration of the North American plate over a mantle plume or hot spot) the answer is no. However, it is difficult to estimate how soon this may occur or to say whether we are still in the latest stage (stage VII) of the Third Volcanic Cycle or whether we are entering stage I of the Fourth Volcanic Cycle.

## DATING OF VOLCANIC TEPHRA IN SEDIMENTS OF THE PARK

Although an effort was made to date ash falls and tuffs in the late Quaternary sediments of the Park some 50% of the analyses gave results that are obviously too old and contain volcanic material of detrital origin. The significance of the remaining ages with respect to the glacial deposits of the Park has been more than adequately addressed by G.M. Richmond (Richmond, 1986 and 1987). I wish merely to document the analytical data associated with the ages cited in the above mentioned references (see Table 3).


## ACKNOWLEDGEMENTS

I wish to thank Gerald Cebula and Jack Groen for their efforts in providing the many mineral separates for this study. I also wish to thank Harald Mehnert for his assistance in argon extractions and mass spectrometry and for keeping the equipment functioning during this time.

## APPENDIX I

As this study has spanned a number of years the analytical techniques used to measure the isotopic composition of the argon extracted from the various minerals and whole rock basalts and obsidian samples evolved and became more reliable and precise. All argon samples were analysed in the static mode (Reynolds, 1968) using a 6", 60- magnetic sector single focusing mass spectrometer. The ion current was amplified using a vibrating reed electrometer (VRE, Cary Model 31) with a $10^{11}$ohm input resistor. Initially the amplified signal was displayed on a poteniometric recorder and the signal intensities read using an accurately ruled measuring rod. However, such a system has inherent problems such as slide wire wear with resultant nonlinearity, inability to measure small signals (primarily $^{36}Ar$) with any degree of precision, and possible analyst bias. Argon spikes (or tracers)) of approximately $3x10^{-11}$ moles of enriched $^{38}Ar$ were employed. Such spikes were suitable for samples which were 1-2 Ma in age but required inordinately large samples when dealing with rocks as young as 100,000 years. A major change was initiated around 1970 when an expanded scale system of recording was employed (Shields, 1966). This resulted in a ten fold gain in precision in measuring the $^{40}Ar$ and $^{39}Ar$ but no appreciable gain was made in measuring the $^{36}Ar$ signal because of lack of improvement in the signal to noise ratio in the most sensitive range of amplification. A metering valve was next employed to manufacture tracers of approximately $5x10^{-11}$ moles of $^{36}Ar$. This greatly reduced sample requirements (1 gram of sanidine at 1 Ma and approximately 10-15 grams at 100,000 years) Introducing nearly half of the argon gas sample into the mass spectrometer (actually the volume of gas analysed was roughly the same) in contrast to the 10 percent normally used with the larger tracers resulted in a ten fold gain in the amplitude of the $^{36}Ar$ signal with attendant gain in precision. With a sizable $^{36}Ar$ signal even for young samples, the complicating factor of a low radiogenic $^{40}Ar^*$ content was substantially mitigated.

A third stage of improvement came in 1972 when an integrating digital voltmeter (IDV) was used to measure the voltage from the VRE. The signal from the IDV was then fed to a minicomputer (PDP11 initially and then at a later time an HP 9830A) and the $^{40}Ar/^{38}Ar$ and $^{40}Ar/^{36}Ar$ were determined when the mass spectrometer run was completed and the ratios subjected to a linear regression analysis to determine the initial composition of the gas when first introduced into the mass spectrometer. At this stage the $^{40}Ar/^{38}Ar$ ratios could be determined with a coefficient of variation of less than 0.1 percent (typically 0.02-0.03%)) while the $^{38}Ar/^{36}Ar$ ratio would be measured with a coefficient of less than 0.25 percent. These precision values indicate only how well the isotopic composition of the gas can be determined but do not take into consideration factors such as excess radiogenic argon, possible sample inhomogeneity, or incomplete degassing of the sample during fusion (a problem with the more viscous rhyolite samples).

Argon was extracted from all samples using RF induction heating. The extraction apparatus and techniques for gas purification follows that of Evernden and Curtis (1965) and need not be treated in further detail. All young sanidine samples were etched in a weak solution of hydrofluoric acid (12% by volume of 50% HF) for 20 minutes and in such cases the molybdenum crucibles were outgassed in vacuum at approximately 1700°C to reduce blank contribution of air argon.

The potassium content of all mineral and whole rock samples was determined by isotope dilution analysis. The spike used was $^{41}K$ (approximately 83% enriched). Samples were digested by means of conventional techniques and potassium was precipitated from solution by use of sodium tetraphenolboron to remove all elements that might have interfered with or altered running parameters in the mass spectrometer. To insure stability and to control isotopic fractionation during the mass spectrometer analysis, all samples were analysed using the triple filament configuration.

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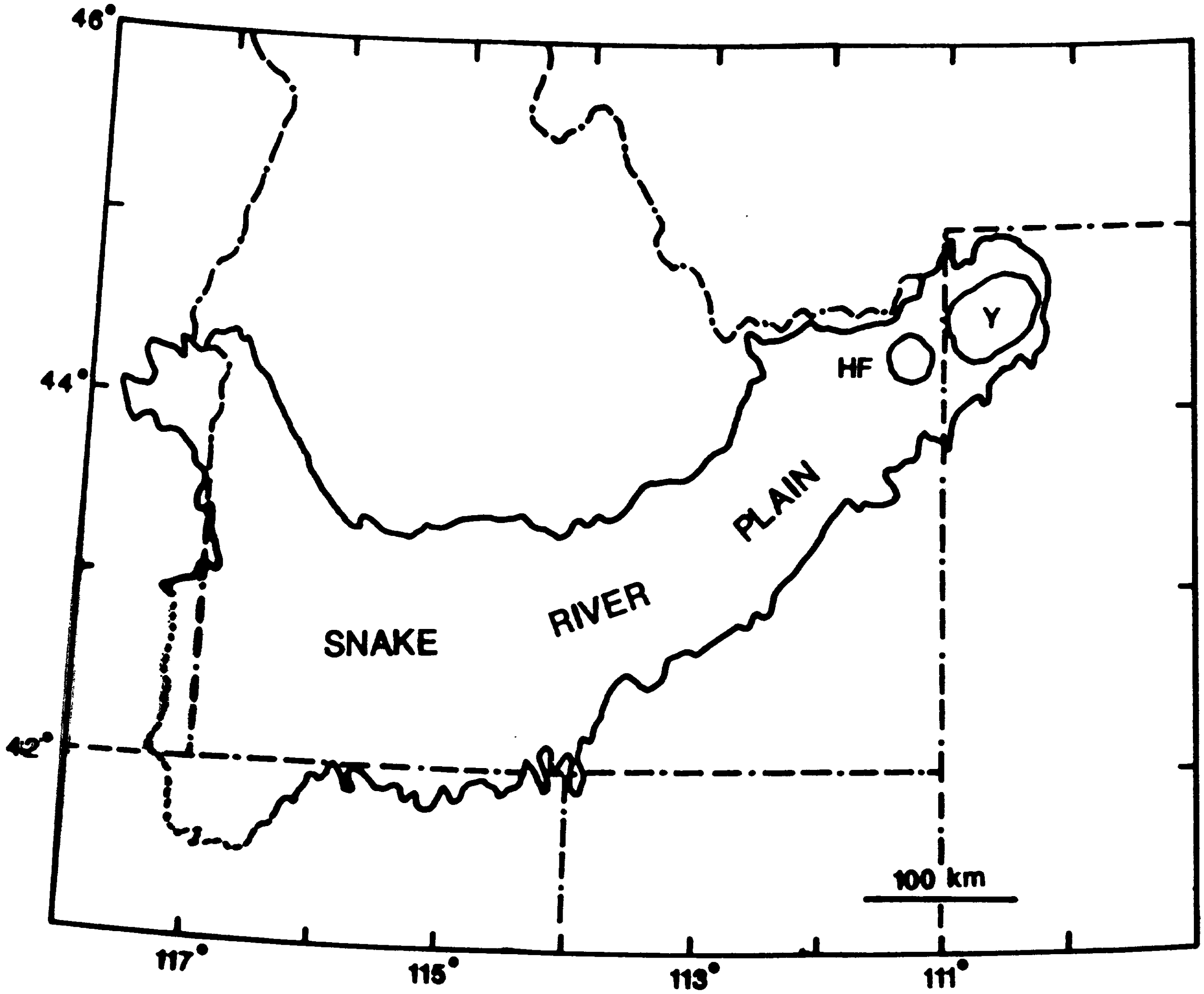


Figure 1. Index map for the Snake River Plain-Yellowstone Plateau province showing locations of the Yellowstone Caldera (Y) and Henry's Fork Caldera (HF) for reference.

