PETROLOGY, STRUCTURE, AND EVOLUTION OF A PRECAMBRIAN VOLCANIC AND PLUTONIC COMPLEX, TONTO BASIN, GILA COUNTY, ARIZONA

Thesis by

Clay Michael Conway

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To my *father*, *Cecil Marr Conway*,
who, as a driller, introduced me to geology and approvingly observed the course of my schooling until his passing in 1973;

To my *mother*, *Inez Nielson*,
whose influence in my formative years enables any success obtained in this study or in other pursuits;

and, with utmost love and appreciation,

To my *wife*, *Tamara Leigh Wilde*,
who, during the years of study, patiently carried an added burden of responsibility at home, while continually encouraging me in my work.

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On a smoggy November Saturday in 1966 I was intercepted on a hillside in the Tick Canyon area of Soledad Basin by Professor Leon T. Silver. With other new graduate students enrolled in Dr. Silver's field geology course I was mapping stratified rocks of the Oligocene Vasquez Formation. His only comment upon examining my map was: "All you need is time." That encouragement meant a great deal to an insecure new graduate student in the critical, competitive Cal Tech environment.

In subsequent years, Lee Silver, as my thesis advisor, has continued to provide the confidence, as well as the 'needed time' and much more, which enabled me to complete a Ph.D. study that has brought much personal satisfaction. For his infectious optimism and enthusiasm, continual moral support, and extensive financial support I am thankful. I feel a particularly strong sense of gratitude for the atmosphere of intellectual freedom in which I was allowed to work. Its value and the resultant personal growth, both only recently recognized, will have been worth the frustration and lost time of bad decisions and dead-end projects, and the painfully slow, independent maturation of perspectives, concepts, and hypotheses. Finally, the study itself was conceived by Professor Silver and benefits immeasurably in its perspective because of his pre-eminent studies of the Precambrian of the southwest and in its general content because of his keen insights into geologic processes and their manifestations.

An earlier study by Gordon Gastil in the Precambrian of Tonto Basin provided an indispensable foundation for the present work. Dr. Gastil generously provided assistance as I began my work and permitted reproduction of a portion of his map (see Plates 1 and 2 of this study).

I owe special thanks to Jay D. Murray for his friendship and profitable discussions of field and petrologic problems and to Kenneth R. Ludwig for enjoyable cooperative efforts in our studies of the Precambrian of Arizona. Lively discussions with Thomas A. Anderson were also beneficial.

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Janet Boike and Irene Keyes typed portions of the thesis. Susan McCurdy and Hortense Reece aided in occasional typing and various clerical matters during the course of the study.

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"The oldest rocks of the (Tonto Basin) district...
constitute a very interesting and intricate record.
Unfortunately, however,
as is so often true of the older pre-Cambrian,
this record is only dimly legible and is generally so fragmentary
that it is very difficult to read it."

Carl Lausen and Eldred Wilson, 1925
Arizona Bureau of Mines Bulletin 120

ABSTRACT

Precambrian exposures in Tonto Basin, central Arizona, are among the best in the southwest and the rocks are superbly preserved. Stratigraphic, structural, and petrologic relations of the Tonto Basin rocks, as determined in this study, contribute to our understanding of an important interval of Precambrian history in the southwest, and to the petrogenesis of volcanic and plutonic rocks emplaced in a great silicic alkali magmatic event.

In the only detailed field study within the Tonto Basin prior to the present work, Gordon Gastil defined a stratigraphic sequence fundamentally eugeosynclinal (wacke, slate) in lower parts becoming more miogeosynclinal upward (conglomerate, sandstone) and culminating with a great thickness of rhyolite. Current mapping shows that the extrusive rhyolite sequence is about 2 km thick and is overlain by a km of quartzite. Through joint efforts of L. T. Silver, K. R. Ludwig and the author, a correlation is apparent with corresponding eugeosynclinal, rhyolite and quartzite sequences in the Mazatzal Mountains. The names Alder Group, Haigler Group, and Mazatzal Group are proposed for the respective sequences in both areas. The Alder Group includes not only Gastil's lowermost Alder Formation (here renamed Breadpan Formation) but all of his overlying formations beneath the Haigler rhyolite. Haigler Group in Tonto Basin is composed of Winter Camp Formation, Haigler rhyolite undivided, and overlying Oxbow Rhyolite. The first was the basal part of Gastil's Haigler Formation, and the Oxbow Rhyolite remains as defined by Gastil. Haigler rhyolite undivided includes most of Gastil's Haigler Formation, much of his Hell's Gate Rhyolite (the remainder is intrusive), and extrusive rhyolite which is wide-

spread in Tonto Basin outside Gastil's mapped area. The name Christopher Mountain Quartzite is proposed for quartzite of the Mazatzal Group overlying Haigler Group rhyolites in Tonto Basin.

The folded sedimentary and volcanic strata of these three groups occur in a NE-SW belt flanked on both NW and SE by large granite bodies. The southeasterly granite, near Young, was shown by Gastil to be intrusive into Alder Group strata. The northwesterly granite (Payson Granite) was not mapped by him in detail. He hypothesized that both granites were part of a single widespread batholith and that the Payson Granite was gradational through granophyre and intrusive rhyolite into contemporaneous rhyolite (Haigler Group). L. T. Silver subsequently obtained U-Pb zircon ages of 1730 ± 15 m.y. for the Payson Granite, 1650 ± 15 m.y. for the granite at Young, and 1715 ± 15 m.y. for a rhyolite flow in the Alder Group (Flying W Formation), in apparent disagreement with both aspects of Gastil's hypothesis. This apparently placed Payson Granite in a northern, older regional geochronologic province (volcanic rocks ∿ 1750 - 1820 m.y.; plutonic rocks ∿ 1720 - 1760 m.y.) and the granite at Young and associated stratified rocks in a southern, younger regional province (volcanic rocks ∿ 1700 - 1720 m.y.; plutonic rocks ∿ 1650 - 1700 m.y.), suggesting that Payson Granite might be part of a basement upon which the volcanic and sedimentary rocks were deposited.

Major findings of the present study relating to this problem are that Payson Granite-granophyre, granophyre-intrusive rhyolite, and intrusive rhyolite-extrusive rhyolite contacts are non-gradational intrusive contacts and that Payson Granite has a smooth upper surface dipping gently and apparently concordantly southward beneath the sedimentary and volcanic strata. Enormous composite sills intruded, each beneath the preceding, in the sequence (1) rhyolite porphyry (Hell's Gate Rhyolite and King Ridge Rhyolite), (2) granophyre (Green Valley Granophyre), and (3) alaskite along the upper Payson Granite surface primarily between granite and Haigler rhyolite but locally into the folded stratified rocks (including Alder and Mazatzal Group rocks).

The sills are widespread along the upper Payson Granite surface and no direct relationship between Payson Granite and the stratified rocks could be determined. However, at Gisela where the felsic sills are locally absent, Payson Granite intrudes a small body of distinctive fine-grained rock characterized by megacrysts of plagioclase (mafite porphyry). Another of the small scattered masses of mafite porphyry intrudes Haigler rhyolite. It is hypothesized that all mafite porphyries are a single generation of igneous intrusive rock and that all occurrences are correlative. If this is so, Payson Granite must be younger than Haigler rhyolite. In support of this hypothesis, sedimentary and volcanic rocks of nearby pendants in diorite of the Gibson Complex (a differentiated gabbro-diorite body intruded by Payson Granite) contain lithologies similar to those in the Alder and Haigler Group strata.

From independent structural considerations an intrusive contact relation between Payson Granite and the stratified rocks is preferred over alternative basement and thrust contact hypotheses. This preference is based primarily on the apparent continuity of the sub-planar southward-dipping upper granite surface beneath the Gibson Complex. The intrusive hypothesis is also supported by an apparent distribution of more differentiated granite near the upper contact, suggesting a roof zone.

The hypothesized intrusive relation of the Payson Granite to the stratified rocks provides the first suggestion of a structural relation between rocks of the northern and southern geochronologic provinces and places the Payson Granite, and probably the Gibson Complex, within the interval of a great silicic alkali magmatic event in Tonto Basin, intermediate in age between Haigler rhyolite and the felsic hypabyssal sills. The regional implication is that latest plutonism in the northern province overlapped (along the two-province boundary) with earliest volcanism of the southern province.

All Precambrian X units in Tonto Basin have been folded and/or faulted. Primary textures in massive volcanic and plutonic bodies and quartzite are virtually unmodified and penetrative deformation is present only in less competent strata farthest from the large plutonic bodies. Earliest deformation was large-scale folding on NE-SW axes with shallow plunges. This was followed by thrusting and reverse faulting to the northwest under the same regime of NW-SE compression. These early structures were disrupted by left-lateral strike-slip and east-side-down normal offset on NE-SW to N-S faults. All deformation is probably older than Precambrian Y Apache Group rocks and presumably occurred in the interval 1715-1650 m.y. prior to intrusion of the granite at Young and possibly immediately subsequent to the earlier magmatic activity.

The deformation sequence suggests that Tonto Basin was initially the site of foreland folding and thrusting as the southern, basin crustal block impinged northwestward upon the slightly older proto-cratonic mass. It appears that regional tectonic stresses then shifted to give rise to a left-lateral couple in which the southern block was translated northeastward with a strike-slip system developing along or near the two-province boundary. Similarity of this hypothetical tectonic evolution to some modern tectonic histories may imply similar crustal processes.

Haigler rhyolite and rhyolite, granophyre, and alaskite sills are all silicic alkali rocks of similar and distinctive chemical composition. These leucocratic rocks are generally characterized by late-stage alteration of mafic silicate phases to hematite, and by coarse exsolution and pervasive hematite clouding of feldspars. In rare gray (unoxidized) facies, sodic (?) pyroxene (and amphibole?) is preserved in granophyre and intrusive rhyolite. Biotite in alaskite is poorly preserved. Alteration is attributed to hydrothermal activity associated primarily with intrusion of Green Valley Granophyre. Indications of slight alkali depletions and enrichments in Haigler rhyolite and Green Valley Granophyre, respectively, suggest some alkali exchange during the hydrothermal event. From textural and mineralogical evidence in granophyre, alkali enrichment may have occurred in the magmatic state.

Consideration of normative data and feldspar character of the silicic alkali rocks in light of experimental work on the petrogeny's residua system leads to the interpretations that the magmas were water-undersaturated at the deep site of phenocryst formation and that certain magmas originated by partial melting. The enormous volume of silicic rocks and the near absence of intermediate rocks in Tonto Basin argues against an origin by differentiation and suggests that all magmas formed by partial melting.

In a petrogenetic model based on these interpretations, on evidence for minimum depths of emplacement, and on comparative temperatures of formation (estimated by hypersolvus and subsolvus feldspar characteristics and mafic mineralogy), phenocrysts of the porphyritic rocks formed in an intermediate-level region of magma chambers where the various magmas began to crystallize at different temperatures depending on the degree of water-undersaturation. The Payson Granite magma may have been a high, early member. Upon ascension most magmas became water-saturated and were either extruded as ash-flow tuffs or crystallized as relatively coarse sill rocks (alaskite, granophyre, spherulitic rhyolite). Hottest, driest magmas perhaps did not become water-saturated and were extruded as viscous flows or emplaced as fine-grained porphyritic sills. Extreme textural variations and parallel variations in mineralogy in sills of comparable composition and emplacement level are best explained by variable water content.

The Tonto Basin silicic alkali province is a well-preserved, deeply exposed analog of modern ash-flow tuff caldera complexes, notable in its remarkable similarity, particularly in chemical composition, to the Yellowstone rhyolite plateau of Wyoming. Aspects of the petrogenetic model above are compatible with new evidence for the existence of magmas beneath Yellowstone.

Rhyolite and/or granophyre and granite of other silicic alkali provinces (including Yellowstone) commonly occur bimodally with basalt or with tholeiitic layered gabbro bodies. The predominantly silicic rocks in

Tonto Basin are associated with small amounts of mafic volcanic and hypabyssal rocks and the large mafic Gibson Complex is thought to have differentiated from a basaltic magma. The analogy with other bimodal terranes may break down, however, because the Gibson Complex has a calc-alkaline differentiation trend. The calcic character of the Gibson Complex is compatible with inclusion of the complex as part of the northern older province, but seems incompatible with the hypothesized contemporaneity of the Gibson Complex and the silicic alkali rocks. The apparent anomalous differentiation might be explained by assimilation of water by the magma upon intrusion into water-rich Alder Group sediments.

Anorogenic tectonic settings observed for other silicic alkali provinces imply that the Tonto Basin magmatism occurred as a post-orogenic event subsequent to orogeny of the northern province and prior to that of the southern province, or perhaps in a site of back-arc extension during the magmatic stage of the later orogenic cycle.

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INTRODUCTION

PREVIOUS WORK AND PURPOSE OF THIS STUDY

The Tonto Basin alkali rhyolite complex, the largest and probably the best-preserved rhyolite mass in the Precambrian of the southwestern United States, has heretofore been examined only in reconnaissance. The present field and petrologic study was initiated in an effort to determine the evolutionary history of these rocks and their structural and age relationships to associated Precambrian batholithic and stratified geosynclinal rocks. Specific objectives of the study are outlined in the following paragraphs. Because some of these objectives are the solutions of problems arising from earlier studies, previous work in the area will first be reviewed.

After a cursory field examination, Eldred Wilson (1939) designated a quartzite body underlying Christopher Mountain in the northeastern part of the present study area to be Mazatzal Quartzite, correlating it with type Mazatzal Quartzite thirty miles westward in the Mazatzal Mountains. He found the quartzite only in fault contact with granite and rhyolite but reported finding inclusions of both rhyolite and quartzite in the granite.

Mapping a few miles south of Christopher Mountain, Gordon Gastil (1958) worked out the structure and stratigraphy of a geosynclinal section consisting of slate, wacke, conglomerate, quartzite, and (mostly mafic) volcanic rocks. Gastil suggested that a quartzite unit (Houden Formation) midway up the section might be correlative with the

Mazatzal quartzite. He also examined in reconnaissance the rhyolite complex and concluded that it is underlain by the geosynclinal sequence.

The rhyolite and the predominantly clastic section occupy, respectively, northwestern and southeastern portions of a NE-SW trending fold-belt. This paired belt is flanked by large plutonic bodies, the Payson Granite to the northwest and the Young Granite to the southeast. Gastil found that the Young Granite intruded the geosynclinal sequence. In doing reconnaissance along the rhyolite-Payson Granite 'contact' to the northwest, he discovered an interjacent belt of granophyre. It appeared to him that there was a textural gradational change from Payson Granite through granophyre into rhyolite. He hypothesized that the Payson and Young granite bodies, the granophyre, and the rhyolite were all consanguineous and were essentially simultaneously intruded into or extruded upon, as the case may be, the sedimentary strata.

L. T. Silver (1964, 1967, pers. comm.) obtained U-Pb zircon apparent ages of 1730 ± 15 m.y. and 1650 ± 15 m.y. for the Payson and Young granites, respectively, and 1715 ± 15 m.y. for rhyolite in the Flying W Formation just below the Houden Quartzite in the geosynclinal section. Thus the upper part of the stratified sequence appeared to be intermediate in age between the two flanking granite bodies. This would mean that the rhyolite belt, if indeed underlain by the geosynclinal section, could not be contemporaneous with Payson Granite; it would be younger. The apparent ages conflicted with Gastil's hypothesis and were potentially contradictory to the relationship reported by

Wilson of rhyolite (possibly of the rhyolite belt) inclusions in granite (possibly Payson Granite).

On the basis of the zircon ages one could not rule out Gastil's hypothesis. Payson Granite had not been mapped and there was no assurance that it was not composed of separate intrusions of varying age. Likewise, the rhyolite belt had not been mapped and so the possibility existed that while some of the rhyolite might indeed overlie the geosynclinal sequence, some might also be older than these strata and possibly of the same age as Payson Granite. Lastly there are always complicating factors which make radiometric age determinations subject to some question, and in this case even if the 1715 ± 15 m.y. and 1730 ± 15 m.y. numbers represent true ages of formation of the respective rocks there is an overlap in the assigned errors.

Solutions to the apparent contradictions outlined above were hopefully to be obtained in the field mapping undertaken in the present study. The initial objective was to determine the nature of the granite-granophyre-rhyolite transition. It would also be necessary to define and map units within the rhyolite terrane in an effort to determine whether the entire mass is younger than the geosynclinal section or whether some might be of an older generation. Another objective was to extend mapping of the quartzite at Christopher Mountain thought by Wilson to be part of the regionally important Mazatzal Quartzite and to determine its relationship to the rhyolite mass.

The solutions of these stratigraphic, structural and sequential problems take on regional significance. Field and radiometric age studies in the Precambrian of the southwest defined a northern, older (1725-1820 m.y.) province and a southern, younger (1650-1720 m.y.) province (see pages 18-25 for references and a more extended discussion). Tonto Basin apparently lies athwart the boundary between the provinces because it contains representatives of both-- the Payson Granite of the northern, and the Young Granite and Flying W rhyolite of the southern. This is the only locality known where representatives of both provinces are essentially 'in contact' with each other, thus providing a unique opportunity to attempt a determination of the nature of the two-province contact.

Finally, the nature and origin of the rhyolite belt itself was investigated. The rhyolite, even though folded and faulted, appeared to be in an excellent state of preservation and would hopefully be amenable to studies of primary textures, mineralogy, and chemistry. Gastil estimated the thickness of the rhyolite 'section' of intrusive porphyry, flows, and pyroclastic and epiclastic rocks to be 10,000 feet. Even though much diminished in surface exposure from its original extent by vagaries of folding, faulting, erosion, and distribution of younger cover, this ancient volcanic pile appears to underlie about 100 square miles in upper Tonto Basin, with possible equivalents elsewhere in the region. The enormity of the rhyolite mass and its spectrum of lithologies suggested its origin might be similar to that of modern, well-studied rhyolite provinces associated with calderas.

LOCATION, PHYSIOGRAPHY, ACCESSIBILITY, CONDITIONS

The study area is in the central mountainous region of Arizona in northern Gila County. It lies immediately at the base of the great south-facing Mogollon escarpment and on the northern fringe of the Sierra Ancha (Figure 1). The mapped area comprises a good deal of the upper rugged Tonto Creek drainage basin which includes Tonto Creek and tributaries which drain the slopes of the Mogollon Rim, and Spring Creek and minor tributaries which drain the northern Sierra Ancha and empty into Tonto Creek in the south-central part of the study area. Lower Tonto Creek and a major tributary, Rye Creek, flow in a major SSE trending valley (herein referred to as the Tonto-Rye valley) which separates the high upper Tonto Basin area and the Sierra Ancha from the Mazatzal Mountains to the west.

Elevations in the mapped area range from about 6700 feet at Christopher Mountain in the northeast to about 3700 feet at Gisela in the southwest where the Tonto Creek gorge opens up into the Tonto-Rye valley. There is considerable local relief throughout most of the area and in the Tonto Creek and lower Spring Creek and Haigler Creek gorges steep walls rise 1000-1500 feet above the creek bottoms.

The upper Tonto Creek drainage system has profoundly modified and is deeply entrenched into a tableland which is still defined locally either by remnants of nearly flat-lying Precambrian Apache Group or lower Paleozoic strata or by low-relief topography reflecting nearness to the ancient late Precambrian/early Paleozoic erosional surface. The former is true of the southeastern part of the map area and the latter

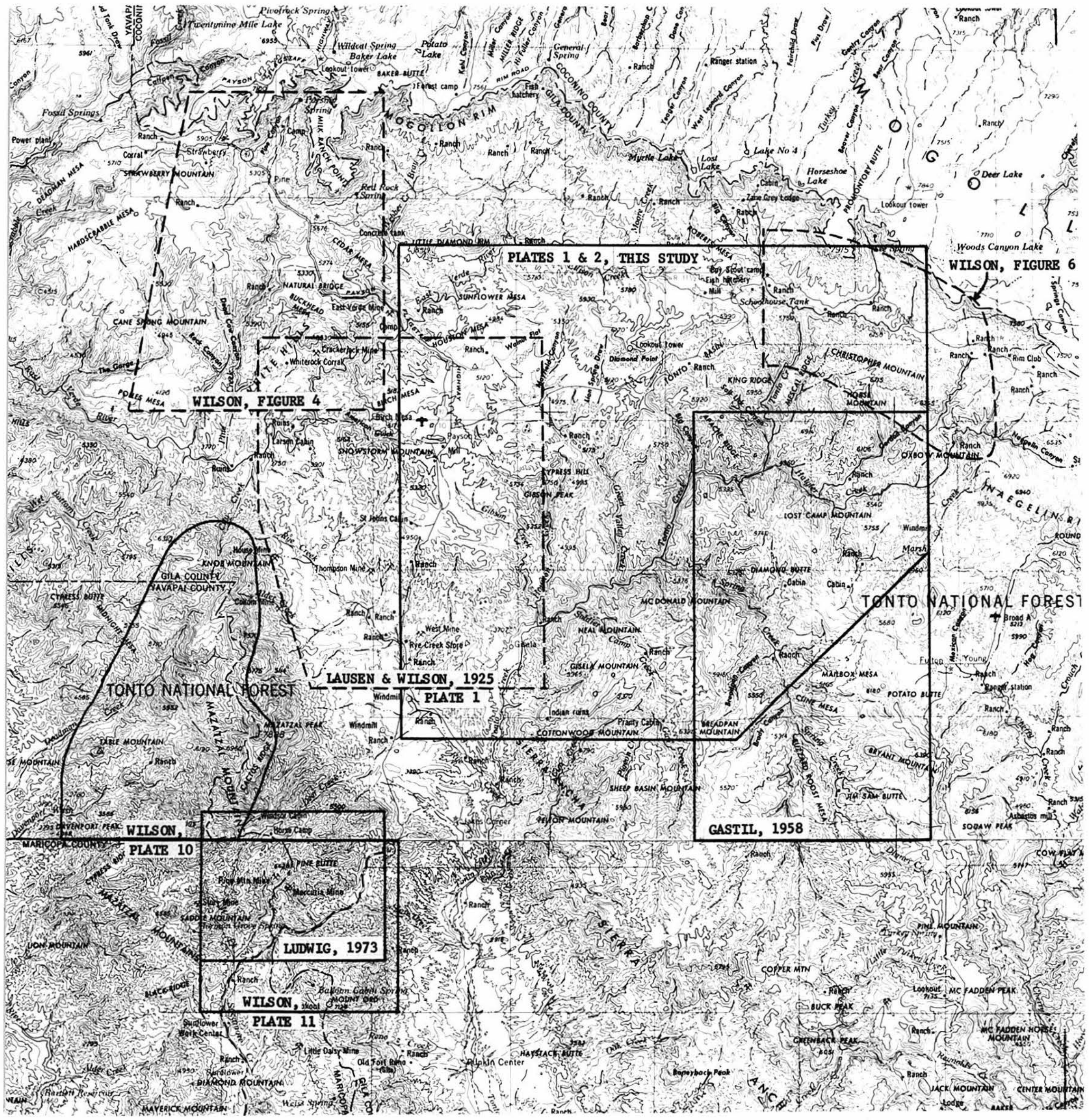

Figure 1. Locations of Precambrian study areas in the northern Gila County–Mazatzal Mountains region on portions of the Mesa and Holbrook 1:250,000 topographic maps. Wilson's (1939) plates are larger, more detailed maps whereas his figures and the plate from Lausen and Wilson (1925) are small preliminary sketch maps. See Figure 2 for location of the area of this figure.

of the northwestern parts in the vicinity of Payson.

