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November 15, 1971

Mr. John E. Kinnison
Kaiser Exploration and Mining Company
5938 North Oracle Road
Tucson, Arizona 85704

Dear John:

Thank you for the enlarged copy of the old Red Rock Quadrangle in the Tucson Mountains.

The class in Advanced Structural Geology is now finishing a structure section in the Brown Mountain Quadrangle. The section was started in 1965-66. Hope to have it published in next year's Digest.

Regards.

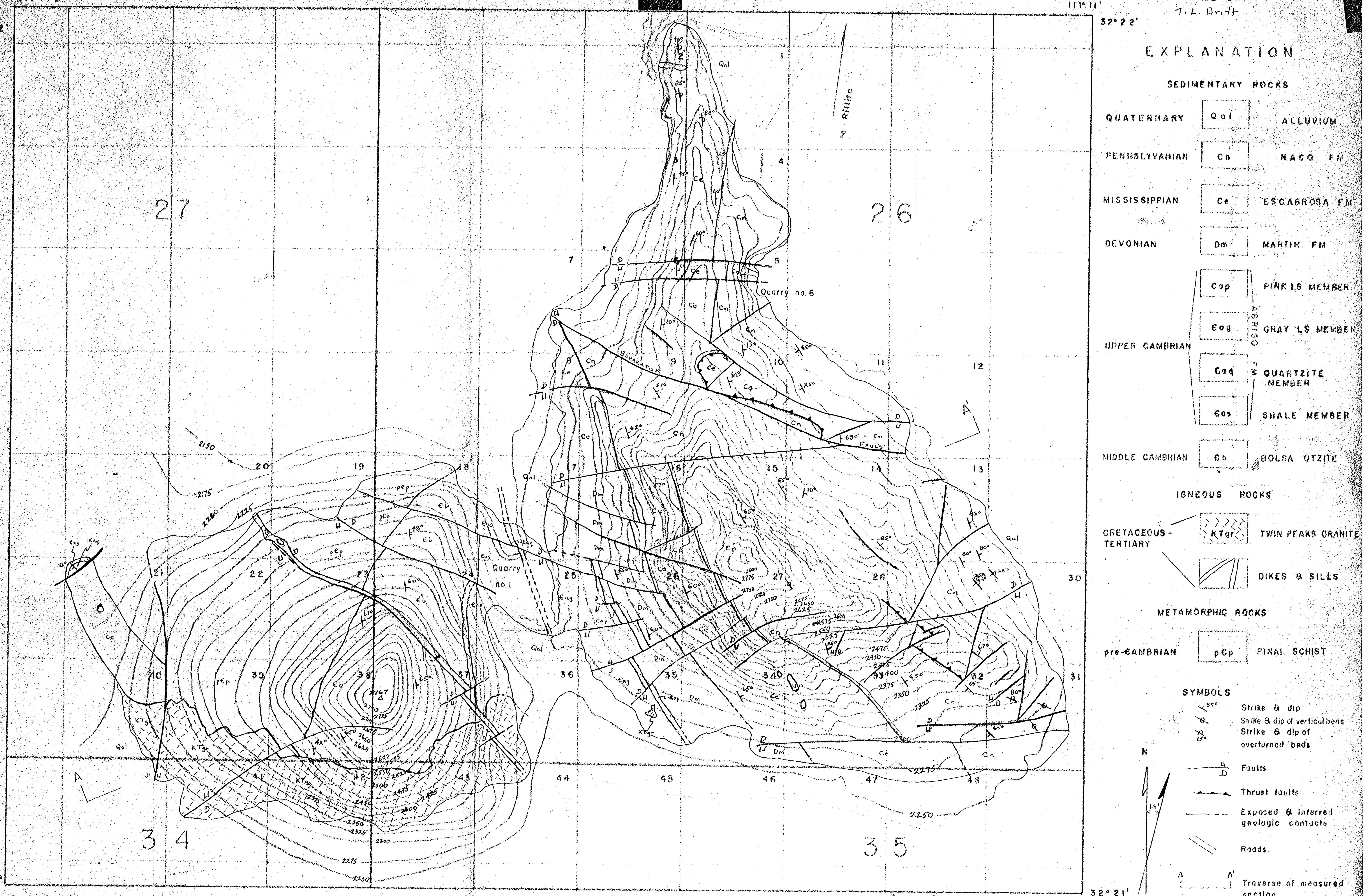
Sincerely,

Evans B. Mayo

Evans B. Mayo

EBM:srg

Picacho De Calera
T. L. Britt



GEOLOGIC MAP OF THE TWIN PEAKS AREA, PIMA COUNTY, ARIZONA

GEOLOGY BY T. L. BRITT, 1955

SCALE 1/3375

500 0 500 1000 FT

CONTOUR INTERVAL 25 FT.

PLATE I

JFK Files — Tucson N/S GENERAL Pima Co

Compliments

MB

A GEOLOGIC-GEOCHEMICAL STUDY
OF THE
CAT MOUNTAIN RHYOLITE

by

Michael Bikerman

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1962

ACKNOWLEDGMENTS

Thanks are due many people who aided me in this project. The work was done in 1960-1962 while I was on a research assistantship (supported by AEC contract AT (11-1)-689) in the Geochemistry Section of the Geochronology Laboratories of the University of Arizona. Dr. Paul E. Damon, my thesis advisor, encouraged and helped me in all phases of the study. Other faculty members of the University were of assistance in various aspects of the study; particular mention must be made of Dr. Dubois' aid in photomicrography and of the valuable discussions held with Dr. Mayo.

Interesting and worthwhile suggestions were received from conversations with AGI visiting geologists, Drs. R. W. van Bemmelen and Stewart Agrell. My colleagues in the Geochemistry Laboratory were helpful in many ways in various parts of the project. Thanks also are due George Gladfelter and Richard Hewlet for the use of the computer in the counting calculations. Finally, a word of thanks to my wife, Viola, for her aid and forbearance during the past months.