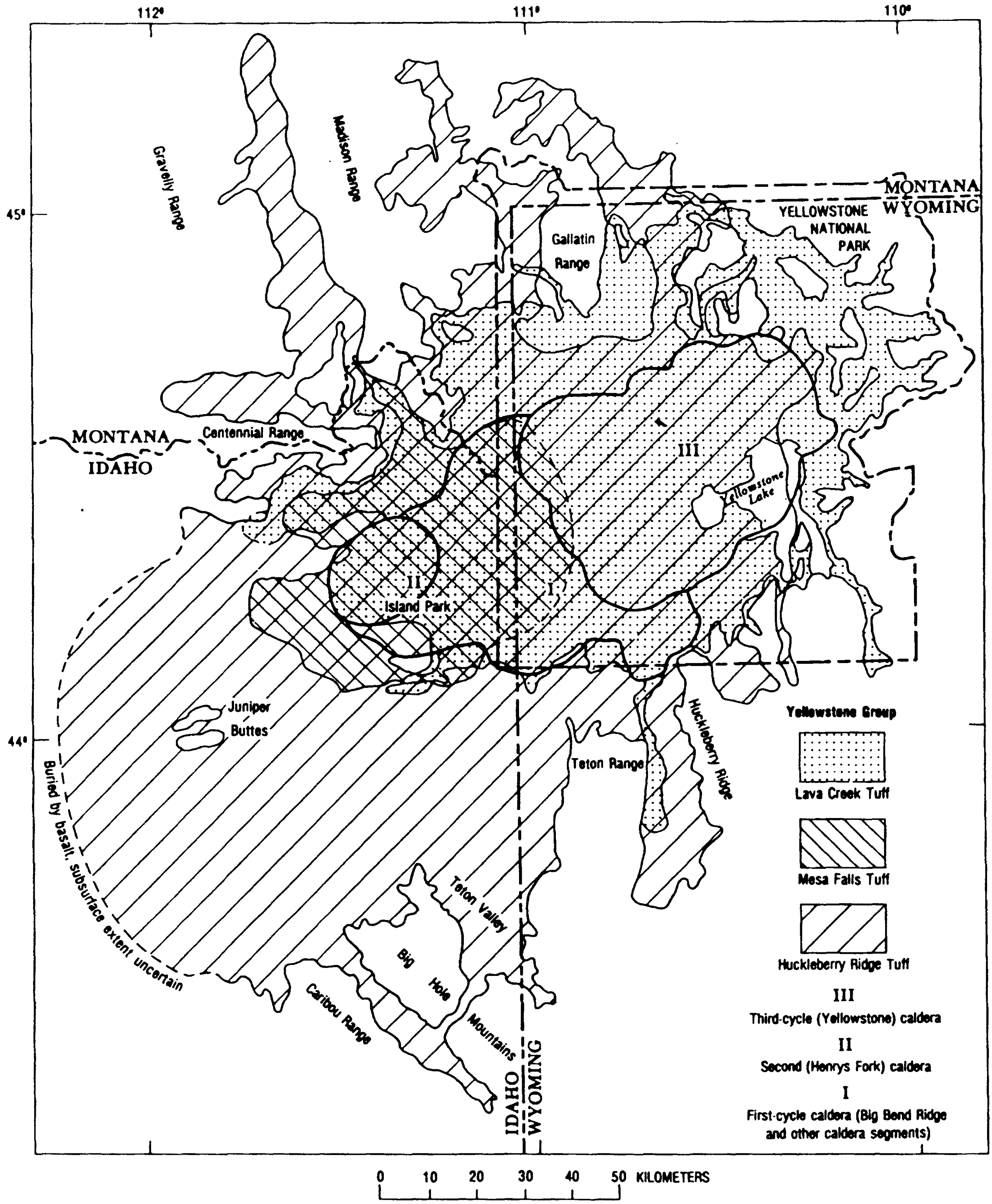


Figure 2. Map showing reconstructed original distribution of ash-flow sheets of the Yellowstone Group and interpreted configurations of the calderas of the three cycles of the Yellowstone Plateau volcanic field.

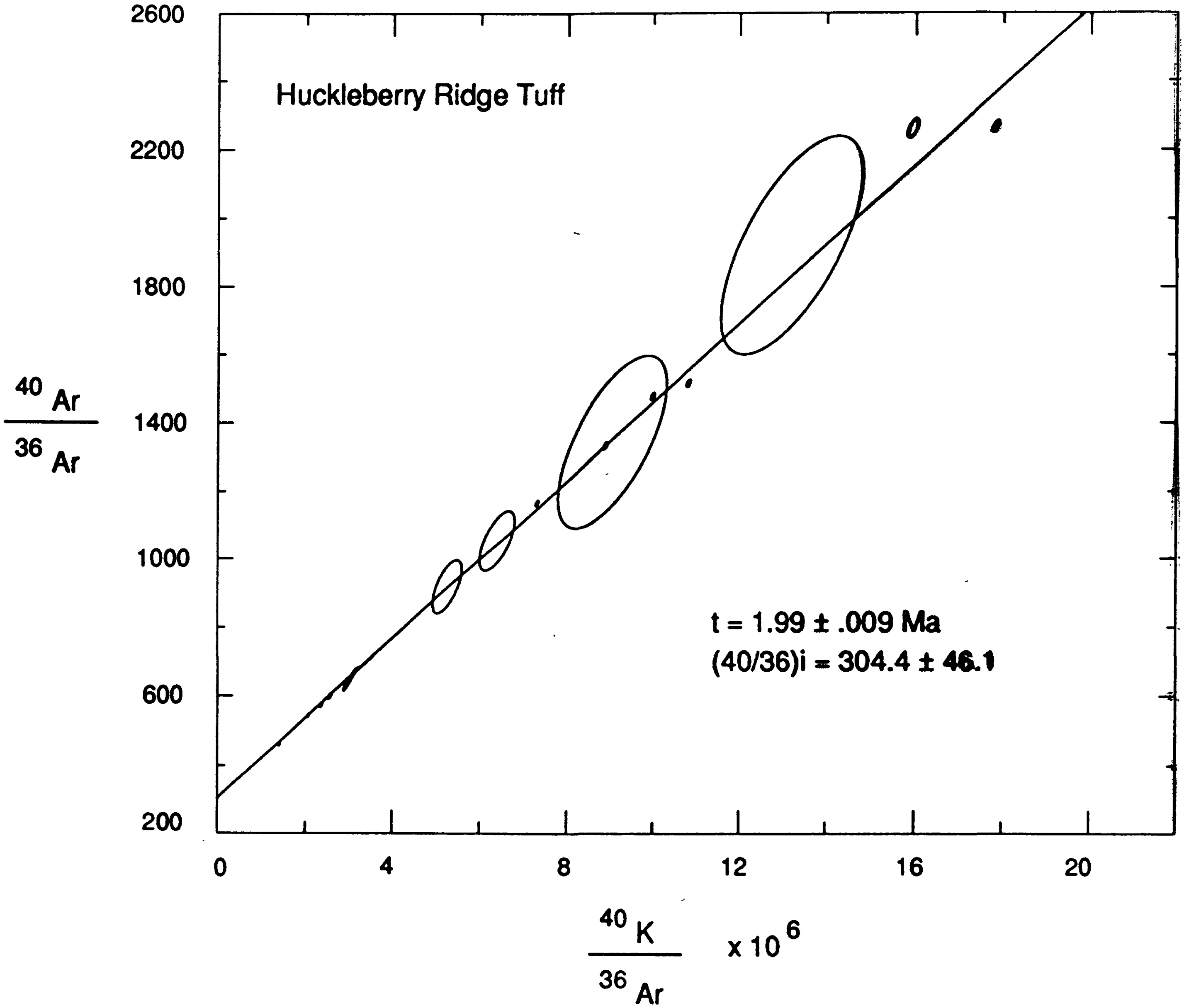


Figure 3a. $^{40}Ar/^{36}Ar$ vs $^{40}K/^{36}Ar$ correlation diagram for all the data for the Huckleberry Ridge Tuff.

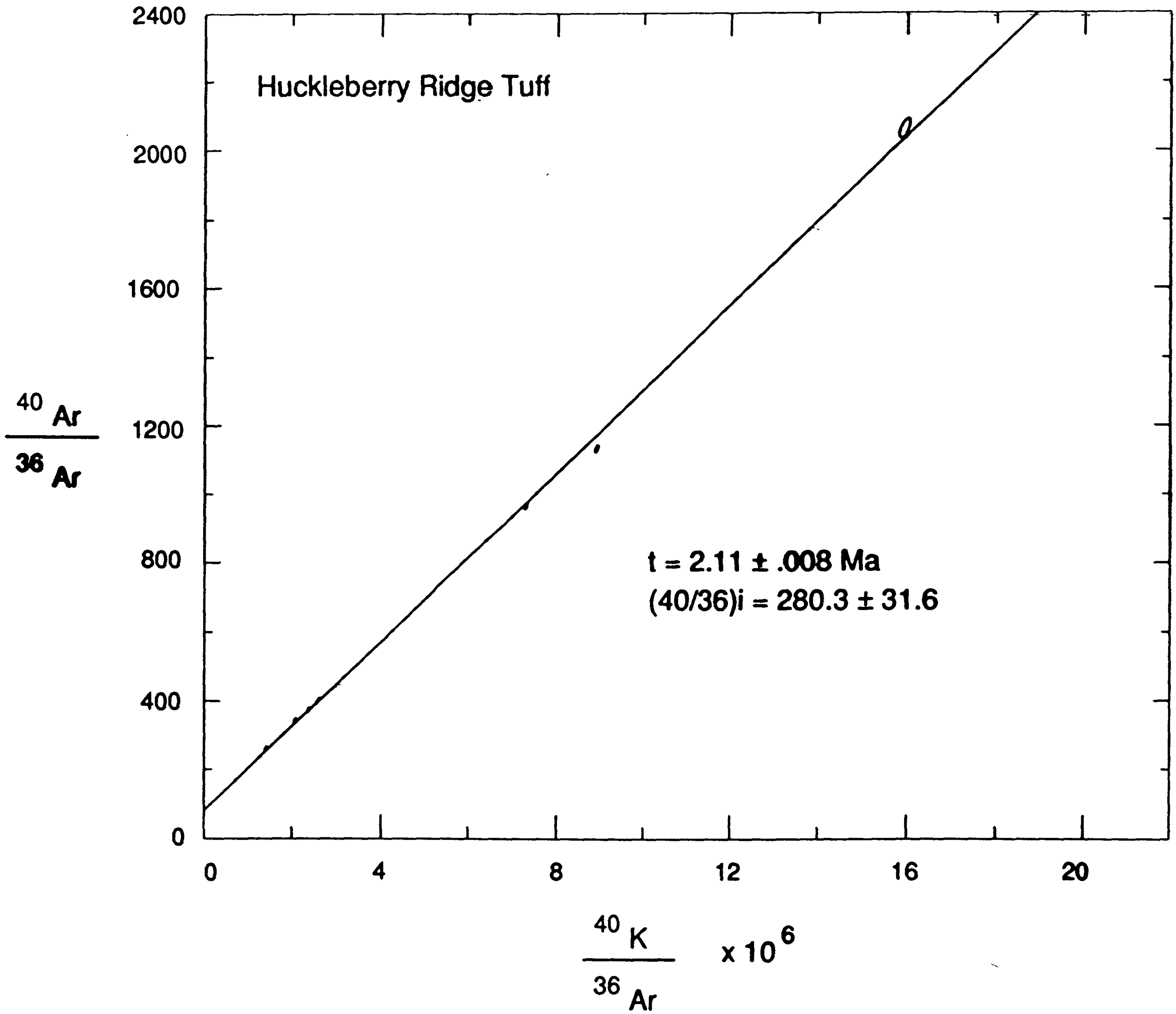


Figure 3b. $^{40}Ar/^{36}Ar$ vs $^{40}K/^{36}Ar$ correlation diagram for selected data for the Huckleberry Ridge Tuff. Data were selected on the basis of minimum variance and ages which are statistically older than the rejected values which are thought to reflect partial degassing.