Arizona state paved highways 260 and 87, respectively, cross the northern part and lie just to the west of the mapped area. They intersect at Payson, a town of several thousand, which was a convenient source of supplies and lodging during the field study. Much of the area mapped west and north of Tonto Creek is accessible within an hour by dirt roads and jeep trails from highways 260 or 87. Camping, to avoid excessive travel-time loss, was necessary in parts of the Green Valley Hills nearer Tonto Creek. The area south and east of Tonto Creek is accessible by dirt roads and jeep trails leading westward from the Chamberlain trail, a dirt road from highway 260 to Young, and from Young itself. Young is a two-hour drive from Payson, either via highway 260 and the Chamberlain trail or highways 260 and 288 (improved dirt), and an additional 1-3 hours, partially on 4-wheel drive roads, are required to reach interior parts of the mapped area. Camping was necessary for all mapping stints in this region. Gasoline and most supplies are available at Young, but facilities are generally very limited and lodging is poor unless one can put up in a residence.

A reliable, well-maintained, 4-wheel drive vehicle is essential to field study in Tonto Basin. On both sides of Tonto Creek 4-wheel drive 'rut-roads' fortunately permit access so that all areas except the deep gorges can be reached in long walking days from camps. Most of the jeep trails are not maintained and were only pushed in by cat for the purpose of building stock tanks. Some jeep trails coincide with horse trails shown on available 15' maps but most were located by talking to local cattlemen and by referral to aerial photographs. Many or most of these trails may appear on the new $7\frac{1}{2}'$ topographic sheets (see page 10), some of which the author has seen only in early pre-culture stages of preparation.

Tonto and Haigler Creeks, and also Houston Creek below lower Star Valley and Spring Creek below the Flying W Ranch, carry water year round. All other drainages are intermittent; most flow only during rains and some carry a little water continuously during the wet seasons, which are in mid-winter and mid-summer. One can usually cross Tonto and Haigler Creeks by rock-hopping, but during spring runoff and in the summer thundershower season it is difficult or impossible to cross lower Tonto Creek. Along much of Tonto Creek and lower Haigler Creek the canyon walls are very steep and intermittently box up the floor; creek bottom traverses require swimming or difficult climbs up the walls around the deep pools.

Vegetation cover is light to moderately heavy in the study area but is very seldom dense enough to hamper field work. Only occasional manzanita thickets and rare scrub oak thickets, both generally on high north slopes, were of difficult penetration and these could generally be avoided (except when following contacts) by utilizing aerial photos in traverse planning. Intermediate to higher elevations are forested with pinon pine, alligator juniper, black-jack and other oak varieties, and localized yellow pine stands above 5000 feet. Tree density drops off with decreasing elevation and trees give way entirely to low chaparral below about 3500 feet, except along drainage bottoms. At intermediate to lower elevations the succulents agave, sotol, lechugilla, and yucca are abundant, and common cacti are prickly pear and cholla. Saguaro cactus and ocotillo are abundant locally at the lowest elevations along lower Tonto Creek. Catclaw can be troublesome at lower elevations.

The best field months are April, May, September, and October because the weather is relatively cool and dry. June is usually the hottest and driest month, and during July and August spectacular afternoon thundershowers are very common. Field work during the thundershower season is actually quite enjoyable, but one must be prepared to spend an hour or two on many afternoons sitting under a poncho.

The entire field area is in the Tonto National Forest and portions lie in the Payson, Pleasant Valley and Tonto Basin Ranger Districts, the respective ranger stations being in Payson, Young, and Punkin Center. Personnel at the stations are helpful in providing maps, road information, forest service regulations, and general information. During the early summer dry season fire hazard is often extreme and the general public may be restricted from entering forest lands. A special permit may be (or may not be, depending on the disposition of the resident ranger) obtained to undertake field work at such times.

In sum, all factors are conducive to highly enjoyable and profitable field work in Tonto Basin. The climate is very agreeable, and there is a great variety of flora, animal life, and spectacular scenery over the 4000-foot elevation range. One can get a vehicle into most places, but access is difficult enough that few people other than cattlemen who hold the grazing permits, forest service personnel, and occasional deer hunters get into the interior areas. Best of all, from the geologist's point of view, exposure is superb. An exceedingly high bedrock exposure factor permits very close, continuous mapping of contacts and affords an uncommonly high probability of exposure of exact contacts and other important relations.

FIELD WORK AND METHODS OF RESEARCH

Mapping was accomplished during the four summer field seasons of 1969-1972, consuming 10 months actual field time. Mapping was done on enlargements (3X) of portions of the 15' Diamond Butte (1937), Promontory Butte (1952), Payson (1936), and Pine (1952) topographic quadrangle maps. The quality of the topography on these maps is on the whole very good. Advance 7½' sheets became available as the project neared completion. Complete aerial photographic coverage (most at 1:15,800, some at 1:37,000) was obtained and was invaluable as a general aid to mapping and in geologic interpretation.

The 200-square mile area of Plates 1 and 2 was partially mapped in detail and partially in reconnaissance. The area underlain by most of the rhyolite and granophyre — north of Diamond Butte, east of Green Valley Creek, and west of Christopher Mountain — was very intensively studied. Likewise, detailed mapping was done in the McDonald Mountain/McDonald Pocket area and in the vicinity of Gisela. A great portion of the field time was spent mapping and carefully studying relations along the Payson Granite-Green Valley Granophyre contact, and along the many internal and external contacts of the granophyre, intrusive rhyolite and extrusive rhyolite. The large areas underlain by Payson Granite and the

Gibson Complex and inaccessible portions of the Tonto Creek gorge and lower Spring Creek were mostly mapped only in reconnaissance. Photo mapping only was done very locally. Several weeks were spent in that part of the area shown in Plates 1 and 2 which was mapped by Gordon Gastil (1958); samples were collected, type sections were examined and the integration was made at southern limits of current mapping.

Most units were very heavily sampled and extensively studied petrographically. Over 300 thin sections were cut. Modal analyses of even-grained plutonic and hypabyssal rocks were carried out on single thin sections using a mechanical point-count stage. Statistical criteria as developed by Chayes (1956) were utilized to determine accuracy for granite modes. Identification of minerals and determination of approximate compositions was done by standard optical methods, except that plagioclase composition for some alaskites was determined by a revised dispersion method (Morse, 1968) using a monochrometer. Thirty samples were prepared for chemical analysis (see Appendix).

ORGANIZATION OF DISSERTATION

The body of this report is concerned only with Tonto Basin rocks of the Precambrian X time interval (1600-2500 m.y.; James, 1972). Precambrian Y (800-1600 m.y.) and younger rocks and Tertiary structure are discussed only briefly in the following section of the Introduction.

An overview will first be given discussing the regional Precambrian setting, and correlation and stratigraphy of the Tonto Basin rocks. A rock-stratigraphic nomenclature is suggested which contains some new and some old names and which has its basis in a correlation between rocks of the Mazatzal Mountains and Tonto Basin. This section is very important in integrating past studies and current findings and provides the reader with a framework of stratigraphy and sequence to which the remainder of the report, or portions in which the reader may be interested, can be referred. It will be especially helpful to study the generalized map (Plate 2) in conjunction with the overview chapter.

Discussion in the chapter on geologic units is tied very closely to the geologic map and map explanation (Plate 1), and documentary reference is repeatedly made to station numbers on the map which can be readily located with the marginal letter-numeral index. Description of geologic units proceeds generally, but not strictly, from oldest to youngest (bottom to top in the Plate 1 Description of Map Units), but the sequential position of the plutonic rocks in the discussion reflects only an hypothesis of relative age. The relative positions of the groupings in the Plate 1 Correlation of Map Units reflects those relations that are known with a considerable degree of certainty — the internal stratigraphic sequence, the plutonic rock-pendant sequence, the internal hypabyssal sequence, and that the latter group of rocks is younger than both the former.

References to contact relations demonstrating relative age are very important and numerous. In order to avoid repetition and to provide a degree of consistency, the field relations indicating a relative age relationship between two bodies are discussed with the unit interpreted to be the younger of the two.

Essentially all the evidence for the internal correlations and intrusive and stratigraphic sequences which are so critical to petrologic and structural interpretations and to overall petrogenesis are presented in the chapter on geologic units. It is a reference section to all discussions that follow. Of particular importance are the sections on the Gisela pendants, and especially the mafite porphyry, which describe relations suggesting to the author a possible sequential relationship between plutonic rocks of the Payson Granite and the Gibson Complex and Haigler rhyolite, thus offering hope for solving the most difficult and crucial field problem of the study — the relationship of the plutonic rocks to the stratified sequence.

The first part of the structure chapter also deals with the relationship between the plutonic and stratified rocks by considering solely from the structural point of view the alternative hypotheses for the origin of the sub-planar, southward-dipping, upper Payson Granite surface. The independent structural arguments support and expand the hypothesis arising from the Gisela pendant and mafite porphyry relations.

Also important in the structure chapter is the interpretation of overall deformational style and sequence in Tonto Basin which may have far-reaching implications for a significant interval of tectonic history in the Precambrian of the southwest.

In parts of the chapter on petrography and petrology are found tables of modes, average chemical compositions, and comparative (internal and external) compositions which have immediate utilization in the discussion. Plate 4 contains all chemical analyses, CIPW norms and other parameters for rocks analyzed in this study and for three rocks analyzed by Gastil.

Introducing the chapter on petrography and petrology is an important short section dealing with the metamorphic and alteration processes which have operated to modify Tonto Basin rocks, and analyses of the extents to which they have been effective.

Whereas there is at least some discussion of every map unit in the chapter on geologic units, only the major igneous rock bodies or types and the Gisela pendants are covered in the petrography and petrology chapter. Any petrography of other units (e.g., Christopher Mountain Quartzite) is discussed in conjunction with field relations. The plutonic rocks, Gisela pendants, and mafite porphyry are discussed under the same headings as in the earlier chapter, but the volcanic and hypabyssal rocks are discussed under headings indicating common petrographic character. This chapter, in addition to providing basic petrographic description and special descriptions of analyzed samples, has the objectives of:

1) demonstrating parentage or origin of the Gisela pendants and mafite porphyry compatible with the field relations suggesting a relationship between the plutonic rocks and Haigler rhyolite;
2) considering probable internal differentiation histories for the Gibson Complex and Payson Granite and implications thereof;
3) presenting various petrologic problems which relate to the origin and modification of the volcanic and hypabyssal rocks;
4) providing a basic understanding of the crystallization and

intrusive histories of the individual silicic alkali rock bodies (rhyolite, granophyre, alaskite) as a groundwork for the chapter on petrogenesis.

The chapter on petrogenesis deals almost entirely with the origin and evolution of the silicic alkali rocks, the definition of the alkali rhyolite event, and the general characteristics of the Tonto Basin alkali rhyolite province. This treatment is independent of the plutonic rocks but it is shown, in accord with the preferred hypothesis relating plutonic and volcanic rocks, that Payson Granite can be integrated into the petrogenetic model for the evolution of the silicic alkali magmas. Finally in this chapter the overall character of the Tonto Basin alkali rhyolite province is discussed and comparisons are made with other great pyroclastic volcanic fields and with various provinces having alkali rhyolite, granophyre or granite of similar composition. Implications for tectonic regime and problems relating to the bimodality (basically, the significance of the Gibson Complex) of the Tonto Basin igneous complex are discussed.

ROCKS YOUNGER THAN PRECAMBRIAN X AND TERTIARY STRUCTURE

Time and space limitations preclude a discussion in the present writing of the Precambrian Y Apache Group, the Paleozoic strata, and Tertiary igneous and sedimentary rocks shown on the map (Plate 1). The reader is referred to Shride (1967) and Huddle and Dobrovolny (1950), respectively, for general discussions of the Apache Group and Paleozoic rocks of central Arizona.

Observations on the pre-Apache Group and pre-Paleozoic System erosional surfaces, on Tertiary structure, and on Tertiary sedimentation and volcanism provide insights into the post-Precambrian X history of the area. These findings, particularly as relating to the late Tertiary history and the transition in the northern Gila County region from the basin-range province to the Colorado plateau, will be reported at a later time.

The northwest-southeast system of faults shown on Plates 1 and 2 is considered to be Tertiary in age. The compound Diamond Rim fault, mapped both in this study and by Titley (1962), was found by Titley to offset Tertiary sediments and to be overlain by Quaternary(?) basalt to the west of the present study area. The other northwest-southeast faults, by virtue of similar trend and throw seem to be related and all roughly parallel topographic features — Mogollon Rim, Rye-Tonto valley — clearly related to Tertiary structure.

Movements on the Tertiary faults are vertical and displacements range up to about 300 meters. The Precambrian structural pattern is practically undisrupted by these faults and they are for the most part ignored in the structural discussions of this work.

OVERVIEW

REGIONAL PRECAMBRIAN SETTING

Figure 2 shows the distribution of Precambrian rocks in Arizona and serves as an index map for Figure 1 and for areas to be referred to in the following discussion. The purpose of this section is to briefly summarize the state of understanding of Arizona Precambrian geology when the present work was initiated. More important and more recent studies will be emphasized. The reader is referred to Anderson (1951) for a more comprehensive review of earlier work.

Stratified older Precambrian rocks throughout Arizona have been weakly-to-strongly metamorphosed and deformed and intruded by vast masses of plutonic rock. In the Grand Canyon the stratified rocks were given the name Vishnu schist (Walcott, 1890; Noble and Hunter, 1917), in the southeast part of the state at Globe and Bisbee Pinal schist (Ransome, 1903, 1904), and in the Jerome-Prescott area in the central part of the state Yavapai schist (Jaggar and Palache, 1905; Lindgren, 1926).

Wilson (1939) mapped and subdivided a sequence in the Mazatzal Mountains which he thought was correlative, at least in part, with the type Yavapai schist only 50 miles to the northwest. He found that this sequence was overlain by a quartzite-slate-quartzite sequence which he called Deadman Quartzite, Maverick Shale, and Mazatzal Quartzite. He considered that certain scattered, smaller exposures of quartzite in the Gila County/Yavapai County area were correlative with Mazatzal

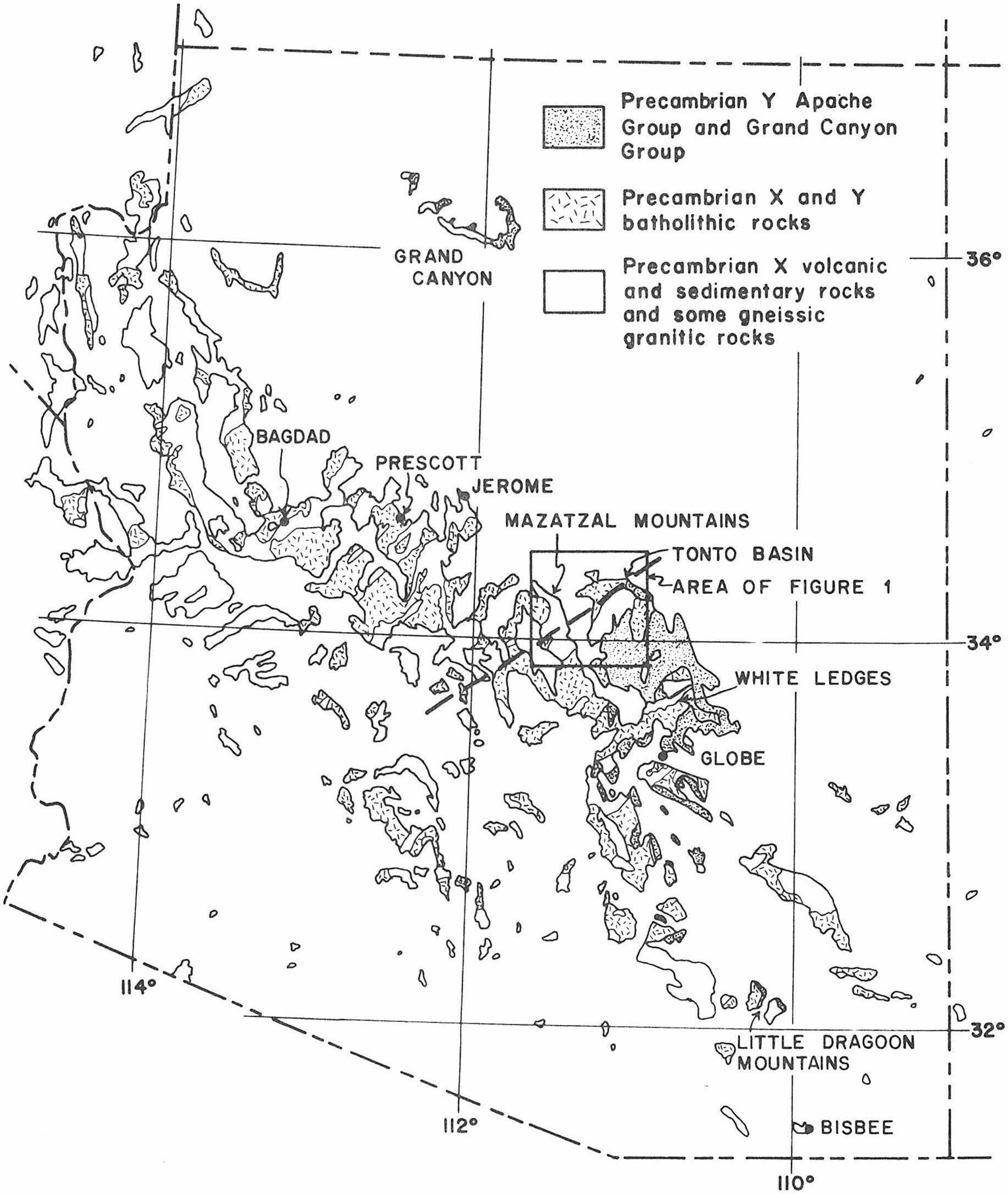

Figure 2. Precambrian exposures in Arizona. Modified from Basement Map of the United States (Bayley and Meuhlberger, 1968). Dashed line indicates approximate trend and position of the two-province boundary (see text).

Quartzite. Wilson concluded that the Mazatzal Quartzite and the Yavapai Group (replacing the name Yavapai schist) were folded and faulted prior to intrusion of granite. The orogenic event causing the deformation and culminating in intrusion of plutonic rocks he called the Mazatzal Revolution.

In numerous USGS publications by Anderson, Creasey, Kreiger, Blacet and others from the late 50's to very recent years the complex structure and detailed stratigraphy of the type Yavapai rocks in the Jerome-Prescott area have been largely deciphered. Anderson _et al_. (1955) suggested that the stratified rocks of the Bagdad area, about 40 miles west of Prescott, were generally correlable on the basis of similar lithology and structure with the Yavapai schist.

Cooper and Silver (1964), in reporting studies in the Little Dragoon Mountains of southeastern Arizona, raised the possibility that Pinal schist and Yavapai schist might be different facies of a geosynclinal system which was the site of the Mazatzal orogeny. Silver, in his doctoral dissertation (1955), had been more explicit in making the important contribution that the Pinal schist graywackes were a geosynclinal facies and in suggesting on the basis of regional structure and potential facies changes northwestward that the geosynclinal trough trended northeast-southwest across Arizona and New Mexico. He pointed out that if Yavapai and Pinal schists were time-equivalent the former would more likely be a eugeosynclinal facies because of much greater abundance of volcanic rocks whereas the wacke-rich Pinal schist might be transitional toward a miogeosynclinal facies.

Gastil was concurrently working on a doctoral study in Tonto Basin and suggested (1958) that the lower strata there, of geosynclinal character, were correlative with Wilson's Yavapai Group and Mazatzal Quartzite in the Mazatzal Mountains, while an upper sequence, comprised mostly of rhyolite, was younger than Mazatzal Quartzite.

Livingston (1968), in his doctoral study, mapped a rhyolite-quartzite sequence at White Ledges in southern Gila County which he suggested also might be correlative with rhyolite of the Yavapai Group and the Mazatzal Quartzite of the Mazatzal Mountains. Darton (1925) had considered that the White Ledges strata belonged to the Pinal schist.

Nowhere have Vishnu, Yavapai or Pinal schist strata or Mazatzal strata been found to rest upon plutonic rocks or earlier strongly deformed stratified rocks. From field studies there is no evidence of more than one orogenic event in the state, but neither is there concrete evidence for correlating Vishnu, Yavapai and Pinal terrains, though such was suggested by Lindgren (1926). Anderson (1951) cautioned against correlations based on similar lithology and structure of the widespread Precambrian terrains, and pointed out that the possibility of multiple orogenic episodes should not be dismissed. At the same time, however, he was skeptical of a proposal by Hinds (1936), having its basis in a supposed angular unconformity beneath Mazatzal Quartzite, that the Mazatzal Quartzite marked a period of sedimentation between two orogenies, Wilson's Mazatzal Revolution being the second. Silver (1955, p. 144) and Wilson (1939, p. 1161) also pointed out weaknesses in Hinds' arguments and the current study indicates there is little unconformity beneath the quartzite in Tonto Basin originally correlated by Wilson with type Mazatzal Quartzite. This matter is extremely complicated by the fact that correlation of Wilson's scattered Mazatzal Quartzite occurrences has not been clearly established, though widely accepted. Whether or not all the quartzite occurrences are correlative, however, Hinds' thesis appears to be quite without basis in fact.

With the advent of radiometric dating otherwise unresolvable problems of correlation and history in the Precambrian of Arizona have become somewhat more tractable.

