VOLCANOES OF ARIZONA

Uinkaret, 277
San Francisco, 278
Sunset Crater, 280
Mormon, 282
Hopi Buttes, 283
Springerville, 285
San Carlos, 286
Sentinel Plain, 287
Geronimo, 287

UINKARET
Arizona

Type: *Monogenetic cones and flows*
Lat/Long: *36.5°N, 113.1°W*
Elevation: *1,555 m*
Eruptive History: *1.2 Ma to 12,500 yr BP*
Composition: *Basanite, alkali olivine basalt, hawaiite, tholeiitic basalt*

Late Cenozoic volcanism extends across a broad region from southwestern Utah to the north rim of the Grand Canyon in western Arizona. In the Grand Canyon region, lavas are strongly alkalic, whereas transitional varieties and tholeiitic basalt, together with minor andesite, occur further north in Utah. The lavas lie astride the Basin and Range–Colorado Plateau transition zone, which is characterized by major Late Cenozoic normal faulting.

The relative ages of lavas can be readily established from morphological relations, with the oldest capping mesas or buttes, and the most recent occupying present drainage valleys. Many of these young flows have no soils developed on them and have well preserved flow features and associated cinder cones. The youngest measured age is 12,500 yr BP for a young flow at the Grand Canyon.

The Uinkaret volcanic field at the north rim of the Grand Canyon in the Grand Canyon National Monument is especially noteworthy. The lavas are alkalic and commonly contain peridotite inclusions. **Vulcan's Throne**, a Quaternary cinder cone on the rim of the Canyon, is cut by recent fault movement on the Toroweap fault. Late Cenozoic lava flows have repeatedly flowed down Toroweap Valley and several adjacent valleys into the Grand Canyon, at times forming large lava dams. Flows are exposed on the walls of the Grand Canyon, often interbedded with fluvial and lacustrine sediments, up to 600 m above present river level. Several of the dams are estimated to have been at least 200 m high. The most recent flows in the Grand Canyon have cascaded over the rim of the Esplanade to the river 1,000 m below. Within the river itself is a volcanic neck, **Vulcan's Forge,** 25 m in diameter and rising 15 m above the river.

How to get there: *Volcanic features between St. George, Utah, and Grand Canyon National Mon-*

ument can be reached by an unpaved, scenic route over Mount Trumbull. It is not well suited for passenger cars. A more direct route to the Monument is to proceed east from St. George to Hurricane, then southeast on Utah 59, which becomes Arizona 389. At 8.5 km past Pipe Springs National Monument, turn south on the gravel road to Grand Canyon National Monument (~90 km). There is a campground on the rim of the inner gorge of the Grand Canyon, and a rail descends to the Colorado River. Once you leave paved roads, either at St. George or Arizona 389, there are no services. The round trip from St. George to the Grand Canyon and return via Arizona 389 is ~470 km. A "must" is the excellent guidebook by Hamblin and Best (1970), which includes a detailed road log complete with 23 air photos covering the whole field trip route.

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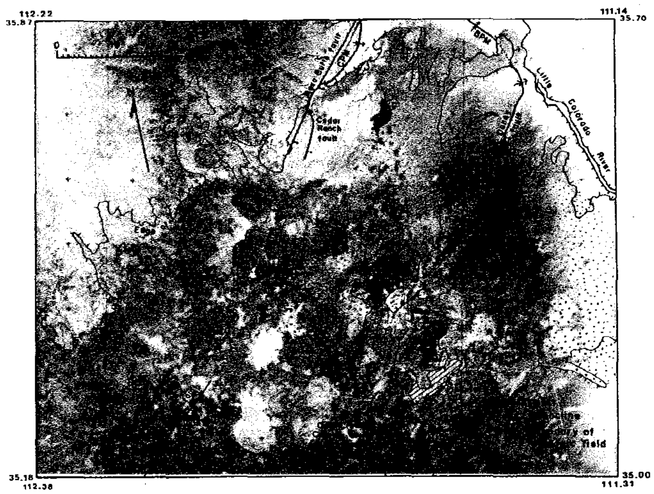
William Nash



SAN FRANCISCO: Major features of San Francisco volcanic field. Major western silicic centers: Bill Williams Mountain (BW), Sitgreaves Mountain (SIT), and Kendrick Peak (KP), with the adjacent trachyte of Bull Basin Mesa (BBT). Major eastern intermediate to silicic centers: San Francisco Mountain (SF) and O'Leary Peak (OLP). Additional dacite domes or dome complexes: Davenport Hill (DAV), Dry Lake Hills (DLH), and Elder Mountain (EM). Additional rhyolite domes: RS Hill (RS), Government Mountain (GM), Slate Mountain (SLT), Hochderffer Hills (HH), White Horse Hills (WH), and Sugarloaf (SGLF). Sunset Crater cinder cone (SC) and related tephra blanket. Area dominated by vents of Brunhes age (stippling). Coconino (CPM) and Black Point (BPM) monoclines. NASA Landsat RBV image E-31041-17154-D.

SAN FRANCISCO
Arizona

Type: *Polygenetic volcanic field with basaltic cones and silicic stratovolcano*
Lat/Long: *35.4°N, 111.75°W*
Elevation: *3,850 m*
Eruptive History: *Episodic eruption from ~ 6 Ma to <1 ka; generally northeast to east progression*
Composition: *Basalt to rhyolite*

The San Francisco volcanic field is one of several dominantly basaltic volcanic fields of late Cenozoic age near the south margin of the Colorado Plateau. The volcanic field, which is predominantly of Pliocene and Pleistocene age, is just north of a broad transition zone between the Colorado Plateau and Basin and Range provinces. K-Ar ages indicate a general northeastward progression of volcanism during the past 15 Ma across the transition zone from central Arizona onto the plateau.

The San Francisco field lavas, ranging in composition from basalt to rhyolite, erupted through Precambrian basement and the overlying kilometer-thick cover of nearly horizontal sedimentary rocks, mostly of Paleozoic age. The volume of volcanic rocks is ~500 km^3; they cover an area of ~5,000 km^2.

