State of Oregon
Department of Geology and Mineral Industries
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O-03-03

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Geologic Map of the Merrill and Malin Quadrangles, Klamath County, Oregon

by

Margaret D. Jenks and Ian P. Madin,
Oregon Department of Geology and Mineral Industries

2003

NOTICE

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Oregon Department of Geology and Mineral Industries Geological Map Series, ISSN 0278–3703
Published in conformance with ORS 516.030

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INTRODUCTION

The area covered by this map is located in south central Oregon (Figure 1) on the south edge of Klamath County. It is approximately 20 km southeast of the city of Klamath Falls, and the California / Oregon state border is the southern boundary of the map. The principal geographic features in the area are the north edge of theTule Lake Valley, which extends to the south into California, the highlands east of Stukel Mtn., Buck Butte and the highlands to the east, the south end of Poe Valley, and the north trending Dodds Hollow (Figure 1). The area is drained by the Lost River, which flows through the southwest corner of the mapped area. No other perennial streams drain the area, but it does contain a number of annual streams, with flows in the spring or during high-runoff storms. Two towns are located within the mapped area, Merrill (pop. 870) and Malin (pop. 760). The Tule Lake valley is irrigated agricultural ground, supporting crops including potatoes, mint, and hay. The upland areas are used for cattle grazing in the spring and early summer, and the south PoeValley area is principally used for cattle ranching and hay production.

The area was previously included in two geologic maps, both 1:250,000 scale (Peterson and McIntrye, 1970; Sherrod and Pickthorn, 1992). This present mapping is the first 1:24,000 scale map of the area. The field work was completed during the summer and fall, 2000 and spring, 2001.

EXPLANATION OF MAP UNITS

Surficial Deposits

Qmf Fill (Modern)--Unconsolidated and unsorted boulders, gravels, sands, silts, and soil that have been moved to create the dams of the small reservoirs located throughout the mapped area. Thickness is variable, depending upon the height of the dam.

Qml Modern lake deposits (Modern)--Unconsolidated and unsorted sand, silt, and clay, presently being deposited within the seasonal lake margins of the small reservoirs located throughout the mapped area. The reservoirs catch and store irrigation water, and thus are essentially dry in the Fall. In some of the lakes, cobble- to boulder-sized rocks of the nearby or underlying volcanic units lie within or on top of the fine-grained lacustrine sediments. Thicknesses are variable, but generally thin, due to the small areas of the reservoirs.

Qal Alluvium (Holocene)--Unconsolidated materials, including clay, silt, sand, and gravel, deposited by streams and in upland basins. The unit is present in small amounts in the channels of all streams in the area, but is only mapped where there is a significant thickness and lateral extent. Includes deposits in natural upland basins. Also includes alluvium in the channel and meander belt of the Lost River.

Ql Tule Lake sediments (Holocene)--Lacustrine sediments deposited within the historic basin of Tule Lake before it was drained for farmland in the early 1900's. Pre-reclamation survey maps of Tule Lake basin by the U.S. Bureau of Reclamation (1905) were used to map the aproximate shoreline based on topography indicative of shoreline features.

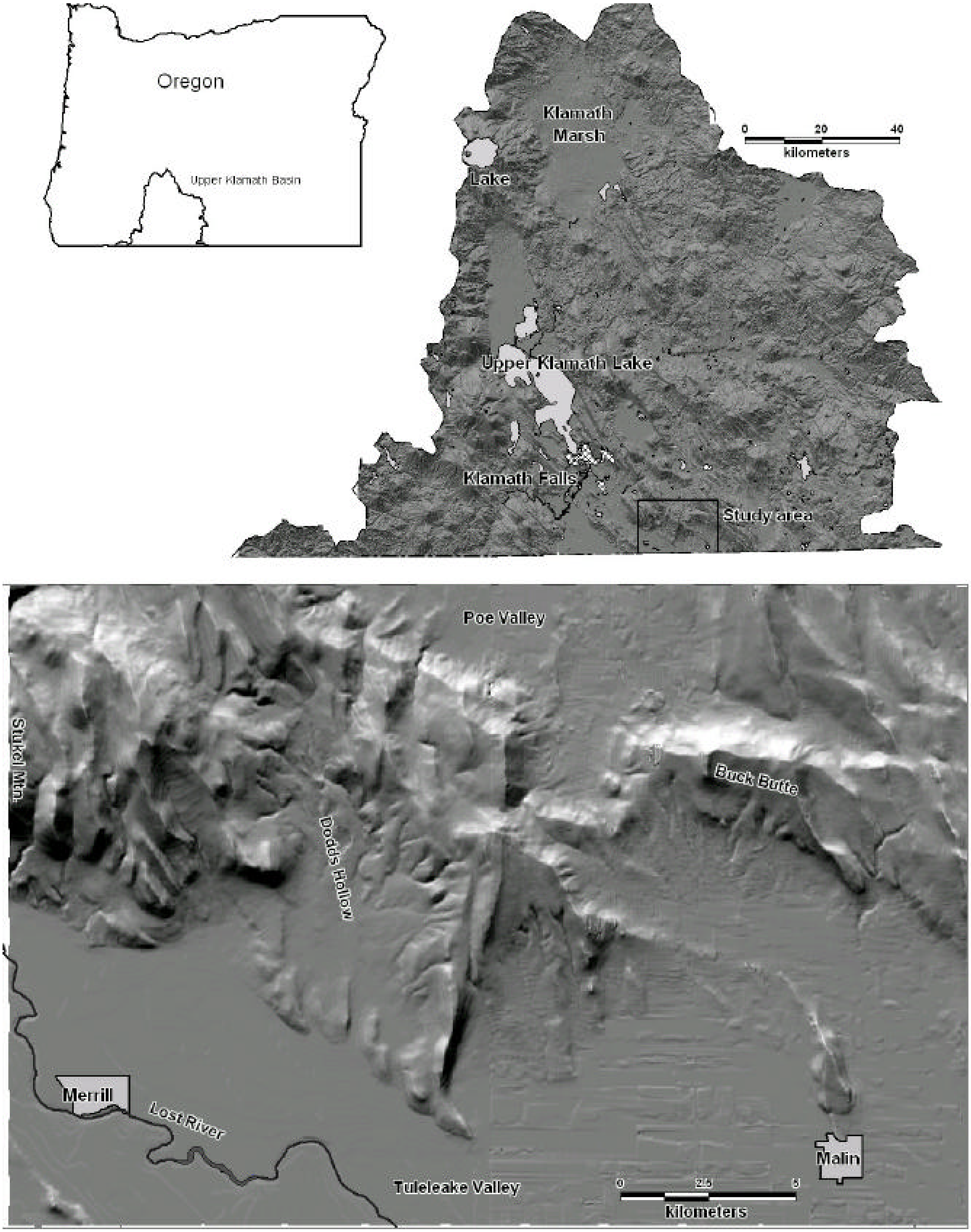


Figure 1. Shaded-relief map of the Merrill and Malin quadrangles, showing the towns of Merrill and Malin. The upper Klamath River basin is shown in the upper part of the figure.

The 1905 shoreline is also shown on the map. The lake level would have naturally changed seasonally and during particularly dry or wet years. Cleghorn (1959) reports that after a very hard winter in 1889-1890, the spring level of the lake reached the barnyard of J. Frank Adams. He was an early settler whose farm was located in NE / NE section 8, T41S, R11E, just east of the junction of Highway 39 and the Malin Road, at approximately the 4070' contour elevation.

Qaf Alluvial fan deposits (Holocene)--Unconsolidated angular to subrounded gravel, mud, clay and soil deposited by debris originating in steep upland ephemeral streams. The materials in this unit are the result of fluvial processes, although significant parts of the deposits are the result of catastrophic downslope movements during thunderstorm and spring runoff flood events.

Qt Talus deposits (Quaternary)--Unconsolidated angular boulders and blocks of volcanic rock deposited by slope processes at the foot of steep fault escarpments and other slopes. The surfaces of the talus deposits are unvegetated, and the deposits typically have extensive networks of voids between clasts. The surfaces of slopes adjacent to talus deposits probably have similar materials present beneath a veneer of soil and vegetation. In some areas, talus forms on relatively gentle slopes, or fills the floors of small drainages. The absence of significant cliffs to feed the extensive talus deposits suggest that they may date from earlier Pleistocene glacial periods, when freeze-thaw cycles were more severe.

Qls Landslide deposits (Quaternary)--Unconsolidated to slightly consolidated chaotic mixtures of angular rock and soil, resulting from debris flow and slump failures. No mechanism for the initiation of the failures can be hypothesized and they could be the result of seismic events or of a wetter climate during the Pleistocene glaciation. Some slides may originate where relatively weak sedimentary interbeds underlie thick lava flow sequences on steep slopes, or on dip slopes of angled beds, as in the case of slides on the east side of Stukel Mountain. The thickness of the debris from each slide is highly variable, depending upon the particular spot within the slide deposit. The toes of each slide contain the thickest deposits.