Silver and Deutsch (1963) and Silver (1963) obtained zircon U-Pb apparent ages of 1650 ± 15 m.y. for a plutonic body intruding the Pinal schist and 1715 ± 15 m.y. for volcanic rocks in the Pinal strata in the Little Dragoon Mountains area. Silver (1964,1967) obtained these same respective ages for volcanic rocks in Wilson's 'Yavapai Group' strata in the Mazatzal Mountains, in Tonto Basin strata mapped by Gastil, and in the White Ledges sequence studied by Livingston, and for plutonic rocks intruding strata in the first two localities. These results placed the Mazatzal Revolution of Wilson in the interval 1650-1715 m.y. and confirmed a general time correlation for stratified sequences in the respective areas. This permitted the specific unit-to-unit correlations suggested by Gastil and Livingston.

In collaborative field and geochronological studies (Silver, 1966, 1967; Anderson _et al._, 1971) in the Jerome-Prescott and Bagdad terrains it was found that volcanic rocks of the type Yavapai Series (time-stratigraphic term introduced by Anderson _et al._, 1971) were extruded in the interval 1750-1820 m.y. and that plutonic bodies intrusive into rocks of the type Yavapai Series range in age from 1725 to 1770 m.y. A granite body in the Grand Canyon inferred to intrude 'Brahma schist' gave an apparent age of 1725 ± 15 m.y. (Pasteels and Silver, 1966). Silver (1967) concluded "that despite lithologic similarities, a regional distinction should be made (with a boundary somewhere in central Arizona) between an older Yavapai series (in the type area) and Vishnu schist to the north, and younger Pinal schist and southern 'Yavapai series' of the Mazatzal Mountains to the south."

Extensive studies of batholithic rocks in Arizona (Silver, 1968) demonstrated the near mutually exclusive occurrences of older rocks to the north and younger rocks to the south of the central Arizona boundary. All plutonic rocks in the age range 1720-1760 m.y. lie north of 33°N latitude and all those in the age range 1650-1700 m.y. lie south of 34°N latitude and east of 112°W longitude. Anorogenic plutonic rocks in the range 1450-1460 m.y. occur in great abundance throughout the state.

K-Ar and Rb-Sr age data (Livingston, 1962; Livingston and Damon, 1968; Wasserburg and Lanphere, 1965; Lanphere, 1968) are in some cases in broad agreement with the zircon U-Pb ages but lack the precise time peakings of the latter data and are generally younger. Lanphere (1968) concluded that Rb-Sr ages considerably younger than zircon ages in Yavapai Series rocks were the result of loss of radiogenic strontium and could therefore only be considered to be minimum ages. Loss of radiogenic daughter product may have similarly affected other apparent Rb-Sr, as well as K-Ar ages of Arizona's Precambrian rocks.

Field and geochronologic studies have shown that the Precambrian X rocks of Arizona are apparently the products of two closely timed orogenic cycles and that the respective volcanic and plutonic rocks lie in northern and southern provinces with an approximate boundary as shown in Figure 2. Apparently both volcanism and plutonism were of much greater duration in the earlier event. Volcanic rocks are mostly intermediate in composition and greatly predominate over sedimentary rocks in the northern province Yavapai Series, but are minor (except near the two-province boundary in Tonto Basin and the Mazatzal Mountains) and more silicic in the Pinal schist and time-correlative rocks of the southern province.

Anderson and Silver (1974) summarize the characteristics of the Yavapai Series and conclude that this sequence is part of a greenstone belt, similar to other volcanic belts which are products of magmatic arcs either at continental-oceanic boundaries or in areas of cratonic 'downwarping and spreading.' This greenstone belt was deformed and intruded by batholithic rocks and apparently became a positive cratonic mass adjacent to the basin in which the Pinal schist and time-related rocks were deposited. The abundance of clean, cross-bedded quartzite in the younger province strata near the two-province boundary attests to a vigorous near-shore environment of deposition probably at the margin of the 'Pinal depositional basin.'

The two-province boundary was most closely defined in the Gila County/Yavapai County area; rocks of both provinces appeared to be present in Tonto Basin and possibly in the Mazatzal Mountains. Under the direction of L. T. Silver, Ken Ludwig in 1968 and the author in 1969 undertook field studies in the Mazatzal Mountains and Tonto Basin to work on specific local problems of structure, stratigraphy and petrology. It was expected that these studies might contribute to the understanding of the geologic nature of the two-province 'contact.'

MAZATZAL MOUNTAINS AND TONTO BASIN STUDIES AND ROCK-STRATIGRAPHIC NOMENCLATURE

In 1939 Wilson published reconnaissance maps of areas in the northern and central Mazatzal Mountains (see Figure 1 for locations) where he found the Deadman Quartzite-Maverick Shale-Mazatzal Quartzite sequence resting on rhyolite which he called Red Rock Rhyolite. He showed the rhyolite in fault contact with units he called Yaeger Greenstone (mafic-to-intermediate volcanic rocks) and Alder series (shale, grit, quartzite, conglomerate), but thought the occurrence of mafic fragments in Red Rock Rhyolite and of rhyolite pebbles in Alder series indicated the following sequence: Yaeger Greenstone overlain by Red Rock Rhyolite overlain by Alder series.* Wilson thought the quartzite-shale-quartzite sequence was younger than the Alder series (though no contact was found) and hypothesized a period of deformation and erosion to explain the depositional relationship of quartzite on rhyolite.

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*These three units constituted the 'Yavapai Group' in the Mazatzal Mountains. This name can no longer be used in the Mazatzal Mountains, according to the studies just reviewed, and neither can Yaeger Greenstone because Wilson's type Yaeger rocks were in Yavapai County and are part of the older type Yavapai Series.

Wilson (1939) also presented crude sketch maps of four areas which were underlain by quartzite that he thought was correlative with Mazatzal Quartzite. Two of these quartzite occurrences are at Natural Bridge and Christopher Mountain (indexed in Figure 1) and the other two are at Del Rio in Yavapai County and at Four Peaks in the southern Mazatzal Mountains. He reported the quartzite at Natural Bridge to be underlain by rhyolite and to contain a rhyolite interbed near the base and that at Christopher Mountain to be in fault contact with granite and rhyolite. He called the rhyolite in both areas Red Rock Rhyolite. No stratigraphic relationship to other rocks was found for quartzite at Del Rio and Four Peaks.

Gastil (1958) defined and provided formational names (Table 3) for a thick, basically geosynclinal sedimentary/volcanic section in the eastern part of the Diamond Butte Quadrangle in Tonto Basin (Figure 1). He gave the name Alder Formation to a thick sequence of slate, wacke, quartzite, and conglomerate, proposing that it correlated with the Alder series of the Mazatzal Mountains. He also proposed that rhyolite and a quartzite-slate-quartzite sequence in the overlying Flying W and Houden Formations correlated with Red Rock Rhyolite, Deadman Quartzite, Maverick Shale, and Mazatzal Quartzite. Mafic volcanic rocks, conglomerate, wacke and an enormous amount of rhyolite in the overlying Board Cabin and Haigler Formations Gastil thought were younger than Mazatzal Quartzite and had no correlatives in the Mazatzal Mountains.

Gastil's proposed correlations required that Wilson's suggested stratigraphic positioning of the Alder series above Red Rock Rhyolite should be reversed. Ludwig's (1973) work in the Mazatzal Mountains showed that Red Rock Rhyolite does overlie Alder series, but it now appears that the foundation for Gastil's suggestion of transposition, his proposed correlation, is incorrect. This will be explained.

Ludwig remapped in much more detail a portion of the central Mazatzal Mountains earlier mapped by Wilson (1939, Plate 11; see Figure 1 for location of these map areas). In this type area for both Alder series and Red Rock Rhyolite Ludwig (1973, p. 143, 169) clarified the relation between the two, showing that the rhyolite overlies the Alder series rocks in the core of the Red Rock syncline and in a probable anticline at Sheep Mountain. The latter mass of rhyolite is probably continuous northward with that found by Wilson to be overlain by Deadman Quartzite on Cactus Ridge.

It was found in the present study that quartzite mapped by Gastil as Houden Formation quartzite in the northern part of his study area cannot belong to the Houden Formation because it rests upon Haigler rhyolite (page 77). Gastil (1958, Plate 2) had shown the quartzite in fault contact with Haigler rhyolite. Thus there are two major quartzite sequences in Tonto Basin and the higher sequence in Gastil's mapped area is continuous northward with the quartzite studied by Wilson at Christopher Mountain. This finding clearly opened up the possibility that the Haigler rhyolite-'Christopher Mountain quartzite' sequence, rather than the Flying W rhyolite-Houden quartzite sequence, might be correlable with the Red Rock Rhyolite-Deadman/Maverick/Mazatzal sequence. If this were so, then all the formations underlying Haigler rhyolite in Tonto Basin might be correlative with the Alder series of the Mazatzal Mountains.

The 'Christopher Mountain quartzite' correlation had already been suggested by Wilson and he had called rhyolite in the Christopher Mountain area (shown in the present study to belong to Haigler rhyolite) Red Rock Rhyolite. Nevertheless, Wilson had no real basis for correlation of either quartzite or rhyolite. Current findings that the great thickness of quartzite rests conformably on a great thickness of rhyolite make his suggestion of correlation credible, but cannot be regarded as conclusive evidence, especially since another quartzite exists lower in the section with rhyolite above (though not resting directly upon) it. It is particularly difficult to dismiss the possibility of the Houden correlation because of the quartzite-slate-quartzite sequence both there and in the Mazatzal Mountains. Nevertheless there do seem to be some common lithologic characteristics of the Mazatzal Mountains quartzites and the 'Christopher Mountain quartzite' which distinguish them both from quartzite of the Houden Formation. These are discussed in the body of this report (page 74).

Strongest support for the potential correlation arises from studies of Red Rock Rhyolite (Ludwig, 1973) and Haigler and Flying W rhyolites (this report). Rhyolite of the Flying W is only 50-60 m thick and it appears in only three of the five Flying W Formation sections measured by Gastil (1958, Fig. 2). Red Rock Rhyolite and Haigler rhyolite both underlie enormous areas and have great thickness; Ludwig (1973, p. 143) estimates the thickness of the former to be

1200 m, and minimum and maximum estimates of thickness for latter are 800 and 3500 m (page 52). Rhyolite from the Flying W Formation is petrographically and chemically distinctive from the highly predominant rhyolite types of the Red Rock and Haigler masses which appear to be remarkably homogeneous and similar (see Table 15 and pages 319 and 326 of this report).

A major contribution of Ludwig's work was the documentation of the volcanic and volcanogenic character of much of the Alder series. In reference to the Tonto Basin sequence, and more especially the pre-Haigler strata, Gastil (1958, p. 1496) stated that "all the sedimentary rocks, despite their range of character, are of volcanic origin." A close comparison of the characteristics of these two sections, as described by Ludwig and Gastil, reveal many similarities in lithology and particularly in up-section changes of volcanic to epiclastic proportions, of composition of the volcanic rocks, and in the maturity of the sedimentary rocks. About 4000 m of section have been estimated in both areas and in neither case is the base seen.

These paralleling general characteristics argue that the two sequences are stratigraphically equivalent and continuous except for probable internal facies changes. Moreover, preliminary investigations by L. T. Silver, K. R. Ludwig, T. H. Anderson, and the author in the region between Tonto Basin and the Mazatzal Mountains have revealed a continuity, with some facies changes, between certain upper Alder series units and pre-Haigler units.

Similar thick sequences in Tonto Basin and the Mazatzal Mountains of geosynclinal rocks overlain by rhyolite in turn overlain by quartzite, taken together with the internal evidences of identity or continuity, argue strongly for correlation. Extensive documentation for these correlations arises from the joint efforts of L. T. Silver, K. R. Ludwig, and the author and will be presented in a publication in preparation. Of great importance to the definition, determination of magnitude, and implications of the Tonto Basin alkali rhyolite event, as presented in this paper, is the correlation between Haigler rhyolite and Red Rock Rhyolite. The proposed correlation necessitates a revision in rock-stratigraphic nomenclature, as shown in Table 1, which is essential to the presentation of the present work; a rationale for the nomenclature follows.

The name Alder has precedence for the pre-Haigler rocks, but because of the great thickness of the section, because of formational designation of units in Tonto Basin, and because series is a time-stratigraphic designation (Am. Comm. on Strat. Nomenclature, 1961), the name Alder Group is proposed. There is in Table 1 no implied unit-to-unit correlation between Formations of the Alder Group in the Mazatzal Mountains (raised from member status given by Ludwig, 1973) and those in Tonto Basin. The latter retain the names given by Gastil, except for Alder Formation, for which the name Breadpan Formation is proposed.

The name Red Rock also has precedence over Haigler but the alkali rhyolite mass in Tonto Basin is much thicker, has been partially subdivided, shows potential for further subdivision, and has minor interlayerings of sedimentary and mafic volcanic rock. Tonto Basin

TABLE 1. PROPOSED CORRELATION AND NOMENCLATURE OF TONTO BASIN AND MAZATZAL MOUNTAINS SEQUENCES

Tonto Basin	Mazatzal Mountains
Mazatzal Group* (> 800 m)	Mazatzal Group* (> 660 m)
Christopher Mountain Quartzite*	Barnhardt Quartzite†
	Maverick Shale
	Deadman Quartzite
Haigler Group* (~ 2000 m)	Haigler Group* (> 1200 m)
Oxbow Rhyolite†	Red Rock Rhyolite
Haigler rhyolite undivided	
Winter Camp Formation*	
Alder Group* (> 3800 m)	Alder Group† (> 4200 m)
Board Cabin Formation	Telephone Canyon Formation†
Houden Formation	Oneida Formation†
Flying W Formation	East Fork Formation†
Breadpan Formation†	Cornucopia Formation†
pre(?)-Breadpan rocks	Horse Camp Formation†
	West Fork Formation†
	crystal lithic tuffs

*newly defined and named group or formation

†previously defined rock-stratigraphic unit with new or modified name.

seems to have been at or near the site of greatest volcanic activity as indicated by the greater thickness, lithologic variety, and the association with much hypabyssal rock of the same composition. Ludwig (1973, p. 115, 145) found that Red Rock Rhyolite apparently increases in thickness northeastward (toward Tonto Basin, some 20 miles distant) and apparent interfingerings of the alkali rhyolite appear in the uppermost Alder Group rocks. It seems reasonable in spite of the precedence of the name Red Rock, that the Tonto Basin section should be the reference section for the rhyolite and it is proposed that the name Haigler be raised to Group status. It is suggested that Red Rock Rhyolite in the Mazatzal Mountains and Winter Camp Formation and Oxbow Rhyolite in Tonto Basin be considered formations in the group. Most of the rhyolite in Tonto Basin remains undivided and shall be referred to in this report as Haigler Group rhyolite undivided or just Haigler rhyolite. Again no formational correlation is implied between the two areas.

The quartzite-slate-quartzite sequence does not occur in the quartzite overlying Haigler Group in Tonto Basin and Wilson's (1939) descriptions of the Deadman and Mazatzal Quartzites in the Mazatzal Mountains do not provide unique distinctions. Whether the slate and an upper quartzite were eroded away or whether a lower quartzite and slate were not deposited in Tonto Basin, or whether the slate wedged out between Mazatzal Mountains and Tonto Basin, are alternatives that cannot presently be evaluated. Consequently it is not known whether the quartzite in Tonto Basin should be correlated with Deadman Quartzite or Mazatzal Quartzite or both. To circumvent this problem, to provide a framework for future correlation and revision, and also to allow continued informal usage of the long familiar name, Mazatzal quartzite, it is proposed that the name Mazatzal be elevated to group status and that the unit formerly designated Mazatzal Quartzite in the type area be given a new name, Barnhardt Quartzite, for superb exposures in Barnhardt Canyon on the east face of the mountains near Mazatzal Peak. The sequence Deadman Quartzite-Maverick Shale-Barnhardt Quartzite would comprise the Mazatzal Group in the type area. As in Tonto Basin, where the name Christopher Mountain Quartzite is proposed for quartzite of the Mazatzal Group, units elsewhere shown to be correlative can be given formational names and included in the Mazatzal Group. All such quartzite can be referred to informally as Mazatzal quartzite.

U-Pb zircon apparent ages (Silver, 1964, 1967; Ludwig, 1973; L. T. Silver, pers. comm.) of certain volcanic rocks in the Mazatzal Mountains, in Tonto Basin, and at Natural Bridge are 1715-1730 m.y. The rhyolite interbedded with the quartzite at Natural Bridge is presently indistinguishable in age from Red Rock Rhyolite of the Haigler Group, and from Flying W rhyolite of the Alder Group; all are 1715 ± 15 m.y. old. For two samples of volcanic rock from the upper two formations of the type Alder Group, Ludwig (1973, p. 179-184) obtained an apparent age possibly just older (1730 ± 20 m.y.) yet still strictly indistinguishable. Thus, though the radiometric determinations are exceedingly important in demonstrating that the Mazatzal Mountains and Tonto Basin sections were deposited in the same short interval of time and are younger than rocks of the Yavapai Series, they provide no help in making the specific correlations herein proposed. In fact, within the framework of the apparent ages both past and current proposed correlations are permissible.

It is highly probable that the quartzite and rhyolite at Natural Bridge belong to the Mazatzal and Haigler groups, respectively. Both sequences are thick, the lithologies are compatible, the conformable relationship is indisputable, and the area is somewhat intermediate between Tonto Basin and the Mazatzal Mountains. Nevertheless, a demonstration of correlation awaits detailed mapping and petrographic and chemical studies.

TONTO BASIN STRATIGRAPHY AND SEQUENCE

The stratigraphic column of Table 2 gives approximate thicknesses, generalized lithologies and most of the subdivisions of the Precambrian X units of the map area. The reader can readily familiarize himself with Tonto Basin geology by studying this column in conjunction with the generalized map (Plate 2) and the cross-sections (Plate 3).

Queried relationships shown between Payson Granite and Hell's Gate Rhyolite and between the Gisela pendants and the Mazatzal Group divide the column into three portions. Internal to each of these three portions the sequential relationship, younger rocks higher in the column, is established; according to the best working hypothesis of the author the entire column is so ordered.

It appears to the author that the plutonic rocks (Payson Granite and the Gibson Complex) intrude the stratified sequence as high in the

TABLE 2

GENERALIZED PRECAMBRIAN STRATIGRAPHY
UPPER TONTO BASIN, GILA COUNTY, ARIZONA

Source	meters	Lithology	Unit	
This Report		alaskite sills and plugs		
This Report		granophyre sills	GREEN VALLEY GRANOPHYRE	
This Report		spherulitic rhyolite sill	KING RIDGE RHYOLITE	
This Report		rhyolite porphyry sills	HELL'S GATE RHYOLITE	
		? ? ? ? ?		
This Report		ferrohastingsite granite biotite granite	PAYSON GRANITE	
This Report		diorite, gabbro, granodio, hbl gphr	GIBSON COMPLEX	
This Report		mafite with plagioclase megacrysts	MAFITE PORPHYRY	
This Report		sedimentary and volcanic rocks	GISELA PENDANTS	
		? ? ? ? ?		
This Report	800	quartzite slate	MAZATZAL GROUP CHRISTOPHER MOUNTAIN QUARTZITE	
This Report; Gastil, 1958	2000	rhyolite: ash-flow tuff, tuff, breccia, aggl, flows, domes (?) mafic volcanic rocks, conglomerate, slate	HAIGLER GROUP OXBOW RHYOLITE HAIGLER RHYO. UNDIV. WINTER CAMP FORMATION	
Gastil, 1958	500	andes porph, wacke, cg, aggl, pillow basalt(?)	BOARD CABIN FORMATION	ALDER GROUP
Gastil, 1958	500	quartzite, slate	HOUDEN FORMATION	ALDER GROUP
Gastil, 1958	500	conglomerate, rhyolite, pillow basalt, wacke	FLYING W FORMATION	ALDER GROUP
Gastil, 1958	1700	slate quartzite wacke conglomerate	BREADPAN FORMATION	ALDER GROUP
		FAULT		
Gastil, 1958	600	mafic volcanic rocks, slate, limestone	PRE-BREADPAN(?) ROCKS	ALDER GROUP

TABLE 3. REVISION OF TONTO BASIN STRATIGRAPHY AND SEQUENCE - STRATIFIED AND HYPABYSSAL INTRUSIVE UNITS

Gastil, 1958		This Report
		alaskite (intrusive)
		Green Valley Granophyre (intrusive)
		King Ridge Rhyolite (intrusive)
Hell's Gate Rhyolite	rhyolite of Apache Ridge and elsewhere	Hell's Gate Rhyolite and rhyolite of Hog Canyon (intrusive)
	rhyolite of Lost Camp Mountain and elsewhere	Mazatzal Group Christopher Mountain Quartzite
?		
Oxbow Mountain Rhyolite		Haigler Group Oxbow Rhyolite Haigler undivided
Haigler Formation		Winter Camp Formation
Board Cabin Formation		Alder Group Board Cabin Formation
Houden Formation		Houden Formation
Flying W Formation		Flying W Formation
Alder Formation		Breadpan Formation
fault		fault
pre(?)-Alder rocks		pre(?)-Breadpan rocks

section as the lower part of the Haigler Group. The Gisela pendants may actually belong to the Haigler and Alder Groups. Evidence is presented to indicate that Green Valley Granophyre and probably Hell's Gate Rhyolite intruded Payson Granite.

It is hypothesized that the Payson Granite intruded subconformably at or near the base of the Haigler Group over most of the mapped area and that this contact was then successively intruded by the hypabyssal rocks. This hypothesis is not held to be inviolate and, indeed, the alternative working hypothesis will be presented that the plutonic rocks are the oldest rocks in the area and a basement upon which the Haigler rhyolite was deposited. The units are ordered in Table 2, however, according to the preferred hypothesis.

The succession as well as the rock-stratigraphic appellations of Table 2 represent some changes and additions over those previously published. Primarily these changes and additions are a revision of the stratigraphy given by Gastil (1958) and are shown in Table 3. Proposals of new names and changes, type localities and reasons for name choices are given in the descriptions of the respective field units. Not shown in this table are the plutonic rocks and Gisela pendants and this points out that a complete stratigraphy and sequence exists for all other rocks in the area independent of the position of the plutonic rocks.

For the units below Gastil's Haigler Formation there is no change in definition or position, but nomenclatural changes are indicated according to the proposal of correlation outlined above. Thicknesses and lithologies of these formations as shown in Table 2 are taken from

Gastil's work and the author has done little more with these units than to examine type areas and to make collections.

Gastil's Haigler Formation, Oxbow Mountain Rhyolite and some of the rhyolite mapped by him as Hell's Gate Rhyolite is here included with other rhyolite newly mapped in the Haigler Group. Most of the rhyolite and associated minor rocks mapped by Gastil as Haigler Formation are here included in Haigler Group undivided and a small basal portion is differentiated as Winter Camp Formation. Oxbow Mountain Rhyolite is shortened to Oxbow Rhyolite.

