SUTTER BUTTES

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INTRODUCTION

The Sutter Buttes form a strangely isolated knobby extrusive center in the middle of the Sacramento Valley, 6 miles northwest of Yuba City (Figure 1). Geologist, traveler, rancher, and Native American alike have pondered the significance of this enigmatic topographic blemish.

This is a guide to the igneous, sedimentary, and structural framework of the Sutter Buttes volcano. Field trip stops include exposures of the igneous and fragmental deposits produced during Quaternary magmatism. We will attempt to summarize many of these aspects of the Buttes during the field trip. We also refer you to Anderson (1983) for a short summary of the geologic evolution of the Sutter Buttes area.

The Sutter Buttes are entirely under private ownership and permission *must* be obtained before entering *any* land. Entrance can be obtained through an organization that offers guided walks into the Buttes: the Middle Mountain Foundation (530) 634-6387.

PREVIOUS WORK

Williams (1929) described the Sutter Buttes as a deeply dissected huge central laccolithic intrusion with attendant extrusions. This work was reinterpreted by Williams and Curtis (1977) as a complex of smaller extrusive and intrusive domes. The domes pushed up and erupted through the surrounding pre-volcanic Sacramento Basin sedimentary section and resulted in a surrounding volcaniclastic apron. Geologic maps of the Sutter Buttes have been published by Lindgren and Turner (1895), Williams (1929), Johnson (1943), Garrison (1962b), and Williams and Curtis (1977) (Figure 2).

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GEOLOGIC OVERVIEW

Williams and Curtis (1977) gave prosaic names to the important geologic features of the Sutter Buttes. The circular Sutter Buttes were formed during the early Pleistocene by piercement intrusions and extrusions of rhyolite and andesite. The central mass of spiny domes was called the Castellated Core. Previously deposited Upper Cretaceous, Eocene, and Miocene to Pliocene strata were warped, folded, and faulted by the intrusions and form a lowland circular ring of outcrops, called the Moat, that flanks the volcanic core of the Buttes. Tuff and breccia, largely re-worked by fluvial processes, form the Rampart outer ring that slopes away from the volcanic center and overlaps the uparched Moat sedimentary rocks.

REGIONAL STRATIGRAPHY

Pre-volcanic sedimentary rocks of the Sacramento Basin are exposed in the Moat of the Sutter Buttes and have been divided in various ways by different workers, resulting in some major differences in age and formation assignments.

Cretaceous Depositional Systems: The oldest strata exposed are generally fine-grained and have been assigned to the Forbes Formation ("Forbes Shale"); overlying beds of sandstone are the Kione Formation ("Kione Sands," "Kione Sand," or "white sand marker bed") (Johnson, 1943; Thamer, 1961; Garrison, 1962a (Figure 3); Williams and Curtis, 1977). Nilsen (1990) provides a summary of the subsurface geology of the Upper Cretaceous units, and Nilsen and Imperato (1990) prepared a field guide to these units around the margins of the Sacramento Valley.

Because previous geologic maps generally emphasized the geology of Tertiary volcanic and plutonic units, the exact distribution of the Forbes and Kione formations in the Buttes area remains unclear. The structural framework of the Upper Cretaceous units

