Iron Gulch Fault Escarpment Investigation, Northwestern Helena Valley

By
Michael Stickney
Montana Bureau of Mines and Geology

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Introduction

Seismic hazards in the Helena valley are of particular concern because the 1935 Helena earthquakes caused structural damage to approximately 60 percent of the buildings in Helena, Montana. The capital city sustained an estimated $4 million (1935 dollars) in damage and four deaths (Scott, 1936). The population of Helena has grown from 11,803 in 1930 to 25,780 in 2000, and approximately 67,500 residents live in the surrounding area. A recurrence of the 1935 earthquake with today's population and infrastructure would be disastrous. As growth and development in the Helena valley continue, it becomes increasingly important to understand the seismic hazards and mitigate the risk wherever possible.

The largest 1935 earthquakes had magnitudes of 5.8, 6.1, and 6.0, on October 12, 18, and 31 respectively, but did not generate primary surface rupture, and the causative fault or faults remain unidentified. As damaging as the 1935 earthquakes were, significantly larger earthquakes have occurred in the Helena valley. Geologic mapping within and around the Helena valley revealed Quaternary faulting (younger than 1.8 million years) (Reynolds 1979, Schmidt 1986, and Stickney, 1987), which is evidence of prehistoric earthquakes with magnitudes of at least 6.5 (dePolo, 1994).

To better characterize seismic hazards in the vicinity of Montana's capital city, the Montana Bureau of Mines and Geology (MBMG) applied for and received a National Earthquake Hazards Reduction Program (NEHRP) grant in 1980 to map the Quaternary geology and faulting of the Helena valley. Part of the NEHRP grant was used to obtain approximately 1,100 aerial photographs of the Helena valley at 1:12,000 scale, taken during early morning and late afternoon low-sun-angle lighting conditions. Using these high-resolution photographs and field investigations, MBMG personnel constructed a detailed map depicting 16 Quaternary units and 20 faults with suspected Quaternary offset in the Helena valley. These units and faults were compiled at a scale of 1:50,000 and published in color as MBMG Geologic Map 46 (Stickney, 1987).

In the northwest part of the Helena valley, Stickney (1987) identified a northwest-trending, northeast-facing escarpment preserved in mid- to late-Quaternary alluvial fan deposits along the eastern margin of the Scratchgravel Hills (fig. 1). This 3-km-long escarpment is approximately parallel to and southwest of Silver Creek and is largely buried by younger alluvial fans. Stickney (1987) interpreted this escarpment as a normal fault with late Quaternary, down-to-the-northeast offset and named it the Iron Gulch fault, after Iron Gulch, the largest drainage on the east side of the Scratchgravel Hills. The position of the Iron Gulch fault is somewhat unusual because it lies low on the range-front slope near the toes of alluvial fans (fig. 2). Typically, range-bounding normal faults lie near the fan heads. However, the Iron Gulch fault is generally consistent with the geometry of the graben that forms the western Helena valley. Surface offset along a normal fault to explain the origin of this escarpment was a reasonable interpretation without the benefit of subsurface exposures.

In 2006, a parcel of property in the eastern half of sec. 23, T. 11 N., R. 3 W., which spans the northern part of the Iron Gulch fault, was proposed for development (fig. 3). The developers requested assistance with characterizing the Iron Gulch fault. An improved understanding of the Iron Gulch fault would allow developers to integrate and accommodate potential hazards from the fault into their plans. The MBMG agreed to study the fault with the understanding that the MBMG would be free to publish the results of this investigation and that this work would contribute to an improved characterization of seismic hazards in the Helena valley and western Montana in general. Operations by the developer provided an opportunity to conduct new research and gain a better understanding of the character and movement history of the Iron Gulch fault.