Major structural features of the San Francisco field include the high-angle Mesa Butte and Oak Creek Canyon fault systems and the Black Point and Coconino Point monoclines. Some, if not all, of these structures probably had their origins during the Precambrian and have been subsequently reactivated. Late Cenozoic faulting continued until at least 0.5 Ma, but deformation of the lavas has been minimal. Lavas of pre-Brunhes age are locally broken by high-angle faults, generally of small displace-

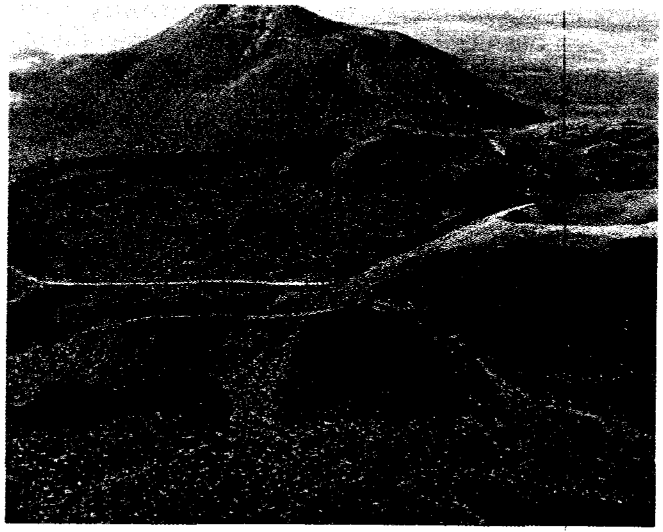
SAN FRANCISCO: San Francisco Mountain, an eroded stratovolcano. Humphreys Peak, the highest point in Arizona, at an elevation of 3,850 m above sea level, is just left of center. A basalt cinder cone is in the middle ground. View is eastward.

ment. With few exceptions the lavas of Brunhes age are not faulted.

Most of the San Francisco field is covered by basalt flows ranging in age from ~6 Ma to <1 ka. Flows erupted from ~600 individual vents, most of which are marked by cinder cones. The basalt is predominantly alkali-olivine basalt and associated plagioclase-rich basalt of hawaiitic composition. Included among the basaltic rocks is basaltic andesite, which has the composition of SiO_2- and K_2O-enriched basalt and commonly contains sieved plagioclase, augite, and olivine and may contain hypersthene amphibole or quartz. Much basaltic andesite was erupted simultaneously from the same vents as alkali-olivine basalt and may be best interpreted as contaminated basalt.

Five conspicuous centers at which eruptions of intermediate to silicic lavas were concentrated occur within the volcanic field. Those in the western part of the field – from southwest to northeast, Bill Williams Mountain, Sitgreaves Mountain, and Kendrick Peak – coincide approximately with the Mesa Butte fault zone. Several smaller silicic domes occur along the same trend. K-Ar ages summarized from the western centers and the nearby domes suggest northeastward progression of eruptive activity:

Volcanic center	Period of activity (Ma)
Bill Williams Mountain	4.2-2.8
Sitgreaves Mountain	2.8-1.9
RS Hill	2.9
Government Mountain	2.1
Kendrick Peak	2.7-1.4
Slate Mountain	1.9-1.5



SAN FRANCISCO: Part of Sunset Crater, Bonito lava flow (produced in Sunset Crater eruption), and O'Leary Peak. Black cinders, deposited during an early phase of the Sunset eruption, mantle pre-Sunset cones and are in turn overlain by the Bonito flow. View is northward.

The western centers consist of closely spaced silicic domes and some viscous flows. **Bill Williams** Mountain, the oldest of the western centers, is composed primarily of andesite and dacite. **Sitgreaves** Mountain consists almost entirely of rhyolite domes. **Kendrick Peak** consists dominantly of dacite and rhyolite domes and flows that were intruded and partly buried by andesite. Trachyte and benmoreite that erupted from the west flank of Kendrick Peak, and scattered basaltic vents that overlie rocks of the western silicic centers, are interpreted as younger and not genetically related to the western-center magma systems.

Two additional intermediate to silicic centers, San Francisco Mountain and **O'Leary Peak** in the eastern part of the volcanic field, may have been localized by the Oak Creek Canyon and Doney fault zones, and are mostly younger than the western centers. The upper part of San Francisco Mountain is a truncated stratovolcano built primarily of porphyritic andesitic and dacitic flows and pyroclastic deposits erupted from ~1.0 to 0.4 Ma. These lavas overlie still older dacite and rhyolite, however, that are as old as 2.8 Ma.

Except for a small volume of plagioclase-rich basalt, basaltic lavas are conspicuously absent within San Francisco Mountain, even though basalt of the same general age was erupted abundantly to the west, north, and east. This virtual absence of basalt may reflect the presence of an evolved magma chamber beneath the stratovolcano that blocked ascent of basaltic magma to the surface.

Trachyte of Bull Basin Mesa, erupted just west of Kendrick Peak, is related by age and composition to a group of benmoreite domes, cinder cones, and flows characterized by high Na_2O contents (~5.0-6.5%) and young ages (1.6-0.33 Ma). The trachyte and these benmoreites occur northwest, west, and south of San Francisco Mountain. Their locations roughly define an arc about the western part of the stratovolcano, and benmoreite xenoliths in a basaltic cinder cone extend the arc north of San Francisco Mountain. Possibly the trachyte and benmoreites mark the western limit of the San Francisco Mountain magma chamber.

The **Sugarloaf** rhyolite dome erupted on the northeast flank of San Francisco Mountain ~0.22 Ma. At about the same time, the O'Leary Peak volcanic center, which includes a pair of dacite-porphyry domes, several dacite flows, an andesite flow, and small rhyolite domes, erupted ~9 km to the northeast. One of the dacite-porphyry domes has been dated at 0.24 Ma and a dacite flow at 0.17 Ma. The O'Leary Peak volcanic center and Sugarloaf are the youngest major silicic eruptives in the San Francisco volcanic field.

