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PRELIMINARY REPORT, MEASURED SECTIONS, AND MAP OF THE GEOLOGY OF THE ASAY BENCH QUADRANGLE, GARFIELD AND KANE COUNTIES, UTAH

by

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SYNOPSIS OF PHYSIOGRAPHY, GEOLOGY AND GEOLOGIC HAZARDS

Geologic mapping in the Asay Bench quadrangle, together with recent mapping in the Cedar Breaks and intervening areas, demonstrates that the Claron Formation and its members extend as mappable units across the southern Markagunt Plateau. This summary report emphasizes stratigraphy of the white member of the Claron and the overlying units, Brian Head Formation (restricted) and younger volcaniclastic beds in the Asay Bench quadrangle. The units are compared to correlative ones at Cedar Breaks. Depositional environments of units, geologic history, and geologic hazards are briefly discussed.

Physiography

Asay Bench quadrangle is in the south part of the High Plateaus of Utah on the Markagunt Plateau and is underlain by gently east-dipping continental strata of Tertiary age. The area is forested and crossed by northeast-flowing streams which have cut valleys 150-300 m deep, exposing non-tuffaceous, fluvial and lacustrine strata of the Claron Formation and younger tuffaceous units. Strata are most deeply eroded in the southwestern quarter. Four cinder cones and several broad lava flows of olivine basalt cover the west-central part of the quadrangle. These morphostratigraphic units (units Qbc and Qbf) are Quaternary in age. When the molten lava erupted, it flowed to low areas, cooled and hardened to a resistant surface. Subsequently, streams cut new valleys down into adjacent soft sedimentary strata leaving the lava as higher benches. Asay Bench is such an old lava flow, the most illustrative of several in the quadrangle. In contrast, the youngest lava flows, probably erupted in Holocene time, lie low in valleys, their fresh, blocky surfaces slightly higher than the streams themselves.

Geology

Structure of the bedrock consists of a regional 1°-3° east dip of strata in a 44-km-wide crustal block. The block, coincident with the Markagunt Plateau, is bounded on the west by the Hurricane Fault and, 4-6 km east, by the Sevier Fault (fig. 1). No definite faults were seen in the quadrangle.

The oldest exposed strata belong to the red member of the Claron Formation (Leith and Harder, 1907) whose age is poorly constrained. Previous workers regarded the basal beds to be as old as latest Cretaceous(?) or Paleocene(?), with most of the formation probably Paleocene and Eocene (Bowers, 1972) or Eocene and Oligocene (Anderson and Rowley, 1975, p. 13); Goldstrand (1994) suggested a late Paleocene to Oligocene age. The Claron generally resembles the Flagstaff Member of the Green River Formation and the North Horn Formation of Late Cretaceous and Paleocene age in north-central Utah (Spieker, 1949; Fouch and others, 1987), but lacks the abundant and well-preserved fossils of these units. Rowley and others (in press) discuss the Claron, its nomenclature, correlations with other formations, and age.

Sedimentary lithostratigraphic units become younger northward. In the southwest, the red member of the Claron (unit Tcr), consists of moderate-reddish-orange and grayish-pink interbedded mudstone, sandstone and limestone. Only the upper 100-150 m of the red member crops out; it is generally poorly exposed and forest-covered, but is well exposed in the upper reaches of Wilson and Asay Creeks and in cuts of Highway 14, near Swains Creek. Channel sandstone, that weathers to a fluted sandstone outcrop (see unit Tcr, measured sections 1 and 3 and figs. 4 and 5) characterize the uppermost part of the red member. The upper member of the Claron, referred to as the white member, is eroded from the southwest quarter of the quadrangle. Farther north, the overlying tuffaceous, very light gray limestone and siliciclastic layers of the Brian Head Formation (restricted) (unit Tbh) crop out on Little Mountain and on the shoulders of Mammoth Ridge. Northeast of the quadrangle, these strata appear to thicken locally and extend under a thick cap of volcanic sand and gravel (units Tvc and Tvg) on the plateau that slopes toward the Sevier River near Hatch, Utah (fig. 1).

Detailed mapping is essential to correlate the fossil-poor Tertiary rocks on the plateau. Units at Cedar Breaks have been traced and extrapolated through areas of concealment 20-30 km eastward into the Asay Bench quadrangle (Moore and Nealey, 1993; Nealey and Moore, unpub. mapping) and northward into the Haycock Mountain quadrangle (Sable, unpub. mapping). Mapping the red member of the Claron Formation was elementary, but mapping the white member was less certain because it changes west to east; marker beds (subunits) vary somewhat in color, grain size, and thickness. At Cedar Breaks, a well-known reference section of the Claron, are three distinctive parts of the white member: a lower white limestone 12 m thick, a middle claystone-sandstone-conglomerate interval 94 m thick, and an upper white limestone, 13 m thick. The lower white limestone (unit Tcwl) is a distinctive cliff, but lava covers it east of Cedar Breaks in the Navajo Lake and Henrie Knolls quadrangles (fig. 1). It reappears north of Asay Bench, where it is divided, interfingers with mudstone, and is less distinctive. Similarly, the upper white limestone is absent in places to the east. Thus, tracing the white member eastward is encumbered by erosion, poor exposures, and variable lithology.

In the northern part of the Asay Bench quadrangle, unit Tcwl is two white limestones, each 2-3 m thick (see measured section 1, units 4 and 7), separated by about 21 m of yellowish-gray to pale-reddish-orange, slope-forming mudstone. However, in the southern part of the quadrangle, the unit is mostly one white clayey limestone resting on the red member of the Claron. In Castle Creek valley, unit Tcwl splits into two thin limestones separated by white limy claystone. Such variation suggests that depositional environments in late Claron time, probably late Eocene (Goldstrand, 1994), changed as streams and lakes shifted within the basin.

North of Asay Creek three subunits of the white member were mapped: a lower white micritic limestone (unit Tcwl), a middle, brown to reddish-brown sandy interval (unit Tcwm), and an upper white micritic limestone (unit Tcwu). South of Asay Creek, unit Tcwu is absent, apparently owing to nondeposition, and a slope-forming interval, the sandy phase (unit Tcws), rests directly on the lower white limestone (unit Tcwl). The sandy phase is as much as 120 m thick, about twice the thickness of the middle sandy interval (unit Tcwm) north of Asay Creek. South of Asay Creek, the sandy phase is friable, light-brown to reddish-brown sandstone, clayey in parts, with 14-20 m of varicolored claystone near its base, and several 2-3-m-thick beds of pinkish-gray, calcium carbonate-cemented chert pebble conglomerate scattered in its upper part; the conglomerate beds pinch out within about 100 m laterally. On the conglomerate, in places, are 2-8-cm-thick layers of numerous wavy, superimposed laminae of calcite crystals. Nearly parallel fibrous and acicular crystals about 2-6 mm long form palisades or slightly radiating fans that make up a lamina. This type of pinkish-gray calcite is probably travertine precipitated from warm spring water largely by growth of algae according to Dwight Schmidt, U.S. Geological Survey (oral commun., 1994). The rock does not resemble a laminar petrocalcic soil horizon, according to Marith Reheis, U.S. Geological Survey (oral commun., 1994), because it lacks "floating" siliciclastic grains, characteristic remnants of detritus which petrocalcic horizons engulf as they slowly accumulate and because fibrous morphology, especially of such long dimensions, is rare in clast-coating soil carbonate (Chadwick and others, 1989). The chiefly fluvial sediments of the sandy phase (unit Tcws) appear to have once graded northward into the fluvial and lacustrine strata of units Tcwm and Tcwu.

In this synopsis Brian Head Formation is used in a restricted sense and refers to the tuffaceous, generally light-gray, multicolored chalcedony-bearing sediments that lie on the white member of the Claron Formation and below the volcaniclastic beds (unit Tvc). The base of the unit was placed at the first (ascending) tuffaceous beds, commonly where fresh, euhedral biotite, judged to be volcanogenic, was seen. The name Brian Head Formation (Gregory, 1945), was abandoned by Anderson and Rowley (1975, p.13), but was used by Anderson (1993, p. 5) in a restricted sense.

Like the Claron Formation, some aspects of the Brian Head Formation (restricted) and overlying rocks change between Cedar Breaks and the Asay Bench quadrangle. Under Brian Head peak (fig. 1), the restricted formation is about 170 m thick, is overlain by a sheet of densely welded ash-flow tuff (Isom Formation), and is underlain by white member of the Claron. In the Asay Bench quadrangle, no Isom Formation is present, the Brian Head Formation is only 35 to 50 m thick and is overlain by volcaniclastic sand and gravel (units Tvc and Tvg); as at Brian Head peak, it rests on the upper white limestone of the Claron (unit Tcwu). The thinness of the Brian Head Formation (restricted) suggests that some strata were eroded before or during deposition of the volcaniclastic deposits (Tvc), the base of which has relief indicative of an erosional surface. The volcanic gravel (unit Tvg) rests directly on the Brian Head Formation on the west part of Mammoth Ridge, suggesting that the older Tvc unit was eroded or not deposited there before the gravel was laid down.

Beds of the white member of the Claron record post-orogenic fluvial and lacustrine deposition of mostly fine-grained detritus in a low-relief, broad basin east of the inactive Sevier thrust belt and west of the Circle Cliffs upwarp of the Laramide orogeny. Besides deposition in rivers and lakes, travertine was deposited by warm springs in the sandy phase in southeast corner of the quadrangle. The sandy phase may record a prograding alluvial plain into the basin. Following deposition, some Claron deposits were altered during diagenesis and (or) pedogenesis (Mullett and others, 1988). Tuffaceous sediments of the overlying Brian Head Formation were deposited as a result of early volcanic eruptions in the Marysvale volcanic field north of the area (Peter Rowley, U.S. Geological Survey, oral commun., 1994). Silicic ash was ejected and accumulated across the basin as airfall ash beds; of these, the oldest isotopically dated one in the Brian Head Formation is 34 Ma (Rowley and others, in press).