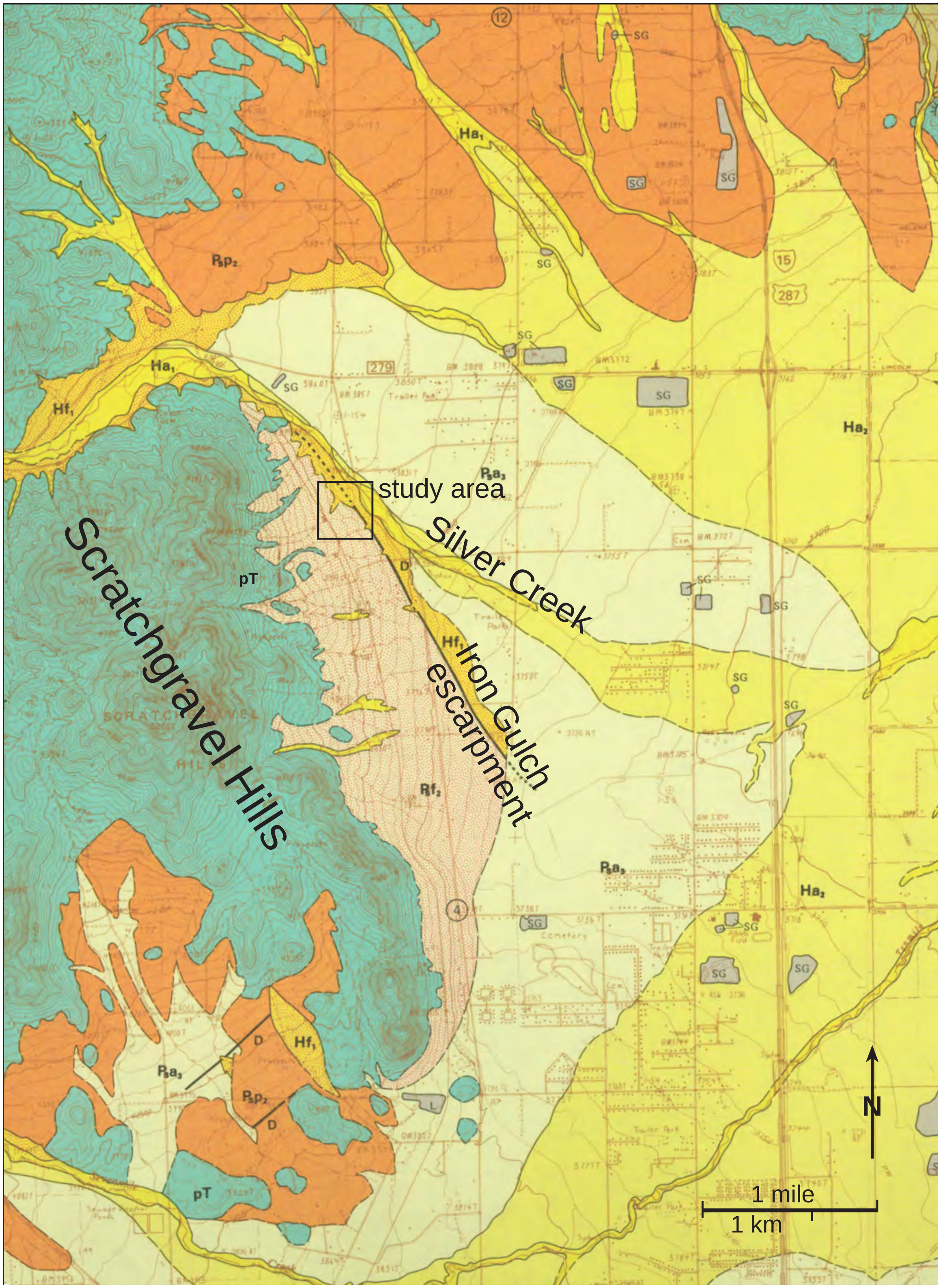

Figure 1. Quaternary geology of the northwestern corner of the Helena valley from Stickney (1987). Units along the Iron Gulch escarpment are P_sf_2—Pleistocene alluvial fan, Hf_1—Holocene alluvial fan, Ha_1—Holocene alluvium along modern stream channels, and pT—pre-Tertiary bedrock undifferentiated.

