GEOLOGIC MAP OF SAN FRANCISCO MOUNTAIN, ELDEN MOUNTAIN, AND DRY LAKE HILLS, COCONINO COUNTY, ARIZONA

By
Richard F. Holm

INTRODUCTION

The igneous rocks of the San Francisco Mountain volcanic center are so variable lithologically and so complexly related structurally and stratigraphically that they are described below in detail in order to make the geologic map more useful. San Francisco Mountain is a composite volcano that was constructed largely during the Quaternary from several silicic lava domes and at least two stratovolcano cones consisting of interlayered lava flows and pyroclastic deposits of andesitic to rhyolitic composition. The volcano rests on a platform of nearly horizontal Paleozoic, and possibly Triassic, strata plus Quaternary or Tertiary basalt lava flows. Dissection of San Francisco Mountain has provided an exceptional view of the core of the volcano, where over 900 m of volcanic rocks are exposed in the Inner Basin and Interior Valley. Because of the exposures, a large number of rock units have been recognized and mapped, and their stratigraphic relationships are interpreted with a relatively high degree of confidence. In spite of the deep dissection, nearly 900 m of igneous rocks, presumably including some of the oldest lavas, still remain buried beneath the Inner Basin. The breach in the northeast flank of the mountain originated from collapse late in the development of the volcano.

Paleozoic sedimentary rocks that crop out on and near Elden Mountain and Little Elden Mountain were tilted and faulted during emplacement of the dacite intrusions and older dacite of Elden Mountain. Structural relationships on the east side of Elden Mountain indicate that the strata were initially pushed up to steep dips and later subsided by rotation normal to strike and displacement along normal faults. Anomalous thicknesses of two or three of the Paleozoic formations imply duplication of beds by faults that must strike nearly parallel to the beds, but such faults have not been located or documented.

DESCRIPTION OF MAP UNITS

SURFICIAL AND LANDSLIDE DEPOSITS (HOLOCENE AND PLEISTOCENE)

Surficial deposits (Qs).—Included in this category are: (1) Alluvium in all drainages, (2) colluvium of silt, sand, pebbles, and boulders, (3) talus on some of the higher and steeper slopes of San Francisco Mountain and Elden Mountain, (4) deposits of till and glacial outwash in the Interior Valley, Inner Basin, and canyons on the outer slopes of San Francisco Mountain, and (5) coarse, unsorted debris-avalanche deposits and lahars containing boulders up to 4 m in diameter, which form fans on the lower outer slopes of San Francisco Mountain. The latter are part of the Sinagua Formation of Updike and Péwé (1970); the most prominent fans are in Hart Prairie, Freidlein Prairie, east of Schultz Peak, east and north of Sugarloaf, and on the south and east sides of White Horse Hills.

Landslide deposit (Ql).—Debris of the dacite breccia of Fremont Peak (Qdbf) and Kaibab Limestone (Pk) on the northern side of Elden Mountain originated as a landslide from the block of Dry Lake Hills that was uplifted during emplacement of Elden Mountain. Fragments of hornblende-biotite dacite and chert on top of Little Elden Mountain probably are the remains of a splash blanket of the landslide.

Landslide breccia of Elden Mountain (Qlbe).—Blocks of dacite (Qdem) up to 10 m in diameter and in haphazard positions were derived from Little Elden Mountain, probably as a rockslide.

IGNEOUS ROCKS

Basaltic rocks peripheral to San Francisco Mountain

Basalt and cinders

Basalt flows and cinder cones (Pleistocene) (Qbb).—Numerous flows that originated from a vent northwest of Fern Mountain cover dacite (Qd) flows from San Francisco Mountain. The lavas are medium- to dark-gray basalts containing microphenocrysts of plagioclase and olivine. Bombs and welded spatter occur on Fern Mountain.

Basalt flows and cinder cones of Hart Prairie (Pleistocene) (Qbhb).—Numerous flows that originated from a small shield volcano near Hart Prairie in the western part of the mapped area cover and underlie andesite (Qaay) flows from San Francisco Mountain. Included in the unit are small intrusions into cinder cone near Michelbach Ranch. The lavas are medium- to dark-gray aphyric basalts containing microphenocrysts of plagioclase and olivine in a fine-grained diktytaxitic matrix of the same minerals plus augite, opaque oxides, alkali feldspar, and minor glass. Cinders are scoriaceous basalt ash, lapilli, and bombs.

Basalt pyroclastic sheet deposits (Pleistocene) (Qbbp).—Scoriaceous basaltic ash and lapilli occur beneath andesite (Qao) and dacite (Qd) lava flows on the north side of San Francisco Mountain.

Basalt flows and cinder cones (Pleistocene) (Qbmb).—Flows uplifted during emplacement of Little Elden Mountain are alkali-rich high-alumina basalts containing normative andesite (hawaiite). Petrographically similar lavas erupted from a small vent on a dacite flow (Qdsy) in the eastern part of the mapped area. The basalts, aphyric in texture, contain microphenocrysts of plagioclase and olivine in a fine-grained, intergranular to microsubophitic matrix of the same minerals plus augite, opaque oxides, and minor glass; alkali feldspar mantles the plagioclase.

Basalt flows and vent deposits (Miocene) (Tob).—Basalt of Switzer Mesa is exposed in Schultz Creek below a dacite flow

(Qddh) from Dry Lake Hills and at the north end of Switzer Mesa, where flows that were tilted to the southwest during the emplacement of the southern Dry Lake Hills lava dome were subsequently covered by dacite flows (Qddh) from the dome. Lithologically identical basalt crops out in the Rio de Flag valley 5 km west of Switzer Mesa. Potassium-argon (K-Ar) age is 5.82±0.34 Ma (Mega-annum) (Damon and others, 1974). The lavas consist of medium-gray basalt that has prominent olivine phenocrysts up to 3 mm in diameter set in a fine diktytaxitic matrix of plagioclase, ophitic augite, olivine, magnetite, and ilmenite.

Rocks of San Francisco Mountain, Elden Mountain, and Dry Lake Hills

Central complex (Pleistocene)

Central complex of San Francisco Mountain (Pleistocene) (Qcc).—Core Ridge and adjacent ridge to the south consist of complexly related lava flows, tuffs, tuff breccias, flow breccias, intrusion breccias, breccia pipes, agglomerates, agglutinates, and small plutons; the rocks are dominantly of andesitic composition, but included are dacite and minor rhyolite. At the western end of Core Ridge, the complex has apparently been displaced down against the rhyolite lava flow of Core Ridge (Qrcr) along a vertical fault. Truncated by the fault are wedge-shaped andesite lava flows, increasing in thickness toward the west, which may have originated as lava lakes in a crater; tuffs, tuff breccias, and agglomerates are interlayered with these flows, which display felty, holocrystalline textures. The amount of fault displacement is unknown, but it probably exceeds 90 m. A possible dacite dome, 50 m in outcrop width, is midway along Core Ridge on its north side. At the northeast end of Core Ridge, several massive andesite lava flows, apparently nearly horizontal, are interlayered with monolithologic flow breccias of similar lithology. On the northeast slope of Agassiz Peak, the western edge of the central complex was located between widely spaced exposures of outwardly dipping andesite lava flows and breccias and inwardly dipping tuff breccias. Within a few centimeters of large plutons, such as the quartz monzodiorite dike (Qmi), the andesites of the central complex are locally recrystallized to pyroxene hornfels facies assemblages and display granoblastic textures. Agglomerates containing well-shaped bombs crop out low on Core Ridge and are among the oldest rocks of the central complex. The rocks and deposits are unaltered.

Extrusive andesitic rocks (Pleistocene)

Andesite of Doyle Peak (Qad).—Alkali-rich andesite lavas that were erupted from a parasitic vent on the lower northeast slope of Doyle Peak cover andesite flows of San Francisco Mountain (Qay) and dacite of Doyle Peak (Qddo); the vent area is buried by younger dacite flows (Qddm). The lavas consist of medium-gray andesite that contains sparse phenocrysts of deep-brown hornblende up to 1 cm in diameter, plagioclase up to 6 mm, and rare hypersthene in a matrix of plagioclase, augite, olivine, an opaque oxide, and glass; hornblende is strongly altered to an opaque oxide and clinopyroxene, and quartz xenocrysts have jackets of clinopyroxene.

Younger andesite of San Francisco Mountain (Qay).—Lava flows and associated autoclastic flow breccias, individually 1 m to about 9 m thick, of medium- to dark-gray to black andesite blanket the hypersthene dacite (Qd) on the upper and middle slopes of San Francisco Mountain. The extrusions, probably erupted from centrally located vents, flowed down all slopes of the mountain except toward the southwest, where they were blocked by an older cone of andesite (Qao) near Agassiz Peak. A few layers of agglomerates and thin agglutinates, probably rootless flows, are interlayered with the lava flows on the upper slopes of San Francisco Mountain, but near the base of the mountain, the unit consists only of block lava flows, typically displaying flow-foliated interiors, that are about 3-6 m thick, exceptionally to 30 m thick, on their edges; ash, lapilli, and tuff breccia beds are minor. Isolated exposures of the lavas are either islands surrounded by surficial deposits or they are erosional remnants of once more extensive flows. The thickest section of the unit is on Humphreys Peak, where dozens of lava flows have an aggregate thickness of over 135 m. On the ridge south of Humphreys Peak, the base of the unit is immediately above a thin tuff bed that contains lapilli of light-gray hypersthene dacite pumice (Qd). On the ridge west of Fremont Peak, the base of the unit is at the bottom of the lowest aphyric (less than 2 percent phenocrysts) andesite lava flow. Of the several lithologic types of andesite that occur in the unit, four of the most distinctive types are: (1) Widely distributed porphyritic lavas having abundant phenocrysts of plagioclase, augite, hypersthene, and magnetite with or without scattered olivine phenocrysts in a hyalopilitic to locally microcrystalline matrix of euhedral plagioclase microlites, pigeonite (with or without augite and hypersthene), olivine, an opaque oxide, and glass; the pyroxene phenocrysts have prominent mantles of pigeonite. (2) Widely distributed dark-gray to black, aphyric (less than 2 percent phenocrysts) lavas composed of closely spaced microphenocrysts of plagioclase and olivine, as well as scattered augite, hypersthene, and magnetite, set in a groundmass of fine to cryptocrystalline plagioclase, pyroxene, olivine, and an opaque oxide and glass; plagioclase forms sparse phenocrysts. (3) Widely distributed dark, porphyritic lavas containing abundant phenocrysts of plagioclase, olivine, and magnetite and scattered augite in a hyalopilitic to intersertal groundmass of plagioclase, olivine, pyroxene, an opaque oxide, and glass; this lithologic type also occurs in the White Horse Hills on the northwest flank of San Francisco Mountain where the andesite lavas were tilted during the emplacement of the rhyolite. (4) Medium-gray lavas very rich in phenocrysts of plagioclase, augite, hypersthene, olivine, and magnetite in a microcrystalline to intersertal matrix of the same minerals plus minor glass; these lavas occur only on the north slope of San Francisco Mountain. Lithologic types 2 and 3 (SiO_2, 55-56 percent) are very similar chemically to the average latite-andesite of Nockolds and others (1978); the other lithologic types are slightly higher in silica and alkalies, although they may still be classified as latite-andesite. K-Ar age of the flow capping Humphreys Peak is 0.43±0.03 Ma (P. E. Damon, written commun., 1977).