A deep linear valley transecting the northeast quadrant of San Francisco Mountain was formed between 0.4 Ma, when the youngest unit of the composite cone was erupted, and 0.22 Ma, when Sugarloaf dome was emplaced as the valley's northeast end. After the Sugarloaf eruption, glaciation further sculptured the valley. Although erosion was important in forming the valley, it seems likely that the erosion was localized by collapse of the northeast quadrant of the volcano. The valley, the aligned vent systems of O'Leary Peak, Sugarloaf, the San Francisco Mountain stratovolcano, and a well-defined, linear aeromagnetic low are all colinear and thus may have formed under the influence of common structural control.

K-Ar dating and paleomagnetic measurements show that eruptive activity at intermediate and silicic volcanic centers was broadly coeval with nearby basaltic volcanism. Furthermore, the predominant age of the surface volcanic rocks increases westward and southwestward. Thus, Brunhes-age lavas, comprising much of San Francisco Mountain, all of the O'Leary Peak center, and >200 basalt cinder cones with their related flows, occur only in the eastern half of the volcanic field. The western half of the volcanic field is underlain by Matuyama and pre-Matuyama lavas. Most are of Matuyama age, but pre-Matuyama lavas dominate in the far southwestern parts at Bill Williams Mountain and among the nearby, southwesternmost basalt cones and flows.

The youngest (<0.2 Ma) basaltic lavas occur north and east of San Francisco Mountain. The most recent eruption, which began ~1065 A.D., produced the Sunset Crater cinder cone, three lava flows, and an extensive air-fall tephra sheet.

How to get there: *The San Francisco volcanic field is in north-central Arizona; Flagstaff is at its southern border. US Interstate 40 passes along the southern edge of the volcanic field, and US Highways 180 and 89, and Arizona Highway 64 transect the volcanic field. Secondary roads, mostly unpaved, provide good access to almost all the San Francisco field.*

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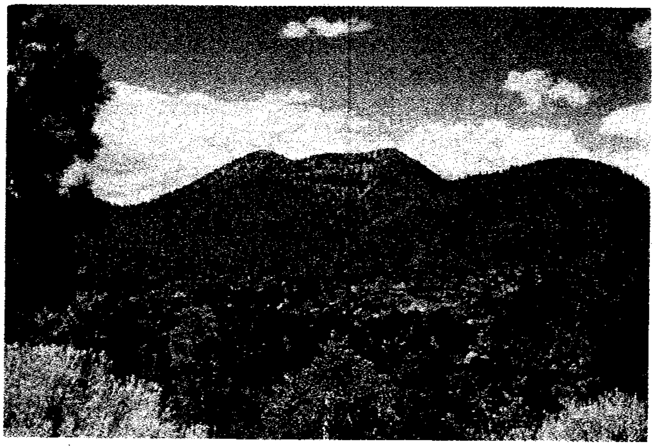
Edward W. Wolfe

SUNSET CRATER
Arizona

Type: *Scoria cone*
Lat/Long: *35.37°N, 111.50°W*
Elevation: *2,447 m*
Height: *300 m*
Volcano field diameter: *60 km*
Eruptive History: *Formed 1064?-1068 A.D.*
Composition: *Alkali olivine basalt*

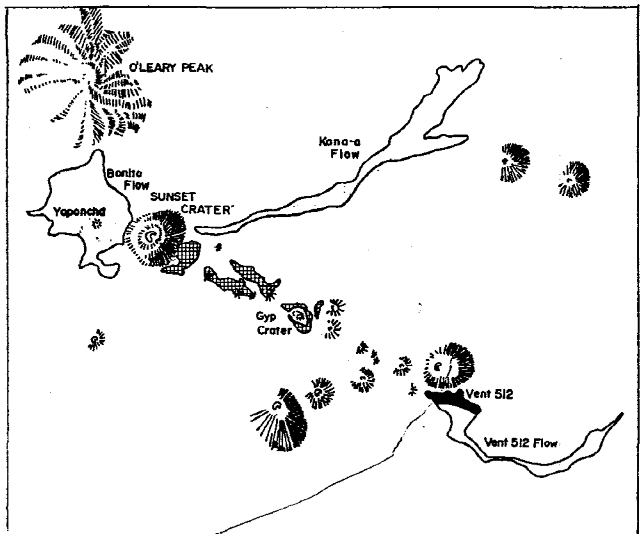


SUNSET CRATER: Profile view provided by Peter Mouginis-Mark.

Sunset Crater is one of the youngest scoria cones in the contiguous United States. The cone is named for the topmost cap of oxidized, red spatter which makes it appear bathed in the light of the sunset. In the 1920s, H. S. Colton saved the cone from severe damage by averting the attempt of a Hollywood movie company to blow it up in order to simulate an eruption. This led to the establishment of the National Monument at Sunset Crater.

The Sunset eruption products are a classic example of monogenetic strombolian volcanism. The eruption began with the opening of a 15-km-long fissure, accompanied by curtain of fire activity and the growth of a small lava flow at the southeast end. Strombolian fountaining then localized near the northwest end and Sunset scoria cone grew, with the simultaneous deposition of a widespread scoria fall layer. At the same time the 11-km-long Kana-a lava flow issued from the cone. This was followed by further cone building and the production of the Bonito lava flow. This flow may have come from the base of the cone, as it has rafted portions of the cone on its surface. The last phase of the eruption featured low-level fountaining that repaired the the cone and deposited the cap of scoria and spatter, which oxidized bright red due to retained heat.

The Sunset event had a severe effect on the Sinagua Indians living in the area at the time, leading to a temporary exodus from the region. Anthropologists accept an unpublished model of the duration of the eruption based on archeomagnetic data. This proposes that the eruption



SUNSET CRATER: Map of Sunset Crater area (Pillies, 1979).

lasted for 100-200 yr, with various phases occurring spasmodically over this period. Such a long, drawn-out eruption is unprecedented. Volcanologic studies of strombolian eruptions, including Sunset, suggest that a duration of a few years is more realistic. The age of the eruption is known from an archaeological site in the vicinity of the crater.

Unusual features of the Sunset eruption products are the comparatively large volume for a strombolian event (~3 km^3 equally shared between the scoria cone, scoria fall, and lava flows) and the wide, sub-plinian dispersal of the fall units, implying a high mass discharge rate of magma. Partly because of these factors, Sunset Crater falls at the upper end of the size range of scoria cones found on Earth.

