Petrology of the Bell Top Formation

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PETROLOGY OF THE BELL TOP FORMATION

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GEOLOGIC SETTING

The Bell Top Formation was named by Kottlowski (1953). Detailed geologic mapping (1:24,000 scale) in the Sierra de las Uvas began in 1970 (Clemons and Seager, 1973). Subsequent studies (Seager and Hawley, 1973; Seager, Clemons, and Hawley, 1975; Seager, 1975; Seager and Clemons, 1975; and Clemons, in press) and reconnaissance investigations have essentially delineated the extent, thicknesses, ages, and regional relationships of the Bell Top Formation.

The Bell Top Formation attains its maximum total thickness of about 1,500 ft in the central Sierra de las Uvas (Fig. 1). It crops out sporadically for 25 mi to the north and northeast, as some members pinch out and others interfinger with the lower Thurman Formation (Kelley and Silver, 1952) in the Rincon Hills, southern Caballo Mountains, and Point of Rocks. Thicknesses also decrease to the south and probably pinch out in the northern West Potrillo Mountains. The Bell Top also wedges out to the west in the Good Sight Mountains. Deposition appears to have been limited abruptly to the east, in the vicinity of Faulkner Canyon and Corralitos Ranch. Thus it was deposited over an area extending 50 mi in a north-south direction and 25 mi wide, which has been named the Good Sight-Cedar Hills volcano-tectonic depression (Seager, 1973).

The depression is floored by the Palm Park Formation (Kelley and Silver, 1952) of Eocene age to the east, and the Rubio Peak Formation (Elston, 1957) of probable Eocene age to the west. Exact relationships between these two units are still to be determined. Potassium-argon ages of several members of the Bell Top Formation indicate an early to middle Oligocene age. A K-Ar age of a basal Uvas Basaltic Andesite (Kottlowski, 1953) flow, overlying the Bell Top, is late Oligocene (Fig. 2).

ACKNOWLEDGMENTS

Descriptions and field data in this paper are based mainly on my observations, but they have benefited greatly from detailed field mapping and interpretations by W. R. Seager. Discussions and field excursions with many geologists have improved my concepts of ash-flow tuffs and volcanic features. Among them are C. E. Chapin, E. G. Deal, W. E. Elston, J. W. Hawley, J. M. Hoffer, F. E. Kottlowski, and W. R. Seager. Twenty chemical analyses were obtained with a grant from the New Mexico Bureau of Mines and Mineral Resources. Two analyses of the basaltic andesite were contributed by J. R. Renault. I am indebted particulary to F. E. Kottlowski, Director, and the New Mexico Bureau of Mines and Mineral Resources for providing thin sections, radiometric age determinations, and continued financial support of the geologic studies upon which this paper is based.

BELL TOP FORMATION

The Bell Top Formation has been divided into 13 informal members. These include 5 ash-flow tuffs, one tuff of uncertain origin, intrusive-extrusive Cedar Hills rhyolite, intrusive-extrusive basaltic andesite, olivine-bearing basalt, and four interbedded sedimentary units. All of the members are not present in any one section but overlapping relationships between sections have made it possible to build the chronologic sequence shown in Figure 2.

Ash-Flow Tuffs

The nomenclature used in this paper to describe ash-flow tuffs is that of Smith (1960), Ross and Smith (1961), and Cook (1965). All of the tuffs in the Sierra de las Uvas ash-flow field appear to be simple cooling units throughout most of their extent. Locally, tuffs 3 and 6 possess some characteristics of compound cooling units. Tuffs 5 and 6 are very similar in outcrop and hand specimen appearance. Otherwise the tuff members can be identified easily in the field. Thicknesses of the ash-flow tuffs do not represent original, true thicknesses because the upper, non-welded zones were mostly eroded before the next unit was deposited.

If the percentage of the tuff consisting of phenocrysts varies widely, the quartz-alkali feldspar-plagioclase ratios of phenocrysts are a useful petrographic characteristic for correlating units (O'Connor, 1963). Modal analyses (1,000 points counted on each thin section) of the Bell Top ash-flow tuffs are plotted as percentage of total phenocrysts rather than percentage of the rock in Figure 3. Although there is a general separation into different areas of the analyses of each tuff, there is much overlap. Figure 4 shows the ranges and means of quartz, sanidine, plagioclase, biotite, hornblende, and total phenocrysts as percentage of the rock. In general, ash-flow tuffs in the Sierra de las Uvas field can be correlated readily using both these parameters. In addition, tuff 5 is distinguished by lack of shards, whereas all the other tuffs contain abundant shards.

Tuff 2

Tuff 2 is a pale red-purple to grayish orange-pink vitric ash-flow tuff. The weathered surface is generally a moderate brown. It has a well developed eutaxitic texture and locally contains spherulitic zones. Small (1 to 3 mm), white pumice fragments give the tuff a streaked and mottled appearance. Similar sized reddish-brown rock fragments vary in abundance from a trace to 3 percent. Small (less than 1 mm) phenocrysts of plagioclase, sanidine, biotite, and quartz make up less than 5 percent of the tuff. They are all rounded crystal fragments and the biotite has been oxidized, with dark borders. Axiolitic shards in a matrix of glass "dust" characterizes the groundmass. The shards generally have colorless rims and pale-brown centers. Minute voids between shards account for much of the porosity, which varies from 1 to 6 percent; in pumice-rich zones porosity ranges up to 16 percent.