Andesite breccia (Qab).—Thin erosional remnants of andesitic lahar breccias are exposed in roadcuts along Schultz Creek. The lahars originated on San Francisco Mountain during extrusion of the younger andesites (Qay). Turbulent flow down the early Schultz Creek valley is indicated by lens-shaped beds about 6 m above the creek and local intimate intermixing with the underlying unconsolidated dacitic pyroclastic flow breccia (Qdbf). Divisible into two units: (1) A lower dark-gray monomictic breccia composed of moderately lithified, unsorted particles of andesitic vitrophyre and andesite ranging in size from ash to blocks as large as 1 m; individual crystals in the ash matrix include plagioclase, olivine, and clinopyroxene; the blocks are dark gray to black, are highly vesicular, and contain phenocrysts of plagioclase and olivine in a matrix of glass or glass with microphenocrysts of plagioclase, olivine, clinopyroxene, and magnetite; the blocks are petrographically similar to certain younger andesite flows (Qay) on the upper slopes of San Francisco Mountain. (2) An upper light-yellowish-brown to red palagonitic polymictic breccia composed dominantly of moderately lithified ash- to lapilli-size particles of gray to black andesite and andesitic vitrophyre, red and black scoriaceous andesite, red to tan to black vesicular tachylite, and crystals of plagioclase and olivine; sparse blocks reach 10 cm in diameter; the contact between the upper and lower units displays evidence of minor mixing.

Younger andesite of Agassiz Peak (Qaay).—Consists of several thick, blocky flows that were extruded from a parasitic vent on the upper west slope of Agassiz Peak. Individual flows are up to 50 m thick on their margins. Distal ends of flows appear to have been diverted toward the south by a small shield volcano in the Hart Prairie area. Phenocrysts of plagioclase, brown hornblende (up to 5 mm long), hypersthene, and sparse augite are set in a medium-gray to pinkish-gray aphanitic matrix of plagioclase, pyroxene, an opaque oxide, and glass. Chemistry, mode, and texture are identical to hornblende andesite in the older andesite of San Francisco Mountain (Qao) on the lower southeast slope of Humphreys Peak in the Inner Basin. K-Ar age is 0.60±0.08 Ma (P. E. Damon, written commun., 1977).

Andesite of Core Ridge (Qacr).—A parasitic cone, now deeply dissected, occurs at the west end of Core Ridge in the saddle between Agassiz and Humphreys Peaks. A crater excavated in older units (Qao, Qrcr) was partly filled with coarse, unsorted, and crudely stratified polymictic debris-avalanche breccias and tuff breccias that contain angular accidental blocks up to 2 m in diameter and are overlain by reddish scoriaceous andesite cinders and grayish-tan tuff; the pyroclastic material was intruded by several andesite plutons, which fed at least three flat-lying lava lake flows that were ponded in the crater of the cone. The plutons are pinkish- to greenish-gray, dense to microvesicular, holocrystalline andesites containing sparse phenocrysts of plagioclase up to 2 mm in diameter, augite with pigeonite rims, and olivine altered to an opaque oxide, bowlingite, and carbonate in a microcrystalline matrix of plagioclase, alkali feldspar, pigeonite, brown hornblende, biotite, and an opaque oxide; vesicles contain tridymite, hypersthene, and cummingtonite(?). The lava lake flows are similar in petrography, except that they lack amphibole and biotite, and their matrix is finer grained and may contain glass. K-Ar age is 0.66±0.03 Ma (P. E. Damon, written commun., 1977). A tuff and tuff-breccia bed, about 15 m thick, between dacite lava flows (Qdff) and the dacite of San Francisco Mountain (Qd) on Fremont Peak may correlate with the pyroclastic units of the andesite of Core Ridge (Qacr).

Pumice of Agassiz Peak (Qpa).—Unconsolidated lapilli and bombs of andesitic (SiO_2, 61.5 percent) pumice and vitrophyre mantle an unrelated andesite dome (Qaao) on the upper southwest slope of Agassiz Peak; lapilli- to bomb-size pieces of identical pumice occur in a thin (a few centimeters thick) bed between lava flows of the older andesite of San Francisco Mountain (Qao) at 12,060 ft on the ridge crest above the Arizona Snow Bowl ski lift. The light-gray to pale-yellow pumice and vitrophyre contain phenocrysts of plagioclase, brown hornblende, hypersthene, and an opaque oxide in a frothy to dense glass matrix. Source of the pumice is unknown.

Older andesite of Agassiz Peak (Qaao).—Small, block-mantled, parasitic andesite dome, as suggested by topography, erupted on the upper southwest slope of Agassiz Peak; the dome is mantled by andesitic pumice (Qpa) of an unrelated eruption and has been covered by andesite lava flows (Qao). Field relationships of the dome and its presumed feeder (Qsi) suggest that the dome was emplaced on older andesite flows of San Francisco Mountain (Qao). The andesite dome (SiO_2, 59.4 percent), consisting of phenocrysts of plagioclase, biotite, and hornblende in a medium-gray groundmass of plagioclase, olivine, clinopyroxene, hypersthene, hornblende, magnetite, glass, and tridymite, is nearly identical in lithology and chemistry to the andesite dike of Snowslide Spring (Qsi), its probable feeder. Xenocrysts of quartz have jackets of clinopyroxene.

Older andesite of San Francisco Mountain (Qao).—The most voluminous unit of San Francisco Mountain consists of interbedded lava flows, autoclastic flow breccias, agglutinates, rootless flows, tuff breccias, and tuffs of andesitic composition that crop out on Agassiz Peak and on the prominent cliffs and steep slopes on the north wall of the Inner Basin. Thinner deposits of the andesites, mainly lavas, occur in the Inner Basin on Fremont Peak and Doyle Peak and on the lower outer slopes of San Francisco Mountain on the north, east, and south sides where block lava flows extend beyond overlying lavas. Structurally disturbed lavas crop out at the north end of Schultz Peak and are exposed in the deeply eroded Weatherford Canyon. The extrusions, which display radial dips, probably erupted from centrally located vents and flowed down all slopes of San Francisco Mountain to construct a stratovolcano centered near the southwest end of the Inner Basin; Agassiz Peak is a dissected remnant of the southwest side of the original cone. The lowest known exposed lavas are pyroxene andesites that crop out above air-fall tuffs low on the Inner Basin side of the ridge south of Beard Canyon. Succeeding the pyroxene andesite, a thick section of hornblende-bearing andesite flows and pyroclastic beds extends well up in the unit on Humphreys Peak and Aubineau Peak to a point where pyroxene and olivine-pyroxene andesite flows and pyroclastic beds reappear and complete the unit. The upper pyroxene and olivine-pyroxene andesites crop out continuously along the north side of the Inner Basin, along the ridge that forms the west side of the Inner Basin, on Fremont Peak, and along the ridge west of Fremont Peak, and they extend to the top of Agassiz Peak. Low on the northwest slope of Doyle Peak are outcrops of interlayered lava flows (1-15 m thick), autoclastic flow breccias, and tuff breccias of dark-gray to black andesite. The extrusions covered a dome, the older rhyolite of Raspberry Spring (Qrro), and in turn were covered by younger rhyolite lavas (Qro). The lava flows and blocks in the breccias are composed of phenocrysts of plagioclase, hypersthene, augite, magnetite, and locally olivine set in matrices of the same minerals plus glass; they range in texture from vitrophyric to hyalopilitic to intersertal and intergranular. Above the rhyolite lavas (Qro) on Doyle Peak, the unit is dominated by pyroxene andesite lavas, but hornblende-bearing lavas occur in the middle of the section. Discordance between the andesite lavas and pyroclastics above and below the rhyolite lavas (Qro) on Doyle Peak suggests a local unconformity within the older andesite of San Francisco Mountain. In Weatherford Canyon and at the north end of Schultz Peak, the unit consists of thick (15-25 m), massive to flow-foliated lava flows of medium- to dark-gray and reddish-brown andesite and dacite. The lavas were pushed up and tilted toward the northwest during the early stage of emplacement of the lava dome of Schultz Peak; subsequent eruptions of dacite of Schultz Peak (Qdso), as well as a later rhyolite flow (Qro), buried the tilted lavas. Phenocrysts in the andesites include plagioclase, augite, hypersthene, and olivine, whereas the dacites contain plagioclase, hypersthene, augite, and brown hornblende phenocrysts and, in addition, commonly have tridymite in vesicles. Although the stratigraphic position of the lavas in Weatherford Canyon is not entirely clear, they may be the oldest exposed rocks of the central composite volcano. The lava flows on the north, northeast, and east flanks of San Francisco Mountain all contain hornblende.

In the Inner Basin, the rootless flows are 0.6-2 m thick, whereas the lavas are 2.5-12 m thick and exceptionally 15-30 m thick; individual pyroclastic deposits are 8 cm to over 30 m in thickness. Low on the outer slopes of San Francisco Mountain, the edges of block lava flows range from 4.5 m to about 60 m in thickness. At the south base of Humphreys Peak in the Inner Basin, a landslide breccia derived mainly from the rhyolite flow (Qrcr) to the south is interlayered with hornblende andesite flows and breccias; blocks of andesite are intermingled with the rhyolite blocks, which may reach diameters of 6 m. The breccia is up to 18 m thick, but rapidly pinches out (within about 60 m) toward the east; this indicates that the avalanches flowed down a valley.

Pyroxene andesites that crop out low on the north side of the Inner Basin are dark-gray lavas bearing plagioclase, hypersthene, augite, and magnetite phenocrysts and microphenocrysts in a hyalopilitic to intersertal matrix of the same minerals plus brown glass. The overlying hornblende-pyroxene andesites are variable color and textural detail, but all contain phenocrysts of plagioclase, hypersthene, augite, brown hornblende, and magnetite; phenocrysts and (or) microphenocrysts of olivine may be present or absent. The hyalopilitic to microcrystalline matrices range in color from medium brownish red through gray to black. Pyroxene and olivine-pyroxene andesites that overlie the hornblende-bearing lavas display variable phenocryst assemblages; they are grouped into four common types, all of which carry magnetite: plagioclase+hypersthene+olivine±augite, plagioclase+augite+olivine, plagioclase+augite+hypersthene, and plagioclase+augite+hypersthene+olivine; pigeonite may occur in the matrix and as mantles on pyroxene phenocrysts in some specimens. The matrices range from hyalopilitic to microcrystalline and are medium to dark gray to brownish gray to black in hand specimen. Interbedded locally within the lower sections of pyroxene andesite and hornblende andesite are lavas of dacitic composition. The andesites range continuously from low- to high-silica types; they are similar chemically and lithologically to the average latite-andesite of Nockolds and others (1978). The andesites on Humphreys Peak yield K-Ar ages of 0.92±0.03 Ma near the east end of the ridge south of Beard Canyon and 0.76±0.07 Ma at the base of the section in Dunnam Canyon (P. E. Damon, written commun., 1977).