How to get there: *From US Route 66 in Flagstaff take US Route 89 north toward Cameron. After ~15 km look for the right turn for Sunset Crater National Monument.*

References

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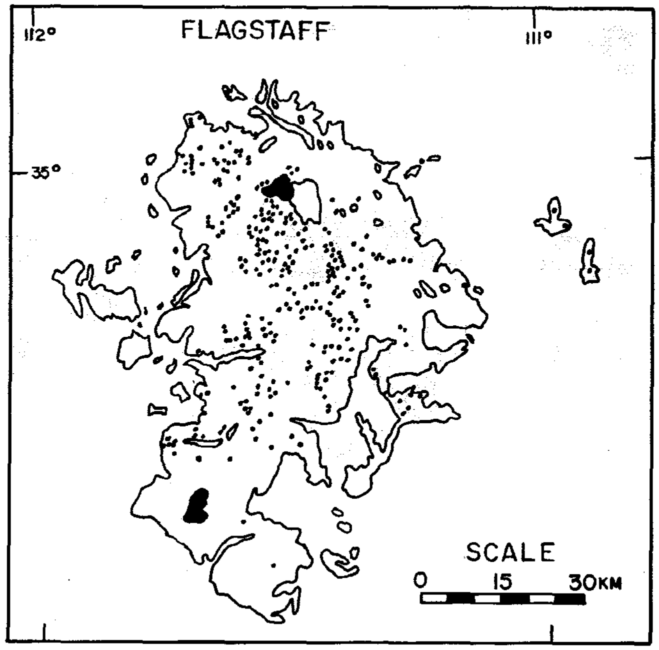
Stephen Self

MORMON
Arizona

Type: *Mono- and polygenetic volcano field*
Lat/Long: *35.0°N, 111.5°W*
Elevation: *1,500 to 2,530 m*
Eruptive History: *Continuous activity from 13.6 to 3.1 Ma*
Composition: *Basanite to rhyolite*

The Mormon volcanic field is one of a group of late Tertiary to Quaternary predominantly basalt fields that rim the Colorado Plateau in the southwestern United States. Located south of Flagstaff, Arizona, and north of the Verde and East Verde Rivers, the field straddles the Mogollon Rim, the boundary between the Colorado Plateau and the Transition Zone to the Basin and Range province. The Mormon volcanic field covers an area of >2,500 km^2 and contains over 250 basalt cinder cones, spatter cones, and lava cones, several shield volcanoes, and numerous large volume sheet flows. Silicic centers composed of andesite to rhyolite flows, domes, and pyroclastic deposits are scattered through the field. These volcanic deposits were erupted upon a basement of sedimentary rocks that include all of the Grand Canyon sequence. The underlying structure of this basement with its steeply dipping faults exerted a strong control on the character of the eruptive units. Tephra and lava cones are elongate or form aligned groups with northwest trends. Numerous basaltic feeder dikes that have northwest trends can also be observed in eroded areas. The volcanic style of the field changed as it evolved. Early erupted large-volume basalt sheet lavas were covered by small-volume shield volcanoes and scoria cones with associated lava flows. Intermediate and silicic magmas were emplaced late during the scoria cone activity. Erosion has subdued the profile of most cones and buried the tops of lava flows beneath mantles of soil; the area is heavily forested with ponderosa pine.

Almost all of the larger volcanic structures are composed of intermediate to silicic rocks. From the southern extent of the field to the northern limit, these centers/mountains are Hackberry, Apache Maid, Round, Table, and Mormon. Hackberry and Mormon mountains are the largest centers; **Hackberry** Mountain



MORMON: Mormon Volcanic field with basaltic cinder cones shown as small black dots and major silicic center as irregularly shaped black areas. Mormon Mountain is in the northern part of the field and Hackberry Mountain is in the southern part. Apache Maid and Stoneman Lake are approximately halfway between these silicic centers.

(late Miocene) contains pyroclastic andesite to rhyolite ash flow deposits. Mormon Mountain (late Pliocene) is a low (~800-m relief) asymmetrical shield volcano composed of andesite and dacite flows, some with well-preserved blocky flow tops and platy terminations, and a rhyolite dome. **Apache Maid**, an asymmetrical scoria cone 300 m high and 1.6 × 2.1 km in diameter, clearly exhibits a three-phase, polygenetic volcanic history. Stage 1 is characterized by basalt pyroclastic eruptions that built the main cone. Stage 2 was dominated by spatter and numerous summit eruptions of lava. Stage 3 produced flank eruptions of mixed basalt and andesite lavas. **Table Mountain** is a relatively thick (45-60 m) andesite lava flow with a crumbly breccia top, and **Round Mountain** is an andesite dome. Another interesting feature, **Stoneman Lake**, is circular in plan and 90 m deep with steep-sided walls of basalt. It is interpreted as a collapse feature above a breccia pipe.

Rock types in the Mormon volcanic field vary from olivine nephelinite to rhyolite; no silica gap is observed. The field is dominated by silicic alkalic basalt and hawaiite. Basaltic lavas contain a variety of xenoliths, ranging from ultramafic cumulates (dominantly pyroxenites) to lower crustal granulites that are partially melted.

How to get there: *The Mormon volcanic field is ~30 km south of Flagstaff, Arizona, and 150 km north of Phoenix, Arizona, and is almost entirely contained within the Coconino National Forest. From Flagstaff the road to Lake Mary continues on, cutting through the center of the field; numerous, well-graded Forest Service roads provide access to the field.*

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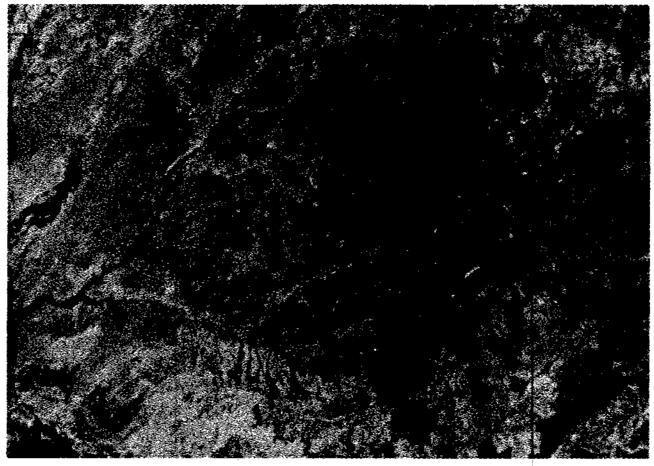
David Gust

HOPI BUTTES
Arizona

Type: *Monogenetic volcano field*
Lat/Long: *35.45 °N, 110.1° W*
Elevation: *1,650-2,080 m*
Volcano Field Diameter: *60 km*
Eruptive History: *8.5 to 4.2 Ma*
Composition: *Monchiquite and limburgite tuff*



HOPI BUTTES: Landsat image of the volcanic field. The dark-colored buttes, each a diatreme or complex of diatremes, dominate the surrounding Painted Desert. The buttes are restricted to a circular area ~60 km wide.