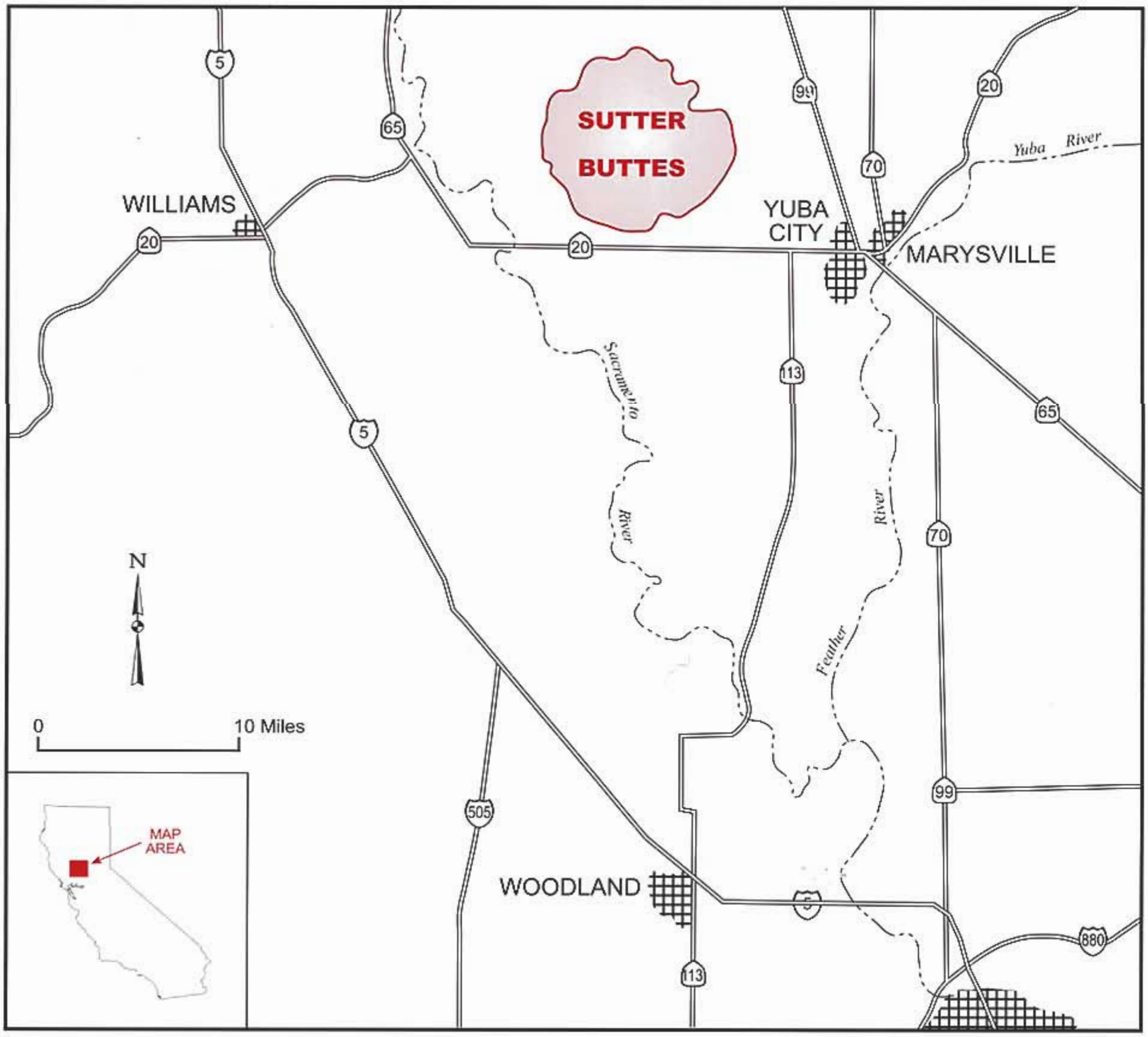

Figure 1. Map of the central Sacramento Basin showing the Sutter Buttes and related outcrop areas.

in and near the Sutter Buttes area is also very complex. Strata adjacent to the piercement intrusions are vertical to overturned and complexly faulted. Quaternary units that dip radially away from the Buttes have covered important flanking folds and faults.

The Forbes and Kione formations crop out along the western, southern, and eastern flanks of the Sutter Buttes. Because outcrops on the western and eastern flanks are largely covered by landslides or are involved in landsliding, much of the stratigraphic emphasis here is on the southern flank. The Forbes Formation in subsurface is reportedly underlain by a thick shale unit, the Funks Shale, which rests conformably on granitic basement rocks. Although the Funks does not crop out in the Buttes area, it does crop out to the west in the Coast Ranges. Neither the Dobbins Shale Member of the Forbes Formation nor the Guinda Formation, which overlies the Funks Formation in the Coast Ranges to the west, has been recognized in the Sutter Buttes area.

Because the base of the Forbes Formation cannot be observed in outcrop, its true stratigraphic thickness is not known. Johnson (1943) indicated a maximum exposed thickness of 2,750- 4,350 feet