Extrusive dacitic rocks

Dacite of Lockett Meadow (Pleistocene) (Qdlm).—Two block-mantled flows, one on top of the other, erupted from a parasitic vent on the east side of Reese Peak; the lower flow is about 30 m thick at its toe, whereas the upper flow is about 60 m thick. The vent has been buried by debris of dark-gray microporphyritic andesites (Qay). The lower flow was deposited on top of a debris fan of material derived from San Francisco Mountain. Scattered phenocrysts and microphenocrysts of plagioclase, brown hornblende, hypersthene, quartz (up to 3 mm in diameter) and magnetite are set in a medium- to dark-gray intersertal to trachytoid matrix of plagioclase, hypersthene, tridymite, magnetite, and glass. The K-Ar age of the rock is 0.41±0.16 Ma (P. E. Damon, written commun., 1977).

Younger dacite of Doyle Peak (Pleistocene) (Qddy).—Consists of thick, block lava flows that were extruded from two closely spaced vents on the upper east slope of Doyle Peak. The largest flow is 135 m thick at its toe 5 km east-northeast of the vents; lava levees form prominent ridges along the margins of the flow. The interior of the flow locally is massive, but typically it displays closely spaced platy joints, which at the vents are steep to vertical, but elsewhere are subparallel to the preextrusion surface. Two smaller lava extrusions flowed east and southeast from the same vents. The light- to medium-gray dacite contains sparse phenocrysts of plagioclase, biotite strongly altered to magnetite, hypersthene, and rare quartz in a fine trachytoid matrix of plagioclase, alkali feldspar, hypersthene, a silica mineral, zircon, and an opaque oxide. K-Ar age is 0.40±0.03 Ma (P. E. Damon, written commun., 1977).

Middle dacite of Doyle Peak (Pleistocene) (Qddm).—Included are one or more lava flows of medium- to dark-gray to black dacite extruded from a vent, or vents, on the northeast slope of Doyle Peak. The flow whose distal end is exposed 2.4 km east of Sugarloaf may have erupted from, and thus formed, the debris-covered ridge south of Lockett Meadow Spring. The vent at the 10,055-ft knob produced a flow that split into two branches around the andesite of Doyle Peak (Qad); the southern branch was subsequently covered by younger dacite (Qddy). Although the flow surfaces commonly are blocky, the interiors typically display planar to locally contorted, closely spaced shear joints that give the rocks a slaty appearance. Phenocrysts are sparse and consist of plagioclase, biotite, hypersthene, and quartz; the matrix ranges from trachytoid to hyalopilitic texture and consists of plagioclase, hypersthene, a silica mineral, an opaque oxide, and glass. The lithology generally resembles the younger dacite (Qddy), although the middle unit (Qddm) contains fewer phenocrysts, lower SiO_2, Na_2O, and K_2O and higher total iron, MgO, and CaO; this dacite (Qddm) may be an early eruption of the same batch of magma that produced the younger dacite lavas (Qddy).

Older dacite of Doyle Peak (Pleistocene) (Qddo).—Thick, block mantled flows from a flank eruption near the 11,060-ft knob on the upper east slope of Doyle Peak cover andesite lavas (Qay). Intrusive relationships below the vent are exposed clearly in the east wall of the cirque on the northeast side of Doyle Peak. Abundant phenocrysts of plagioclase, oxidized biotite and hornblende, hypersthene, and magnetite, and sparse resorbed anorthoclase and quartz, are set in a groundmass that ranges in color from include plagioclase, olivine, and clinopyroxene; the blocks are dark gray to black, are highly vesicular, and contain phenocrysts of plagioclase and olivine in a matrix of glass or glass with microphenocrysts of plagioclase, olivine, clinopyroxene, and magnetite; the blocks are petrographically similar to certain younger andesite flows (Qay) on the upper slopes of San Francisco Mountain. (2) An upper light-yellowish-brown to red palagonitic polymictic breccia composed dominantly of moderately lithified ash- to lapilli-size particles of gray to black andesite and andesitic vitrophyre, red and black scoriaceous andesite, red to tan to black vesicular tachylite, and crystals of plagioclase and olivine; sparse blocks reach 10 cm in diameter; the contact between the upper and lower units displays evidence of minor mixing.

Younger andesite of Agassiz Peak (Qaay).—Consists of several thick, blocky flows that were extruded from a parasitic vent on the upper west slope of Agassiz Peak. Individual flows are up to 50 m thick on their margins. Distal ends of flows appear to have been diverted toward the south by a small shield volcano in the Hart Prairie area. Phenocrysts of plagioclase, brown hornblende (up to 5 mm long), hypersthene, and sparse augite are set in a medium-gray to pinkish-gray aphanitic matrix of plagioclase, pyroxene, an opaque oxide, and glass. Chemistry, mode, and texture are identical to hornblende andesite in the older andesite of San Francisco Mountain (Qao) on the lower southeast slope of Humphreys Peak in the Inner Basin. K-Ar age is 0.60±0.08 Ma (P. E. Damon, written commun., 1977).

Andesite of Core Ridge (Qacr).—A parasitic cone, now deeply dissected, occurs at the west end of Core Ridge in the saddle between Agassiz and Humphreys Peaks. A crater excavated in older units (Qao, Qrcr) was partly filled with coarse, unsorted, and crudely stratified polymictic debris-avalanche breccias and tuff breccias that contain angular accidental blocks up to 2 m in diameter and are overlain by reddish scoriaceous andesite cinders and grayish-tan tuff; the pyroclastic material was intruded by several andesite plutons, which fed at least three flat-lying lava lake flows that were ponded in the crater of the cone. The plutons are pinkish- to greenish-gray, dense to microvesicular, holocrystalline andesites containing sparse phenocrysts of plagioclase up to 2 mm in diameter, augite with pigeonite rims, and olivine altered to an opaque oxide, bowlingite, and carbonate in a microcrystalline matrix of plagioclase, alkali feldspar, pigeonite, brown hornblende, biotite, and an opaque oxide; vesicles contain tridymite, hypersthene, and cummingtonite(?). The lava lake flows are similar in petrography, except that they lack amphibole and biotite, and their matrix is finer grained and may contain glass. K-Ar age is 0.66±0.03 Ma (P. E. Damon, written commun., 1977). A tuff and tuff-breccia bed, about 15 m thick, between dacite lava flows (Qdff) and the dacite of San Francisco Mountain (Qd) on Fremont Peak may correlate with the pyroclastic units of the andesite of Core Ridge (Qacr).

Pumice of Agassiz Peak (Qpa).—Unconsolidated lapilli and bombs of andesitic (SiO_2, 61.5 percent) pumice and vitrophyre mantle an unrelated andesite dome (Qaao) on the upper southwest slope of Agassiz Peak; lapilli- to bomb-size pieces of identical pumice occur in a thin (a few centimeters thick) bed between lava flows of the older andesite of San Francisco Mountain (Qao) at 12,060 ft on the ridge crest above the Arizona Snow Bowl ski lift. The light-gray to pale-yellow pumice and vitrophyre contain phenocrysts of plagioclase, brown hornblende, hypersthene, and an opaque oxide in a frothy to dense glass matrix. Source of the pumice is unknown.

Older andesite of Agassiz Peak (Qaao).—Small, block-mantled, parasitic andesite dome, as suggested by topography, erupted on the upper southwest slope of Agassiz Peak; the dome is mantled by andesitic pumice (Qpa) of an unrelated eruption and has been covered by andesite lava flows (Qao). Field relationships of the dome and its presumed feeder (Qsi) suggest that the dome was emplaced on older andesite flows of San Francisco Mountain (Qao). The andesite dome (SiO_2, 59.4 percent), consisting of phenocrysts of plagioclase, biotite, and hornblende in a medium-gray groundmass of plagioclase, olivine, clinopyroxene, hypersthene, hornblende, magnetite, glass, and tridymite, is nearly identical in lithology and chemistry to the andesite dike of Snowslide Spring (Qsi), its probable feeder. Xenocrysts of quartz have jackets of clinopyroxene.

Older andesite of San Francisco Mountain (Qao).—The most voluminous unit of San Francisco Mountain consists of interbedded lava flows, autoclastic flow breccias, agglutinates, rootless flows, tuff breccias, and tuffs of andesitic composition that crop out on Agassiz Peak and on the prominent cliffs and steep slopes on the north wall of the Inner Basin. Thinner deposits of the andesites, mainly lavas, occur in the Inner Basin on Fremont Peak and Doyle Peak and on the lower outer slopes of San Francisco Mountain on the north, east, and south sides where block lava flows extend beyond overlying lavas. Structurally disturbed lavas crop out at the north end of Schultz Peak and are exposed in the deeply eroded Weatherford Canyon. The extrusions, which display radial dips, probably erupted from centrally located vents and flowed down all slopes of San Francisco Mountain to construct a stratovolcano centered near the southwest end of the Inner Basin; Agassiz Peak is a dissected remnant of the southwest side of the original cone. The lowest known exposed lavas are pyroxene andesites that crop out above air-fall tuffs low on the Inner Basin side of the ridge south of Beard Canyon. Succeeding the pyroxene andesite, a thick section of hornblende-bearing andesite flows and pyroclastic beds extends well up in the unit on Humphreys Peak and Aubineau Peak to a point where pyroxene and olivine-pyroxene andesite flows and pyroclastic beds reappear and complete the unit. The upper pyroxene and olivine-pyroxene andesites crop out continuously along the north side of the Inner Basin, along the ridge that forms the west side of the Inner Basin, on Fremont Peak, and along the ridge west of Fremont Peak, and they extend to the top of Agassiz Peak. Low on the northwest slope of Doyle Peak are outcrops of interlayered lava flows (1-15 m thick), autoclastic flow breccias, and tuff breccias of dark-gray to black andesite. The extrusions covered a dome, the older rhyolite of Raspberry Spring (Qrro), and in turn were covered by younger rhyolite lavas (Qro). The lava flows and blocks in the breccias are composed of phenocrysts of plagioclase, hypersthene, augite, magnetite, and locally olivine set in matrices of the same minerals plus glass; they range in texture from vitrophyric to hyalopilitic to intersertal and intergranular. Above the rhyolite lavas (Qro) on Doyle Peak, the unit is dominated by pyroxene andesite lavas, but hornblende-bearing lavas occur in the middle of the section. Discordance between the andesite lavas and pyroclastics above and below the rhyolite lavas (Qro) on Doyle Peak suggests a local unconformity within the older andesite of San Francisco Mountain. In Weatherford Canyon and at the north end of Schultz Peak, the unit consists of thick (15-25 m), massive to flow-foliated lava flows of medium- to dark-gray and reddish-brown andesite and dacite. The lavas were pushed up and tilted toward the northwest during the early stage of emplacement of the lava dome of Schultz Peak; subsequent eruptions of dacite of Schultz Peak (Qdso), as well as a later rhyolite flow (Qro), buried the tilted lavas. Phenocrysts in the andesites include plagioclase, augite, hypersthene, and olivine, whereas the dacites contain plagioclase, hypersthene, augite, and brown hornblende phenocrysts and, in addition, commonly have tridymite in vesicles. Although the stratigraphic position of the lavas in Weatherford Canyon is not entirely clear, they may be the oldest exposed rocks of the central composite volcano. The lava flows on the north, northeast, and east flanks of San Francisco Mountain all contain hornblende.