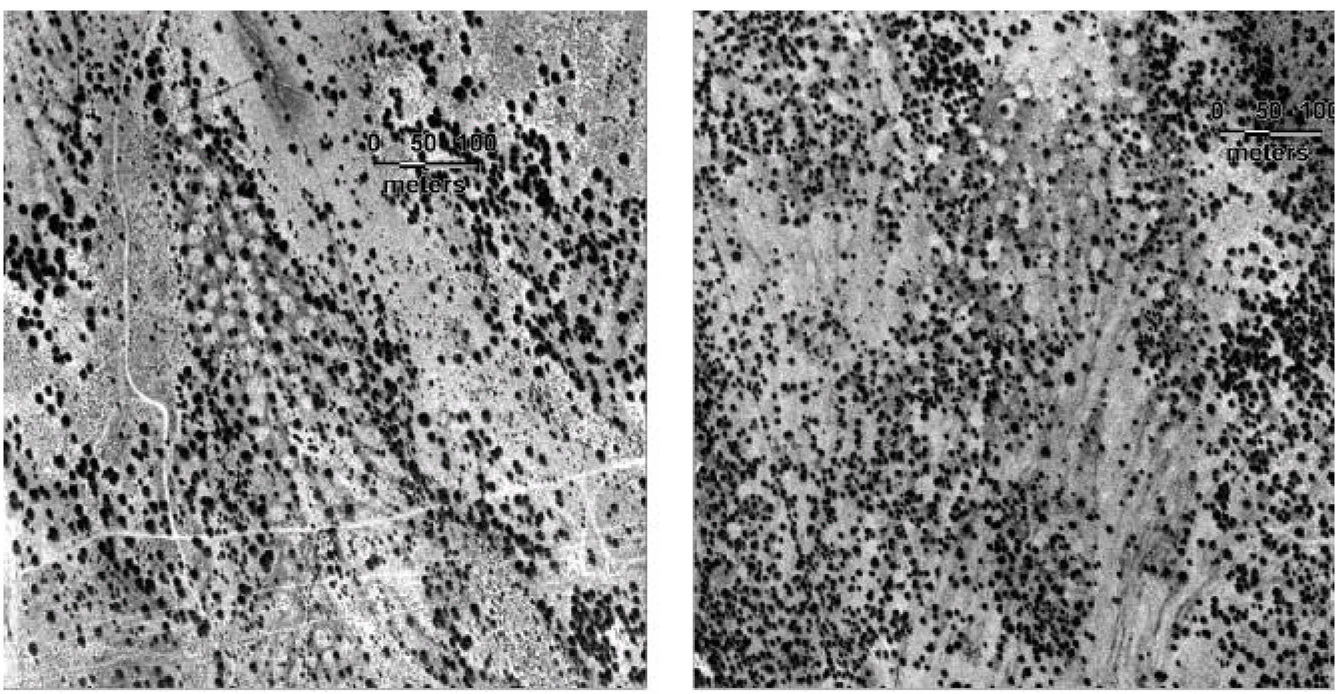
Qas Aeolian and lacustrine sands (Holocene and Quaternary)--Grey to light-brown, subangular to well-rounded, unconsolidated lithic sand deposits. These relatively thick deposits are adjacent to the Tule Lake valley floor. The sands may have started out as lacustrine beach deposits from prehistoric, higher levels of Tule Lake, or of Lake Modoc, a large pluvial lake that Dicken (1980) suggests inundated all of the large valleys of the Klamath River drainage during the Pleistocene. However, the deposits have been significantly altered and moved by wind action. One particularly thick deposit, on the northeast side of Turkey Hill, is presently owned by Bud and Mary Cummings. It is being mined and hauled to California. The sands range from fine to very coarse, and from finely to massively bedded. They are completely uncemented and barely consolidated. The Cummings gravel pit contains a single, foot-thick layer of well-rounded basalt cobbles and boulders. Another bed contains crossbedded fine to medium sand with abundant fresh-looking, somewhat rounded pumice lapilli ranging in size from 1-

2 cm. The crossbedding has amplitudes of up to 6". In early July the sand in the quarry was wet to the touch and the upper surface of the sand bench grows horsetails. A distinctive characteristic of this unit is the lack of angular basalt chunks on the upper faces of the deposits. If present, they would have fallen from the higher elevation basalt flows presently above the sand deposits. The sand deposits are as much as 65 m thick.

Qs Valley floor sediments (Quaternary)--Unconsolidated, primarily finer-grained fluvial and lacustrine sediments. This unit covers the Tule Lake valley floor from the upper historic limit of Tule Lake, to edges of the fault-bounded hills. It is principally a sandy silt deposit and well logs show that it can be as thick as 8 m. Near fault escarpments the unit contains a significant percentage of angular volcanic boulders and gravel. It was probably deposited as shoreline features during previous high-stands of Tule Lake. Similar materials are presently being deposited in Upper Klamath Lake, to the west of the mapped area. The unit also may include a significant aeolian component, especially in the more sandy deposits.

Qoaf Older alluvial fan deposits (Pleistocene)--Thin deposits of cobble to boulder gravel deposited by upland streams probably during Pleistocene glacial periods. The deposits are associated with geomorphic surfaces that are remnants of originally extensive alluvial fans or bajadas. The deposits occur in three places; along the southern margin of the highlands north of Merrill, along the northern margin of the highlands adjacent to Poe Valley, and in Dodds Hollow. Where well-exposed, the deposits are only a few meters thick, and consist of sandy cobble and pebble gravel. The preserved fan surfaces commonly bear a distinctive patterned ground, visible in air photos as a polygonal or

Figure 2. Orthophoto images of patterned ground on unit Qoaf (left image) and unit Tba (right image).



streaky network of light and dark ground (Figure 2). In the field the dark areas are zones of cobble to boulder gravel virtually free of fines, with networks of voids between the clasts extending to depths of tens of cm. The light areas have soil cover and are typically vegetated. This patterned ground is commonly associated with the older alluvial fans, but is also present on surfaces underlain by some of the volcanic bedrock units. The patterned ground typically occurs on relatively gentle slopes.

Qg Conglomerate (Pliocene-Pleistocene?)--Pebble to boulder gravel with a sandy matrix, weakly consolidated. Clasts are predominantly basalt and basaltic andesite lavas within lithic and feldspathic sands. Boulders to 40cm, sub-rounded, some interbeds of tuffaceous feldspathic sand. Deposit is up to 15 m thick. Not associated with obvious remnant fan or bajada surfaces, like the gravel of unit Qoaf. Commonly develops patterned ground.

Sedimentary Units

In the past geologists have placed all of the pre-Quaternary sedimentary deposits within a single unit, called the Yonna Formation (Newcomb, 1958). Based on fossils found in the Yonna Valley area, Peterson and McIntyre (1970) suggest that the fine-grained sedimentary rocks are Pliocene age and stratigraphically all lie within the overall Tertiary basalt / basaltic andesite section. Sherrod and Pickthorn (1992) abandoned the Yonna Formation name, because it included significant amounts of pyroclastic tuffs, both silicic and basaltic, which they mapped as separate units.

Pre-Quaternary fine-grained sedimentary rocks are found throughout the mapped area, both as thin interbeds within the basalt and basaltic andesite lava flows and as thick, laterally extensive deposits in Poe Valley and Tule Lake Valley and Dodds Hollow. Poor exposure and lack of age control make it very difficult to sort out the stratigraphic position, and in many cases even the dominant lithology of these sedimentary rocks. We map the thick sedimentary sections in the basins as Tm, and these rocks are largely mapped on the basis of well logs. The sedimentary rocks interbedded with the basalt and basaltic andesite flow units in the uplands, including the thick section in Dodds Hollow are mapped as Tms, on the basis of scattered outcrops and geomorphic expression.

Tm Basin sedimentary rocks (Pliocene and Miocene)--Tan, white, brown, and grey mudstone, commonly tuffaceous and diatomaceous, with subordinate claystone and sandstone. Typically described by drillers as "chalk" or "shale". Commonly massive, but locally thin bedded where sandstone or siltstone layers are present. Some layers contain a significant percentage of unaltered basaltic ash and cinders. Age poorly constrained, a date on a 3 cm ash layer from an outcrop just west of the southwest corner of the study area is pending. Probable late Pleistocene age vertebrate fossils are reported from irrigation ditch excavations in section 36, T40S, R10E. Fish fossils from a sandy beach deposit in section 32, T40S, R11E have been submitted for identification. Thicknesses are as great as 275 m, at the Merrill municipal well in Merrill (section 2, T41S R10E), 305 m in the Shasta Nursery Well

(OWRD# KLAM-10445, section 23, T41S, R12E), and greater than 270 m at the Lloyd Nelson well in Poe Valley (OWRD# KLAM-10988, section 11, T40S, R11E).

Tms Upland sedimentary rocks (Pliocene-Miocene)--Mudstone, siltstone, claystone and gravel, weakly to strongly consolidated. Predominantly massive tan to white tuffaceous and diatomaceous mudstone, with interbeds of volcaniclastic sandstone and siltstone, including palagonite and hyaloclastite sands. Where well exposed in Dodds Hollow, the volcaniclastic interbeds are tens of cm thick. Unit is up to 140 m thick at the Pope well in Dodds Hollow (OWRD # KLAM-14763, section 29, T40S, R11E), although some degree of dip may exaggerate the thickness at this site. A thickness of 580 m is implied by the outcrop width and dip measured in Dodds Hollow in section 17, T40S, R11E, however, the section may be repeated by unmapped faults. Outside of the large Dodds Hollow exposure, the thickness of Tms is typically a few meters to tens of meters. Age is poorly constrained, a date on pumice from an interbed in section 20, T40S, R11E is pending.

Tms/a Altered mudstone, siltstone and sandstone deposits (Pliocene or Miocene)--Cemented, light tan, fine to medium grained, well-rounded sand deposit. This unit is located in a small area on the north-south ridge in Poe Valley in NESE section 11, T40S, R11E. This part of the Poe Valley is an area of slightly elevated groundwater temperatures, ranging from 70-80^{o} F. Beneath the capping rock of silica cemented sand are alternating layers of white to gray claystone and siltstone, with some brecciated areas. The sand layer contains some petrified wood, mostly small pieces, but well preserved. The entire exposed section is up to up to 5 m, with capping sandstone layer varying up to 1 m thick.