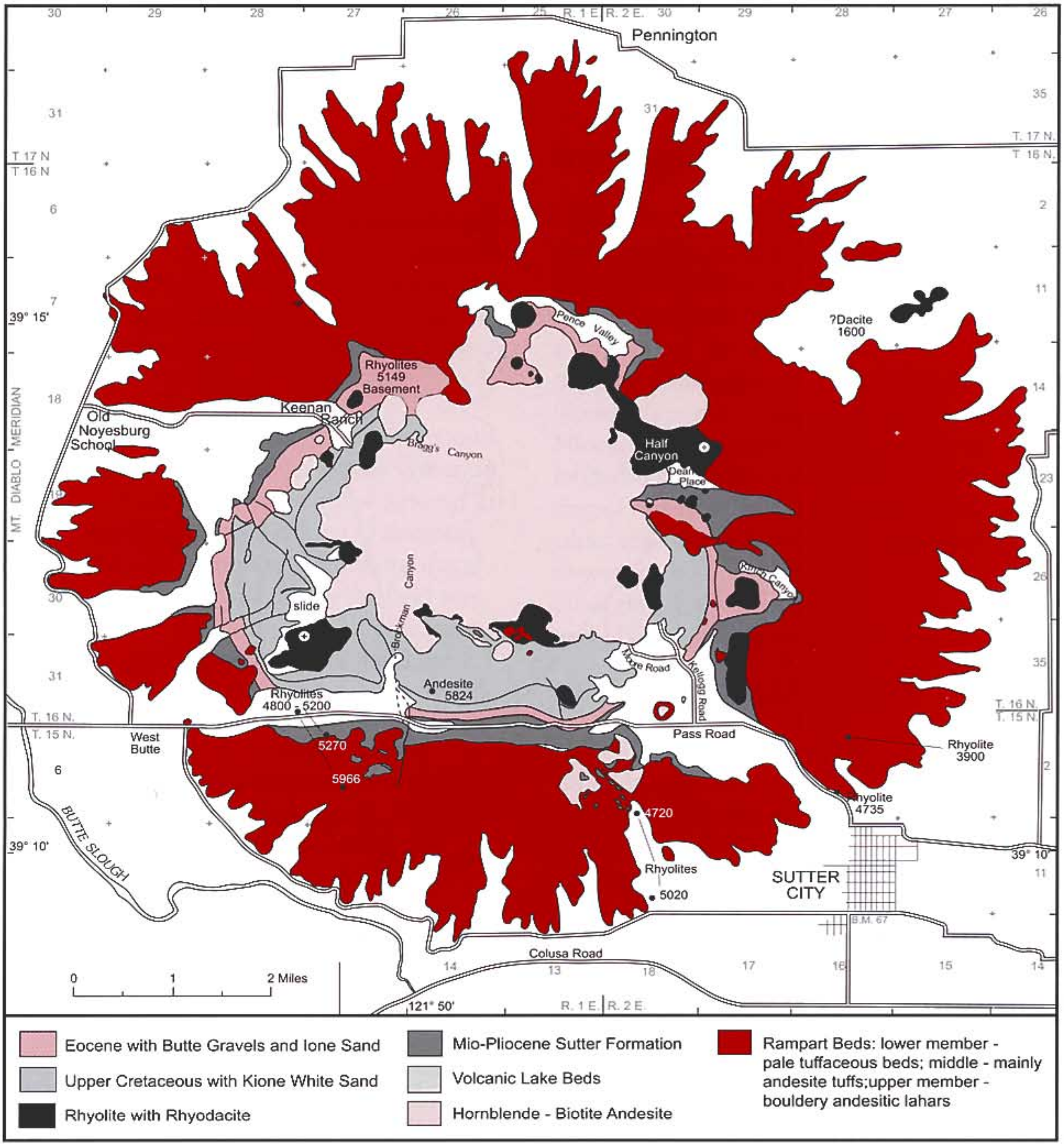

Figure 2. Geologic map of the Sutter Buttes area (Williams and Curtis, 1977).

for the Forbes Formation on the south flank of the Buttes, and Garrison (1962a) proposed a thickness of 2,700-4,000 feet. The basal exposed part of the Forbes Formation generally consists of baked shale, hardened and resistant from contact with volcanic necks. Most of the directly overlying strata that are less resistant do not crop out well and are subject to massive slope failures. Field mapping and hiking along ridges that appear not to have failed suggests that most of the Forbes Formation consists of shale. Although this shale is rarely exposed, it does appear to underlie smooth, grass-covered slopes in much of the area.

Contrary to most published descriptions of the Forbes Formation that describe it as massive shale, it contains prominent conglomerate and sandstone units within its upper part. These beds

Aerial view of Sutter Buttes. *Photo courtesy of U.S. Air Force.*

appear to consist of laterally discontinuous bundles of coarse-grained strata that crop out locally but do not form laterally continuous ridges such as those within the overlying Kione and Ione formations. Only a few of the coarse-grained beds are well exposed.

The bundles of conglomerate and sandstone are about 10-40 feet thick, and generally form sequences that appear to fine and thin upward. The conglomerate contains a variety of lithic clasts, most commonly fine-grained meta-volcanic clasts that are as large as 1 inch in diameter. Rip-up clasts of shale and clasts of ferruginous concretions are also present in these beds. Scattered carbonaceous fragments are present along some bedding surfaces, and abraded molluscan fragments have been observed locally.