Thickness of tuff 2 where exposed, is 'about 70 to 90 ft. It does not crop out far from Bell Top Mountain (Fig. 1) and probably was never an extensive sheet. Its source was probably in the eastern Sierra de las Uvas.

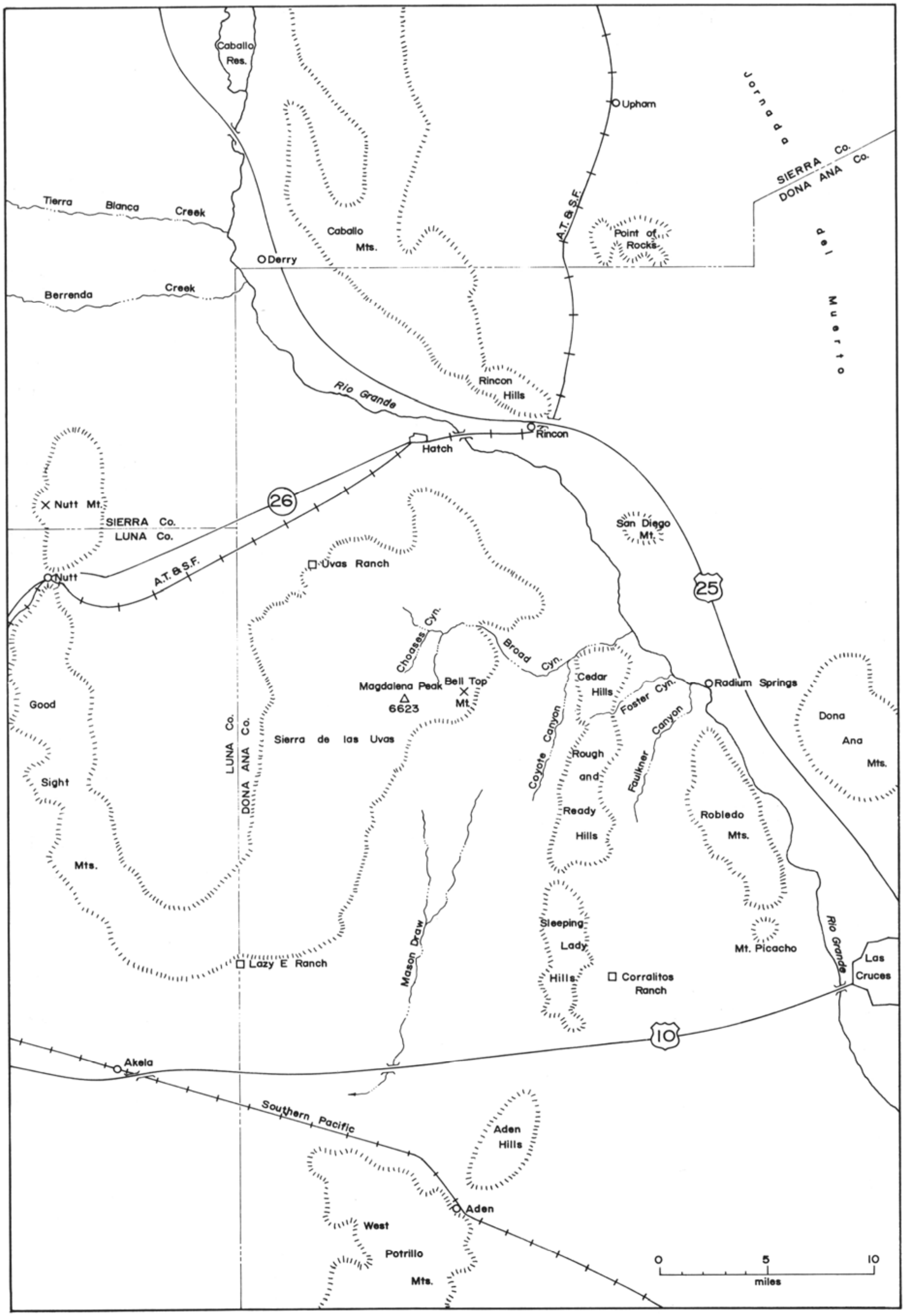

Figure 1. Index map of the Sierra de las Uvas ash flow field.