Tertiary volcanic units

Volcaniclastic units

The study area contains and three different types of hydroclastic/volcaniclastic sediments covering several large areas: vent features (unit Tv), palagonitized tuff (unit Tvs), and pillowed lava flows (unit Tpb). Two of the units, Tv and Tvs appear to be related, with the Tv unit as the proximal facies and the Tvs unit the more distal tuffaceous sediments. These units are located together on the east side of Poe Valley, and extend north into the Bonanza quadrangle. A small area of Tv is also located at the head of Dodds Hollow. The other unit, Tpb, based on appearance of the pillowed pieces and proximity, appears to be the part of the basalt of Easy Creek (unit Tbe) that interacted with water.

All of these units contain minor flows. In most areas these flows are water affected. Water affected lava flows strongly interact with water at the time of their eruption, but do not pillow (Jenks and Bonnichsen, 1989; Jenks, Bonnichsen, and Godchaux, 1992). The water interaction causes the glassy parts of the flows, at the time of emplacement and cooling, to be altered to palagonite and other clay minerals. Unlike subaerially emplaced flows, when erosion or fault displacement exposes water affected flows to the atmospheric elements, they rapidly decompose to soils and clays. This propensity explains the lack of good exposures of most water affected basalt flows.

Single samples of both the Tv unit and the Tvs unit were chemically analyzed (Table 2, samples BC, BD respectively). Both have higher LOI percentages than subaerially emplaced basalt units. This interaction with water changes the percentages of the soluble elements in the analyzed sample. Generally water interaction leads to lower SiO_2, CaO, MgO, Na_2O, and K_2O percentages. The TiO_2, MnO, and P_2O_5 percentages appear to be unaffected, as are some of the minor elements: Zr, V, Cr, Cu, Zn, Co, and Sc. Based on the amounts of these unaffected elements in the Tv and Tvs samples that interacted with water, it appears that they have some affinities to the more primitive Basin and Range basalts in this area (Hart and others, 1984).

Tv Vent deposits (Pliocene and/or Miocene)--Proximal palagonitized cinder and breccia deposits and small flows. The unit is located in three areas on the east side of Poe Valley, in sections 7 & 18, T40S, R12E. Of the three areas, only the two areas in section 18 could be examined, due to landowner access problems with the third. The local farmers and ranchers presently use the vent area in section 7 as a gravel source. The vents in section 18 are very different in their characteristics. The larger of the two vents, in the west central part of the section appears to be a combination of a small flow and pillow breccia. The flow is unusually lacking in vesicles, which may indicate that it was a crater-filling flow. It is very massive, with a distinct conchoidal fracture. In thin section it does not contain any phenocrysts. Groundmass plagioclase and olivine crystals measure up to 3.0 and 0.05 mm, respectively. It does have intergranular pyroxene crystals, up to 3.0 mm. The olivine crystals are not altered to iddingsite, and the opaque minerals are generally blocky. This flow is overlain by fine-grained palagonitic tuff below white and yellow claystone. The center of the vent is made up of a breccia of glassy basalt pieces, similar to pillow breccia pieces. The other section 18 vent is very different, because it is entirely composed of near-vent layers of cindery to scoriaceous palagonitized pieces, up to 3.5 cm, in a greyish gold matrix of finer-grained palagonitized tuff. The layers dip away from a central area, with dips in the range of 4^o-14^o. The upper beds are massive with only crude bedding, but the lower layers have well-defined 2-4 cm layers. The tuff includes some chunks of cold basalt, as well as rip-up clasts of light beige sandy sediments. The thickness of these vent deposits is highly variable.

At the head of Dodds Hollow, a small area of palagonite tuff and palagonite matrix tuff breccia with abundant vesicular basalt clasts appears to be interbedded with Tms tuffaceous mudstone and Tba basaltic andesite flows. Several small pipes of vesicular olivine basaltic andesite (chemistry pending) intrude the tuff and tuff breccia.

Tvs Volcanic tuff deposits (Pliocene and/or Miocene)--Golden brown to orangish brown to black, generally fine-grained palagonitized basaltic tuff deposits. The principal outcrop of this unit is a slightly higher elevation flat on the east side of the Poe Valley. It extends into the Bonanza quadrangle to the north (Hladky, in press).

One other small outcrop of similar looking deposits is mapped on the north side of the Tule Lake valley, in section 29, T40S, R12E. The largest areal extent of this tuff is spatially related to the vent deposits (unit Tv), but does not have any unequivocal relationship to the basalt and basaltic andesite volcanic flows in the area. Thus, it could be either younger or older than these units. The only part of this unit that appears to have some relation to a basalt unit is in section 16, T40S, R12E. In this area the tuffaceous layers are exposed on the west bank of a shallow stream valley, and it appears that they may lap onto the dipping surface of the basalt of Johns Waterhole (unit Tbjw). However, even this apparent relation is obscured by aeolian sand deposits, and is puzzling because the tuff does not outcrop on the east side of the stream bank. In section 13, T40S, R12E, a section of this unit appears to overly the basaltic andesite of Buck Butte (unit Tbab), but this relationship is also equivocal due to poor outcrops. This unit also includes some layers of fine-grained sedimentary rocks, similar in character to the Tms rocks. In general this unit is massive and grades between fine sand and lapilli in the size of the tuff pieces. It appears to be horizontal, but the lack of bedding makes it difficult to judge whether it has been tilted since it was deposited. One thin section contains sparse plagioclase and olivine phenocrysts, 0.5 and 0.3 mm, respectively. All of the joint surfaces are coated with a dark reddish brown stain. The rock is very hard and in many areas it is cemented with crystalline calcite between the tuff pieces. Thus, it is difficult to dig and does not support much plant growth. The base of the unit is not exposed, but the elevated flat surface is 30 m above the floor of Poe Valley. Just west of Adams Point, "brown sandstone" at least 207 m thick was reported in a well log (OWRD # KLAM-14992, section 34, T40S, R11E). Surface exposures of palagonite tuff indicate that this hole penetrates a thick section of Tvs that is overlain by or interbedded with unit Tbap.

Tpb Pillow breccia deposits (Pliocene and / or Miocene)--Massive, cindery deposits with some glassy pillow pieces or areas within a yellow to reddish orange, palagonitized, cindery breccia. The unit is extensive, covering much of the area south of Buck Butte and west to Adams Point. The lithology of the pillows is reminiscent of the basalt of Easy Creek (unit Tbe), except that it is glassy and not diktytaxitic. In addition, it directly underlies subaerial Tbe flows. Within this unit are subordinate layers of palagonitic, basaltic tuffaceous sands, as well as water affected basalt flows. The water affected flows make up the benches separating the Tule Lake Valley floor from the higher ground in the area east of Adams Point. In addition, some areas of this unit include isolated and generally less than 2 m thick sections of fine-grained sediments, mapped elsewhere as upland sedimentary rocks (unit Tms).

Basalt flow units

The following descriptions discuss the basalt composition flow units located throughout the study area . Faulting, subsequent to the eruption of the flows, has altered their positions from horizontal to gently dipping in various directions. The individual flows that make up these units were all erupted onto flat and horizontal surfaces and are relatively thin (1-3 m). No ponded areas, from flowing into a faulted terrain, were found within the quadrangle. The typical outcrop of the individual flows contains a 10-20 cm thick vesicular bottom, a massive, jointed middle, and a scoriaceous to cindery flow top (0.3-0.5 m). However, most of the units also have some areas that interacted with water at the time of their eruption. In these areas the flows are water affected (Jenks and Bonnichsen, 1989; Jenks, Bonnichsen, and Godchaux, 1992).

The uppermost basalt unit within the Malin quadrangle, the basalt of McFall Reservoir (unit Tbmf), has an anomalously young 1.9 ± 1.4 Ma isochron whole-rock Ar^{40}/Ar^{39} age date (Table 2), with a plateau date of <12.3 ± 0.2 Ma. The rock was dated by the Nevada Isotope Geochronology Laboratory at the University of Nevada, Las Vegas. This diktytaxitic lithology, like other diktytaxitic rocks in the area, has extreme excess argon. This anomaly may be the result of the low K_20 percentage (0.22%) in the rock and/or its general lack of interstitial glass in the diktytaxitic texture. The second dated unit in the area is a whole-rock isochron Ar^{40}/Ar^{39} age date by Dr. Robert Duncan at Oregon State University, of 5.72 ± 0.5 Ma (Table 1) for the basalt of Captain Jack Lake (unit Tbcj). Jenks (in press) had previously reported an Ar^{40}/Ar^{39} plateau age of 7.33 ± 0.77 Ma for this sample. However, the laboratory reran the sample with a more sensitive machine, and reports that the new younger date is probably acceptable. This date is more in line with the K/Ar ages reported for similar types of rocks within the Bryant Mtn. quadrangle (Sherrod and Pickthorn, 1992; Mallin, 1989; Mallin and Hart, 1991). The final dated unit in the area is the basalt of Johns Waterhole. The Nevada Isotope Geochronology Laboratory also dated this unit and gives a whole-rock isochron Ar^{40}/Ar^{39} age of 5.4 ± 0.65 Ma (Table 1). The plateau age on this sample was <8.7 Ma. This sample also contained some excess argon, but not to the same extent as the basalt of McFall Reservoir. Thus, the isochron age is probably a reliable date.