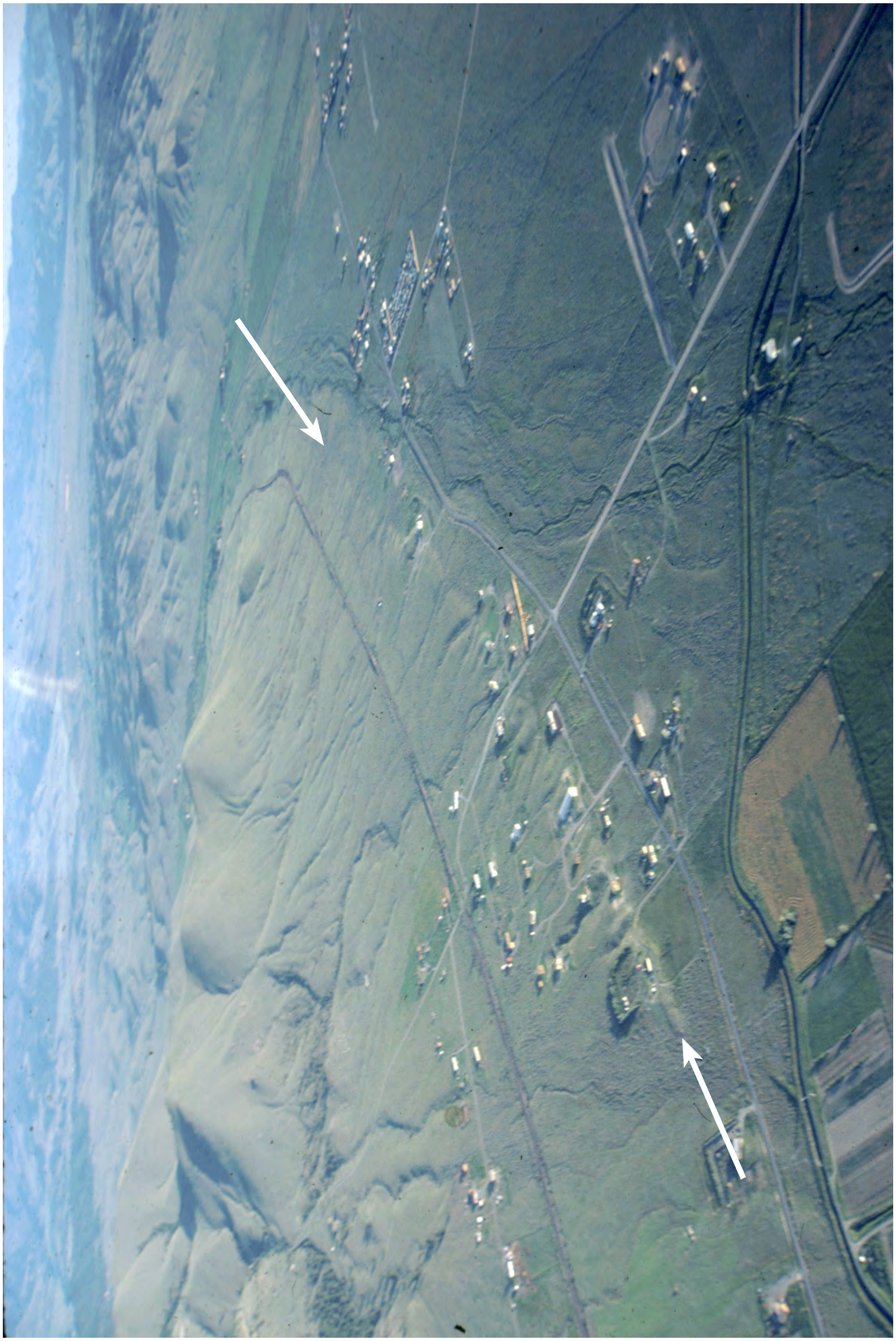

Figure 2. Oblique aerial view of the northwest-trending Iron Gulch escarpment (between white arrows), which Stickney (1987) interpreted as the scarp of a Quaternary normal fault. The channel of Silver Creek runs just to the right of the escarpment. The drainage lying between the grassy hill and the timbered hills is Iron Gulch, the largest drainage in the northeastern part of the Scratchgravel Hills.

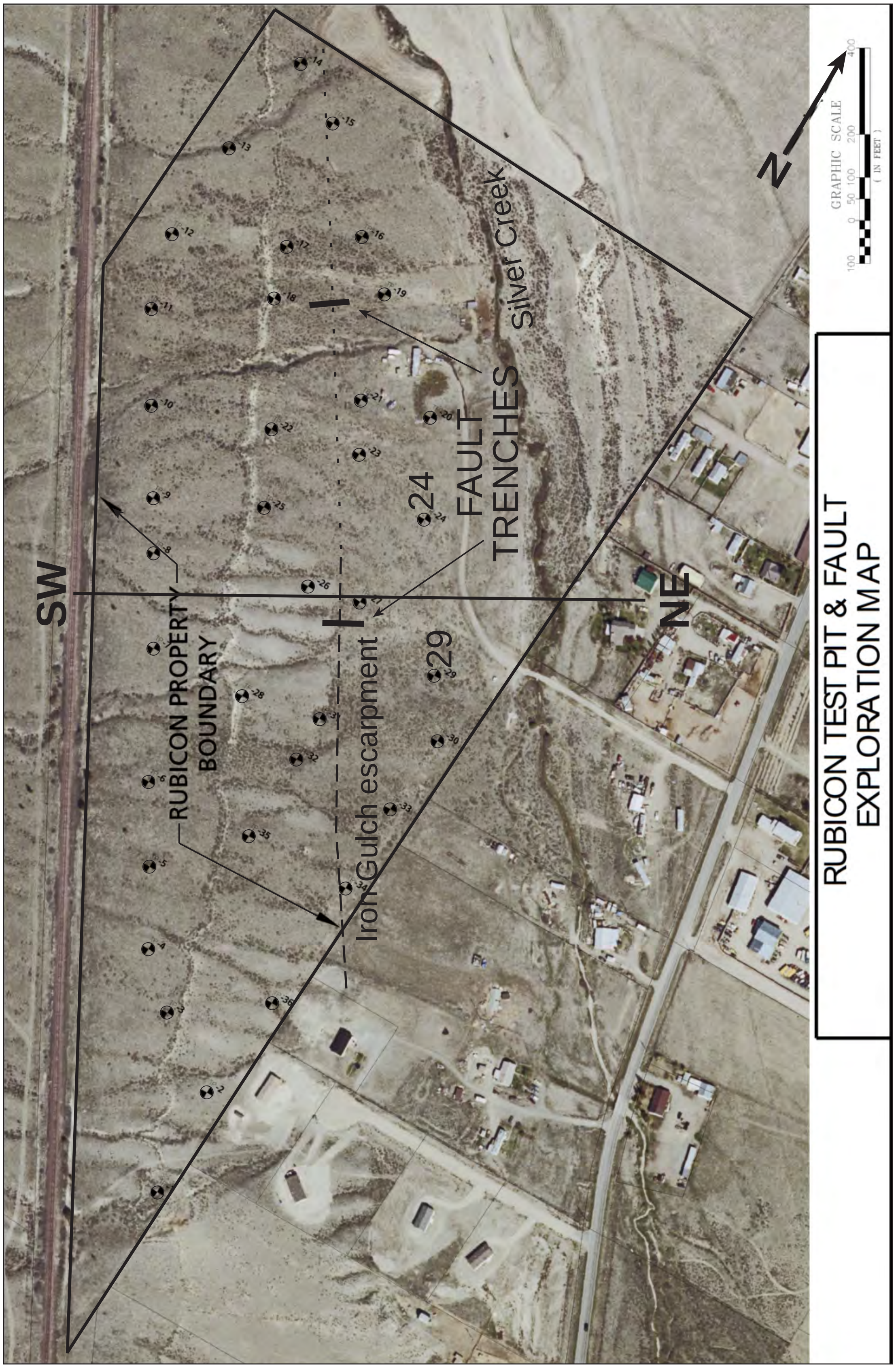

Figure 3. Map of the proposed development superimposed on a vertical aerial photograph showing the locations of soil test pits, trenches, the northern end of the Iron Gulch escarpment, and Silver Creek. The dotted northwestward projection of the escarpment indicates the Iron Gulch fault buried by young alluvial fan deposits inferred by Stickney (1987). The line of section labeled SW–NE is shown in figure 12.

Site Investigation

As part of the pre-development investigation on the 56-acre site, the developers excavated 36 test pits with a backhoe to depths ranging from 4 to 9 ft (1.2 to 2.7 m). Twelve of these test pits were excavated on the east (down-thrown) side of the Iron Gulch fault, and the remaining 24 pits were excavated west of the fault (fig. 3). The investigation included three site visits: an initial visit on January 19, 2006 to examine the soil test pits, on April 1, 2006 to assist with excavation of two trenches across the fault and begin a preliminary trench interpretation; and finally on April 27, 2006 with Larry Smith of the MBMG to complete examination and interpretation of the most revealing fault trench.