Later, andesitic to dacitic lava flows and mudflows and dacitic to rhyolitic ash-flow tuffs were erupted from the Marysvale field and andesitic to rhyolitic ash-flow tuffs were erupted from sources in the Great Basin. Much later, erosion ensued, followed by an influx of coarse river gravels composed chiefly of Marysvale-derived andesitic volcanic rocks, minor quartzite, and some Great Basin rhyolitic tuffs. These gravels form thick beds (units Tvg and Tvc) on Mammoth Ridge and on other divides north (Sable, unpub. mapping) and northeast of the quadrangle (Kurlich and Anderson, 1991). In the southeast corner of the quadrangle, scarce volcanic clasts are exposed in the uppermost 2-3 m of bedding at the top of hill 7879 (radio facility in sec. 15, T. 38 S., R. 6 W.), and on two neighboring hilltops to the south. The pebbles are very pale red purple volcanic porphyry (rhyolitic ash-flow tuff?) and make up less than 1 percent of the mostly chert pebbles. Volcanic pebbles were not seen in the underlying strata of the Tcws unit. Being apparently limited to a few, isolated beds makes their correlation difficult, but three possibilities, are in accord with the regional geology: (1) The volcanic composition suggests correlation to the Brian Head Formation (restricted) or the overlying volcanic sediments (Tvc or Tvg). The latter is unlikely because no dark andesitic clasts were found in the pebbles in question. If the pebbles do correlate to the Brian Head, they are about 30 m lower than equivalent strata along strike 8-10 km north, suggesting they were deposited on a post-Claron erosion surface having at least 30 m of relief. (2) Alternatively, the fluvial pebbles could be derived from early Oligocene, calc-alkalic volcanism (pre-Needles Range Group) in southwestern Utah (Rowley and others, 1979, p. 6). If so, they could be an uncommon volcaniclastic phase of the white member of the Claron. (3) Another possible source would be a young local ash-flow tuff. All three possibilities are speculative pending petrographic study of the pebbles.

During late Tertiary and Pleistocene(?) time, uplift, eastward tilting and stream dissection of the plateau probably occurred at about the same time as movement on the Sevier Fault, 4-6 km east of the quadrangle in the Sevier River valley.

Geologic Hazards

Geologic hazards arise from dynamic earth processes that can endanger life and property. They include flash floods, landslides, swelling of soils, earthquakes, and volcanic eruptions. Evidence of these processes was seen in the Asay Bench quadrangle. Floods. Changes in position of Mammoth and Asay Creeks indicate past sporadic flash flooding. The shifts appear as meander scars, seen in the field and on aerial photographs. Besides moving the channels, large floods usually inundate adjacent low-lying flood plains, depositing sheets of fine alluvium (unit Qal); areas mapped as unit Qal may flood in the future. Areas below watersheds that may flash flood during cloudburst storms, are young alluvial fans (unit Qfy) and areas of combined alluvium and colluvium (unit Qac). Flash flooding, chiefly a summer phenomenon, often discharges debris flows in such small areas in southwestern Utah (Butler and Marsell, 1972, p.35). Debris flows are flowing masses of mud, boulders, and woody debris that accumulated in a watershed and is suddenly flushed out by storm runoff. Landslides. Landslide deposits (unit Qls) exist on some relatively steep (about 20°) hillslopes, but not on lesser slopes. Buildings placed on steep hillslopes could be damaged by downslope sliding or rotation of unstable hillslopes. Units Tbh, Tcr, and Tcw locally contain claystone that is slide-prone. Swelling soils. Problems related to swelling soils may occur in areas shown by map units characterized by claystone. In places such units have a frothy or "popcorn"-looking weathered surface, suggesting presence of clay minerals, such as smectite, that swell with addition of water. The swelling can heave foundations, causing structural damage. Earthquakes. Earthquake risk is difficult to assess because, even though the area is near the potentially active Sevier Fault, no faults or scarps made by earthquakes were seen. Because of sparse habitation in the quadrangle, risk of damage from earthquakes is minimal.

Volcanic eruptions. Widespread and geologically young volcanic rocks, basalt lava, imply some likelihood of future eruptions. Although none have occurred in historic time in the Markagunt Plateau volcanic field, which includes the Asay Bench quadrangle, the field is considered volcanically active (Smith and Luedke, 1984), in geologic time. Volcanic landforms have yielded K-Ar ages of 0.5-1.5 Ma (Best and others, 1980). Previous estimates of ages were based on the youthful appearance of the rocks: Gregory (1949) suggested that volcanic eruptions occurred as recently as 1,000 years ago; Dutton (1879) stated that lava may have erupted near Panguitch Lake in the last century. This lava flow (unit Qbf in Mammoth Creek valley) is morphologically even younger than those dated at 0.5-1.5 Ma. Some flows in the Navajo Lake and Henrie Knolls quadrangles also look very young (Nealey and Moore, unpub. mapping), suggesting that future volcanic activity is possible on the Markagunt Plateau, perhaps in the Asay Bench quadrangle, but more likely just west of it.

Any future eruptions will probably be small in volume, of basaltic and andesitic composition, and form cinder cones and shield-like volcanic centers. Impacts could include disruption of roads, damming of creeks to form small lakes, and burning of forests and man-made structures near erupting cinder cones. Earthquakes associated with such eruptions would probably be small ones, but could trigger landslides. Financial loss could be offset by increased tourism.

DESCRIPTION OF MAP UNITS

Colors use the Munsell system based on matches to color chips appearing in the Rock-Color Chart (distributed by Geological Society of America) and loose-leaf notebook (The Munsell Color Company, Inc., Baltimore, Md.). Where the base of a deposit was not exposed, thickness was estimated. Unconsolidated surficial deposits less than about 0.6 m thick were not mapped. Descriptive terms for limestone, for example, pelmicrite, follow Folk (1959). Sandstone was classified in field and follows AGI (1982).

Alluvium (units Qal, Qsw, Qfy) and colluvium (unit Qc) were mapped separately. Where separation was not practicable, mixed alluvium-colluvium was mapped (unit Qac). Broad, fan-shaped, washed sediment on slopes relatively far from bedrock outcrops was mapped as young alluvial-fan deposits (unit Qfy). Older fan alluvium and colluvium (units Qfo and Qaco) are greatly eroded, destroying most of the landform, resulting in similar-looking deposits. These deposits were distinguished less accurately than matching younger types.

UNCONSOLIDATED SURFICIAL DEPOSITS

Qal **Low-level alluvium (Holocene)**--Gravel, sand, silt and clay deposits in or adjacent to stream channels and on floodplains; moderate-yellowish-brown (10YR 5/4) stratified, moderately well to poorly sorted; in Castle Creek is a firm sandy clay to clayey, pebbly sand; unit interfingers laterally with colluvium (unit Qc) and with sloping valley deposits (unit Qac); base of unit covered. Estimated thickness 1-8 m

Qsw **Sheetwash alluvium (Holocene)**--Silty clay, silty and clayey very fine sand on flats relatively far from bedrock source outcrops; friable to firm; laminated and very thinly bedded; contains lenses of pebbles and scattered charcoal; dry colors moderate-yellowish-brown (10YR 5/4), grayish-orange (10YR 7/4) and light-brown (5YR 5/6); moist color moderate-brown (5YR 3/4); contains common to abundant granules, and scattered small cobbles, of very pale orange (10YR 8/2) to moderate-orange-pink (5YR 8/2) limestone, gray basalt gravel, and locally a trace of chalcedony pebbles. Thickness 0.5-3 m

Qta **Alluvial-terrace deposit (Holocene)**--Similar to Qal unit except surface of deposit is at a level 4-6 m higher than Mammoth Creek; abandoned remnant of former floodplain and channel deposit. About 2-3 m thick

Qfy **Young alluvial-fan deposits (Holocene)**--Presently accumulating and young deposits of crudely stratified gravel, sand, silt, and clay; pale-yellowish-brown (10YR 6/2), light-brown (5YR 6/4), and moderate-yellowish-brown (10YR 5/4); sandy gravel and poorly sorted clayey gravel in high parts of fan grading to pebbly sand in lower parts; sediment in high parts of fan probably are interbedded mass-wasting, debris flow, and alluvial deposits; base not exposed; estimated thickness 2-20 m

Qac **Alluvium and colluvium (Holocene)**--Pebbly and slightly silty, very fine to medium-grained quartz and lithic sand; pale-yellowish-brown (10YR 6/2), pale-brown (10YR 6/3); surficial residuum is light-gray (2.5 YR 7/2) pebbly coarse sand; common to abundant angular limestone and sandstone gravel, minor round chert pebbles; interbedded gravity-transported and washed sediment that accumulates in ravines and on low surfaces downslope from outcrops of Claron Formation and basalt flows; forms small cones and fans; grades upslope to colluvium (unit Qc) on hillslopes of buttes; thickness 1-10 m

Qc **Colluvium (Holocene)**--Generally massive, unsorted and unstratified gravity deposits on slopes and at base of slopes; angular to subangular very coarse to fine rock debris and sand in a matrix of clay and soil material; composed of local bedrock, usually limestone, sandstone, and basalt; 1-5 m thick

