CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-209

Hat Creek, McArthur and related faults
Shasta, Lassen, Modoc and Siskiyou Counties, California

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INTRODUCTION

North-trending normal faults are distributed over a broad area north of Lassen Volcanic National Park (Figure 1). These faults offset basalt of Pliocene to latest Pleistocene age and form prominent scarps up to 500 m high. Fresh scarps (Woodward-Clyde Consultants, 1987), offset young basalt flows (Gay and Aune, 1958; Lydon and others, 1960), and minor seismicity (MacDonald, 1966) suggest that faults in this area are active.

Potentially active strands of the Hat Creek, McArthur and related faults lie within the current Modoc Plateau study region. They are evaluated here for possible zoning under the Alquist-Priolo Special Studies Zones Act (Hart, 1988). Four roughly parallel groups of faults are evaluated in this FER: 1) the Hat Creek fault zone (including the Fall River fault zone of Woodward-Clyde Consultants (WCC),(1987), 2) McArthur fault zone, 3) Pittville fault zone and 4) faults west of the Hat Creek fault zone (Figure 1).

REVIEW OF PREVIOUS WORK

Hat Creek fault zone

The Hat Creek Rim is a prominent west-facing escarpment along the east side of Hat Creek Valley (Figure 1, 2e, 2f). It is about 50 km long and up to 500 m high. The escarpment was first recognized as a fault by Diller (1908). Anderson (1940) produced the first detailed map of faults along part of the Hat Creek Rim in a study of the Hat Creek lava flow. Anderson shows a pattern of left-stepping en echelon scarps along the Hat Creek Rim. The fault along the Hat Creek Rim has been mapped to the south by MacDonald (1964) and to the north by Lydon and others (1960) and Gay and Aune (1958). It has been named the Hat Creek fault by Finch (1933) and MacDonald (1966) and the Hat Creek East fault by Woodward-Clyde Consultants (1987). It is called the Hat Creek fault zone in this report to be consistent with its original name and in recognition of its complexity.

The Hat Creek fault zone offsets lower Pleistocene Burney Basalt along its entire length; it is this resistant unit that forms the prominent escarpment of the Hat Creek Rim. Faults along the base of the Hat Creek Rim offset younger flows from Cinder Butte and Hat Creek Valley. All maps of the fault zone show a distinctive left-stepping pattern of faults with displacement decreasing on one strand as it increases on the adjacent strand. This en echelon pattern suggests a component of right-lateral offset along with the normal offset.

The scarps in the young lava flows at the base of the Hat Creek Rim have been described as "slump scarps" (Finch, 1933; Anderson, 1940) and were not thought to be due to fault movement. "Slump scarps" (a better term is "lava subsidence scarp" (Sharpe, 1938)) form when fluid lava pools against a hill, or an old fault scarp. If a crust forms on the lava and then the fluid lava flows out from under this crust, a scarp will form at the edge of the lava pool. In the case of the Hat Creek flow, lava may have pooled in the upper Hat Creek Valley against the Hat Creek Rim fault scarps, then broken through or flowed around an obstruction, draining the pool and forming lava subsidence scarps along the base of the Hat Creek Rim.

More recent work by Woodward-Clyde Consultants (1987) suggests that the scarps at the base of the Hat Creek Rim are tectonic, not lava subsidence scarps. WCC described a complex scarp about 21 m high consisting of scarps, linear ridges of basalt rubble and linear troughs. Rocks in one scarp and its associated trough have a whitish to brownish weathered appearance while rocks in the other scarp and trough have dark gray unweathered surfaces. Woodward-Clyde Consultants (1987) interpreted this to represent repeated tectonic rupture along this fault since the Hat Creek lava flow was deposited.

The Hat Creek flow has not been dated by any quantitative means. Anderson (1940) considered the flow to be very young based on the fresh flow features, lack of weathering of the basalt and lack of vegetation except in areas of pumice accumulation. He estimated its age to be about 2000 years based on the probable rate of downcutting of the channel of Hat Creek given its gradient, flow and sediment load. Anderson calculated that, at a 0.05 to 0.1 inch per year rate of downcutting, Hat Creek could have cut its deepest channel in 1000 to 2000 years.

Muffler and Campbell (1980) assigned a Holocene age to the Hat Creek flow but more recent work (Muffler and others, 1989) has shown that the flow is overlain by late Tioga outwash (11 to 15 thousand years old) in a gravel pit (locality 1, figure 2f). Woodward-Clyde Consultants (1987) estimated the age of the Hat Creek flow to be about 50,000 years. They based their estimate on the relatively poor preservation of fine flow features and on the relatively thick vegetation cover.

The Hat Creek fault zone has been mapped to the south of the central Hat Creek Valley by MacDonald (1964) (Figure 2e) and to the north by Lydon and others (1960) (Figure 1). MacDonald mapped the faults at the base of the Hat Creek Rim as covered by the "very recent lava flow in Hat Creek Valley". South of Hat Creek Valley the Hat Creek fault zone curves to a more northwesterly trend along the northeast flank of Prospect Peak (MacDonald, 1964) (Figure 2f). East of Prospect Peak in Butte Creek Valley the fault may offset moraines of Tioga glacial age (Kane, 1975). These moraines are reported to be 30 m higher on the west side of the valley than they are on the east, suggesting that 30 m of vertical displacement has occurred since early Tioga time (Kane, 1975). Unfortunately Kane does not show which moraines he measured on a map, nor is it clear where they are offset.