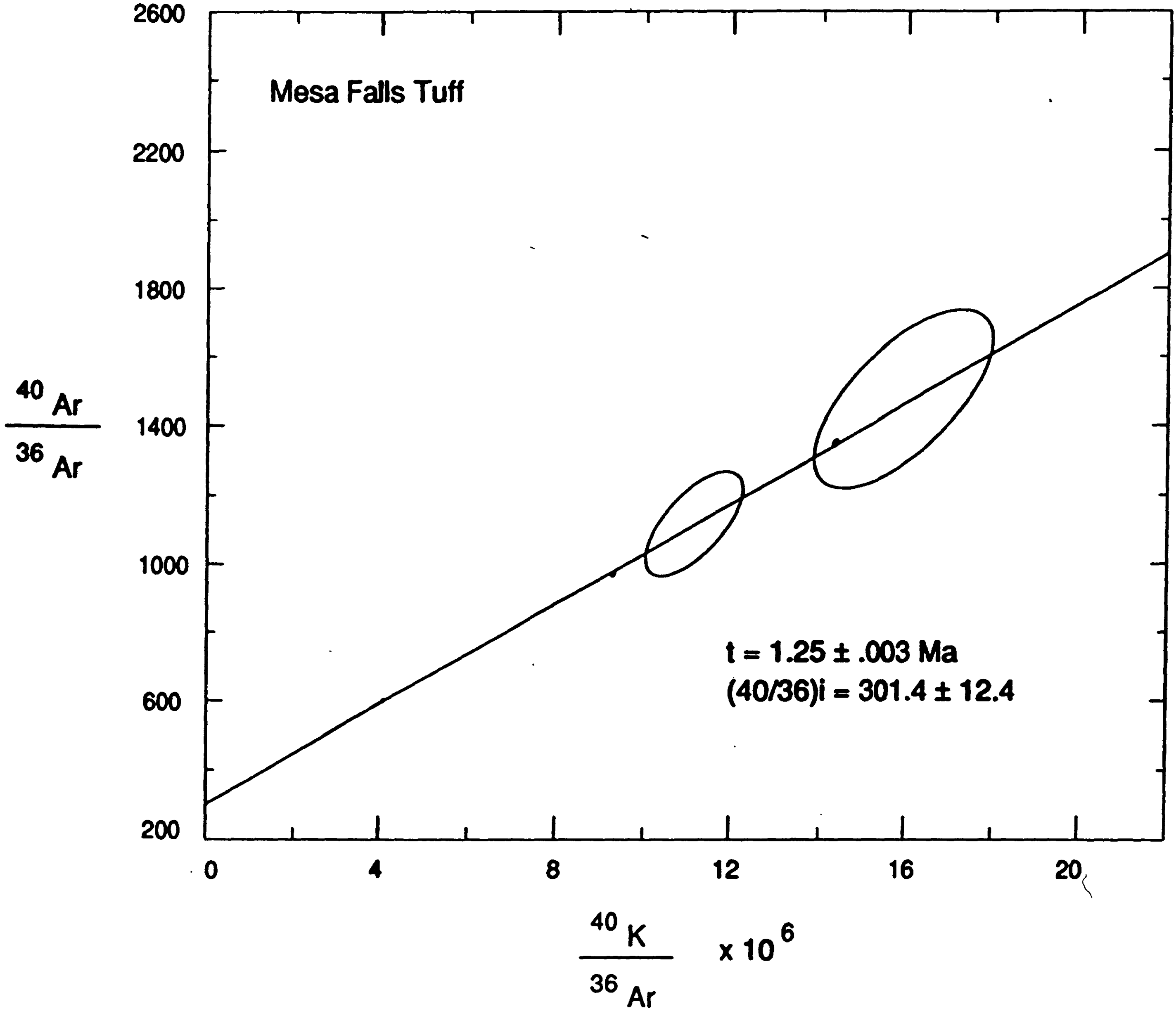


Figure 4. $^{40}Ar/^{36}Ar$ vs $^{40}K/^{36}Ar$ correlation diagram for Mesa Falls Tuff data.

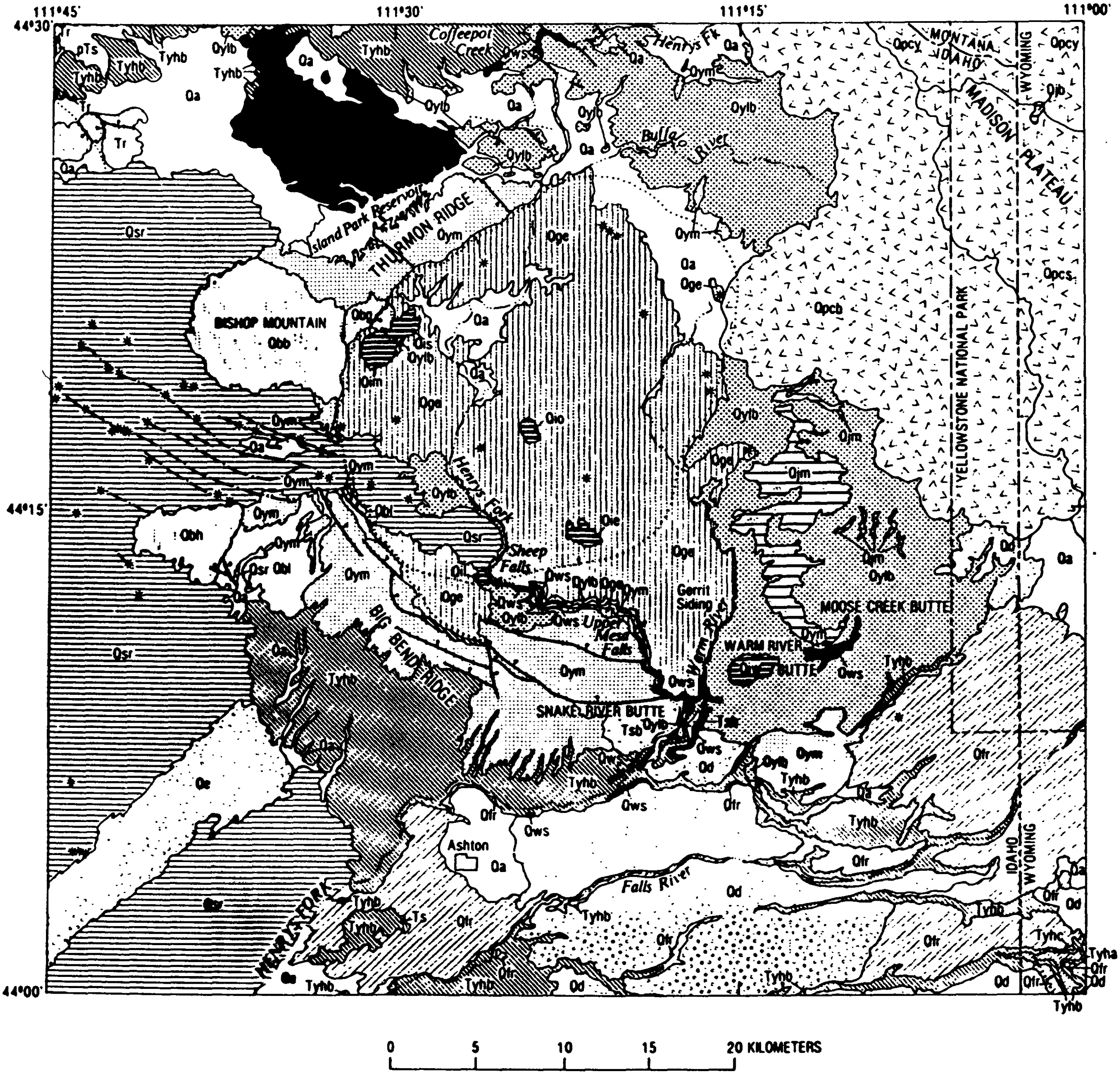


Figure 5. Geologic map of Island Park (after Christiansen, 1982).