Chemically, the basalt units located in the Malin area are all very interesting, because they fall into three, relatively distinct populations (Figures 3,4, and 5, and Table 2). The first and stratigraphically older units are the basalt of Malin, outcropping on Turkey Hill (unit Tbma, Sample AU), and the basalt of Johns Reservoir (unit Tbjw, Samples AR-AT), located throughout the northeast corner of the map, as well as over much of the southwest corner of the adjoining Bonanza quadrangle (Hladky, in press). These two units both plot within the basalt region of the total alkalis/silica plot (Figure 4), but under the calc-alkaline/tholeiite line in the Fe-Mg-alkali ternary diagram (Figure 5). This may be due to their slightly elevated alkali and silica percentages in comparison to the other basaltic units in the quadrangle. The second population of units, the basalt of Easy Creek (unit Tbe, Samples AN-AQ) and the basalt of McFall Reservoir **(**unit Tbmf, Samples AV-AX) show lower K_2O, Na_2O, and TiO_2 percentages, and higher MgO and CaO percentages, similar to the more primitive Basin and Range-affinity high aluminum olivine tholeiites (HAOT) described by Hart and others (1984). These units are diktytaxitic, unlike the rocks of similar chemistry to the east on Bryant Mtn. (Jenks, in press) which display subophitic to ophitic textures. The third chemical type of basalt is represented by only one unit, the basalt of Turkey Hill (unit Tbth, Samples AZ-BB), which is located on the top of Turkey Hill and in the highlands to the north, and east of Buck Butte. All of the analyses of this unit show higher K_2O, Na_2O, and TiO_2 percentages, and lower MgO and CaO percentages (Table 2). These values are similar to the Snake River Plain affinity tholeiites (SROT) of Hart and others (1984). This unit, one of the most unusual in this area, is extremely diktytaxitic and very coarse grained.

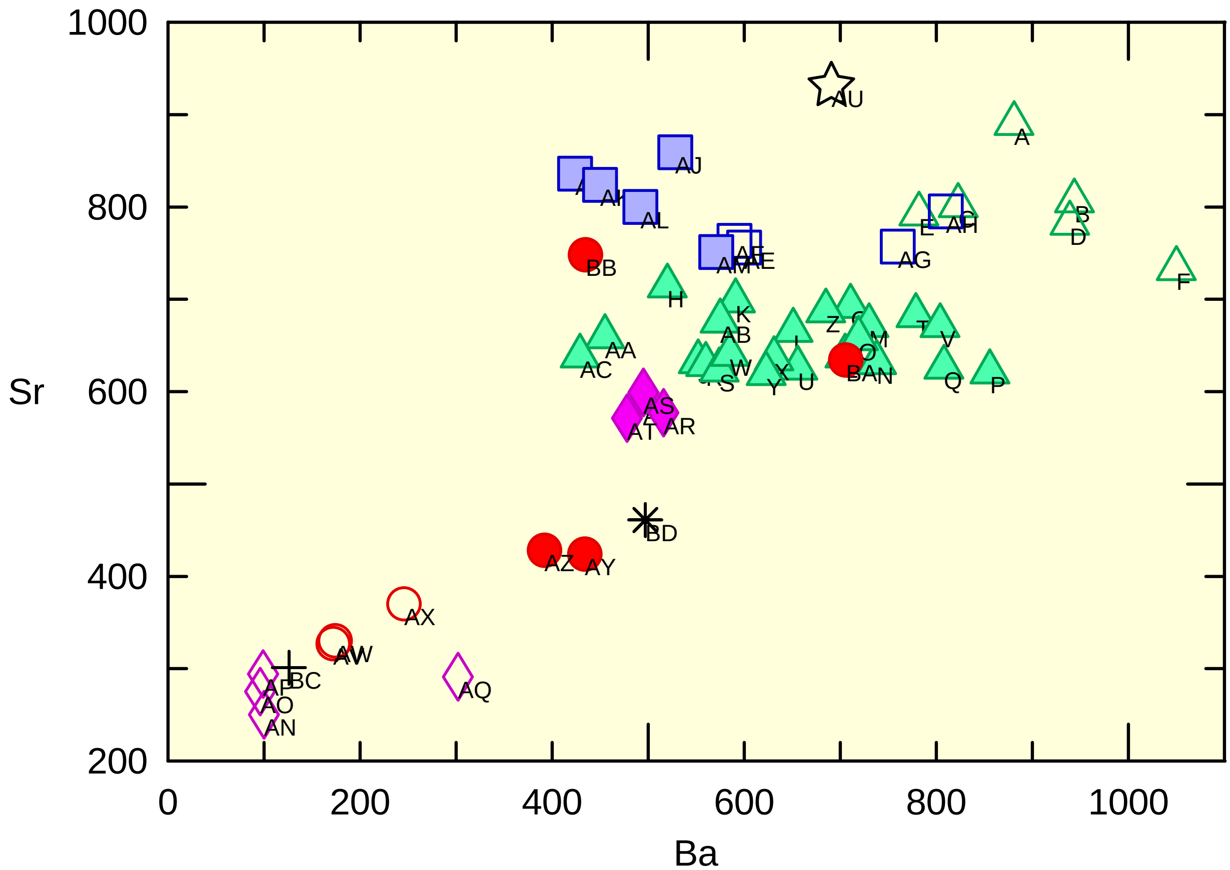


Figure 3. Ba vs Sr plot for volcanic rocks analyzed for this study. Symbols correspond to the samples of the following units: purple diamonds = Tbe, red circles = Tbmf, solid red circles = Tbth, solid purple diamonds = Tbjw, green triangles = Ta, solid green triangles = Tba, blue squares = Tbab, solid blue squares = Tbap, black asterix = Tvs, black cross = Tv, black star = Tbma. Letters correspond to the sample codes in Table 2.

Tbcj Basalt of Captain Jack Lake (Pliocene or Miocene)--Gray to light gray, very diktytaxitic, coarse-grained basalt with seriate plagioclase crystals. Some exposures in the Bryant Mtn. quadrangle (Jenks, in press) also contain olivine phenocrysts and others have glomerocrysts of the larger plagioclase crystals and olivine. This unit is located in the far northeast corner of the Malin quadrangle. It is in fault contact with the basalt of Johns Waterhole (unit Tbjw) and above the basalt of McFall Reservoir (unit Tbmf). In the field it is distinguishable for a prominent seriate texture, with a coarse grained, openwork, very diktytaxitic texture. The groundmass olivine crystals are variable, up to 1.0 mm and have iddingsite rims. The seriate plagioclase crystals range from 0.1 mm up to 4.0 mm. The pyroxene is intergranular, and some thin sections contain more opaque minerals than others. The chemistry of this unit (Jenks, in press) shows a Snake River Plain (SROT) affinity (Hart and others, 1984), with lower MgO (6.2-7.3%) and CaO (9.41-10.01%) values, and higher TiO_2(1.04-1.63%), Na_2O (2.99-3.34%), and K_2O (0.35-0.50%) values. The paleomagnetism of the unit is consistently strongly reversed. Dr. Robert Duncan, Oregon State Uni-

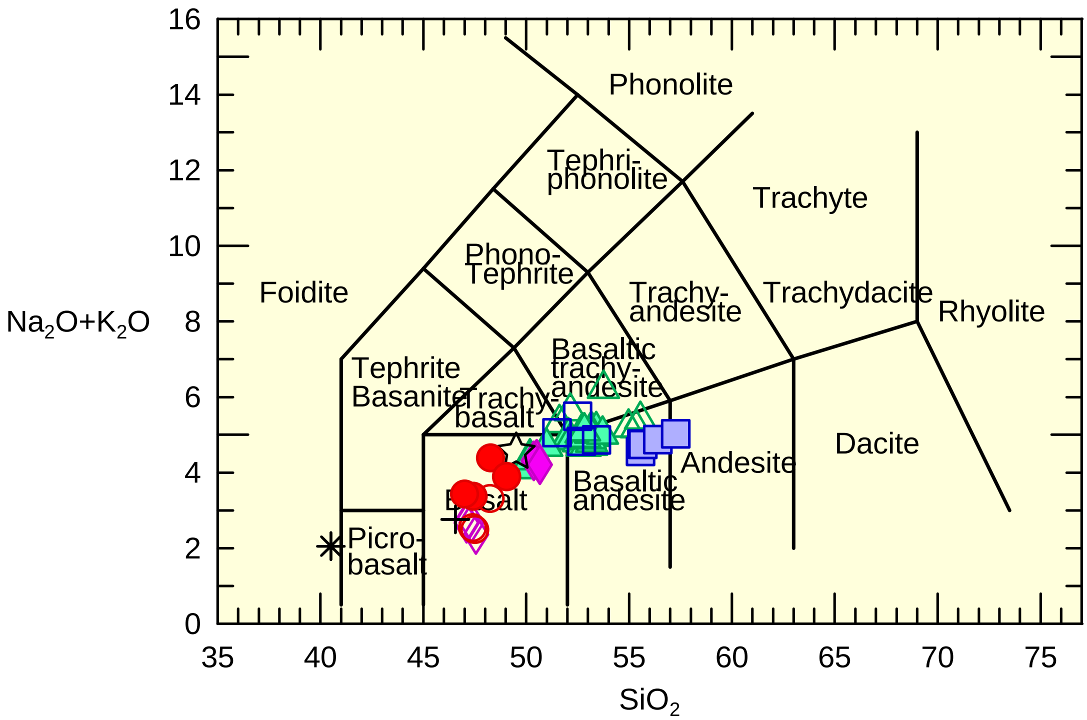


Figure 4. Total alkalies vs silica rock classification from Le Bas and Streckeisen (1991). Symbols used are the same identified samples as in Figure 3.