The bundles of conglomerate and sandstone in the Forbes Formation are generally massive to parallel-stratified and do not contain cross- bedding, *in situ* molluscan fossils, or other features indicative of shallow-marine conditions. However, upsection toward the base of the overlying Kione Formation, hummocky cross-stratification in the uppermost

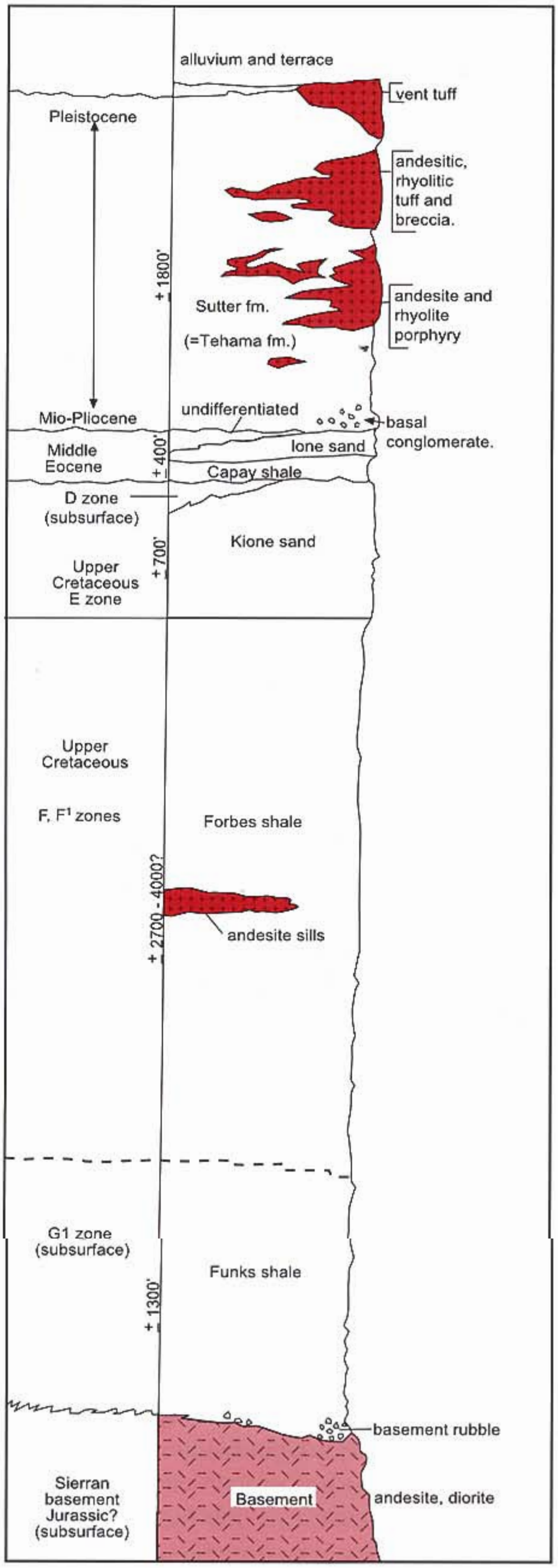

Figure 3. Generalized stratigraphic columns for the Sutter Buttes area (from Garrison, 1962a).

bundles of conglomerate and sandstone can be observed. This feature forms broad, wavy stratification in fine- to medium-grained sandstone, and is interbedded with bioturbated fine-grained sandstone and mud-stone containing molluscan fossils. The upper part of the Forbes Formation in the Sutter Buttes area was probably deposited in shoaling conditions by redeposition of sands from storm waves.

The overlying Kione Formation has many features characteristic of deposition in a complex of deltaic, fluvial, and shallow-marine environments. It locally contains abundant molluscan fossils, particularly oyster fragments, cross-stratified conglomerate and sandstone, plant fossils, rip-up clasts of shale and ferruginous concretions, and lithic pebbles as large as 1 inch in diameter. A few measurements of clast imbrication and cross bedding suggest sediment transport generally toward the west and south. Outcrops of the conglomerate and sandstone of the Kione Formation are more abundant and closely spaced, suggesting that there is less interbedded shale than in the Forbes Formation.