At the north end of Hat Creek Valley the Hat Creek fault splays out into a set of faults called the Fall River fault zone by Woodward-Clyde Consultants (1987) (Figures 1, 2c, and 2e). These faults form a zone about 10 km long and 2½ km wide. Seven faults with down-to-the-east normal displacement bound west-tilted blocks.

These faults offset Plio-Pleistocene and Pleistocene volcanic rocks and Pleistocene lacustrine deposits (Lydon and others, 1960). Pleistocene lake beds of the Fall River Valley locally overlie these faults and are not offset (WCC, 1987). These faults also do not have the sharp, fresh appearance of the scarps along the Hat Creek Rim and McArthur faults according to Woodward Clyde Consultants (1987).

McArthur fault zone

The McArthur fault zone (WCC, 1987) is parallel and very similar to the Hat Creek fault zone. This fault zone (which includes the Butte Creek fault system of MacDonald (1966)) also consists of en echelon, west-dipping normal faults. It is about 60 km long with scarps up to 250 m high.

Faults of the McArthur fault zone offset early Pleistocene basalt, late Pleistocene basalt, Pleistocene alluvium and lake beds in the Fall River Valley and alluvium of the Pit River (Figure 1). The youngest offset alluvium along the Pit River is estimated to be late Pleistocene in age by WCC (1987). The (Holocene) floodplain of the Pit River is not offset by the McArthur fault according to WCC (1987). Scarps in the alluvial and lacustrine deposits of the Fall River Valley are west-facing and about 3-4 m high (WCC, 1987).

The McArthur fault extends to the north across and along the east side of Big Lake (Figures 1, 2c). Strands of the fault offset flows of a young volcanic center mapped by Peterson and

Martin (1980) on the north and east sides of the lake. Peterson and Martin estimated the age of these flows to be Holocene, based largely on similarities to the Hat Creek flow. They accepted Anderson's (1940) 2000 year age estimate for the Hat Creek flow. Anderson's age estimate for the Hat Creek flow is too young as will be discussed later in this report.

Pittville fault

The Pittville fault (also called the Pittville south fault, WCC, 1987) trends somewhat more northwesterly than the Hat Creek Rim or McArthur faults and bounds the east side of the Fall River Valley (Figures 1, 2c). Tertiary basalt is faulted against Pleistocene basalt and lacustrine deposits (Gay and Aune, 1958). This fault extends about 50 km to the southeast, partly controlling the course of the Pit River. Woodward-Clyde Consultants (1987) found no evidence for late Pleistocene movement on the Pittville fault. Peterson and Martin (1980) mapped the north end of the Pittville fault where it offsets the volcanic center north of Big Lake. They consider all the flows from this volcanic center to be Holocene as is discussed above.

Mayfield fault

A group of normal faults that offset latest Pleistocene basalt near the northwest end of the Whitehorse Mountains (Figure 2a) is here informally called the Mayfield fault. It has also been called the Pittville North fault (WCC, 1987). The name "Pittville North fault" implies a connection with the "Pittville South fault" where none is known to exist. It seems more appropriate to refer to the fault by a name of a geographic feature that it passes through. J. Donnelly-Nolan has suggested (p.c. 1990) that the fault should be named for either Julia Glover Flat or Mayfield Ice Cave, both of which lie near the fault. The name Mayfield fault is used in this report. The western fault of this group offsets the Giant Crater lava flow mapped by Champion and Donnelly-Nolan (unpublished) (Figures 2a, 2b, and 2c). The Giant Crater flow has been dated by ^{14}C at 10,580±80 and 10,620±80 years BP (Donnelly-Nolan and others, 1989). This is a Holocene unit, and the faults that offset it are active by definition.

Faults west of the Hat Creek fault zone

Faults west of the Hat Creek fault zone offset Tertiary through early Pleistocene volcanic rocks. South of the Pit River, these faults have been grouped into a "Hat Creek West fault" by Woodward-Clyde Consultants (1987). The terms "Hat Creek East fault" and "Hat Creek West fault" are not used in this report because the Hat Creek East fault was previously named the Hat Creek fault (Finch, 1933; MacDonald, 1966) and the faults west of

Hat Creek do not form a narrow linear zone and appear to be of varying ages.

East- and west-dipping normal faults are distributed over a broad area of the Burney and Prospect Peak quadrangles (Figures 2d and 2f) and extend to the north on the Pondosa and Hambone quadrangles (Figures 2b and 2a). These faults tend to be relatively short (generally 5 to 10 km) and broadly curved. MacDonald (1964), Gay and Aune (1958), and Lydon and others (1960) mapped these faults as offsetting Miocene, Pliocene and Plio-Pleistocene volcanic bedrock.

WCC (1987) examined numerous Quaternary faults west of the Hat Creek fault zone (Figure 1) but did not map them in detail. Scarps described by WCC are up to 50 m high and "eroded and devoid of any more recent appearing scarps, like those along the Hat Creek East or McArthur faults." (WCC, 1987). The exception to this is a scarp along Rocky Ledge east of Burney (Figure 2d). This scarp is about 30 m high and 6 km long and is described as similar in appearance to the faults along the Hat Creek Rim (WCC, 1987).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD WORK

Geomorphic evidence for recent faulting was interpreted on aerial photographs and plotted on 15-minute topographic maps (Figures 2a, 2b, 2c, 2d, 2e and 2f). Aerial photographs taken by the USDA in 1955 and the USFS in 1983 at a scale of 1:20,000 and 1:24,000 were used for the entire area. Additional false-color infrared photos, taken by the USFS in 1980 were available for part of the area but were not used because of their small scale. Other aerial photographs taken by the USGS and USDA were briefly reviewed at the Soil Conservation Service office in Fall River Mills on August 9, 1989.