The dark brown Hopi Buttes dominate the surrounding red-, white-, and tan-colored landscape of the Painted Desert in north-central Arizona by commonly rising to heights of 180 m. Individual buttes are underlain by a diatreme, or by a complex of diatremes, whereas most of the buttes are capped by monchiquite flows. Several sediment-filled maars form inconspicuous low hills, while others may be buried beneath the alluvium. The diatremes and maars erupted into the late Miocene–early Pliocene Hopi Lake.

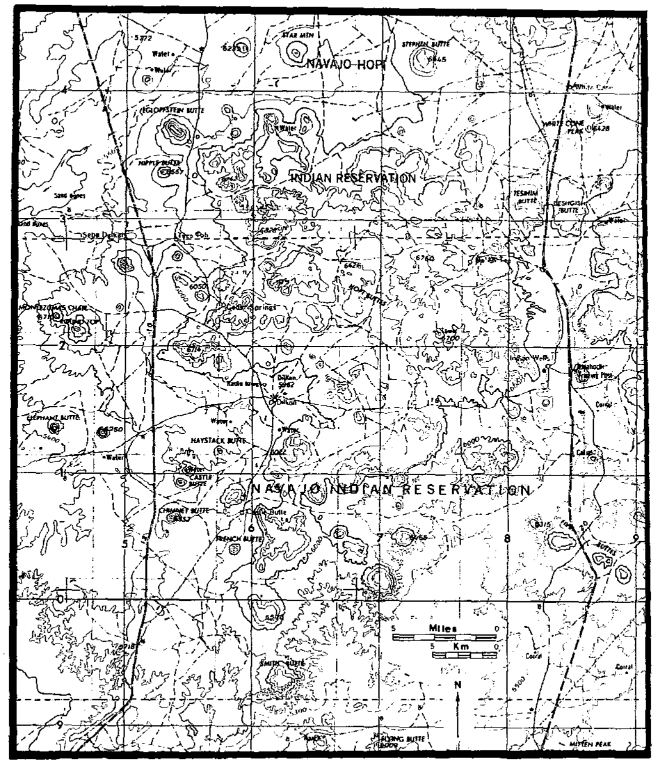
The volcanic rocks of the diatremes and maars are monchiquite and limburgite tuffs; both contain augite (most abundant), olivine, and biotite phenocrysts. These rocks are distinguished from normal alkali basalt of the southern Colorado Plateau by (1) the absence or paucity of orthopyroxene, hornblende, and plagioclase, and the presence of zeolites and feldspathoids, and (2) their extreme silica undersaturation and high H_2O, TiO_2, and P_2O_5 contents. Volcanic rocks that form tuffaceous deposits (limburgite tuffs) are both air fall and water-laid in origin. The major difference between the monchiquite and limburgite tuffs is textural; that is, they contain similar mineralogy and chemistry, but the monchiquite is coarser grained, forms flows, and has augite microlites in the groundmass, in contrast to the glassy matrix of the limburgite tuffs. The latter are commonly composed primarily of brown glass, and calcite amygdules and open-space fillings surrounded by black opaque iron oxides. Many of the diatremes contain maar-lake sediments, which include fine-grained clastic and carbonate (travertine) rocks, limburgite tuff and tuff breccia, agglomerate, blocks of sedimentary rocks derived from the vent walls (most notably the Wingate Sandstone), and monchiquite dikes, necks, and flows. The violent eruptions of these diatremes may have resulted from the exsolution of magmatic gas as magma ascended through the crust. Alternatively, they may have been due to the interac-

HOPI BUTTES: Morale Claim maar adjacent to the southwest side of the monchiquite flow-capped Red Clay mesa. The whitish-yellow lacustrine (travertine) sediments contrast sharply with the black monchiquite flow.

tion of magma with water-saturated rocks beneath Hopi Lake.

The age of the Hopi Buttes volcanic rocks appears to straddle the Miocene–Pliocene boundary. Nineteen K-Ar age determinations on flows, dikes, and tuff beds by M. Shafiquallah and P. E. Damon established that most volcanism and maar crater formation occurred between 8.5 and 6 Ma, with minor igneous activity extending until about 4.2 Ma.

Many trace elements, most notably the incompatible ones, are unusually abundant in the monchiquites compared to normal basaltic volcanism: Ag, As, Ba, Be, Ce, Dy, Eu, F, Gd, Hg, La, Nd, Pb, Rb, Se, Sm, Sn, Sr, Ta, Tb, Th, Tn, U, V, Zn, and Zr. Uranium was apparently sufficiently enriched in the magma and the residual hydrothermal fluids to form uraniferous travertine deposits. Twenty-three of the maars have travertine beds with uranium concentrations >100 ppm, and the **Morale Claim** diatreme contained sufficient uranium (as high as 5,000 ppm) to have supported minor uranium mining during the 1950s. The absence of an Eu anomaly suggests that the magma did not reside for any appreciable time at depths <50 km. Because the monchiquite is probably mantle-derived, with little crustal influence, yet contains incompatible elements such as U along with high CO_2 and H_2O (commonly believed to be concentrated by crustal contamination), the magmas may have



HOPI BUTTES: USGS topographic map.

been derived from a mantle inhomogeneity that lay beneath the continental shield.