On the initial January 19, 2006 visit, all 36 test pits were examined and four geologic units were described in the pits. From oldest to youngest they are:

Granodiorite bedrock. Granodiorite was exposed in six test pits 4 to 6 ft (1.2 to 1.8 m) below the ground surface in the northern part of the proposed development area. This dark gray bedrock is deeply weathered to grus in the test pits, and the backhoe typically excavated 1.5 ft (0.5 m) below the top of this unit. At the very northern edge of the property, bedrock boulders are exposed at the surface, and small gullies have eroded through the thin veneer of sediment to expose bedrock.

Old alluvial fan deposits. Old alluvial fan deposits are exposed in test pits west of the Iron Gulch fault. The old alluvial fan deposits consist of poorly sorted gravelly silt with angular to sub-angular clasts in crude sub-horizontal beds 8 to 20 in (20–51 cm) thick. Clasts include blue-gray argillite, some of which are very weathered, and very dark igneous clasts up to 8 in (20 cm) in diameter, all of which are highly weathered (fig. 4). The upper 3 ft (1 m) of this deposit has high concentrations of cal-

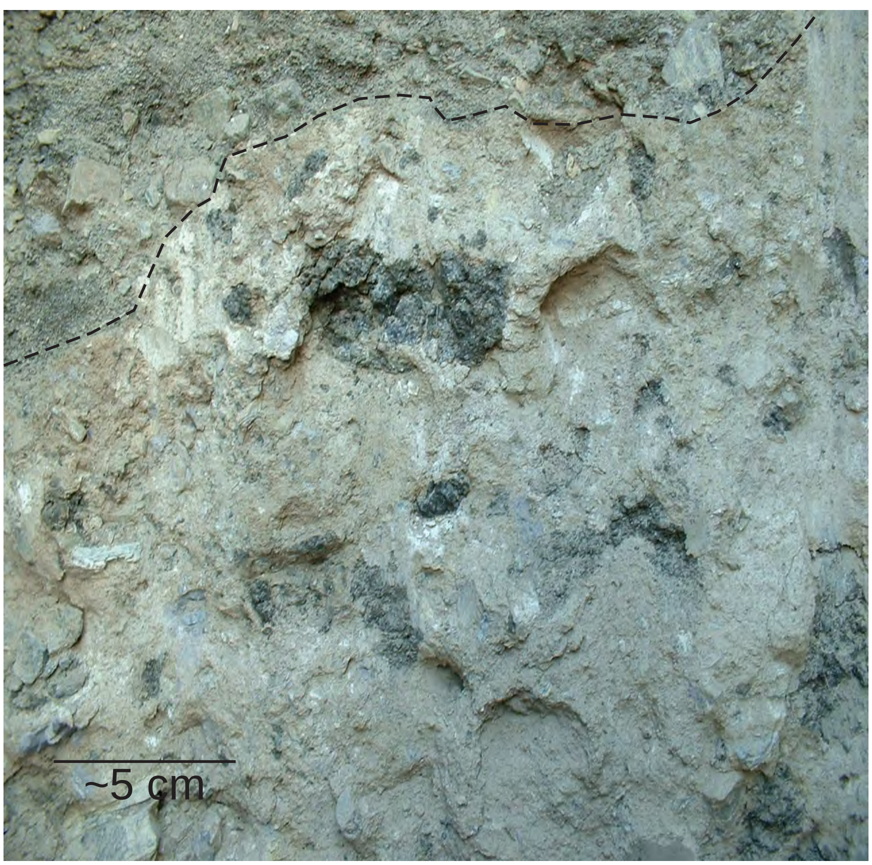

Figure 4. Light-colored old alluvial fan deposits containing dark, highly weathered clasts of igneous rock. Darker-colored young alluvial fan deposits are visible above the dashed contact.

cium carbonate that coat all clasts and cements the fine-grained materials to produce a light yellowish gray color (5Y8/1). The color of the fine-grained matrix below the high-carbonate zone is moderate yellowish brown (10YR5/4). The age of these deposits is not known but is estimated to be late to middle Pleistocene (10,000 to 750,000 years) on the basis of clast weathering and calcrete accumulation, with the more probable age being greater than 50,000 years and possibly much older.

Loess deposits. The five eastern-most pits lying closest to Silver Creek exposed a layer of loess ranging up to 8 ft (2.4 m) thick. This very weakly bedded deposit consists of cohesive, tan, very fine sandy silt (fig. 5) and lies beneath young alluvial fan deposits.

Young alluvial fan deposits. Young alluvial fan deposits consist of gravelly, sandy silt with lenses and channels of gravelly sand up to 6 in (15 cm) thick (fig. 6). These deposits include well-sorted coarse sand and sub-rounded pebble and cobble gravel deposited in small channels that interfinger with lenses of silt and fine sand. There are commonly sharp contacts between the silty units and the incised channel deposits and also between the young alluvial fan deposits and the underlying older alluvial fan deposits (fig. 7). The channel deposits are medium yellowish brown (5YR5/2), and the silt lenses are light yellowish gray (5YR7/1). The bottom surfaces of most clasts have weakly developed carbonate rinds, while some clasts have thicker rinds on the tops or sides. These clasts with randomly oriented rinds together with fragments of calcrete rinds incorporated into the deposit suggest that these clasts were reworked from the older alluvial fan deposits.