Tertiary Depositional Systems: Eocene strata of the Capay Formation ("Capay Shale") and the Ione Formation (Ione "sand") unconformably overlie the Cretaceous units. The Capay Formation is about 250 feet thick in most of the area but may be as thick as 400 feet on the western flank of the Buttes. It consists chiefly of greenish-gray shale and claystone with interbedded buff-colored sandstone that is locally rich in ferruginous concretions. Glauconite is common, and carbonaceous layers are reported by Williams and Curtis (1977) from the northern and eastern flanks of the Buttes. Abundant benthic foraminifers and ostracodes indicate a Penutian (early Eocene) to Ulatisian (early middle Eocene) age and deposition in generally shallow-marine conditions (Stipp, 1926; Merriam and Turner, 1937; Israelsky, 1940; Marianos and Valentine, 1958; Olson, 1961).

The overlying Ione Formation is approximately 150 feet thick (Thamer, 1961; Garrison, 1962a) and consists chiefly of friable, white-weathering, quartzose sandstone of middle Eocene age. The Ione Formation is regionally as thick as 900 feet, crops out along the west flank of the Sierra Nevada, and consists of deltaic, lagoonal, and fluviatile deposits (Creely, 1965; Gillam, 1974). Its lower member rests on a deeply weathered lateritic surface and consists of quartzose and anauxitic sandstone, claystone, and local coals.

The Ione Formation grades laterally southward and eastward into the Domengine Formation, a shelf sandstone widespread in the Sacramento Basin, that records westward progradation of a tide- and wave-dominated deltaic system (Bodden, 1983; Cherven, 1983). Williams and Curtis (1977) report the presence of anauxite in quartzose sandstone of the Ione Formation, and noted the presence of numerous conglomeratic layers within and above the Ione Formation that they assign to the Butte Gravels; they also reported Eocene megafossils from a prominent conglomeratic bed 700 feet above the top of the Kione Formation on the south flank of the Buttes. Williams and Curtis (1977, p. 12) indicate a maximum thickness of about 1,200 feet for the Butte Gravels, whereas previous workers assigned much of this sequence to the Sutter Formation (Thamer, 1961; Garrison, 1962a).

The Eocene deposits are overlain by the nonmarine Sutter Formation (Dickerson, 1913), which consists chiefly of fine-grained sandstone, siltstone, tuff, and minor amounts of gravel. A prominent conglomerate forms the base of the unit. The stratigraphy and age assignments of the Sutter Formation have been particularly complex and varied. Williams and Curtis (1977) concluded that the Sutter Formation ranged in age from Oligocene to Pliocene and that it generally rested conformably on Eocene strata, although locally the contact was unconformable. Most other workers have equated the Sutter Formation or Sutter "beds" with the Tehama Formation, a widespread Miocene, Pliocene, and Pleistocene unit in the Sacramento Basin (Thamer, 1961; Garrison, 1962a). Williams and Curtis (1977) argue that the Sutter Formation was derived from the Sierra Nevada rather than the Coast Ranges and Cascade Range, the chief source area for the Tehama Formation. They also contend that the Sutter Formation is 600-1,000 feet thick in the Sutter Buttes area, rather than the 1,800 feet proposed by other workers.

VOLCANIC GEOLOGY

Williams and Curtis (1977) divided the magmatic episode at the Sutter Buttes into a prevolcanic period of intrusion, uplift and erosion, followed by a period of volcanic dome extrusion with attendant explosive eruptions. The following discussion summarizes and adds to their account.

The magmatic episode appears to have occurred in Early to Middle Pleistocene. Williams and Curtis report K-Ar dates ranging from 2.4 to 1.4 Ma for the volcanic activity. However, more recent $^{40}Ar/^{39}Ar$ dating (Hausback and others, 1990) on single crystals of sanidine extracted from the oldest erupted volcanic deposits at the Sutter Buttes indicates that volcanism began about 1.59 Ma. Dated samples were derived from a rhyolite pyroclastic breccia in the lower Rampart beds on the south side of Pass Road in the Sutter Buttes. These beds directly overlie the prevolcanic Sutter Formation and record the earliest, explosive eruptions at the Sutter Buttes volcano. These new dates are approximately 0.8 my younger than the previously reported K-Ar date from this same site (Hausback and others, 1990).

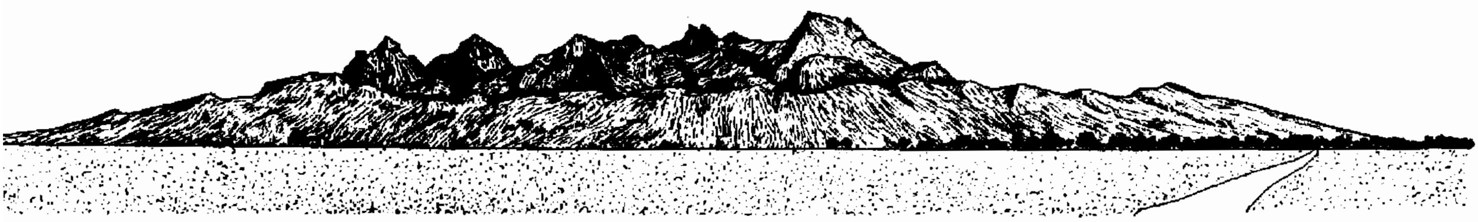

Figure 4. View of the sutter Buttes from near Williams, 20 miles to the west (Williams, 1929).