In the Inner Basin, the rootless flows are 0.6-2 m thick, whereas the lavas are 2.5-12 m thick and exceptionally 15-30 m thick; individual pyroclastic deposits are 8 cm to over 30 m in thickness. Low on the outer slopes of San Francisco Mountain, the edges of block lava flows range from 4.5 m to about 60 m in thickness. At the south base of Humphreys Peak in the Inner Basin, a landslide breccia derived mainly from the rhyolite flow (Qrcr) to the south is interlayered with hornblende andesite flows and breccias; blocks of andesite are intermingled with the rhyolite blocks, which may reach diameters of 6 m. The breccia is up to 18 m thick, but rapidly pinches out (within about 60 m) toward the east; this indicates that the avalanches flowed down a valley.

Pyroxene andesites that crop out low on the north side of the Inner Basin are dark-gray lavas bearing plagioclase, hypersthene, augite, and magnetite phenocrysts and microphenocrysts in a hyalopilitic to intersertal matrix of the same minerals plus brown glass. The overlying hornblende-pyroxene andesites are variable color and textural detail, but all contain phenocrysts of plagioclase, hypersthene, augite, brown hornblende, and magnetite; phenocrysts and (or) microphenocrysts of olivine may be present or absent. The hyalopilitic to microcrystalline matrices range in color from medium brownish red through gray to black. Pyroxene and olivine-pyroxene andesites that overlie the hornblende-bearing lavas display variable phenocryst assemblages; they are grouped into four common types, all of which carry magnetite: plagioclase+hypersthene+olivine±augite, plagioclase+augite+olivine, plagioclase+augite+hypersthene, and plagioclase+augite+hypersthene+olivine; pigeonite may occur in the matrix and as mantles on pyroxene phenocrysts in some specimens. The matrices range from hyalopilitic to microcrystalline and are medium to dark gray to brownish gray to black in hand specimen. Interbedded locally within the lower sections of pyroxene andesite and hornblende andesite are lavas of dacitic composition. The andesites range continuously from low- to high-silica types; they are similar chemically and lithologically to the average latite-andesite of Nockolds and others (1978). The andesites on Humphreys Peak yield K-Ar ages of 0.92±0.03 Ma near the east end of the ridge south of Beard Canyon and 0.76±0.07 Ma at the base of the section in Dunnam Canyon (P. E. Damon, written commun., 1977).

Extrusive dacitic rocks

Dacite of Lockett Meadow (Pleistocene) (Qdlm).—Two block-mantled flows, one on top of the other, erupted from a parasitic vent on the east side of Reese Peak; the lower flow is about 30 m thick at its toe, whereas the upper flow is about 60 m thick. The vent has been buried by debris of dark-gray microporphyritic andesites (Qay). The lower flow was deposited on top of a debris fan of material derived from San Francisco Mountain. Scattered phenocrysts and microphenocrysts of plagioclase, brown hornblende, hypersthene, quartz (up to 3 mm in diameter) and magnetite are set in a medium- to dark-gray intersertal to trachytoid matrix of plagioclase, hypersthene, tridymite, magnetite, and glass. The K-Ar age of the rock is 0.41±0.16 Ma (P. E. Damon, written commun., 1977).

Younger dacite of Doyle Peak (Pleistocene) (Qddy).—Consists of thick, block lava flows that were extruded from two closely spaced vents on the upper east slope of Doyle Peak. The largest flow is 135 m thick at its toe 5 km east-northeast of the vents; lava levees form prominent ridges along the margins of the flow. The interior of the flow locally is massive, but typically it displays closely spaced platy joints, which at the vents are steep to vertical, but elsewhere are subparallel to the preextrusion surface. Two smaller lava extrusions flowed east and southeast from the same vents. The light- to medium-gray dacite contains sparse phenocrysts of plagioclase, biotite strongly altered to magnetite, hypersthene, and rare quartz in a fine trachytoid matrix of plagioclase, alkali feldspar, hypersthene, a silica mineral, zircon, and an opaque oxide. K-Ar age is 0.40±0.03 Ma (P. E. Damon, written commun., 1977).

Middle dacite of Doyle Peak (Pleistocene) (Qddm).—Included are one or more lava flows of medium- to dark-gray to black dacite extruded from a vent, or vents, on the northeast slope of Doyle Peak. The flow whose distal end is exposed 2.4 km east of Sugarloaf may have erupted from, and thus formed, the debris-covered ridge south of Lockett Meadow Spring. The vent at the 10,055-ft knob produced a flow that split into two branches around the andesite of Doyle Peak (Qad); the southern branch was subsequently covered by younger dacite (Qddy). Although the flow surfaces commonly are blocky, the interiors typically display planar to locally contorted, closely spaced shear joints that give the rocks a slaty appearance. Phenocrysts are sparse and consist of plagioclase, biotite, hypersthene, and quartz; the matrix ranges from trachytoid to hyalopilitic texture and consists of plagioclase, hypersthene, a silica mineral, an opaque oxide, and glass. The lithology generally resembles the younger dacite (Qddy), although the middle unit (Qddm) contains fewer phenocrysts, lower SiO_2, Na_2O, and K_2O and higher total iron, MgO, and CaO; this dacite (Qddm) may be an early eruption of the same batch of magma that produced the younger dacite lavas (Qddy).

Older dacite of Doyle Peak (Pleistocene) (Qddo).—Thick, block mantled flows from a flank eruption near the 11,060-ft knob on the upper east slope of Doyle Peak cover andesite lavas (Qay). Intrusive relationships below the vent are exposed clearly in the east wall of the cirque on the northeast side of Doyle Peak. Abundant phenocrysts of plagioclase, oxidized biotite and hornblende, hypersthene, and magnetite, and sparse resorbed anorthoclase and quartz, are set in a groundmass that ranges in color from reddish brown to pink to light gray; glassy rocks are dark gray; groundmass constituents of plagioclase, alkali feldspar, hypersthene, a silica mineral, an opaque oxide, zircon, and glass range in texture from hyalopilitic to cryptocrystalline to microcrystalline. Deep-maroon xenoliths that are as much as 10 cm in diameter are conspicuous in their abundance. The xenoliths may be porphyritic or aphyric; those that have phenocrysts contain scattered crystals of plagioclase, olivine, and augite in a felty matrix of tabular plagioclase, strongly acicular hornblende, hypersthene, olivine, clinopyroxene, apatite, and an opaque oxide; vesicles in the xenoliths may be occupied by light-brown cummingtonite(?) and tridymite.

Younger dacite of Elden Mountain (Pleistocene) (Qdey).—An autoclastic flow breccia of yellowish-gray to light-yellowish-brown dacite, erupted from a vent between Little Elden Mountain and Dry Lake Hills, consists of blocks that are moderately to highly vesicular, range in size from 2 cm to 2 m in diameter, and are weakly to moderately held together, apparently by welding without an ash matrix; the lenticular shape of the larger blocks may be due to stretching downslope. Although the block lava flow is at least 50 m thick, it appears to lack a dense interior. Xenoliths of fine, red sandstone may be seen in cuts along the Mount Elden road. The breccia was extruded onto the eastern Dry Lake Hills lava dome, on the Paleozoic strata uplifted during the earlier intrusive stage represented by the dacite intrusions and tuffisite of Elden Mountain (Qdti), and on the following block lava flows of Elden Mountain (Qdem). Phenocrysts of plagioclase, hypersthene (with olivine inclusions), brown hornblende, biotite, and magnetite occur in a hyalopilitic matrix of plagioclase, hypersthene, fayalitic olivine, and glass; tridymite occurs in vesicles.

Middle dacite of Elden Mountain (Pleistocene) (Qdem).—Exogenous lava domes form Elden Mountain and Little Elden Mountain. Numerous well-defined flow lobes up to 75 m thick radiate from several closely spaced vents on Elden Mountain; Little Elden Mountain flows appear to have erupted from a northeast- to north-trending fracture that connects with the vents of Elden Mountain to the south. Vertical flow foliations on the east side of Little Elden Mountain were formed by flowage past tilted Paleozoic strata at shallow depths beneath the vents; the steep flow foliations can be traced continuously into north- and east-dipping lava flows. The lavas are intrusive into the dacites (Qdti) and tilted Paleozoic formations along the north end of Elden Mountain. Various types of extensional and shear joints are well displayed by the flows, whose surfaces typically are mantled by smooth, round blocks 2-6 m or more in diameter (Kluth, 1974). The massive dacite contains abundant phenocrysts of plagioclase (up to 5 mm long), hypersthene (with olivine inclusions), magnetite, and minor augite and brown hornblende, in a light-gray to pinkish-gray micrograpitic matrix of plagioclase, alkali feldspar, a silica mineral, zircon, and fayalitic olivine; tridymite is common in the vesicles. K-Ar age determinations of two flows on the southeast side of Elden Mountain are 0.49±0.06 Ma and 0.57±0.03 Ma (P. E. Damon, written commun., 1977).

Older dacite of Elden Mountain (Pleistocene) (Qdeo).—The crumble breccia of an endogenous lava dome was constructed coevally with the intrusive emplacement of the early biotite-hornblende dacite (Qdti); the breccia is now largely buried by block lava flows (Qdem). Exposed only on the north side of Elden Mountain, the crumble breccia covers a lava flow (Qddh) from the eastern dome of Dry Lake Hills. The angular blocks range from 2 to 30 cm in diameter, rarely up to 1 m . Abundant phenocrysts of plagioclase (up to 5 mm long), hornblende (up to 7 mm), hypersthene, biotite, and magnetite are set in a brownish-red microgranitic matrix of plagioclase, alkali feldspar, quartz, and an opaque oxide.

Pumice of Reese Peak (Pleistocene) (Qpr).—Unconsolidated lapilli and blocks up to 15 cm in diameter of light-gray pumice occur in a thin bed between dacite (Qd) and andesite (Qay) near the top of Reese Peak; accessory blocks up to 15 cm of vesicular, light-gray dacite and dense, black vitrophyre are identical to rocks in the vitrophyre plug of Reese Peak (Qvri) on the upper south slope of that peak, the probable source of the pumice. The pumice consists of scattered phenocrysts of plagioclase, hypersthene, brown hornblende, biotite, and fayalitic olivine set in a matrix of frothy glass.

Dacite of San Francisco Mountain (Pleistocene) (Qd).—Lava flows and autoclastic flow breccias of hypersthene dacite form one of the most distinctive and widespread units in the area. The lavas are mantled with blocks up to 3 m in diameter; some flow interiors are massive, but more commonly they display platy shear joints 1-5 cm apart. Individual flows range from 12 m to 74 m thick at their margins. On weathering, the lava flow blocks become smoothly rounded by disintegration to distinctive angular particles a few millimeters to a few centimeters in size. The lavas, probably erupted from a central vent, flowed down slopes and paleovalleys on all sides of San Francisco Mountain, except toward the southwest where they were blocked by an older cone of andesite (Qao) near Agassiz Peak.

Explosive eruptions produced both an air-fall pumice and a densely to moderately welded tuff. The pumice, found locally as lapilli in a thin bed between the older (Qao) and the younger andesites (Qay) on the ridge south of Humphreys Peak, can be traced from the ridge northeastward into the Inner Basin, where it lies on top of a dacite flow (Qd) and is overlain by younger andesite lavas (Qay). The welded tuff, deposited in a structurally controlled paleovalley, is exposed at the base of the unit only in the Inner Basin, where it crops out as a crescent-shaped bed 0-9 m thick on the southeast slope of Humphreys Peak.