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ILLUSTRATIONS

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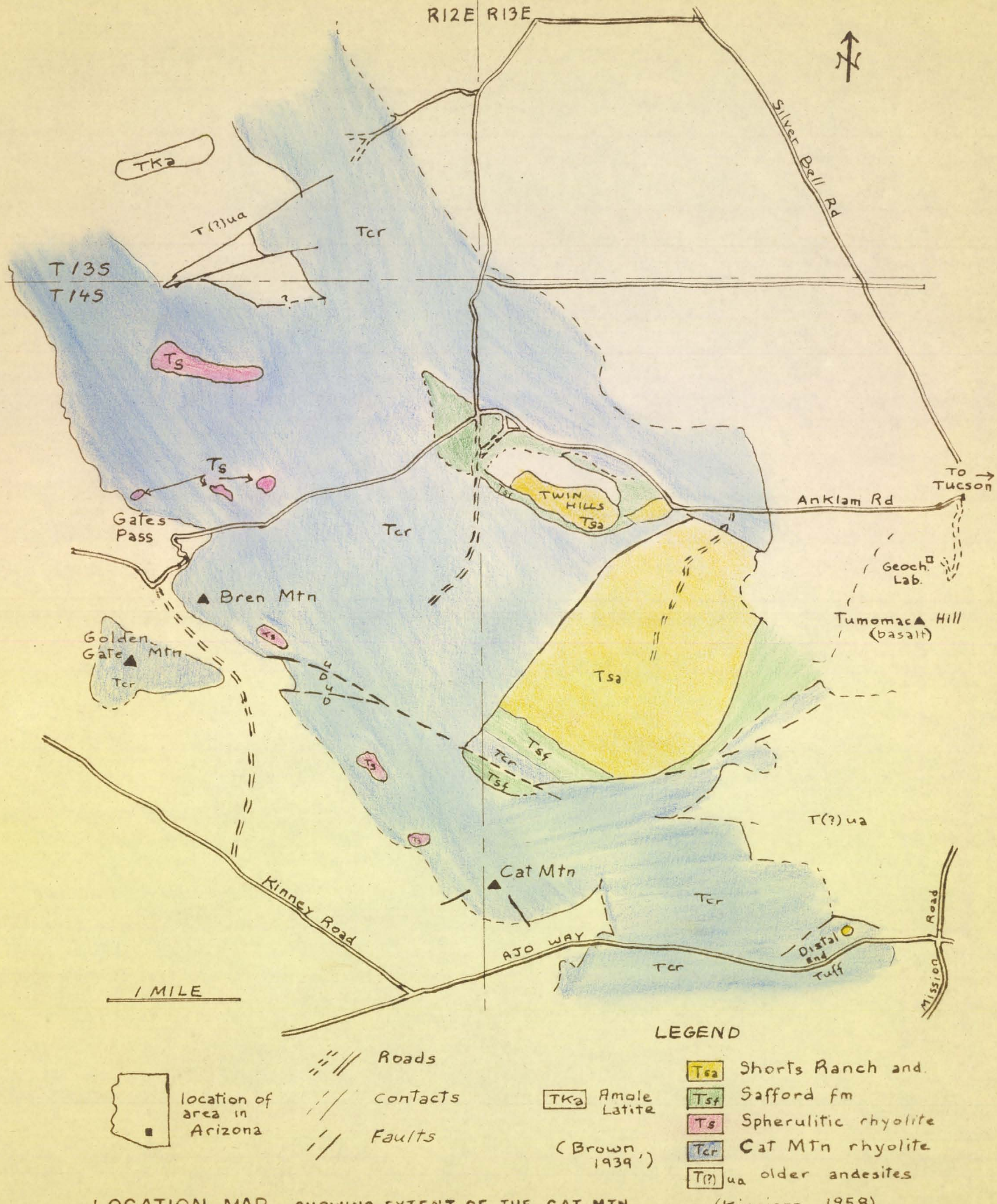
CHAPTER 1

INTRODUCTION

1.1 Problem

The Cat Mountain rhyolite is the major exposed unit in the southern portion of the Tucson Mountains, Pima County, Arizona. (See Plate I.) The name, Cat Mountain rhyolite, was originally given to the formation by Brown (1939). In his paper, Brown (1939) thought that the Cat Mountain rhyolite was a series of rhyolite flows and mud flows. Later work (Kinnison, 1958; Taylor, 1959) postulated a nuee ardente origin for the unit, and the rock was renamed a welded tuff.

The present study was undertaken to determine the nature of the Cat Mountain rhyolite using the ashflow concepts of Smith (1960a, 1960b), Ross and Smith (1961), and others as a guide. Tertiary ash flows are very common in the Basin and Range province and are thought to be pene-contemporaneous with the block faulting (Mackin, 1960). A detailed knowledge of the nature of the individual flows is a necessary prerequisite for any later correlation between flows. The current study of the Cat Mountain rhyolite was undertaken with this wider scale feature in mind.



LOCATION MAP SHOWING EXTENT OF THE CAT MTN RHYOLITE & RELATED UNITS

This report includes the results of field, microscopic, and geochemical study of the Cat Mountain rhyolite, supported by library research into welded tuffs in general, and the Tucson Mountains specifically.

1.2 Previous Work

The Tucson Mountains were mapped in the early 1930's by Brown (1939). This work is the only complete and comprehensive study of the range available, and, while some of the ideas advanced by Brown are now obsolete, it is still of great value. Several unpublished theses of The University of Arizona have covered various parts of the range. Of particular interest to this study are those of Imswiler (1959), Whitney (1957), Kinnison (1958), and Taylor (1959).

1.3 General Geology

1.3.1 General Statement. The Tucson Mountains are predominantly a pile of tilted volcanic rocks overlying with angular unconformity the Amole formation and related units. The volcanics range in age from Cretaceous (?) to Quaternary; the latter being basalts exposed just east of the Tucson Mountain range proper. A complete dating study of the volcanics is in progress within the Geochemistry Section of the University of Arizona Geochronology Laboratories, but no results are yet available. The Amole

Color photograph omitted

redbeds are considered to range from lower Cretaceous to upper Tertiary by Kinnison (1958). Underlying the Amole Group are limestones and other rocks of Paleozoic age. The pre-Cretaceous outcrops are noted mostly for their absence in the Tucson Mountains.

1.3.2 Structural Geology. The Tucson Mountains are an eroded horst between the grabens of the Avra Valley to the west and the Santa Cruz Valley to the east. The exact locations of the bounding faults are not known, but, assuming a block faulting origin for the range, the general location would be near the edge of the pediments. Secondary faults abound throughout the range, the area south of Ajo Road being particularly dissected (Kinnison, 1958).

There are no major fold structures in the post Amole rocks of the Tucson Mountain range.

Joints are well developed in some of the volcanic units, and the ones in the Cat Mountain will be discussed later.

1.3.3 Provenience of the Cat Mountain Rhyolite. The Cat Mountain rhyolite forms the easterly dipping slope of the Tucson Mountains and the main portion of the western escarpment. Stratigraphically, it lies above the Tucson Mountain "chaos," (named by Kinnison, 1958) and below the Safford Tuff (Brown, 1939). This interpretation is being changed somewhat in this work, particularly as the chaos is now considered to be a member of the Cat Mountain rhyolite formation. Using the new interpretation, the Cat Mountain rhyolite lies unconformably on Amole beds, and is in turn covered conformably, with gradational contact in places, by the Safford tuff.

To the north of the range, the Cat Mountain disappears, as higher stratigraphic units become more prominent.

In several places, the Cat Mountain formation is punched through by intrusives. The most common of these is the spherulitic rhyolite, which forms small knobs standing a little above the surrounding terrain. Outcrops of this intrusive are commonly associated with the Tucson Mountain chaos (Kinnison, 1958). The possibility that the spherulitic rhyolite has a relationship to the Cat Mountain rhyolite is entertained later on in this thesis.

Other intrusives include the Biotite rhyolite (which is actually a quartz latite and, in part, a flow rock) and younger andesites, both exposed south of Ajo Road (Kinnison, 1958).

CHAPTER 2

GEOLOGY OF THE CAT MOUNTAIN RHYOLITE

2.1 General Statement

This section contains the result of field and petrographic studies of the Cat Mountain rhyolite. The work was done using Brown's (1939) and Kinnison's (1958) maps as a base. No mapping as such was attempted, but the changed interpretation of the chaos unit as presented here would require an extension of the boundaries of the Cat Mountain rhyolite.

2.2 Structure

Joint patterns were measured in several different areas of exposure of the Cat Mountain rhyolite. (See Plate III.) Predominant joint directions in the more welded portions are about N40-60E with dips ranging from vertical to twenty degrees of vertical in either direction. A second set running sixteen degrees or less east or west from a north-south line and dipping nearly vertically accompanies the first set in most places.

A third set crosscutting the second at right angles and with high angle southerly dips is also quite common.

Figure 1. Cat Mountain from the Southeast.