How to get there: *Take I-40 east from Flagstaff, Arizona, and then follow either Route 87 north from Winslow (east side of the volcanic field) or Route 77 north from Holbrook (west side).*

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SPRINGERVILLE
Arizona

Type: *Monogenetic volcanic field*
Lat/Long: *34.25°N, 109.58°W*

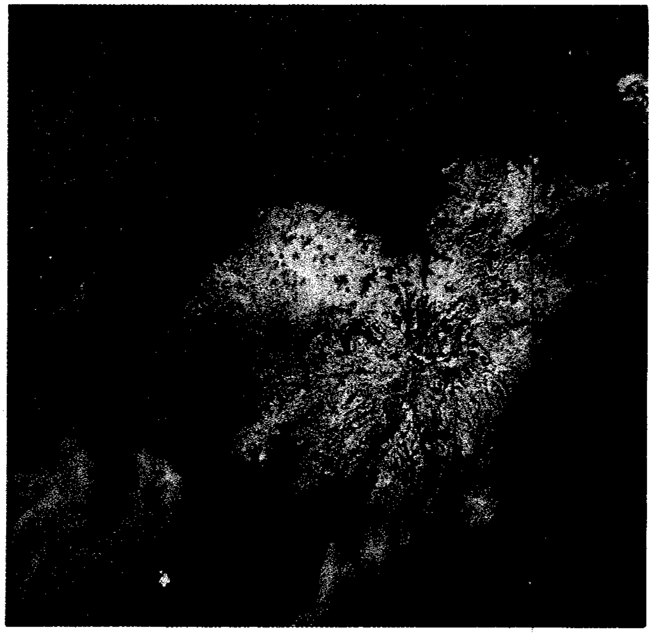
Elevation: *2,200 to 3,100 m*
Relief: *900 m*
Volcanic Field Size: *50 × 80 km, 2,600 km^2*
Volcanic Field Volume: *~300 km^3*
Eruptive History: *2.5 to 0.3 Ma*
Composition: *47% alkali basalt, 28% hawaiite, 24% tholeiite, 2% mugearite and benmorite*

The Springerville volcanic field is noted for its size and volume (about half that of the San Francisco volcanic field, 300 km to the northwest), and its "classic" cinder cone field morphology. More than 380 vents and lava flows are clustered together in a ranch lands setting of grasslands, ponderosa pines, and aspens. The field was unmapped and geologically largely unknown until 1979. Like other Colorado Plateau marginal volcanic fields, it is characterized by a variety of basaltic rocks of transitional to alkalic affinities.

A large stratovolcano, **White Mountains Baldy**, lies immediately south of the field, and in many respects resembles the large stratovolcanoes associated with the cinder cone fields of both the San Francisco and Mount Taylor volcanic fields. However, White Mountains Baldy is morphologically degraded and much older (~8 Ma), whereas the volcanic field is morphologically youthful and <2.5 Ma. Therefore, on the basis of the absence of a clear age or volcanological connection between the two volcanic features, the White Mountains Baldy volcano is not further considered.

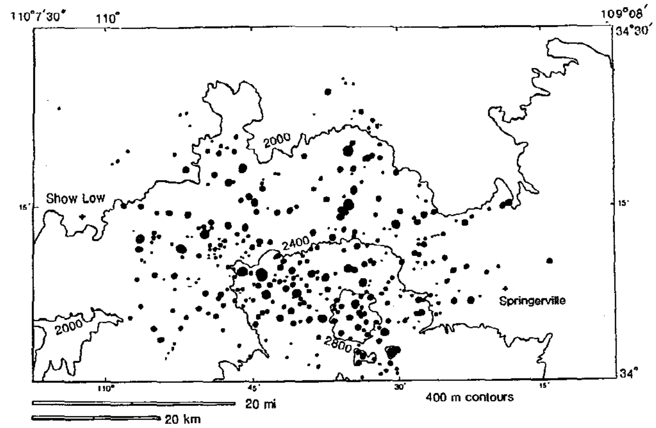
The cinder cones that make up most of the vents in the field are eroded only slightly; several have unbreached summit craters, but most have channeled flanks. A few lava flows also exhibit youthful and rough surface textures, consistent with their measured ages of only a few hundred thousand years. Unusual vents in the Springerville field include maars (5, including the youngest, **Cerro Hueco**), young cinder cones (**Twin Knolls,** estimated by K-Ar dating as 0.3 Ma), and viscous domes (**Wolf** Mountain).

Based on detailed correlation of vent locations and independently determined relative and absolute ages of corresponding lava flows, the locus of volcanism within the field migrated eastward at ~2.9 cm/yr. This is apparent in the distribution of morphologically youthful vents: the youngest are on the eastern side near Springerville, and the older units are generally on the western side of the field near Show Low. The greatest concentration of vents and the greatest diversity of lava types and vent structures occur near the center of the field. The estimated eruption recurrence interval from 2.0 to 0.3 Ma is 4,600 yr. The average effusion rate is ~1.5×10^{-4} km^3/yr.



SPRINGERVILLE: Space Shuttle photograph of the Springerville volcanic field. North to the upper left; the topographic map covers only the northern half of the snow-covered field.

Linear fissure-type vents are not common, and in this respect the field differs from the Mount Taylor–Mesa Chivato field, 200 km to the northeast. Many vents are closely linked to associated Quaternary tectonic deformations, and some flows locally show evidence of slight tilting and folding. Structure and elevation drop down along at least two regional northwesterly-trending arcuate topographic steps or scarps which have a variety of types of deformation (folds, strike-slip faulting, pull-apart basins, and linear graben). These structural patterns may result from the location of the field at the intersection of the Rio Grande rift structural trend (northeast) and the northwest–southeast Transition Zone between the Basin and Range–Colorado Plateau.



SPRINGERVILLE: Regional topographic map showing the location, shape, and size (in black) of vent deposits (mainly pyroclastic cones).

SPRINGERVILLE: View west from the highest point in the Springerville volcanic field (Greens Peak) toward clustered cinder cones of the central and higher elevation parts of the field.