Geomorphic expression of faulting and units offset by faults were field checked by Chris Wills and Glenn Borchardt on August 7-11, 1989. Geomorphic evidence for recent faulting was noted and the degree of weathering or soil formation was examined at several localities where evidence for or against Holocene fault offset was expected to be particularly clear, based on the aerial photo interpretation.

Hat Creek fault zone

Hat Creek Rim is the 250 to 500 m high escarpment that forms the eastern side of Hat Creek Valley (Figures 2e and 2f). The west facing scarp is capped by early Pleistocene basalt and is largely covered by talus. A normal slip rate of 0.25 mm/yr can be calculated based on approximately 500 m of offset in 2 million years. This slip rate is a minimum because total offset on the fault may be considerably greater than the present topographic relief. A smaller right-lateral component of movement is suggested by the en echelon arrangement of scarps and benches along the fault (noted by MacDonald (1966)).

Evidence for recent movement on the Hat Creek fault zone is largely confined to the western-most faults at the base of the escarpment. Here the fault offsets young basalt flows that originated in Hat Creek Valley. The multiple scarps and troughs described by WCC (1987) also occur along these western faults. The ages of these youngest basalt flows and the nature of the scarps in them are the major problems in resolving the recency of movement along the fault.

In an attempt to resolve the difference between Anderson's (1940) 2000-year age estimate for the Hat Creek flow and WCC's (1987) 50,000-year estimate for the same flow, weathering of the basalt and development of soils were examined in the field.

Weathering of basalt is not distinguishable between the Hat Creek flow, basalt boulders in a Tioga age moraine, and a "Tahoe age" moraine mapped by Kane (1975). Muffler (pers. comm.,1989) considers Kane's "Tahoe" moraine to be of Tioga age. Tahoe age moraines in the area are reportedly much more weathered, with deeper soils, thicker weathering rinds on clasts, and colors in the 7.5YR range (Crandell, 1972; Muffler. p.c., 1989). Weathering of the Hat Creek flow does not appear to be appreciably greater than weathering on the Tioga moraines. Soil development consists of thin silt and iron coatings on basalt blocks. These coatings are in the 10YR color range (10YR6/4d5/3m). This slight weathering is consistent with a latest Pleistocene to Holocene age.

Based on the weathering of the basalt, Anderson's (1940) estimate of a 2000-year age for the Hat Creek flow seems too young. This is demonstrated by Muffler's finding that Tioga outwash overlies the flow (Muffler and others, 1989). Woodward-Clyde Consultants' 50,000-year estimate may be somewhat high. Based on brief examination of the Hat Creek flow and Tioga-age moraines, the Hat Creek flow probably does not predate the end of the Tioga glaciation by more than 10,000 or 20,000 years. The age of the flow is thus probably between 15,000 and 35,000 years.

Scarps in the Hat Creek flows were examined in the field at Lost Creek (Locality 2, Figure 2e) and west of Murken Bench (Locality 3, Figure 2e). At Lost Creek the fault is defined by a scarp about 10 m high, fissures on the upthrown block and a trough along the base of the scarp. On a 1983 aerial photograph the creek on the surface of the Hat Creek basalt flow appears to be sharply offset vertically. Unfortunately, the streambed has recently been modified as part of a hydroelectric project and the relation between the fault and stream channel can no longer be observed in the field.

West of Murken Bench the fault is defined by a side-hill trough or fissure, 3 to 8 meters deep that separates flat lying lava flows on the upthrown side of the fault from steeply west dipping flows on the downthrown side. The steeply dipping flows are probably a block between two strands of the fault. Total offset between the flat-lying flows on the upthrown side and the equivalent flows on the downthrown side is at least 20 m. Offset across the fissure at the upper fault is 1 m. Offset of 20 m in approximately 25,000 years yields a rough slip rate of 0.8 mm/year.

The scarps at the base of the Hat Creek Rim are considered to be tectonic, rather than lava subsidence scarps (Finch 1933; Anderson, 1940) for the following reasons: 1) The scarp profile described by WCC (1987) with two different ages of scarps could not have formed as a cooling feature in a single volcanic flow. 2) Scarps of about the same height offset the Hat Creek flow and older flows from Cinder Butte. 3) The lava exposed at locality 3 (Figure 2e) did not form from a single deep pool of lava. At this location three separate flows are exposed in the wall of a fissure. Each flow had cooled as a horizontal sheet before the scarp was formed.

The eastern scarps of the Hat Creek fault zone (Figure 2e) are higher than the western scarps but are covered by smooth talus slopes at approximately the angle of repose. Troughs or benches in the talus suggesting recency were not observed in the talus slopes. A stream terrace appears to be offset on the north bank of Lost Creek east of locality 2 (Figure 2e), however, indicating that Holocene movement has probably occurred on this strand of the fault.

The strands of the Hat Creek fault zone merge southward into a single fault east of Old Station (Figure 2f). To the south, the fault bends southeasterly and topographic expression of the fault becomes less prominent. On the north flank of Prospect Peak the fault is covered by a lava flow considered to be "post-glacial" (Finch, 1929) possibly less than 2000 years old (WCC, 1987). The fault emerges from beneath the lava flow and forms a side-hill valley and southwest-facing scarp across the northeast flank of Prospect Peak. The southwest-facing scarp that defines the fault here is relatively eroded in appearance, suggesting a lack of Holocene movement on this portion of the fault.