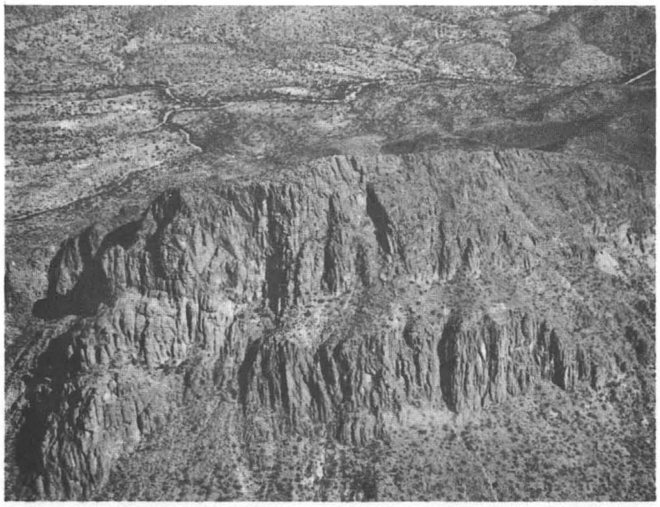


Figure 2. Cat Mountain from the SSW. Note: Jointing on upper welded zone and slumped blocks below it.

PLATE III

In the less welded zones below the welded zones, the joint directions are not as clearly defined except where alteration has occurred. A northwest direction is found somewhat more frequently in these zones than in the harder welded areas.

Alteration zones around the joints are commonly encountered. Hematite and limonite are the replacing minerals forming red and orange yellow bands often coated in turn by a black surficial deposit of manganese (?).

The intensity of alteration varies quite randomly throughout the Cat Mountain rhyolite, but tends to be more frequent south of Cat Mountain itself.

No attempt is made here to assign joints to a specific origin. Undoubtedly, many of the joints in the hard welded portions are normal cooling joints, but the continuation of many of the alignments into non welded material indicates that the later tectonic activity is also reflected in the present joint pattern.

2.3 Petrography

The first petrographic study in the Tucson Mountains was done by Guild (1905), before any of the formations in the range were named. From his given locations, it seems that the rhyolite which he describes is the Cat Mountain rhyolite. The photomicrographs accompanying the text show the characteristic eutaxitic texture of the welded portion of the unit, but, in accordance with the usage of the time, Guild called it "flow structure." Guild did notice some of the most characteristic features of the petrography of the Cat Mountain rhyolite, including the small (less than 3 mm usually), quite equidimensional phenocrysts of quartz, and the same sized highly altered orthoclases; the lack of clean biotite; the presence of black specks (magnetite) in the groundmass; and the similarity of the embayed quartz in the "rhyolite" (welded phase) and "tuff" (non welded phase).

The two main phases of the Cat Mountain rhyolite are the tuffaceous, poorly welded to non welded phase and the harder, more competent, ridge forming welded phase.

2.3.1 Non Welded Tuff. The tuffaceous phase is found underlying the welded zone along the western escarpment of the range and grades up fron non welded material in the "chaos" into the welded phase in a normal ash flow sequence.

Another interesting exposure of the tuff is in the area just west and south of the Quarry Hill gravel pit, with excellent outcrops in a small quarry just south of Ajo Road. This particular location was mapped as Safford tuff by Brown (1939) and as an unwelded island of Cat Mountain rhyolite by Kinnison (1958). Kinnison noticed the grading of this material into normal welded Cat

Mountain rhyolite, but offered no explanation. The interpretation of this area is that it is the distal end of a comparatively small ash flow, a separate cooling unit, which had its source to the south of Ajo Way. If the outcrops are followed south, they are seen to become progressively more indurated and welded, and eventually become indistinguishable from any other welded phase of the Cat Mountain rhyolite.

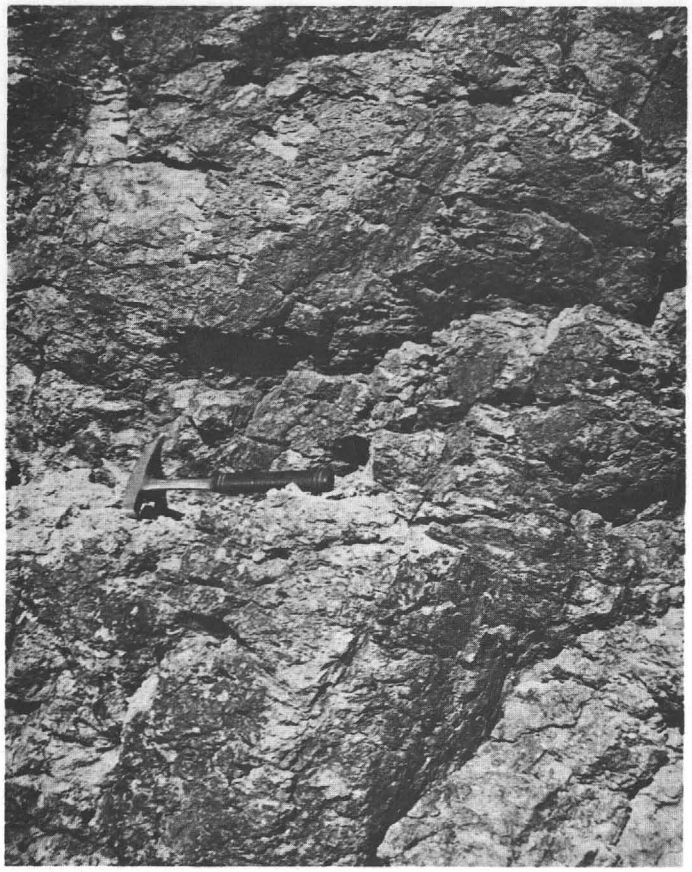
The non welded material is a white to grey, yellowish weathering, non indurated material containing many dark xenoliths, and light grey to white pumice fragments, ranging from a few millimeters to several inches in length. Hollow spherical lithophysae about an inch in diameter, surrounded by a narrow alteration zone, are found rather rarely. Under the petrographic microscope, the grey groundmass is seen to consist of fine glass shards showing slight compression, but retaining their original y-shaped or slightly curved shapes. Ross and Smith (1961) show several photomicrographs of similar bubble wall fragments.

Axiolites are developed in some of the larger shards, in areas of devitrification; while in other areas, the shards remain nearly completely black under crossed nicols, indicating that little or no devitrification has occurred. Specks of magnetite and hematite are ubiquitous.

The index of refraction of the glass lies between the indices of sanidine and quartz, and very close to the index of lakeside cement (1.537). Hydration, and oxidation of the iron content, have the effect of raising the index (Ross and Smith, 1961), and lowering the apparent silica content so that no precise determination of the composition by this means is possible. It does seem, however, that the matrix is probably closer to a latite in composition than a rhyolite.

Phenocrysts of subhedral to anhedral embayed quartz are common, and make up about five percent of the rock. The squarish in section quartz ranges in size from 1/3 mm to 2 mm on edge, with the larger sizes being more common. Altered subhedral orthoclase showing occasional carlsbad twinning is also found. The orthoclase is generally orange under plane polarized light and a blue color in reflected light; its color and alteration inhibit its study under crossed nicols. The amount of orthoclase is about two to three percent of the total rock.

Plagioclase feldspar in euhedral altering phenocrysts makes up about one-half a percent of the rock. Actually, the euhedral grains are usually broken off, leaving a crystal bordered part with one broken edge. The composition of the plagioclase is oligoclase-andesine.



Coarse Eutaxitic Texture Developed on Weathered Surface of the Lower Welded unit. The dark horizontal streaks are cavities formed by weathering of pumaceous material.