An explanation has already been given for the naming of Christopher Mountain Quartzite which was found to overlie Haigler Group rhyolite undivided and Oxbow Rhyolite.

Most of the rhyolite mapped by Gastil in the Apache Ridge-Hell's Gate area was found to be part of a more extensively distributed hypabyssal intrusive body for which the name Hell's Gate Rhyolite is retained. Rhyolite of Hog Canyon, incorrectly mapped by Gastil with Oxbow Rhyolite, intrudes Christopher Mountain Quartzite. Other rhyolite, probably Hell's Gate Rhyolite, was also found to intrude Christopher Mountain Quartzite, and it is possible that the main Hell's Gate mass intruded the same quartzite.

Hell's Gate Rhyolite is intruded by the very extensive Green Valley Granophyre, only a tiny portion of which occurs in Gastil's mapped area (at Cherry Spring) and which he did not differentiate from Hell's Gate Rhyolite.

Bodies mapped as granophyre by Gastil in the Cherry Spring area are here called alaskite and were found to intrude the Green Valley Granophyre. Other alaskite outside the area mapped by Gastil is also considered to be younger than the granophyre.

There is very little in print regarding the plutonic rocks and the reader will find reference to limited previous work in the sections describing these rocks. The name Payson granite has been used informally for many years by geologists interested in the area and it is suggested that this name be given formal status. Gibson Complex is a name introduced here for a variable, but primarily dioritic mafic body which is intruded by Payson Granite. The Gisela pendants are roof pendants in the Gibson body, still incompletely mapped.

This study is to a great measure an extension of the excellent work begun in Tonto Basin by Gordon Gastil, and the present understanding of structure and stratigraphy is based in the excellent groundwork he laid. Some revisions in areas which he was able to map only in reconnaissance (mainly in northern parts of his Plate 2) have been necessary, but this does not detract from the very important pioneering contribution which he made.

GEOLOGIC UNITS

ALDER GROUP

A brief summary of lithology, taken primarily from Gastil's work (1954, 1958), but derived in part from examination of most of the type sections by the author, is given here. One may refer to Gastil's paper for more detail and for structure and distribution. The Alder Group formations as shown on Plate 1 are taken directly from Gastil's map (1958, Plate 2) except that the Board Cabin Formation is extended westward from Houden Mountain toward McDonald Mountain.

Pre(?)-Breadpan Rocks

Mafic flow and pyroclastic rocks, slate and very minor limestone are virtually the only lithologies in the pre(?)-Breadpan strata which occur southeast of the Breadpan Canyon fault (Q-15,16) in juxtaposition with rocks of the Breadpan Formation. Penetrative deformation is intense southeast of the Breadpan Canyon fault and amygdaloidal structures in the pre(?)-Breadpan basalt(?) are elongate 10 or 20 to 1.

About 500 m of the chloritized mafic volcanic rock and 300 m of slate are exposed. The mafic rock is massive and volcanic structures are seen only on favorable weathering surfaces. The slate differs from that of the higher(?) formations in that it lacks interbeds of quartzite and pebble conglomerate and contains occasional thin interbeds of very fine-grained brown limestone. This is the only limestone found in the Precambrian X rocks of Tonto Basin.

An enormous body (400 m thick) of partially uralitized pyroxenite is thought by Gastil (1954, p. 60) to be a near concordant intrusive into the pre(?)-Breadpan rocks.

Breadpan Formation

The name Breadpan Formation, for extensive exposures in Breadpan Canyon, is proposed to replace the name Alder Formation. Breadpan Formation is composed entirely of clastic rocks finer than cobble conglomerate; Gastil's definition of the top of the formation is below the first appearance of cobble conglomerate or volcanic rock.

A lower member (more than 1200 m) consists of thin interbeds of sericite slate, quartzite, pebble conglomerate and graded quartz wacke. Ripple marking and cross-lamination are not common. A middle member (90-300 m) is composed almost entirely of cross-bedded quartzite, similar in character to the quartzite of the Houden Formation. An upper member (180 m) is argillaceous and in contrast to the lower member includes beds of chert and feldspathic wacke.

These thicknesses and this sequence apply to the formation only on the western slopes of Houden Mountain. Facies changes are relatively rapid along strike.

Rhyolite pebbles were noted in the upper part of the Breadpan Formation in Spring Creek. This is the earliest known occurrence of felsic volcanic rock in the overall Tonto Basin sequence.

Flying W Formation

The Flying W Formation is a lithologically heterogeneous unit varying from about 100 to 400 m in thickness. Mafic and felsic volcanic rocks and pebble to boulder conglomerate, composed of the same volcanic lithologies, are practically the only rock types. Four of the five sections measured by Gastil (1958, Figure 2) consist entirely of highly varying proportions of these rock types; the fifth is similar but contains also a small amount of quartzite and slate.

The mafic volcanic rocks are phenocryst-poor and sometimes amygdaloidal. Gastil reported the presence of pillows and it seems quite possible that the monolithologic 'conglomerate' of Plate 5A consists of fairly well preserved pillows in a matrix of reworked basalt fragments.

In the type section (1617, P-17) the rocks are little deformed and a foliation in the rhyolite is apparently a primary pyroclastic foliation. Gastil divided the felsic flows into rhyolite and keratophyre sub-units, both of which are called alkali rhyodacite in this report (see petrographic descriptions, page 319). The chemically analyzed sample (Ar-Gi-W rhy #1A, Q-16) from the former sub-unit is the Flying W rhyolite sample dated by L. T. Silver and was supplied by him. An analyzed mafic volcanic rock (1617, P-17) is apparently altered (mainly silicified) iron-rich basalt.

Houden Formation

The Houden Formation consists of a lower quartzite unit, a middle slate and argillaceous unit, and an upper quartzite unit. A basal pebble conglomerate 10-30 m thick is often present; pebbles are white quartz, chert, fine-grained quartz-aggregate rocks, and volcanic rocks. These pebble species, in addition to feldspar, are found generally as much finer fragments throughout the quartzite of the Houden Formation.

The lower quartzite member varies from 100 to 400 m in thickness and the upper quartzite is 100 to 150 m thick. Both are composed almost entirely of gray to white, cross-laminated clean quartzite in 0.1-1 m beds. Petrographic characteristics of this quartzite are compared with Christopher Mountain Quartzite on page 74.

The central slate unit is as thick as 100 m but thins eastward and is missing along the eastern boundary of the Diamond Butte quadrangle. This slate is gray, purple or brick-red, characteristically evenly- and finely-laminated and free of cross-lamination. It varies from fine-grained quartzite, siltstone, and minor slate at the base to slate and graded wacke in the upper part.

Board Cabin Formation

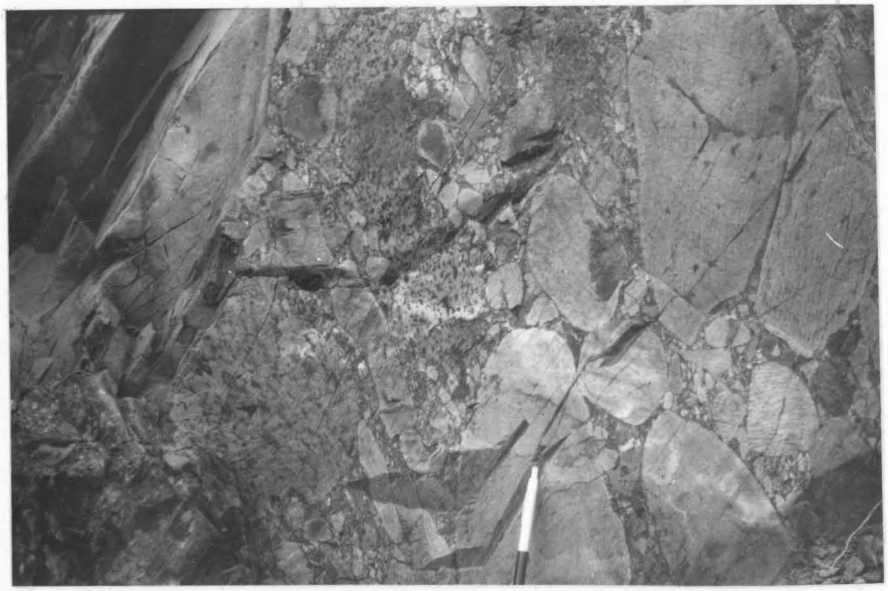
Porphyritic and non-porphyritic mafic volcanic rocks, and pebble to boulder conglomerates, composed mostly of the same lithologies, but also containing some more intermediate clasts, predominate in the Board Cabin Formation. The volcanic rocks occur mostly as massive flows but also with pillow structure and as agglomerates. There is a great variation in pyroclastic texture and a transition into conglomerates. Lithic and feldspar wacke, which undoubtedly derive mostly from the mafic volcanic rocks, are also abundant. Quartzite and slate are minor and the former occurs mostly as interbeds near the base of the formation, which is defined as the first appearance of volcanic rock or distinctly volcanic sediments above the quartzite of the Houden Formation.

Gastil's (1958, Figure 4) four measured sections range in thickness from 250 to 600 m, the latter value being the thickness of the type section in Board Cabin Draw (O,N-16).

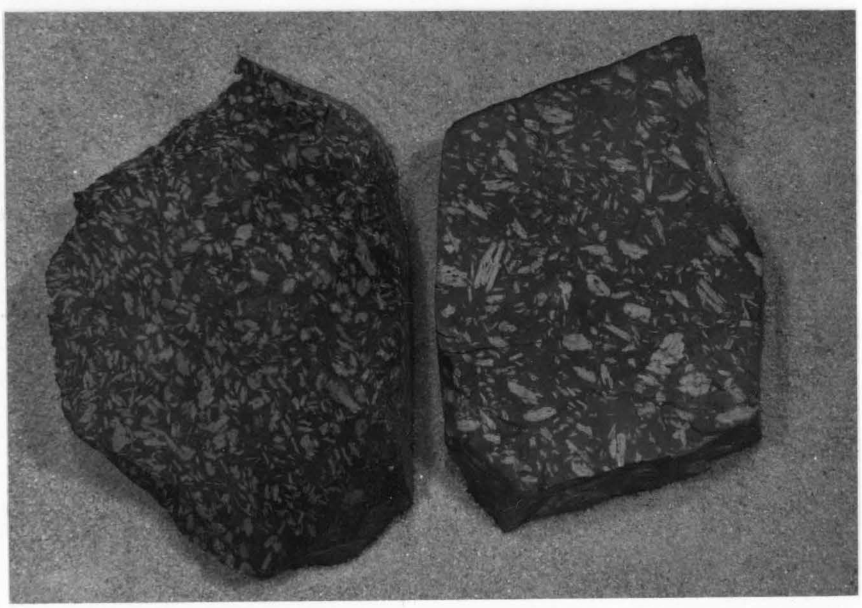
The most abundant lithology in the type section, including near-monolithologic conglomerate, is a distinctive andesite porphyry, the petrographic character of which is described on page 316 and for which a chemical analysis was obtained (1600, O-16). Platey plagioclase phenocrysts constituting 20-30% of this rock type are generally bimodal in size (about 3-5 mm and 1 cm) and are clustered and twinned on (010). A typical sample from the thick, lower, flow section and one from an upper conglomerate clast (Plate 5B) are two textural variants.

Although the andesite porphyry flows constitute about one-fourth of the type section, none occur in the other three measured sections. It was found in reconnaissance, nevertheless, that this lithology occurs extensively to the southwest of Gastil's study area. The sections measured by Gastil in the eastern part of the Diamond Butte quadrangle contain the highest proportion of wacke and conglomerate. Gastil noted that a volcanic facies of this formation is prominent to the west and that little sedimentary rock occurs west of Board Cabin draw.

PLATE 5. ALDER GROUP



A. Monolithologic 'pillow conglomerate' in Flying W Formation. Possible pillows in matrix of basalt fragments. (1617, P-17)



B. Two common textural variants of Board Cabin Formation andesite porphyry. Compound, platey plagioclase phenocrysts have a bimodal size distribution. Sample on left is from a conglomerate clast at the top of the formation (2231, N-16); the one on the right is from a flow near station 1600 (0-16). Specimens are about 15 cm in the longest dimension.

HAIGLER GROUP

Gastil (1954, p. 42) grouped all units above his Board Cabin Formation comprised mainly of extrusive rhyolite into the Colcord Group. He (Gastil, 1958, Table 1) subsequently dropped the group designation. With the exceptions of that rhyolite of the Hell's Gate area now known to be intrusive, and the Gun Creek Formation in southwestern Diamond Butte quadrangle (not examined in this study), the units earlier designated as the Colcord Group now appear to be lithologically and stratigraphically related and are again collectively proposed for group status. However, in view of the publication and common use of the name Haigler Formation during the intervening years in reference to most of the extrusive rhyolite it is proposed that the group designation be Haigler Group. Two units in the group are proposed for formation status, but most of the rhyolite has been insufficiently studied to be given final rock-stratigraphic assignment. Therefore most of the rhyolite and minor associated sedimentary and mafic volcanic rock remains undivided and will be referred to throughout this report informally as Haigler rhyolite, Haigler conglomerate, etc. It is probable that formations will be broken out of this undivided portion of the group in the future.

Winter Camp Formation

Winter Camp Formation is the name proposed for a 300 m sequence of alkali rhyodacite, conglomerate, and tuff breccia overlying rocks of the Board Cabin Formation at the southeastern base of Diamond Butte (N-16).

The name Winter Camp is taken from the line camp designated Upper Corral on the Diamond Butte map but referred to as Winter Camp by local people. Gastil (1954, p. 44) had originally called this sequence Winter Camp Formation but in his published report (1958, p. 1054) he referred to it as the lower member of the Haigler Formation. He divided it into five sub-members, rhyolite I, conglomerate I, rhyolite II, tuff breccia, and conglomerate II.

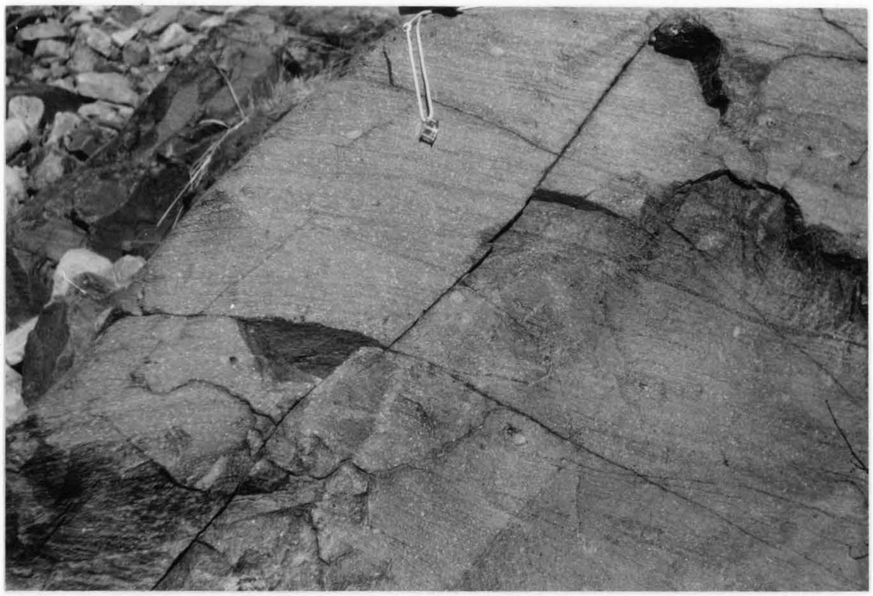
Petrographic and chemical analyses in the present work indicate that the volcanic rocks of the Winter Camp Formation are alkali rhyodacite rather than rhyolite. This distinguishes the Winter Camp sequence from the alkali rhyolite which predominates in all other units of the Haigler Group. Nevertheless the appearance of these rocks marks a profound change in the local stratigraphic succession from the underlying mafic volcanic rocks and sedimentary rocks. It seems reasonable to include the Winter Camp rocks in the Haigler Group but to recognize their distinctive character by applying a formation name. Gastil's sub-members can be referred to as members and the first and third as rhyodacite I and rhyodacite II.

Gastil was unable to establish stratigraphic continuity with the much more extensive Haigler rhyolite to the north. No further effort to establish that relation was made by the author, but it was found that more rhyodacite, separated by fine-grained mafic intrusive rock, apparently overlies the conglomerate II member. This rhyodacite should also be included in the Winter Camp Formation and the upper contact with Haigler rhyolite (yet undefined in the field) should be the horizon above which alkali rhyolite predominates.

Much of the Winter Camp Formation is conglomerate which consists entirely of volcanic pebbles and cobbles of Winter Camp rhyodacite, various similar rhyodacite, dacite(?), rhyolite(?) porphyry rocks, and of underlying Board Cabin rocks. The lower member (rhyodacite I) is a pyroclastic-epiclastic unit which, though more like rhyodacite II in overall composition, contains abundant fragments of Board Cabin lithology and in clastic character resembles some horizons in the Board Cabin Formation. Rhyodacite II is a strongly laminated flow (Plate 6A) from which analyzed sample 7-1-1611 was collected. Rhyodacite above conglomerate II, from which analyzed sample 7-1-1604A was collected, is similar. The tuff breccia member, a chaotic mixture of irregular 1-10 cm pumice blocks in a tuff matrix, is phenocryst-poor and is probably rhyodacite or dacite.

Although the stratigraphic relationship between Winter Camp Formation and Haigler rhyolite was not demonstrated there is no doubt that both these units overlie the Board Cabin Formation. From overall structure in the Winter Camp area it is quite clear also that Winter Camp Formation gives way upward to Haigler rhyolite. The extent of Winter Camp Formation seems to be limited, however, and its relation to Haigler rhyolite undivided may be an inter-tonguing near or at the base of the alkali rhyolite sequence. Locally in lower parts of the Haigler rhyolite are rhyodacitic crystal-lithic wackes or tuffs and rhyodacite flows with inclusions of Board Cabin andesite porphyry (Plate 6B) which may be Winter Camp correlatives (see pages 53 and 54).

PLATE 6. WINTER CAMP FORMATION



A. Outcrop of flow-banded alkali rhyodacite from which analyzed sample 7-1-1611 was collected. The rock is dark gray-brown on fresh surfaces. White plagioclase phenocrysts are conspicuous on weathered surfaces. (1611, N-16)

B. Possible Winter Camp rhyodacite in Picket Pen fault slice containing an inclusion of Board Cabin andesite porphyry. (40, N-9)

Haigler Rhyolite Undivided

Haigler rhyolite undivided consists almost entirely of extrusive alkali rhyolite which displays great structural and textural variety. Slightly less siliceous felsic volcanic rocks, mafic volcanic rocks and slate are very rare except in the type area along Haigler Creek. Gastil (1958, p. 1505) described the minor rock types, conglomerate, slate and wacke, and mafic volcanic rocks, which occur as lens-shaped units within Haigler rhyolite of the type area. These units are shown, as mapped by Gastil, on Plate 1.

In masses newly assigned to the Haigler rhyolite, or newly mapped, the author found non-rhyolite lithologies abundant only in the Christopher Creek fault slice (C,D-17). Elsewhere they are not distinguished on the map. In this fault slice amygdaloidal basalt and epiclastic rock containing mafic lithic fragments are fairly abundant. Very minor tuffaceous and wacke rocks are also present.

Outside the type area conglomerate, composed mostly of extrusive rhyolite clasts, is the most abundant of the minor rock types.

The volume of undivided rhyolite of the Haigler Group is in sum greater than that of the two units extracted and given formational status. The main contributions of this study are the determination of the overall stratigraphic position and a general lithologic and petrographic characterization of the rhyolite sequence.

Various fault-bounded structural blocks contain large masses of extrusive rhyolite and in all there is one criterion or more, lithologic, stratigraphic, or structural, to indicate that the rhyolite is indeed a part of the Haigler Group. The regional structural picture clearly reveals that great thicknesses of extrusive alkali rhyolite usually occur stratigraphically above either the Board Cabin Formation of the Alder Group or above the Winter Camp Formation. Where these units are not present sheets of granophyre and intrusive rhyolite separate the extrusive rhyolite from the upper surface of the Payson Granite. Stratigraphically overlying the rhyolite in several structural blocks is the Christopher Mountain Quartzite. In one block Oxbow Rhyolite intervenes below the quartzite and above the undivided rhyolite. Although some of these stratigraphic relations are not found in each block there are no contradictions. In the following section brief descriptions of relations will document the features of stratigraphic and structural correlation.

DISTRIBUTION, STRUCTURE, AND CORRELATION

<u>Structural block east of Lost Camp fault</u>. The largest continuous mass of extrusive rhyolite lies in the structural block bounded by the Lost Camp fault and the Breadpan Canyon fault between Oxbow Mountain and the northwestern part of Houden Mountain. This rhyolite is overlain to the north by Oxbow Rhyolite and Christopher Mountain Quartzite in the Big Ridge syncline and Oxbow Mountain anticline. Although little structural control was developed southwestward across the wide expanse of rhyolite the Oxbow Mountain anticline is likely to be continuous with the open anticline in the Winter Camp area. In the latter area Board Cabin Formation is overlain by Winter Camp Formation and apparently, in sequence, by Haigler rhyolite undivided. Paralleling this anticline on the southeast is a syncline defined in the folding of Houden Formation

and Board Cabin Formation rocks one mile southeast of Winter Camp. This syncline may continue northeastward through Marsh Ranch and beyond.

The major folds in this structural block are much complicated by minor folding and faulting. Attitudes in the crests of these folds (Plate 1) at both upper and lower rhyolite contacts are shallow (15-30°) indicating that fold axes plunge shallowly northeastward. The shallow northeast plunge of the Big Ridge syncline is the most obvious. The rhyolite is exposed 'down-dip' to the northeast for about 6 miles between Winter Camp and Oxbow Mountain. From an estimated regional plunge the thickness of the rhyolite is crudely calculated to be about 3500 m. The uncertainties in this estimate are such that it is considered a maximum thickness. Complex internal structures could result in an exaggerated apparent thickness.

Northwest of Oxbow Mountain the Big Ridge syncline is warped northward around the bend in the Lost Camp fault and is overturned toward the northeast beneath Horse Mountain and Christopher Mountain. On the west slopes of Horse Mountain the quartzite of the syncline rests unconformably on extrusive rhyolite, continuing the relationship which exists to the south. The extrusive rhyolite undoubtedly lies at depth beneath the quartzite throughout the Horse Mountain/Christopher Mountain area. The two fault slices of rhyolite along the Lost Camp fault on Christopher Creek (C,D-17) and Bull Tank Canyon (F-18) are slices of Haigler rhyolite partially dragged down when the eastern wall of the fault subsided relative to the western. At station 810 in the more northern of these slices, some thin (few meters) interbeds of quartzite may indicate nearness to the upper contact with the Christopher Mountain Quartzite.