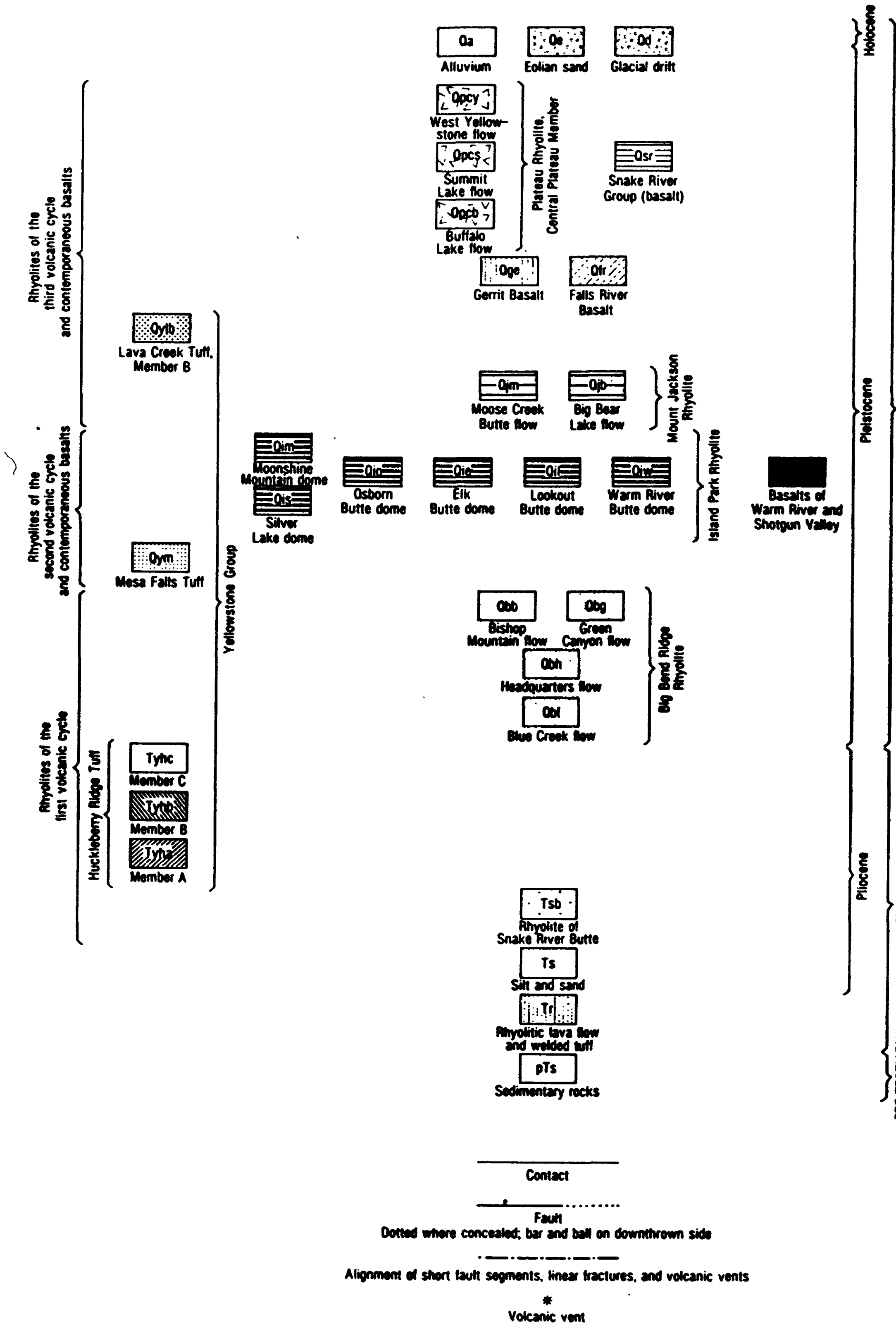


Figure 5a. Explanation for Figure 5.

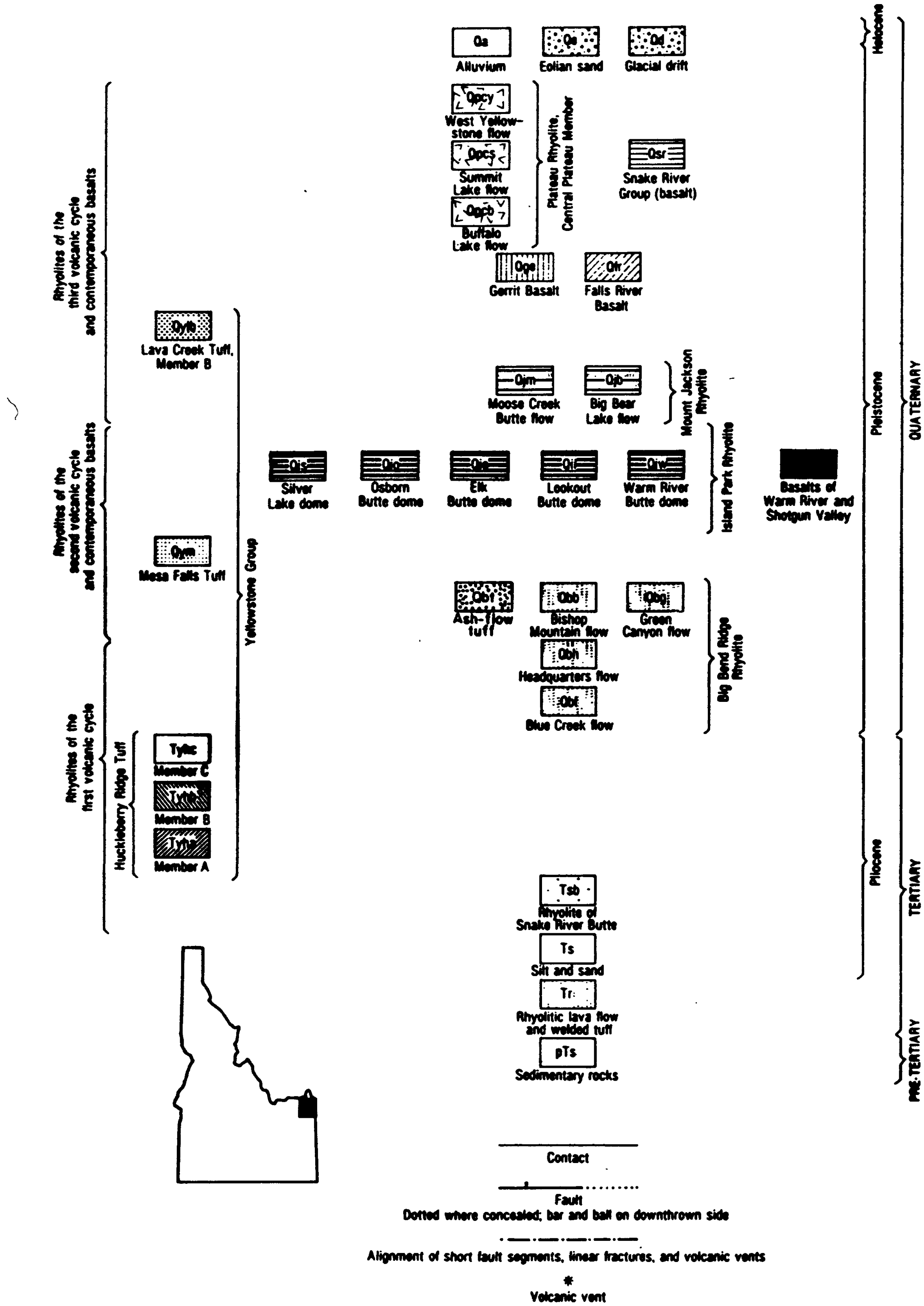


Figure 5b. Explanation for Figure 5.