PLATE IV

Xenoliths of several different rock types are found in the rock. Andesitic material, dark grey to black in hand specimen and up to one-half inch in size is quite common. Under the microscope, it appears as a matrix of fine plagioclase microlites with magnetite phenocrysts and shows a marked but narrow alteration-resorption rim. 1 mm to 5 mm sized fragments of fine grained sandstone and arkose are also present. These tend to be focal points for silicification-devitrification of the groundmass.

2.3.2 Chaos Member. The chaos member is a non welded, devitrified and altered volcanic glass bearing large amounts of xenoliths of various sizes and compositions in it. The glass is pale orange brown in transmitted light and yellow in reflected light. Under crossed nicols, it has a salt and pepper devitrified appearance very much like the non welded ash flow tuffs above it. No individual glass shards could be distinguished, probably because of the pulverization they received from the large number of phenocrysts and xenoliths and also because of the presence of pervasive calcitic alteration.

Phenocrysts of embayed quartz, altering feldspar, and hematite rimmed square magnetite are common. The subhedral to anhedral quartz makes up about ten to twelve

Figure 1. Upper Welded Unit in Twin Hills Area on the Eastern Flank of the Range. Collapsed pumice shards showing fraylike edges. Plane polarized light.

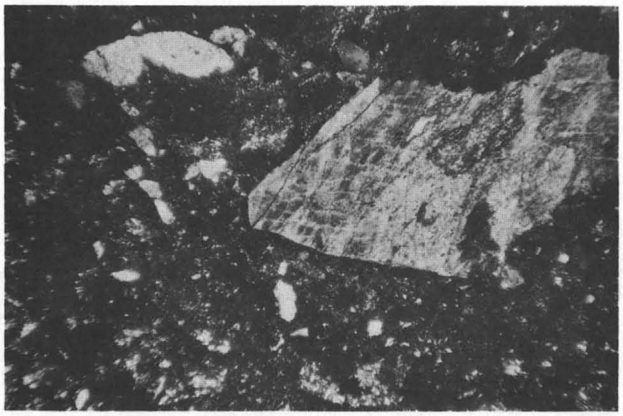


Figure 2. Chaos Matrix. Crossed nicols.

PLATE V

percent of the rock. The orthoclase fragments are mostly completely altered to calcite, but a few crystals showing the characteristic orange clay alteration of the Cat Mountain rhyolite are found. Plagioclase of oligoclase-andesine composition is found as broken subhedral to euhedral pieces, always with some degree of calcite alteration. The total amount of feldspar is around five percent, with no division possible between orthoclase and plagioclase because the calcite replacing pieces of each cannot be separated. Magnetite, and its alteration products, makes up about two percent of the rock. The hematite is concentrated around xenoliths and the magnetite phenocrysts. See Plate V, figure 2.

Xenoliths in the chaos range from massive blocks to fragments under a millimeter in size. The large blocks are made up of all the underlying units, and the microscopic xenoliths reflect the same source. In thin section, the chaos is seen to be made up of about thirty percent or forty percent xenolithic material.

Except for the larger xenolithic fraction, and the lack of recognizable shards, the matrix of the chaos is seen to be very similar to the lower unwelded unit of the Cat Mountain rhyolite.

The transitions from the non welded to the welded phases are gradual and no definite lines of demarkation can be drawn.

2.3.3 Welded Zones. Generally speaking, the welded zones are harder, show coarse eutaxitic texture on weathered surfaces (Plate IV, figure 1), have better developed joint patterns, and weather into steep cliffs (Plate III, figures 1 and 2).

Petrographically, there is not very much difference between the two types. In hand specimen, the welded tuff is red, purple, yellow, tan, or grey in color. The weathered color is darker than the fresh, and often masked by black manganese coating. Caliche is developed on a few joint faces to a thickness of half an inch or so. On freshly broken surfaces, black xenoliths of varied size are seen, making up from two to fifteen percent of the rock. Some xenoliths have a reaction rim around them; others don't. The reaction rims are more common in the stratigraphically higher portions of the flow, probably as a result of vapor phase alteration. Calcite veins were found in one area on the flanks of Cat Mountain itself, and these are of secondary origin.

Glassy quartz, and white to orange orthoclase, phenocrysts are common and make up five to fifteen percent of the rock. Both types of phenocrysts are commonly 1-3mm in size.

Pumice fragments are more tightly compacted in the densest welded part of the unit, such as is found capping the western escarpment. Staining tests, discussed in detail later on in this report, show a concentration of potassium in the tightly squeezed pumice shards, as opposed to the less compacted shards above and below.

Microscopic examination of the welded portions shows a brown colored groundmass under plane polarized light, and varying shades of orange-red to yellow brown under reflected light. The groundmass is composed of altered and devitrified glass and small pumice shards, with color being due to the presence of small blebs of hematite. In some sections, the hematite specks are interconnected; in others, they are individual pieces. The shards show characteristic squeezing around xenoliths and phenocrysts as illustrated in Plate VI, figures 1 and 2. Surface hardening of the rock by silicification is common, and the surface zone of about 1 cm thickness usually shows enrichment in iron. In the photographs, Plates V, VI, VII, and VIII, groundmass quartz and feldspar appear as small white blotches, and magnetite and hematite as black specks. Axiolitic and spherulitic growths are fairly common except where masked by later alteration. Fraylike ends (Plate V, figure 1) on pumice shards are evidence of the original pumaceous nature of the rock (Ross and Smith, 1961).

Phenocrysts of quartz and feldspar are common and together may form up to twenty percent of the total rock. The usually encountered values are about five percent quartz and three to six percent feldspar. Most of the feldspar is orthoclase or sanidine in varying degrees of alteration, but about one eighth of the total feldspar is alkaline plagioclase. The quartz is subhedral in squarish or rhombic pieces and shows resorption along the edges and sometimes centers (Plate VIII, figure 2) of the crystals. The subhedral sanidines are altered along their cleavage traces and edges to a fine grained material of greater birefringence, which probably is sericite. Orthoclases are nearly completely changed to a clay. Remnant cleavage traces are preserved in the pattern of growth of the clay. The plagioclases are nearly euhedral in the welded zone also. They show incipient alteration along twin plane boundaries, and are replaced by calcite to varying degrees. Some plagioclase crystals are nearly half calcite pseudomorphs, and all are full of small calcite blebs.

The only other minerals present outside of the xenoliths are rare, highly macerated, biotite remnants; squarish crystals of magnetite; blebs of hematite; and a few amorphous appearing stringers of a hydrous iron silicate.

Sandstone, arkose, andesite, and a few rare specks of limestone make up the xenolith composition of the unit. The xenoliths range from less than a millimeter to a centimeter in size.

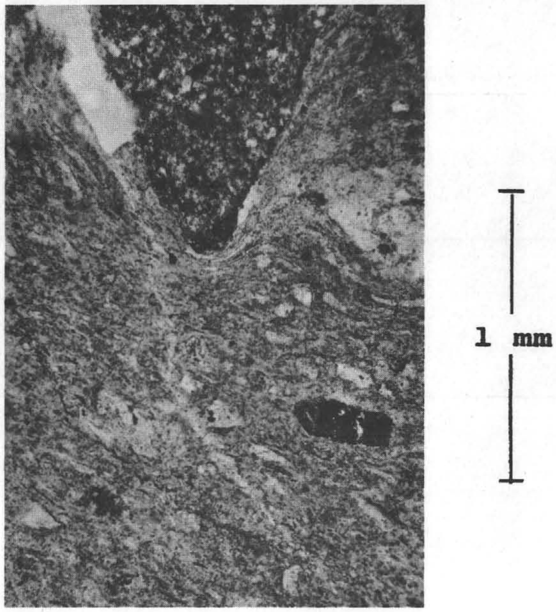
Secondary limonite-hematitic alteration is seen both in the field and under the microscope. It consists primarily of alteration of rock on the sides of joints and fractures. Post-iron manganese alteration is fairly well developed on joint surfaces, but quite rare in thin section (Plate VII, figure 1).