Structural block between the Lost Camp fault and the Green Valley Creek fault. Basically this block consists of the fragmented Tonto Basin syncline. Christopher Mountain Quartzite rests upon Haigler rhyolite in the core of the syncline from McDonald Mountain to Lower Corral. The base of the rhyolite is not seen in the northwestern limb of the syncline, but in the opposing limb the rhyolite rests conformably (p. 56) upon Board Cabin Formation. About 800 m of rhyolite is exposed in the southeastern limb, but a complete thickness cannot be estimated because the upper part of the rhyolite is cut out by faulting (see structure sections).

Relations at Bull Mountain (L-15) suggest that perhaps the rhyolite appearing in the limb of the Tonto Basin syncline is rolled back over the Board Cabin Formation in an anticline (discussion in structure section, p. 205). The anticline axis may be truncated at a low angle a few miles northwestward by the Lost Camp fault because rhyolite at Lost Camp Mountain shows no evidence of anticlinal folding (flow foliations are mostly to the northwest) and in Haigler Creek near the fault (1534, J-17) an interbedded unit of rhyodacitic crystal-lithic wacke or tuff strongly resembles some of the Winter Camp lithology and suggests that this position may be near the base of the rhyolite strata. Granophyre intrudes the rhyolite approximately along strike a mile to the southwest and also 2 miles to the northeast. This may also indicate proximity to the base of the rhyolite inasmuch as extensive granophyre (Green Valley Granophyre) occurs beneath rhyolite and intrusive rhyolite northward in the broad nose of the Tonto Basin syncline.

Assuming that all the Lost Camp mass dips northwestward, about 70°, the apparent thickness is about 2500 m. Faults have cut off both the top and the base of the sequence, but because of the possibility of duplication due to internal folding it cannot properly be considered a minimum estimate.

Extrusive rhyolite overlying King Ridge Rhyolite in the southern Mescal Ridge area is structurally within the Tonto Basin syncline and except for faulting would be continuous (beneath gravel cover) with the rhyolite of Lost Camp Mountain.

The Picket Pen fault slice, a mile west of McDonald Mountain, contains only extrusive rhyolite and a few small bodies of intrusive rhyolite. Though only a few flow foliation attitudes were obtained, these consistently have intermediate dips to the southeast. This is consistent with this sequence being a part of the northwest limb of the Tonto Basin syncline. This block has not been downdropped as far as those of McDonald Mountain to the east where quartzite rests upon the rhyolite. There are indications that the lower exposures of rhyolite in this slice are near the base of the Haigler rhyolite stratigraphy. At station 40 in Tonto Creek (N-9) rhyodacite like that of the Winter Camp Formation was found and within it are inclusions of Board Cabin andesite porphyry (plate 6B).

Intensively foliated and sheared extrusive rhyolite (some Hell's Gate Rhyolite could be present) south of Gisela Mountain (S-7,8) apparently overlies Board Cabin andesite porphyry (Brushy Hollow) and Houden quartzite (Reef Ridge). Purple slate and strongly foliated breccia similar to that found at the base of Christopher Mountain Quartzite at McDonald Mountain occur against the Green Valley Creek fault and suggest that the fault south of Cocomunga Canyon developed approximately along the Haigler rhyolite-Christopher Mountain Quartzite contact.

Structural block west of the Green Valley Creek fault. The central part of Gisela Mountain was not examined at all. The presence in both the north and south flanks of the same type of extrusive rhyolite found in great thickness in the Haigler elsewhere suggests the central area is the same. The internal structure is not well determined. The few flow foliation attitudes observed on the north strike northwestward and several dip northward roughly perpendicular to the southward dipping contact with Green Valley Granophyre. In the south the flow foliation attitudes dip consistently southward.

The possibility will be discussed (page 84) that the rhyolite might be continuous northward with the eastern Gisela pendant which in its northern half might contain underlying rocks of the Alder Group. Thus the northern limit of the rhyolite might be essentially the stratigraphic base and, despite the northward-dipping flow foliations, the Gisela Mountain mass as a whole might dip southward.

Rhyolite of Gisela Mountain is separated from Payson Granite by southward-dipping sheets of granophyre and intrusive rhyolite. This relationship is different only in scale from that in the northwestern limb of the Tonto Basin syncline on the eastern side of the Green Valley Creek fault. This repetition of structural and lithologic elements suggests that the extrusive rhyolite of Gisela Mountain correlates with Haigler rhyolite in the other structural blocks.

Black Mountain, an isolated mass of bedrock projecting up through

Tonto-Rye valley sediments four miles west of Gisela Mountain is comprised entirely of well-layered extrusive rhyolite dipping moderately southward. This rhyolite is interpreted as continuous at depth with that of Gisela Mountain.

CONTACT RELATIONS

The relationship of the Haigler rhyolite to underlying Winter Camp Formation and Board Cabin Formation was developed in the previous section basically from the overall structural picture. No clear-cut transition was observed from Winter Camp Formation into Haigler rhyolite. The contact with Board Cabin Formation was walked out only in the Bull Mountain-Ruin Mountain area (M-14,15) and continuous exposure of the contact was found only at station 1662. There, over a distance of about 150 meters, there is a continuity of stratigraphy wherein a finer facies of andesite porphyry of the Board Cabin Formation gives way westward into a fine green wacke or slate which then grades into lighter colored, more slatey or tuffaceous rock. About 70 meters of this variably colored slatey rock is intruded by three thin sills of Hell's Gate Rhyolite and is overlain by about 7 meters of dirty quartzite, wacke and olive slate in which a number of graded beds indicate that stratigraphic top is west toward the rhyolite. Overlying this thin arenaceous sequence is about 30 meters of conglomerate consisting of rhyolite pebbles and cobbles, then a 30-meter layer of brown and black slate. Above that is essentially all massive flow-banded rhyolite.

This contact transition confirms the placement, by the criterion of regional structural position, of the rhyolite above the Board Cabin Formation.

LITHOLOGY

Extensive traversing and sampling was undertaken in the rhyolite of all the structural blocks discussed above except for the type area mapped by Gastil. Most, if not all, of the numerous structural and textural varieties are present in each of the major blocks. Several unifying petrographic characteristics argue for correlation of the various rock types in the different blocks. These features are 1) similarity in phenocryst populations and, 2) very low color index.

Most rocks are characterized by the presence of quartz and alkali feldspar phenocrysts, though plagioclase is present in much and predominates over alkali feldspar in some. Phenocryst abundance varies from a few percent to about 10% but most often is perhaps 4-5%. Feldspar phenocryst phases rarely are as large as 5 mm and are commonly in the 1-3 mm range. Abundant 0.5-1.5 mm crystals of quartz often coexist with fewer and larger feldspar crystals. Phenocrysts in the Haigler rhyolite are smaller and less abundant than in the Hell's Gate Rhyolite.

Virtually no mafic phenocrysts are present. The normative color index is 2-3%. Magnetite or hematite, often clustered (in some cases possibly pseudomorphs after mafic silicate minerals), is found in the groundmass. Biotite, chlorite, and epidote are rare and very minor. These secondary metamorphic minerals are the only mafic silicate minerals present.

Haigler rocks vary greatly in color but for the most part are reddish and relatively light-colored (brown, tan, orange). Less frequently the rocks are dark brown, gray or greenish, and occasionally very light green, tan or yellow bleached areas are encountered. Petrographic and chemical analyses indicate the dark rocks are more reduced. The lighter, more altered rocks occur in zones generally associated with faulting or tectonic foliation.

Structures and textures in the extrusive rocks are very well preserved and of fascinating variety. Basically, however, there are four structural types: flows, ash-flows, pyroclastic breccias and epiclastic breccias. Perhaps most common are strongly flow-foliated varieties, apparently simple viscous flows. The flow surfaces may be highly contorted or sub-planar (Plate 7A) and may be very simple and continuous over long distances or complexly disrupted by devitrification textures.

Ash-flow tuff, identified by the presence of conspicuous flattened pumice fragments, is nearly as abundant as the simple flow rocks. The platey pumice texture in Plate 7B is a typical variety (partially welded ?) in the ash-flow structural spectrum. Also seen in this photo are 3-5 cm devitrification areas lacking both radial texture and hollow interiors.

At station 1850 on Bull Mountain (L-15) a single ash-flow unit was briefly examined which appears to have many features of a cooling unit (Smith, R.L., 1960). The coherence as a single flow was supported by the consistent presence through all textural varieties of distinctive 1-5 cm exotic fragments of light-colored rhyolite (see Plate 8A). From south to north (probably upward in the flow) the first phase encountered was dense black obsidian-like rock with tan lamellae (Plate 8A). Though sometimes much deformed, as in Plate 8A, the tan lamellae are just as often planar and are discontinuous (length to width ratios of 10:1 to 20:1). It is concluded that these are flattened pumice fragments in a zone of dense welding. This rock apparently differs from more typical rock of the densely welded zone, in that both pumice and matrix normally become dark and megascopically indistinguishable (Smith, 1960, p. 155). This unit is perhaps 20-30 meters thick. Above that is about 50 meters of rather normal coarse ash-flow tuff probably of a partially welded zone (similar to that pictured in Plate 7B). Dark pumice fragments in a generally red-brown matrix have cross-sections as large as 3 x 30 cm. They are often spherulitic but may retain trace amounts of the fibrous lamellar texture which formed during compression of the pumice blocks. This unit gradually passes upward into similar rock modified by the development of lithophysae. Coalescing lithophysae with drussy cavities become so abundant in the central part of the zone as to make identification of pumice fragments almost impossible. Upward the lithophysae eventually decrease in abundance and platey fragments (generally much smaller, 0.2 x 3 cm) again become distinct. The lithophysae zone, about 50 m thick, is apparently a zone of vapor-phase crystallization. Some 30-40 meters into the upper finer ash-flow zone (apparently still partially welded) a sample was collected in which trace amounts of original glass, so identified by apparent isotropy (Plate 38), is apparently preserved in the inter-pumiceous groundmass. Above this zone is a breccia zone, apparently not a part of the flow unit.

Although there was no opportunity to study this flow in detail, it seems to document the presence of classical ash-flow tuff and a cooling unit in this ancient volcanic terrane, emphasizes the excellent preservation of primary structure, and illustrates the potential for further deciphering the internal character of the rhyolite sequence.

Less abundant than the above lithologies are varieties of breccias. A common type is that shown in Plate 8B which may be a tuff breccia or an autobrecciated viscous flow. Another variety appears to be a pumice breccia and in some instances is probably from the upper unwelded portions of ash flows. Other types of pyroclastic and epiclastic breccias are also present and in some the transition is made to conglomerate. Locally beneath the overlying Christopher Mountain Quartzite, there is a rather thick (few meters to perhaps 30 meters) immature epiclastic breccia composed entirely of rhyolite fragments. However, conglomerates do not seem to exist in this horizon but may be generally in the lower portions of the Haigler rhyolite.

A very rare lithology (Plate 9A) suggests that some of the volcanism may have been sub-aqueous. Sorting and bedding of crystals and pumice(?) lapilli as seen in this photograph require the agency of water. Field relations for this lithologic type were not determined.

ENVIRONMENT OF DEPOSITION

The presence of abundant ash-flow tuff may reasonably be taken to mean that much of the Haigler rhyolite was deposited sub-aerially (Rankin, 1960). Interlayered conglomerate deposits indicate either sub-aerial erosion and (stream) transport or reworking above wave base, or both. They were formed above sea level or very near shore.

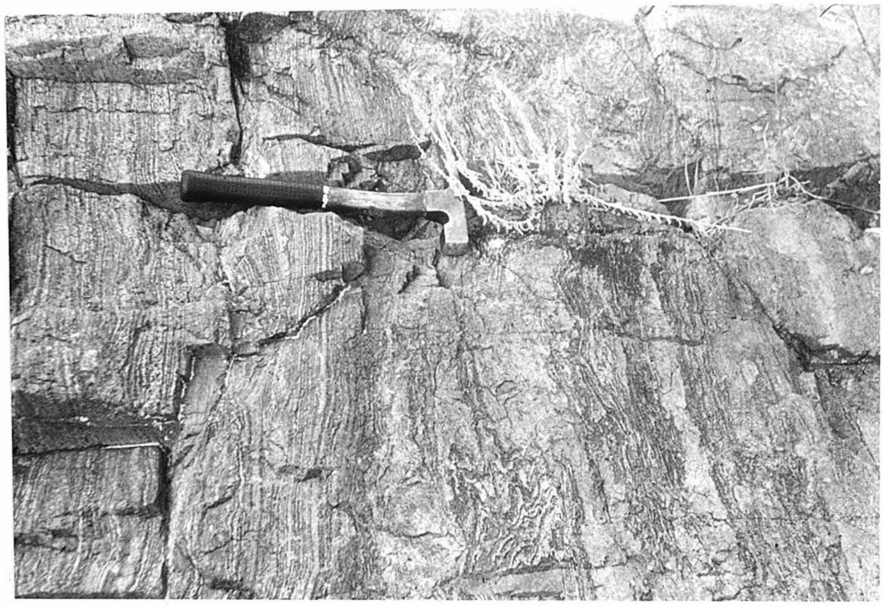
It seems likely in view of the presence of wackes and pillow lavas in the underlying Board Cabin Formation and of the overlying shallow water quartzite that the rhyolite edifice may have been erected in or near shallow water. Gastil (1958, p. 1505) noted that in the lenses of mafic volcanic rock and sedimentary rock within the Haigler rhyolite there are pillow lavas, graded beds, and thinly bedded black slate, all of which require deposition in water. He inferred "that the sediments accumulated in water between coalescing centers of rhyolitic eruption. The 'basins' were sufficiently quiet to permit the accumulation of graded sediment but sufficiently near shore to receive the deposition of coarse conglomerate." This seems to be a very good assessment of the conditions prevailing during volcanism.

According to Fiske (1969) marine pyroclastic flows are characterized by graded bedding in which there is an upward increase in pumice. It may be that the pumice(?)-rich upper portion of the photograph of Plate 9A is the top of such a graded bed (inverted). Finer-grained material in the lower part of the photo would presumably then be the base of another submarine flow. It would be important in further study to gather more documentation of sub-aerial versus sub-aqueous volcanism to get a better assessment of the relative importance of the two in the origin of the Haigler rhyolite.

Oxbow Rhyolite

Oxbow Rhyolite, named by Gastil for best exposures on the southwest

PLATE 7. HAIGLER RHYOLITE UNDIVIDED

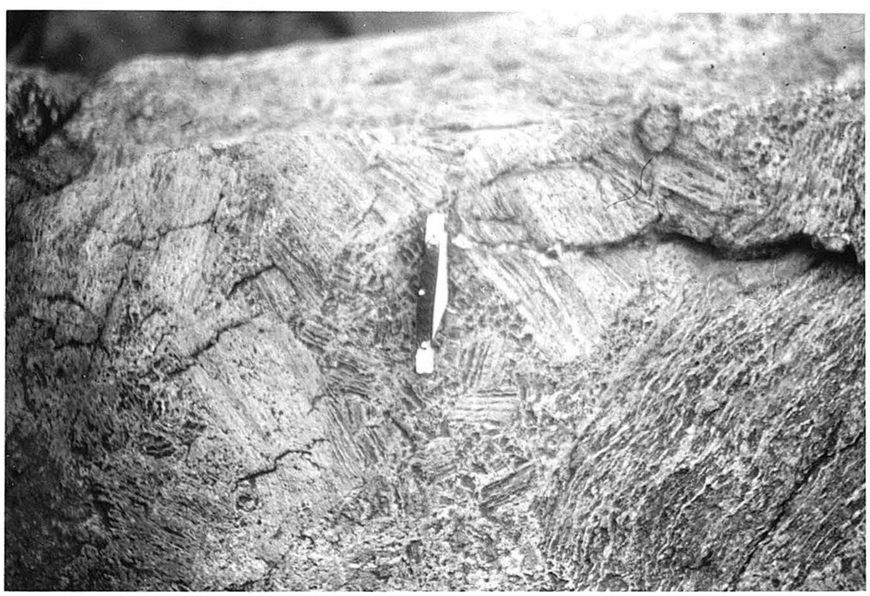


A. Laminar flow foliation typical of much of Haigler rhyolite. (1749, L-14)

B. Ash-flow tuff. Flattened pumice fragments and bulbous devitrification features. (1801, K-17)

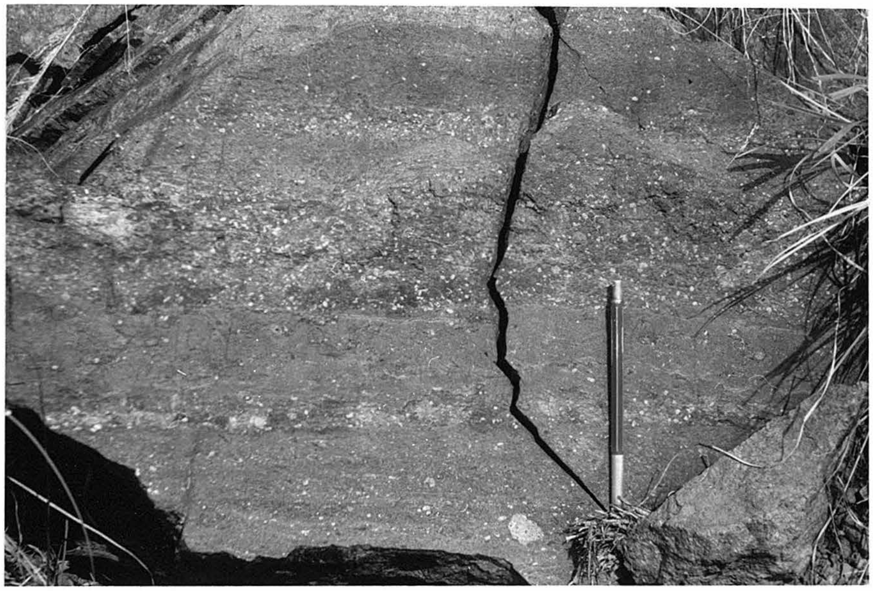
PLATE 8. HAIGLER RHYOLITE UNDIVIDED

A. Possible deformed and densely welded portion of a zoned ash-flow tuff cooling unit (see text). Note light and one dark lithic inclusions. (1850, L-15)



B. Tuff breccia or autobrecciated viscous flow. (1734, K-13)

PLATE 9. HAIGLER AND OXBOW RHYOLITE



A. Rare bedded lithology in Haigler rhyolite undivided in which crystals and (dark) pumice(?) lapilli are sorted. (1807, J-17)

B. Boulder of Oxbow Rhyolite, structurally homogeneous except for dark pumice lenses. (1956, I-20) corner of Oxbow Mountain (I-21), is a crystal-rich, massive, and homogeneous extrusive rhyolite body. It occurs only east of Lost Camp fault and extends at least 1.5 miles east of the margin of Plate 1 to the Chamberlain trail near Haigler Creek (Sec. 12, R 13 E, T 10 N). This unit was mapped only along its upper contact with Christopher Mountain Quartzite in the Big Ridge syncline, but was examined in various places including its lower contact with Haigler rhyolite undivided in the type area.

The author confirmed Gastil's (1958, p. 1506) interpretation that the Oxbow Rhyolite rests upon Haigler rhyolite undivided. Examination of the contact relations in the vicinity of station 1976 (I-21) revealed a conformity of bedding attitudes in sedimentary rocks and a thin mafic flow of Haigler rhyolite undivided with the lower contact of the Oxbow Rhyolite and lamellar structures (indistinct pumice plates) in the Oxbow Rhyolite. Gastil suggested from "the relation of the porphyry (Oxbow) to rock units older than the Haigler Formation" that part of the Oxbow Rhyolite is intrusive. He was apparently referring to the relation between intrusive rhyolite of Hog Canyon and Christopher Mountain Quartzite, which he thought was Houden quartzite. As far as the author could determine, the Oxbow Rhyolite is entirely extrusive; the Hog Canyon rhyolite is an independent unit.

A unique and consistent phenocryst assemblage clearly distinguishes Oxbow Rhyolite from any other intrusive or extrusive unit in the study area. Phenocrysts make up about 20-25% of the rock and 1-6 mm (seriate distribution) euhedral quartz crystals predominate by a factor of 2 to 3 over 1-3 mm alkali feldspar crystals. The groundmass is fine and generally even-grained. Mafic phenocrysts are absent in the very leucocratic rock. Where well-preserved the groundmass is dark red-brown, but in most places is a medium brown and in shear zones is strongly bleached.

Oxbow Rhyolite is, for the most part, very massive and structureless. However, as described by Gastil, "the lower part of the unit contains shards (pumice lenses) flattened parallel to bedding and contorted about phenocrysts." Upward from the base the pumice fragments gradually become less distinct and less platey (Plate 9B). In most of the body pumice fragments are discerned with difficulty or not at all.

Flattened pumice texture suggests that Oxbow Rhyolite might be a welded ash-flow tuff but weak or absent layering, the massiveness and textural homogeneity, and the rapid change in thickness seem to argue against that origin. Oxbow Rhyolite is only 100-150 m thick for several miles along the southeastern limb of the Big Ridge syncline, is absent except in upper Lost Camp Canyon (K-17) along the opposite limb, and thickens to perhaps 800 m around the nose of the Oxbow Mountain anticline (see structure section A-A'). A characteristic of ash-flow tuffs is deposition in widespread even blankets.

It seems probable that Oxbow Rhyolite was a dome or a very thick viscous flow. The observed fragments would have been rubbly surficial blocks reincorporated and flattened, particularly near the base, in advancing magma. Central and higher portions remained very massive and structureless. Absence of gas cavities and only weak devitrification in the pumiceous(?) areas suggest the magma was volatile-poor. This may be compatible with a viscous dome origin.

Viscous domes commonly form above the ring fracture in the moat area of resurgent cauldrons (Smith and Bailey, 1969, Fig. 2). There is evidence that Oxbow Rhyolite formed in this manner. Only beneath the Oxbow Rhyolite does significant conglomerate, slate, wacke, and mafic volcanic rock occur in the upper part of Haigler rhyolite (see cross-sections A-A' and B-B'). Erosion of caldera scarps would have resulted in rapid infilling by rhyolite debris and the slate and pillow lava (Gastil, 1958, p. 1505) in the mafic volcanic rock would have formed in a caldera lake.