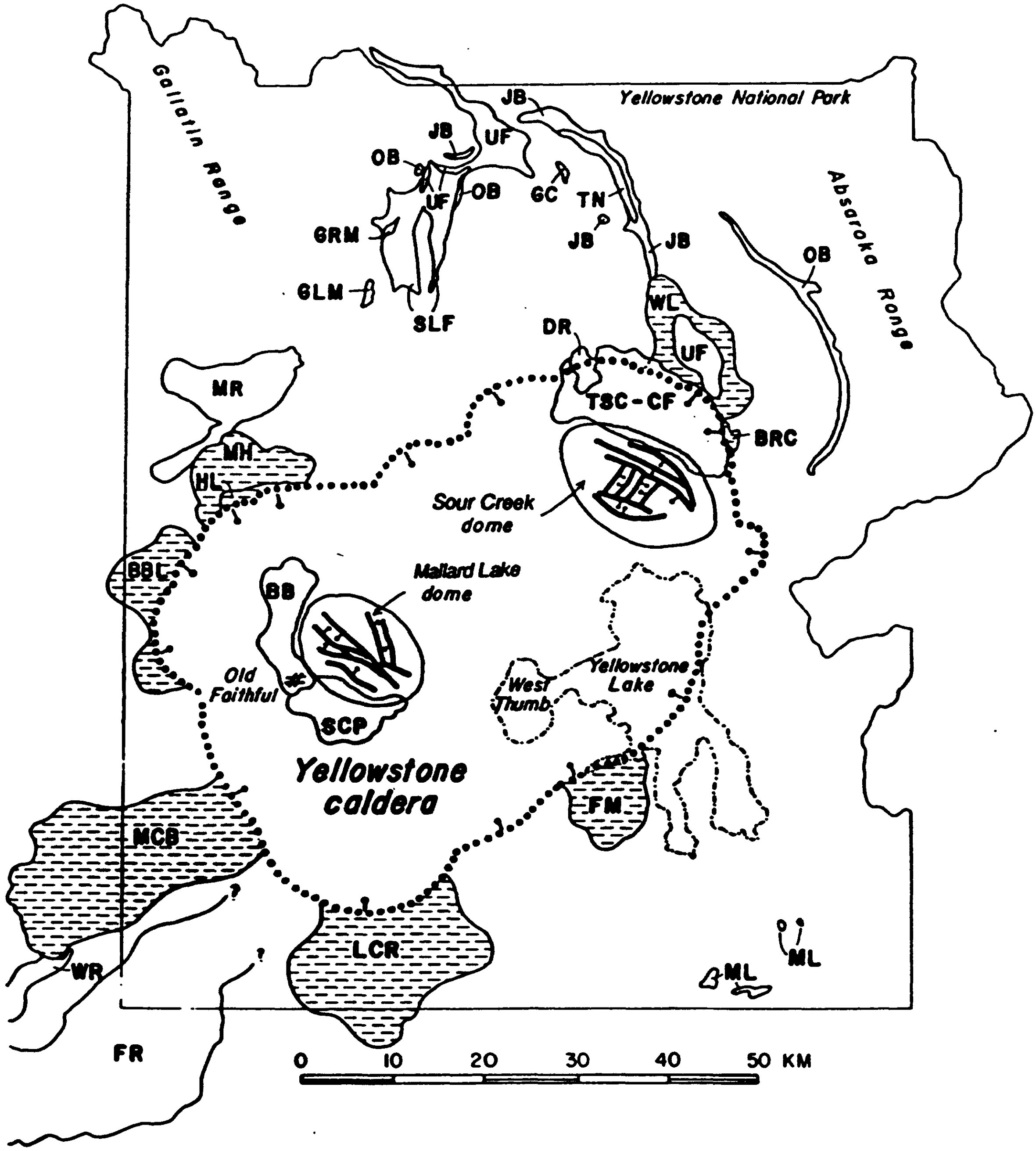


Figure 6. Generalized map showing partially reconstructed distribution of basalts and third-cycle precaldera and early postcaldera rhyolites in and near the Yellowstone caldera. Also indicated are the two resurgent domes, the Sour Creek and Mallard Lake domes. Precaldera rhyolitic lavas truncated by the 0.6 Ma collapse are: BBL Big Bear Lake flow; BRC Broad Creek flow; FM Flat Mountain flow; HL Harlequin Lake flow; MH Mount Haynes flow; LCR Lewis Canyon Rhyolite; MCB Moose Creek Butte flow; WL Wapiti Lake flow. Low $^{18}O$ postresurgent rhyolites of the Upper Basin member (emplaced in the caldera moat) are: BB Biscuit Basin flow; CF Canyon flow; DR Dunraven Road flow; SCP Scaup Lake flow; TSC tuff of Sulphur Creek. Basalts are: FR Falls River basalt; GC Basalt of Geode Creek; GLM Grizzly Lake mixed lavas; GRM Gardner River mixed lavas; JB Junction Butte basalt; ML basalt of Mariposa Lake; MR Madison River basalt; OB Osprey basalt; SLF Swan Lake Flat basalt; TN basalt of the Narrows; UF Undine Falls basalt; WR basalt of Warm River. For ages and stratigraphic sequence see Table 2.

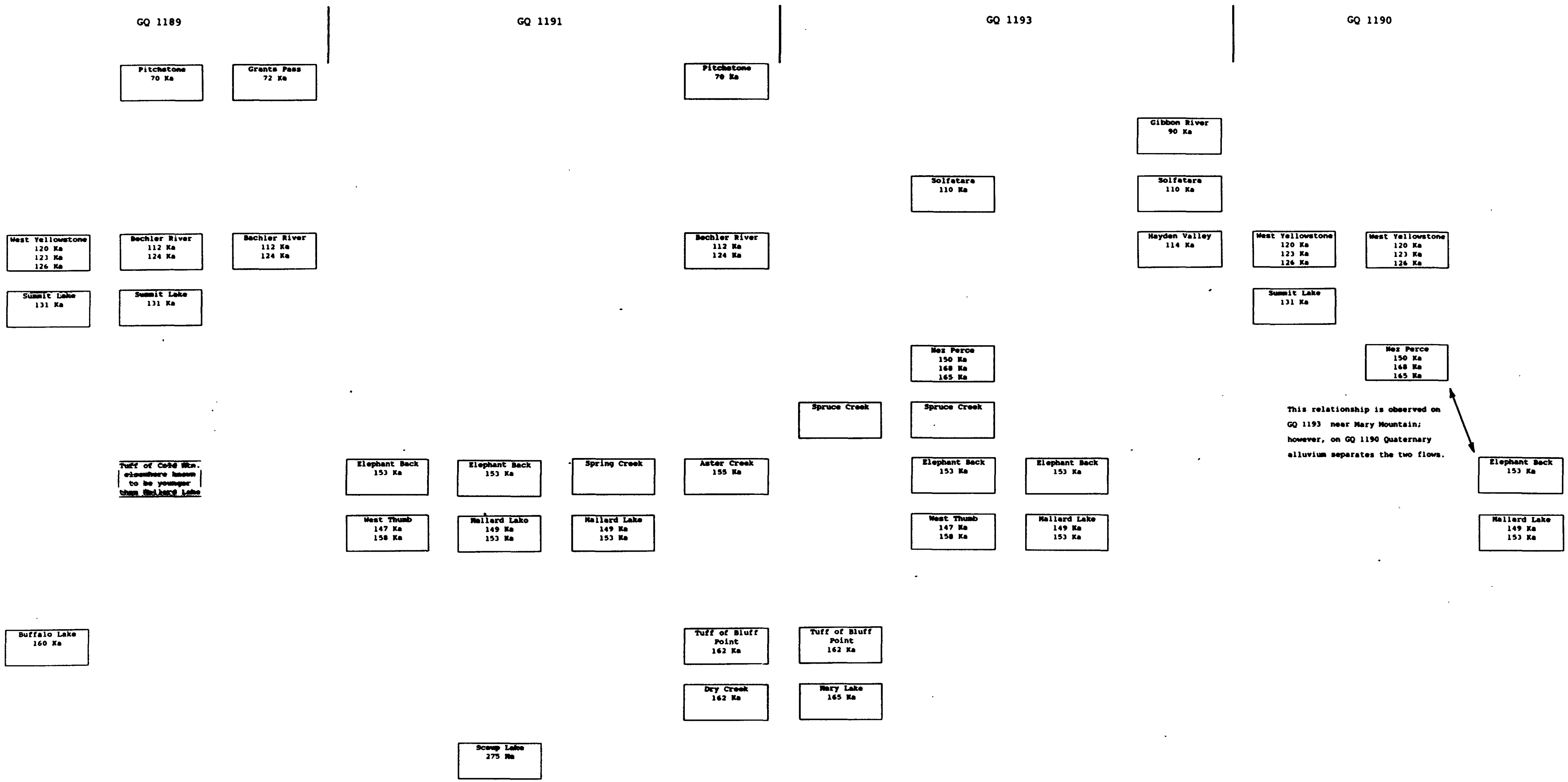


Figure 8. Stratigraphic relationships and ages for flows of the Central Plateau member and the Mallard Lake member of the Plateau Rhyolite.