Qt **Talus (Holocene)**--Steeply sloping accumulations of coarse, angular rock fragments below cliffs and steep, rocky slopes. Chiefly medium-light-gray (N6) to medium-dark-gray (N4) basaltic rock; minor amounts of sandstone and limestone. Base covered; thickness estimated 1-20 m

Qls **Landslide deposits (Holocene)**--Heterogeneous mix of sand, clay, and angular rocky debris; gravitationally displaced soil and bedrock, broken and disaggregated. Most slumps are on moderately steep slopes; about 2-8 m thick

Qtg **Alluvial-terrace gravel (Holocene to late Pleistocene?)**--Coarse gravel composed chiefly of flood-transported basaltic talus near the confluence of Strawberry and Swain's Creeks; probably interbedded and mixed with sandy alluvium. Inferred from aerial photographs; deposit was not examined. Estimated thickness 2-6 m

Qfo **Old alluvial-fan deposits (Pleistocene)**--Remnants of sloping alluvium; surfaces of deposits are more dissected and 6-13 m higher topographically than subjacent surfaces of young fan alluvium (unit Qfy). Very pale grayish orange (10YR 8/4) very fine to coarse quartz sand; silty and pebbly; 10-25 percent lithic and accessory sand grains; common pebbles, small cobbles, and scarce small boulders of very pale orange limestone, and minor amounts of volcanic clasts derived from unit Tvg; common chert and quartzite pebbles; crudely bedded and poorly sorted. As much as 12 m thick

Qaco **Old colluvium (Pleistocene)**--Remnants of interbedded alluvium and mass wasting deposits; poorly sorted gravel in a matrix of sand, silt, and clay; surfaces slope 5°-9° toward valleys and are 8-12 m higher than subjacent younger colluvium (unit Qc); composed chiefly of limestone and sandstone, but contains some volcanic clasts locally. Estimated thickness 2-6 m

ROCK UNITS

Qbf, Qbc **Olivine basalt flows and cinders (Holocene? and Pleistocene)**--Medium-gray (N5) to medium-dark-gray (N4), fine- to medium-grained. Ubiquitous olivine phenocrysts average 1-2 mm in diameter; sparse to common plagioclase phenocrysts average 1-2 mm in length; rare clinopyroxene phenocrysts average 1-2 mm in length. Phenocrystic phases form common glomerocrystic clots in some flows; quartz xenocrysts are rare. Flows are commonly vesicular or vuggy. Surface of older flows locally veneered by residuum and sheetwash composed of moderate-yellowish-brown (10YR 5/4) silty and clayey fine lithic sand, with scattered basalt gravel; a moderate-brown (5YR 4/4) clayey, angular blocky B horizon is well developed in places. Vent areas for many of the flows in the central and southwestern parts of the map area are located in the Asay Bench.

Vents for flows in the northwestern part of the Asay Bench quadrangle are chiefly to the west in the adjoining Henrie Knolls quadrangle. Young flows in the valley of Mammoth Creek were erupted from vents in the Panguitch Lake area, a few kilometers northwest. Within the quadrangle, adjoining flows that are compositionally distinctive are separated by a dash-dot line symbol on map.

Chemically, the rocks range in composition from basalt to trachybasalt and trachyandesite (Streckeisen, 1979) (Figure 1; table 1). Silica content ranges from about 46.5-51.5 weight percent SiO_2. Rocks of similar composition occur about 20 km west in the Navajo Lake quadrangle (Moore and Nealey, 1993) and adjacent parts of the Markagunt Plateau (Lowder, 1973). Trace-element contents in volcanic rocks from the Asay Bench quadrangle vary significantly. Concentrations of incompatible elements Ni and Cr vary by factors of 24-25, whereas Rb, an element that is usually incompatible in basaltic magmas, varies by a factor of 18. The abundance of Sr varies by a factor of 4 and has the lowest abundance in a lava flow that contains abundant plagioclase-olivine glomerocrysts (samples NPB22 and NAB72). The same flow also has low Ba, La, Ce, Nb and total alkali contents. Thickness about 2-25 m

Tvg **High-level volcanic gravels (late Tertiary)**--(Probably equivalent to valley-fill deposits of Kurlich and Anderson, 1991 and Sevier River Formation of Callaghan, 1939). Subrounded to subangular gravel, pebbles to boulders as large as 0.5 m diameter; composed of various dark-colored, vesicular and porphyritic volcanic (andesitic?) rocks, mostly moderate-brown (5YR 4/4); some rhyolitic ash-flow tuff, including Isom Formation; most volcanic rocks probably derived from Marysvale volcanic field; less than 0.5 percent of clasts are well-rounded quartzite cobbles of tan, reddish-brown, gray, pale orange. Unit is partly consolidated; erosional remnants of beds form rounded, medium-gray hills and minor ridges atop Mammoth Ridge. Bedding obscured by gravel float. Surface residuum is dark-yellowish-brown (10YR 4/2) gravelly, silty, very fine to coarse lithic and quartz sand. On aerial photographs unit is uniform light-greenish-gray to medium-gray and, viewed in stereovision, appears as smooth, rounded hills. Basal contact obscured by float, but unit appears to cut into underlying unit Tvc; near the westernmost exposure on Mammoth Ridge, Tvg beds appear to rest directly on Tbh unit. May be Pleistocene in part. Eroded thickness about 16-24 m in the quadrangle; thickens north and northeast of quadrangle

Tvc **Volcaniclastic deposits (late Tertiary)**--(may be equivalent to valley-fill deposits of Kurlich and Anderson, 1991 and may include upper part of Brian Head Formation as mapped by Sable (unpub. mapping in Haycock Mountain quadrangle). Interbedded sandstone, pebbly sandstone, and conglomerate. Unit forms a subtle but distinctive, moderate-orange-pink, earthy, low-angle slope below rounded gravel hills made of unit Tvg and above the light-gray shoulder slope of unit Tbh. On the pebbly, earthy slope, thin, nearly hidden ledges of moderately consolidated sandstone crop out. Sandstone is light-brown (5YR 5/6), silty, fine- to coarse-grained volcanic litharenite; poorly sorted; framework grains--20 percent black and brown chert, 20 percent volcanic lithic grains, 50 percent quartz, 10 percent clay grains; clay-silt-calcareous matrix makes up 5-30 percent of entire rock volume; friable. Conglomeratic sandstone matrix is moderate orange pink (5YR 8/4) and contains gray, polymict volcanic, porphyritic clasts; subangular clasts are granules to small pebbles; about 12-60 m thick

Tbh **Brian Head Formation (Early Oligocene? to Late Eocene)**--Interbedded limestone, tuffaceous limestone, sandstone, claystone, chalcedony, chert pebble conglomerate, and porcellanite. Limestone is yellowish gray (5Y 8/1) to very pale orange (10YR 8/2), some is light greenish gray (5GY 8/1) with fine pale-green (5G 7/2) mottles; forms a angular gravelly to earthy slope; poorly exposed, some beds contain trace of biotite, and are slightly tuffaceous. Sandstone and silty mudstone are light and of low density and thin- to medium-bedded; varicolored chalcedony nodules 10-30 cm across and in discontinuous thin beds. One bed about 4 m above base is light-gray (N7), soft, plastic clay "gumbo", about 1 m thick; contains abundant euhedral biotite (volcanogenic?). Upper 6-12 m of unit is interbedded sandstone, claystone, and chert-pebble conglomerate composed of rounded, medium- to very coarse grained quartz and chert in moderate-reddish-orange (10R 6/6) clay matrix. Upland surface covered by lag of abundant chert and quartzite rounded pebbles and granules--black, dark and light brown, reddish-brown, white. A few porous, calcite-cemented sandstone beds 15-30 cm thick, moderate-orange-pink (10R7/4). Float contains pieces of a calcite-cemented sandstone and chert conglomerate, light-brown (5YR 6/4). Base of unit generally covered and approximately located; in measured sections base was defined at first (ascending) appearance of euhedral biotite inferred to be volcanogenic; unit forms rounded shoulder slope on Mammoth Ridge and Little Mountain. Thickness approximately 35-50 m

Claron Formation (Oligocene to Late Paleocene)

White member--in the north consists of lower white limestone (Tcwl), middle sandy unit (Tcwm), and upper white limestone (Tcwu); in the southeast consists of lower white limestone overlain by sandy phase (Tcws) which may correlate in part to the middle sandy unit in the north.