During the initial examination of test pit 24 (figs. 3 and 5), a cluster of small charcoal pieces (fig. 8) was collected 7.8 ft (2.4 m) below the ground surface from near the base of the loess unit (fig. 5). The largest pieces of charcoal were carefully separated from the enclosing loess and submitted to Beta Analytic Radiocarbon Dating Laboratory for ^{14}C dating. The sample yielded an acceleration mass spectrometer radiocarbon age of 10,220 ± 40 years before present (2 sigma calibrated age 12,330 to 11,710 calibrated years before present; sample number BETA-214514, Appendix A). This age for a sample within 6 in (15 cm) of the base of the loess unit indicates that the loess began to accumulate shortly before the beginning of the Holocene epoch (10,000 years ago) and is mostly Holocene in age.

In test pit 29 (fig. 3), a 0.4–0.8-in (1–2 cm) layer of volcanic ash was collected 7.7 ft (2.35 m) below the ground surface and 3.8 ft (1.15 m) below the top of the loess layer that was overlain by 3.9 ft (1.2 m) of young alluvial fan sediment. The thickness, whitish gray color, and burial depth of this ash suggest that it is probably the ash of Mount Mazama, which blanketed western Montana 7,620–7,640 calibrated years before present (Hallet and others, 1997) and is exposed elsewhere in the Helena valley (Stickney, 1987). This volcanic ash occurrence reinforces the contention that the loess exposed in test pits below the Iron Gulch fault is Holocene (see note on page 14).

Another important field relation is a fluvial gravel exposed only in the very bottom of test pit 24 (fig. 5) beneath the loess and about 6 in (15 cm) below the dated charcoal sample. This sandy gravel consists of rounded to sub-rounded greenish gray, tan, and purple clasts of quartzite and siltite up to 5 in (13 cm) in diameter. Most of the sand fraction of this unit consists of well-rounded lithic fragments. The bottom of test pit 24 only just reached the fluvial gravels, so their thickness and bedding characteristics are unknown. However, the degree of clast rounding and variety of clast lithologies contrasts with, and distinguishes these fluvial gravels from, the older and younger alluvial fan deposits exposed in other test pits at this site. The similarity between fluvial gravel clasts in the bottom of test pit 24 and the clasts exposed along the modern channel of nearby Silver Creek indicate that ancestral Silver Creek deposited these fluvial gravels.

The initial examination of the test pits and the resulting ^{14}C age suggested two possible scenarios to explain the Iron Gulch fault

Figure 5. Test pit 24 exposes tan-colored loess. The radiocarbon sample came from the visible wall near the base of the pit indicated by the arrow. Fluvial gravels are exposed at the very bottom of the pit. Excavation is approximately 3 ft (1 m) wide.

Figure 6. Layered sandy channel deposits in a young alluvial fan. Dashed line indicates contact between young alluvial fan deposits eroded into and deposited on top of older alluvial fan deposits.

Figure 7. Gravelly, sandy channel deposits that comprise the young alluvial fan deposits incised into and overlying lighter-colored old alluvial fan deposits. Horizontal extent of photograph is approximately 6 ft (2 m).

Figure 8. Loess deposit containing dark pieces of embedded charcoal collected for radiocarbon dating.

scarp. If the scarp resulted from surface offset along the Iron Gulch fault, then the causative earthquake must have occurred during the very latest Pleistocene, shortly before the beginning of Holocene, and was subsequently deeply buried by younger alluvial fans. The second scenario also explains the observations but does not involve young fault offset and calls into question the existence of the Iron Gulch fault. In this scenario, a much larger late Pleistocene Silver Creek eroded laterally into the distal toes of the older alluvial fans shed from the Scratchgravel Hills. A loess layer then accumulated on the floodplain terrace of this creek channel and was subsequently buried by younger alluvial fans. To distinguish between these two scenarios, two trenches were excavated to expose the subsurface contact relations between the geologic units near the escarpment.

Trenches

The southernmost of the two trenches extends northeastward (perpendicular to the trend of the escarpment) for approximately 90 ft (27 m), from old alluvial fan deposits lying west of the Iron Gulch fault to young alluvial fan deposits east of the fault (fig. 9). In the key section of the trench 59 to 78 ft (18 to 24 m) from the west end, near the surface escarpment, the south trench wall was marked off in a 1-m-square grid. The contacts between differing lithologic units were marked with nails and flagging. These contacts, along with larger rocks and pebbles, were mapped at a scale of 4 in = 1 m (1:98.4).

The trench log (fig. 10) shows that older alluvial fan deposits exposed in the western part of the trench are truncated by an irregular, east-dipping contact that is overlain by a poorly sorted, gravelly and sandy silt unit containing crude horizons of larger clasts that are oriented with their long axes dipping gently eastward (fig. 11). This poorly sorted, dipping unit with oriented clasts is interpreted as a colluvial wedge that mantles an erosional face incised into the toe of the older alluvial fan deposits. The colluvial wedge deposits are in turn overlain by younger alluvial fan deposits that consist of gravelly, sandy silt and contain numerous small channels filled with moderately to poorly sorted gravelly sand (figs. 6 and 7). Despite a careful search, no evidence for fault offset was identified in the trench. The contacts of several nearly horizontal layers within the old alluvial fan deposits are not offset (fig. 10), and evidence of shearing such as disrupted zones or steeply oriented clasts was absent.