Although the upper age limit of volcanism has not yet been determined, preliminary $^{40}Ar/^{39}Ar$ results from biotite crystals derived from several of the volcanic domes from the core of the Sutter Buttes yield ages from 1.56 to 1.36 Ma.

Prevolcanic Intrusion: Necks of Sutter Buttes magmas began intruding some time before the initial volcanic ejections. These initial intrusions were largely rhyolitic and caused substantial tilting and uplift of the pre-volcanic Cretaceous through Tertiary section. The Rampart volcaniclastic beds lie unconformably atop the tilted Moat section, suggesting that substantial deformation and erosional stripping of the pre-volcanic Cretaceous and Tertiary section had already taken place before volcanic eruptions began.

Volcanic Episode: Intrusion and uplift continued as volcanic eruptions began, resulting in further deformation of the Moat rocks. Williams and Curtis (1977) state, "No other volcanic region that we know of exhibits stronger or more extensive deformation of overlying beds by rising magmas than can be seen in the Sutter Buttes."

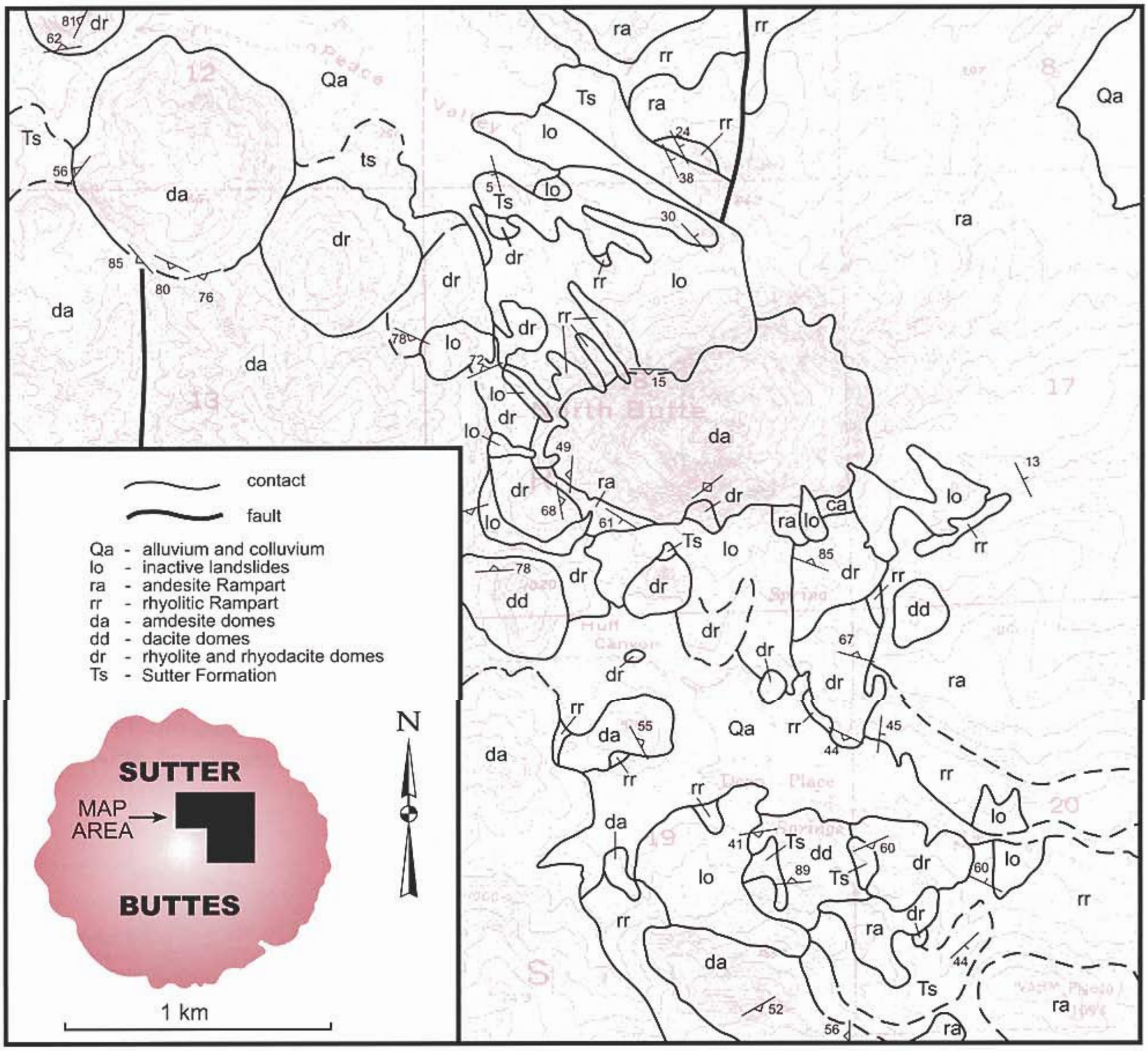

Figure 5. Preliminary geologic map of a portion of the northeastern Sutter Buttes volcano.

Extrusives at the Sutter Buttes range from 55-71% SiO_2 (mafic andesite to rhyolite), all of which form viscous domes with the exception of some tabular lavas that erupted at a satellite vent in the southeast sector of the Buttes. The silicic domes are biotite rhyolites and hornblende-biotite rhyodacites, which form a discontinuous outer ring of the Castellated Core. This distribution is probably structurally controlled by a circular fracture network formed during the prevolcanic intrusion and uplift. The crude circular vent distribution of the rhyolites is concentric with an outer network of arcuate high-angle reverse faults that underlie the Moat and Rampart along the north, east, and south sides of the Buttes (Williams and Curtis, 1977; Harwood and Helley, 1987). These faults may be the result of central uplift and domal flexure caused by multiple injection of intrusive necks into the central Sutter Buttes area before any magmas had reached the surface. Later, andesite domes invaded and extruded into the interior of the ring of rhyolite domes, forming the high, spiny peaks so characteristic of the core of the Sutter Buttes (Figure 4).