Tcwu **Upper white limestone**--Micritic limestone, very pale orange (10YR 8/2), pale-yellowish-gray (5Y 9/1), weathers pale-yellowish-gray to white (N9); sparse, dispersed fine quartz sand grains in places; contains pale-blue (5PB 7/2), very pale blue (5PB 8/2), and bluish-white (5B 9/1) chalcedony wavy veins and vugs, double laminae chalcedony linings 0.2-0.8 cm thick on walls of vugs; some vugs filled with drusy quartz crystals 0.05 mm long. Limestone pisolitic in part, contains intraclasts of micrite in part; horizontal separations of lime mud 0.5-1 mm thick form discontinuous plates 2-4 cm across (desiccated lime mud?) intercalated with finely brecciated pelmicrite; voids and cracks between clasts filled with lithified lime mud, later cemented by calcite and silica giving a crackled appearance that cuts across indistinct bedding; coarse sparry calcite rhombohedrons fill some chalcedony-lined cracks and veins. Such features indicate rock has undergone significant diagenetic siliceous and calcareous alteration 24-50 m thick

Tcwm **Middle sandy unit**--Sandstone and claystone, interbedded. Sandstone, dark-yellowish-orange (10R 6/6), yellowish-gray (5Y 7/2) very fine grained, moderately well-sorted, rounded grains; trace of clay grains, chert and quartzite litharenite, calcareous; cross-bedded; mostly friable, some beds moderate to strongly cemented; forms steep sandy grayish-orange (10YR 7/4) slope, but where moderately well-cemented forms cliffs, 7.5-12 m high. Claystone, very pale orange (10YR 8/2), yellowish-gray (5Y 7/2), dark-yellowish-orange (10YR 6/6), a few 1-m-thick beds of claystone are very dusky red (10R 2/2). Tcwm unit forms earthy slope with scarce sandstone ledges. About 60 m thick on Sawyer Point, 67 m thick at measured section 3 (Mammoth Ridge), 54 m thick at measured section 1 (see Measured Sections)

Tcws **Sandy phase of white member**--Chiefly claystone, sandstone, sandy siltstone, and unconsolidated sand; unit contains interbeds of travertine, chert-pebble conglomerate, and limestone (unit is probably equivalent in whole or part to unit Tcwm and may be equivalent in part to Tcwu). Weak; easily erodes into rounded, oakbrush-covered, earthy hillslopes and rounded ridges veneered by smooth, round, chert and quartzite pebbles, black, white, red, brown, olive green. Claystone, very pale orange (10YR 8/2), light-brown (5YR 5/6) to moderate-brown (5YR 4/6), silty, sandy; contains hard calcareous claystone nodules 0.5-2 cm diameter, weathers to earthy slope. Sandstone and sandy siltstone, yellowish-orange (10YR 7/6), weathers grayish orange (10YR 7/4), poorly exposed, forms sandy slope. Continuous and conspicuous sandstone ledge 6 m thick (sandstone cliff marker bed shown on map) 49 m above base of unit (visible in Highway 14 cuts south of quadrangle), very pale orange (10YR 8/2) and pinkish-gray (5YR 8/1) weathers yellowish gray (5Y 2/2), "salt-and-pepper" quartzose sublitharenite, trough crossbedded, chert grains, calcareous; numerous small caves and large cavities weather out, giving it a "swiss cheese" appearance. Unconsolidated sand, same color as sandstone, fine-grained. Conglomerate, pinkish-gray (5YR 8/1) to yellowish-gray (5Y 8/1), weathers very pale orange (10YR 8/2) and pale yellowish orange (10YR 8/6); chert and quartzite granules and small pebbles, subrounded to rounded in very hard sandy marl cement; chiefly massive bedding. conglomerate beds are 0.5-3 m thick and pinch out laterally within 100-200 m; disintegrated conglomerate forms pebble lag on highest hilltops; lag contains less than 1 percent small round pebbles of very pale purple (5P 7/2) to very light brownish gray (5YR 7/1) rhyolitic(?) porphyritic ash-flow tuff having abundant feldspar phenocrysts 1 mm long, bronze biotite less than 1 percent. Travertine, distinctly laminated acicular crystalline limestone, very pale orange (10YR 8/2) to white (N9); laminae are 0.2-0.6 cm thick and composed of countless vertical acicular calcite crystals, 0.5 mm thick, whose length equals the lamina thickness. Limestone, pinkish-pale-yellow (2.5Y 7/4), micrite, beds 0.3-1 m thick, pinch out laterally. Eroded thickness of unit Tcws is 35-134 m

Tcwl **Lower white limestone**--Limestone, claystone, and sparse, thin interbeds of clayey, calcareous sandstone. Limestone is white (N9), micrite, pelmicrite, pure in places, elsewhere silty to very fine sandy (quartz, as much as 5-10 percent in places); fine wiggly veinlets and subspherical voids filled with very fine crystals of calcite; thin to medium bedded; contains sparse, very thin, 1.5 mm diameter ostracode(?) bivalve shells; breaks into equant angular pieces 1-25 cm across owing to intersecting vertical joints and horizontal parting; micritic limestone beds forms a ledge 1- to 2-m-thick at base and at top of Tcwl unit (Sawyer Point and northward) and a single, 12-14 m thick white limestone cliff in south half of quadrangle. Claystone moderate-reddish-brown (10R 4/6), yellowish-gray (5Y 7/2), mottled moderate-reddish-brown (10R 4/6); forms very pale orange (10YR 8/2), usually bare earthy slope in middle of unit. Unit Tcwl generally is 26-36 m thick; maximum thickness 55 m

Tcr **Red member of Claron Formation** --Alternating beds of calcite-cemented sandstone, calcareous mudstone and sandy limestone. Approximately the upper 100-150 m is exposed in quadrangle. Channel sandstones (so-called fluted sandstone) are characteristic of the upper 50-60 m and crop out as fluted ledges and small cliffs on a moderate-reddish-orange, fine gravelly slope. The fluted sandstone is bimodal, silty, very fine to fine-grained and other beds are very fine to coarse-grained; also common are granules and small pebbles of yellow, yellow-brown, black and gray, subangular chert and granules of reddish-orange (10R 5/6) clayey, calcite-cemented, fine quartzose sandstone. Obscure trough crossbeds. Top of bed pockmarked by round depressions, which link to vertical, nearly parallel, cylindrical holes and vertical rounded columns, that appear as fluting. Forms rounded ledges and large talus blocks; sandstone is usually 0.7-2 m thick, rarely 10-12 m thick where channel sands are stacked, forming a cliff (SW¼ sec.18, T.37 S., R.7 W.). Slope-forming units above and below fluted sandstone are crumbly, calcareous, clayey sandstone that grades upward to sandy, clayey limestone. Sandstone is cherty, very fine to fine-grained sand, calcareous-cemented, moderately strong, bimodal (very fine and medium), subangular to subrounded sand; some of the clay matrix is finely mottled (moderate orange pink 10R 7/4, grayish-orange-pink 10R 8/2, moderate-reddish-orange 10R 6/6, dark-yellowish-orange 10YR 6/6, very pale orange 10YR 8/2). Mudstone is between ledges as beds 2-3 m thick, is generally sandy and calcareous, firm, reddish-orange (10R 5/6), light-red (2.5 YR 6/8) and reddish-yellow (5YR 7/8); forms earthy slopes veneered by fine, angular gravel of hard sandy marl and mudstone. Limestone best exposed near south edge of map near Swains Creek and in cuts of State Highway 14 south of quadrangle. Limestone is variegated pale colors: very pale grayish orange (10YR 8/4), very pale orange (10YR 8/2), white (N9), pale-pinkish-gray (5YR 9/1) and rarely moderate-orange-pink (10R 7/4) to pale-reddish-brown (10R 5/4); microcrystalline to medium crystalline 0.2-1 mm long calcite; in places contains common spherical and oblong pellets or ovoids (0.5-2 mm diameter) made of white micrite or moderate-reddish-brown (10R 4/6) clay; fractures uniformly and hackly and in places like porcelain; moderately strong, brecciated and recemented in places, (breccia formed as intraclasts of dried lime mud separated from mass of sediment, which was then covered by more lime mud) cut by fine calcite spar that fills veins and vugs; small dissolution cavities common on outcrop; scarce high-spire, coiled snail shells about 4 mm long; forms round shoulder slope on broad interfluves. Base covered, exposed thickness about 100-150 m; where entire red member is exposed at Cedar Breaks National Monument, it is about 298 m thick (Moore and Nealey, 1993)

MAP SYMBOLS

CONTACT--Dashed where approximately located or inferred; questioned where uncertain

contact between compositionally distinctive lava flows

STRIKE AND DIP OF BEDS

MONOCLINE

f ARTIFICIAL FILL

NPB-20 SAMPLE LOCATION FOR GEOCHEMICAL ANALYSIS

MS-1 MEASURED SECTION

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MEASURED SECTIONS

Seven sections were measured in the Asay Bench quadrangle. Two, numbers 1 and 3, are described in this preliminary report.

MEASURED SECTION 1, NORTHWEST QUARTER OF ASAY BENCH QUADRANGLE, GARFIELD COUNTY, UTAH

Measured section base begins near the center of the west border of the NW¼ sec. 24, T. 37 S., R. 7 W. and extends east-northeastward to the top of hill 8445. Bedding dips 1.5° E. Top of section is top of exposure (8445 ft above sea level, from topographic map

[measured by D.W. Moore, Aug. 5, 1992]

Claron Formation (part):

White member (middle white unit of Bowers (1972), (part):

9. Limestone, very pale orange (10YR 8/2) to white (N9), weathers same colors, microcrystalline, contains common voids filled with finely to medium crystalline calcite spar;

1-3 percent very fine grained quartz and chert sand grains; slightly silty, some argillaceous beds; beds 5-30 cm thick; weathers to rough, broken ledges 2 m thick and to angular pieces 1-10 cm across and thin flaggy pieces that clink when struck; upper 3 m of unit contains sparse thin interbeds of calcareous quartzose sandstone, fine-grained quartz and tan, black, red lithic (?) sand grains; eroded top of unit is top of hill. Unit 9 is **upper white limestone**, map unit **Tcwu** on Asay Bench quadrangle geologic map. Unit 9 is 13.7 m (45 ft) thick

8. Claystone, variegated, main colors are very pale orange (10YR 8/2) and dark yellowish-orange (10YR 6/6); chiefly clay containing little to no silt or sand; common very pale orange (10YR 8/2) nodules composed of microcrystalline (micrite) limestone that grade laterally to very thin discontinuous beds having 5 percent very fine quartz sand and weather as rounded lumps 2-4 cm in diameter that cover the outcrop; claystone is friable to firm; sparse channel-fill sandstone occurs as lenticular beds (see description below); unit 8 forms a distinctive slope, pale-yellowish-orange (10YR 8/2) and is easily recognizable in west-central Asay Bench quadrangle; basal contact of unit forms the most persistent and sharp contact among all units mapped; it is visible and traceable on the bare hillslopes of buttes in the quadrangle. Unit 8 is the **middle subunit of white member** (unit **Tcwm** on geologic map).