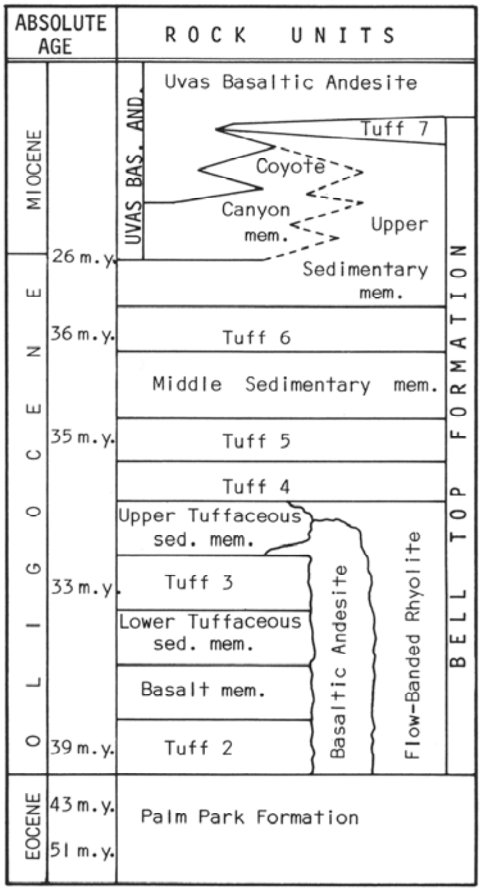

Figure 2. Diagrammatic stratigraphic chart of the Bell Top Formation. The ages are K-Ar determinations run by Geochron Laboratories. Ages of tuffs 2, 5, and 6 were determined from biotite samples; tuff 3 age was determined on a whole rock sample.

Tuff 3

Tuff 3 is generally a grayish orange-pink, poorly to moderately highly welded, vitric ash-flow tuff containing up to 20 percent pale-red pumice fragments. In the Sierra de las Uvas

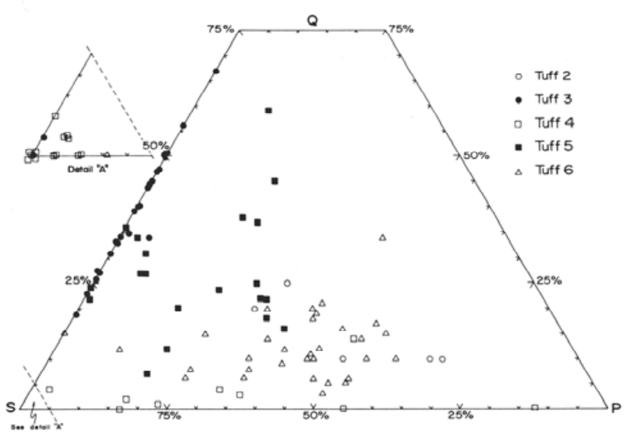

Figure 3. Modal analyses of Bell Top Formation tuffs. Mineral contents are in volume percent of total phenocrysts calculated to 100 percent. P (plagioclase), Q (quartz), S (sanidine).

the upper and lower parts are very porous and even the more indurated central part, which has columnar joints on cliff faces, is slightly porous. It is grayish-red, and generally denser in the Cedar Hills (Fig. 1). The maximum thickness of tuff 3 is 350 ft, measured in the southeastern Sleeping Lady Hills. Its composition and texture are more variable there than elsewhere in the region. The upper part is pale-red, moderately welded, and pumice-free. This is gradational downward into similar tuff with small (3 mm avg.) darkened pumice fragments. Gradationally below this is a very pale-orange, moderately welded tuff with abundant, darkened (grayish-red), slightly flattened pumice fragments up to 15 mm long. Below this zone, the pumice is well flattened in a pale-red tuff. This in turn grades downward to an orange-pink tuff containing up to 20 percent dark reddish-brown, equant pumice and rock fragments. The poorly- to non-welded basal part is grayish-pink with abundant light-gray pumice lumps. Thickness of tuff 3 decreases to the west and northwest, and does not occur to the east.

Small, rounded phenocrysts of sanidine and quartz make up less than 5 percent of the tuff. Only 2 of the 28 thin sections examined contained even a trace of plagioclase phenocrysts, and only 11 sections contained oxidized biotite flakes (up to 0.4 percent). Rock fragments vary in abundance from a trace to 5 percent, averaging about 1.5 percent. Colorless glass, and partly devitrified axiolitic shards in a matrix of glass "dust" and minute crystal fragments, less than 0.05 mm in size, characterize the groundmass.

The Cedar Hills vent zone (Seager, 1973; Seager and Clemons, 1975) apparently was the source of tuff 3. Dikes and intrusive masses of tuff 3 are exposed in the northern Cedar Hills. Near the head of Foster Canyon (Fig. 1), one dike of tuff 3 and several possible intrusive bodies of tuff 3 intrude part of the upper tuffaceous sedimentary member (Fig. 2). This member overlies tuff 3 along the sides of the canyon. One explanation for this anomalous situation is that tuff 3 throughout the region is generally a multiple-flow simple cooling unit. It may be a compound cooling unit in the Sleeping Lady Hills. This would also necessitate the upper tuffaceous sedimentary member to have interfingered with tuff 3.