The northern trench was excavated across the inferred northward projection of the fault. No escarpment is present at this trench site, which is sited entirely on young alluvial fan deposits. In the upper (westward) end of the trench, about 3 ft (1 m) of young alluvial fan deposits overlie a similar thickness of old alluvial fan deposits, which rest on bedrock. Eastward (downslope) along the trench, the younger alluvial fan deposits become thicker and the underlying old alluvial fan deposits progressively thin. Approximately 65 ft (20 m) along the trench, the old alluvial fan deposits pinch out and the young alluvial fan deposits rest directly on bedrock. The gently eastward-dipping bedrock–old/young alluvial fan contact was exposed along the full length of the northern trench but was nowhere offset by faulting. The weathered granodorite bedrock exposed in the floor of the trench did not show evidence of faulting or shearing.

Conclusion

The contact relations between lithologic units mapped in the trenches do not support the interpretation that the Iron Gulch escarpment resulted from tectonic faulting. Neither trench showed any evidence of tectonic faulting. Rather, the escarpment observed at the surface seems to have resulted from lateral erosion of ancestral Silver Creek into the toes of the older alluvial fans. This over-steepened erosional face was then mantled by locally derived colluvial material mobilized by surficial processes such as soil creep, and larger stones lay with their long axes oriented down the surface slope. The floodplain or a fluvial terrace of Silver Creek was likely vegetated

Figure 9. Excavation of southern trench. Note the darker color of the excavated material just in front of the backhoe where younger alluvial fan material was encountered.

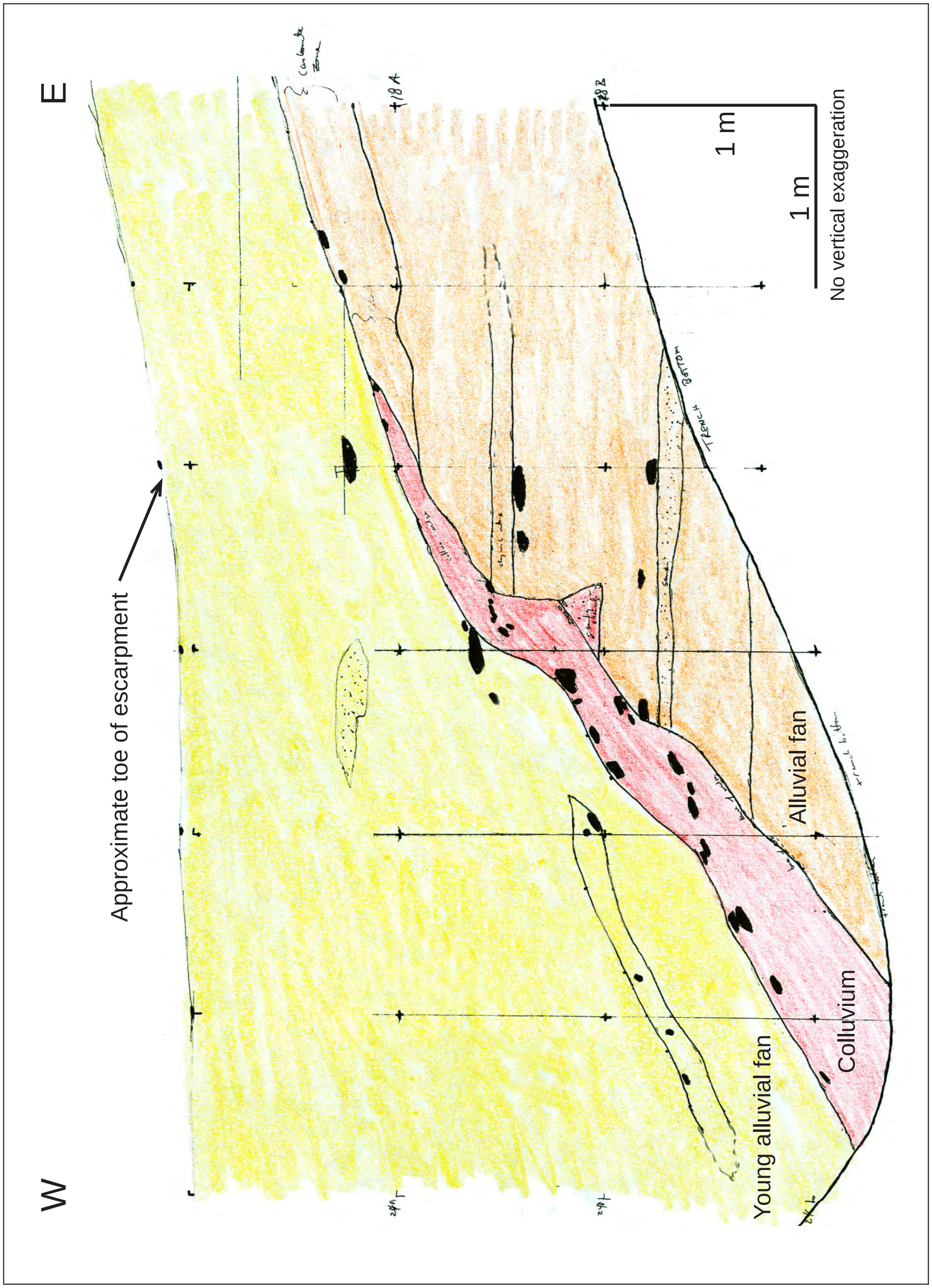

Figure 10. Log of a portion of the trench across the Iron Gulch escarpment. Grid ticks are 1 m apart.

Figure 11. Close-up view of colluvial wedge deposit exposed on the south wall of the southern trench. Note the gently eastward dipping orientation of the largest clast (approximately 4 in (10 cm) long) and some of the smaller clasts. The dashed line shows the contact between the upper surface of the colluvial wedge and the bottom of the young alluvial fan deposits.

and by the beginning of Holocene was accumulating windblown dust and silt that became the loess layer observed in the soil test pits excavated below the escarpment. The colluvial wedge and adjacent loess were later buried by younger alluvial fans, whose upslope feeder channels minimally dissected the older alluvial fan surfaces. Figure 12 shows a schematic cross section of this interpretation.