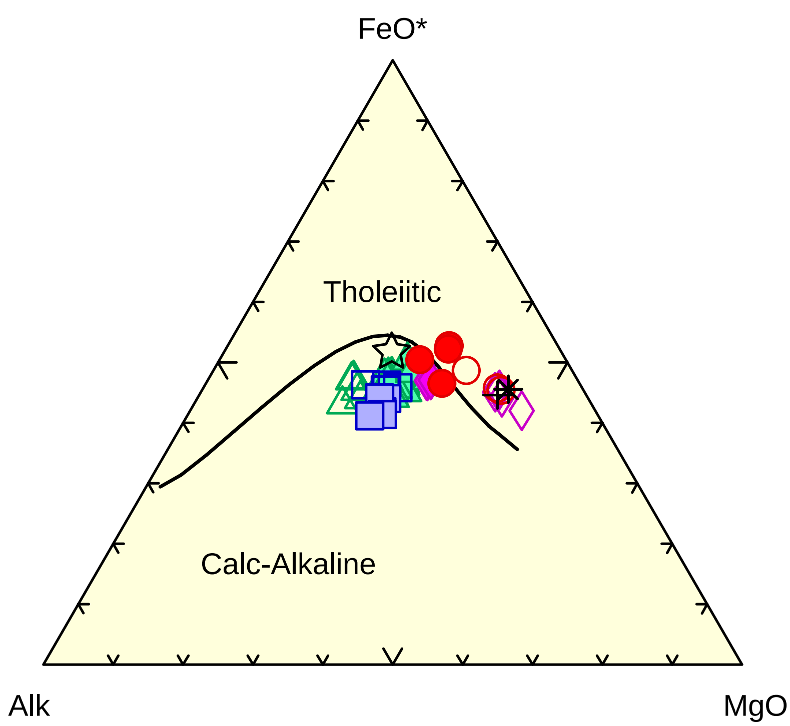


Figure 5. Rock classification after Irvine and Baragar (1971). Symbols used are the same identified samples as in Figure 3.

versity, determined an Ar40/Ar39 whole-rock isochron age date of 5.72 ± 0.5 Ma for a sample of this unit from station MJ99-82 in the Bryant Mtn. quadrangle. The maximum thickness of this unit in the Malin quadrangle is 5 m.

Tbe Basalt of Easy Creek (Pliocene or Miocene)--Gray, medium to coarse grained, medium to coarsely diktytaxitic basalt. This unit is located over much of the west side of the Malin quadrangle, but thins to the east against the main part of Buck Butte. It is possible that the vent for this unit is the hill (upper elevation 5344) on the western edge of the Malin quadrangle. However, this call is based on the shape of that hill, rather than a change in character in that area to more scoriaceous flows, which are more typical of basaltic vent flows. It overlies the basalt of the pillow breccia unit (unit Tpb), and may be the subaerial equivalent of that unit. It also overlies the basaltic andesite flows (unit Ta), the basaltic andesite of Buck Butte (unit Tbab), and the undivided sedimentary deposits (unit Ts). In the field this unit appears to be very similar to the basalt of Captain Jack Lake (unit Tbcj) and the basalt of McFall Reservoir (unit Tbmf). Some of the lower flows of this unit are water affected, and in one area (SW section 20, T40S, R12E) it appears to have slightly ponded in some low areas in the underlying sediments. It thins against Buck Butte to a single, massive, flow. It has no phenocrysts, and the seriate groundmass plagioclase are variable in size, up to 2.0 mm. The groundmass olivine crystals are also variable, up to 0.4 mm and have iddingsite rims. One sample shows intergranular pyroxene crystals as large as 4.0 mm. The chemistry of this unit (Table 2) suggests that it is a fairly primitive HAOT with Basin and Range to transitional affinities (Hart and others, 1984). It has higher MgO (8.8 and 9.4%) and CaO (11.04 and 11.11%) values, and lower TiO_2(0.91 and 0.97%), Na_2O (2.48 and 2.52%), and K_2O (0.17 and 0.18%) values. Throughout its exposure the unit appears to dip gently to the south and southeast. The paleomagnetic measurements of this unit were almost all reversed. The unit varies in thickness from 5-15 m.

Tbmf Basalt of McFall Reservoir (Pliocene or Miocene)--Gray, medium grained, medium diktytaxitic basalt. This unit is the youngest unit within the Malin quadrangle and covers most of the ridges east of Buck Butte. A small area is also present on the top of Turkey Hill. It overlies the basalt of Turkey Hill (unit Tbth) throughout most of its exposure. On the unit's north edge it is also above the basalt of Johns Waterhole (unit Tbjw). It is only overlain in one small area by the basalt of Captain Jack Lake (unit Tbcj). In the field the unit is distinguishable from the underlying Tbth unit by a distinctive difference in crystal size as well as a difference in paleomagnetic polarity. The basalt of McFall Reservoir is one of the few distinctly normal units within the Malin quadrangle, while the basalt of Turkey Hill is reversed, like most of the other basalt units. This unit has very rare, large olivine (2-3 mm) and plagioclase (2-4 mm) individual phenocrysts. Groundmass plagioclase and olivine crystals are variable in size, up to 0.4 mm and 0.2 mm respectively. The intergranular pyroxene phenocrysts (clinopyroxene?) are up to 4 mm across. Chemically, this unit has Basin and Range-type basalt affinities (Hart and others, 1984) (Table 2). Therefore, it has higher CaO (up to 11.98%) and MgO (up to 8.84%) values, and lower K_2O (up to 0.22%) and P_2O_5 (0.12%) values. The thickness of this unit is variable, up to 35 m.

Tbgr? Basalt of Grohs Reservoir (?) (Pliocene or Miocene)--Gray to greenish gray, non-diktytaxitic, basalt. This unit, located along the rim on the south end of Turkey hill, above the city of Malin's swimming pool, has been tentatively correlated to a unit on the east side of the Tule Lake Valley in the Bryant Mtn. quadrangle (Jenks, in press). This correlation is based on the appearance of the unit, which is different from the other units in the Malin quadrangle, but similar to the basalt of Grohs Reservoir. In the Malin quadrangle the unit is above the basalt of Turkey Hill (unit Tbth). It dips slightly to the south and the outcrop disappears just south of the swimming pool where the rim disappears. It contains large olivine phenocrysts, and has a dotted texture that usually is indicative of ophitic rocks. The flows of the unit have numerous, rounded scoriaceous areas and areflowbanded. In a gravel pit cliff, a red sediment layer up to 0.6 m thick is between this unit and the underlying Tbth unit. A single paleomagnetic reading for this unit was normal (2 of 3 measurements), which is unusual for units in the Malin quadrangle. A thin section of a sample in the Bryant Mtn. quadrangle shows no olivine or plagioclase phenocrysts, but instead large, euhedral, subophitic, clinopyroxene crystals. The plagioclase groundmass crystals are variable in size, up to 1.4 mm, and the groundmass olivine crystals are up to 0.15 mm, with no iddingsite alteration. The thin section also contains sparser than normal opaque minerals. Despite its unusual appearance, the rock is basalt in composition, with Basin and Range flow affinities in its chemistry (Hart and others, 1984). It has low TiO_2 (0.96%) and P_2O_5 (0.15%) values, and high MgO (9.08%) and CaO (11.48%) percentages (Jenks, in press). In the Malin quadrangle the unit has variable thickness, up to 5 m.

Tbth Basalt of Turkey Hill (Pliocene or Miocene)--Gray, extremely diktytaxitic, extremely coarse grained basalt. This unit is the most singular of any of the basalt composition units in the Malin quadrangle, and thus its flows are an excellent marker bed within the basalt stratigraphy. It covers the top of Turkey Hill and is also present in the ridges and fault scarps in the north part of the Tule Lake valley--east of Buck Butte and north of the present Malin garbage transfer station. In addition, two small outcrops of the unit are on the uppermost rim of Buck Butte. The basalt of Turkey Hill is above the basalt of Malin (unit Tbma) and the basaltic andesite of Buck Butte (unit Tbab). Through most of its exposure it is below the basalt of McFall Reservoir (unit Tbmf), but on the southern edge of Turkey Hill in the town of Malin, it is below a unit that is tentatively correlated to the basalt of Grohs Reservoir (unit Tbgr?). It is so coarse grained that in some areas the rock resembles a diorite in color and texture. Some of the lower flows of this unit are noticeably water affected, particularly on Turkey Hill. The seriate plagioclase crystals observable in samples in the field are up to 0.5 cm. Thin sections of this unit contain some to rare olivine phenocrysts, up to 1.0 mm, and the plagioclase crystals range from 0.2 to 5.0 mm. The pyroxene crystals are intergranular and up to 3.0 mm in size. The opaque minerals are generally blocky and iddingsite alteration of the olivine crystals varies from some to complete. One sample on the south end of Turkey Hill contains abundant interstitial glass. Chemically, this unit has Snake River Plain-type basalt affinities (Hart and others, 1984) (Table 2). Therefore, it has lower CaO (up to 9.9%) and MgO (up to 6.87%) values, and higher TiO2 (up to 1.49%), K2O (up to .89%) and P2O5 (0.56%) values. The paleomagnetism of the unit is generally reversed, which helps in distinguishing it from the overlying normally magnetized basalt of McFall Reservoir (unit Tbmf). Thickness of this unit is variable, up to100 m, with the thickest section on the top of Turkey Hill.