Tuff 4

Tuff 4 is a grayish red-purple, densely welded, vitric-crystal ash-flow tuff. Aside from its dark color, its most distinctive characteristic is the content of abundant, darkened, flattened, pumice fragments up to 1 ft long. Length to thickness ratios of the fragments are about 6:1. The upper and lower parts are much more porous and crumbly tuff. Euhedral to subhedral phenocrysts of sanidine and plagioclase comprise up to 15 percent of the tuff. A few of the crystals are slightly rounded by resorption effects. A trace up to 1 percent of slightly oxidized biotite is present in all thin sections examined. Quartz is present in only about one third of the sections, and in amounts of less than 0.5 percent of the tuff. The groundmass is composed of large, colorless to very pale-brown, devitrified shards, some with dark brown borders, in a matrix of magnetite, crystal fragments, and glass.

Maximum thickness (about 180 ft) of tuff 4 is in the northern Cedar Hills. From there it thins to 10 ft in the Rincon Hills (Seager and Hawley, 1973), 60 to 90 ft in the Sierra de las Uvas, and 20 ft in the southern Sleeping Lady Hills. It pinches out around the west sides of the rhyolite domes and flows of

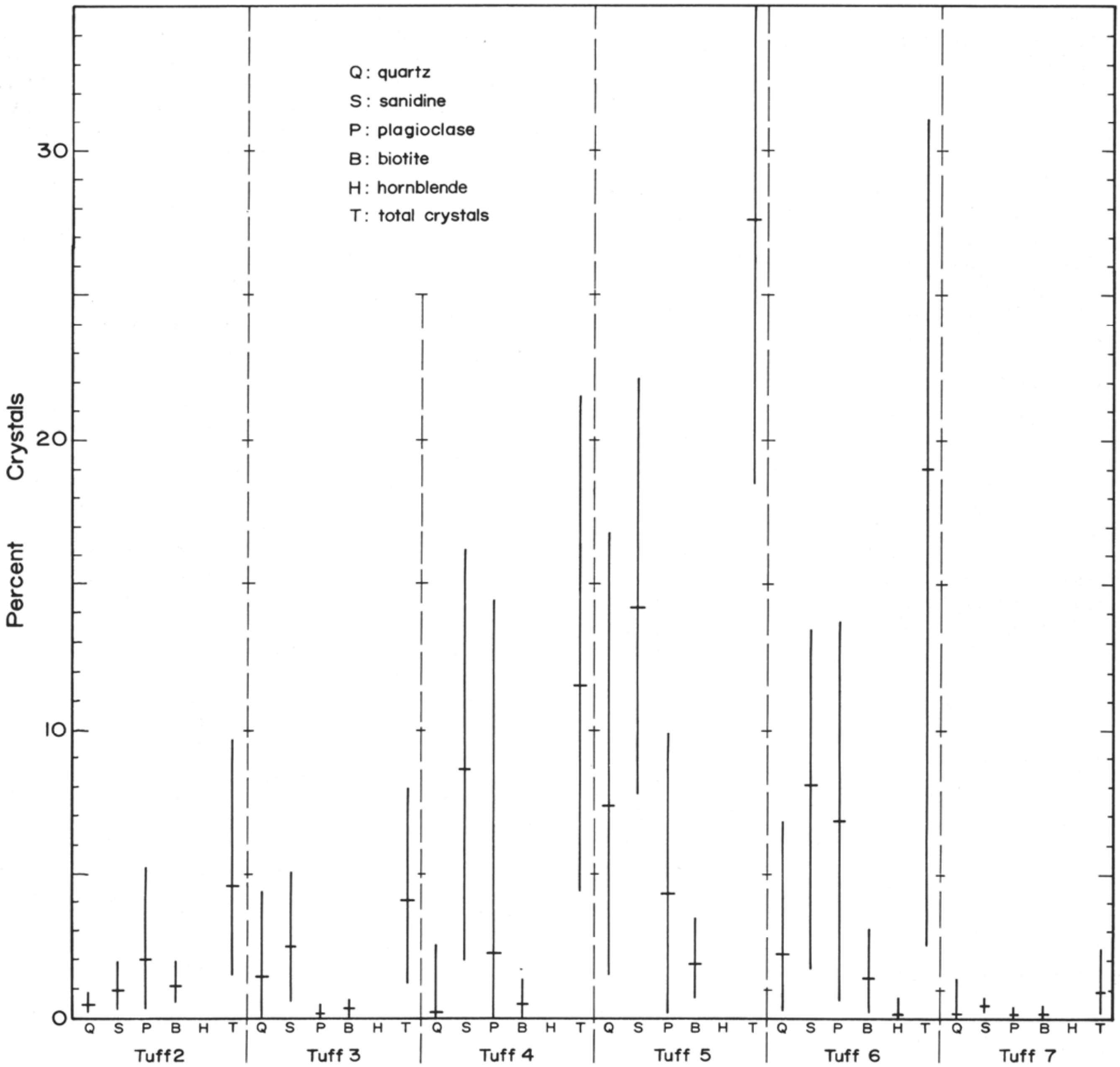

Figure 4. Abundance of various crystals in Bell Top Formation tuffs; calculated as percent of total rock. Length of vertical lines show ranges; short horizontal lines represent means.

the southern Cedar Hills and Rough and Ready Hills and is not present in these areas, although its normal stratigraphic horizon is well exposed in many places. The source for tuff 4 may have been in the northern Cedar Hills near Broad Canyon (Fig. 1).