[At 26 m (85 ft) above base of unit 8 is base of a channel-fill sandstone, 0-3.6 m (0-12 ft) thick, pale-yellowish-orange (10YR 8/6), very fine to fine-grained quartzose, slightly feldspathic and cherty, silty; calcareous; trough crossbedded, medium bedded; pinches out laterally; forms weak ledge. On Buck Knoll (3 km southeast) are similar channel-fill sandstone units that rest on second very pale orange limestone up from base of exposed section; another thinner channel-fill sandstone is higher on the grayish-orange slope that corresponds to unit 8 on Buck Knoll]

<u>Note</u>: unit 8 is reddish <u>locally</u> like the characteristic color of the lower red member of the Claron Formation, but unit 8 is part of the upper white member. If this is realized, confusion of this unit with the red member is minimized when tracing discontinuously exposed units eastward from Cedar Breaks National Monument. For example, unit 8 is moderate-reddish-orange (10R 6/6) mixed with grayish-orange (10YR 7/4) on the next divide north of this measured section, i.e. the hill labelled 8210 on Asay Bench quadrangle (west-central sec. 12, T. 37 S., R. 7 W.). This reddening persists to the north at least another 3-5 kms, and is evident on slopes below the prominent white limestone bench (unit 9) the "upper white limestone".

unit 8 is (54 m) 176 ft thick

Units 7 through 4 inclusive are **lower white limestone** (map unit Tcwl) of the white member of Claron Formation, consisting of two thin, white micritic limestones, one at the top (unit 7) and one at the bottom (unit 4), <u>therefore equivalent to the informal mapping unit, lower white limestone in Cedar Breaks National Monument</u>

7. Limestone, white (N9) on fresh broken surface; microcrystalline, medium-bedded; parts are pelmicritic--very fine (0.5 mm) spherical, white (N9) pellets in a very pale orange (10YR 8/2) micrite matrix; common, finely crystalline, "augenlike" irregular calcite spar inclusions 1 cm across; forms a ledge made of 3 to 4 beds about (0.6 m) thick each

unit 7 is 2-3 m (6-9 ft) thick

6. Mudstone, yellowish-gray (5Y 7/2), with moderate-reddish-brown (10R 4/6) mottles; forms a bare slope almost everywhere in middle part of unit Tcwl

unit 6 is 19 m (63 ft) thick

5. Mudstone, moderate-reddish-brown (10R 4/6), weathers pale-reddish-orange (10R 7/6); soft, calcareous; contains lenticular beds (2-40 cm thick) of very light gray (N8) sandstone that weather grayish-pink (5R 8/2) and are composed of subrounded very fine grained quartz and chert sand grains, silty; very firm rock strength; lower 0.6 m of unit is yellowish-gray (5Y 7/2) and contains abundant very fine grained quartz sand; unit forms a pale-reddish-orange (10R 7/6) slope

unit 5 is 2-2.4 m (7-8 ft) thick

4. Limestone, white (N9), microcrystalline, contains pellets (pelmicrite) in part; some beds contain about 5-10 percent quartz silt and very fine sand; contains sparse minute, curving bivalve shells ostracodes?; fine voids (0.2-1 mm dia.) and wiggly veinlets filled with finely crystalline calcite spar; moderately strong, breaks along discontinuous wavy parting and closely spaced (10-20 cm) vertical joints forming roughly equant, blocky pieces 0.5-25 cm across; forms minor persistent ledge; a lower white limestone bed forms weak ledge 0.6 m (2 ft) thick at base. Unit 4 is believed to be lowest unit in Claron white member. Unit 4 is the first white and pure limestone (ascending) in this part of quadrangle and above which the prevalent moderate-reddish-orange (10R 6/6) of the Claron Red member is supplanted by other prevalent colors (chiefly very pale orange (10YR 8/2) and white (N9))

unit 4 is 2 m (6 ft) thick at this section, but is about 3-3.5 m (10-12 ft) thick on next exposed hillslope 2.5 km north (estimated by looking through binoculars)

Total of eroded white member of Claron Formation...93 m (306 ft)

Red member (lower pink member of Bowers, 1972), units 1 through 3 fall within map unit **Tcr** on geologic map of Asay Bench quadrangle

3. Mudstone, yellowish-gray (5Y 8/1), pinkish-gray (5YR 8/1); faint, small mottles moderate-reddish-orange (10R 6/6) in color; contains 15-30 percent fine-grained, round quartz, chert, and siliceous lithic sand grains; medium thick interbeds of yellowish-gray (5Y 7/2) calcareous mudstone, containing minor fine quartz sand; unit contains interbeds of pinkish-gray (5YR 8/1) sandstone that is weak to moderately strong and breaks into irregular angular shapes and to rectangular blocks 3-8 cm across; unit weathers to a pinkish-gray (5YR 8/1) earthy slope

unit 3 is 10 m (34 ft) thick

2. Sandstone (the "fluted sandstone"), white (N9) and very light gray (N8), weathers very light gray (N8), fine-grained clear quartz and black, brown, and pale-red chert grains; calcareous, 5 percent calcareous clay cement; 2-4 percent of grains are medium sand size and rounded; few well-rounded grains; contains uniformly distributed white (N9) clay granules and coarse-grained black chert sand that impart a "salt-and-pepper" appearance; near the base, unit contains lenses and thin beds of granules and spherical claystone pebbles as large as 1 cm diameter; faint medium-scale trough crossbedding; crops out as massive, fluted, and somewhat cavernous rounded ledge; vertical, cylindrical features (burrows?), spaced 10-30 cm apart and filled with white, sandy calcareous clay or clayey fine sand weather to holes and vertical cylindrical cavities 2-5 cm in diameter (a few are 15 cm diameter) throughout the outcrop giving it the "fluted" look. Possible causes of fluting: (1) piping, (2) faunal burrowing(?) penecontemporaneous with deposition, (3) modern differential weathering(?), or (4) combined

factors(?). Rock is moderately strong; spheroidal blocks 1-2 m across fall and roll downslope; laterally, unit tapers to a gray, very fine-grained quartzose sandstone, 20-30 cm thick before pinching out within 100 m horizontal distance; irregular, undulatory base; fluvial channel sandstone

unit 2 is generally 0-3 m (0-10 ft) thick; rarely 12 m thick

1. Mudstone, sandstone, and limestone, interbedded. Mudstone moderate-reddish-orange (10R 6/6), moderate-orange-pink (10R 7/4), with mottles very pale orange (10YR 8/2) to pinkish-gray (5YR 8/1); some mottling along tubular shapes 2-5 mm in diameter suggestive of plant root channel; calcareous, sandy (10-30 percent quartz and chert, fine to very fine grained, subround to round sand grains). Sandstone, like unit above, lenticular, channel-fill; weathers to fluted ledges; interbedded with sandy, clayey limestone. Interbedded units form red slope which weathers to very coarse "popcorn" and "gibber gravel" (angular pieces of marl and sandstone 0.5-10 cm across). Thickness of unit 1 not measured, but estimated to be more than 15 m (50 ft)

base of section, not base of exposure

Incomplete upper part of red member ....27 m 90 ft
Total section measured.......................119.5 m **392 ft**

MEASURED SECTION 3, MAMMOTH RIDGE, NORTHEAST QUARTER OF ASAY BENCH QUADRANGLE, GARFIELD COUNTY, UTAH

Measured section base begins near west edge of NW¼ sec. 15, T. 37 S., R. 6 W., approximately 7290 ft elevation at break in slope between hillslope and young alluvial-fan deposits (unit Qfy). Measured northward to top of Mammoth Ridge and to jeep road. Top of section is top of exposure (approx. 7960 ft elevation). [measured by D. Moore, Lloyd Lefevre, and Marta Sanders, June 23, 1993]

Brian Head Formation (restricted) (part)

5. Tuffaceous limestone, sandstone, minor conglomerate and silicified mudstone. Predominantly limestone in lower half of unit. Bedding covered; weathered unit forms a shoulder slope on Mammoth Ridge that is covered with angular gravel derived from covered beds; rock characteristics inferred from float: Limestone, yellowish-gray (5Y 8/1), very pale orange (10YR 8/2), light-greenish-gray (5GY 8/1); contains small pale-green (5G 7/2) mottles in places; contains medium-gray (N5) chalcedony nodules 2-6 cm dia., roughly robust discoid. Near base, is 2- m-thick zone of siliceous and clayey nodules 0.5-2 cm that contain volcanogenic(?) phenocrysts of biotite and volcanic rock fragments; 12 m above base limestone is yellowish-gray (5Y 8/1), micritic, and contains white rounded pebbles (0.5-3 cm dia.) of volcanic tuff; very fine volcanic glass shards; pieces of chalcedony and porcellanite that are light greenish-gray (5GY 8/1) weather out on slope. Sandstone (chiefly in upper third of unit), yellowish-gray (5Y 7/2) to grayish-yellow-green (5GY 7/2) weathers pale-olive (10YR 6/2), light-brown (5YR 5/6) and grayish-orange (10YR 7/4); volcanic litharenite, fine- to medium-grained, contains coarse, subround grains of light brown quartzite; poorly sorted, low density,

tuffaceous. Upper 4-5 m of unit is interbedded pastel-colored, tuffaceous sandstone, laminated porcellanite, minor limestone, and conglomerate. Sandstone is very pale orange (10YR 8/2) to moderate-reddish-brown (10R 4/6). Conglomerate is sandy with small black and brown chert pebbles, minor white chert and white and reddish-brown subround quartzite pebbles; weathers to a silty, sand soil, moderate-brown (5YR 3/4). Porcellanite is pale-yellowish-orange (10YR 8/6), laminated, sonorous, silicified mud or ash. Thin tuffaceous micrite weather out as grayish-pink (5R 8/2) angular pieces containing 10 percent dispersed quartz and lithic grains. Unit 5 is map unit **Tbh** on Asay Bench quadrangle map