The "Tahoe" age lateral moraine of Kane (1975) (locality 10, Figure 2f) appears to be right laterally offset by approximately 300 meters. This moraine is probably Tioga age, based on the degree of surface boulder weathering (this study, Muffler, p.c. 1989). This amount of offset of a 15,000 year old feature yields an unreasonably high slip rate of 20 mm/yr. It seems more reasonable that a pre-existing bedrock ridge deflected the Tioga age glacier, causing the lateral moraine to appear offset.

The Hat Creek fault zone splays out at its northern end into a series of faults called the Fall River fault zone by WCC (1987) (Figure 2e). These faults form broad, talus-covered scarps in Pleistocene basalt, similar to other faults west of the Hat Creek Rim. Evidence for latest Pleistocene or Holocene movement was not observed on any of these faults.

McArthur fault zone

The McArthur fault zone is located east of and parallels the Hat Creek fault zone and forms a similar en-echelon pattern of scarps (Figures 2c, 2e and 2f). West-facing scarps up to 250 m high along the Butte Creek Rim form the southern half of the zone. The two streams that cross the Butte Creek Rim, Butte Creek and an intermittent drainage east of Lost Creek, have incised canyons part of the way through the escarpment. Both creeks are notably steeper at or closer to the fault, suggesting recurrent offset possibly continuing into the Holocene. The southernmost segment of the McArthur fault offsets alluvium in a meadow along Butte Creek (locality 11, Figure 2f). This meadow is only about 5 km downstream from the end moraines of Tioga-age glaciers. It is therefore probably underlain by late Tioga outwash and possibly younger alluvium. Offset of this surface is a strong suggestion of Holocene movement on this strand of the McArthur fault.

Geomorphic evidence for latest Pleistocene to Holocene displacement was not observed along the McArthur fault from Negro Camp Gulch to Bald Mountain. Scarps are broader, talus covered and incised by minor drainages. The erosionally degraded appearance of the scarps suggests that the fault has not been active in Holocene time. At one location, (locality 4, Figure 2e) a small alluvial fan has covered the fault. The development of a Bt horizon, thick weathering rinds on clasts and red color (7.5YR) in the soil on this fan suggests that it is of late Pleistocene age. See description of Soil 1, Appendix A.

North of Bald Mountain (Figure 2e) the McArthur fault forms smaller, fresher appearing scarps in younger rocks (Figure 2e and 2c). South of Fall River Valley, the McArthur fault forms a sharp scarp in late Pleistocene basalt (WCC, 1987). In Fall River Valley it forms scarps and tonal lineaments in alluvium and lacustrine deposits. North of Fall River Valley it is again expressed as sharp scarps in late Pleistocene basalt.

Because the basalt flows north and south of the Fall River Valley have not been dated, the best evidence for recent movement on the McArthur fault can be found in the Fall River Valley. A west- facing scarp in alluvium, flanked by a large closed depression, between McArthur and Big Lake suggests recent displacement. Two bevels were observed at locality 5, (Figure 2c) suggesting that this scarp represents two earthquakes, each of which was accompanied by 1 1/2 to 2 meters of vertical ground displacement.

Soil development suggests that the alluvium offset by the fault was deposited during the Tioga glacial stage (see description of soil 2, Appendix A). Soils show a weak Bt horizon and, at one location, clay bands that are interpreted to be evidence of a drying climate. (G. Borchardt, pers. comm. 1989).

A low, irregular scarp and tonal lineament were observed along the trend of this fault in the Holocene floodplain of the Pit River south of McArthur (locality 6, Figure 2c). This scarp was field checked and appears to be a fault scarp, not an erosional feature.

A parallel, mostly east-facing scarp crosses the Fall River Valley about 3 km east of the previously described fault. This fault has formed a very sharp scarp locally over 2 m high in alluvium that has very weak soil development and is probably of Holocene age (see description of Pastolla Series by the Soil Conservation Service, Soil 3, Appendix A). This sharp scarp, closed depression and tonal lineaments in plowed fields indicate Holocene offset along this fault.

Pittville fault

The Pittville fault is the easternmost of the north trending faults in the Fall River Valley area. It bounds the east side of the Fall River Valley and forms a prominent scarp in Tertiary basalt (Figure 2c). Recency of movement is indicated north of Fall River Valley where the Pittville fault forms a scarp in late Pleistocene basalt. At locality 7 (Figure 2c) a 1 1/2 to 3 m scarp in basalt has open fissures up to 2 m deep on its upthrown side. Alluvium on the upthrown side of the fault has either been offset from its equivalent on the downthrown side or has been ponded by tilting of the upthrown block. This alluvium is probably of Holocene age based on weak soil development (Soil 4, Appendix A), indicating that fault movement has occurred in Holocene time.

Mayfield fault

A set of north-trending, sharp, fresh scarps in late Pleistocene basalt on the Hambone quadrangle (Figure 2a) is here called the Mayfield fault. It was also called the Pittville North fault by WCC (1987). The westernmost of the scarps is up to about 30 m high and has minor closed depressions along a side-hill trough at locality 8 (Figure 2a).

Portions of this fault offset the Holocene Giant Crater flow of Donnelly-Nolan and others (1989). Scarps and fissures in the Giant Crater flow extending south from Mayfield Ice Cave (Figure 2a) are probably related to the same fault. At Mayfield Ice Cave it is possible to compare the 2-4 m high, relatively linear fault scarp with smaller, more weathered lava subsidence scarps that surround two closed depressions in the basalt flow. The differences suggest that fault offset has occurred since the lava cooled.