The lava flows contain abundant phenocrysts of plagioclase and hypersthene plus sparse augite and magnetite in a microcrystalline to hyalopilitic matrix of lath-shaped plagioclase microlites, alkali feldspar, hypersthene, clinopyroxene, an opaque oxide, a silica mineral, and glass; tridymite is common in the vesicles; the centers of some thick flows display microgranitic texture consisting of subhedral feldspar and anhedral quartz. The matrix varies from light to medium gray where it is microcrystalline to dark gray to black at the base of some flows where it is glassy; oxidized rocks are pinkish to reddish gray. In the light-gray pumice on the ridge south of Humphreys Peak, phenocrysts identical to those in the lavas are set in frothy glass. The welded tuff is stratified, the lower part consisting of black, eutaxitic, densely welded glassy layers (15-30 cm thick) that alternate with less densely welded layers rich in lapilli-size lithic pyroclasts; the upper part of the tuff is moderately welded. The welded tuff consists of coarse ash, lapilli and blocks (up to 30 cm in diameter) of essential pumice, accessory hypersthene dacite vitrophyre, and accidental andesite in a black to red crystal-vitric ash matrix; the eutaxitic texture resulted from compaction of the pumice pyroclasts and possibly also from downslope flowage after deposition of the hot tephra in the paleovalley; the tuff dips 15° NW. The K-Ar age of the dacite is 0.75±0.17 Ma (P. E. Damon, written commun., 1977).

Dacite lava flows of Fremont Peak (Pleistocene) (Qdff).—Several lava flows of strongly flow-foliated, highly vesicular dacite were erupted during the final stage in the emplacement of a lava dome near Fremont Saddle; near the vent the lavas were extruded on a crumble breccia of the earlier endogenous stage of the dome (Qdf). Abundant phenocrysts of plagioclase (up to 5 mm long), brown hornblende, biotite, hypersthene, magnetite, and rare augite are in a microcrystalline to hyalopilitic matrix of plagioclase, alkali feldspar, hypersthene, fayalitic olivine, a silica mineral, an opaque oxide, zircon, and glass; tridymite is common in the vesicles. On fresh surfaces the rock is light gray. Deep-maroon xenoliths (up to several centimeters in diameter) of mafic composition are abundant locally.

Dacite dome of Fremont Peak (Pleistocene) (Qdf).—An endogenous lava dome in Fremont Saddle consists of dense to vesicular dacite that has steeply dipping flow foliations. The dome displays intrusive relationships with the older rhyolite dome (Qrf) along the western margin; a crumble breccia can be identified locally at the sides of the dome. Abundant crystals of plagioclase (up to 5 mm long), hornblende, biotite, hypersthene, magnetite, and rare augite occur as phenocrysts in a groundmass of plagioclase, alkali feldspar, hypersthene, a silica mineral, an opaque oxide, scattered fayalitic olivine, zircon, and glass. The rock is light gray where fresh, but hydrothermal alteration has locally changed the groundmass to colors of light yellow, lavender, and greenish gray.

Dacite breccia of Fremont Peak (Pleistocene) (Qdbf).—Block and ash breccias blanket the lower south slope of San Francisco Mountain; these breccias were deposited from hot-debris avalanches that were generated by collapse of the growing lava dome (Qdf) in Fremont Saddle. The debris avalanches flowed down the south flank of Fremont Peak and bifurcated around the Dry Lake Hills, the northern dome of which is covered by a thin splash blanket of the breccia. Uniformly oriented paleomagnetic poles measured in the blocks indicate the breccia was deposited at a temperature above the Curie point (K. L. Tanaka, oral commun., 1981). The preserved thickness of the breccia east of the Dry Lake Hills is 110 m, whereas the toe of the southwestern lobe is a minimum of 23 m thick; scattered blocks of the breccia occur on the tilted basalt lava flows (Qbmb) east of Elden Mountain. A roadcut in Schultz Creek valley exposes three breccia beds, the bottom two of which are each overlain by thin (2-cm-thick) ash layers from settled dust clouds; the entire deposit probably was formed from many avalanches.

The chaotic, unsorted, and unconsolidated breccia consists dominantly of a light-gray matrix of dacite lapilli and ash, broken crystals, pumice and glass shards, and isolated round to angular blocks (0.1 m to 2 m in diameter, but locally exceeding 7 m) of dacite identical in lithology to the dacite dome in Fremont Saddle (Qdf); fine ash and dust are distributed throughout the matrix. Crystals in the matrix are those that occur as phenocrysts in the blocks (plagioclase, hornblende, biotite, hypersthene, magnetite). Rare accidental blocks in the breccia include dense riebeckite rhyolite (Qrf), vesicular rhyolite and obsidian (Qro), older dacite of Schultz Peak (Qdso), and dacite (Qao) from Weatherford Canyon. The breccia can be traced upslope on Fremont Peak to the point where it disappears beneath thick lava flows of hypersthene dacite (Qd).

Pumice of Fremont Peak (Pleistocene) (Qpf).—Consists dominantly of unconsolidated air-fall deposits of angular lapilli- to block-size fragments of white to light-gray pumice that were erupted probably during the early stage of the emplacement of the lava dome in Fremont Saddle (Qdf). The pumice mantles a hornblende dacite lava flow (QThd) 2.4 km east of Sugarloaf, is exposed in pits along U.S. Highway 89 about 19 km north of San Francisco Mountain (Dennis, 1981), and occurs in a small outcrop at the west end of the valley between Sugarloaf and North Sugarloaf; scattered lapilli and blocks of pumice lie in a tuff between older andesite (Qao) and younger dacite (Qd) on the upper west slope of Fremont Peak, on the upper south slope of Aubineau Peak, and in the first saddle on the ridge northeast of Humphreys Peak. East of Sugarloaf, the pumice displays massive, normal-graded and reversely graded beds containing several thin interlayers of ash and lahars for a minimum thickness of 15 m (Dennis, 1981); the lower beds of pumice are aphyric and of rhyolitic composition (SiO_2, 73.7 percent), whereas the upper beds are porphyritic and of dacitic composition (SiO_2, 66.3 percent). Basaltic scoria is interlayered between beds of aphyric pumice and slightly porphyritic pumice. The dacitic pumice contains phenocrysts of plagioclase, brown hornblende, biotite, hypersthene, and fayalitic olivine in a pumiceous glass matrix; olivine locally mantles hypersthene phenocrysts. The pumice weathers light yellow. Numerous types of xenoliths occur in the deposits (Dennis, 1981), but the most conspicuous are accidental xenoliths of slate, phyllite, fine-grained schist, metagraywacke, and greenstone from the Precambrian units beneath San Francisco Mountain; accessory xenoliths of dacite are identical in lithology to the lava dome in Fremont Saddle (Qdf). Accessory(?)xenoliths of bluish-gray alkali-feldspar rhyolite, very similar in composition to the aphyric pumice, may have been derived from a dome on Fremont Peak that was completely disrupted during the eruption of the pumice. Similar xenolith suites in both the aphyric and porphyritic pumice beds suggest a common source.

Younger dacite of Reese Peak (Pleistocene) (Qdry).—Included in this unit are a lava dome and related flows that were emplaced on the northeast flank of San Francisco Mountain. The dome intruded the older andesite of San Francisco Mountain (Qao) and was subsequently covered by hypersthene dacite lavas (Qd); block lavas from the dome flowed 7 km to the north. Abundant phenocrysts of plagioclase (up to 6 mm long), brown hornblende, and hypersthene occur with sparse augite and rare biotite in a microcrystalline to hyalopilitic groundmass of plagioclase, alkali feldspar, hypersthene, an opaque oxide, zircon, and glass; silica minerals occur locally in the vesicles. The groundmass varies from dark to light gray and is reddish where oxidized. In the Inner Basin, the erosionally dissected dome forms steep slopes covered with loose rubble, the blocks of which contain more vesicles upslope; the lava flows to the north are mantled with blocks (up to 3 m in diameter) that weather to smooth, round surfaces. Xenoliths of Precambrian metamorphic rocks are comparatively numerous; they typically contain interstitial glass, which indicates partial anatexis.

Younger dacite of Humphreys Peak (Pleistocene) (Qdhy).—Block lava flows of low-silica dacite (SiO_2, 61.5 to

63.0 percent) crop out on the lower northwest slope of Humphreys Peak near Fern Mountain and Little Spring; the northern flow, 25 m thick at its margin, covers a basalt lava flow (Qbmb) and in turn is covered by lava flows of hypersthene dacite (Qd). Phenocrysts of plagioclase, hornblende, hypersthene, and biotite are set in a medium- to light-gray hyalopilitic matrix of plagioclase, hypersthene, fayalitic olivine, and glass; silica minerals line some vesicles.

Dacite of Aubineau Peak (Pleistocene) (Qdap).—Three distinctive units from the top down are: (1) Dacite lava flow, 53-70 m thick, massive, containing phenocrysts of plagioclase and oxidized mafic minerals in a pinkish-gray, highly vesicular matrix of plagioclase, alkali feldspar, an opaque oxide, tridymite, and glass. (2) Welded tuff, 30-50 m thick, eutaxitic. Lapilli and bombs are elongated, apparently flattened, fragments of dacite lava that contain phenocrysts of plagioclase, hornblende, hypersthene, and biotite in a dense, trachytoid groundmass; the tuffaceous matrix consists of broken phenocrysts, lithic fragments, an opaque oxide, and fine ash; tridymite has crystallized in pore spaces. (3) Massive, polymictic tuff breccia, 12-80 m thick, composed dominantly of randomly oriented flow-foliated lapilli and blocks of dense biotite-hypersthene-hornblende-plagioclase dacite up to 2.5 m in diameter, but includes a variety of types of older andesite of San Francisco Mountain (Qao) and rhyolite of an unknown source; toward the top of the breccia, the dacite blocks increase in abundance relative to the andesite. The lapilli and blocks are isolated in a pinkish-gray to light-red porous matrix of ash-size lithic fragments of dacite and andesite plus broken crystals of plagioclase, hypersthene, hornblende, and biotite; fine ash is distributed throughout; tridymite in the pores appears to be a cement. The bottom of the map unit is not exposed; the top is overlain by a 1-m-thick air-fall tuff, above which are older andesite lava flows of San Francisco Mountain (Qao).

Dacite of Agassiz Peak (Pleistocene) (Qda).—Dark-gray to yellowish-brown vesicular lava flows of dacite bear abundant phenocrysts of plagioclase, hornblende, hypersthene, biotite, and magnetite in a fine matrix of plagioclase, alkali feldspar, a silica mineral, pyroxene, olivine, and an opaque oxide; tridymite is common in the vesicles. The dacite is covered by andesite lava flows (Qao); it is exposed only in a deep valley on the middle south slope of Agassiz Peak.