Tuff 5

Tuff 5 is a pale red-purple to grayish-pink, moderately to highly welded, crystal-vitric ash-flow tuff. Abundant white, equant, pumice fragments less than an inch in diameter characterize the upper part. They are flattened and up to 3 in. long in the middle part; then decrease in size and abundance downward and are scarce in the lower part of the tuff. Partly resorbed and embayed subhedral to anhedral fragments (0.5 to 4 mm) of sanidine, quartz, plagioclase, and biotite comprise 19 to 39 percent of the tuff; averaging 27 percent. Biotite is more oxidized in the upper part of the tuff. Doubly terminated quartz dipyramids are abundant in anthills built from tuff 5. The groundmass is characterized by a microcrystalline mosaic of minute crystal fragments, magnetite, glass, and a scarcity of visible shards. The few shards present are generally colorless, axiolitic, with brownish centers.

Tuff 5 attains its maximum thickness of 300 ft in the vicinity of Choases Canyon (Fig. 1). It thins to 120 ft in the Cedar Hills, 55 ft in the Rincon Hills (Seager and Hawley, 1973), 10 to 15 ft at Point of Rocks, and 20 to 40 ft in the southern Caballo Mountains. It is not present in the Rough and Ready Hills, Sleeping Lady Hills, or Good Sight Mountains. It origin ally covered about 1,400 sq mi in the Good Sight-Cedar Hills depression. The source may have been in the northeastern Sierra de las Uvas.

Tuff 6

Tuff 6 resembles tuff 5 in megascopic appearance. Thin section examination shows that it differs in several aspects: 1) its phenocryst content is slightly lower (averaging 19 percent); 2) the average content of quartz and sanidine are lower than in tuff 5, whereas plagioclase is higher; 3) the groundmass contains abundant axiolitic shards; and 4) a trace to 0.6 percent hornblende phenocrysts are present in most of the tuff 6 sections. In the Sierra de las Uvas, the upper 5 to 10 ft of tuff 6 is a darker colored, dense rock which breaks with smooth, subconchoidal fracture.

The basal unit of tuff 6 at the southern end of the Sleeping Lady Hills is denser than normal, richer in phenocrysts, and deficient in pumice fragments. This unit has not been observed at other localities of tuff 6 outcrops. It may indicate that tuff 6 is a compound cooling unit there and a simple cooling unit to the north and northwest. If this is correct, it would indicate that the source of tuff 6 was probably in this area and that the early ash-flow was not as extensive as the later one. Although the greatest measured thickness (100+ ft) of tuff 6 is also in the southern Sleeping Lady Hills, I hesitate to use this as evidence of a nearby vent due to the general variability of tuff 6 thicknesses in the Sierra de las Uvas field. Measured sections have shown thicknesses of 100 ft southeast of Uvas Ranch (Fig. 1), 25 ft in Choases Canyon, 65 ft west of Magdalena Peak, 28 ft north of Bell Top Mountain, and 35 ft in the Rincon Hills (Seager and Hawley, 1973). It thins to about 15 to 20 ft at Point of Rocks and 20 to 30 ft in the southern Caballo Mountains; it is missing in the northern Cedar Hills. Tuff 6 also covered about 1,400 sq mi of the Good Sight-Cedar Hills depression.

Tuff 7

Tuff 7 is a light-gray, dense, vitric tuff that breaks with a smooth, subconchoidal fracture. It contains less than 1 percent sanidine, quartz, plagioclase, and biotite phenocrysts in a pale yellowish-brown groundmass of axiolitic shards, minute crystal fragments (less than 0.03 mm), magnetite, and glass. Its maximum thickness of 20 ft was measured about 1 mi northwest of Bell Top Mountain. It crops out discontinuously in the northern Sierra de las Uvas and Rincon Hills, generally not exceeding 5 to 8 ft in thickness. Its thickness ranges from 0 to 15 ft in the southern Caballo Mountains. Its origin and source are unknown. Sparse, small-scale cross bedding, observed in the Sierra de las Uvas, and the predominantly shard composition suggests it may be a welded air-fall tuff. However in the southern Caballos, flattened pumice fragments up to 2 in. long appear more typical of an ash-flow tuff.

Cedar Hills Rhyolite

Circular to elongate domes, dome complexes, and short, stubby flows of flow-banded rhyolite form most of the high peaks in the Cedar and Rough and Ready Hills. Two smaller domes and a dike crop out 4 mi west of the Sleeping Lady Hills. Flow-banding in the pale-red, pale grayish-red, pale-brown, and grayish-red rocks is produced by color streaking and platy jointing parallel to flow directions. A pale yellowish-brown, flow-banded microvitrophyre crops out in upper Foster Canyon. Very dusky-red to black vitrophyre crops out around the margin of a dome in the eastern Cedar Hills and at the base of flows and intrusive margins in the Rough and Ready Hills.