Unit 5 is 47.2 m (155 ft) thick

Incomplete Brian Head Formation ....47.2 m (155 ft)

Claron Formation
White member
upper white limestone

4. Limestone, white (N9) to very pale orange (10YR 8/2); mottle pale pinkish-gray (5YR 9/1); mostly microcrystalline (micrite); some very fine grained quartz sand dispersed in parts of unit; in places contains finely crystalline calcite spar that fills vugs 0.5-2 cm across (dismicritic limestone); some limestone beds contain intraclasts (intramicritic limestone); appears brecciated, mixed, and possibly burrowed locally; oncolites(?), extremely thinly laminated spherical inclusions 1 mm-1 cm dia.; breaks down to angular to subrounded hackly pieces 0.5 cm to 1 m across; strong rock strength; small dissolution cavities in places; forms a slope covered by fine, angular debris. Unit 4 is map unit **Tcwu** on Asay Bench map

Unit 4 is 40 m (130 ft)thick

3. Sandstone and claystone, interbedded. Sandstone, dark-yellowish-orange (10YR 6/6), fresh and weathered color. Silty, very fine grained to medium-grained; "salt-and-pepper" sublitharenite. Poorly sorted to moderately well-sorted; in places, contains calcium carbonate-cemented, pebble-size nodules that are light-gray (N7) to yellowish-gray (5Y 8/1). Some beds are very clayey, others are clean sand; calcareous, friable to firm; bedding obscure; weathers to a loose, sandy, steep light-brown slope that becomes more reddish where clayey; one-third way up from base, slope becomes clayey and silty, with yellowish-gray (5Y 8/1) mottles common to abundant. This zone also contains hard carbonate-cemented irregular zones. Middle of unit contains 3-6 m of claystone, that is moderate reddish-brown (10R 6/6), calcareous; weathers to a steep, earthy slope that is light-brown (5YR 5/6) to moderate reddish-orange (10R 6/6). Lower 49 m of unit 3 forms slope. Upper 18 m forms jagged sandstone cliff that grades into a brown, sandy slope laterally; sandstone in cliff has strongly undulating base, is medium- to coarse-grained, contains clay pebbles up to 2 cm dia., weathers moderate-yellowish-brown (10YR 5/4), freshly broken rock is variegated light-brown (5YR 5/6) and dark-yellow-orange (10YR 6/6). Trough crossbedded and crosslaminated; beds are 20-40 cm thick, sets of crossbeds are from 1-2 m thick. Some beds are clayey, very fine-grained quartzose and litharenite. Cliff-forming unit is 18 m thick. Unit 3 is **middle sandy unit** (map unit **Tcwm**) on Asay Bench map

Unit 3 is 67 m (220 ft) thick

lower white limestone

2. Limestone and claystone. Unit consists of three distinct subunits--in descending order: (a) an upper claystone, (b) a middle white limestone, and (c) a lower claystone. (a) Upper claystone subunit, yellowish-gray (5Y 7/2), mottled moderate-reddish-brown (10R 6/6), soft; contains calcareous concretions; weathers to a earthy slope that is very pale orange (10YR 8/2); about 8 m thick. (b) middle limestone, white (N9), micritic to pelmicritic, minor dismicrite (calcite spar-lined vugs and oblong cavities as much as 20 cm long and 5-6 cm wide) argillaceous (kaolin?) in places; contains abundant, wavy paper-thin calcite veinlets; forms a discontinuous cliff with columns and pinnacles in places or a whitish shoulder slope; profoundly fractured along vertical, wavy joints and slightly dissolved along horizontal bedding planes; base grades down into claystone below. Limestone is about 8 m thick. (c) The lower claystone is moderate-orange-pink (10R 7/4) and very pale orange (10YR 8/2), sandy, calcareous; breaks into angular fine pebble-size pieces; firm and friable; contains hard, irregular calcareous concretions 2-8 cm across; forms lowest, persistent whitish (pale-orange-pink 10R 8/4) uniform slope in map area; subunit is about 13.5 m thick. Unit 2 is map unit **Tcwl** on Asay Bench quadrangle map, **lower white limestone**.

unit 2 is 30 m (98 ft) thick

Total thickness of white member of Claron Formation is 137 m (448 ft)

Red member

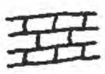
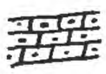
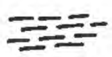
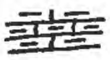
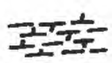
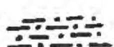
1. Claystone, sandstone, and limestone, interbedded. Claystone, moderate-reddish-brown (10R 4/6) and dark-yellowish-orange (10YR 6/6), silty, calcareous, with light-olive-gray (5Y 6/1) mottles; contains hard, quartzose, sandy calcareous nodules, irregular shaped, 1-10 cm in diameter; contains less than 10 percent fine-grained black chert sand. Sandstone, grayish-pink (5R 8/2), weathers moderate-orange-pink (10R 7/4), grayish-orange-pink (5YR 7/4), fine-grained, reddish-orange claystone grains 10-25 percent; trace of dark accessories; quartz 75-90 percent; some granules are reddish claystone and as much as 5 percent of granules are quartzite. Forms rounded ledges that are vertically fluted. Ledges are 0.3-2 m thick; beds pinch out laterally within 100 m. Limestone, moderate-pink (5R 7/4), microcrystalline, locally very sandy, ranging to calcareous sandstone; angular, fine blocky fracture, forms a slope. Unit 1 is map unit **Tcr** on Asay Bench quadrangle map

measured part of unit 1 was 47 m (154 ft) thick;

Incomplete red member of Claron Fm. ....47 m (154 ft)

Total section measured ....231 m (757 ft)

SYMBOLS IN COLUMNAR SECTIONS

	concretions
	mica
	chalcedony
	nodules and clay pebbles or granules
	sparse small snails
	burrows
	oncolites, 1 mm-1cm in diameter
	pebble-size calcareous nodules
	microcrystalline limestone (micrite)
	sandy micrite
	mudstone or claystone
	sandstone
	clayey micrite
	calcareous mudstone
	siltstone
	crossbedded sandstone

Tbh	Brian Head Formation
Tcw	white member of Claron Formation
Tcwu	upper white limestone
Tcwm	middle part
Tcwl	lower white limestone
Tcws	sandy phase
Tcr	red member of Claron Formation

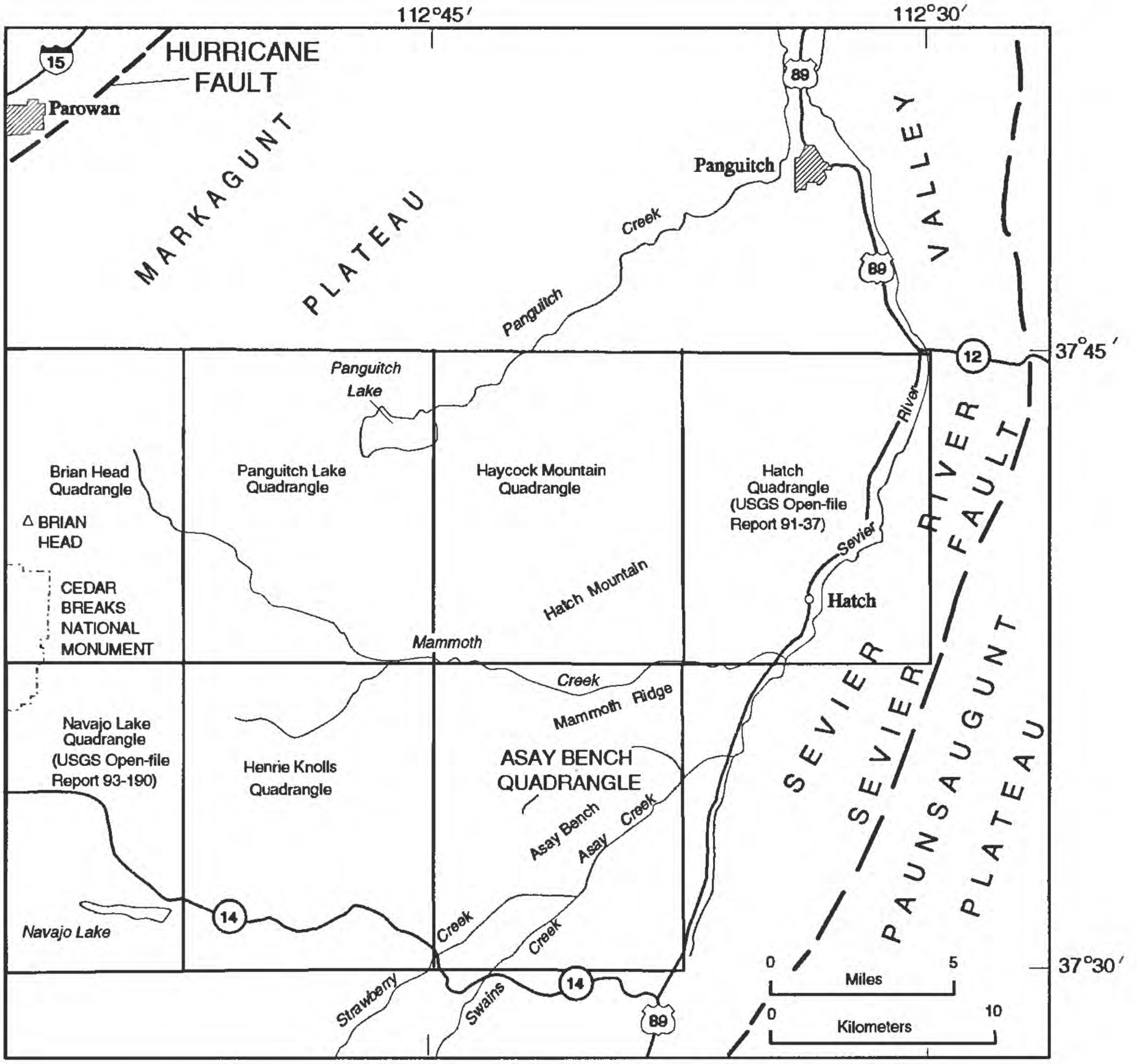


Fig. 1 Location of Asay Bench quadrangle and features mentioned in text.