The age of formation of the escarpment is not well-constrained. The ^{14}C age and suspected Mazama ash indicate that it formed before Holocene. The degree of rounding and degradation of the escarpment crest is consistent with pre-Holocene development. The areal distribution and relative ages of the alluvial fans that Stickney (1987) mapped are generally correct, but new information from the trenches and soil test pits refutes his interpretation of the Iron Gulch escarpment as a normal fault scarp. The feature mapped as the Iron Gulch fault is erosional in origin. It should be removed from Quaternary fault databases because it is not a fault and does not contribute to the seismic hazard of the region.

Note on Loess Accumulation Rate

The rate of early Holocene loess accumulation was estimated by dividing the time interval between the ^{14}C charcoal age (11,932 ±128 calendar years before present) and the Mount Mazama eruption age (7,605 ± 29 calendar years before present) (Hallet and others, 1997) into the estimated loess thickness separating these two age horizons. The stratigraphic thickness of loess separating these two age horizons is problematic because the charcoal and volcanic ash were exposed in different test pits. The Mazama ash was exposed in test pit 29, and the charcoal was collected in test pit 24, 360 ft (110 m) north of test pit 29. Both test

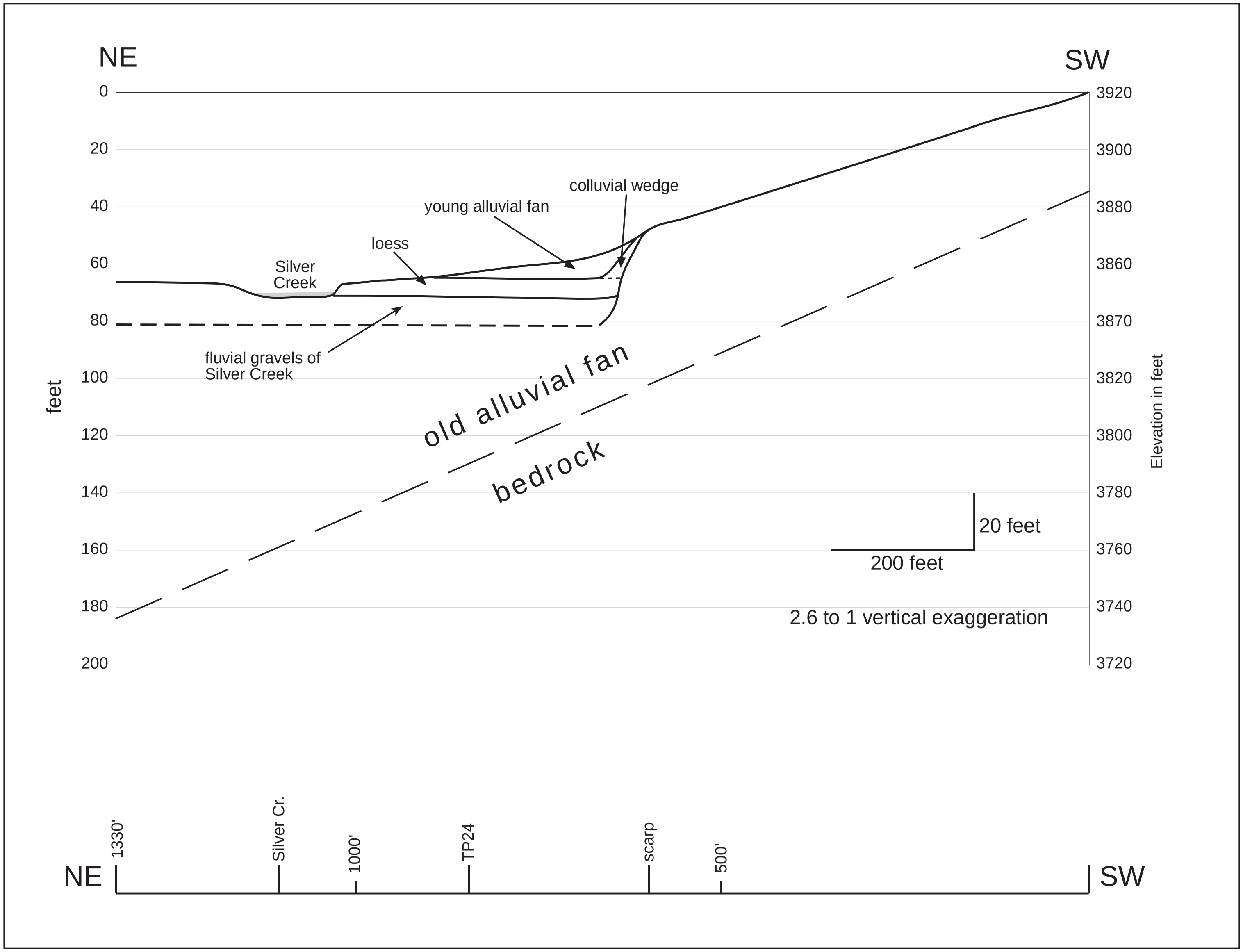

Figure 12. Schematic cross section of the Iron Gulch escarpment showing the inferred contact relations between the Quaternary units present in the study area. There is no control on the depth to the bottom of the fluvial gravels. The bedrock contact is penetrated by a water well at the northeast end of the cross section and is assumed to be sub-parallel to the old alluvial fan surface.