Phenocryst content ranges from less than 1 percent to 18 percent, with the rhyolite in the Rough and Ready Hills containing the higher amounts. Phenocrysts, ranging in size from 0.3 to 2 mm, are predominantly sanidine, with oligoclase and biotite in lesser amounts. Plagioclase is more abundant in some of the rhyolite in the western Cedar Hills. In thin sections, fluidal texture is shown by alignment of feldspar laths and microliter in a light-brownish, cryptocrystalline to vitric matrix. Two chemical analyses are shown in Figure 5.

Microvesicular to vesicular, lithophysal, and spherulitic textures are common in many of the rocks. Chalcedony-lined geodes have formed in the flow-banded rhyolite at several locations, notably in secs. 11 and 22, T. 21 S., R. 2 W.; and west side of sec. 11, T. 22 S., R. 2 W.

Oxide Wt. Percent	SAMPLES													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	78.2	48.5	74.1	73.2	56.54	56.73	71.8	73.4	70.1	67.1	72.9	75.0	78.6	75.9
TiO_2	0.23	2.54	0.07	0.08	1.83	1.79	0.28	0.16	0.21	0.40	0.21	0.16	0.20	0.18
Al_2O_3	10.9	15.9	11.7	12.0	15.97	16.24	13.9	13.2	13.1	16.0	13.9	12.6	12.6	11.3
FeO	1.0	12.3	1.0	0.86	8.28	7.46	0.86	0.57	0.71	1.43	0.71	0.57	1.0	1.0
MnO	0.03	1.76	0.02	0.01	0.15	0.15	0.02	0.02	0.04	0.06	0.04	0.04	0.02	0.04
MgO	0.53	6.23	0.07	0.23	4.10	3.51	0.16	0.03	0.13	0.46	0.40	0.17	0.20	0.20
CaO	0.70	7.84	0.08	0.20	6.47	5.68	0.21	0.17	0.28	1.04	0.31	0.36	0.45	0.45
Na_2O	2.6	2.9	3.4	2.8	4.39	4.59	4.5	4.0	4.0	4.3	2.8	3.3	3.0	2.7
K_2O	4.9	1.0	5.4	5.5	2.41	2.56	5.3	5.5	5.5	5.1	5.2	4.7	4.5	4.7
P_2O_5	0.05	0.95	0.05	0.10	0.0	0.13	0.05	0.05	0.10	0.35	0.20	0.20	0.10	0.10

Figure 5. Major-oxide composition of Bell Top Formation volcanic members. Sample 1, tuff 2; 2, basalt; 3, lower tuff 3; 4, upper tuff 3; 5 and 6, basaltic andesite; 7 and 8, Cedar Hills rhyolite; 9, lower tuff 4; 10, upper tuff 4; 11, lower tuff 5; 12, upper tuff 5; 13, lower tuff 6; 14, upper tuff 6.

Basaltic Andesite

Plugs, dikes, and short flows of basaltic andesite (Fig. 2) are exposed in an east-trending zone from just east of the Lazy E Ranch (Fig. 1) to the Sleeping Lady Hills. Its trend swings northeast in the Sleeping Lady Hills and is apparently terminated by a southern extension of the Cedar Hills vent zone. Similar andesite crops out 2 mi north of Bell Top Mountain and in the Cedar Hills.

The basaltic andesite is typically a finely crystalline, dark-gray to black rock. Flow rock generally possesses well-developed platy joints, but in the Cedar Hills it is more massive and vesicular. Reddish-brown cinder beds cropping out in the west-central slope of the Sleeping Lady Hills are part of a cinder cone vent.

Thin sections show that less than 3 percent of the rock is composed of small (0.5 to 3 mm), blocky, zoned (An_{40-55} plagioclase phenocrysts. These are in a pilotaxitic or intersertal matrix of plagioclase (An_{30-45}) laths, partly resorbed pyroxene, oxidized hornblende and biotite, magnetite, and glass. Microvesicles (less than 1 mm, avg. 0.04 mm) comprise up to 10 percent of some sections. Two chemical analyses are included in Figure 5.

Basalt

A finely crystalline, grayish-black, olivine-bearing basalt (Fig. 2) crops out in the eastern Sierra de las Uvas and Cedar Hills. In the Sierra de las Uvas it consists of a single flow ranging from zero to 62 ft thick. South of Foster Canyon it contains several flows and interbedded muddy conglomerate with a total thickness of 150 ft. Therefore, the source is believed to have been in the Cedar Hills.

Olivine phenocrysts 0.5 to 2 mm in diameter comprise a trace to 4 percent of the rock. They are partly resorbed and show minor alteration to iddingsite and fibrous aggregate (serpentine and chlorite?). Some sections have an intergranular or subophitic texture. Others are intersertal with labradorite (An_{65-70}) laths up to 0.15 mm long, smaller pyroxene grains, magnetite, and brownish glass. One chemical analysis is included in Figure 5.