Fragmental deposits were continually shed from the growing assemblage of volcanic domes. Volcanic activity at the Sutter Buttes coincides with the Nebraskan glacial period (1.6-1.3 Ma, Chorley and others, 1984). Eruptions during this wet climatic period may explain the thorough reworking of the pyroclastics of the Rampart and central lacustrine deposits (mentioned below). Early silicic eruptions gave rise to rhyolite tuffs and lithic breccias deposited unconformably on the Sutter Formation as the lower Rampart. These fragmental rhyolite deposits were also locally tilted as the extrusive domes continued to rise. Andesite eruptions followed and, in part, may have been contemporaneous with rhyolitic extrusions. Resultant andesitic middle Rampart deposits overlie, locally in distinct angular unconformity, the lower Rampart. The final stage of deposition consisted of coarse blocky andesite diamicts of the upper Rampart (Figure 5). These units were deposited as both lahars and pyroclastic flows probably derived by dome collapse. The upper Rampart deposits record the final stages of volcanism; hence, they show little or no deformation from dome intrusion and form the gently inclined slopes, so characteristic of the Rampart apron.

In the center of the Castellated Core of andesite domes is a small oval-shaped deposit of lacustrine beds (Figure 6). These sediments were deposited in a deep crater lake during the explosive eruption phase of volcanism and have since been intruded and deformed by the surrounding andesite domes. The lakebeds form a 1,000-ft thick section of reworked lapilli tuff and tuff breccia deposited as a sequence of turbidites (Zaffran, 1988).

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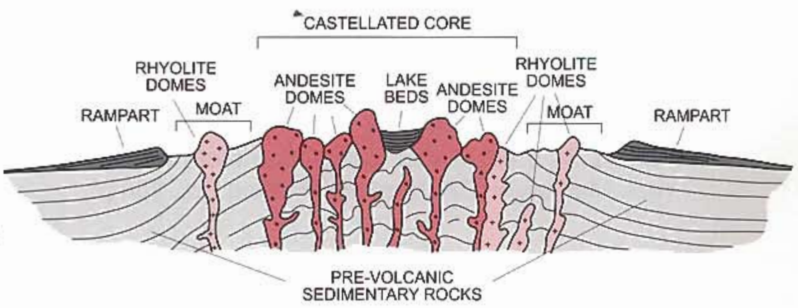

Figure 6. Castellated core.

REFERENCES

Anderson, W., 1983, The Sutter Buttes: a naturalist's view: Chico, CA, The Natural Selection Publishers, 326 p.