MAZATZAL GROUP

Christopher Mountain Quartzite

PREVIOUS WORK AND CORRELATION

The quartzite of Christopher Mountain was first described by Wilson (1922, 1939). In both papers he correlated it with Mazatzal Quartzite of the Mazatzal Mountains. Initially (1922, p. 307) he stated that the Christopher Mountain body "directly overlies Precambrian schists and granites, with stratigraphic hiatus of unestimated magnitude." Subsequently, he stated (1939, p. 1149): "In the eastern Tonto Basin area no Deadman quartzite and Maverick shale are exposed, but more than 1000 feet of typical Mazatzal quartzite is faulted against, and presumably overlies, Red Rock rhyolite." Apparently the basis for correlation with quartzite in the Mazatzal Mountains was the lithology.

Darton (1925, p. 235) noted that a 'lower quartzite' (overlain unconformably by Dripping Spring Quartzite of the Apache Group) rested upon granite in Haigler Creek. Wilson (1939, p. 1149) corrected Darton's petrographic designation saying that the granite is actually rhyolite, but he mentioned nothing about the relation to quartzite and in that vicinity showed on his map (1939, Fig. 6) a fault contact between quartzite and rhyolite. This author surmises that the rhyolite mentioned is Oxbow Rhyolite and that the quartzite is Christopher Mountain Quartzite. The quartzite would overlie the rhyolite in an eastward extension of the eastern limb of the Big Ridge syncline off the map area a few miles east of Oxbow Mountain.

Gastil (1954, 1958) believed that the quartzite-slate-quartzite sequence of the Houden Formation was correlable with the Deadman quartzite-Maverick shale-Mazatzal quartzite sequence of the Mazatzal Mountains. Gastil thought all of the thick quartzite bodies in the Tonto Basin area belonged to this sequence and mapped quartzite of the southern Big Ridge syncline (south of Horse Mountain) as Houden Formation in fault contact with Haigler and Oxbow Mountain rhyolite. He stated (1950, p. 26) that this quartzite was continuous north of his map area to Christopher Mountain and he also noted the existence of other exposures of 'Houden' quartzite west of his map area in upper Gun Creek, in the Soldier Camp area, and in a belt from McDonald Mountain to Lower Corral.

Since Gastil's study there has been nothing in the literature regarding the quartzites of Tonto Basin. The Geologic Map of Gila County (Wilson _et al_., 1959) shows the quartzite (designated Mazatzal, rather than Houden) as mapped by Gastil in the Big Ridge and Lost Camp Canyon areas, but not his other Houden exposures. In the current investigation it was found that quartzite continuous southward from Christopher Mountain rests with depositional unconformity on rhyolite of the Haigler Group in the Big Ridge syncline. A similar relationship was observed for quartzite in the Tonto Basin syncline. Because of the identical stratigraphic position and close spatial association quartzites of these two masses are clearly equivalent and are called Christopher Mountain Quartzite. This quartzite is distinguished from the Houden Formation which is unquestionably beneath the Haigler Group at a much lower stratigraphic position. Moreover, there is a noteworthy lithologic difference between quartzite in the two intervals above and below the Haigler Group rhyolite.

It must yet be determined whether various quartzite exposures immediately south of the present map area and west of Gastil's map area belong to the Houden Formation or to Christopher Mountain Quartzite.

LITHOLOGY

Christopher Mountain Quartzite is subdivided into two units, a basal slate-conglomerate-reworked rhyolite unit, and the overlying quartzite. The lower unit is highly variable in lithology and thickness (0-50 meters) but is characterized by purple coloration and by rhyolite clasts in the coarser detrital rock. In places the degree of reworking is very slight. Sorting is poor and bedding indistinct except in the slate.

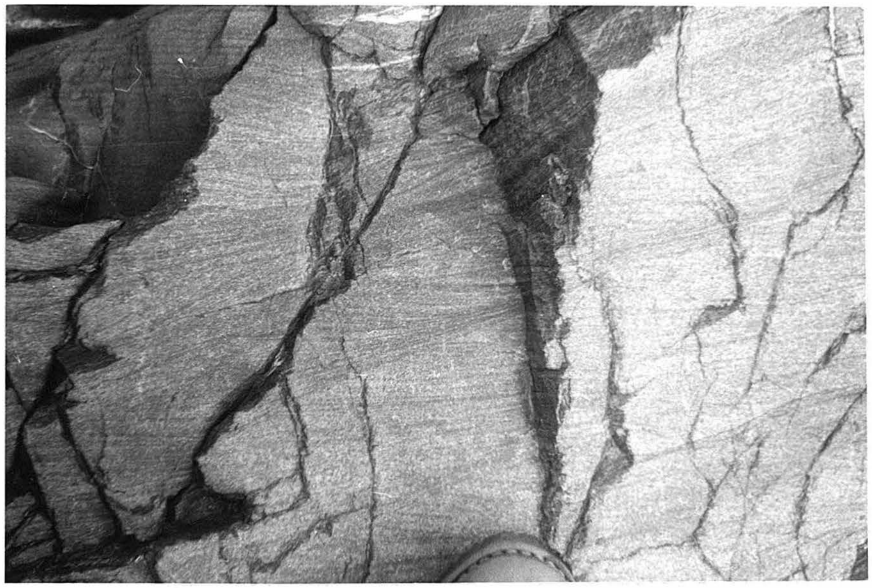
The quartzite unit is quite homogeneous in character. Only rarely were slate interbeds found and these mostly near the base. There is much variation in grain size in the sand-granule range, but generally the grains are medium to very coarse (0.2-2 mm) and throughout the sequence are common to rare thin granule to pebble (0.2-1 cm) interbeds. Most quartz grains are clear but some, again more commonly in the coarser beds, are milky. Jasper and, less frequently, reddish rhyolite(?) clasts are quite common, particularly in the coarser beds. The rock is strongly cemented and a fresh surface broken across grains is highly vitreous.

Quartzite beds are generally 0.1 to 2 meters thick and are distinctly cross-stratified internally (Plate 10A). Stratigraphic tops are readily determined almost anywhere from the cross-bedding. Ripple marks are fairly common at bedding surfaces.

A nearly universal characteristic of the quartzite is the purplish cast to its basically brownish or reddish color (Plate 11A). Wilson (1939, p. 1125) considered this to be a characteristic of all the scattered quartzite bodies he correlated with type Mazatzal quartzite: "Its weathered surfaces are pale brown, reddish brown, light gray or nearly white, but with a characteristic purplish tint that is particularly noticeable from the distance." Light-colored (tan to pinkish) rocks are the exception in the Christopher Mountain Quartzite.

The following petrographic description is based on study of three thin sections, each of a different variety of the quartzite. Subrounded to well-rounded quartz and jasper (about 100:1 or 50:1) grains comprise 80-90% of the rock, indicating a high degree of maturation. Jasper has a very high hematite content. Lithic fragments occur in

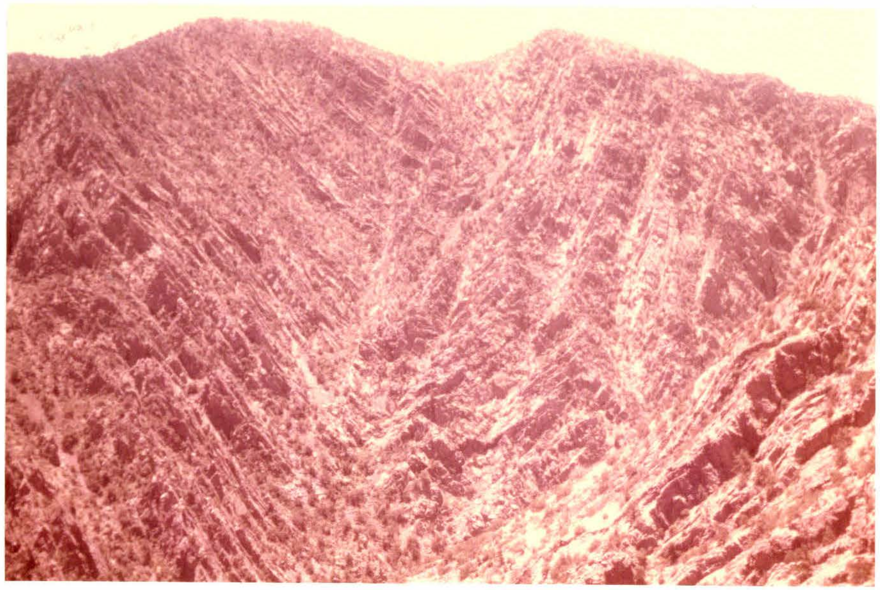
PLATE 10. CHRISTOPHER MOUNTAIN QUARTZITE



A. Typical cross-lamination in Christopher Mountain Quartzite.

B. Slightly foliated pebble/granule breccia of reworked Oxbow Rhyolite at base of Christopher Mountain Quartzite. (1933, I-20)

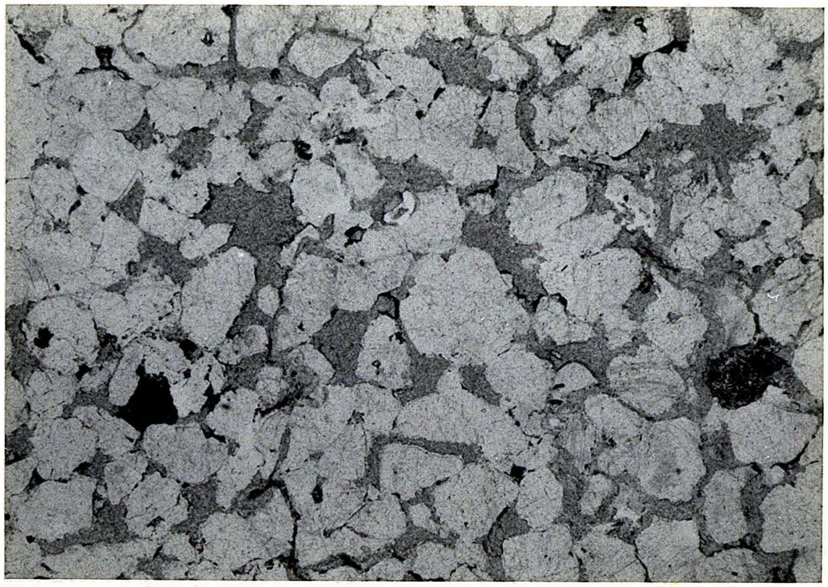
PLATE 11. CHRISTOPHER MOUNTAIN AND HOUDEN QUARTZITES



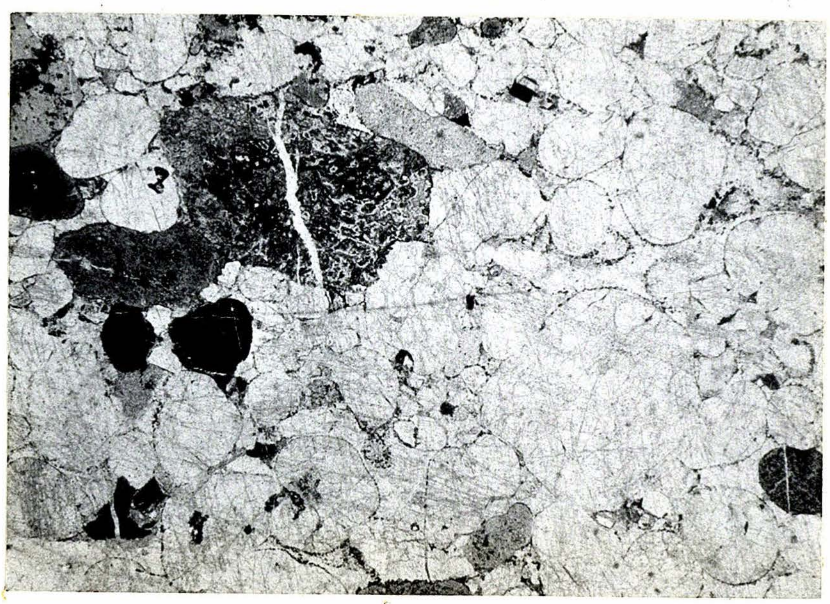
A. Christopher Mountain Quartzite occupying the axis of the Tonto Basin syncline. Note lavender hue of quartzite. Photo taken from station 1697 (M-12) looking southwest across Spring Creek gorge.

B. Quartzite samples from Christopher Mountain Quartzite (5 specimens to the left) and Houden Formation (6 on right) showing much of the internal variation in color and grain size observed in the field. The two groups are distinct in that the Christopher Mountain Quartzite samples have a redness virtually absent in the Houden rocks. Largest specimen is 13 cm in length.

PLATE 12. MAZATZAL GROUP QUARTZITE



A. Christopher Mountain Quartzite, Tonto Basin. Sericite matrix has nearly obliterated relict evidence of an early episode of quartz cementation. Dark grain to the left is jasper, the one on the right is a felsic volcanic fragment. Plane-polarized light, 6 x 9 mm.



B. Barnhardt Quartzite, Mazatzal Mountains. Sericite (gray as in Plate 12A) is sparse and quartz cementation is thorough. There are several jasper (darker) and felsic volcanic fragments in the field. Plane-polarized light, 6 x 9 mm.

trace amounts and are sites of much less pronounced hematite concentration. They have diverse fine-grained granular textures which strongly suggest they are of felsic volcanic parentage (Plate 12A).

Fine hematite, and possibly magnetite, disseminated and clustered in the matrix make up perhaps a half percent of the rock. It is undoubtedly the hematite which gives the rock its dark and purplish color. Zircon is the only other accessory heavy mineral noted.

Sericite, constituting 5-15% of the rock occurs mostly along grain boundaries but also as probable pseudomorphs after feldspar. Fine opaque grains occasionally define an original rounded grain boundary within a larger quartz domain. This is evidence of an early stage of quartz overgrowth and cementation. Much of the overgrowth was obliterated in a later event in which sericite marginally replaced the quartz (Plate 12A).

Comparison with Houden Formation quartzite. Houden quartzite shares most lithologic characteristics of Christopher Mountain Quartzite. Bedding and cross-lamination character is equivalent and variations in grain size are analogous. It contains jasper plus lithic grains and sericitized feldspar(?), in lesser and greater amounts, respectively, than found in Christopher Mountain Quartzite. Microscopic features, rounding, overgrowth and marginal sericitization, are identical and quartz and sericite contents are comparable.

The only major difference is that Houden rocks have much less iron oxide. This is magnetite (and ilmenite?) in generally discrete grains rather than the very fine irregularly clustered and disseminated hematite typical of Christopher Mountain quartzite. Consequent to this very different oxide mineralogy Houden quartzite is much lighter-colored, usually gray to white (Plate 11B). However, there is some overlap of the color variations which exist in both units.

Zircon grains were found in two and tourmaline in one of the four thin sections examined. Gastil (1958) also found apatite and chlorite. The reader is referred to Gastil's work for more extensive description.

Comparison with Barnhardt Quartzite. The author, in company with K. R. Ludwig, spent several days in the vicinity of Mazatzal Peak in the Mazatzal Mountains. A number of samples were collected of Barnhardt Quartzite, Maverick Shale, and uppermost Deadman Quartzite.

Essential megascopic characteristics of Barnhardt Quartzite appear to be indistinguishable from those of Christopher Mountain Quartzite. The only significant petrographic difference is that only a trace amount of sericite exists in the Barnhardt Quartzite samples; original quartz overgrowth and cementation is extensive (Plate 12B). The one thin section cut of Deadman Quartzite is much like those of the Barnhardt Quartzite except that it contains several percent of sericite (often with chlorite cores) as lensoid tablets considerably larger than the quartz grains, and a dozen or more grains each of zircon and tourmaline.

Comment. Abundant sericite in both Houden and Christopher Mountain Quartzites, and its paucity in the Mazatzal Mountains samples may reflect different metamorphic histories of the two areas rather than primary mineralogical differences. It seems possible that sericite was introduced into both Christopher Mountain and Houden quartzites during the hydrothermal event accompanying intrusion of hypabyssal felsic rocks (page 381).

DISTRIBUTION AND STRUCTURE

Christopher Mountain Quartzite is the uppermost stratified Precambrian unit exposed in Tonto Basin. The great bulk of this formation, along with extensive masses of underlying strata, was removed by erosion before deposition of the Precambrian Y Apache Group.

From McDonald Mountain to Derrick Pocket the quartzite is the core unit in the Tonto Basin syncline. Dissection of the syncline by Spring Creek gorge provides a superb exposure of the bedding and structure (Plate 11A).

Quartzite bedding attitudes and the contact with underlying rhyolite define the Big Ridge syncline in its southern (Haigler Creek, lower Gordon Canyon) and central (Big Ridge, Horse Mountain) exposures. Cross-bedding in the quartzite is the main criterion for defining the overturned northern extension of the Big Ridge syncline beneath Christopher Mountain. The position of the axis of the overturned syncline is not well known north of the Diamond Rim fault.

In Bull Tank Canyon (F-19) steeply-dipping overturned beds in the western limb of the syncline are over 300 m thick. Inadequate structural control does not permit a good estimate of thickness in the great Christopher Mountain mass, but in the northwestern part of the mountain where beds appear to dip southward at about 20-30° for approximately a mile and a half the quartzite may be greater than 800 m thick. The base of the section is not exposed there.

CONTACTS WITH HAIGLER GROUP RHYOLITE

Gastil (1958, Plate 2) has previously interpreted some quartzite-rhyolite contacts in the Big Ridge syncline as being faults. The following section will argue that they are all sedimentary contacts.

Along the contact on the western limb of the syncline in Lost Camp Canyon (K-17), on the south nose of Horse Mountain (H-19), and in Bull Tank Canyon (F-19) bedding attitudes in the basal beds are conformable to the contact and cross-bedding indicates tops as being up into the quartzite. The underlying rock is dark purplish or reddish slate, wacke, breccia conglomerate or rhyolite. Bedding or flow-foliation in rhyolite is roughly parallel to the contact. At Lost Camp Canyon the conglomerate clasts are rhyolite. Minor lithic wacke usually occurs between this and the quartzite. In Bull Tank Canyon, in an excellent exposure of the overturned contact, a pebble or granule sedimentary breccia composed entirely of rhyolite rests directly on an irregular rhyolite surface. For 10 to 15 meters of section this breccia alternates with and grades into fine purple slate. The overlying 75-100 m is purple slate which gives way upward to a great thickness of virtually monolithologic quartzite.

On the opposite limb of the Big Ridge syncline the quartzite-Oxbow Rhyolite contact was mapped from the Haigler Creek-Gordon Canyon junction to Hog Canyon. Bedding in the quartzite was again found to be conformable to the contact. Underlying Oxbow Rhyolite is stained a dark red-purple to a depth of about 10-20 m. Only a trace of purple slate occurs along this contact; the quartzite-rhyolite contact is quite sharp. The exact sedimentary contact was observed in several places at which thin granule breccias of disintegrated and slightly reworked rhyolite were found (Plate 10B).

Quartzite also rests unconformably on the rhyolite in the Tonto Basin syncline. The sedimentary contact on the western slope of McDonald Mountain (N,O-10) and between McDonald Mountain and Soldier Camp Creek (P-9) consistently reveals a transitional zone from Haigler rhyolite up into quartzite in which a variable thickness of reworked rhyolite detritus usually grades upward into purple to maroon slate and/or sedimentary breccia or conglomerate containing felsic volcanic clasts. Commonly these incompetent rocks are strongly foliated and clasts are flattened. The transition from slate into quartzite may be sharp, gradational or cyclic. At one locality a purplish altered rhyolite was found at the top of the slate sequence in possible slight angular unconformable contact with the quartzite.

At Derrick Pocket (L,M-12) the purple slatey rocks are absent but beneath the quartzite rhyolite of a generally epiclastic character is stained purplish to a depth of about 50 m. A sharp contact with overlying quartzite was observed at station 1704 and, though there is a weak foliation in the coarse breccia, there is no evidence of shear.

The deep red-purple coloration of all rocks beneath Christopher Mountain Quartzite is probably due both to weathering of the rhyolite prior to deposition of the quartzite and to subsequent leaching of iron (and manganese?) from quartzite down into the rhyolite. The latter is suggested by the fact that purplish staining in rhyolite is most intense (along the Oxbow Rhyolite contact, I-20) where the basal 50-60 meters of quartzite is tan or pink rather than the normal dark-brown or purplish.

Internal structures of the rhyolite beneath the quartzite must be better determined before confidence can be placed in any estimation of degree of folding and erosion prior to quartzite deposition. At present one must look as much to gross contact relations as to local minor structure along the contacts for hints as to timing of folding and erosion in relation to sedimentation.

The absence of a basal conglomerate of any significance and the common presence of a little slate along the basal contact are intriguing, and certainly are clues to the conditions existing during deposition of the quartzite. Absence of conglomerate indicates topographic prominence which might be explained by deformation and concurrent uplift. There is no evidence for pronounced pre-quartzite deformation, however, and a simpler explanation for the apparent relief is that the central, higher parts of a great volcanic edifice constructed during the Tonto Basin alkali rhyolite event (page 251) were in Tonto Basin. The presence of much coarse basal conglomerate in the Mazatzal Mountains and at Pine Creek (assuming correlation) is compatible with this idea; thinner rhyolite in the distal parts of the field might have received an apron of gravel cover.

A shallow sea may then have transgressed the volcanic construct. Even high parts were submerged deeply enough that shale was initially deposited locally under quiet water conditions. Subsequent deposition of cross-bedded sandstone was apparently almost entirely above the wave-base level.

GISELA PENDANTS

DISTRIBUTION AND LITHOLOGIES

Metavolcanic and metasedimentary rocks intruded by diorite and hornblende granophyre of the Gibson Complex in the Gisela area (N,O,P-5, 6,7 and Figure 4) are interpreted in part at least as being pendants. These rocks are mapped as the Gisela pendant unit and occur as 1) a 3-mile-long north-south belt within the diorite, 2) a 1-mile-long belt between hornblende granophyre and Green Valley granophyre, and 3) a small mass at the southernmost tip of exposed diorite. The main body of mafite porphyry is probably also a pendant in diorite but is discussed under a separate heading.

Only limited mapping was done in the pendant rocks and large areas of diorite were not examined. Therefore, many pendant contacts are inferred and pendants or stoped blocks other than shown may exist. Designating all these masses as pendants may be somewhat arbitrary. The western mass was certainly engulfed by diorite magma and intricately intruded on all sides, but whether it is a pendant or a giant inclusion cannot be determined. The eastern body is intruded on one side by rocks of the Gibson Complex (hornblende granophyre) and is limited by the post-diorite intrusion of Payson Granite and Green Valley Granophyre on the north and east. Tertiary gravel covers the southern part. Contact relations were not determined for the third, smaller mass mentioned above. Because these bodies share some equivalent or similar lithologies and similar metamorphic modification and because the western mass is demonstrably engulfed by diorite, they are treated as the Gisela pendant map unit.