Tbma Basalt of Malin (Pliocene or Miocene)--Dark gray, very fine-grained to glassy basalt. Outcrops of this unit are small and found only on Turkey Hill. It underlies the basalt of Turkey Hill (unit Tbth) and is the lowest elevation unit on the west side and north end of Turkey Hill. In the roadcut on the south side of Turkey Hill this unit is separated from the overlying Tbth flows by a sediment thickness that includes massive pinkish tan silt layers as well as layers of thinly bedded fine-grained basalt cinders. The flows of this unit are rubbly and form hoodoos with some massive bulbous areas as well as lava "dikes" into the overlying rubble. The flows have stretched vesicles and flowbanding, and some appear to have been water affected. A thin section of the unit shows that it has two clumps of plagioclase phenocrysts, from 0.1-3.0 mm. The sparse olivine phenocrysts range from 0.2 to 0.8 mm. The groundmass plagioclase crystals are aligned and variable in size, up to 0.4 mm, and the groundmass olivine crystals are up to 0.05 mm. The texture of the rock is ophitic with pyroxene crystals massively overgrown with small plagioclase crystals. The opaque minerals are segregated to the areas between the pyroxene crystals, and the olivine crystals are completely altered to iddingsite. The chemistry of the unit is similar to the basalt of Johns Waterhole (unit Tbjw), in that it plots on the TAS diagram (Figure 4) within the basalt box, but on the AFM diagram (Figure 5) it plots below the tholeiite/calc alkaline line. However, the distance between the outcrops of these two units is too great to place them within the same unit. In comparison with the other basalt composition units in the area, the basalt of Malin has a slightly higher SiO2 content (49.51%), and slightly elevated Na2O (3.42%), and K2O (1.12%) percentages. The total exposed thickness of the unit ranges from 3 to 25 m, but the base of the unit is not exposed.

Tbjw Basalt of Johns Waterhole (Pliocene or Miocene)--Medium gray, not diktytaxitic, olivine-phyric basalt, with glomercrysts of olivine as well as plagioclase and olivine. This unit is located in the throughout the north part of the Malin quadrangle, and extends north into the Bonanza quadrangle (Hladky, in press). Stratigraphically, this unit is beneath only small areas of the basalt of McFall Reservoir (unit Tbmf). It has a fault contact with the basalt of Capt. Jack Lake. It is above the volcanic sediments unit in one area on the east side of Poe Valley, but in another location has an uncertain relationship with these sediments. On the upper rim of Buck Butte it overlies the basaltic andesite of Buck Butte. Flows of this unit are massive, but thin, with numerous flows in stair steps on the dip-slope exposures of the ridges. Some flows are flowbanded and others show slight water affected tendencies. The flows of this unit are distinguishable in the field by their abundant clumps of small olivine phenocrysts which are sometimes combined with small plagioclase crystals and by its fine-grained, not diktytaxitic matrix. Thin sections of the rock reveal that the larger plagioclase phenocrysts are “wormy” and zoned, ranging from 0.3-1.5 mm. The olivine phenocrysts range in size from 0.4 to 2.0 mm, and are not altered to iddingsite. One thin section contains no pyroxene, but the other two have rare to slight small intergranular crystals. The opaques are finely disseminated in the glass. Like the basalt of Malin (unit Tma), the basalt of Johns Waterhole is different than the other basalt unit, in that it plots on the TAS diagram (Figure 4) within the basalt box, but on the AFM diagram (Figure 5) it plots below the tholeiite/calc alkaline line. The distance between the outcrops of this unit and the Tbma unit precludes placing them within the same unit. In comparison with the other basalt composition units in the area (Table 2), the basalt of Johns Waterhole has a slightly higher SiO_2 content (50.37-50.66%), and slightly elevated P_2O_5 (0.39-0.45%), and K_2O (0.9-1.0%) percentages. The paleomagnetic readings on this unit strongly reversed and a whole-rock isochron Ar^{40}/Ar^{39} age date on sample MJ00-26 is 5.4 ± 0.65 Ma (Table 2). The base of this unit is not exposed, but exposures generally range from 20-100 m.

Tbu Basalt, undivided (Pliocene or Miocene)--Located in the east side of the Malin quadrangle, this unit is mapped in areas where the basalt exposures are poor. It may be made up of several different basalt lithologies, which are the same or different from the other mapped basalt lithologies on the east side of the Malin quadrangle and the west side of the Bryant Mtn. quadrangle (Jenks, in press). Stratigraphically, the unit underlies, in different locations, the basalt of McFall Reservoir (unit Tbmf), and is in fault contact with the basalt of Johns Waterhole (unit Tbjw) and the basalt of Capt. Jack Lake (unit Tbcj). Both the thickness and exact extent of this unit is unknown.

Older basaltic andesite units

The oldest volcanic units within the mapped area are distinctly different both chemically and in their appearance from the basaltic section (Table 2, Figures 3-5). Chemically, the flows fall within the basaltic trachyandesite and basaltic andesite areas of the IUGS volcanic classification system (LeBas and Streckeisen, 1991) (Figure 4), and within the calc-alkaline area of the FeO-MgO-alkaline ternary diagram (Figure 5). In their appearance the basaltic andesite flows either are generally glassy or extremely rubbly, although some of the lower flows in one area appear to be somewhat crystalline. Exposures of these units are somewhat poor, especially on the north side of Buck Butte. The onlap relationship of the younger basalt flows to these units suggests that the basaltic andesite flows were higher areas when the basalts were erupted. The basalt flows thin against and surround the "hills" of the basaltic andesite flows. No age dates for these units exist within the mapped area, but dates on similar rocks in the Bryant Mtn. and Langell Valley quadrangles to the east (Jenks, in press), suggest an middle Miocene age between 7.3 and 8.2 Ma. In the eastern half of the area these units are overlain by the basalt of Johns Waterhole, which has a whole-rock isochron Ar^{40}/Ar^{39} age date of 5.4 ± 0.65 Ma (Table 1). An age for unit Tbap is pending.

Comparing these units chemically to other basaltic andesite and basaltic trachyandesite units in the surrounding quadrangles, they appear to be most similar to the basaltic andesite lithologies in the Dairy quadrangle (Hladky, in press). In terms of the basaltic andesite units in the Bryant Mtn., Langell Valley, and Bonanza quadrangles (Jenks, in press; Hladky in press), these units are higher in TiO_2, Al_2O_3, and CaO percentages and lower in SiO_2 and K_2O percentages.

Ta Basaltic andesite aa flows (Miocene)--Red and black, cindery to scoriaceous, breccia and rubble flows. This unit is located in two areas-in the north slope of the east end of the main Buck Butte ridge, and in the north / northwest oriented, east-facing rim on the west side of the quadrangle. Stratigraphically, the flows of this unit are within the section of the basaltic andesite of Buck Butte (unit Tbab) and are differentiated from this unit solely on their appearance. The unit is below the basalt of Easy Creek (unit Tbe) and the pillow basalt unit (unit Tpb). At the north end of the west side rim, in Poe Valley, this unit is underlain by a baked red sediment layer above a 10 m section of fine-grained sediments. The flows of this unit have the appearance and characteristics of aa lava flows. In general they are linear areas of rubble and breccia, with a few thin central sections of glassy basaltic andesite. The stack of flows is up to 6 in number, and thin sediment layers are present between some of the flows. Individual cinder or scoria pieces are 2-15 cm in diameter. The cause of the rubbly character of the flows is not apparent, and they could be mistaken for near-vent agglomerate, if not for the sediment interbeds and the linear character of the rubble piles. The rubbly and massive areas of the flows are both fine-grained with no obvious phenocrysts visible during an inspection of outcrop samples. In thin section phenocrysts of plagioclase and olivine are rare to sparse--the plagioclase from 0.1 to 1.5 mm, and the olivine from 0.2 to 3.0 mm. The texture is neither ophitic nor diktytaxitic, with no pyroxene crystals. The samples contain some to very abundant glass, and in one sample the plagioclase are aligned. Chemically (Table 2, Samples A-F), samples of the more massive middle parts of the flows all plot in the basaltic trachyandesite field of the TAS plot (Figure 4). Their chemistry overlaps that of the basaltic andesite and basaltic trachyandesite flows mapped as the basaltic andesite of Buck Butte (unit Tbab). The overall character of the flows of this unit makes paleomagnetic measurements difficult. However, two parts of the massive areas had somewhat normal readings (4 of 6 samples). In the Buck Butte exposure, the aa flows are 150 m thick. The base of the west side rim unit is not exposed, but its thickness varies up to 200 m.

Tbab Basaltic andesite of Buck Butte (Miocene)--Dark-gray to black, glassy to very fine-grained, basaltic andesite and basaltic trachyandesite flows. This unit is exposed only on Buck Butte. On the west side of Buck Butte, the younger basalt of Easy Creek (unit Tbe) thins against an older high of this unit. On the east side of the butte and in two areas on the upper ridgeline of the butte, this unit is overlain by the basalt of Turkey Hill (unit Tbth). In one area below the eastern escarpment of the butte, the unit is overlain by the basalt of McFall Reservoir (unit Tbmf). On the north side of the butte the unit encloses an outcrop of basaltic andesite aa flows (unit Ta). Also on the west part of the steep north face of Buck Butte, this unit contains a thickness of palagonitic tuff, presumably of basaltic andesite composition. Most of this tuff is massive, but some layers are finely layered with sand and silt rip-ups within a fresh black glassy cinder matrix. This area of tuff may represent an early and now buried vent of the basaltic andesite, but in general the tuff layers appeared to be distal facies. Conversely, the tuff layers may be unrelated to the overlying basaltic andesite flows. Outcrops of this unit contain numerous, thin (2-3 m) subaerial flows. The entire unit dips gently to the south, and therefore the flows form stairsteps down the south side of the butte. The flows generally contain some stretched vesicles. Thin sections of this unit contain abundant glomerocrysts of plagioclase phenocrysts or plagioclase and olivine phenocrysts. The plagioclase and olivine phenocrysts range from 0.1 to 4.0 mm and 0.15 to 3.0 mm, respectively. In outcrop some plagioclase crystals appear to be aligned in the areas around the vesicles. The iddingsite alteration of both the phenocryst and groundmass olivine crystals ranges from none to complete. The interstitial glass varies from some to abundant, with inclusions of very finely crystalline opaque minerals. Chemically (Table 2, Samples AE-AH), this unit is both basaltic trachyandesite and basaltic andesite, according to the IUGS volcanic classification system (LeBas and Streckeisen, 1991) (Figure 4). Flows from the uppermost elevation point on the west end of the butte, near a group of radio towers, plot in the basaltic andesite field of the TAS diagram (Figure 4). Flows on the east end of the butte, underlying unit Tbth, plot in the basaltic trachyandesite field of the TAS diagram (Figure 4). However, all of the flows are fairly similar in chemistry, and when compared with the basaltic units are higher in SiO_2 (51.5-53.42%), Na_2O (3.71-3.98%), and K_2O (1.11-1.51%) percentages (Table 2). The basaltic andesite of Buck Butte is different in chemistry from the basaltic andesite composition rocks in the Bryant Mtn. and Langell Valley quadrangles to the east (Jenks, in press). In fact they appear to be more similar in composition to the basaltic andesite rocks in the Dairy quadrangle (Hladky, in press) to the northwest of the Malin quadrangle. In general the flows of this unit have reversed paleomagnetism. The base of this unit is not exposed, but on the north side of Buck Butte this unit has an exposed thickness of more than 350 m.