As seen above, the composition of the Cat Mountain rhyolite probably is closer to a quartz latite, but no change in name is proposed at this time.

2.4 Volcanology and Tectonics

The Cat Mountain rhyolite is definitely established as an ignimbrite or ash flow tuff after the criteria outlined by Smith (1960a, 1960b). The areal extent (about 24 square miles) is large compared to its thickness (average about 350 to 400 feet). It shows good eutaxitic texture, gradations from non welded to partly welded to welded tuff and back to partly and non welded again. In one area, west and south of Quarry Hill gravel pit, located in sections 28, 29, 32, and 33, T14S, R13E, a non welded distal end (Smith, 1961b) is found.

Figure 1. Middle Welded zone on Bren Mountain. Andesite xenolith with compressed shards.



plane polarized light

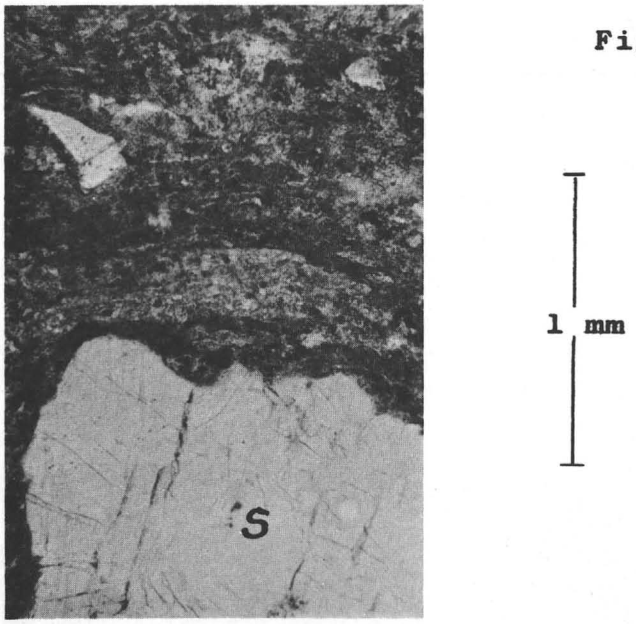
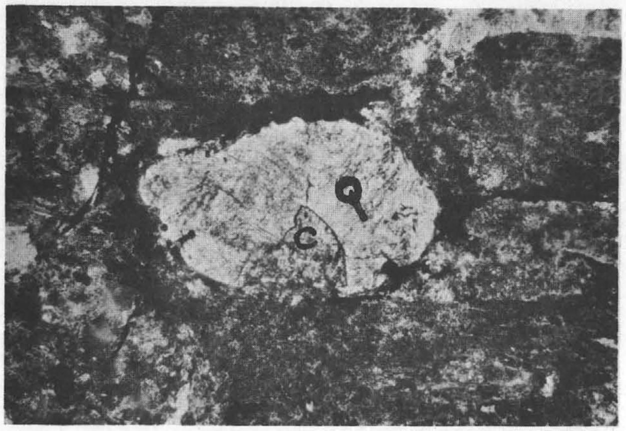


Figure 2. Same Welded Zone as figure 1. Large sanidine (S) phenocryst showing alteration along cleavage planes. Small resorbed quartz phenocrysts. Light grey zone between phenocrysts is axiolitic structure in a bent and compressed pumice shard.

plane polarized light

PLATE VI



├──1 mm──┤

Figure 1. Lower Welded Zone on Bren Mountain. Brown matrix, large phenocryst of quartz (Q) showing growth of calcite (C). Note: Black manganese filling in fissures around the phenocryst.

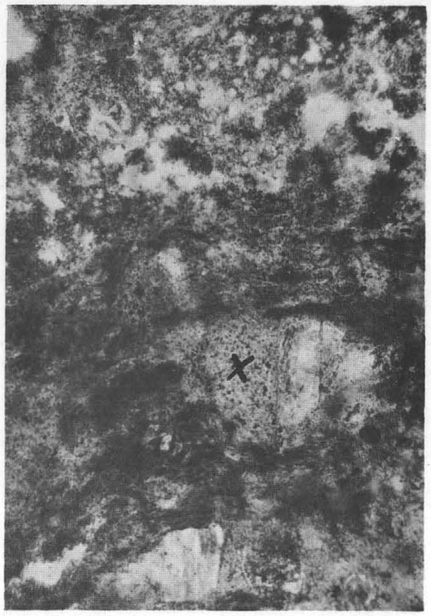
Both Pictures under Plane Polarized Light.

├──1 mm──┤

Figure 2. Bren Mountain, Partly Welded Unit below Figure 1. Devitrified shards, showing eutaxitic texture.

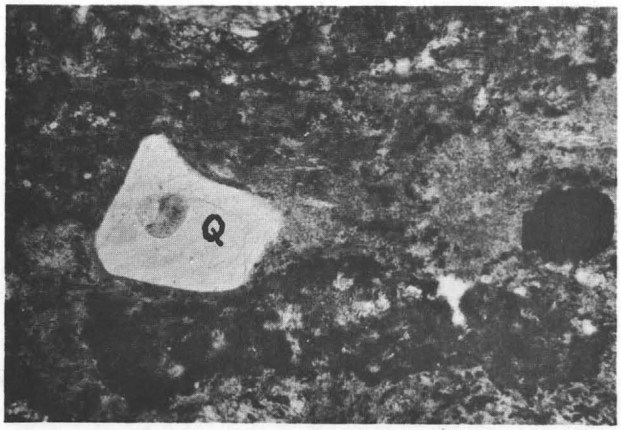
PLATE VII

Figure 1. Upper Welded Zone on Cat Mountain. The strong eutaxitic texture is masked by devitrification. Resorbing xenolith of andesite (X). Other white spots are quartz-feldspar.



1 mm

Both Photographs under Plane Polarized Light.



1 mm

Figure 2. Lower Welded Unit on Cat Mountain. Eutaxitic texture less well developed than in figure 1. White resorbed quartz phenocryst (Q). Black phenocryst on the right is magnetite.

PLATE VIII

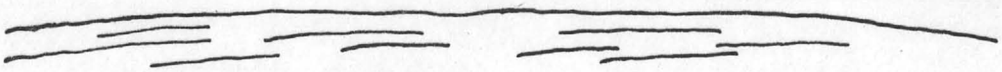
The relationship of the chaos megabreccia to the main mass of the Cat Mountain rhyolite is not as clear. Kinnison (1958) postulated that the chaos was formed by landslide and mudflow from material brought up by a major thrust fault, in an origin completely unconnected with volcanism. The current study presents a different approach for two main reasons. The first reason is that no other evidence for the presence of a major thrust fault was found in the field. Secondly, no line of demarkation between the chaos unit and the overlying "rhyolite" was found. Actually, the matrix of the chaos is a tuff completely indistinguishable in the field from the overlying Cat Mountain tuff. Using the maxim of parsimony, or "Occams' Razor," that "the hypothesis with the fewest assumptions is to be preferred" (Beveridge, 1957), it seems logical that if the tuffs are identical, a hypothesis assigning a common origin to the two units is to be preferred over any other. A careful study of volcanic processes provides the following hypothesis which seems to answer the questions raised. First, a short review of these processes may be of benefit to the reader.