Dacite of Dry Lake Hills (Pleistocene) (Qddh).—A cluster of at least eight coalesced lava domes extruded along regional fractures that strike N. 30°-40° W. and N. 55° E. south of San Francisco Mountain. Steeply dipping flow foliations defined by aligned phenocrysts and closely spaced fractures (5-30 cm) are common at the tops of the domes. The southern dome tilted the basalt lava flows of Switzer Mesa (Tob) during its emplacement. Three domes on the southeastern side of the cluster each extruded a small, block lava flow; the easternmost flow was covered by lavas from Elden Mountain (Qdeo and Qdey), and a 170-m-thick lava flow was extruded from the western row of domes onto the Tertiary basalt of Switzer Mesa; ramping structures are preserved locally on the lava flows. All the lava domes and flows are petrographically similar; they consist of abundant phenocrysts of plagioclase (strongly resorbed), hornblende (up to 5 mm long), hypersthene, and magnetite; olivine occurs sporadically, invariably inside jackets of pyroxene. The matrix is light to medium gray to lavender in color and consists of microcrystalline plagioclase, alkali feldspar, pyroxene, an opaque oxide, olivine, and a silica mineral; glass is minor. Dark-gray to deep-maroon xenoliths are numerous; ranging up to 25 cm in diameter, they may be aphyric or contain phenocrysts of plagioclase and olivine, with or without brown hornblende, in a fine felty groundmass of plagioclase, pyroxene, hornblende, an opaque oxide, apatite, and brown glass.

Older dacite of Reese Peak (Pleistocene) (Qdro).—A lava flow of low-silica dacite (SiO_2, 62.0 percent) crops out below the older andesite flows (Qao) on the lower northeast flank of Reese Peak. The flow is greater than 24 m thick at its distal margin; the bottom of the flow is not exposed. Strongly resorbed phenocrysts of plagioclase (up to 10 mm long), along with brown hornblende, hypersthene, biotite, and magnetite, are set in a vesicular, brownish-gray to lavender hyalopilitic matrix of plagioclase, alkali feldspar, pyroxene, olivine, an opaque oxide, and glass; tridymite occurs locally in vesicles.

Younger dacite of Schultz Peak (Pleistocene) (Qdsy).—Consists of a block lava flow of dacite erupted from a dike (Qdsi) on the east side of Schultz Peak; the flow is about 60 m thick, although the bottom is not exposed. Phenocrysts of plagioclase, hornblende, olivine, augite, sparse hypersthene, and magnetite occur in a medium- to dark-gray hyalopilitic matrix of plagioclase, pyroxene, an opaque oxide, and glass; tridymite occupies vesicles. A small erosional remnant of the flow crops out low on the southeast flank of Schultz Peak.

Older dacite of Schultz Peak (Pleistocene) (Qdso).—Included are an exogenous lava dome on the southeast flank of San Francisco Mountain and lithologically identical satellite domes that are partly buried beneath younger lavas on Doyle and Fremont Peaks. Erosion has extensively dissected the block lava flows, but the general morphology of the lobes is recognizable. Locally, silica-cemented autoclastic flow breccias stand out in erosional relief, but most surfaces are covered with loose, weathered blocks. Early during emplacement, the dome pushed up and tilted to the northwest the older andesite and dacite lavas of San Francisco Mountain (Qao); subsequent extrusions from the dome and one of the satellite domes partly buried the tilted lavas.

Strongly oxidized phenocrysts of hornblende (up to 7 mm long) and biotite, together with plagioclase, are set in a light-gray to pink trachytoid to microgranitic groundmass of plagioclase, alkali feldspar, a silica mineral, zircon, and pyroxene; glass and cryptocrystalline material are rare, occurring mainly near the intrusive contact at the north end of Schultz Peak. Olivine, augite, and hypersthene, as well as alkali feldspar and green clinopyroxene, occur sporadically as phenocrysts, but may reach several percent locally. Tridymite is common in the vesicles and may coat breccia fragments. Deep-maroon xenoliths, ranging generally from 1.2 to 8 cm, are conspicuous in most outcrops; phenocrysts of plagioclase, olivine, augite, and locally hornblende occur in a fine felty matrix of plagioclase, apatite, and oxidized acicular hornblende. The K-Ar age is 0.75±0.04 Ma (P. E. Damon, written commun., 1977).

Older dacite of Humphreys Peak (Pleistocene) (Qdho).—One or possibly two coalesced lava domes form the lower north slope of Humphreys Peak. Underlying rocks are not exposed, but in view of the dome's elevation (about 11,200 ft), it may have been emplaced on an early cone of San Francisco Mountain;

younger andesite lavas (Qay) partly cover the dome. Abundant phenocrysts of plagioclase, biotite, brown hornblende, and hypersthene occur in a light-gray to pink microcrystalline matrix of plagioclase, alkali feldspar, hypersthene, an opaque oxide, and tridymite. Deep-maroon xenoliths, 1.2-8 cm, are commonly aphyric, but may have scattered phenocrysts of plagioclase and hornblende in a felty matrix of plagioclase, hypersthene, acicular hornblende, and apatite; glass is interstitial.

Dacite of Hart Prairie (Pleistocene or Pliocene) (QTdp).—A block lava flow of dark-gray to brown, aphyric (less than 2 percent phenocrysts) dacite (SiO_2, 65 percent) crops out in Hart Prairie. Outcrops are isolated from other lava flow units by overlying coarse surficial deposits. Source of the flow is unknown. Although its petrography is unlike any unit now exposed on San Francisco Mountain, it is chemically similar to the dacites. Sparse phenocrysts of andesine, fayalitic olivine, and magnetite are scattered in a strongly trachytoid matrix of oligoclase, alkali feldspar, pyroxene, an opaque oxide, and glass.

Hornblende dacite (Pleistocene or Pliocene) (QThd).—A block lava flow of dacite is exposed in several isolated outcrops 2.4 to 3.8 km east of Sugarloaf. The base of the flow is not exposed; unconsolidated pumice of Fremont Peak (Qpf) rests on the top of the flow. Both the dacite flow and the pumice are overlain by coarse surficial deposits. The source of the flow is unknown, although its chemical composition is similar to the dacites of San Francisco Mountain. Scattered phenocrysts of plagioclase, brown hornblende (up to 4 mm long), and magnetite are in a medium-gray intersertal groundmass of plagioclase, alkali feldspar, orthorhombic pyroxene, biotite, and glass.

Tephra of North Sugarloaf (Pliocene) (Ttns).—Lithic tuff and lapilli tuff were deposited on a block flow on the south flank of North Sugarloaf. The tuff is overlain by the unconsolidated tephra of Sugarloaf (Qts). The angular ash and lapilli particles and scattered blocks are poorly sorted, poorly stratified, and moderately well cemented; the tuff is white to pale yellow where cemented by clay, but is deep brownish red to orange where cemented by iron oxide. The tephra particles are accessory lithic clasts of North Sugarloaf dacite lithology.

Dacite of North Sugarloaf (Pliocene) (Tdns).—The dacite erupted to form an exogenous lava dome at the northeast base of San Francisco Mountain; a small dome that extruded immediately southeast of the larger dome is of identical lithology. The lava flows are mantled with vesicular blocks several centimeters to about 1 m in size; dissection locally exposes the dense, flow-foliated interior of the dome. Biotite phenocrysts and rare plagioclase are in a groundmass of plagioclase and alkali feldspar microphenocrysts set in a light-gray to light-brown felsitic matrix of alkali feldspar, quartz, zircon, and oxidized mafic minerals. The K-Ar age is 2.78±0.13 Ma (P. E. Damon, written commun., 1977); this places the dome as the oldest known volcanic rock in the San Francisco Mountain volcanic center. The top and south sides of the dome are covered by a very thick to several-meter-thick blanket of tephra from Sugarloaf (Qts).

Extrusive rhyolitic rocks (Pleistocene)

Rhyolite of Sugarloaf (Qrs).—The alkali-feldspar rhyolite forms an endogenous lava dome that was emplaced within a tuff ring in the entrance to the Interior Valley at the northeast base of San Francisco Mountain. Angular blocks of flow-foliated rhyolite, 10 cm to 1 m across, on the dome make up a crumble breccia through which spines project near the top and around the rim of a small crater; flow structures in the spines, both open fractures and banding, dip steeply toward the center of the dome. The alkali-feldspar rhyolite contains phenocrysts of albite, sanidine, biotite, quartz, and rare fayalite (up to 2 mm in diameter) in a light-gray to light-brown, highly vesicular microvitrophyric matrix of alkali feldspar, quartz, fayalite, zircon, and glass; granitic microxenoliths having granitic and micrographic textures are common. The K-Ar age of 0.22±0.02 Ma (P. E. Damon, written commun., 1977) places the rhyolite of Sugarloaf as the youngest volcanic rock in the San Francisco Mountain volcanic center.

Tephra of Sugarloaf (Qts).—A tuff ring of unconsolidated rhyolite tephra was emplaced by phreatomagmatic pyroclastic surge processes during the initial stages of eruption of the Sugarloaf magma (Sheridan and Updike, 1975); the deposit mantles the top and south side of North Sugarloaf and the top of the dacite flow of Lockett Meadow (Qdlm); the tephra probably has been eroded south of Sugarloaf (Dennis, 1981). Depositional units in the tuff ring include crossbedded sand-wave beds, massive beds, and inversely graded plane beds (Sheridan and Updike, 1975). The tephra consists dominantly of essential ash and lapilli of moderately vesicular to moderately pumiceous alkali-feldspar rhyolite containing phenocrysts of quartz, albite, sanidine, biotite, and fayalite; the essential pyroclasts are identical in lithology to the rhyolite dome of Sugarloaf (Qrs); highly frothy pumice is rare. Phenocrysts in accessory vitrophyre are identical to those in the essential pyroclasts. Accidental xenoliths of andesite, dacite, and rhyolite of San Francisco Mountain lithologies were obtained from thick deposits of debris through which the tephra erupted. Xenoliths of Paleozoic formations are rare.

Rhyolite and rhyolite obsidian (Qro).—Two thick, flow-foliated lava flows of vesicular and spherulitic alkali rhyolite containing thin (a millimeter to a few centimeters thick) lenses of dense, black obsidian erupted from a rhyolite dome (Qrf) exposed on the north slope of Fremont Peak. One lava flow, now exposed in Doyle Saddle, flowed about 2.5 km down the southwest flank of San Francisco Mountain, and the other flowed almost 3 km to the east and southeast; the latter flow, about 85 m thick, is exposed in the Inner Basin on the northwest slope of Doyle Peak and in Weatherford Canyon. Both lava flows have been covered by younger lavas of the older andesite of San Francisco Mountain (Qao). The lavas are porphyritic, typically having phenocrysts of quartz and sanidine, but locally contain, in addition, either aegirine-augite or riebeckite; rarely the phenocryst assemblage consists of sanidine, anorthoclase, sodian ferrohedenbergite(?), and fayalite. The matrix, pinkish gray to bluish gray, is dominated by felsitic to microgranitic to trachytic alkali feldspar and quartz and has variable amounts of riebeckite, aegirine-augite, aenigmatite, glass, and devitrified glass; vesicles commonly contain tridymite, acmite, and quartz, but amethyst occurs locally; zircon is a ubiquitous accessory mineral. On top of the flow in Doyle Saddle, loose blocks of highly vesicular to slightly pumiceous glass contain phenocrysts of sanidine, sodian ferrohedenbergite(?), and fayalite. K-Ar ages are 0.70±0.10 Ma on obsidian from Doyle Saddle and 0.87±0.15 Ma on rhyolite from Weatherford Canyon (E. H. McKee, written commun., 1973).

