GEOLOGIC MAP OF VOLCANIC ROCKS ALONTHE EAST SIDE OF CENTRAL CHINO VALLEY, YAVAPAI COUNTY, ARIZONA

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Sullivan Buttes Latite and Associated Xenoliths

The Sullivan Buttes Latite is an intermediate, high-potassium volcanic rock located in the Transition Zone geologic province of central Arizona. The latite outcrops in Chino Valley, along the southwestern border of the Colorado Plateau. Lava flows, volcaniclastic deposits, and intrusive bodies of latite are found in the Chino Valley area (Tyner 1984). Radiometric dates of 21 to 27 Ma have been obtained from the latite, placing them in the Upper Oligocene to Lower Miocene (Nealey and Sheridan 1989). The latite is of interest as it contains a distinctive xenolith suite. The suite includes eclogite, amphibolite, clinopyroxenite, garnet websterite, granulite, and spinel peridotite (Nealey and Sheridan 1989). Xenocrysts of pyroxene, amphibole, plagioclase and quartz are common in the latite (Tyner 1984), and have been interpreted as originating in the lower crust to upper mantle. The xenoliths have been the subject of considerable study, including work by Arculus and Smith (1979); Schulze and Helmstaedt (1979); and Tyner and Smith (1986). The latite was characterized chemically and petrographically in detail by Tyner (1984), who was able to identify six distinct units within the latite on the basis of geochemistry and mineralogy. These units are amphibole, amphibole-biotite, biotite-pyroxene, mafic, basaltic, and upper latite.

Well-exposed buttes of biotite-pyroxene latite located 8 km to the east of the town of Chino Valley (north of Perkinsville Road) were mapped, geochemically and petrographically analyzed, and studied with respect to xenolith size distributions in order to provide constraints on the rheology and possible xenolith transport mechanisms operating during rise and emplacement of the latite. The buttes are interpreted as erosional remnants of two geochemically distinct lava flows of which the lower one-half to one-third remains. Magma water content at crystallization is estimated at 4-5% at average upper crystallization temperatures (at 1kbar) of 1039 ± 73 °C for the western flow and 870 ± 79 °C for the eastern flow. Histograms of frequency versus major diameter for garnet-pyroxenites and pyroxenites exhibit a pronounced skew towards small (<7 cm) xenoliths.

Apparent viscosities of melt-xenolith suspensions are estimated to range from 10^4 to 10^2 Pas for water contents of 3-7%. Minimum ascent velocities of melt-xenolith suspensions are estimated to range from 1.0 to 0.1 ms^{-1}. Reynold's Number values for conduit radii of 1-10 m range from 0.01 to 127, indicating laminar flow of the suspension. The observed size distribution of xenoliths has been interpreted using existing experimental and numerical models of particle flow in a cylindrical conduit. These models suggest that large xenoliths will concentrate in the conduit center while small xenoliths concentrate near the conduit walls prior to crystallization of the magma. The development of a magma yield strength (estimated to be 10^5 - 10^2 Pa) due to crystallization would tend to prevent the redistribution of xenoliths during horizontal lava flow. The observed skew of xenolith diameters is the result of preservation of the lower one-half to one-third of an initially parabolic to plug-like distribution profile. The research of which the present paper is a part is fully discussed in Stefanov (1992).

Field Relations

Outcrops of Sullivan Buttes latite are expressed topographically as low, highly jointed, rubble-covered buttes and higher, less dissected peaks. The buttes are surrounded by circular aprons of latite talus and silty alluvial cover. Alluvium is quite extensive and reaches thicknesses of at least 1 meter, and seems to have been derived primarily from erosion of the latite. Several rounded hills of Martin Dolomite capped by Redwall Limestone are present in the northeast and southeast portions of the field area. The alluvial aprons surrounding these outcrops are composed predominantly of carbonate-derived silt-sized particles. Stream cuts and washes contain a variety of sediments derived from the surrounding Proterozoic and Paleozoic rocks as well as the proximal latite.

Latite in the area is present as gray and pink varieties of massive, non- to poorly-vesiculated rock. Both latite varieties contain phenocrysts of light- to dark-green subhedral clinopyroxene (1-5 mm) and light brown to black euhedral to subhedral biotite (1-5 mm) in a fine-grained groundmass of feldspar and oxides. This latite is identified as the biotite-pyroxene type described by Tyner (1984). The latite contains abundant (8-10%) rounded to subrounded lower crustal to upper mantle xenoliths and xenocrysts.