Tbap Basaltic andesite of Adams Point--dark grey to black, glassy to fine grained basaltic andesite and andesite flows. Outcrops typically somewhat platy, with large vesicles elongate parallel to the platiness. Typically weathers brown or purplish brown. Flows typically 10 m thick or greater. Most outcrops show considerable thickness of jointed pahoehoe style lava, but one outcrop in the Pope pit (Section 4, T41S, R11E, Table 2, Sample AK) is an aa flow with lobes of massive lava in a rubble matrix. In hand specimen the rock is typically glassy, medium to fine grained with few vesicles, and rarely diktytaxitic. Phenocrysts are rare, and olivine is visible only in a few flows, then only in small amounts. Chemically (Table 2, Samples AI-AM), this unit is distinct from the other basaltic andesites , having both substantially higher and lower TiO_2, P_2O_5 and total Fe percentages than units Ta or Tbab (Table 2, Samples AI-AM). The unit has substantially higher SiO_2 and Al_2O_3, and lower TiO_2, P_2O5, MgO and total Fe than unit Tba. The age is poorly constrained, but the unit is at the bottom of the exposed section in the west half of the study area, and is likely one of the oldest units in the entire area. A date on a sample from the Pope Pit is pending. The unit outcrops as a series of low hills at the south end of Dodds Hollow, and is overlain to the north by unit Tms in Dodds Hollow and unit Tpb. It also outcrops near the top of the ridge north of Adams Point (Sample AL) where it is overlain by the basalt of Easy Creek (unit Tbe).

Younger basaltic andesite units

Tba Undifferentiated basalt and basaltic andesite flows (Pliocene?)--Grey to black, glassy to medium grained, holocrystalline, porphyritic and seriate basalt and basaltic andesite flows. These flows make up most of the highlands surrounding Dodds Hollow on the Merrill quadrangle, where they are poorly exposed beneath relatively thick colluvial and soil cover. Talus (unit Qrt) and patterned ground are common on surfaces underlain by this unit, which is consistent with thick colluvial cover, and natural outcrops are generally restricted to the tops of ridges. The lack of exposure, similarity of lithologies, and the great variety of textures and chemistry made it impractical to distinguish and map individual units within this group, and so all are lumped in one unit. This lack of individual units is consistent with unit Tba in the adjacent Dairy quadrangle to the north (Hladky, in press). In hand specimen, the rocks are typically fine to coarse grained seriate and diktytaxitic. Vesicles are common, and olivine is visible in most samples. Chemically (Samples G-AD, Table 2) the rocks in this unit are calc-alkaline basalts or basaltic andesites (Figures 4, 5), but there is little apparent relationship between chemistry, lithology and/or geographic distribution. One exception is a group of three samples (Table 2, Samples AB, AC, AD) which are markedly lower in SiO_2 and higher in MgO, CaO, TiO_2 and total Fe than the rest of the Tba samples. These samples occur in stratigraphic succession on the west flank of a major fault block in section 12, T40S, R10E, and might be a mappable unit if the exposure was better. These rocks are generally medium to coarse grained seriate olivine basalts, slightly dixtytaxitic, but not substantially different in appearance from many other Tba samples. Two other correlations are worth noting in the Tba unit chemistry. Samples P and Q; U and X (Table 2) respectively have such similar chemistries that each pair probably represents a single flow. These sample pairs are separated by significant distances, suggesting that Tba flows may have lateral extents of at least 2-3 km. Tba flows are commonly water affected, resulting in brown, palagonite-rich lava that weathers easily to grus, and forms slopes with little exposure. The age of the unit is poorly constrained. Similar rocks mapped in the adjacent (to the north) Dairy quadrangle had ages of 3.85 ± 0.06 Ma to 4.44 ± 0.04 Ma (Hladky, in press). The thickness of the unit is difficult to determine, since the base is not seen, but must be at least 250 m.

STRUCTURE

The mapped area lies within the extensional Basin and Range tectonic province that dominates the physiography of the state of Nevada, and extends into southern Idaho and south-central Oregon. Within the mapped area the predominant grain of the structure mimics the overall trends of the Basin and Range province--large, north-to-northwest trending graben valleys, separated by large horst mountain blocks.

Two tectonically controlled valleys are part of the mapped area. To the north the map contains the southern end of Poe Valley, which extends for kilometers to the northwest. In the south part of the map is the northern edge of the extensive Tule Lake Valley that continues to the south into California. The valleys are separated by a highland area that includes Buck Butte on the east and east side of Stukel Mtn. on the west.

Within the highland areas are numerous smaller, fault-controlled ridges. Most of these ridges were created by movements on north to northwest-trending normal faults that mimic the predominant regional north-northwest trending faulting. However, these faults are all cut by a major east-west trending fault that creates the Buck Butte hill in the northeast quadrant of the mapped area. With as much as 300 m of apparent displacement, this fault not only creates a major highland area, it also affects the groundwater system of the mapped area. Static water levels across this fault change by as much as 30 m, with average water elevations of 4120 feet in Poe Valley on the north side of the fault, and 4020 in the Tule Lake Valley on the south side of the fault (Ned Gates, personal communication, 2000). The Buck Butte fault appears to be a continuation of the east/west faults that cuts all of the other fault trends on the north end of Bryant Mtn., to the east of this mapped area (Jenks, in press). While these east/west faults on Bryant Mtn. appear to have some oblique strike slip movement, similar movement does not appear to have occurred on the Buck Butte fault. In the northwest part of the mapped area, the Buck Butte fault appears to rotate to the northwest and die out as motion is transferred to a series of less prominent northwest trending structure.

The southern part of the higlands separating Poe and Tulelake Valleys is also fault bounded, by several en echelon north/northwest to northwest trending southwest-side down faults, most prominently the Adams Point fault. The displacement on the Adams Point fault is uncertain, probably on the order of 100-300m, and it does not form the same prominent escarpment as seen along the Buck Butte fault.

A prominent tectonically-controlled horst, called Turkey Hill, dominates the geography north of the city of Malin. This hill was created by movements on normal faults on either side of the hill. Northwest of the hill the bounding faults turn and mimic the east/west trend of the Buck Butte fault. This creates a small high that separates the area north of Turkey Hill from the larger Tule Lake Valley to the south. The volcanic units on Turkey Hill and the east/west trending high are the same as the units on the top of and east of Buck Butte, so the faulting must be younger than the emplacement of those lava flows.

Equally significant to the overall structure of the area are the consistent dips of some of the units. South of Buck Butte all of the units dip to the south/southwest at attitudes varying from 7^{o} to 15^{o}. The units on Turkey Hill, and the high area to the northwest of it, all dip to the southwest, suggesting that the dips created by the Buck Butte fault are continued by the similar east/west faulting that created the Turkey Hill and related east/west trending high. In contrast, the interbedded Tba and Tms units in the Dodd Hollow area show a consistent dips of 13^{o} to 26^{o} west-southwest. The north trending ridge north of Adams Point appears to be a structural divide between the Dodds Hollow section and the more gently and southerly dipping section to the east.

A north trending, east side down fault is inferred at the southwest edge of the map. This fault is the extension of the Gillem fault, a major structure bounding the west side of Tule Lake valley in California (Donnelly-Nolan and Champion, 1987). The Gillem fault is apparent as a N-trending escarpment just south of the edge of the mapped area, and bedrock exposures at Anderson Dam on the Merrill quadrangle show unit Tm sediments faulted by N-trending structures.

The age of the faulting within the mapped area is problematic. Some geologists in the area (Peterson and McIntryre, 1970; Sherrod and Pickthorn, 1992) have suggested that the onset of major Basin and Range faulting in this region was Pleistocene, or perhaps late Pliocene. Other authors (Hart, and others, 1984, Murray, in press, Black, in press) postulate a much older 7.0 Ma or Miocene age for the onset of the predominant north/northwest-trending, high-angle Basin and Range faulting. Because the age of the volcanic units within the mapped area is early Pliocene to middle Miocene, there are no younger lavas with which to bracket the age of the faulting that cuts these units. From the relatively young, undissected appearance of the fault scarps, and the few established streams within the mapped area, it is possible to infer that the ages of the major northwest-trending faults that formed highland vs. valley parts of the mapped area are relatively young. However, these faults also do not appear to have moved within the recent past, because none of the talus slopes or landslide debris fans in the area shows any sign of offset. Only the Adams Point fault appears to have been active during the Quaternary and forms a subdued scarp 2-4 m high in unit Qs sediments. Sherrod and Pickthorn (1992) mapped two northwest trending buried Holocene faults within unit Qs bracketing the Lost River northwest of Merrill. We found no evidence for these faults.

Peterson and McIntyre (1970) suggest that the Klamath Basin area may have undergone a period of warping that produced broad, gentle folds that affected the older basaltic andesite and sedimentary sections. Within the mapped area, the consistent dips of the Buck Butte and Turkey Hill highs could be the result of this warping, or simply a response to the faulting that formed those hills.