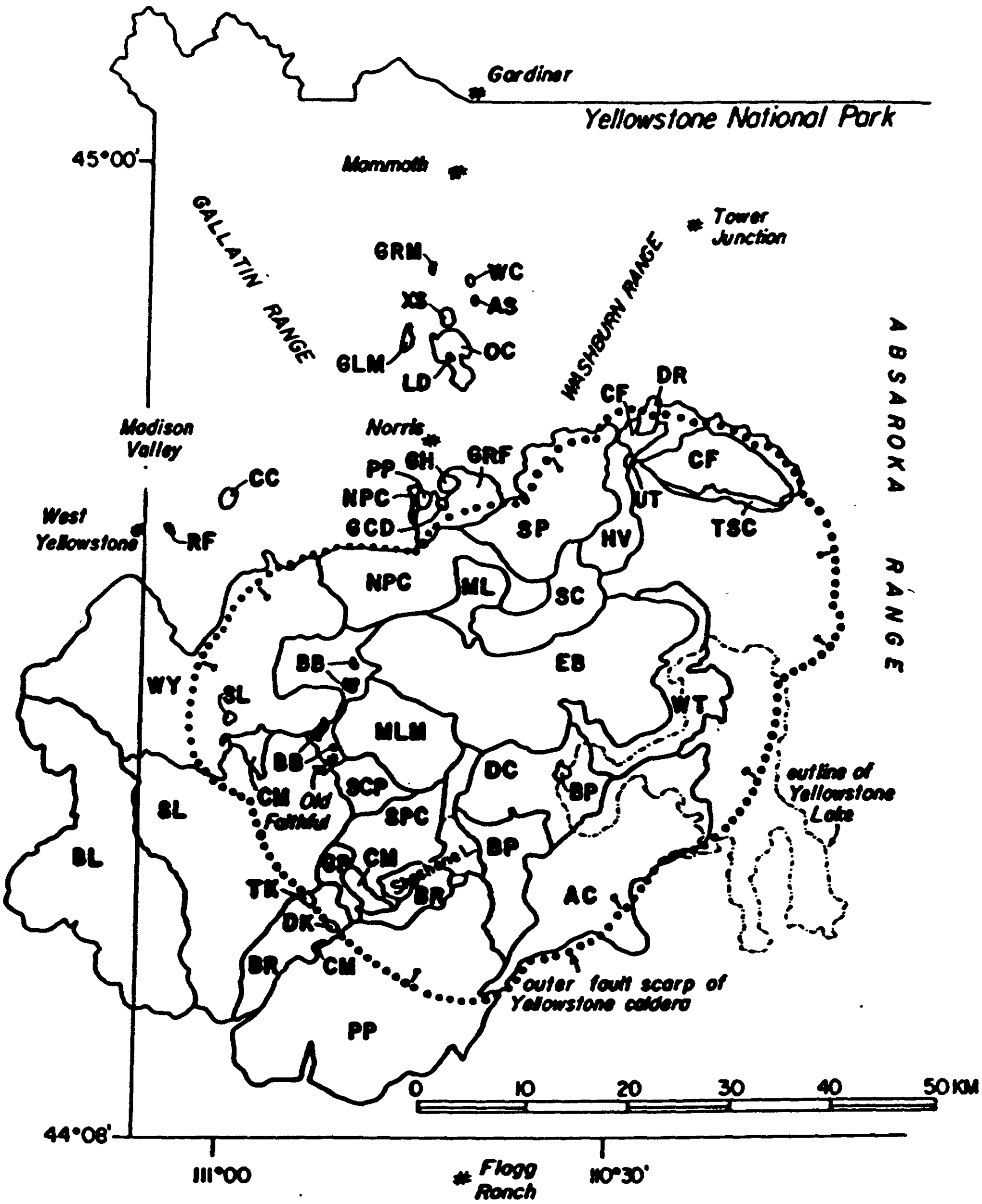


Figure 7. Locations of third-cycle postcaldera and extracaldera rhyolites relative to the Yellowstone caldera and the boundary of Yellowstone National Park. Extracaldera rhylites: AS Apollinaris Spring dome; CC Cougar Creek flow; GCD Geyser Creek dome; GH Gibbon Hill dome; GLM Grizzly Lake mixed lavas; GRF Gibbon River flow; GRM Gardner River mixed lavas; LD Landmark dome; OC Obsidian Cliff flow; PH Paintpot Hill dome; RF Riverside flow; WC Willow Creek dome; XS Crystal Spring flow. Upper Basin member: BB Biscuit Basin flow; CF Canyon flow; DR Dunraven Road flow; SCP Scaup Lake flow; TSC tuff of Sulphur Creek; UT tuff of Uncle Tom's Trail. Mallard Lake member: MLM. Central Plateau member: AC Aster Creek flow; BL Buffalo Lake flow; BP tuff of Bluff Point; BR Bechler River flow; CM tuff of Cold Mountain Creek; DC Dry Creek flow; DK Douglas Knob dome; EB Elephant Back flow; GP Grants Pass flow; HV Hayden Valley flow; ML Mary Lake flow; NPC Nez Perce Creek flow; PP Pitchstone Plateau flow; SC Spruce Creek flow; SL Summit Lake flow; SP Solfatara Plateau flow; TK Trischman Knob dome; WT West Thumb flow; WY West Yellowstone flow.

Table 1

Comparison of Geomagnetic Polarity Time Scales

| Mankinen and Dalrymple (1979) | | Shackleton et al. (1990) Hilgen (1991); Langereis and Hilgen (1991) |
|---|---|---|
| Bruhnes N / Matuyama R: 0.73 Ma | | Bruhnes N / Matuyama R: 0.78 Ma |
| 0.90<br>0.97 | Jaramillo | 0.99<br>1.07 |
| 1.10 | Cobb Mtn. | 1.17<br>1.19 |
| 1.67<br>1.87 | Olduvai | 1.77<br>1.95 |
| 2.01<br>2.04 | Reunion I | 2.14<br>2.15 |
| 2.12<br>2.14 | Reunion II | |
| R / Gauss N: 2.48 | | R / Gauss N: 2.60 |

Table 2a. K-Ar data for rhyolites and basalts of the first volcanic cycle.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radioagenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Huckleberry Ridge Tuff | Member C devitrified | Huckleberry Ridge | 7YC-285C | 2510 | Sanidine | 6.82 | 24.26 | 74.6 | 2.05 ± 0.02 |
| | Member B, devitrified | Crown Butte | OCB-66-01 | 1484 | Sanidine | 7.05 | 24.99 | 71.9 | 2.04 ± 0.10 |
| | | | | 1489 | | 6.98 | 24.16 | 78.0 | 1.99 ± 0.15 |
| | | | | 2500 | | 7.05 | 24.52 | 77.8 | 2.01 ± 0.02 |
| | Member A, devitrified, near top | Crown Butte | OCB-66-02 | 1564 | Sanidine | 7.35 | 27.01 | 84.3 | 2.12 ± 0.09 |
| | | | | 2247 | | 7.39 | 25.80 | 48.3 | 2.01 ± 0.03 |
| | | | | 2248 | | " | 25.83 | 35.9 | 2.01 ± 0.03 |
| | | | | 2249 | | " | 25.94 | 50.6 | 2.02 ± 0.02 |
| | | | | 2250 | | " | 26.35 | 45.5 | 2.05 ± 0.03 |
| | | | | 2251 | | " | 25.49 | 54.2 | 1.99 ± 0.02 |
| | | | | 2499 | | 7.35 | 25.29 | 79.5 | 1.98 ± 0.02 |
| | Member A, devitrified, near middle | Crown Butte | OCB-66-03 | 1565 | Sanidine | 7.28 | 25.62 | 67.6 | 2.03 ± 0.12 |
| | | | | 2526 | | 7.29 | 24.55 | 80.5 | 1.94 ± 0.02 |
| | Basal Airfall | Mount Everts | 68-0-46 | 2090 | Sanidine | 7.36 | 27.11 | 86.9 | 2.12 ± 0.03 |
| | | | | 2509 | | 7.39 | 24.38 | 86.9 | 1.90 ± 0.02 |
| | | | | 2495 | Pyroxene glass encrusted | 0.38 | 1.235 | 20.4 | 1.86 ± 0.04 |
| | | | | 2484 | Glass shards | 4.19 | 16.17 | 26.9 | 2.22 ± 0.04 |
| Rhyolite of Snake River Butte | Snake River Butte flow | Warm River | 2YR-118 | 2842 | Sanidine | 7.94 | 27.42 | 57.4 | 1.99 ± 0.02 |

Table 2a. Continued.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Junction Butte Basalt | Upper Flow | Mount Everts | 70-0-65 | 2361 | Basalt | 0.53 | 1.845 | 20.7 | 2.01 ± 0.05 |
| | Overhanging Cliff flow | Overhanging Cliff | 70-0-59 | 2360 | Basalt | 0.92 | 3.443 | 26.3 | 2.15 ± 0.04 |
| Big Bend Ridge Rhyolite | Headquarters Flow | Flow front west of Blue Creek | 81YH 83 | 4589 | Sanidine | 5.47 | 17.62 | 45.1 | 1.86 ± 0.03 |
| | | | | 4611 | | | 16.91 | 69.2 | 1.78 ± 0.02 |
| | | | | 4618 | | | 17.72 | 57.7 | 1.81 ± 0.02 |
| | Blue Creek Flow | So. of High Point | 81YH 81 | 4544 | Sanidine | 6.03 | 18.31 | 25.0 | 1.75 ± 0.04 |
| | | | | 4613 | | " | 18.63 | 40.1 | 1.78 ± 0.03 |

Table 2b. K-Ar data for rhyolites and basalts of the second volcanic cycle.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Island Park Rhyolite | Osborne Butte dome | Osborne Butte | 69-0-20 | 3114 | Sanidine | 8.28 | 18.40 | 50.8 | 1.28 ± 0.01 |
| | Warm River Butte dome | Warm River | 78 YH 25 | 4588 | Sanidine | 8.35 | 18.36 | 52.2 | 1.27 ± 0.017 |
| | | | | 4616 | " | " | 16.43 | 12.0 | 1.13 ± 0.040 |
| Mesa Falls Tuff | Pumice, distal | Ashton Highway | 8YC-460A | 1844 | Sanidine | 8.42 | 18.69 | 80.0 | 1.28 ± 0.08 |
| | | | | 2522 | Sanidine | 8.31 | 18.23 | 78.1 | 1.26 ± 0.01 |
| | Basal, devitrified | Upper Mesa Falls | OCB-66-04 | 1483 | Sanidine -50+80 Mesh | 8.10 | 17.80 | 73.5 | 1.27 ± 0.09 |
| | | | | 1488 | Sanidine, -80+100 mesh | 8.11 | 16.31 | 67.4 | 1.16 ± 0.11 |
| | | | | 2521 | Sanidine -80-+100 Mesh | " | 17.56 | 69.5 | 1.25 ± 0.01 |
| Big Bend Ridge Rhyolite | Tuff of Lyle Spring | Lyle Spring | 81IP 199 | 4546 | Sanidine | 7.94 | 18.13 | 50.3 | 1.32 ± 0.02 |
| | | | | 4623 | " | " | 14.54 | 38.4 | 1.06 ± 0.02 |
| | Green Canyon Flow | SE ridge | 81IP 212 | 45.91 | Sanidine | 8.22 | 17.32 | 46.5 | 1.22 ± 0.02 |
| | | | | 4617 | " | " | 16.02 | 56.6 | 1.12 ± 0.02 |
| | Bishop Mountain Flow | 1 mile W of lookout | 81IP 201 | 4592 | Sanidine | 9.82 | 20.66 | 52.3 | 1.21 ± 0.02 |
| | | | | 4610 | " | | 18.75 | 41.6 | 1.10 ± 0.02 |
| | Moonshine Mountain Dome | NE nose | 81YH 88 | 4590 | Sanidine | 8.14 | 17.78 | 54.5 | 1.26 ± 0.02 |
| | | | | 4619 | " | " | 17.44 | 47.1 | 1.24 ± 0.02 |
| Basalt and Sediments of the Narrows | Ash bed | East side of the Narrows | YG-69-4 | 2100 | Sanidine | 8.19 | 20.75 | 76.1 | 1.46 ± 0.02 |
| | | | | 2524 | " | 8.24 | 22.40 | 86.0 | 1.57 ± 0.02 |
| | Ash bed | Bumpus Butte | 70-0-61 | 2431 | Sanidine | 8.31 | 22.62 | 84.3 | 1.57 ± 0.01 |
| | | | | 3862 | Sanidine, Handpicked | " | 21.76 | 82.4 | 1.51 ± 0.02 |