Van Bemmelen (1961) classifies volcanic eruptions according to the gas content and composition, or viscosity. High viscosity, acid composition lavas are of three types depending on their gas content: plugs and domes for low gas content; Pelean eruptions (nuees ardentes) if medium in gas content; and ash flows (ignimbritic eruptions) for highly gas charged magmas. Another pertinent breakdown of particulate or fluidized eruptions is given by Smith (1960a). In this classification, the size in cubic kilometers of the deposit is correlated with its vent type. The Cat Mountain rhyolite, with about seven cubic kilometers presently exposed and an unknown amount lost in block faulting, falls in either the top of class four (1-10 cu km) or the bottom of class five (10-100 cu km). This range of sizes is predominantly erupted from multiple fissures or craters. Since no craters are known, multiple fissures will be used in the working hypothesis.

The general sequence of events (see Plate IX) postulated for the formation of the Cat Mountain formation began with the formation of the Tucson Surface (Kinnison, 1958), a peneplane on top of the Amole group sediments and older rocks.

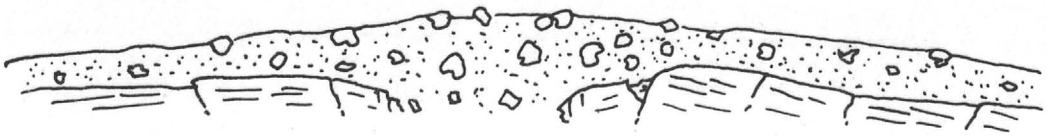
Rising magma then stoped its way through the Precambrian and Paleozoic sediments and younger rocks in many places, rising sufficiently rapidly so that the stoped off pieces of rock did not have time to be assimilated into the magma. This rising magma disrupted the Tucson Surface sufficiently to allow the formation of a basal conglomerate (Kinnison, 1958). This, and later

PLATE IX



STEP 1 TUCSON SURFACE

STEP 2 NUEE ARDENTE ERUPTION



STEP 3 "CHAOS" FORMED

STEP 4 TWO ASH FLOW ERUPTIONS

STEP 5 COOLING, WELDING, & INTRUSION OF SPHERULITIC RHYOLITE

STEP 6 TILTING & BLOCK FAULTING

VOLCANIC HISTORY

collapse, produced the present erratic attitude of the Amole beds underlying the Cat Mountain rhyolite. The state of the magma in these upper reaches of the conduits probably was a two phase mixture of comminuted magma and huge xenoliths in a continuous gas medium (van Bemmelen, 1961). Upon reaching the surface, in several places concurrently, the magma erupted in violent Pelean type explosions, hurling the mixture of cooling lava (ash) and the freshly engulfed broken blocks out on the surface around the various fissure vents. This gave rise to the present distribution of thick chaos with large blocks in certain areas (near vents) with the comparatively rapid thinning typical of nuee ardente deposits. The distribution of chaos blocks noted by Whitney (1957) with younger blocks further north (away from the postulated vent) follows logically. Similar studies in other areas undoubtedly would show the same characteristic.

Following the nuee ardente eruption came minor collapse of the surface accompanied by true ash flows. These derived from the same magma whose dissolution into two phases became more efficient with the expulsion of the large, cold blocks. The exact number of eruptions and the duration of each pulse is not known. There is no evidence for more than two ash flows from any one vent, and the presence of even two flows is debatable in some sections. In the area around Ajo Way, and on Bren Mountain, there appear to be two zones of welding separated by a zone of indurated, but less welded, material. On Cat Mountain itself, this two fold division is not as clear. Here the division at the same stratigraphic horizon is marked by a change in the predominent color of the rock from white above to red below. Microscopic study of material collected above and below the color transition shows a slight but inconclusive increase in degree of welding below the transition zone.

Assuming that there were two major ash flows from each of the separate vents, then the second one was hotter than the first, as the upper welded zone in all cases is much thicker and more competent than the lower.

The final phase of the Cat Mountain series of eruptions was the last gasp squeezing up of viscous magma into, and sometimes through, the ash flow sheet. This material was named the spherulitic rhyolite by Brown (1939), and usually outcrops in the areas of thickest chaos exposure--the postulated source areas. The few exposures of spherulitic rhyolite in other environments indicate either erosion of the Cat Mountain formation or the existence of intrusions in new fissures. Examination of outcrops of spherulitic rhyolite in areas of no thick welded tuff covering indicates that the spherulitic rhyolite intrusive broke through forcefully enough to completely disrupt the bedding in the blocks left in the vent area and hot enough to induce welding in the previously unwelded ash. Microscopic examination of the intrusive shows that the rock is much freer from xenoliths than the extrusive rhyolite. The decrease in xenolith content from the chaos flow through the ash flows to the rhyolite intrusive is quite conspicuous under the microscope and probably reflects a purging of extraneous material from the magma.

The Safford formation was deposited on the level top of the cooling ignimbrite. The tuffs of this formation preceded the sediments which, to a large extent, are reworked tuffs themselves. Later on, the Shorts Ranch and upper andesite flows emerged on the surface, and these, in turn, were followed at an unspecified time by the major block faulting.

CHAPTER 3

GEOCHEMICAL STUDY OF THE CAT MOUNTAIN RHYOLITE

The main efforts in this study were directed towards the radiometric determination of potassium throughout the Cat Mountain Rhyolite using techniques already proven in the laboratory (Damon, et al, 1960). This counting data was supplemented by staining tests to determine the location of potassium within the samples, and by a flame photometric and an x-ray fluorescence check on a specific sample.

3.1 Radiometric Study

The radiometric study involved the α and β counting of crushed and sized fractions of rock samples. Samples set aside for counting were pulverized and sieved. The sieve fraction between 60- and 200- or 300-mesh was normally used for counting.

β counting was done in a lead shielded low level anti coincidence counter, using three-quarter inch diameter planchettes. β counts measured derived primarily from the radioactive decay of potassium 40 to calcium 40. Secondary sources of β counts are the decay series of uranium and thorium and the decay of rubidium 87.

The β counting analysis for potassium was corrected for uranium and thorium by α counting. α counting was done using a two-inch circular thick source planchette and a two-inch low level scintillation head. No correction for rubidium was applied, so that the results as finally acquired are listed as potassium plus rubidium. X-ray fluorescence (C. M. Bock, personal communication) indicated a 145 ppm Rb content in the crosschecked sample, or a correction well within the statistical error of the potassium determination alone.

The procedure employed for β counting involved counting a sample overnight (usually sixteen to eighteen hours) and a background, starch, during the day. Occasional checks on 24-hour starch counts indicated that no significant diurnal variation in background occurred. Periodically, a Columbia River basalt standard and potassium dichromate were counted; the basalt for a normal sample length of time, and the dichromate for an hour or two.

In the α counting, the samples and background starch were alternated at 24-hour intervals. The longer starch count was necessary as the background was very low and showed diurnal variations. The Columbia River basalt was counted intermittently as a standard sample.

Raw results obtained for each counter were total count and time of count for both sample and background on either side of the sample. This information was then reduced to true β count per minute and true α count per hour by subtracting the background counting rate from the sample counting rate. The corrected sample counting rates were then inserted into the equation (see below) for potassium content, and the percent potassium plus rubidium in the rock determined.