Rhyolite of Fremont Peak (Qrf).—A lava dome of alkali rhyolite, exposed by erosion on the south side of the Inner Basin, is the probable source for the rhyolite lava flows (Qro). The dome was intruded by a dacite dome (Qdf) and was covered by younger lavas (Qao and Qd). Although the ground surface is covered with loose blocks, the dense texture of the rhyolite suggests deep erosional dissection of the dome. Scattered phenocrysts of sanidine (up to 5 mm long) and rare riebeckite, along with quartz and sanidine microphenocrysts, are set in a compact, light-bluish-gray groundmass of microcrystalline alkali feldspar and quartz together with dendritic crystals of aegirine-augite, riebeckite, and aenigmatite; zircon is a common accessory mineral.

Rhyolite of Core Ridge (Qrcr).—The thick, vesicular lava flow of contaminated alkali rhyolite at the southwest end of Core Ridge was fed from a small plug of alkali microgranite (Qmgi). On its east side, the flow abuts gently dipping andesite lavas (Qcc) that were presumably dropped down along a steep fault. On the west, the flow was disrupted during the initial cratering stage of the parasitic vent of the andesite unit (Qacr), and blocks of the rhyolite occur in the overlying breccia (Qacr) and also in a tuff between the truncated flows of older andesite (Qao) and the overlying aphanitic lavas (Qacr) on the sharp ridge between Agassiz and Humphreys Peaks. The westward dip of faint flow foliation in the rhyolite carries it below west-dipping andesite lavas (Qao) on the Agassiz-Humphreys ridge to the west. Abundant phenocrysts of anorthoclase, sanidine, and aegirine-augite zoned to aegirine, as well as scattered quartz, occur in a light-gray to light-brown felsitic to microgranitic groundmass of alkali feldspar, quartz, sodian clinopyroxene, and zircon; xenocrysts of labradorite and andesine are mantled sharply with alkali feldspar; cores of augite in the pyroxene phenocrysts may also be xenocrysts. Red mafic xenoliths are common. K-Ar age is 0.87± 0.03 Ma (P. E. Damon, written commun., 1977).

Younger rhyolite of Raspberry Spring (Qrry).—A small plug of vesicular alkali-feldspar rhyolite was intruded into the core of a rhyolite lava dome (Qrro) near Raspberry Spring in the Inner Basin late during the eruption of the dome. The rock is light gray where unaltered, but fractures, vesicles, and phenocrysts typically are coated with reddish-orange iron oxide. Abundant phenocrysts of sanidine, anorthoclase, quartz, green clinopyroxene (ferrohedenbergite?), and hastingsitic amphibole and a few scattered xenocrysts of hypersthene, andesine, and iddingsite pseudomorphs of olivine are in a microcrystalline matrix of alkali feldspar, quartz, and dendritic crystals of aegirine-augite and amphibole.

Older rhyolite of Raspberry Spring (Qrro).—A lava dome of alkali-feldspar rhyolite was found near Raspberry Spring in the Inner Basin. The dome was buried by andesite lavas (Qao) but has been exhumed by erosion. The rhyolite may be comagmatic with the younger, more alkaline, rhyolite plug (Qrry). Abundant phenocrysts of quartz (up to 2.5 mm in diameter), oligoclase, anorthoclase (with oligoclase cores), sanidine, and strongly oxidized biotite are in a light-gray compact matrix of microcrystalline alkali feldspar and quartz; zircon is a common accessory mineral. K-Ar age is 1.82±0.16 Ma (E. H. McKee, written commun., 1973).

Intrusive rocks (Pleistocene)

Intrusive dome of Humphreys Peak (Qdhi).—A small, shallow, dome-shaped pluton of dacite is exposed on the ridge northeast of Humphreys Peak. The 6- to 24-m-thick feeder dike, which is not cut by any younger dikes, extends about 1.4 km to the south where it crosses Core Ridge. On the lower southeast slope of Humphreys Peak, the feeder dike cuts a dike that fed andesite lavas (Qay). No evidence exists to indicate the pluton vented at the surface. Abundant phenocrysts and microphenocrysts of plagioclase, biotite, brown hornblende, and hypersthene occur in a light-gray microcrystalline groundmass of plagioclase, alkali feldspar, tridymite, hypersthene, zircon, and an opaque oxide; in the feeder dike, hornblende is olive-green in color.

Andesite dikes and sill (Qai).—Vertical to steeply dipping andesite dikes are generally about 3 m in thickness, but range from 0.3 m to 20 m. Dikes in Core Ridge appear to be randomly oriented, but those in the walls of the Inner Basin are arranged radially, converging on Core Ridge. Dikes are confined to the Inner Basin, except for one on the upper north slope of Aubineau Peak and one very small dike, too small to map, that cuts a rhyolite flow (Qro) in Weatherford Canyon. Some very short dikes in Core Ridge and the walls of the Inner Basin are not shown on the map. One andesite sill, dipping northeast, crops out on the east end of the ridge near the mouth of Beard Canyon; the top of the sill has been eroded, but the bottom has a 2- to 7-cm-thick glassy margin in contact with underlying tuff breccia (Qao). Typical phenocryst assemblages are plagioclase+hypersthene+augite+an opaque oxide and plagioclase+olivine+augite+an opaque oxide; the groundmass is dark gray to black where glassy and medium gray or light brown where microcrystalline; groundmass textures include hyalopilitic, intersertal, intergranular, trachytoid, and hypidiomorphic; silica minerals typically are absent, but cristobalite occurs in trace amounts in a few dikes.

Dacite dikes (Qdi).—Dacite dikes, emplaced mainly in Core Ridge and the north wall of the Inner Basin, are vertical to steeply dipping and typically about 8 m thick, but range from 1 m to 100 m. A radial pattern converging on Core Ridge is displayed. The dominant phenocryst assemblage is plagioclase+hornblende+biotite+hypersthene+an opaque oxide, but an assemblage of plagioclase+hornblende+hypersthene±augite+an opaque oxide also occurs; rarely is hornblende absent. A silica mineral occurs in the groundmass and vesicles of all the dacite dikes, commonly as an abundant constituent. Groundmass textures typically are microcrystalline, but some dikes are felty or trachytoid; rarely are they microgranitic or hyalopilitic. On fresh surfaces the dikes are light to medium gray to light brown. The dike nearest the east end of the ridge south of Beard Canyon yielded a K-Ar age of 0.95±0.20 Ma (P. E. Damon, written commun., 1977).

Quartz monzodiorite dike (Qmi).—The irregular, complexly shaped dike extending northeast along and near the crest of Core Ridge for 1,080 m is cut only by the feeder dike of the intrusive dome of Humphreys Peak (Qdhi) and a few small andesite and dacite dikes (Qai, Qdi). The quartz monzodiorite dike is one of the main feeders for the andesite lavas of San Francisco Mountain (Qay). Thin aphanitic margins grade abruptly into the phaneritic interior of the dike. Phenocrysts of plagioclase, hypersthene, augite, and olivine rimmed by pigeonite and inverted pigeonite are found in a fine- to medium-grained matrix of plagioclase, augite, pigeonite, inverted pigeonite, magnetite, and ilmenite; quartz and alkali feldspar, locally intergrown in granophyre that displays micrographic texture, and scattered scraps of green hornblende and biotite occur interstitially in the hypidiomorphic to intergranular matrix. Olivine invariably is altered to pseudomorphs of phyllosilicates and carbonate. On fresh surfaces the rock is medium gray to medium brown; it weathers orange brown.

Dacite intrusions and tuffisite of Elden Mountain (Qdti).—Early-stage intrusive rocks are exposed at the west and north sides of the broad recess between the lava domes of Elden Mountain and Little Elden Mountain. Three distinctive units, in order of emplacement, are: (1) Biotite-hornblende-hypersthene dacite. The early intrusive magma formed an intrusive dome that tilted and faulted the Paleozoic strata, injected a 12-m-thick dike along a fault, and broke through to the surface to build an endogenous lava dome (Qdeo). The initial eruption generated a pyroclastic flow that deposited a pumiceous breccia south and west of Elden Mountain. Abundant phenocrysts of plagioclase, hypersthene (containing olivine inclusions), olive-green to brown hornblende, biotite, and an opaque oxide occur in a fine-grained light-gray groundmass of plagioclase, alkali feldspar, quartz, pyroxene, zircon, and olivine; typically, the groundmass texture is hypidiomorphic, but near the intrusive contact, the texture is trachytoid, and it becomes hyalopilitic within a few centimeters of the Temple Butte Formation. (2) Tuffisite dikes and pipes. Intrusive into the biotite-hornblende-hypersthene dacite and the lower part of the Temple Butte Formation are tuffs 2 cm to several meters in thickness; they occur in isolated outcrops along and near the lower contact of the Temple Butte Formation. Angular to rounded lithic clasts that range in size from medium sand to boulders are isolated in a gray to light-brown matrix of finely comminuted silicate minerals or carbonate, depending on the local country rock; lithic clasts include the biotite-hornblende-hypersthene dacite, Temple Butte Formation, Supai Group, aphyric basalt, andesite, and all the lithologies in the pyroclastic flow breccia of Fremont Peak (Qdbf) that probably slid from its higher, upturned position into the tuffisite's vent. Crystals of sand size, generally angular, include plagioclase, hypersthene, hornblende, biotite, and magnetite; the crystals were derived mainly from the dacite intruded previously. (3) Hornblende-pyroxene dacite. Intrusive sheets into the biotite-hornblende-hypersthene dacite and the tuffisite crop out in discontinuous bodies between the cliffs formed by the middle dacite of Elden Mountain (Qdem) and the Temple Butte Formation. Abundant phenocrysts of plagioclase, hypersthene, hornblende, magnetite, and sparse augite are set in a light-gray to light-brown matrix of fine-grained plagioclase, alkali feldspar, pyroxene, zircon, and quartz in a hypidiomorphic texture. Relaxation of stresses following the emplacement of these early-stage intrusions may have allowed the tilted Paleozoic strata to subside by rotation normal to strike and displacement along faults.

Vitrophyre plug of Reese Peak (Qvri).—Dense, black vitrophyre forms a plug cutting the younger dacite (Qdry) on the upper south slope of Reese Peak. The plug is at least 30 m in diameter, but could be larger as the margin is covered by colluvium; the exposure is protected from erosion by a resistant, crosscutting andesite dike (Qai). The vitrophyre is dacitic in composition and contains phenocrysts of plagioclase, hypersthene, brown hornblende, biotite, an opaque oxide, and sparse fayalitic olivine in dense glass. Accessory xenoliths are abundant; they contain the same phenocryst assemblage in a light-gray hyalopilitic to vitrophyric matrix. Accidental xenoliths include the younger dacite of Reese Peak (Qdry), andesite similar in petrography to the older andesite lavas and pyroclastics of San Francisco Mountain (Qao), and devitrified rhyolite of unknown origin. The accessory xenoliths are identical to dacite blocks in the pumice of Reese Peak (Qpr), which indicates that the vitrophyre plug was the source of the pumice.