How to get there: *The Springerville volcanic field lies between the towns of Show Low and Springerville, Arizona, along Highways 60 and 260; it is 75 km south of the Petrified Forest National Park. The topographic summit of the field is accessible from either highway by following signs to "Greens Peak" Lookout.*

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SAN CARLOS
Arizona

Type: *Monogenetic volcanic field*
Lat/Long: *33.25°N, 110.25°W*
Elevation: *1,000 m*
Eruptive History: *4.2(?) to 1.0 Ma*
Composition: *Basanite to hawaiite*

The San Carlos volcanic field is the smallest of the late Neogene fields in Arizona and is the southernmost member of the Jemez Lineament volcanoes. Cone and lava flow remnants capping deeply dissected Gila River gravels cover <50 km^2 total area. The volcanic field has long been known for its abundance of peridotite and kindred nodules in the basalt of Peridot Mesa, the largest remnant. Many of the lherzolite nodules contain gem-quality olivine megacrysts >2 cm in size.

The **Peridot Mesa** vent is the only one of four vents having any volcanological distinction. It is a diatreme/tuff ring with a rather extensive lava flow (containing the nodules) which may be "rootless," having originated in a fountain over the pre-basalt tuff ring.

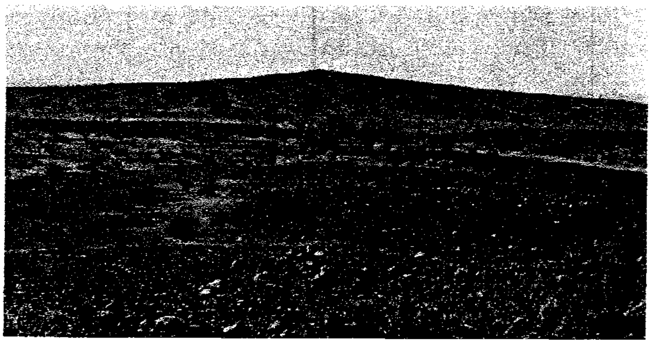
How to get there: *The field is ~40 km east of Globe, Arizona, and is entirely within the San Carlos Apache reservation; it is not possible casually to visit either the mines or the other volcanoes. Available samples have been collected only by people who "know somebody" in the tribe.*

References

Shafiqullah, M., et al., 1980, K–Ar geochronology and geologic history of southwestern Arizona and adjacent areas: *Ariz. Geol. Digest 12*, 201–260.

Wohletz, K. H., 1978, The eruptive mechanism of Peridot Mesa vent, San Carlos, Arizona: *Ariz. Bur. Geol. Min. Tech. Spec. Pub. 2*, 167-173.

Daniel J. Lynch



SENTINEL PLAIN: Typical low-aspect-ratio lava cone. None of the flows in this field retain any primary flow-top structures.

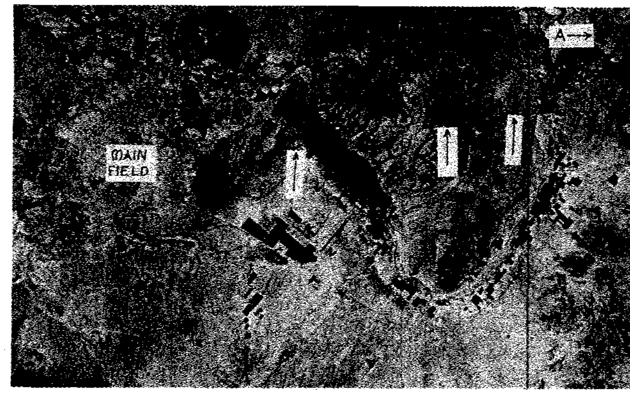
SENTINEL PLAIN
Arizona

Type: *Monogenetic volcanic field*
Lat/Long: *32.8°N, 113.2°W*
Elevation: *160 m*
Eruptive History: *3.3 to 1.3 (?) Ma*
Composition: *Alkali basalt*

The Sentinel Plain volcanic field comprises 600 km^2 of thin (<2 m) basalt flows erupted onto a low-relief surface of aggraded Gila River gravel west of Gila Bend. Four additional isolated vents with 10-20 km^2 of similarly thin basalt lie along a line extending 50 km to the northeast across the S-shaped bend in the Gila River. All but one of the vents in this field are low-aspect-ratio lava cones. Vent morphology indicates basalt effusion without appreciable pyroclastic activity.

The extensive main part of the field contains only 12 identifiable eruptive centers. Cone contours constitute elongate ovals oriented northwest–southeast, and pairs of cones are aligned in this direction. Cone flanks and flow surfaces are entirely of erosional-aggradational origin with significant accumulation of soil carbonate. Contacts between flows from different vents are obscure. Flow bases exposed along the river in the northern part of the field are remarkably rubble-free.

The **Arlington** cone, northeasternmost of the separate cones, is morphologically identical to the others and appears to be monogenetic. However, 6 K-Ar ages determined in site studies for the nearby Palo Verde nuclear power generating station fall between 3.3 and 1.3 Ma, a range that encompasses all the other ages in the field. Although the K-Ar ages indicate the field was active for 2 m.y., the physiography suggests penecontemporaneous fissure eruption of flood-like basalt in the main part of the field.



SENTINEL PLAIN: Landsat view; arrows point to the outlying cones along the "Gila Bend," A is the Arlington cone. The main part of the field is extensively covered with soil carbonate and blown sand.

How to get there: *The Sentinel Plain volcanic field is ~125 km southwest of Phoenix, Arizona. Interstate Highway 8, from Gila Bend to Yuma, passes through the northern part of the field, but most of it is in the Luke Air Force Base Bombing Range; it is unsafe to leave public roads.*

Reference

Shafiqullah, M., et al., 1980, K-Ar geochronology and geologic history of southwestern Arizona and adjacent areas: *Ariz. Geol. Digest 12*, 201–260.