Table 2b. Continued.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Basalt and Sediments of the Narrows | Ash bed | East side of the Narrows | YG-69-4 | 2100 | Sanidine | 8.19 | 20.75 | 76.1 | 1.46 ± 0.02 |
| | | | | 2524 | " | 8.24 | 22.40 | 86.0 | 1.57 ± 0.02 |
| | Ash bed | Bumpus Butte | 70-0-61 | 2431 | Sanidine | 8.31 | 22.62 | 84.3 | 1.57 ± 0.01 |
| | | | | 3862 | Sanidine, Handpicked | " | 21.76 | 82.4 | 1.51 ± 0.02 |
| Basalts and sediments of the Narrows | Upper flow | East side of the Narrows | 70-0-64 | 2363 | Basalt | 1.03 | 3.00 | 2.1 | 1.68 ± 0.56 |
| | | | | 3512 | Basalt | " | 1.88 | 1.2 | 1.05 ± 0.45 |

Table 2c.. K-Ar data for rhyolites and basalts of the third volcanic cycle.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Lava Creek Tuff | Member B, distal vitrophyre | Grassy Lake Reservoir | OCB-66-15 | 1351 | Glassy rhyolite | 4.00 | 10.71 | 5.8 | 1.54 ± 0.35 |
| | | | 6YC-13D | 1632 | Glassy rhyolite | 3.63 | 6.522 | 4.5 | 1.04 ± 0.31 |
| | Member B, glassy top | Sheepeater Cliff | 68-0-48 | 1846 | Sanidine | 7.12 | 7.592 | 51.1 | 0.615±0.085 |
| | | | | 2508 | " | 7.04 | 7.509 | 50.9 | 0.615±0.007 |
| | Member B, basal vitrophyre | Lower Lava Creek | 7YC-325 | 2518 | Sanidine | 7.87 | 9.180 | 70.0. | 0.673±0.006 |
| | Member A, upper part | Rabbit Creek drill hole | Y5-516 | 1630 | Sanidine | 6.75 | 6.668 | 32.0 | 0.569±0.066 |
| | | | | 2515 | " | " | 7.175 | 59.6 | 0.612±0.006 |
| | Member A, lower part | Tuff Cliff | 69-0-49 | 1843 | Sanidine | 7.63 | 8.486 | 49.9 | 0.641±0.093 |
| | | | | 2513 | " | 7.55 | 8.207 | 52.2 | 0.627±0.007 |
| | Airfall | Grand Canyon | 68-0-45 | 2516 | Sanidine | 6.74 | 8.418 | 74.9 | 0.720±0.007 |
| | | Notch Mountain | 70W30 | 3942 | " | 7.63 | 8.553 | 13.2 | 0.646±0.026 |
| Mount Jackson Rhyolite | Mount Haynes flow | Mount Jackson | OCB-66-10 | 1567 | Sanidine | 6.90 | 7.700 | 39.0 | 0.643±0.107 |
| | | | | 2514 | " | 6.89 | 7.279 | 51.7 | 0.609±0.006 |
| | Harlequin Lake flow | Madison Canyon | OCB-66-11 | 1568 | Sanidine | 6.94 | 9.695 | 63.0 | 0.805±0.136 |
| | | | | 2520 | " | 6.98 | 10.16 | 62.9 | 0.840±0.008 |
| | Flat Mountain flow | Flat Mountain | 81Y 224 | 4593 | Sanidine | 4.89 | 7.801 | 23.2 | 0.919±0.05 |
| | | | 81Y 223 | 4620 | Sanidine | 2.59 | 4.227 | 9.4 | 0.941±0.05 |
| | Moose Creek flow | | 81YH 98 | 4548 | Sanidine | 7.78 | 16.68 | 69.4 | 1.24 ±0.015 |
| | | | | 4615 | " | " | 16.40 | 80.4 | 1.22 ±0.014 |
| | Rhyolite of Broad Creek | Broad Creek | 9YC 493 | 4545 | Sanidine | 7.59 | 12.71 | 18.1 | 0.966±0.05 |
| | | | | 4612 | " | " | 15.14 | 48.4 | 1.15 ±0.015 |
| | Wapiti Lake flow | Grand Canyon | OYC 601 | 2517 | Sanidine | 8.07 | 16.43 | 68.1 | 1.17 ± 0.01 |
| | | | | 2527 | Glass | 4.70 | 9.963 | 10.7 | 1.22 ± 0.06 |

Table 2c..Continued.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Lewis Canyon Rhyolite | Lewis Canyon flow | Lewis Canyon | OYC 563 | 2523 | Sanidine | 7.04 | 11.36 | 58.1 | 0.929±0.009 |
| | | | OYC 563 | 4594 | Sanidine` | 6.02 | 10.09 | 24.3 | 0.966± 0.05 |
| | | | new sample | 4612 | " | " | 7.394 | 31.5 | 0.708±0.012 |
| Undine Falls Baalt | Upper flow | Undine Falls | 70-0-66 | 2364 | Basalt | 0.44 | 0.449 | 11.7 | 0.585±0.026 |
| Basalt of Warm River | Warm River flow | Fish Creek Road | 6YC144 | 3511 | Basalt | 0.23 | 0.3028 | 7.6 | 0.752±0.052 |

Table 2d. K-Ar data for early post-caldera rhyolites and basalts of the Third Volcanic Cycle

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Plateau Rhyolite, Upper Basin Member | Scaup Lake flow | Scaup Lake | 8YC-441 | 1845 | Sanidine | 6.70 | 3.086 | 11.3 | 0.226±0.089 |
| | | | | 2442 | " | 6.60 | 3.150 | 11.9 | 0.275±0.011 |
| | Biscuit Basin flow | Midway Basin | YM-406 | 1867 | Sanidine | 7.22 | 6.785 | 87.6 | 0.542±0.042 |
| | Dunraven Road flow | Dunraven Pass Road | YG-68-1 | 2497 | Plagioclase | 1.09 | 1.272 | 23.0 | 0.672±0.019 |
| | | | | 2041 | Glass | 4.32 | 5.079 | 3.0 | 0.678±0.236 |
| | | | | 2042 | " | " | 5.092 | 3.1 | 0.680±0.224 |
| | | | | 2043 | " | " | 4.638 | 3.0 | 0.619±0.211 |
| | | | | 2487 | " | " | 4.716 | 3.1 | 0.629±0.105 |
| | Canyon flow | Upper Falls | 69-0-16 | 2094 | Plagioclase | 1.30 | 1.555 | 37.7 | 0.692±0.018 |
| | | | | 2505 | " | 1.30 | 1.383 | 32.2 | 0.613±0.011 |
| | Tuff of Sulphur Creek | Grand Canyon | 8YC-477A | 1866 | Sanidine | 4.97 | 25.05 | 85.1 | 2.90 ± 0.08 |
| | | Broad Creek | 9YC-492 | 2519 | Sanidine | 4.23 | 6.963 | 25.6 | 0.948±0.017 |
| | | | | 2504 | Plagioclase | 1.08 | 2.082 | 29.2 | 1.11 ± 0.02 |
| | | | | 2506 | " | " | 2.039 | 15.7 | 1.09 ± 0.04 |

Table 2e K-Ar data for extra-caldera rhyolites of the Third Volcanic Cycle.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Plateau Rhyolite, Roaring Mountain Mbr. | Crystal Spring flow | Obsidian Lake | 8YC-396A | 1859 | Glass | 4.03 | 0.5347 | 5.7 | 0.077±0.067 |
| | | | | 2489 | " | " | 0.5568 | 30.7 | 0.800±0.002 |
| | Obsidian Cliff flow | Obsidian Cliff | OCB-66-06 | 1860 | Glass | 4.18 | 1.238 | 7.1 | 0.171±0.094 |
| | | | | 2466 | " | 4.13 | 1.311 | 29.7 | 0.183±0.003 |
| | Cougar Creek dome | Cougar Creek | 6YC-138 | 2496 | Sanidine | 4.31 | 2.935 | 27.6 | 0.393±0.007 |
| | | | | 1868 | Glass | 4.51 | 3.224 | 23.5 | 0.412±0.115 |
| | | | | 2485 | " | 4.47 | 3.104 | 55.3 | 0.401±0.004 |
| Obsidian Creek Member | Willow Park dome | Hill 8109 | OYC-608 | 2492 | Sanidine | 5.16 | 2.831 | 32.8 | 0.317±0.005 |

Table 2f. K-Ar data for Mallard Lake Member and rhyolites of the Central Plateau Member of the Plateau Rhyolite and miscellaneous basalts.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Plateau Rhyolite, Central Plateau Member | Buffalo Lake flow | Latham Spring | 69-0-19 | 2433 | Sanidine | 7.35 | 2.044 | 34.2 | 0.160±0.003 |
| | Nez Pierce Creek flow | Upper Mesa Road | 72-0-76 | 2843 | Sanidine | 7.39 | 1.920 | 24.7 | 0.150±0.003 |
| | | Firehole River | OCB-66-12 | 1853 | Sanidine | 7.38 | 1.478 | 10.8 | 0.116±0.282 |
| | | | | 2438 | " | 7.28 | 2.121 | 33.8 | 0.168±0.003 |
| | | Gibbon Canyon | 72-0-72 | 2850 | Sanidine | 6.57 | 1.884 | 19.4 | 0.165±0.004 |
| | Elephant Back flow | Elephant Back Mountain | YG-70-6 | 2378 | Sanidine | 7.31 | 1.941 | 34.0 | 0.153±0.002 |
| | West Thumb flow | West Thumb | OCB-66-14A | 1856 | Sanidine | 7.41 | 1.948 | 28.6 | 0.152±0.062 |
| | | | | 2366 | " | 7.26 | 1.853 | 19.3 | 0.147±0.004 |
| | | | | 2476 | Glass | 4.46 | 1.217 | 7.1 | 0.158±0.011 |
| | Aster Creek flow | Flat Mountain Arm | YG-70-15 | 2370 | Sanidine | 7.41 | 1.987 | 25.8 | 0.155±0.003 |
| | | | | 2478 | Glass | 4.35 | 1.455 | 35.3 | 0.193±0.003 |
| | Tuff of Bluff Point | Bluff Point | 69-0-17 | 2369 | Sanidine | 7.30 | 2.045 | 36.7 | 0.162±0.002 |
| | Mary Lake flow | Mary Lake | YG-72-7 | 2844 | Sanidine | 7.39 | 2.120 | 22.0 | 0.165±0.004 |
| | Dry Creek flow | Continental Divide | OCB-66-13 | 1857 | Sanidine | 7.36 | 2.669 | 36.0 | 0.209±0.072 |
| | | | | 2429 | " | 7.39 | 2.080 | 35.1 | 0.162±0.002 |
| Mallard Lake Member | Mallard Lake flow | Isa Lake | 69-0-18 | 2372 | Sanidine | 6.94 | 1.793 | 16.0 | 0.149±0.005 |
| | | Mallard Lake Trail | 2YR-62 | 2551 | Sanidine | 7.22 | 1.912 | 15.0 | 0.153±0.005 |