A north-trending fault at locality 9 (Figure 2a) also has a very fresh-appearing scarp. The vertical upper scarp and a trough along the base of the scarp both suggest recent movement along the fault. To the north, the channel of Tuft Creek has been offset vertically. Slight incision of the scarp also suggests Holocene faulting. Other roughly parallel faults to the east are similar in appearance, but the easternmost is relatively eroded and has probably had no offset in Holocene time.

Faults west of the Hat Creek fault zone

North to northwest trending normal faults are distributed over a broad area on the Burney and Prospect Peak quadrangles (Figures 2d and 2f) west of the Hat Creek fault zone and extend to the north on the Pondosa and Hambone quadrangles (Figure 2b and 2a). These faults are generally short (5-10 km), discontinuous, and often broadly curving. They do not seem to form a consistent pattern or a narrow zone. Faults are described below from west to east.

A broad, rubbley, east-facing scarp extends approximately 12 km north from U.S. Highway 299 west of Burney (Figure 2d). This fault offsets Pliocene and early Pleistocene basalt (Lydon and others, 1960). The broad and generally degraded appearance of this scarp suggests that there has been no movement on it in Holocene time. Both the scarp about 1 km north of Highway 299 in Burney and the scarp on the east side of Lookout Mountain near Black Ranch are eroded, talus covered scarps. Weathered basalt boulders on the ground surface and the absence of breaks in slope in the talus indicate that these faults have not been active in Holocene time.

A sharp east-facing scarp up to about 50 m high in early Pleistocene basalt follows Rocky Ledge about 3 km east of Burney (Figure 2d). Recency of movement along this fault is indicated by closed depressions at the base of the scarp and small scarps, troughs and benches in talus. In the field, closed depressions were observed along the side-hill troughs in talus. The exposed surfaces of boulders along these troughs ranged from very fresh to significantly weathered, suggesting that the talus has been "stirred" by faulting in Holocene time.

To the north, a sharp west-facing scarp continues on approximately the same trend. This scarp is marked by closed depressions at its base, one of which has been artificially enlarged for use as a pond at a lumber mill (Figures 2d and 2b).

A series of northwest-trending scarps are distributed between the Rocky Ledge fault and Hat Creek (Figure 2d). These are relatively degraded, though closed depressions do occur locally. These faults are probably less active than the Rocky Ledge fault but are well defined and may have moved relatively recently (possibly in Holocene time).

Faults mapped by MacDonald (1964) on the Prospect Peak quadrangle (Figure 2f) are generally broad, degraded scarps in Tertiary to Pleistocene volcanic rocks. A relatively fresh appearing scarp in older alluvium between Badger Mountain and Prospect Peak (in section 34, R5E T32N) suggests that some of these scarps have had displacement in latest Pleistocene time. No clear evidence for Holocene offset was observed.

A sharp east-facing scarp in early Pleistocene basalt parallels Hat Creek between Cassel and Doyles Corner (Figure 2d). The steepness of the scarp and a closed depression at its southern end suggest relatively recent movement. Hat Creek may have erosionally enhanced the scarp, however, making it appear younger than it actually is.

Two faults southeast of Cassel also appear relatively fresh. The western fault is defined by a scarp in early Pleistocene basalt and a tonal lineament in latest Pleistocene to Holocene alluvium. The eastern fault is defined by scarps and tonal lineaments in the most recent basalt flows of Cinder Butte (late Pleistocene). This scarp also partially impounds Rising River Lake. The relatively slight incision of the scarp by outflow from the lake probably indicates Holocene movement on the fault.

Other faults north of Cassel on the Burney and Jellico quadrangles (Figures 2d and 2e) are generally defined by rounded scarps in early Pleistocene basalt. A right-stepping en echelon arrangement of scarps is prominent along two of these faults. Lava flows from Cinder Butte have been channeled along two other scarps (Figure 2e). The lava is not offset, indicating little or no movement since this late Pleistocene lava was deposited.

Faults extending to the north of the Pit River on the Pondosa and Hambone quadrangles (Figures 2b and 2a) are also defined by rounded, talus covered scarps in early Pleistocene and older rocks. Geomorphic evidence for recent offset was not observed on any of these faults.

SEISMICITY

The USGS - Caltech catalog shows a broad scatter of small earthquake epicenters in the area surrounding the Hat Creek and McArthur faults. The small number of recorded epicenters is probably partly due to a low level of seismicity in the area and partly due to a lack of instrumentation. The U.C. Berkeley Catalog (Bolt and Miller, 1971) shows a north-northwest trending alignment of 5 M≥4 events recorded between 1940 and 1972. These epicenters roughly parallel, and lie west of the Hat Creek Rim, consistent with a west-dipping normal fault. These events are poorly located however, and cannot be definitely related to any surface faults.

CONCLUSIONS

Portions of the Hat Creek, McArthur, Pittville, and Mayfield faults and some of the faults west of the Hat Creek fault zone have been active in Holocene time and should be zoned for special studies. The faults all have predominantly normal offset. Together the active portions of these three zones form a fault system nearly 100 km long (Figure 1). Faults considered to be active are highlighted in yellow on Figures 2a, 2b, 2c, 2d, 2e and 2f.

Hat Creek fault zone

The Hat Creek fault zone is a major, west-dipping normal fault with left-stepping traces suggestive of a right-lateral component of displacement (Figures 2e and 2f). Maximum topographic relief on early Pleistocene basalt is 500 m. If the age of this unit is assumed to be 2 million years, a minimum 0.25 mm/yr slip rate can be calculated. Vertical offset of the latest Pleistocene Hat Creek flow suggests a slip rate of approximately 0.8 mm/yr.