Bodden, W.R., III, 1983, Depositional environments of the Eocene Domengine Formation outcrop on the north side of Mt. Diablo, California *in* Cherven, V.B. and Graham, S.A., editors, Geology and sedimentology of the southwestern Sacramento Basin and East Bay Hills: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 29, p. 43-57.

Cherven, V.B., 1983, Stratigraphy, facies, and depositional provinces of the middle Eocene Domengine Formation, southern Sacramento Basin *in* Cherven, V.B. and Graham, S.A., editors, Geology and sedimentology of the southwestern Sacramento Basin and East Bay Hills: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 29, p. 59-72.

Chorley, R.J., Schumm, S.A. and Sugden, D.E., 1984, Geomorphology: London, Methuen and Co., Ltd., 605 p.

Creely, R.S., 1965, Geology of the Oroville (15') Quadrangle, Butte County, California: California Division of Mines and Geology Bulletin 184, 86 p.

Dickerson, R.E., 1913, Fauna of the Eocene at Marysville Buttes: California University Department of Geological Sciences Bulletin, v. 7. p. 257-298.

Garrison, L.E., 1962a, The Marysville (Sutter) Buttes, Sutter County, California: California Division of Mines and Geology Bulletin 181, p. 69-72.

Garrison, L.E., compiler, 1962b, Generalized geologic map of Marysville Buttes: California Division of Mines and Geology Bulletin 181, Plate 4, scale 1:62,500.

Gillam, M.L., 1974, Contact relations of the lone and Valley Springs formations in the Buena Vista area, Amador County, California: MS thesis, Stanford University, Stanford, CA, 180 p.

Harwood, D.S. and Helley, E.J., 1987, Late Cenozoic tectonism of the Sacramento Valley, California: U.S. Geological Survey Professional Paper 1359, 46 p.

Hausback, B.P., Swisher, C.C. III and Curtis, G.H., 1990, New $^{40}Ar/^{39}Ar$ ages from the Sutter Buttes volcano, California: American Geophysical Union, EOS, Transactions, v. 71, no. 43, p. 1646.

Hendrix, L.B., 1980, Sutter Buttes - Land of Histum Yani: Marysville, CA, Normark Printing Co., 154 p.

Israelsky, M.C., 1940, Notes on some Foraminifera from Marysville Buttes, California: Sixth Pacific Science Congress, v. 2, p. 569-580.

Johnson, H.R., 1943, Marysville Buttes (Sutter Buttes) gas field: California Division of Mines Bulletin 118, p. 610-615, scale 1:100,000.

Lindgren, W. and Turner, H.W., 1895, Marysville Folio: U.S. Geological Survey Geologic Atlas of the United States, Folio, v. 17.

Marianos, A.W. and Valentine. J.W., 1958, Eocene ostracode fauna from the Marysville Buttes, CA: Micropaleontology, v. 4, p. 363-372.

Merriam, C.W. and Turner, F.E.. 1937, The Capay middle Eocene of northern California: California University Department of Geological Sciences Bulletin, v. 24, p. 91-114.

Nilsen, T.H., 1990, Santonian, Campanian, and Maestrichtian depositional systems, southern Sacramento Basin, California *in* Ingersoll, R.V., and Nilsen, T.H., editors, Sacramento Valley Symposium and Guidebook: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 65, p. 95-132.

Nilsen, T.H. and Imperato, D.P., 1990, Geologic field trip guidebook to Upper Cretaceous gas-producing strata, northern and central Sacramento Basin, California *in* Ingersoll, R.V. and Nilsen, T.H., editors, Sacramento Valley Symposium and Guidebook: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 65, p. 153-181.

Olson, R.E., 1961, Correlation of Eocene strata exposed in Fig Tree Gulch, Sutter County, California: Report of the Annual Field Trip of the Geological Society of Sacramento, p. 32-35.

Stipp, T.F., 1926, The Eocene Foraminifera of the Marysville Buttes: MA thesis, Stanford University, Stanford, CA, 70 p.

Thamer, D.H., 1961, Report of the annual field trip of the Geological Society of Sacramento, p. 36-41, map scale 1:48,000.

Williams, H., 1929, Geology of the Marysville Buttes, California: California University Department of Geological Sciences Bulletin, v. 18. p. 103-220, map scale 1:62,500.

Williams, H. and Curtis, G.H., 1977, The Sutter Buttes of California: University of California Publications in Geological Sciences, v. 116, 56 p., map scale 1:62,500.

Zaffran, L.L., 1988, The central lakebeds of the Sutter Buttes, California: Senior thesis, Geology Department, California State University, Sacramento, CA, 31 p.