Rocks of the Gisela pendants are slightly to extensively modified by contact metamorphism. Metamorphic recrystallization is apparently strongest in the northern parts of the western belt and weakest in the eastern belt. The metamorphic rocks are generally fine-grained hornfelses in which relict igneous and sedimentary features are often discernible. In the discussion that follows igneous and sedimentary rock names will be used, except as indicated, with the understanding that the rocks are metamorphosed. Lithologies found, in approximate order of abundance, are sedimentary rocks, mostly feldspathic graywackes, rhyolite and mafic volcanic rocks.

The southern half of the eastern pendant is apparently entirely rhyolite including the small southern tip isolated by gravel cover, and the northern half is mostly mafic volcanic rocks. Also present in the northern part are fine-grained dark graywacke and minor reddish-mottled, dark smokey gray, medium- to coarse-grained quartzite(?). There seems to be some small-scale brittle deformation in the heterogeneous northern area.

Though somewhat recrystallized, rhyolite in the excellent exposure on Tonto Creek (1460, P-7) is clearly extrusive. Volcanic breccia and possibly ash-flow tuff are among the lithologies.

The dark mafic rocks include a porphyry with abundant 5 mm plagioclase phenocrysts, a phenocryst-poor variety with 3-5 cm bulbous structures probably analogous to lithophysae in rhyolite, and a volcanic breccia. Dense fine-grained dark graywacke is strongly layered and may be most abundant in the central part of the mass where it seems to be in contact with rhyolite. Although layering in the graywacke is probably primary bedding, no clear-cut sedimentary structures indicative of stratigraphic tops were observed.

Layering and contacts in the eastern pendant are generally steep and trend roughly east-west. These structures are clearly truncated at a high angle by both hornblende granophyre on the west and Green Valley Granophyre on the east.

A plagioclase phenocryst mafic porphyry essentially identical to that occurring in the northern part of the eastern pendant is present in the small southern pendant.

Rock types in the large western pendant are generally, and in some instances precisely, equivalent also to those just described for the eastern pendant. Very similar dark graywacke, some rhyolite, and a tiny amount of identical smokey-gray quartzite(?) were found in the southern part of the body. The graywacke seems to predominate in the south and is practically the only rock type found in the central part of the pendant. The northern third of the pendant was not examined at all. Northward in the pendant metamorphic grade apparently increases; locally the rocks are gneissic hornfelses and parentage is more difficult to determine.

Because of both metamorphic recrystallization and a pre-metamorphic (?) foliation the rhyolite of this pendant is more difficult to characterize than that of the eastern pendant. Good local definition of phenocrysts is the main field criterion for identification as rhyolite. Primary flow structures were not found.

Layering attitudes in the pendant are quite variable but tend to strike roughly parallel to the long direction of the body.

Texture and mineralogy of the Gisela pendants are documented in the section on petrography (page 261) and interpreted in terms of original lithology.

ORIGIN

The Gisela pendants might be from an older sequence of rocks (possibly of the 1780-1820 m.y. northern province, page 23) seen nowhere else in the study area. Alternatively, they might belong to the Haigler and Alder groups. These alternatives coincide with the two major alternative hypotheses for the overall evolution of the entire Tonto Basin Precambrian complex. If the pendants belong to the Alder-Haigler sequence, the plutonic bodies are younger than all of the sedimentary-volcanic units mapped (with the possible exception of the Christopher Mountain Quartzite). If, on the other hand, the pendants are unrelated to the Alder-Haigler rocks, other hypotheses, notably that the plutonic rocks and pendants were a basement upon which at least the upper part of the sedimentary-volcanic sequence was deposited, are plausible.

The field relations having a possible bearing on the origin of the pendants follow: 1) Generally steeply dipping flow banding in the northwesternmost Haigler rhyolite of Gisela Mountain (Figure 4) strikes northwestward perpendicular to the NE-SW trending contact of the rhyolite with hornblende granophyre (actually the contact with the narrow intervening undifferentiated mafite unit). 2) Flow banding in rhyolite of the southern part of the eastern pendant and contact and bedding attitudes in the central and northern parts of the pendant strike roughly east-west and are thus similar in attitude to the flow banding in Haigler rhyolite which is separated from rhyolite of the pendant only by 400 meters of gravel cover. 3) Green Valley Granophyre of Neal Mountain may have intruded between Payson Granite and Haigler rhyolite simply by inflation. There is no evidence, of course, that the granite and rhyolite were ever in contact, and intervening rocks may have been present prior to the intrusion of the granophyre. Such intervening rocks may have been an eastward extension of the eastern pendant. Lacking evidence for this, the possibility remains that the Haigler rhyolite may have been lifted away from the granite by a distance equivalent to the thickness of the granophyre.

Observations 1) and 2) may be interpreted to imply that the Haigler rhyolite was truncated not only by the intrusion of the narrow mafite unit but by hornblende granophyre as well, and that there may be a continuity of both lithology and structure from the eastern pendant into the Haigler rhyolite. If such a continuity exists, the eastern pendant at least is reasonably composed of Haigler rhyolite and underlying units of the Alder Group. Inasmuch as the north-south granite-granophyre sequence immediately east of Gisela is correlative with the same sequence east and north across the Green Valley Creek fault, it is part of the northeast limb of the Tonto Basin syncline. The upper units of the Alder Group, then, would logically be exposed north of the Haigler mass of Gisela Mountain because that direction would be downsection. The position of the mafic rocks in the northern part of the eastern pendant would then be about right to correlate with the mafic rocks of the Board

Cabin Formation, although they apparently do not contain the distinctive Board Cabin andesite porphyry. Quartzite and graywacke in the pendants might also have their correlatives in the Alder Group.

The absence of a contact relationship between hornblende granophyre and undisputed Haigler rhyolite, coupled with observation 3), requires that the foregoing interpretation be considered very cautiously. Upon intrusion of Green Valley Granophyre there might have occurred approximately 1000 m (thickness of Green Valley Granophyre at western end) of fault movement between Haigler rhyolite and the hornblende granophyre-pendant block. Evidence for such faulting might be obscured by intrusion of mafite undifferentiated along the hypothetical fault but this is contrary to the suggestion (page 280) that vitreous black 'porphyry' is hybridized mafite porphyry which is intruded by hornblende granophyre.

Other arguments could be raised in opposition to an interpretation that pendants are composed of Haigler Group and Alder Group lithologies. One could imagine the hornblende granophyre (or the entire Gibson Complex) standing in sharp relief against granite on a pre-Haigler erosional surface so that Haigler flows lapped onto it, thus explaining the strong discordance between the contact and flow foliation. Rhyolite 'of the eastern pendant' could even be continuous, feasibly, with Haigler rhyolite and not belong to the pendant but overlie both hornblende granophyre and non-rhyolite pendant rocks. This is considered to be highly unlikely, however, because at station 1460 the rhyolite is metamorphosed and contains dikes probably derivative from hornblende granophyre. Also, felsite inclusions in the eastern part of the hornblende granophyre may have come from this rhyolite.

The author is of the opinion that a more detailed field and petrographic study of the pendants might provide definitive data regarding their origin. This is highly desirable because it would be independent of the arguments developed elsewhere (page 95), having to do with mafite porphyry contact relations, that Payson Granite and probably Gibson diorite are younger than Haigler rhyolite, which relationships, if true, would compellingly favor a derivation of the pendants from the Alder-Haigler sequence.

Radiometric determination of absolute age of the pendants would be yet another approach to the problem. One might expect either a 1780-1820 m.y. or a 1715 m.y. age since these are the consistently obtained ages of volcanic rocks of the northern and southern regional Precambrian provinces, respectively.

MAFITE PORPHYRY AND ASSOCIATED ROCKS

Small masses of mafite porphyry, mafite undifferentiated and buchite occur primarily in the vicinity of the Connolly Ranch (P-6) near Gisela. Their distribution and relationship to more extensive major rock types in this area are shown in the preliminary map of Figure 3. Field relations in this area and interpretations of origins (page 273) of these lithologies are the basis for the hypothesis advanced in this study that Payson Granite and the Gibson Complex are younger than Haigler Group rhyolite.

Buchite

Buchite was found as a single large mass about 350 m in the longest dimension and as inclusions a meter or less in diameter in both hornblende granophyre and mafite undifferentiated (localities symbolized 'B' in Figure 3). The large mass is surrounded on three sides by Quaternary gravel and bounded on the east by mafite undifferentiated. The buchite texture is consistent and distinctive and there is little doubt that the inclusions have the same derivation as the large mass.

Buchite is characterized by a well-displayed megascopic texture in which a lacework of (usually dark brown) irregular films or layers of quenched and devitrified melt occurs between and around remnant quartz and feldspar. On a planar surface the melt appears as continuous and coalescing vermicular dark bands up to two mm in width between discontinuous and highly irregular quartz and feldspar areas (Plate 13A). The greatest degree of partial melting was observed in the northern part of the large mass. In the south central part of the body partial melting was slight and its expression difficult to see megascopically. Originally possessed of a good granitic texture, the rock strongly resembles quartz monzonite found at station 2218 (P-6) about a mile to the northwest across Tonto Creek.

Petrographic and petrologic criteria suggest that buchite was formed by partial melting of quartz monzonite upon intrusion by mafite porphyry (page 276).

Mafite Porphyry

Mafite porphyry is a most peculiar and distinctive rock type characterized by enormous euhedral plagioclase (up to 4-5 cm), 3-6 mm subhedral alkali feldspar; and 1 mm anhedral quartz crystals set in a

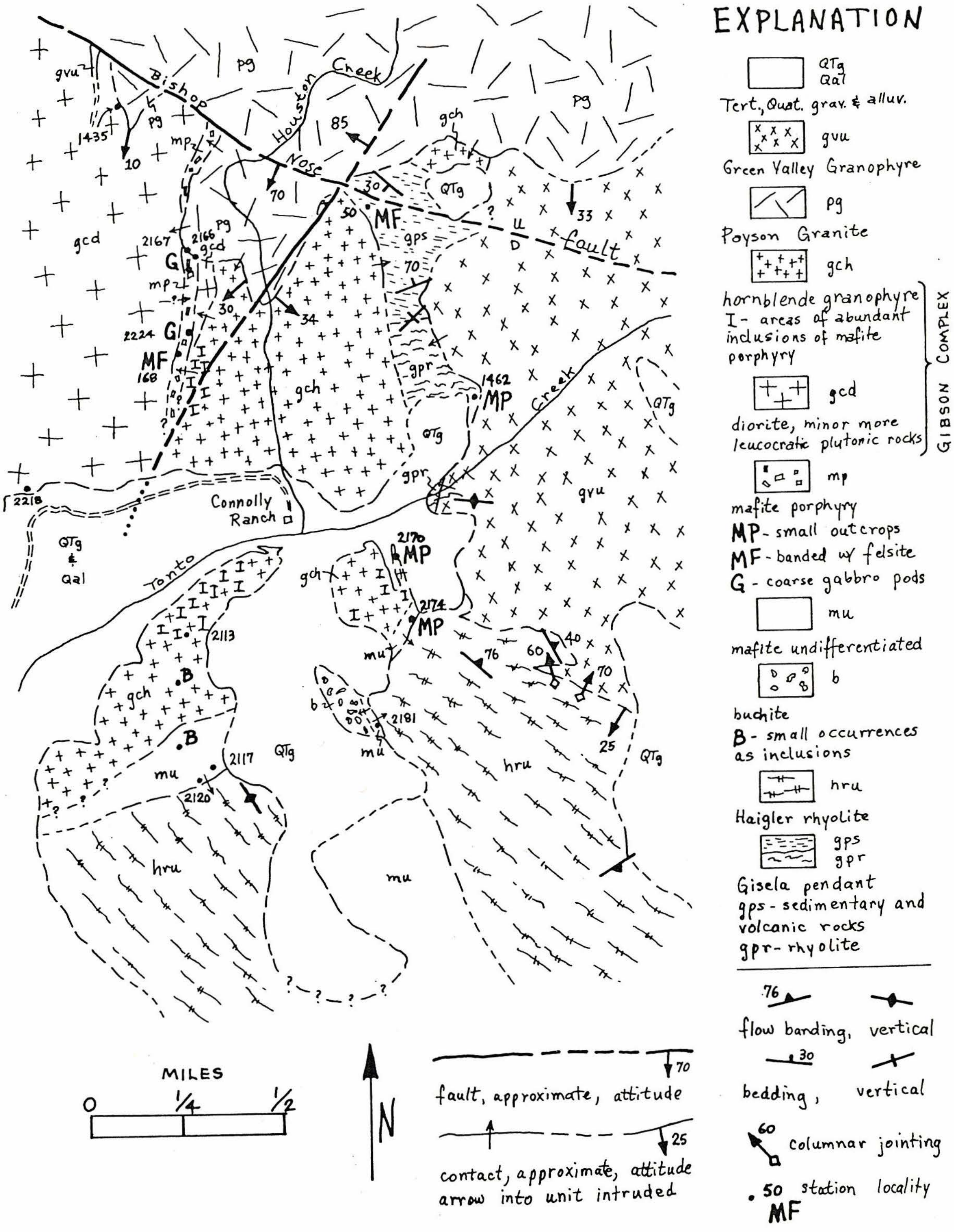
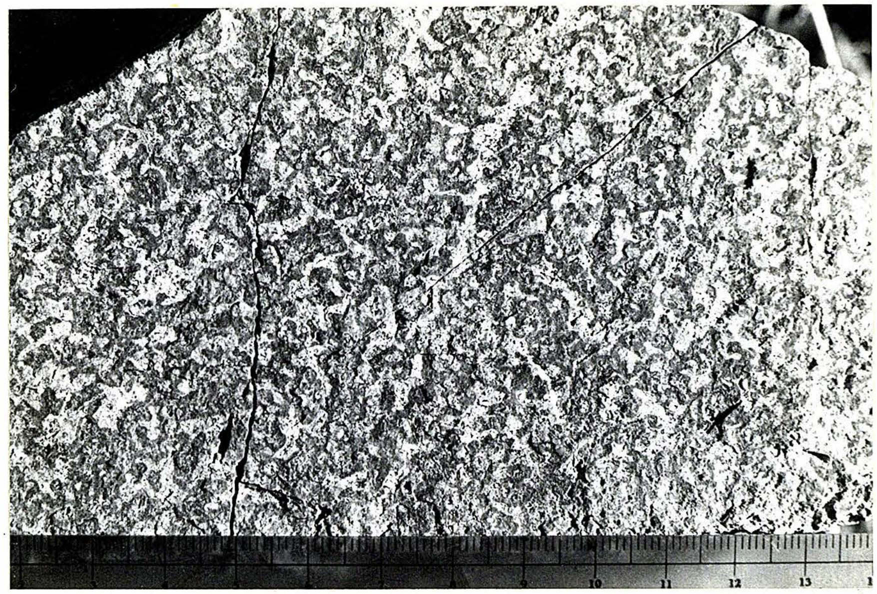
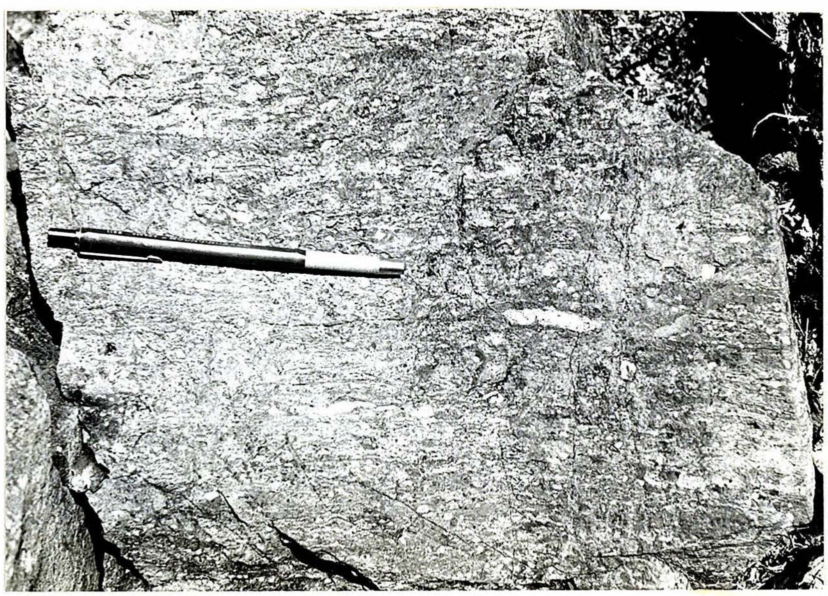


Figure 3. Geology in the vicinity of the Connolly Ranch at Gisela (see Figure 4 for location). Field stations, identified by number or letter symbol, or both, are referred to in the text.

PLATE 13. BUCHITE AND BANDED MAFITE-FELSITE

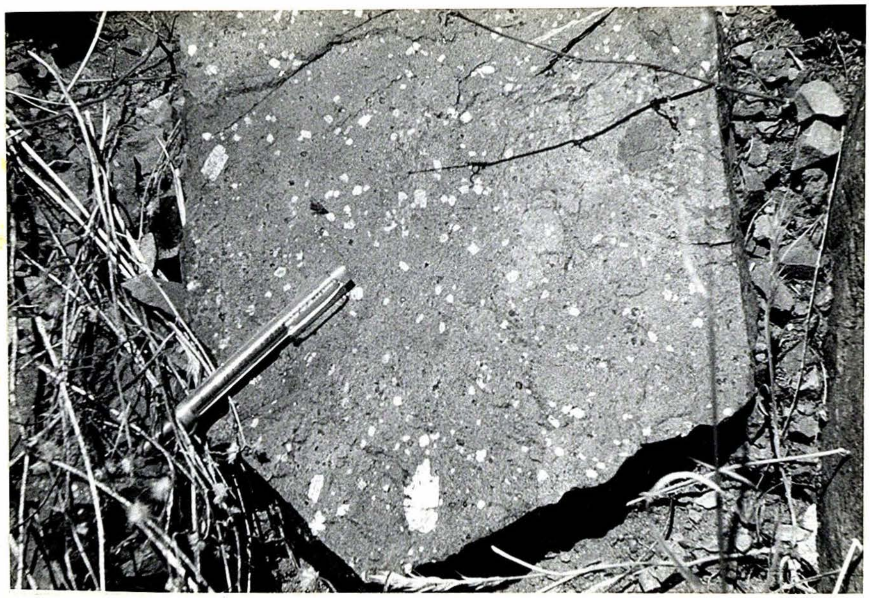


A. Buchite. Dark coalescing, vermicular areas are quenched and devitrified melt. Light areas are remnant quartz and feldspar. See Plate 29 for photomicrographs.

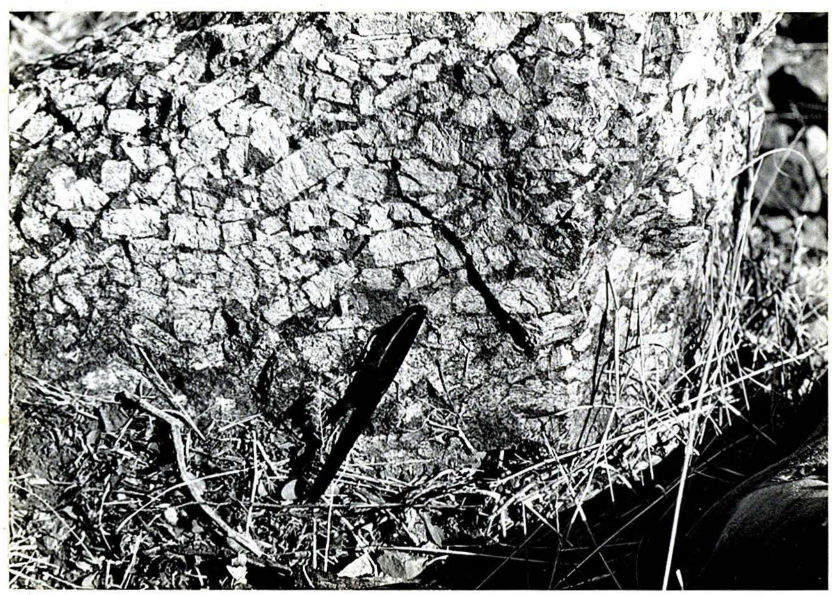


B. Banded mafite-felsite from block at station 168 (O-6) within main mass of mafite porphyry. Felsic and mafic portions are intimately interlayered on mm to cm scale. White blocky areas in dark layers are plagioclase crystals.

PLATE 14. MAFITE PORPHYRY



A. Mafite porphyry. Large white crystals are plagioclase, smaller light-colored crystals are both plagioclase and alkali feldspar, small dark-rimmed features are hornblende-mantled quartz crystals. Note 3 cm mafic-rich clot in upper right. (168, 0-6).



B. Gabbroic pod associated with mafite porphyry. Plagioclase mega-crysts are identical to those of mafic porphyry. See text for further description. (2224, 0-6) very fine-grained (0.1 mm) dark groundmass (Plate 14A). Rarely, clots even darker and finer-grained than the groundmass are present (Plate 14A). Although variable, mafite porphyry is readily distinguished in the field.

There are three types of occurrences of the mafite porphyry: 1) A single large elongate mass occurs approximately along the diorite-hornblende granophyre contact at Gisela (O,P-6, and Figures 3 and 4). 2) Scattered small exposures occur mostly in the area of Figure 3 and are located in that figure by the symbol 'MP.' 3) Fragmental inclusions of mafite porphyry are ubiquitous throughout the Blue Dog phase of the Hell's Gate Rhyolite and in parts of the hornblende granophyre of the Gibson Complex.

MAIN MASS

The trend across topography of the main mass north of Connolly Ranch suggests it may be a vertical to steeply-eastward-dipping tabular body varying in thickness from a few tens of feet to perhaps a hundred feet. It was probably intruded by diorite of the Gibson Complex by which it is flanked on both east and west. Payson Granite and hornblende granophyre of the Gibson Complex cut diorite-mafite porphyry contacts from the east.

The population of plagioclase megacrysts varies considerably in size and abundance from place to place but there seems to be no systematic variation with respect to the geometry of the body.