CORRELATION OF MAP UNITS

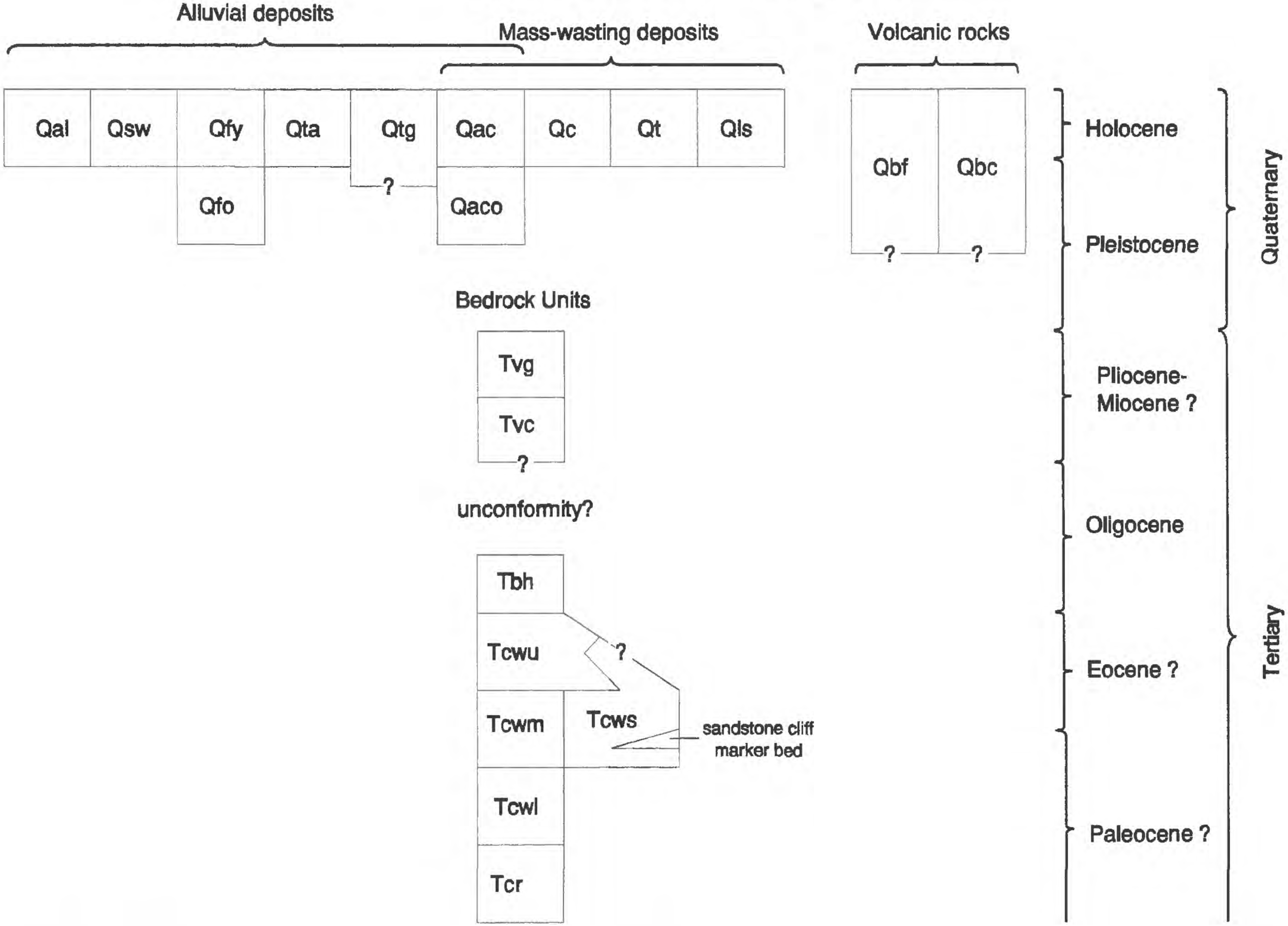


Table 1. Hand sample descriptions of analysed samples.

1. NPB19: Fine-grained, medium dark gray olivine-plagioclase-clinopyroxene basalt: vesicular: olivine phenocrysts average 1 mm in diameter: plagioclase phenocrysts attain maximum lengths of 2 mm: clinopyroxene average 1 mm in diameter, forms glomerocrystic clots. Source unknown but probably erupted from one of the Strawberry Knolls cinder cones

2. NAB62; Medium-grained medium gray olivine-plagioclase basalt: vesicular; plagioclase phenocrysts average 2 mm in length; olivine phenocrysts average 1 mm in diameter. Source is Stawberry Knolls

3. NPB20: Medium-grained, medium gray olivine-clinopyroxene basalt: vesicular; olivine phenocrysts average 2 mm, attain maximum dimensions of 4 mm; sparse clinopyroxene phenocrysts average less than 1 mm in diameter; rare quartz xenocrysts. Age of flow is 0.52 ± 0.05 Ma (Best and others, 1980). Source uncertain but probably Asay Knoll

4. NPB21: Fine-grained, light gray olivine basalt: vesicular; olivine phenocryst average 1 mm in diameter. Source unknown but local vent is suspected

5. NAB76: Medium-grained medium dark gray olivine-plagioclase basalt: vesicular; olivine phenocrysts average 2 mm, partially iddingsitized; plagioclase phenocrysts average 1 mm in length; olivine-plagioclase glomerocrysts attain maximum dimensions of 4 mm, olivine appears to have nucleated before plagioclase. Source unknown

6. NAB 72: Medium-grained, medium gray olivine-plagioclase basalt: vuggy; olivine phenocrysts average 1 mm in diameter; plagioclase phenocryst average 2 mm in length; common plagioclase glomerocrysts attain maximum dimensions of 4 mm. Flow contains lava tubes. Flow erupted from cinder cone in the central part of the Henrie Knolls quadrangle; flow same as NPB22

7. NPB22: Medium-grained, medium dark gray olivine-plagioclase glomerocrystic basalt: vuggy; olivine phenocrysts average 1 mm in diameter: plagioclase phenocrysts average 2mm in length; very common olivine-plagioclase glomerocryts average 3 mm in diameter, attain maximum diameter of 5 mm. Flow contains lava tubes, the largest of which is Mammoth Cave. Flow erupted from cinder cone in central part of Henrie Knolls quadrangle, flowed through Duck Creek valley; flow same as NAB72

8. NAB83: Medium-grained, medium gray olivine basalt: vuggy; olivine phenocrysts average 2 mm, contain spinel microlites; rare plagioclase microphenocrysts. Source unknown

9. NAB81: Medium-grained, medium light gray olivine basalt: massive; olivine phenocrysts average 2 mm in diameter, iddingsitized. Source unknown

10. NAB84: Fine-grained, medium gray olivine basalt: massive to slightly vuggy; sparse olivine phenocrysts average 1 mm in diameter; rare plagioclase phenocrysts attain maximum lengths of 1.5 mm. Source unknown

11. NAB75: Fine-grained medium dark gray olivine-clinopyroxene basalt: massive; olivine phenocrysts average 1 mm in diameter, partially iddingsitized; sparse clinopyroxene phenocrysts average 1 mm in diameter; clinopyroxene glomerocrysts average 1 mm in diameter. Source unknown