Portions of the Hat Creek fault zone have strong evidence for Holocene offset. The scarps along the Hat Creek Rim are the sharpest and highest scarps in the area (Figure 2e). The fresh scarps, troughs, and fissures in latest Pleistocene basalt at their base are tectonic features (localities 2 and 3, Figure 2e), not lava subsidence scarps as previously proposed (Finch, 1933; Anderson, 1940). Portions of the Hat Creek fault zone on the northeast flank of Prospect Peak and the many splays at the north end of the fault are much more erosionally degraded and probably have not been active in Holocene time.

McArthur fault zone

The McArthur fault zone is also a north to northwest trending normal fault (Figures 2c, 2e and 2f). The southern portion of this fault along the Butte Creek Rim forms a similar en echelon pattern as the Hat Creek fault, indicating down-to-the-west normal faulting with a small right-lateral component. Total offset of early Pleistocene basalt is approximately 250 m. Offset of probable late Tioga outwash at locality 11 (Figure 2f) suggests Holocene displacement on the southernmost strands of the fault. Geomorphology along a short segment of the fault south of Bald Mountain is more subdued and does not suggest Holocene offset. The fault is covered at one point by late Pleistocene alluvium (locality 4, Figure 2e).

The section of the McArthur fault zone north of Bald Mountain offsets late Pleistocene basalt north and south of Fall River Valley, latest Pleistocene alluvium (locality 5, Figure 2c) and Holocene alluvium (locality 6, Figure 2c). Age of the offset units and the steepness of the scarps in unconsolidated deposits (locality 5, Figure 2c) indicate that Holocene offset has occurred along this portion of the fault.

Pittville fault

Prominent west-facing scarps in Tertiary volcanics define the Pittville fault along the eastern edge of the Fall River Valley (Figure 2c). Smaller scarps in latest Pleistocene to Holocene basalt extend to the northwest. Offset or ponded Holocene alluvium at locality 7 (Figure 2c) indicates that this fault has been active in Holocene time.

Mayfield fault

The Mayfield fault is a group of normal faults at the northwestern end of the Whitehorse Mountains, approximately on trend with the McArthur fault. These faults are defined by fresh scarps, sidehill troughs and closed depressions (Figures 2a, 2b, 2c). The westernmost scarps offset a basalt flow of early Holocene age (Donnelly-Nolan and others, 1989). The freshness of the geomorphology and the youth of the offset units indicate that the western strands of the Mayfield fault have been active in Holocene time. Geomorphic features along the easternmost strand are more degraded, probably indicating no offset in Holocene time.

Faults west of the Hat Creek fault zone

Normal faults are distributed over a broad area of the Prospect Peak, Burney, Pondosa and Hambone quadrangles (Figures 2f, 2d, 2b and 2a). These faults are generally defined by rounded, talus covered scarps in volcanic bedrock. Offsets of Holocene deposits and geomorphology suggestive of recent offset were observed along Rocky Ledge, several faults west of Hat Creek, and two faults west of Rising River Lake (Figure 2d). These faults are defined by fresh scarps, side-hill troughs and closed depressions. The fresh appearance of the geomorphic features, the scarps in the most recent flows of Cinder Butte and the lack of incision of one scarp by outflow from Rising River Lake all suggest Holocene offset on these faults.

RECOMMENDATIONS

Those faults highlighted in yellow on Figures 2a, 2b, 2c, 2d, 2e and 2f should be zoned for special studies. References on the Porcupine Butte, Indian Springs Mountain 7.5-minute quadrangles (NE 1/4 and SE 1/4 of the Hambone 15' quadrangle) and the East of Pondosa 7.5' quadrangle (NE 1/4 of the Pondosa 15' quad) should be Champion and Donnelly-Nolan (unpublished), Wills (this report) and Woodward-Clyde Consultants (1987). On the Timbered Crater and Day Quadrangles (NW 1/4 and NE 1/4 of the Fall River Mills 15'-minute quadrangle) the references should be Champion and Donnelly-Nolan (unpublished), Peterson and Martin (1980), Wills (this report) and Woodward-Clyde Consultants (1987). References on the Dana, Burney Falls (SW 1/4 and SE1/4 Pondosa 15' quadrangle) Fall River Mills, Pittville (SW 1/4 and SE 1/4 Fall River Mills 15' quadrangle), Burney, Cassel (NW 1/4 and NE 1/4 Burney 15' quadrangle), Hogback Ridge, Cable Mountain, Murken Bench, Jellico (NW 1/4, NE 1/4, SW 1/4 and SE 1/4 Jellico 15' quadrangle), Swains Hole and Old Station (NW 1/4 and NE 1/4 Prospect Peak 15' quadrangle) 7.5-minute quadrangles should be Wills (this report) and Woodward-Clyde Consultants (1987). It will be necessary to transfer the fault locations from the 15-minute quadrangles used for this report to new 7.5- minute quadrangles when the zone maps are compiled. Most of the 7.5-minute quadrangles listed were not available on 9/1/89.

C. J. Wills

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February 15, 1990

Report reviewed
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4/25/90

OK - EWH
5/14/90

APPENDIX 1: Soil Descriptions

Soil 1: described by C. Wills and G. Borchardt 8/8/89

Soil developed on a small alluvial fan that issues from an unnamed drainage two canyons, North of Negro Camp Gulch in NW ¼ NW ¼ Section 31 T35N R6E. Soil is formed on an alluvial fan derived from volcanic rocks (mainly basalt) at 4200 feet on a 5° westward slope with good drainage. Climate is semi-arid. Vegetation is open Oak - Ponderosa Pine - Cedar forest.