pits lie similar distances east of the escarpment and west of Silver Creek. Test pit 29 lies to the south, closer to the larger and more active portion of the Iron Gulch alluvial fan. In test pit 29, 3.9 ft (1.2 m) of young fan alluvium buries the loess. The Mazama ash was observed 3.8 ft (1.2 m) below the top of the loess, 7.7 ft (2.35 m) below the surface. Unfortunately, test pit 29 bottomed in loess, and the full thickness of the loess layer is unknown but is at least 6 ft (1.8 m). The full thickness of the loess layer exposed in test pit 24 is 8 ft (2.4 m). Assuming that the loess in test pit 29 has a similar thickness to that measured in test pit 24, then approximately 4 ft (1.2 m) should separate the deeper charcoal-bearing horizon from the Mazama ash lying 3.9 ft (1.2 m) down into the loess. Using a 4 ft (1.2 m) loess thickness results in an average early Holocene accumulation rate of 9.17 x 10^{-4} ft/year (0.28 mm/year).

Acknowledgments

The author would like to acknowledge John Herrin and Russ Reed of Rubicon Development and thank them for excavating the trenches, obtaining the ^{14}C age, providing figure 3, and also for their curiosity and enthusiasm. Thanks also to Larry Smith of the Montana Bureau of Mines and Geology for spending a Saturday in the field examining the exposed sediments and for discussions and review of the draft manuscript. Edward C. Bingler wrote the successful grant that funded the Helena Valley mapping project. He also provided the 1980 photograph used on the cover and in figure 2. The measured radiocarbon age was calibrated using http://www.calpal-online.de/index.html.

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Appendix A

Radiocarbon Dating Results

Dr. Russ Reed

Report Date: 3/21/2006

Montana Bureau of Mines and Geology

Material Received: 2/14/2006

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 214514	10200 +/- 40 BP	-23.5 o/oo	10220 +/- 40 BP

SAMPLE : RUB1CONTP24
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 10380 to 9760 (Cal BP 12330 to 11710)

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-23.5:lab. mult=1)

Laboratory number: **Beta-214514**

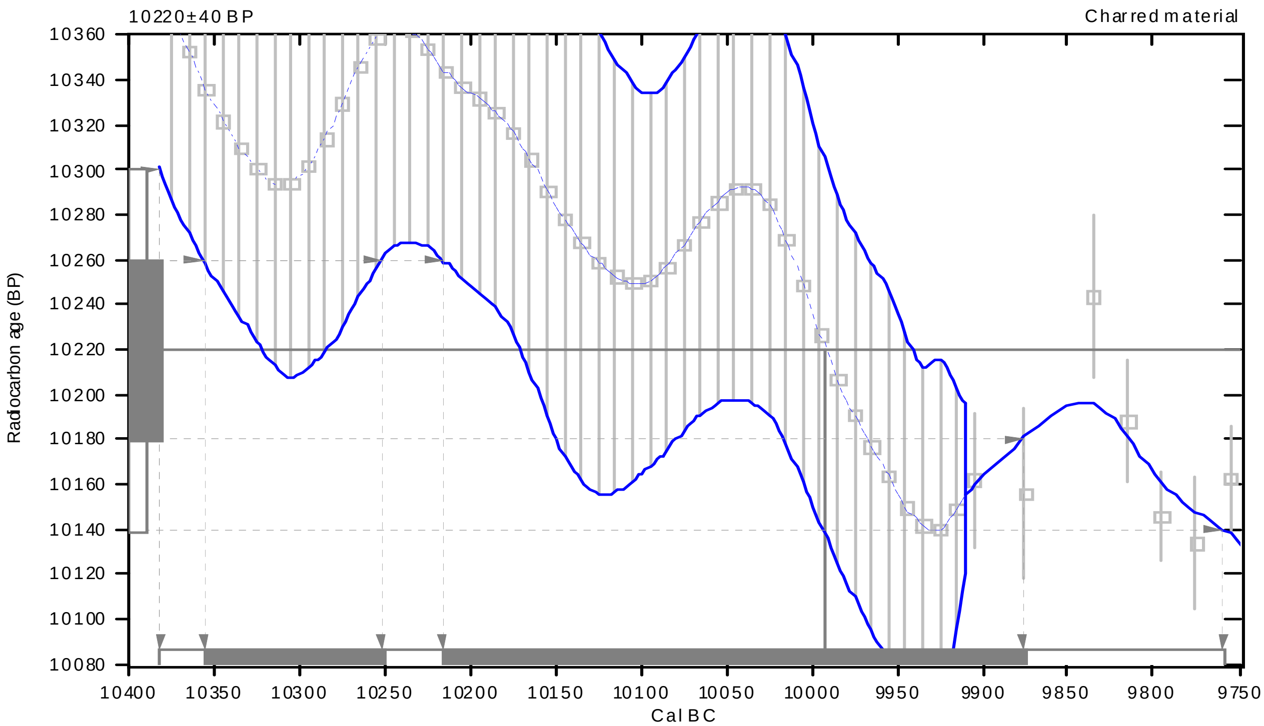
Conventional radiocarbon age: **10220±40 BP**

2 Sigma calibrated result: (95% probability) **Cal BC 10380 to 9760 (Cal BP 12330 to 11710)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 9990 (Cal BP 11940)

1 Sigma calibrated results: (68% probability) Cal BC 10360 to 10250 (Cal BP 12310 to 12200) and Cal BC 10220 to 9880 (Cal BP 12170 to 11830)



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Database used

INTCAL98

Calibration Database

Editorial Comment

Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii

INTCAL98 Radiocarbon Age Calibration

Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083

Mathematics

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • E-Mail: beta@radiocarbon.com