While none of the major fault planes are exposed within the mapped area, it appears that the dips of the normal faults are similar to the 50^{o}-60^{o} dips measured in other Klamath Basin areas on similar, but exposed fault planes. Thus, it can be assumed that the faulting within the map area is principally high-angle normal faulting of the Basin and Range type. Near and within some of the larger and smaller fault planes, the volcanic flows have been bent. These bent lava flows near fault planes are persistent throughout the mapped area, suggesting that fault drag is the principal cause of any high angle dips in the area.

GEOCHEMISTRY

The fifty-six geochemical samples listed in Table 2 were analysed by Dr. Stanley A. Mertzman, Franklin and Marshall College, Lancaster, PA. The samples were collected from the massive interior portions of the lava flows, with care being taken to avoid areas of alteration or significant post-eruption deposits in each flow's vesicles. The whole-rock analyses for major and trace elements were performed using a Phillips 2404 X-ray fluorescence vacuum spectrometer equipped with a 102 position sample changer. The Loss on Ignition (LOI) was determined by heating accurately pre-weighed amounts of sample rock powder to 950°C for one hour, and then reweighing the sample to determine the relative percentage of weight gain and loss. The amount of ferrous Fe was titrated using a modified Reichen and Fahey (1962) method.

GEOLOGIC HISTORY

The oldest units within the mapped area are the various basaltic andesite units. In general, these are fine grained to glassy rocks with pilotaxitic textures, and very few phenocrysts. The flows of these units range from massive flows to aa-type flow breccias. These units were faulted and probably eroded before any of the other units within the mapped area were deposited. Thus, they formed the topography of low hills and broad valleys into which the sediments and basaltic rocks were deposited. No vent areas have been located for these units, but the lack of exposure could mean that the vent areas are located in downfaulted and/or covered areas.

Onto this surface containing basaltic andesite flows, and possibly sediments, the basalt flows were then deposited. A whole-rock isochron Ar^{40}/Ar^{39} age of 5.4±0.65 Ma (Table 1) has been obtained for the basalt of Johns Waterhole (unit Tbjw) flows in the northeastern corner of the map. As this unit is the oldest basaltic unit in the eastern part of the mapped area, it represents a maximum age for the section of basaltic units. The basaltic rocks vary systematically in their phenocryst contents, paleomagnetic readings, overall characteristics, and chemistries. This fact makes them relatively easy to distinguish in the field, and thus they are mapped as separate units. One unit in particular, the basalt of Turkey Hill (unit Tbth), is an excellent marker layer within the basaltic stratigraphic section because of its extreme diktytaxitic and very coarse grained character. In their chemistries the units appear to vary systematically from the oldest flows that are somewhat like the underlying calc-alkaline rocks, to Snake River Plain affinity rocks, then to Basin and Range affinity rocks, and finally in the youngest unit, back to Snake River Plain affinities. The paleomagnetic signatures seem to echo these trends, with the lowest units reversed, the Basin and Range units normal and the uppermost unit reversed.

The basaltic units appear to have erupted onto relatively low topographic relief terrain, as they make laterally extensive "puddles" of thin flows, with few areas of ponded lavas. In addition, overall fairly large areas, especially the older flows of the units. have strongly interacted with water. Both pillowed and water affected flows are common throughout the eastern part of the mapped area, and the only subaerial flows are less than 10 m thick and cap the ridge lines. Interbedded with the pillowed and water affected flows are sediments and basaltic pyroclastic tuffs.

The exact relationship of the sedimentary materials, as well as most of the volcaniclastic units, is presently problematic. Lack of exposure of the basalt contacts with these sediments makes it difficult to relate the stratigraphy of the two types of rocks to each other. In the south end of Poe Valley extensive areas of palagonitic tuff and their related vent areas floor the valley and appear to be the youngest units in the section. However, layers similar in appearance are within the Buck Butte escarpment and on the south side of Buck Butte, within the extensive pillow breccia unit. Dating of these units is difficult, although pumiceous material and fish fossils within the sediments are presently being evaluated and dated. Within Dodds Hollow it appears that a relatively thick sequence of sediments of unit Tms was deposited in a local basin at the same time as eruption of the ~ 4 Ma unit Tba.

These sediments appear to overlie unit Tbap farther south, but no contact relations have been seen. Unit Tm sediments in the northern edge of the Tule Lake valley, west of Adams Point, are exposed in a complex relationship in an excellent roadcut in Section 5 T41S, R11E. At this site, Tm appears to have been deposited over an active fault zone with Tbap on the upthrown side.

The youngest units in the area are the valley-fill sediments, the stream alluvium and alluvial fan deposits, the various deposits resulting from mass wasting activities, and the lacustrine sediments deposited byTule Lake before it was drained. Stream deposits that formed bajadas and fans are mapped as unit Qoaf, and are found in the western part of the mapped area. These fans were probably deposited during Pleistocene pluvial periods, and appear to have been graded to a higher base level than the current drainage system. Numerous large landslides are located within the mapped area, along the Buck Butte fault, and in the highlands between Dodds Hollow and Stukle Mountain. Other smaller rock fall and mass wasting features are related to the major fault escarpments in the area. The valley fill deposits and the Holocene Tule Lake deposits are both the result of sedimentation in the succession of lakes occupying the Tule Lake valley. The shoreline level of the Pleistocene to Recent lakes varied over broad areas, due to the low relief of the lake basin floor, as well as various changing climatic regimes. During the Pleistocene the Tule Lake valley is postulated to have been part of a much larger lake, Lake Modoc, which inundated all of the valleys in the Klamath River basin (Dicken, 1980). After that lake drained the Lost River established its present channel and Tule Lake receded to a seasonally fluctuating, but fairly stable extent that was present before the lake was drained in the early 1900's.

RESOURCES AND HAZARDS

Gravel and aggregate resources

The local ranchers and farmers have established a number of small gravel and borrow pits throughout the mapped area. Materials from these pits have generally been used locally to pave gravel roads and cattle feed lots. In the southeast side of Poe Valley, two pits mine materials from the vent areas associated with the basaltic pyroclastic tuff units. In Dodds Hollow one small pit mines the gravels of unit QTg. Extensive pits mine a large basaltic tuff deposit just off the southwestern edge of the map. The aeolian sand deposits on the sides of Turkey Hill, in the eastern part of the mapped area are still being exploited in a major way in the Cummings pit. Sands from this pit are hauled by truck to the San Francisco and Sacramento Valley areas of California. All of the pits exploit units that are extensive enough to provide for the needs of the local inhabitants for the foreseeable future.

Surface and ground water resources

In comparison to other areas in the Klamath Basin (Jenks, in press), this mapped area contains few springs. The only mapped springs in the area, in SESW section 19, T40S, R11E, appear to be fault controlled. The ranchers in the area have built numerous small reservoirs to contain runoff and either to supplement irrigation water from wells and the Lost River, or for use to water cattle herds.

Numerous wells have been drilled within both the Poe and Tule Lake Valleys for use as domestic, stock, and irrigation water sources. A study of the well logs of high production wells, both deep and shallow, and low production deep wells, as part of this geologic mapping project, shows some correlation to area and lithologic sequence. The high production wells appear to be related to the major fault escarpments in the area, and generally tap into the deeper basalt aquifer. In general wells drilled in the highland areas that pass through only volcanic sequences are low production wells, even when they are drilled to some depth. Good examples of this problem are the wells drilled by Richard Saachi (OWRD KLAM-10140 and KLAM-14815, sections 26 & 27, T40S, R12E), and the well drilled on the top of Turkey Hill by Ron McVey (no KLAM number). All three only intersect lava flows approximately 300 m in total depth, and have production of less than 25 gpm.

Two specific areas within the valleys have low production deep wells. The first area is west of Harpold Road, in south Poe Valley. Wells in that area intersect up to 160 m of fine grained sediments, with productions of less than 25 gpm. The other area is in the northwest corner of the Malin part of the Tule Lake Valley. In that area the intersected lithologies are variable, and no ready explanation is available for the lack of production.

Geothermal resources

A survey of measured temperatures as documented in the well logs shows groundwater temperatures generally range from 45^{o}-55^{o}F. Several locations in the mapped area show slightly elevated temperatures, in the range of 70^{o}-90^{o}F. One area is in the south end of Poe Valley, along and west of Harpold Road; a second is in the Malin side of the Tule Lake Valley, on the far eastern side of the mapped area and below the major valley/highland fault escarpment in secs. 34 & 35, T40S, R12E; and the third is in Dodds Hollow. Thus, it appears that there are no exploitable geothermal resources within the mapped area.

Earthquake and mass wasting hazard

No earthquake epicenters have been recorded within the mapped area. However, area residents report that they felt the 1993 series of earthquakes that rocked the nearby Klamath Falls area. The principal hazards related to earthquakes in the area are mass wasting movements, either as slides or large block rockfalls. As discussed in the description of the landslide deposit unit (unit Qls), several large landslides, of probably ancient age, were found within the mapped area. Given the recent history of seismic activity in the Klamath Basin area, it seems likely that the ancient slides originated in response to major earthquakes. Thus, it is possible that similar earthquake-generated slides will happen in the future.

ACKNOWLEDGEMENTS

This mapping was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under assistance award #00HQAG0014. The authors are grateful to the ranchers and landowners throughout the mapped area for their permission to survey their lands. We appreciate the efforts of Ned Gates and the other staff members of the Oregon Water Resouces Department, to provide us with information about well locations and well logs. Our thanks to the staff geologists of the Oregon Department of Geology and Mineral Industries for their discussions and in-the-field observations. *The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.*

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