Gray latite is predominant throughout the area. The western buttes are composed of gray latite that has apparently been intruded by pink latite which is present along fractures and as small dikes. The eastern buttes are primarily resistant pink latite underlain by gray latite and surrounded by gray latite talus. The monolithologic character of both color types suggests that they are the same latite which has undergone a differential weathering process or crystallized under different conditions. Contacts of the gray and pink latite are sharp to gradational with no observed changes in mineralogy or texture. Observed xenolith and xenocryst types and amounts do not differ significantly in the gray and pink latite . These observations are in contrast to those of Esperanca and Holloway (1986) concerning the gray and pinkish-orange latites of Camp Creek, Arizona, which have appreciably different grain sizes and xenolith amounts.

Textural character of the latite exposures is dominated by a northwest-southeast trending vertical joint cleavage that is expressed strongly in the western half of the area. Joints are less prominent in the eastern portion of the locality and trend north-south. Post-Upper Tertiary faulting and folding has taken place in this area (Krieger 1965); therefore, the joints could be structural in origin or may have resulted from cooling and contraction of the lava. Subsequent weathering along the joint planes has produced the incised, slabby texture observed at many of the buttes. The lack of similar jointing in adjacent country rock suggests that the joints originated from cooling of the lava. Resistant gray latite outcrops frequently exhibit a cobblestone-textured weathering surface, which was not observed in the pink latite. The texture is possibly governed by microscopic or chemical controls as no associated macroscopic features were observed.

Flow textures present in the lava consist of lineations, foliations, and possible sparse vesicles. Lineations are defined by alignment of feldspar laths in the groundmass. Where 3 dimensions can be observed, foliations are defined by alignments of feldspar grains and phenocrysts. Use of vesicles as a flow indicator is ambiguous due to small pits left by weathered-out xenoliths and xenocrysts. These pits weather in a manner that makes them indistinguishable from vesicles. Flow textures in the western part of the field area suggest a primary extrusion of lava along a west-northwest to east-southeast trend. Some of the flow indicators (both lineations and foliations) deviate from the northwest-southeast trend and possibly represent small breakout flows along the flank of the main extrusion or deflection of the main flow by paleotopographic barriers.

Eclogite xenoliths are less weathered in the vicinity of the latite-dolomite contact in the eastern portion of the field area and retain unaltered garnet and clinopyroxene. The xenoliths are found primarily as float. It is most likely that these xenoliths are the remnants of a flow that has been removed by erosion, leaving the xenoliths behind as lag deposits. The freshness of these xenoliths relative to other xenoliths in the field area is problematical. Reaction between the host latite and xenoliths or post-emplacement weathering apparently did not occur to the same degree as in other parts of the field area. The average size of the float xenoliths is approximately 10 to 15 cm in diameter.

The western lava flow remnants are locally bordered by a lahar which outcrops on the southwestern flank of Butte 5128 (peak elevation) between the 4860 and 4840 foot elevations. The lahar is exposed for approximately 100 meters as a flat-lying elliptical surface which trends northwest-southeast. The lahar is reddish-brown in color and is composed of angular to subangular clasts of red and highly altered gray latite, xenoliths, and xenocrysts in a fine-grained matrix of comminuted red and gray latite. Clast diameters range in size from approximately 5 mm to 60 mm. The unit is poorly sorted with no bedding or flow direction indicators. The highly oxidized nature of the outcrop suggests that the lahar may have been hot during emplacement. The reddish color may also be due to post emplacement oxidation.

The lahar outcrop does not contain clasts of pumiceous debris, and glassy material that may have been present has had ample time to devitrify (approximately 25 million years). Upper and lower contacts of the lahar are obscured by alluvial cover which hinders a more definite characterization of its nature and lateral extent. Because no evidence of structural disturbance is present in the area, field relations are assumed to be unchanged from the time of emplacement. The lahar is stratigraphically overlain by massive gray and pink latite.

Directly to the south of the lahar outcrop are three flow remnants. These buttes are similar in morphology to the buttes located immediately north and east. The northern edge of the peak of Butte 5098 contains a 9 meter wide, northwest-southeast trending volcanic breccia. Clasts of latite in the breccia are angular and range in size from pebbles to boulders, including a large (approximately 3 meters in diameter) block of gray latite apparently foundered from lava overlying the breccia. Sparse eclogite and altered

amphibolite xenoliths are included in the breccia. Contacts of the breccia and adjacent wall rock are gradational, with some clasts near the contact partially separated from the walls of the intrusion. The clasts of latite and xenoliths are supported in a vesiculated red and gray latite lava. The small size and lack of discernable eruptive products near the breccia suggest that this is not an eruptive "micro-vent" but a "jostle breccia" similar to those observed in basal layers of Snake River Plain rhyolites (Bonnichsen and Kauffman 1987).