The equation used is based on the known chemical composition of the Columbia River basalt (CRB) standard and the potassium content of C. P. potassium dichromate.

$$\% K_x = \frac{N_x}{N_s} K_s - CN_a$$

where

N_x is the β cpm of the sample

N_s is the average β count of the potassium dichromate

K_s is the potassium content of the dichromate (26.57%)

C is the constant correction factor for this counter, based on the CRB standard α count

N_a is the α cph of the sample.

The α correction factor (C) was computed, using the formula above, and substituting the values for CRB for the α and β counts (N_x and N_s) and the percent potassium. The factor computed was .022% K/α/hour, for the counters used.

The data is tabulated in Table I, which gives the sample number and location, the corrected α and β counts with their respective standard deviations, the α/mg/hr factor for easier cross referencing of the data, and, finally, the potassium content with its error calculated from the standard deviations of the counting rate. Checks were made on sample 15-N-T (200-mesh) with flame photometry (R. C. Erickson, personal communication), giving a value of 3.79 $\pm$ .02 s. d. percent K, and by x-ray fluorescence (C. M. Bock, personal communication), giving 3.89% K, as compared with the 3.80 $\pm$ .08% K obtained radiometrically.

Another check was performed by running the Smithwick shale standard through as a routine sample. The results give a potassium content of 1.63 $\pm$ .07% as compared to the standard value (Adams, et al, 1958) of 1.6%. The reproducibility of the radiometric analysis was checked on sample 10-F-2, giving results of 3.93 $\pm$ .07% K and 3.90 $\pm$ .08% K. Other checks on the reproducibility of β counting gave equally good results.

Table I. Radiometric Potassium Determinations

Location and No. of Sample	α cph	Error S.D.	α/mg/hr	β cpm	Error S.D.	% K	Error	Remarks
				Ajo Way section				
27-J-1	29.44	1.41	1.34	5.84	.07	4.53	.07	Distal end tuff
27-J-3	35.51	1.40	1.61	5.80	.09	4.36	.09	Distal end tuff
27-J-15	34.15	1.45	1.55	5.76	.08	4.36	.09	Hilltop S. of Ajo Way
25-S-6	36.15	1.56	1.64	5.28	.08	3.89	.08	W. of 27-J-15
2-0-5a	33.82	1.43	1.53	7.07	.09	5.53	.09	Distal end tuff N. of
2-0-6a	38.01	1.43	1.73	7.44	.16	5.76	.15	27-J samples
				Cat Mountain section				
10-F-2	39.30	1.55	1.78	5.37	.08	3.90	.08	Upper welded zone
10-F-6a	29.58	1.31	1.34	5.43	.09	4.17	.08	Middle welded zone
10-F-10	36.45	1.52	1.65	4.75	.09	3.41	.08	Lower partly welded zone
				Bren Mountain section				
15-N-T	32.83	1.43	1.49	5.21	.09	3.90	.08	Upper welded zone
15-N-T (200-mesh)	38.68	1.51	1.76	5.25	.08	3.80	.08	Check sample (see text)
15-N-8	30.28	1.47	1.37	5.39	.09	4.12	.08	Middle welded zone
15-N-14	29.12	1.37	1.32	4.16	.08	3.05	.08	Lower partly welded zone
				Lower welded zone just east of Cat Mountain				
2-N-2	34.72	1.51	1.58	5.57	.09	4.18	.09	N. of Ajo Way
				Eastern end of the range near Sweetwater Drive				
18-J-2	37.00	1.52	1.68	5.17	.09	3.77	.09	
18-J-4	38.35	1.60	1.74	5.22	.09	3.79	.09	

(continued)

Table I. Radiometric Potassium Determinations (continued)

Location and No. of Sample	α cph	Error S.D.	α/mg/hr	β cpm	Error S.D.	% K	Error	Remarks
Twin Hills section								
17-M-1	31.91	1.36	1.45	5.43	.09	4.11	.09	On hill S. of Twin Hills
17-M-3	30.88	2.36	1.40	5.06	.09	3.81	.09	In creek bed N. of 17-M-1
17-M-6a Safford tuff	33.94	1.54	1.54	5.91	.09	4.50	.09	Light grey xenolithic tuff
17-M-7 Safford tuff	28.63	1.45	1.30	5.72	.08	4.44	.08	Coarse xenolithic tuff
Gates Pass Road eastern portion								
3-J-1	32.98	1.32	1.50	6.95	.10	5.44	.09	
Comparison Standard--Smithwick Shale								
RP-102	22.77	1.32	1.03	2.41	.07	1.63	.07	
Counting Standard--CRB								
CRB	11.79	3.93	0.54	1.24	.02	0.84	.02	

The significance of the results is that there is a very close relationship between the calculated potassium contents of widely spaced samples within the same horizon. For example, the upper main welded zone has potassium contents ranging from 4.11 ± .09% at the eastern end of the range to identical values of 3.90 ± .08% found on top of Cat and Bren Mountains. The middle less distinct welded zone, which was defined only vaguely in the field and microscopic studies on Cat Mountain, shows up well in comparing the potassium content of this exposure to that of the better defined equivalent zones on Bren Mountain and in the Ajo Way section. The values are: Cat Mountain, 4.17 ± .08% K; Bren Mountain, 4.12 ± .08% K; and Ajo Way section, 4.18 ± .09% K.

The lower non or partly welded zones, as exemplified by the distal end section, show somewhat higher than average potassium percentages (from 4.36 in partly welded rock to 5.76 in clean tuff), due probably to retention of volatiles which would be lost in devitrification. The rather more weathered samples from the topmost tuffaceous units, above the main welded zone, show a lower than expected 3.80% average composition caused by leaching out of the potassium by weathering, or perhaps reflecting a lower original potassium percentage.

Examination of the α counting data separately fails to reveal any significant features about the uranium and thorium distribution within the sampled part of the Cat Mountain rhyolite.

3.2 Staining Tests.

Staining tests for potassium and calcium were undertaken on several polished slabs of the Cat Mountain rhyolite. The technique used was that of Bailey and Stevens (1960), involving a preliminary etch by HF; treatment with $BaCl_2$ to allow the barium ions to replace calcium ions; staining the etched slab with sodium cobaltinitrite to show the potassium distribution; rinsing and then staining with potassium rhodizonate to show the barium (ex-calcium) distribution. The potassium salts stain yellow, and the calcium salts stain red in this method.

The results of the cobaltinitrite stain tests showed a strong concentration of potassium in the flattened pumice shards in the welded samples, and in the shards and matrix of the tuffs. The matrix in the welded zones and the potassic feldspars also stained yellow, but, because of their greater competency, they required a longer exposure time to both the HF and the cobaltinitrite.

The rhodizonate staining showed that most of the calcium in the rock was in the andesitic xenoliths, with lesser amounts in the hard to stain plagioclases. Staining a sample of the unwelded rock with rhodizonate stain alone indicated that the matrix contained a small amount of evenly disseminated calcium, which is completely masked by the potassium yellow stain, if both are used. X-ray fluorescence indicated a net calcium content of .63% in the welded 15-N-T (200-mesh) sample (C. M. Bock, personal communication).

CHAPTER IV

CONCLUSIONS

The Cat Mountain rhyolite is a composite unit containing several stages produced in the evolution of a single magma. These stages include the basal blocky nuee ardente deposit, the two ash flow sheets, and the final fissure closing intrusions. The changes in the magma consisted mostly of variations of the gas content, or effectiveness of magmatic degassing.