Tuffisite dikes (Qti).—Tuffisite dikes on the south slope of Aubineau Peak in the Inner Basin range in thickness from 0.3 m to 3 m within individual dikes, but generally are about 0.6 m to 1.2 m thick; dike margins are sharp, but may be irregular. Subangular to rounded pebbles and cobbles are scattered through a light-brown matrix of fine to medium sand and interstitial silt and clay. Pebbles and cobbles are mostly of Precambrian rocks and include greenschist, mica schist, phyllite, metadacite, metaconglomerate, jasper, and diorite; Paleozoic rock units identified are the Kaibab Limestone, Coconino Sandstone, Supai Group, and Temple Butte Formation; volcanic lithic clasts are mainly andesites similar to those of the older andesite of San Francisco Mountain (Qao). The fine to medium sand is dominantly quartz, many grains of which are well rounded and possess overgrowths; these grains presumably were derived from the Coconino Sandstone. Plagioclase, rare epidote, hypersthene, and brown hornblende also occur as sand. Lithic particles of coarse to very coarse sand and granules include obsidian, andesite, felsite, basalt, chert, and most of the Precambrian lithologies. On eruption of the tuffisite, a thin tuff bed containing similar lithologies was deposited on or very near the top of the older andesites (Qao); this tuff, now exposed on the upper south slope of Aubineau Peak, is overlain by scattered pieces of dacite pumice identical to the pumice of Fremont Peak (Qpf), above which are the dacite lavas of San Francisco Mountain (Qd).

Andesite dike of Snowslide Spring (Qsi).—The andesite dike in the valley between Core Ridge and the small ridge to the southeast in the Inner Basin is 730 m long and up to 35 m thick; the N. 58° E. strike coincides with the northeast trend of the Interior Valley. Horizontal columnar joints normal to the walls of the dike are prominent in the outcrops. The dike intruded between volcanic breccias of Core Ridge and several phaneritic plutons on the smaller ridge; emplacement of the dike appears to have been along a fault in the volcano that is related to regional northeast fractures. The rock (SiO_2, 59.3 percent) has a complex mineral assemblage consisting of abundant phenocrysts of plagioclase (some with reversely zoned margins), biotite, and hornblende, as well as scattered hypersthene and augite, along with microphenocrysts of plagioclase, hornblende, olivine, hypersthene, augite, and magnetite, all set in a microcrystalline groundmass of plagioclase, clinopyroxene, alkali feldspar, and tridymite. Hornblende and hypersthene phenocrysts may be partly or completely replaced by magnetite and pigeonite or cummingtonite, and biotite typically displays a sieve-texture replacement by magnetite and feldspar. Sparse quartz crystals have thin jackets of clinopyroxene; one specimen contains a large allanite crystal, and zircon occurs in all specimens. On fresh surfaces the rock is medium gray, but it weathers light brown. This dike and the small dome of older andesite on Agassiz Peak (Qaao) have a similar chemical composition and lithology, which indicate that the dike was feeder for the dome.

Microdiorite plug (Qmdi).—A phaneritic, dark- to medium-gray plug crops out on the crest of the small ridge southeast of Core Ridge in the Inner Basin. Phenocrysts of plagioclase, augite, olivine, magnetite, and scattered hypersthene occur in a fine-grained hypidiomorphic to xenomorphic groundmass of plagioclase, augite, pigeonite, inverted pigeonite, hornblende, biotite, ilmenite, magnetite, and minor residuum of quartz and alkali feldspar that locally display micrographic intergrowth. Olivine is rimmed with pyroxene and biotite and generally has been replaced by pyroxene-magnetite symplectite pseudomorphs; pyroxene commonly is rimmed with hornblende, which in turn is rimmed with biotite. Plagioclase is zoned from labradorite to oligoclase and may be mantled with very thin rims of alkali feldspar. This plug (SiO_2, 55.3 percent), intrusive into the pyroxene leucodiorite plug (Qpli), probably was a feeder for some of the older low-silica andesites of San Francisco Mountain (Qao).

Pyroxene leucodiorite plug (Qpli).—A phaneritic, dark-brownish-gray to medium-brown plug crops out on the small ridge southeast of Core Ridge in the Inner Basin. Toward the center of the plug, the rock is medium grained and has a hypidiomorphic granular texture; the major minerals are plagioclase (zoned from sodic labradorite to oligoclase), augite, hypersthene, pigeonite, inverted pigeonite, olivine, ilmenite, and magnetite; minor alkali feldspar may form partial mantles on plagioclase, as well as occur interstitially with small amounts of quartz. In the margin of the plug, the rock is porphyritic and has phenocrysts of plagioclase, augite, hypersthene, and olivine in a fine-grained hypidiomorphic groundmass; the pyroxene phenocrysts are mantled with pigeonite. Olivine displays a reaction relationship with low-calcium pyroxene. Deuteric cummingtonite(?) and biotite grew interstitially and at the expense of pyroxene, whereas olivine was altered to carbonate and phyllosilicates. The plug probably was a feeder for some of the older low-silica andesites of San Francisco Mountain (Qao); it was cut by the andesite dike of Snowslide Spring (Qsi).

Dacite dike of Schultz Peak (Qdsi).—A dacite dike cuts the east side of Schultz Peak. Where the dike is crossed by the water pipeline road from the Inner Basin, it is about 30 m thick; from the level of the road, the dike becomes narrower downslope and widens upslope, although above 8,600-ft elevation, thick colluvium covers the contacts and obscures the dike. Phenocrysts of plagioclase, hornblende, augite, olivine, and magnetite are set in a medium-gray hyalopilitic groundmass of plagioclase, pyroxene, an opaque oxide, and glass; tridymite occurs in the vesicles. The dike was the feeder for the dacite lava flow east of Schultz Peak (Qdsy).

Microgranite plug (Qmgi).—A medium-gray to pinkish-gray plug of contaminated alkali microgranite crops out on the small ridge southeast of Core Ridge in the Inner Basin. Abundant phenocrysts of anorthoclase, sanidine, and ferrohedenbergite and scattered quartz are set in a fine-grained xenomorphic to microgranitic groundmass of alkali feldspar, quartz, green clinopyroxene, and magnetite. Xenocrysts of andesine are mantled by thin, sharp rims of alkali feldspar; olivine xenocrysts are altered to phyllosilicates and opaque oxides; hypersthene xenocrysts are unaltered. Green to light-brown amphibole, biotite, and chlorite are deuteric. Fluorite is a conspicuous accessory mineral. Similarities of chemical composition and lithology suggest that the plug was the feeder for the alkali rhyolite lava flow of Core Ridge (Qrcr).

Rhyolite dike (Qri).—A north-striking dike in the Inner Basin crops out at the lower end of the cirque between Agassiz and Fremont Peaks. Although the dike is surrounded by surficial deposits that cover contacts, its surface expression is a well-defined low ridge that indicates the dike is about 75 m thick and 260 m long. The alkali rhyolite consists of scattered phenocrysts of sanidine and aegirine-augite and microphenocrysts of sanidine and quartz in a light-gray, compact groundmass of microcrystalline alkali feldspar and quartz, dendritic crystals of aegirine-augite, and aenigmatite; zircon is a conspicuous accessory mineral. K-Ar age is 0.95±0.08 Ma (P. E. Damon, written commun., 1977).

Rhyolite vitrophyre breccia (Qrbi).—A thin intrusion breccia forms the margin of the alkali-feldspar rhyolite plug (Qrry) where it intruded the core of the lava dome (Qrro) near Raspberry Spring in the Inner Basin. Abundant angular xenoliths of alkali-feldspar rhyolite of this lava dome (Qrro) are found in a dark-reddish-brown, partly devitrified glass matrix that contains isolated phenocrysts of anorthoclase, sanidine, quartz, and oxidized mafic minerals.

SEDIMENTARY ROCKS

Kaibab Limestone (Permian) (Pk).—Thickly to thinly bedded limestone, sandy limestone, and calcareous sandstone form hogbacks east of Elden Mountain; the formation is also exposed on the uplifted block west of Little Elden Mountain. The rocks are cream to light yellowish brown; they weather light brownish gray on pitted and knobby surfaces. Chert nodules and vugs lined with quartz are common. Thickness is 105 m.

Coconino Sandstone (Permian) (Pc).—Poorly exposed beneath the Kaibab Limestone on hogbacks east of Elden Mountain and on the uplifted block west of Little Elden Mountain. The quartz sandstone is fine to medium grained, well sorted, and white to light brown; grains are well rounded. Large-scale high-angle planar-wedge crossbeds are distinctive. The rocks weather readily to sandy soil. Combined thickness of the Coconino Sandstone and Toroweap Formation is about 230 m in Oak Creek Canyon 35 km south of Elden Mountain (Mears, 1950).

Schnebly Hill Formation of Blakey (1980) (Permian) (Psh).—Resistant beds form a hogback east of Elden Mountain; the unit consists of fine-grained sandstones and siltstones that are thinly to thickly bedded, display low- to high-angle planar and trough crossbeds, and are brick red. Thickness is 264 m. Equivalent to A member of Supai Formation of McKee (1945) in Oak Creek Canyon.

Hermit Formation of Blakey (1980) (Permian) (Ph).—Poorly exposed on a dip slope hogback of the Supai Group east of Elden Mountain. The rocks are thinly to thickly bedded siltstones and fine sandstones that contain minor lenses of conglomerate. Fresh and weathered surfaces are deep red to brownish red; the rocks weather readily. Thickness is 137 m; Blakey (1980) reports a thickness of about 90 m along the Mogollon Rim 40 km south of Elden Mountain. Equivalent to B member of Supai Formation of McKee (1945) in Oak Creek Canyon.

Supai Group of Blakey (1980) (Permian and Pennsylvanian) (PPs).—Consists of alternating fine-grained well-sorted quartz sandstones, silty sandstones, and siltstones; minor, thin (0.3-1.5 m), gray limestone and sandy limestone beds occur throughout. Dark-red sandstone and siltstone beds are cemented by hematite; with increasing calcite cement, the beds are orange, pink, and white. The rocks are thinly to thickly bedded and contain ripple-laminated beds, planar beds, low-angle crossbeds, and massive beds. Thickness is 326 m; Lane (1977) reports a thickness of 128 m at Sycamore Canyon about 50 km southwest of Elden Mountain. Upper part is equivalent to C member of Supai Formation of McKee (1945) in Oak Creek Canyon.

Redwall Limestone (Mississippian) (Mr).—Thickly to massively bedded, finely to coarsely crystalline crinoidal limestone containing sandy and dolomitic beds in the lower part. On fresh surfaces the rocks are white to bluish gray; they weather light gray to yellowish. The middle member is cherty. Local clay and silt beds are red. Thickness is 62 m (Farrar, 1980).

Temple Butte Formation (Devonian) (Dt).—The exposed rocks are thinly to moderately bedded, aphanitic to finely to coarsely crystalline, gray dolomites that have thin interlayers of red to maroon shale and local intraformational conglomerate; some beds in the upper part are limy and fossiliferous. Stromatolitic beds are thinly laminated. The dolomite is bleached white adjacent to the intrusive contact with the biotite-hornblende dacite of Elden Mountain (Qdti), but it is not obviously recrystallized. Only the upper 47 m of the formation are exposed (Beus, 1969).

Because of its composition at the type locality and elsewhere, this unit was described originally as the Temple Butte Limestone. Near San Francisco Mountain, however, it consists of dolomite, shale, and some conglomerate. Because of these lithologies, the unit is here designated as the Temple Butte Formation in the area of this report. Beus (1973) also has applied this designation to Temple Butte.

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