A - 0 to 9 cm brown, (7.5YR5/4d); to dark brown (7.5YR3/4m), loam, weak medium granular structure; soft, friable, slightly sticky, non plastic; abundant roots, pH 6.42 clear smooth boundary

B1 - 9 to 20 cm brown (7.5YR4/4d), to dark brown (7.5YR3/4m), loam, medium moderate sub-angular blocky structure; slightly hard, friable, slightly sticky; 7-12 mm weathering rinds on basalt and dacite, pH 6.36, clear smooth boundary

B2t- 20 to 45 cm, brown (7.5YR5/4d) to dark brown (7.5YR3/4m), loam; medium moderate sub angular blocky structure; soft, friable, slightly sticky and slightly plastic; thin clay films on cobbles and in pores pH 6.31

Soil 2: described by G. Borchardt & C. Wills 8/11/89

Soil developed on flat-lying alluvium of Fall River Valley SE ¼ SW ¼ Section 9 T37N R5E in locality mapped as Dudgen Soil by Soil Conservation Service, elevation 3310, moderate-poor drainage (gullying) climate is semi-arid, vegetation is grass/sage

A - 0-8 cm light brownish gray (10YR6/2d) to dark grayish brown (10YR4/2m), silty loam; fine moderate subangular blocky structure; extremely hard, slightly sticky slightly plastic; many fine dendritic roots and pores, clear smooth boundary

B1t -8-17 cm brown (10YR5/3d4/3m), silty clay loam; very coarse strong prismatic structure; extremely hard, sticky, plastic; vertical drying cracks to 42 cm, clear smooth boundary

B2t -17-42 cm light yellowish brown (10YR6/4d) to dark yellowish brown (10YR4/4m), silty clay loam; moderate strong prismatic structure; extremely hard, sticky, plastic; common moderate clay films, abrupt smooth contact

B1tkg-42-56 cm light yellowish brown (10YR6/4d), to dark yellowish brown (10YR4/4m), silty clay loam; coarse moderate platy structure; slightly hard, slightly sticky, slightly plastic. Calcite films < 1 mm thick over continuous moderate clay films on peds + in pores, abrupt smooth boundary

B2tkq-56-110 cm light yellowish brown (10YR6/4d), to dark yellowish brown (10YR4/4m), silt loam; moderate to coarse strong blocky structure; extremely hard, nonsticky, non plastic; calcite films as above, abrupt wavy boundary

C1 - 110-230 cm light yellowish brown (10YR6/4d), to dark yellowish brown (10YR4/4m), silty loam, sandy loam and loamy sand; massive; slightly hard, nonsticky, non plastic

An alluvial sequence consisting of interbedded clayey silt, fine sandy silt, and coarse gravelly sand. Clayey layers 2-10 cm thick, massive, light yellowish brown silty sand beds 5-40 cm thick, fine wavy laminations. light yellowish brown coarse gravelly sand at base of exposure is 30 cm thick with west dipping cross beds, is composed largely of basalt clasts

Soil 3, by Soil Conservation Service, 1984

2184

Photo No. VDYK 4-166B
File No. 302-C1
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PASTOLLA SERIES

The Pastolla series consists of very deep, poorly drained soils in basins. These soils formed in stratified alluvium from ash and lake sediments. Slopes range from 0 to 2 percent.

Soil of the Pastolla series are medial, (calcaareous), mesic Mollic Andaquepts.

Typical pedon of the Pastolla series is in an area of Pastolla muck, 0 to 2 percent slopes, in the McArthur Swamp Area, 800 feet N ofthe flowing well and approximately 900 feet S and 300 feet W of projected NE corner of Sec. 29, T.38N., R.5E., Fall River Mills SW Quadrangle.

Oa--0 to 5 inches; black (N 2/0) and black (N 2/0) crushed muck, very dark gray (10YR 3/1) dry; strong fine granular structure; soft very friable, moderately smeary, nonsticky and nonplastic; many very fine roots throughout; many very fine tubular pores; mildly alkaline (pH 7.8); abrupt smooth boundary.

2A1--5 to 10 inches; black (N 2/0) and black (10YR 2/1) crushed mucky silt loam, dark gray (10YR 4/1), light gray to gray (10YR 6/1), and black (10YR 2/1) crushed dry; moderate medium subangular blocky structure; slightly hard, friable, moderately smeary, slightly sticky, slightly plastic; common very fine pores; moderately alkaline (pH 8.2); abrupt smooth boundary.

2A2--10 to 11 inches; black (N 2/0) crushed mucky silt loam, very dark gray (10YR 3/1) dry; moderate fine subangular blocky structure; slightly hard, friable, moderately smeary, slightly sticky and slightly plastic; common very fine roots and few fine roots throughout; many very fine tubular pores; slightly effervescent; moderately alkaline (pH 8.3);abrupt smooth boundary.

2A3--11 to 19 inches; black (10YR 2/1), dark grayish brown (10YR 4/2), and black (10YR 2/1) crushed mucky, silt loam, gray (10YR 5/1) and light gray to gray (10YR 6/1) dry; moderate fine subangular blocky structure; slightly hard, friable, weakly smeary, slightly sticky and slightly plastic; common very fine roots and few fine roots throughout; many very fine tubular pores; strongly alkaline (pH 8.5); abrupt smooth boundary. Thin strata 1/4 to 1/2 inch ashy material. (Combined thickness of the A horizon is 10 to 19 inches thick.)