The Pelean stage of violent eruption involves rapid cooling of the erupted material by adiabatic expansion of the gas (van Bemmelen, 1961) so that the emplacing temperatures are too low to allow welding. The temperature of the "chaos" was sufficiently above that of some of the engulfed material expelled from the fissure vents, that thick cooling rims formed in the tuffs enclosing some of the xenoliths. The activity within the upward stoping magma was of a sort that preserved the bedding and composition in the larger stoped blocks of sediment. Some small blocks show the effects of heat and silicification.

The ash flow which followed the Pelean eruption apparently was emplaced somewhat closer to its permissive cooling limit than the second upper ash flow. Permissive cooling (Boyd, 1961) is the difference between the erupting temperature and the minimum welding temperature of the rock. The original temperature, heat retentivity and emplacement times of the upper flow were such that a large continuous welded zone was formed. The lower welded zone is less continuous, and shows more lateral variation in the field. The second ash flow (upper welded zone) eruption produced incipient welding in the upper portion of the first sheet, leaving the present nebulous transition zone.

After the ash flow eruptions, a final upward push into the fissures thrust the now degassed magma into, or through, the overlying ignimbrite forming the spherulitic rhyolite intrusions. These intrusions have a similar relationship to the Cat Mountain rhyolite as the Pelean spine had to the Pelean eruptions.

Petrographic study of the ash flow portions of the Cat Mountain rhyolite indicates that the silica content, as estimated from phenocryst abundance and corrected groundmass index, is about seventy percent. The corrections to the index of refraction of the groundmass are approximations for the effect of hydration and alteration. While the given percentage of silica is somewhat low for a true rhyolite, and indicates that the rock is an adamellite (Nockolds, 1954) or quartz latite, the evidence is not sufficiently good to propose changing the formation's name at this time.

Radiometric study was again proven to be a useful tool in making correlations when combined with conventional geological methods. (See also Taylor, 1960, and Halva, 1961.) The degree of confidence placed in the use of this parameter will increase as the limits of its usefulness are better defined.

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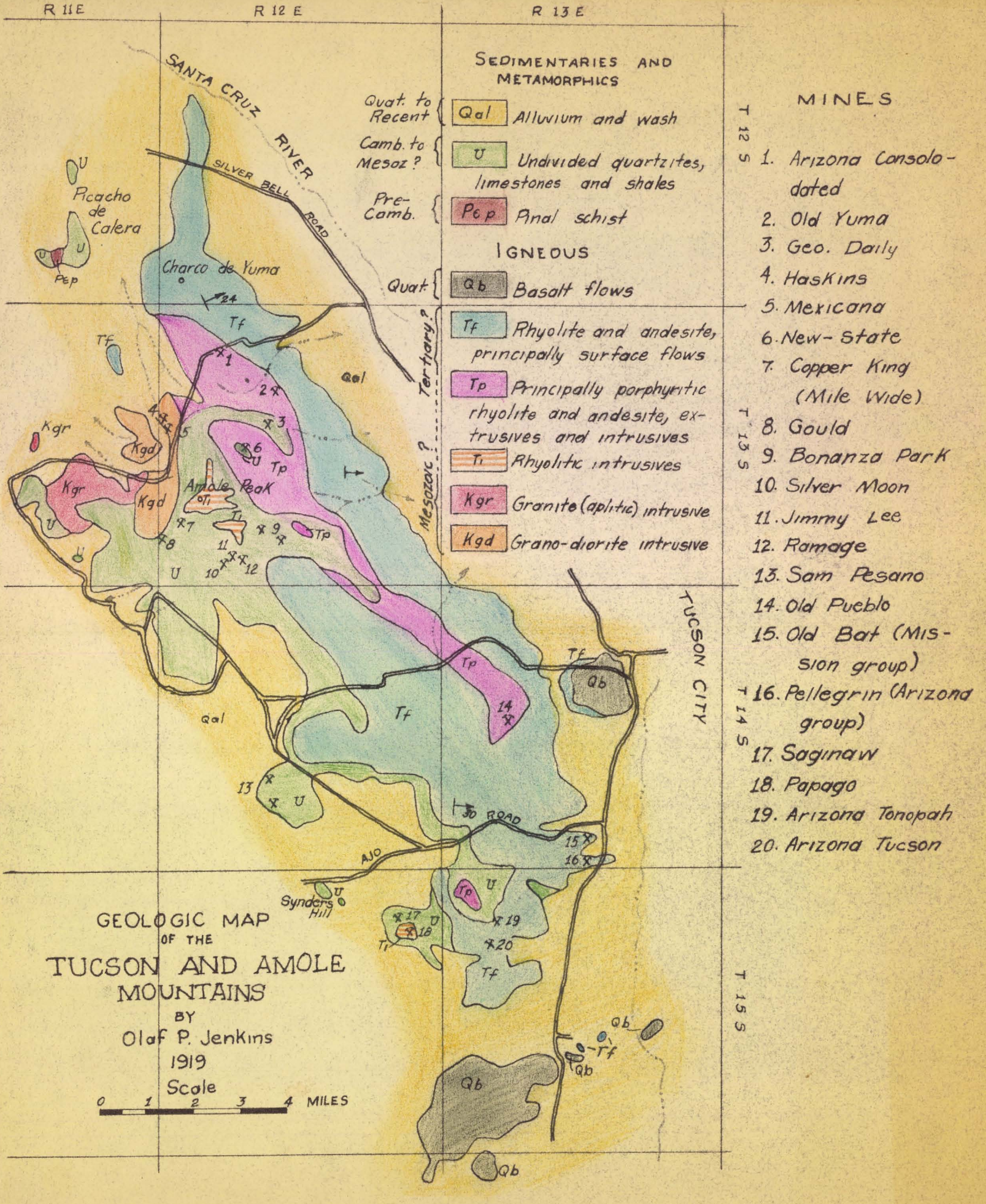

R 11 E
R 12 E
R 13 E
T 12 S
T 13 S
T 14 S
T 15 S
SANTA CRUZ RIVER
SILVER BELL ROAD
Picacho de Calera
Charco de Yuma
Amole Peak
TUCSON CITY
AJO ROAD
Synders Hill
SEDIMENTARIES AND METAMORPHICS
Quat. to Recent — Qal — Alluvium and wash
Camb. to Mesoz? — U — Undivided quartzites, limestones and shales
Pre-Camb. — Pcp — Pinal schist
IGNEOUS
Quat. — Qb — Basalt flows
Tertiary? — Tf — Rhyolite and andesite, principally surface flows
Tp — Principally porphyritic rhyolite and andesite, extrusives and intrusives
Ti — Rhyolitic intrusives
Mesozoic? — Kgr — Granite (aplitic) intrusive
Kgd — Grano-diorite intrusive
MINES
1. Arizona Consolodated
2. Old Yuma
3. Geo. Daily
4. Haskins
5. Mexicana
6. New-State
7. Copper King (Mile Wide)
8. Gould
9. Bonanza Park
10. Silver Moon
11. Jimmy Lee
12. Ramage
13. Sam Pesano
14. Old Pueblo
15. Old Bat (Mission group)
16. Pellegrin (Arizona group)
17. Saginaw
18. Papago
19. Arizona Tonopah
20. Arizona Tucson
GEOLOGIC MAP OF THE TUCSON AND AMOLE MOUNTAINS
BY Olaf P. Jenkins
1919
Scale
0 1 2 3 4 MILES