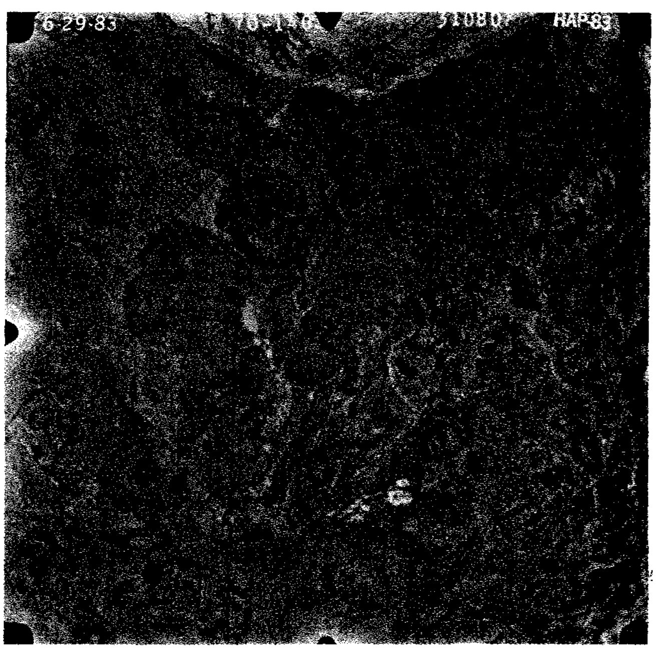
Daniel J. Lynch

GERONIMO
Arizona

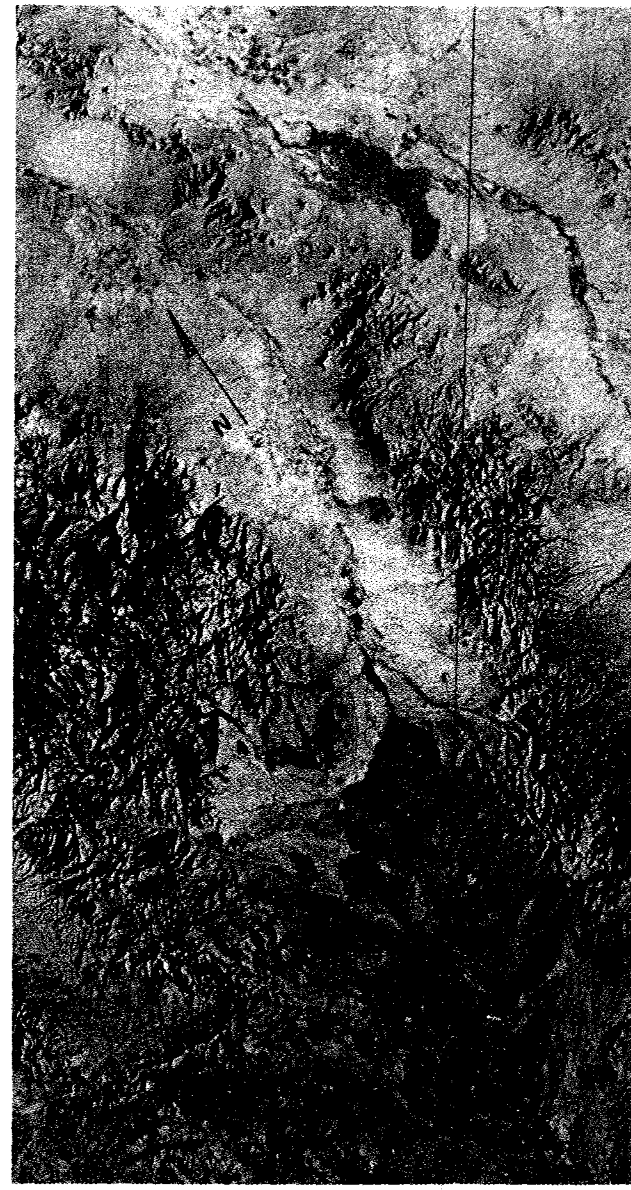
Type: *Monogenetic volcanic field*
Lat/Long: *32.5°N, 109.25°W*
Elevation: *1,300 m*
Eruptive History: *3.2 to 0.3 Ma*
Composition: *Basanite to hawaiite*

The Geronimo (or **San Bernardino**) volcanic field covers an area of 850 km^2 in the northern end of the San Bernardino valley in southeast-

*GERONIMO: **Paramore** maar crater and tuff ring, looking north. This maar, ~800 m long, is younger than the surrounding cones. The tuff contains numerous ultramafic nodules. Photograph by P. Kresan.*



GERONIMO: Eastern portion, including Paramore crater. National High Altitude Photography Program vertical view.



GERONIMO: The Geronimo field from a Skylab photograph. The dark-toned basalt is easily seen. The Animas flow (top) lacks a pyroclastic cone at its source.

ern Arizona. One hundred forty eruptive centers have been identified; five are tephra-ring maar craters, and the rest are pyroclastic cones in various stages of erosion. The cones are composed of agglutinate or a heterogeneous mixture of pyroclast types; the majority appear to have been breached during construction. Lava flow surfaces are eroded flat or are filled with aeolian material. Eroded flow margins constitute prominent landforms in the mountains on both sides of the valley.

The San Bernardino valley is an asymmetric graben, deepest on the west. Crustal extension is still active in the area as shown by a century-old, 4-m-high fault scarp that extends 60 km from a point south of the field. Some lava flows have been offset by post-3.2-Ma normal faulting in the adjacent mountains. Despite the evidence for east–west extension beneath the field, there is no clear stress-field control of vent location or distribution.

Lavas and tephras contain abundant nodules of spinel lherzolite, wherlite, websterite, clinopyroxenite, harzburgite, amphibole peridotite, and two-pyroxene granulite. Megacrysts of plagioclase, aluminous augite, kaersutite hornblende, and magnetite are common. Strontium and neodymium isotope studies of the nodules, megacrysts, and lavas conclude that the mantle source of the basalts produced magma in a billion-year-earlier partial melting episode, and that this source was enriched in light rare-earth elements prior to producing the modern magmas.

How to get there: *The Geronimo volcanic field is in the southeast corner of Arizona, ~60 km east of Bisbee. Highway 80, from Douglas to the New Mexico border, cuts through the field, which is largely on private ranch land.*

References

Kempton, P. D., Dungan, M. A., and Menzies, M. A., 1982, Petrology and geochemistry of ultramafic xenoliths from the Geronimo volcanic field: *Terra Cognita* 2, 222.

Lynch, D. J., 1978, The San Bernardino volcanic field of southeastern Arizona, in Callender, J. F., Wilt, J. C., and Clemons, R. E. (eds.), *Land of Cochise*, New Mexico Geol. Soc. 29th Field Conf. Guidebook, 261-268.

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