Table 2f. Continued.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Plateau Rhyolite, Central Plateau Member | West Yellowstone flow | West Yellowstone | OCB-66-09 | 1584 | Sanidine -48+100 mesh | 6.50 | 1.490 | 18.7 | 0.132±0.061 |
| | | | | 2575 | Sanidine, -24+48 mesh | 6.93 | 1.437 | 23.8 | 0.120±0.003 |
| | | | | 2475 | Glass | 4.24 | 0.7964 | 20.4 | 0.108±0.003 |
| | | | YG-72-5 | 2839 | Sanidine | 6.91 | 1.478 | 10.2 | 0.123±0.006 |
| | | | | 2840 | " | " | 1.511 | 16.8 | 0.126±0.004 |
| | | Firehole River | YM-405A | 1863 | Sanidine | 6.90 | 0.861 | 41.5 | 0.072±0.012 |
| | | | | 2513 | " | 6.91 | 1.166 | 35.6 | 0.097±0.002 |
| | Bechler River flow | Gregg Fork | YG-70-8 | 2491 | Sanidine | 6.97 | 1.350 | 18.7 | 0.112±0.003 |
| | | | | 2490 | Glass | 4.53 | 0.9346 | 17.8 | 0.119±0.003 |
| | | Iris Falls | 72-0-75 | 2845 | Sanidine | 6.97 | 1.495 | 15.9 | 0.124±0.004 |
| | Summit Lake flow | Madison Lake | YG-70-10 | 2432 | Sanidine | 6.54 | 1.487 | 19.4 | 0.131±0.003 |
| | | | | 2477 | Glass | 4.27 | 0.7625 | 22.3 | 0.103±0.003 |
| | | Bechler Meadows | YG-70-9 | 2428 | Sanidine | 6.73 | 1.234 | 14.2 | 0.106±0.004 |
| | | | | 2483 | Glass | 4.30 | 0.9744 | 8.3 | 0.131±0.008 |
| | | | 72-0-73 | 2486 | Sanidine | 6.84 | 1.250 | 16.4 | 0.105±0.003 |
| | Solfatara Plateau flow | Virginia Meadows | OCB-66-07 | 2373 | Sanidine | 5.96 | 1.138 | 17.7 | 0.110±0.003 |
| | | | | 2852 | " | 5.95 | 1.111 | 7.6 | 0.108±0.007 |
| | Hayden Valley flow | Yellowstone River | YG-67-2 | 1684 | Sanidine | 6.88 | 1.276 | 11.6 | 0.107±0.015 |
| | | | | 2089 | " | 6.87 | 1.361 | 9.6 | 0.114±0.011 |
| | | | | 2371 | " | 6.90 | 1.180 | 11.2 | 0.099±0.005 |
| Plateau Rhyolite, Central Plateau Mbr. | Pitchstone Plateau flow | Pitchstone Plateau | YG-68-4 | 2374 | Sanidine | 6.69 | 0.8107 | 15.5 | 0.070±0.002 |

Table 2f. Continued.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| | Grants Pass flow | Bechler Summit | YG-70-13 | 2440 | Sanidine | 7.10 | 0.8807 | 14.8 | 0.072±0.003 |
| | | | | 2463 | Glass | 4.23 | 0.5986 | 16.1 | 0.082±0.003 |
| | Gibbon River flow | Vent dome | YP-52-78 | 1130 | Glass | 3.98 | 0.5988 | 7.9 | 0.087±0.054 |
| | | | | 2427 | " | 4.05 | 0.6303 | 20.5 | 0.090±0.002 |
| | | Gibbon Hill dome Hill 8065 | 81Y-20 | 4549 | Sanidine | 4.96 | 0.9966 | 9.4 | 0.116±0.008 |
| | | Norris Basin | YM-3A | 1865 | Sanidine | 2.54 | 0.7000 | 15.9 | 0.159±0.051 |
| | | | | 2498 | Plagioclase | 1.27 | 0.4548 | 6.1 | 0.207±0.018 |
| | | | | 2479 | Glass | 4.04 | 0.9674 | 24.8 | 0.148±0.003 |
| Gerrit Basalt | Hatchery Butte flow | South of Pineview | YG-72-4 | 2841 | Basalt | 0.63 | 0.2179 | 12.4 | 0.199±0.009 |
| Osprey Bassalt | Lamar River flow | Lamar Canyon | P-104 | 2365 | Basalt | 0.65 | 0.2502 | 2.8 | 0.220±0.041 |

Table 3. K-Ar data for sedimentary deposits of the Yellowstone Plateau volcanic field.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Cemented kame | Pumice-block bed at base | Lower Geyser Basin | YM-554 | 1870 | Sanidine | 7.05 | 1.654 | 24.5 | 0.135±0.046 |
| Lakeshore sediments | Pumice bed (upper BL, or P/BL interval) | Chipmunk Creek | YG-70-11 | 2435 | Sanidine | 6.71 | 1.231 | 22.1 | 0.106±0.003 |
| | Pumice bed picnic area | Spruce Forest | YG-68-3 | 1855 | Sanidine | 6.86 | 1.764 | 37.3 | 0.126±0.076 |
| | | | | 2494 | Sanidine | 6.88 | 1.832 | 42.0 | 0.153±0.002 |
| | Pumice bed (BL or older) | Clear Creek | YG-70-12 | 2439 | Sanidine | 6.84 | 3.053 | 57.5 | 0.257±0.003 |
| Sediments of Potts Hot Springs | Rhyolite boulder | Gravel pit | YG-66-3 | 1485 | Sanidine -80+100 mesh | 7.46 | 1.632 | 40.6 | 0.126±0.076 |
| | | | | 1487 | Sanidine -80+80 mesh | 7.44 | 1.702 | 39.6 | 0.132±0.081 |
| | | | | 2377 | Sanidine | 7.41 | 2.083 | 68.2 | 0.162±0.002 |
| | Reworked pumiceous ash bed at base | Gravel Pit | 8YC-476 | 1858 | Sanidine | 6.13 | 1.884 | 21.5 | 0.177±0.092 |
| | (Probably tuff of | | | 2376 | | 6.11 | 1.804 | 18.5 | 0.170±0.005 |
| | Bluff Point) | | | 2465 | Glass | 4.39 | 1.284 | 24.0 | 0.169±0.004 |
| Reworked tuff of Bluff Point | Below Lake beds below Aster Creek flow | Flat Mountain Arm | YG-70-14 | 2434 | Sanidine | 7.26 | 2.829 | 42.6 | 0.225±0.003* |

Table 3. Continued.

| Stratigraphic Unit | Subunit or Lithology | Locality | Sample No. | Run No (DKA) | Sample Material | K (Wt. %) | $^{40}Ar$ radiogenic (moles/gm x $10^{-12}$) | Percent radiogenic $^{40}Ar$ | Age (Ma ± 1σ) |
|---|---|---|---|---|---|---|---|---|---|
| Sediments of Upper Falls | Pumice bed in rim sandstone | Upper Falls | YG-70-2 | 2444 | Sanidine | 5.60 | 0.997 | 13.0 | 0.103±0.004 |
| | Pumiceous flow below "rusty sand" | Upper Falls | YG-70-7 | 2436 | Sanidine | 6.79 | 3.776 | 13.9 | 0.321±0.011* |
| | Pumice | Upper Falls | YG-68-2 | 1848 | Sanidine | 7.39 | 3.784 | 52.7 | 0.295±0.067* |
| | | | | 2095 | " | 7.23 | 3.777 | 28.3 | 0.297±0.009* |
| | | | | 2437 | " | 7.38 | 3.490 | 48.1 | 0.273±0.003* |
| | Pumice above orange zone | Upper Falls | YG-70-5 | 2441 | Sanidine | 7.22 | 9.489 | 80.1 | 0.758±0.007 |
| Bull Lake moraine | Ash bed | Hebgen Lake Narrows | YG-70-19 | 2430 | Sanidine | 6.51 | 5.435 | 54.1 | 0.481±0.005* |
| Fluvial sediments | Pumice pebbles | Pelican Creek | YG-69-6 | 2096 | Sanidine | 6.10 | 12.82 | 47.0 | 1.21 ±0.023* |
| Sediments of Sevenmile Hole | Pumice | Sevenmile Hole | YG-67-5 | 1850 | Sanidine | 5.73 | 26.3 | 88.1 | 2.65 ± 0.17* |
| Sediments of Lower Falls | Tuff of Uncle Tom's Trail | Lower Falls | YG-70-3 | 2443 | Sanidine | 5.70 | 70.75 | 87.8 | 7.14 ± 0.06* |

*Ages assumed to be too old for the stratigraphic position of the sediments