The eastern portion of the study area contains two flow remnants which exhibit well-formed columnar jointing (Butte 5481 and a small cylindrical butte directly to the southwest). Exposed columnar joints are approximately 10-13 meters in height on both of the exposures. These structures are preserved in pink latite. The exposures of columnar jointed lava are separated by approximately 75 meters difference in elevation . The field relations can be interpreted as upper and lower colonnade structures or as a contiguous structure separated by faulting. An alternative interpretation involves paleotopographic control on a lava flow followed by erosion, however, textural evidence to support this interpretation was not observed. The similarity in height of the collonades on both buttes suggests that they may represent an originally continuous structure that has been affected by post-emplacement faulting.

Columnar jointing present in the field area provides a rough estimate of the degree of vertical preservation of the observed lava flow. The lack of preserved flow tops and flow top-derived talus suggest that a significant portion of the flow in the field area has been removed. The high amount of latite-derived sediment present in the field area supports this interpretation. The columnar joints present in the field area are interpreted to represent a lower colonnade structure, suggesting that the lower half of flows are preserved in the study area.

Foliation trends and the morphology of Butte 5261 suggest that it may be an extrusive dome. The degree of preservation of xenoliths increases in the vicinity of this structure, with eclogite nodules retaining unaltered garnet. The high degree of weathering of the structure makes a more precise determination of its nature difficult. Lava flow remnants present to the west may have originated from this area. Krieger (1965) suggested that Butte 5481 was a vent location; mapping for the present study suggests that Butte 5481 is a large lava flow remnant. The higher elevation of Butte 5481 compared to other flow remnants in the field area may be due to paleotopographic control or post-eruptive faulting in the area. No fault traces were observed adjacent to Butte 5481, however, erosion of the latite may have obscured any evidence of faulting.

Butte 5261 contains several isolated outcrops of olivine basalt along the eastern flank. A basalt dike trending southeast is present on the lower eastern flank of Butte 5261. The isolated outcrops of basalt on the upper flank of Butte 5261 and the dike are identical in

hand specimen. No surface connection between the outcrops was observed. The flatlands to the south of butte 5261 contain abundant basalt lag. A possible interpretation of the basalt-latite relations is a dike-sill system which has been dissected and exposed by erosion (cross-section B-B').

Lineations in latite immediately adjacent to the dike are parallel to the dike trend, suggesting forcible intrusion of the basalt and fracturing of the host latite. The intrusive nature of the basalt indicates a later age than that of the host latite. The dike may be related to the eruption of basalt near Mingus Mountain approximately 14 Ma ago (McKee and Anderson 1971).

Contacts of the latite with country- and basement-rock are sparse in the area due to alluvial and colluvial cover. Basement rock (Prescott Granodiorite) outcrops to the southeast of Butte 5128, but contacts between the latite and granodiorite are obscured by colluvium. The granodiorite is cut by a greenstone dike of presumably Proterozoic age. This exposure of granodiorite is possibly a fault block that was uplifted prior to emplacement of the latite. Evidence of faulting, if present, is obscured by colluvial and alluvial cover. Studies of the Proterozoic geology of the Chino Valley area suggest that the predominant basement rock is Mazatzal Quartzite, which outcrops to the west of the field area (Krieger 1965). Rare xenoliths of recrystallized quartzite and schistose material were observed in the latite.

The latite contacts Martin Dolomite in the northeast of the field area. No definitive latite-dolomite contact was observed due to overlying alluvial sediments and destruction by human activities. Nevertheless, contacts between latite and country rock can be approximately located by mapping float. The latite near the dolomite contact is light brown, less competent than gray or pink latite, and contains a higher proportion of biotite than that observed in other latite outcrops. An outcrop of obsidian is located on the northeastern flank of Butte 5150 (the butte is composed of Martin Dolomite and Redwall Limestone). Unfortunately, the outcrop is located within an area of dolomite that was apparently mined or blasted at some time in the past. This "Holocene reworking" has obscured the original field relations between the obsidian and dolomite. The outcrop displays a northwesterly trend, and the fragmentary contacts that remain suggest that the obsidian was emplaced as a dike in the dolomite.

In hand specimen, the obsidian consists of aphyric black glass that becomes progressively more devitrified from southeast to northwest. Orange-brown layers of possible devitrified glass are common throughout the outcrop and range in thickness from 1mm to <30mm. Some layers of black glass contain vesicles that are filled in with devitrified material. This obsidian dike may be the result of the intrusion of a silica-rich differentiate of the latite magma which reacted with the surrounding dolomite.

Discussion

Previous workers (Krieger 1965, Arculus and Smith 1979) have identified the latite buttes located to the north of Perkinsville Road in Chino Valley as intrusive plugs. However, the large volume of apparently latite-derived sediment, lack of well-exposed contacts of latite and country rock with intrusive relationships, and a rough alignment of measured foliations and jointing suggests that these buttes are remnants of a lava flow that has been dissected by erosion. Another possible origin for the buttes is that they are the remnants of a remobilized welded tuff that has devitrified.