Sedimentary Members

Four tuffaceous sedimentary members are included in the Bell Top Formation. In ascending order they are: lower tuffaceous sedimentary member, upper tuffaceous sedimentary member, middle sedimentary member, and upper sedimentary member. The Coyote Canyon member of the Uvas Basaltic Andesite is in part correlative to the upper sedimentary member (Fig. 2). These members would have had less confusing names if the geologic study of the whole field had been completed before any of the individual geologic quadrangle maps had been published. All sedimentary members are not present at any one locality.

Lower tuffaceous sedimentary member

The lower tuffaceous sedimentary member consists of light-gray and orange-pink, air-fall tuff; granular, sandy mudstone; tuffaceous breccia; and pebble-cobble conglomerate. It contains abundant glass shards and montmorillonitic clay in the finer-grained beds. Small pumice fragments, angular basalt clasts, and rounded pebbles and cobbles of Palm Park Formation rocks are common in the unit. Total thickness generally ranges from 30 to 100 ft, thinning to the west away from its source in the Cedar Hills vent zone.

Upper tuffaceous sedimentary member

The upper tuffaceous sedimentary member is of similar lithology. The more tuffaceous zones are porous, friable, and poorly bedded. Some zones contain 2- to 10-inch beds with shaly partings and well developed crossbeds. Most are poorly sorted, tuffaceous volcanic arenites, composed of fresh angular quartz, sanidine, plagioclase, pumice, and ash-flow tuff fragments in a matrix of shards and clay.

Paleozoic carbonate cobbles and boulders, probably erupted with the tuff, are abundant in the lower part of the member in upper Foster Canyon. Opalized palm wood fragments are present in lesser amounts. Accessory tuff 3, basalt, and andesite fragments increase in abundance up through the member until they comprise about 30 percent of the unit. The uppermost beds in Foster Canyon are predominantly pumice, shards, and microvitrophyre fragments. Interbedded blocks and slabs up to 100 ft long of tuff 3 and basalt are included in the upper part of the member at this same locality. Total thickness generally ranges from 30 to 300 ft, but about 800 ft is present in upper Foster Canyon. It thins to the west away from its source in the Cedar Hills vent zone.

Middle sedimentary member

The middle sedimentary member is light-colored, tuffaceous siltstone and sandstone with conglomerate lenses. Pale yellow-brown to pale grayish-orange siltstone and sandstone form poorly-bedded, 30 to 40 ft thick massive units interbedded with thin- to medium-bedded units. The rocks are poorly sorted, siliceous volcanic arenites composed of angular plagioclase, quartz, sanidine, and ash-flow tuff fragments in a matrix of devitrified shards and clay. They are poorly cemented with calcite and zeolites. Conglomerate lenses are mostly cross-bedded channel fills of well-rounded ash-flow tuff pebbles and cobbles enclosed in poorly-sorted tuffaceous sand matrix. Total thickness ranges from 50 to more than 200 ft, increasing toward the axis of the Good Sight-Cedar Hills depression.

Upper sedimentary member

Light-gray to reddish-brown tuffaceous sandstone and conglomerate comprise the upper sedimentary member. Lithologically it resembles the middle sedimentary member but contains more biotite, ash, and pumice fragments, more low-angle crossbeds, and more and thicker conglomerate beds. Cobble and boulder size rounded clasts of tuffs 3, 4, 5, and 6, vesicular basaltic andesite, and flow-banded rhyolite are abundant. Two 2-ft thick vitric tuff beds are separated by 15 ft of medium-grained sandstone and pebble conglomerate about midway in the member, 2 mi north of Bell Top Mountain. Total thickness in the Sierra de las Uvas ranges from 200 to 500 ft. Thickening coincides with an increase in number of conglomerate beds and greater quantity of flow-banded rhyolite debris toward the southeast. Thus the source area was most likely the area of flow-banded rhyolite domes in the Cedar and Rough and Ready Hills.

SUMMARY

The petrogenesis of the Bell Top Formation volcanic rocks is problematic. Limited chemical information from randomly collected samples, shown in Figures 5 and 6 do not clearly