3C1--19 to 22 inches; yellowish brown (10YR 5/4), strong brown (7.5YR 4/6), and brown to dark brown (7.5YR 4/4) crushed silt loam, pale brown (10YR 6/3) and yellow (10YR 7/6) dry; moderate very fine subangular blocky structure; soft, very friable, nonsticky and slightly plastic; few very fine roots and fine roots throughout; many very fine and common fine tubular pores; strongly alkaline (pH 8.5); abrupt smooth boundary.

4C2--22 to 29 inches; very dark gray (10YR 3/1) and very dark gray (10YR 3/1) crushed, silty clay, light gray to gray (10YR 6/1) and light gray (10YR 7/1) dry; moderate medium subangular blocky structure; hard, friable, moderately smeary, slightly sticky, slightly plastic; few very fine roots throughout; many very fine and fine tubular pores; moderately alkaline (pH 8.3); abrupt smooth boundary. Small pieces of obsidian and fibers of organic matter.

5C3--29 to 38 inches; dark grayish brown (10YR 4/2) and dark grayish brown (10YR 4/2) crushed, loam, light gray (10YR 7/1) dry; massive hard, friable, moderately smeary, slightly sticky, plastic; few very fine roots throughout; many very fine and fine tubular pores; moderately alkaline (pH 8.3); abrupt smooth boundary.

6C4--38 to 47 inches; grayish brown (10YR 5/2) and grayish brown (10YR 5/2) crushed, clay, gray (10YR 5/1) dry; massive; very hard, friable, sticky and plastic; few very fine roots throughout; few very fine and fine tubular pores; slightly effervescent; mildly alkaline (pH 7.5); abrupt smooth boundary.

7C5--47 to 55 inches; yellowish brown (10YR 5/4) and yellowish brown (10YR 5/4) crushed, loam, light gray (10YR 7/2) dry; moderate fine subangular blocky structure; slightly hard, very friable, nonsticky and slightly plastic; few very fine roots throughout; few very fine and fine tubular pores; moderately alkaline (pH 8.1); abrupt smooth boundary.

8Cq--55 to 64 inches; dark yellowish brown (10YR 4/4), brown to dark brown (7.5YR 4/4), and brown (7.5YR 5/4) crushed, coarse sandy loam, light gray (10YR 7/1) and brownish yellow (10YR 6/6) dry; many fine distinct reddish yellow (7.5YR 6/6) mottles; strong fine angular blocky structure; hard, very friable, brittle, nonsticky and nonplastic; many clay films in pores; few very fine tubular pores; violently effervescent; moderately alkaline (pH 8.1).

Depth to weakly cemented material is 40 to 60 inches, and the depth of stratified alluvial deposits is 60 inches.

The O horizon dry color is N 4/0; 10YR 5/1, 4/1, 3/1. Moist color is N2/0; 10YR 3/1, 2/1. Organic carbon ranges from 16 to 20 percent. Clay content ranges from 27 to 35 percent. Bulk density is 0.35 to 0.45. Reaction is neutral to moderately alkaline.

The A horizon dry color is 10YR 3/1, 4/1, 4/2, 5/1, or N 4/0. Moist color is 10YR 2/1, 3/1, 3/2, 4/1, or N 2/0 moist. Mottles are 10YR 6/1, 2/1; 2.5YR 5/4 dry and 2.5Y 4/4; N 2/0 moist. Organic carbon ranges from 5 to 13 percent. Texture is silt loam or silty clay loam. Clay contents ranges from 20 to 30 percent. Bulk density is 0.40 to 0.50. Reaction is moderately to very strongly alkaline.

The C horizon dry color has a value of 5 to 8, chroma of 1 or 2, and hue of 10YR. Moist color has a value of 5 to2, chroma of 3 to 0, and hue of 10YR and 2.5YR. Organic carbon ranges from .3 to 4.0 percent. Texture is silt loam, loamy silty clay and clay. Clay content ranges from 10 to 45 percent. Bulk density is 0.30 to 0.85. Reaction is moderately to very strongly alkaline.

Soil 4: described by G Borchardt & C Wills 8/10/89

Soil developed on flat lying alluvium in NE ¼ NE ¼ section 33 T39N R5W elevation 3420' moderate-poor drainage vegetation is grass (dry meadow) exposure is a stream bank

A - 0-20 cm brown (10YR5/3d), to dark brown (10YR3/3m), sandy clay loam; weak thin platy structure; soft, slightly sticky, slightly plastic; abundant roots; clear smooth boundary

ABw- 20-50 cm brown (10YR5/3d), to dark brown (10YR3/3m), sandy clay loam; strong moderate angular blocky structure; very hard, slightly sticky, slightly plastic; clear smooth boundary

ABwb- 50-105 cm grayish brown (10YR5/2d), to dark grayish brown (10YR3/2m), sandy clay loam; strong moderate angular blocky structure; very hard, slightly sticky, slightly plastic; clear smooth boundary

2Bt -105-165 cm brown (7.5YR5/2d), to dark brown (7/5YR3/2m) coarse sandy clay loam; massive, slightly sticky, plastic; thin clay films, abrupt boundary

C - 165-225 cm grayish brown (10YR5/2) dry to brown (10YR4/3) moist, silty clay, slightly sticky, plastic.

C2 -basalt? bedrock encountered with hand auger at 225 cm

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