The lack of recognizable flow margins, pyroclastic layers, soil horizons, and well-exposed latite-country rock contacts prevents straightforward interpretation of the volcanology of the area. There is indirect evidence that suggests an extrusive origin for the buttes. The most important feature is the rough alignment of joint and foliation orientations that can be traced along a northwest-southeast trend in the western portion of the field area. This trend changes to a more east-west orientation in the central portion of the field area. Krieger's (1965) field data, though sparse, are in general agreement with these trends.

The lack of inclusions of limestone or dolomite in the northeastern portion of the field area, where the latite-country rock contact can be best approximated, argues against an intrusive origin for the latite buttes. Contact metamorphism of the country rock and grain size variations in the latite that would be expected near an intrusive contact were not observed. The outcrops of latite present in the field area occupy the same stratigraphic position with minor variations that are possibly due to post-emplacement faulting or paleotopographic controls. No physical evidence to suggest that more than one lava flow is present in the field area (such as internal contacts) was observed on the buttes .

The criteria used by Hauseback (1987) and Bonnichsen and Kauffman (1987) to distinguish primary lava flows from remobilized pyroclastic flows have been used to test the likelihood of a pyroclastic origin for the latite. The latite outcrops do not contain significant lithic fragments of the surrounding country rock, nor was basal tephra observed in the field area. The lack of basal tephra is particularly significant near Butte 5481, which is the proposed vent area of Krieger (1965). Thin section analysis of the latite did not reveal relict pyroclastic textures (i.e. bubble shards, fiamme, or broken phenocrysts), but trachytic flow textures are common. While these observations do not preclude the possibility of complete remobilization of welded tuff, they do require that the latite last moved as a lava. This conclusion is similar to that reached by Bonnichsen and Kauffman (1987) for Snake River Plain rhyolites.

The lahar observed on the lower southwest flank of Butte 5128 may have been emplaced contemporaneously with the lava or may have been formed at a significantly later time. The reddish color of the outcrop may indicate high temperatures which would suggest a

syn- or rapid post-eruptive emplacement time of formation of the lahar. The lack of carbonized plant remains in the deposit, however, suggests a cool lahar formed subsequent to lava emplacement and cooling which has been oxidized. The relative homogeneity of the clasts in the lahar (latite, sparse xenoliths, and xenocrysts) and lack of accidental lithics suggest that the deposit was formed due to mobilization of eroded or fragmented latitic material rather than fluidization of near-vent eruptive products. Small lahars with similar characteristics to the field area deposit were observed during the 1980 eruption of Mount St. Helens (Janda, *et al.* 1982). These lahars were mobilized by accelerated melting of debris-laden snow and the emplacement of hot pyroclastic flows.

The volcanic breccia located on the northeastern flank of Butte 5098 does not appear to be a flow margin or basal breccia due to its position in the inferred lava stratigraphy. Similar breccias have been recognized in Snake River Plain rhyolites by Bonnichsen and Kauffman (1987). A review of their photographs and descriptions of breccias found in the rhyolites suggests that the breccia observed on Butte 5098 is a jostle breccia. This type of breccia is formed when cooled lava is broken up and moved by underlying, less viscous, hotter lava coupled with explosive steam release due to the introduction of meteoric water into the lava. The presence of the lahar near Butte 5128, if the lahar was formed during eruption, might suggest that significant meteoritic water may have been present during emplacement of the latite.

The general lack of recognizable pyroclastic units in the field area, especially near the proposed vent area of Butte 5481 (Krieger 1965), suggests that the eruption of the Sullivan Buttes latite in this part of Chino Valley was effusive rather than explosive. Trachytic texture of the latite indicates emplacement as a flowing material. Butte 5481 is composed of massive latite with areas of well-developed columnar jointing which is similar to other buttes in the field area with the exception of Butte 5261. This butte has a more rounded morphology than the other latite outcrops and lacks the steeply inclined jointing observed on other buttes. The low lava dome-type described by Blake (1989) is characterized by a low, rounded profile and a lack of a rubble collar and spines due to low lava viscosity. Butte 5261 has a similar morphology to this dome type, and has foliations suggestive of a radial-outward flow of lava. If Butte 5261 is an eroded dome, it may represent a vent area for the eastern flow.

The alkali-olivine basalt dike and sills located on the eastern flank of Butte 5261 indicate that this part of Chino Valley experienced igneous activity subsequent to the emplacement of the latite. Geochemical and petrographic study of the basalt suggests that it may be related to the late Miocene-early Pliocene Hickey Formation basalts described by McKee and Anderson (1971). Mingus Mountain, located approximately 14 miles to the southeast of the dike, was one of the major eruptive centers for the Hickey basalts, dated at 12.9 Ma (McKee and Anderson 1971). Age dating of the basalt dike would be necessary to determine if it is contemporaneous with the Mingus Mountain activity.

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