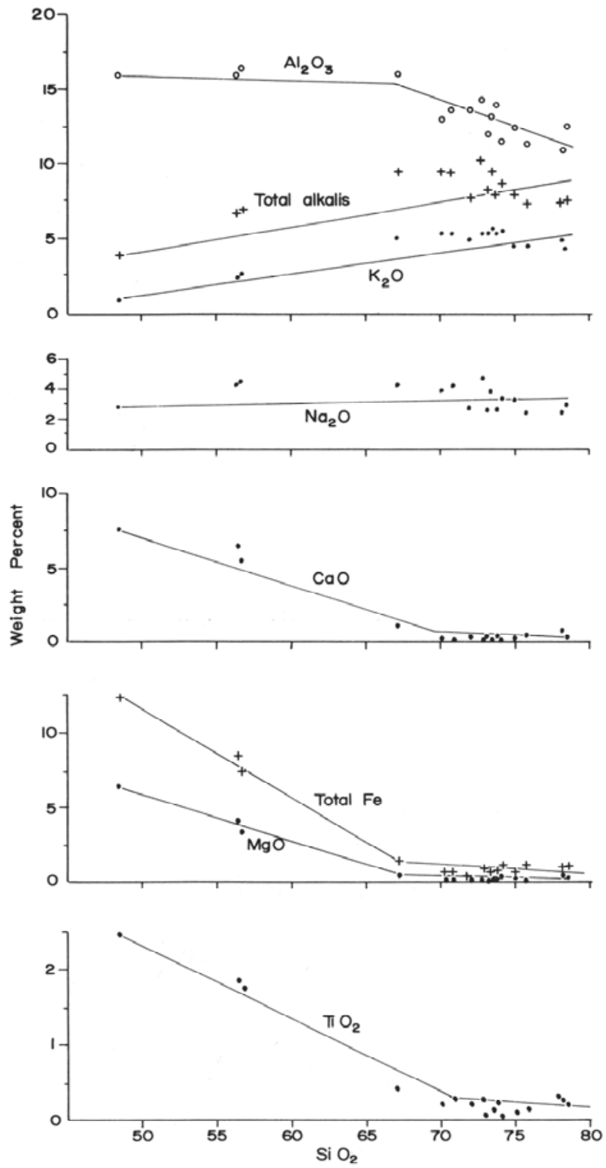

Figure 6. Silica-variation diagram for Bell Top Formation volcanic rocks.

show any definite fractionation trends, close affinities between the different calc-alkalic rock types, or consistent evidence of an "inverted magma chamber" in the ash-flow tuffs. Usually chemical affinities of different rock types may be best illustrated by a silica-variation diagram in which all oxides define linear trends with little scatter. The trends of all oxides except Na and K for the Bell Top rocks (Fig. 6) have a change in slope between the andesite and rhyolite. Elston and others (1968) noted a kink in the variation diagrams of rocks from the Mogollon field also at about 66 percent $Si0_2$, corresponding to the appearance of sanidine, quartz, and biotite phenocrysts. Sodium only varies in weight percent from 4.0 to 4.8 in tuff 4, flow-banded rhyolite, and basaltic andesite as silica varies from 56.5 to 73.5 percent. In the same rocks potassium varies from 2.4 to 5.5. Lipman (1965) indicated that the chemistry of vitric and devitrified tuffs may be significantly altered by ground water leaching, thus causing increase of Na and SiO_2, and decrease of K, Mg, Ca, and Al in crystalline rocks relative to their vitric parts.

Crystal content of the ash-flow tuffs provides some evidence for differentiation of a single parent magma (Figs. 3, 4). Total crystal content increases in successively younger tuffs. Tuff 7 may represent magma depleted in crystals by the voluminous eruptions of tuffs 5 and 6. Tuff 3 is relatively rich in quartz and contains no plagioclase, whereas plagioclase increases in abundance in tuffs 4, 5 and 6. Biotite is more common in the younger tuffs and only tuff 6 contains even a trace of hornblende. Some of the deviation from a uniform trend may be due to eruptions of basalt between tuffs 2 and 3, and basaltic andesite between tuffs 3 and 4.

Field relations suggest that the olivine-bearing basalt, tuff 3, basaltic andesite, and Cedar Hills rhyolite were erupted from the Cedar Hills vent zone. Their ages are within a maximum of 4 m.y. of each other and may be within 1 m.y. or less. Therefore they probably all came from the same magma. Tuff 4 may have had its source in the northern end of the Cedar Hills vent zone. One sequence which might be postulated is: 1) eruption of basalt from deep part of the magma chamber left a more siliceous magma enriched in volatiles; 2) this was in part responsible for a nuee ardente type eruption of tuff 3 from the upper part of the magma; 3) reactivation of the deep conduits might account for the basaltic andesite from magma not as mafic as the earlier basalt; 4) magma in the upper levels, degassed by tuff 3 eruption(s), then formed the abundant flow-banded rhyolite dome complexes which temporarily plugged the vents; 5) crystals formed in the remaining siliceous magma until volatiles accumulated and pressures increased to cause another nuee ardente eruption of tuff 4.

Tuffs 2 and 5 may have been erupted from vents in the eastern Sierra de las Uvas. Possibly tuff 2 came from the "Cedar Hills" magma chamber early in its development, and thus would account for part of the remaining mafic part to be later erupted as basalt. Sources of tuffs 6 and 7 are unknown at this time.

There was a general leveling of topography during deposition of the Bell Top Formation, even to the extent of filling the subsiding Good Sight-Cedar Hills depression. Each of the successively younger tuffs is more extensive than its predecessor, culminating in tuff 6, which originally spread over about 1,400 sq mi. Tuff 7 (with only a maximum thickness of 20 ft), although probably not as extensive as tuff 6, crops out sporadically for 30 miles from near Bell Top Mountain northward to the Caballo Mountains where it is still 15 ft thick.

The tectonic history of the Sierra de las Uvas tuff field is described by Seager (see paper in this guidebook).

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