TABLE 2 Geochemical data for basalt samples

Sample number	1	2	3	4	5	6	7	8	9	10	11
Field number	NPB19	NAB62	NPB20	NPB21	NAB76	NPB22	NAB72	NAB83	NAB81	NAB84	NAB75
Major oxide composition, values in weight percent											
SiO_2	48.0	48.9	51.4	50.6	50.7	49.6	48.9	51.1	51.4	49.3	46.6
Al_2O_3	15.9	15.9	15.5	16.1	16.3	16.5	16.8	16.2	16.2	16.9	12.5
$FeOT_3$	10.3	10.2	8.9	9.8	11.2	12.6	12.7	10.0	9.3	11.6	10.7
MgO	7.87	8.23	7.63	7.89	7.82	6.98	7.19	7.97	7.08	7.66	12.50
CaO	8.47	8.25	7.72	7.62	8.63	9.88	9.67	7.88	7.61	9.65	10.90
Na_2O	3.63	3.76	3.64	3.94	3.18	3.28	3.12	3.56	3.95	3.14	2.90
K_2O	1.80	1.89	2.35	1.67	3.18	0.50	0.37	1.35	1.73	0.58	1.23
TiO_2	2.18	2.21	1.60	1.79	0.95	1.42	1.48	1.42	1.64	1.33	1.86
P_2O_5	0.77	0.72	0.73	0.60	1.21	0.21	0.22	0.46	0.60	0.29	0.79
MnO	0.15	0.15	0.13	0.14	0.27	0.18	0.18	0.15	0.14	0,17	0.17
LOI	0.96	0.19	0.03	<0.01	0.17	<0.01	<0.01	0.19	0.07	<0.01	0.21
Trace element composition, values in parts per million											
Nb	42	39	22	25	<10	9	<10	16	8	16	57
Rb	14	23	25	20	16	12	<10	16	180	24	18
Sr	1200	900	1200	790	550	335	320	770	810	1350	880
Zr	320	295	270	260	148	132	132	194	315	230	235
Y	23	27	24	26	24	31	24	24	15	24	22
Ba	1200	650	1500	610	640	255	260	910	1600	1500	870
Ce	96	88	128	68	57	30	<30	81	86	122	95
La	45	43	55	21	<30	13.7	<30	31	40	42	60
Cu	nd	48	nd	nd	60	nd	110	51	35	49	73
Ni	nd	144	nd	nd	142	nd	108	142	12	215	295
Zn	nd	71	nd	nd	77	nd	80	84	66	70	82
Cr	nd	255	nd	nd	220	nd	188	240	26	265	620

nd = no data

LOI = loss on ignition at 925°C

Major elements determined by X-ray spectroscopy; J.Mee, J.E. Taggart, D.F. Siems, analysts

Trace elements determined by X-ray spectroscopy; J. Kent, analysts

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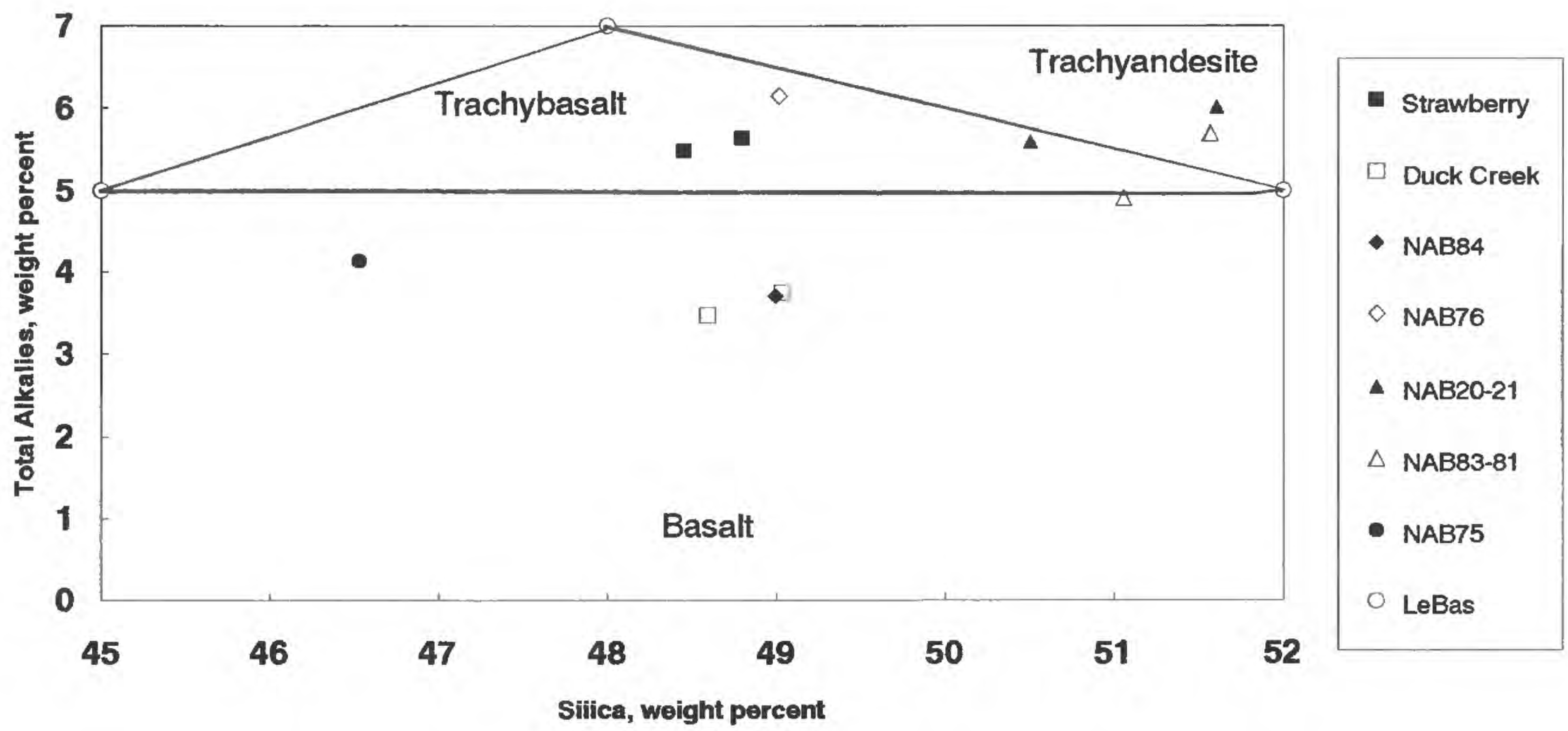

FIG.2 Geochemistry of basalt samples

FIG.3 Columnar section depicting measured section 1

hill 8445, 1/2 mile NE of Burrows Flat, NW1/4 sec.24,T.37S.,R.7W.

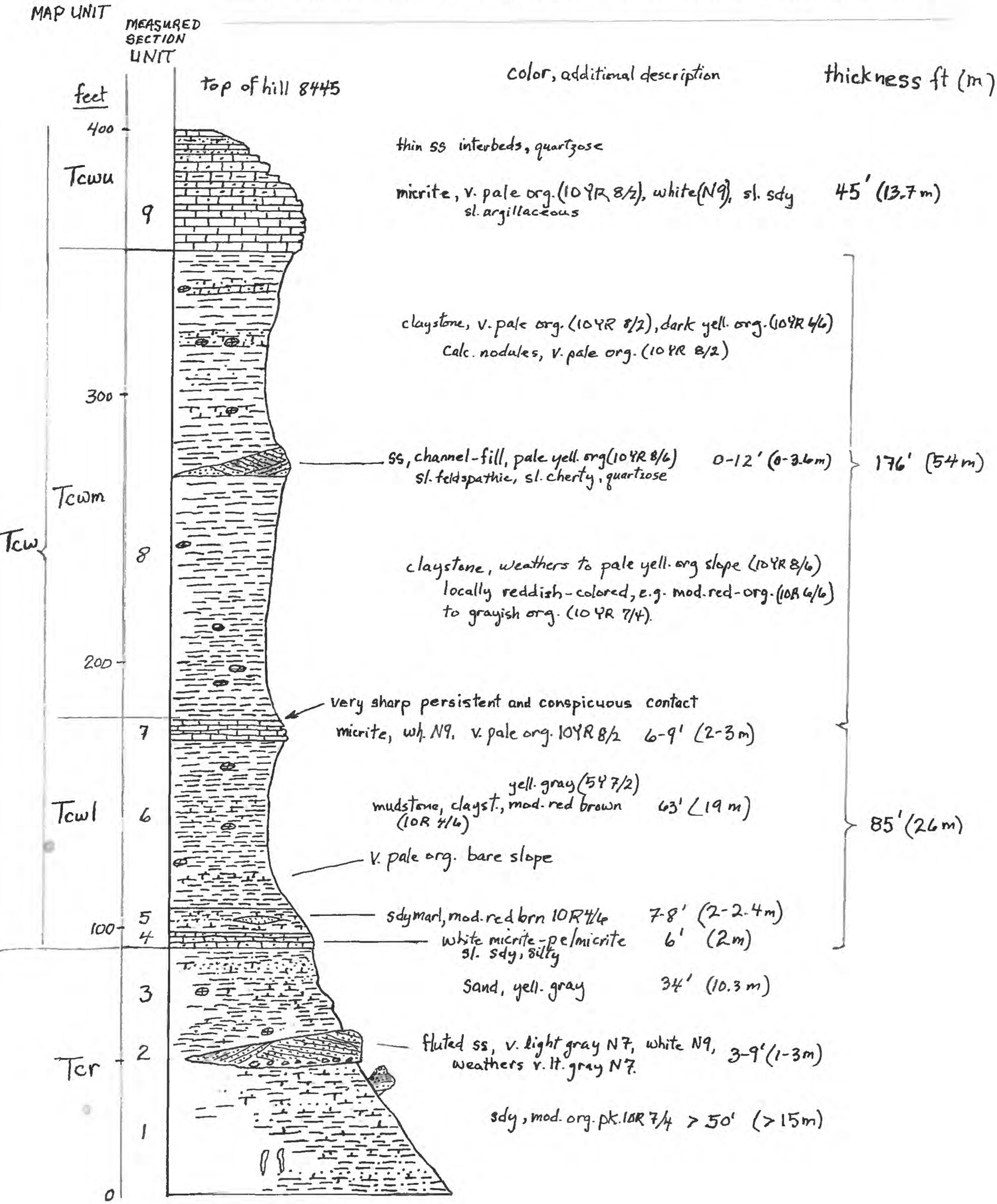

FIG.4 COLUMNAR SECTION DEPICTING MEASURED SECTION 3

West edge NW 1/4 Section 15 T.37S., R.6W.