Plagioclase megacrysts comparable in appearance and size to those scattered throughout the mafite porphyry were also found in one or more very coarse-grained, discrete gabbroic pods (Plate 14B) cropping out in a 36 square-meter area at station 2224. Plagioclase content in these outcrops ranges from about 50 to 70 percent. The dark matrix between plagioclase crystals is composed of very coarse-grained (few mm to few cm) oxides and ferromagnesian silicates (altered) and is thus strikingly different from the mafite porphyry groundmass. As seen in Plate 14B there is a weak orientation of the blocky plagioclase crystals which are moderately platey parallel to (010).

This megacryst-rich rock appears to be completely within mafite porphyry though right at the eastern contact of the mafite porphyry with diorite. Plagioclase megacrysts in the mafite porphyry increase in abundance eastward toward this occurrence. In a complete exposure there was seen to be a sharp contact between normal mafite porphyry and a hemispheric portion of a gabbroic nodule with a radius of curvature of about 0.5 meters. On the borders plagioclase is locally finer-grained, with a fragmental appearance. A similar fragmental texture is also seen between large euhedral to anhedral plagioclase crystals in the interior of the gabbroic pods.

Surface float of identical megacryst-rich material was seen north of station 2224 in the vicinity marked 'G.'

At station 168, indicated 'MF' in Figure 3 , only a few feet from the diorite but apparently entirely within mafite porphyry is a 6 x 9 m block comprised entirely of discontinuous but quite regularly inter-leaved 0.1 to 3 cm lenses and laminae of distinctly different dark and light materials (Plate 13B). The light layers contain several percent 1-3 mm quartz and alkali feldspar crystals in a very fine-grained felsic matrix. The dark portion is very fine-grained, hornblende-rich, and contains a few percent white plagioclase crystals usually less than a centimeter but rarely several centimeters in length. Mafic layers in the block of banded mafite-felsite are continuous at the margins with mafite porphyry which surrounds the block.

SCATTERED OCCURRENCES

Several very small exposures of mafite porphyry similar to the type lithology occur within a mile of the main mass and are designated 'MP' in Figure 3 (1462, 2170, 2174; O,P-6,7). A tiny exposure also occurs 3½ miles upstream from Gisela along Tonto Creek in the Picket Pen fault slice (40, N-9). There is a questionable occurrence 3½ miles south of the main occurrence in Curry Basin (151, S-6). Mafite porphyry at all these occurrences, with the possible exception of station 2170, is within or against either Haigler rhyolite or rhyolite of the eastern Gisela pendant.

At station 1462 within extrusive rhyolite of the eastern Gisela pendant is an area of several tens of square meters within which there is an excellent, irregular outcrop of typical mafite porphyry. The mafite porphyry appears to be surrounded by rhyolite of the pendant, but no exact contacts were seen. Large blocks (few meters) of mafite porphyry are associated with hornblende granophyre containing abundant small inclusions of mafite porphyry at station 2170. It was not determined whether the larger blocks were also inclusions. At station 2174 mafite porphyry was found to intrude Haigler rhyolite of the Gisela Mountain mass. Near the well-exposed contact the mafite porphyry contains numerous 1-2 cm fragments of the extrusive rhyolite. Mafic clots similar to that shown in Plate 14A are very abundant at this station. Plagioclase megacrysts are much less abundant than in the main mass.

The Picket Pen fault slice occurrence is a 1.5 m outcrop, isolated by Tonto Creek channel sand cover, of typical mafite porphyry in which was found a knife-sharp intrusive contact with Haigler rhyolite. Although the origin of this contact could not be determined with certainty, it seems likely, in the absence of large exotic blocks in the extrusive rhyolite, that the mafite porphyry is a dike and not an inclusion. At the Curry Basin locality a relatively large mass (more than 30 m across) of mafite with rare euhedral plagioclase megacrysts was found within an area of extrusive rhyolite. Contact relations were not determined. Alkali feldspar and quartz insets are either absent or rare.

Banded mafite-felsite similar to the block found in the main mass of mafite porphyry is associated with sedimentary and mafic volcanic rocks in the northern part of the eastern Gisela pendant (50, 0-6). This locality is designated 'MF' in Figure 3. Contact relations were not determined. No separate mafite porphyry was observed.

IMPORTANCE AND CONSANGUINITY OF MAFITE PORPHYRY

At station 2174 a mafite porphyry intrudes Haigler rhyolite. The main mass of mafite porphyry is intruded by Payson Granite and probably by diorite of the Gibson Complex. If these two occurrences of mafite porphyry are correlative, then Payson Granite and probably the Gibson Complex are younger than Haigler rhyolite.

The concentration of mafite porphyry inclusions in hornblende granophyre along a southward projection of the main mafite porphyry mass and eastward to the vicinity of stations 2170 and 2174 (see Figure 3; areas of abundant mafite porphyry inclusions indicated by 'I') suggests that mafite porphyry on either side of the hornblende granophyre body may have once been continuous. Hornblende granophyre may have disrupted and separated by east-west inflation a continuous or near-continuous north-south body of mafite porphyry now represented in exposure by the main mass and only small exposures in the vicinity of 2170 and 2174. Stations 50 and 1462 would have been very close to this body in its pre-hornblende granophyre geometry. Regardless of whether such a dissection and inflation occurred, the various mafite porphyry outcrops are still quite closely associated spatially. This, and the persistent recurrence of the peculiar, distinctive lithology argue strongly for correlation. The probability seems small indeed that the very unique mafite porphyry would be created at two widely separate times or by two separate means in the same locality. The problem of correlation, and of origin, will be discussed in detail in the petrography-petrology section.

The hypothesis that Payson Granite and the Gibson Complex are younger than Haigler rhyolite arises from both the tentative interpretation of Gisela pendant origin (page 83) and the mafite porphyry relationships. The mafite porphyry interpretation is the most compelling. The hypothesis was developed subsequent to the last field work.

A very detailed field and petrologic study of the mafite porphyry and associated lithologies should be made before a note of finality is attached to this hypothesis.

Mafite Undifferentiated

Occurring between the hornblende granophyre and extrusive rhyolite of Gisela Mountain, and in a large arm penetrating the rhyolite, is a heterogeneous mass of fine-grained dark rock. At least three main variants are present in this unit: 1) mafite porphyry at station 2174, 2) vitreous black 'porphyry,' a phase with a fine-grained almost vitreous black groundmass and about 5 percent 1-3 mm quartz and alkali feldspar crystals, and 3) mafite granophyre, a phase possessing an extremely fine, intricate micrographic groundmass.

Both the mafite granophyre and the vitreous black 'porphyry' contain ubiquitous plagioclase megacrysts and fine-grained dark clots similar to mafite porphyry groundmass, and both are less mafic in bulk composition than mafite porphyry. All internal contacts on a large scale were obscure and appeared to be very irregular and/or gradational. On a small scale in the vicinity of these contacts apparent inclusions of mafite porphyry were found in vitreous black 'porphyry' and of the latter in mafite granophyre.

The two small northeastern segments of mafite undifferentiated (P-6,7) seem to be mostly vitreous black 'porphyry' which grades heterogeneously into more mafic rock toward contacts with Haigler rhyolite. At stations 2174 and 2181 the more mafic marginal rock contains fragments of the rhyolite; at the former it is clearly mafite porphyry. Near station 2174 abundant diffuse mafic clots appear to be strung out in vitreous black 'porphyry.' At station 2181 there is a gradation from fine-grained rock at the contact to coarser-grained, less mafic rock nearer the buchite mass.

The southern largest mass of mafite undifferentiated may be composed mostly of mafite granophyre. Both mafite granophyre and vitreous black 'porphyry' occur in the western segment. Vitreous black 'porphyry' in the latter area at station 2117 (P-6) contains blocks of Haigler rhyolite as large as a few meters.

Contacts of mafite undifferentiated phases with the buchite mass and with hornblende granophyre appear to be sharp but no definitive contact relations were seen. However, in the western exposure 1-2 meter blocks of buchite ('B' in Figure 3) were found as inclusions in mafite granophyre and perhaps in vitreous 'porphyry.'

An interpretation is presented (page 282) that vitreous black 'porphyry' is hybridized mafite porphyry. Other alternatives are considered. Mafite granophyre is petrographically similar to hornblende granophyre of the Gibson Complex.

GIBSON COMPLEX

Introduction

A plutonic mass, composed mainly of diorite but also containing significant amounts of gabbro and intermediate rocks, underlies 50-60 square miles immediately south and west of Payson. It is bounded on the north by the Payson Granite and on the west and south by the

Tertiary and Quaternary valley fill in the East Verde River, Rye Creek and lower Tonto Creek drainages. This body, shown on the state map of Arizona (Wilson _et al._, 1969) as Precambrian greenstone (unfoliated greenstone derived from metamorphism of mafic flows and intrusive rock), is herein designated the Gibson Complex. The name is taken from Gibson Peak and Gibson Creek, both underlain by the easternmost part of the complex. The location of the mafic mass is marked by pronounced anomalies on the magnetic and gravity maps of the state of Arizona (Sauck and Sumner, 1971; West and Sumner, 1973).

The northern and central parts of the complex are expressed as moderately well-defined physiographic tableland which stands somewhat higher than the Payson granite to the north and east. This generally deeply weathered highland has poor exposure and little relief. Roundish boulders of gabbro and diorite, wholly or partially freed and rotated from original bedrock position by spheroidal weathering and erosion, are common and occasionally litter the slopes. Only locally are excellent, well-preserved bedrock outcrops found.

Best exposures of the complex are in the western, southern and eastern margins where deeply incised drainages and steep slopes descend one to two thousand feet into the East Verde River and Rye, Tonto and Houston Creek drainages. Unfortunately, deuteric alteration is more severe in the southeastern area where exposure is best.

In the present study limited reconnaissance and some detailed mapping was confined to the eastern half of the body. Most of the central part of this area, between Round Valley and Gisela, was not

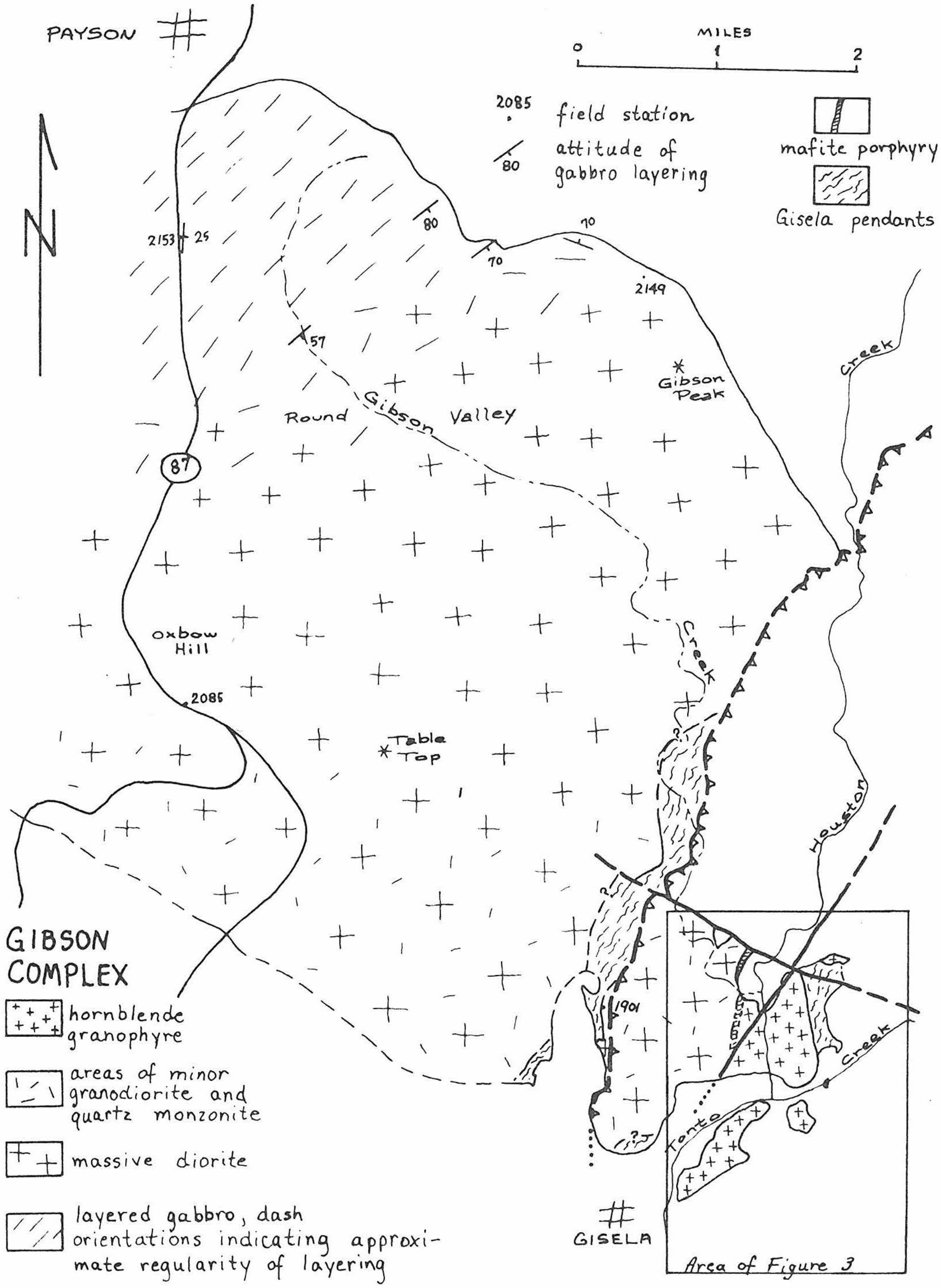


Figure 4. Approximate distribution of rock types in the eastern part of the Gibson Complex. Field stations are referred to in the text. See Figure 3 for station localities in the area of Figure 3.

examined. Several weeks were spent in the Gisela area in an effort to determine the relationships between rocks of the Gibson Complex, Payson Granite, Green Valley Granophyre, Haigler rhyolite and Gisela pendants. A preliminary sketch map of the eastern portion of the Gibson Complex (Figure 4) shows the approximate distribution of lithologies.

The Gibson body was first examined by Lausen and Wilson (1925) who briefly described it as hornblende diorite with no lithologic variation except for local plagioclase enrichments and both mafic and felsic dikes. Putman and Burnham (1963) collected a series of samples from the Gibson Complex and the Payson Granite in a SW-NE traverse from the Tonto-Rye valley to the Diamond Rim as part of a geochemical survey of some plutonic rocks in Arizona. In the complex, referred to by them informally as the Payson diorite, they found both diorite and gabbro.

In the Gisela vicinity Payson Granite was found to intrude diorite and hornblende granophyre of the Gibson Complex. This conflicts with the report of Lausen and Wilson (1925, p. 18) that diorite just west of Payson has intruded Payson Granite. Lausen and Wilson also report that the diorite intrudes schist at Bishop Knoll (N-4). This schist must be the Gisela pendant rocks which were found, indeed, to be intruded by diorite.

The Gibson Complex is characterized by inhomogeneity on a large scale and locally, e.g., layering in the gabbro, on a small scale. There is a transition from layered gabbro in the northwest through massive diorite to small bodies more intermediate in composition in the south and southeast. This transition is apparently gradational from gabbro into diorite but abrupt changes of texture or mode observed in a few traverses suggest that internal contacts exist between phases of the diorite as well as between diorite and the southern units. There appears to be a gap in lithologic range between diorite and granodiorite with quartz diorite being scarce or absent. Where observed, the strike of the steeply-dipping gabbro layering is roughly perpendicular to the NW-SE trend of compositional change. These features suggest that the Gibson body is tilted southward and that the southern more felsic units are higher-level, possibly discordant differentiated members. This hypothesis is supported by the occurrence of 'roof' pendants in the Gisela area.

Gabbro and Diorite

LITHOLOGY AND DISTRIBUTION

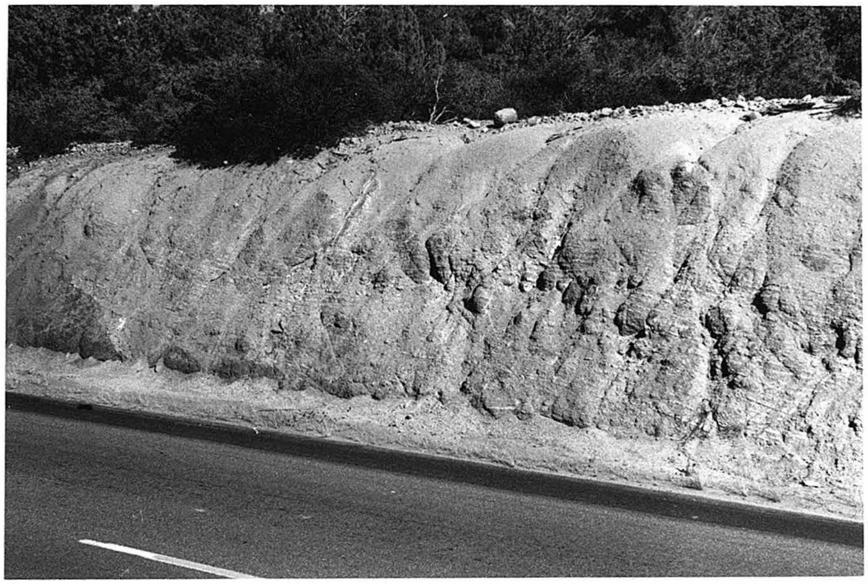
In the area north of Round Valley there is considerable systematic compositional variation in gabbro and diorite. Diorite occurs in the vicinity of Gibson Peak; westward toward Payson the rock becomes generally more mafic, its plagioclase becomes more calcic, and the pyroxene/hornblende ratio increases. Layering becomes discernible very approximately where the rock becomes gabbroic. It appears that layering is approximately co-extensive with the gabbro and that the gradation into diorite is perpendicular to the strike of the layering. Gabbro was identified only in the area between Round Valley and Payson.

Weak to moderately strong layering in the gabbro is due to both compositional layering and to igneous lamination. In the eastward gradation into diorite the igneous lamination continues to be discernible after the composition layering has disappeared. The former is weakly expressed in some of the diorite. The igneous lamination is due to sub-parallel orientation of plagioclase tablets and the compositional layering (Plate 15A) is expressed by alternating plagioclase- and hornblende-, or pyroxene-rich layers usually 3-10 cm thick. These occur as sub-layers within much larger leucocratic and mafic zones up to several dozens of meters thick.

The layering attitudes taken are quite consistent in orientation except for two very near the granite contact (J-5). One-half mile to the east diorite near the granite (2149) displays a wavy foliation interpreted to be a deformation foliation. It is likely that these anomalous structures developed upon intrusion of the Payson Granite or during faulting which may have preceded and controlled intrusion of the Payson Granite (page 248).

Diorite was found to be by far the most predominant rock type in the Gibson Peak area, in the Oxbow Hill area, on the slopes north of Gisela and along the unimproved road between Gisela and Round Valley. Diorite varies considerably in texture and mode and, though there are exceptions, is generally coarsest (about 2 mm average grain size) and most mafic in the northern areas. A coarse textural variant found only in the Gibson Peak area contains 1 cm highly poikilitic hornblende crystals. A similar texture occurs in southeastern gabbro. In the southeasternmost part of the complex, near the hornblende granophyre, the diorite is particularly heterogeneous on a local scale.

PLATE 15. GIBSON COMPLEX



A. Composition layering in leucogabbro. Light-colored plagioclase layers alternate with thicker (5-10 cm) pyroxene(?)-bearing layers. Layers apparently dip away from a contact with more mafic rock to the left. Roadcut on highway 87 one mile south of Payson. (2153, J-2)

B. Hornblende granophyre containing abundant inclusions of mafite porphyry. Station 2113 (P-6) south of Tonto Creek.

Several fine-grained variants include some dark mafic-rich rocks. At least some of the lithologic changes in the diorite are discontinuous and abrupt suggesting that the diorite was emplaced in pulses.

In the excellent roadcut exposures of Oxbow Hill (2085, M-2), diorite is cut by numerous mafic porphyritic dikes which are in turn cut by felsic dikes. Most of these dikes are sub-parallel and dip steeply east to southeast; some are oblique to the major set. The porphyry texture of the mafic dikes indicates these bodies intruded relatively cold diorite and thus they probably are not related to the gabbro of Round Valley. Associated felsic dikes, whose intrusion was probably controlled by fractures developed upon or following cooling of the complex, are probably genetically related to the Payson Granite or to the felsic sills intruded along the Payson Granite-Gibson Complex contact. This notion is supported by the more leucocratic character of the dikes and the increase in their abundance northward toward the granite and highly leucocratic sills.

CONTACT RELATIONS

Excellent contact relations visible at station 1901 (0-5) and immediately south clearly prove that diorite intruded metavolcanic and metasedimentary rocks of the western Gisela pendant. Numerous 1-5 m blocks of metamorphic rock were found to be encompassed by diorite as far as 50 m from the contact. Locally the diorite has a one-foot thick gradationally chilled border zone at the contact and small diorite dikelets penetrate the metamorphic rock and contain small inclusions of the same.

Diorite is not found in contact with the eastern pendant. A small outcrop of dioritic(?) rock within the pendant may be dike rock from the main diorite mass to the west, however.

The main mass of mafite porphyry appears to be a pendant within diorite. Within a few feet of the mafite porphyry at station 168 (0-6) inclusions of felsite were found in the diorite. This felsic rock may have been wall rock for intrusion of mafite porphyry prior to diorite emplacement. Sparse contact data were obtained in the vicinity of station 2224 which indicate that mafite porphyry was intruded by the diorite. A probable partially exposed inclusion of mafite porphyry was found in diorite and a narrow 1.5 m dike(?) of diorite was found in mafite porphyry. In a thin section containing the intrusive contact it appears that diorite may be slightly chilled and that a plagioclase megacryst is irregularly truncated by the contact. Indirect evidence for intrusion by diorite is a textural modification, probably a metamorphic crystallization (page 272), of mafite porphyry near the diorite.

Hornblende Granophyre

Hornblende granophyre occurs near Gisela at the extreme southeastern fringe of the Gibson Complex (Figures 3 and 4) where it separates Gibson diorite from the eastern Gisela pendant, Green Valley Granophyre, mafite undifferentiated, and Haigler rhyolite. Though variable, it is basically quartz monzonitic in composition. It is discussed apart from the following section on granodiorite and quartz monzonite because of its unique lithology and important contact relations.

LITHOLOGY

Throughout the hornblende granophyre micrographic texture usually can be seen with the hand lens. About half of the typical specimen is quartz-alkali feldspar micrographic intergrowth, about a third plagioclase, and about one-sixth hornblende. In the main, it is medium-grained. The body displays inhomogeneity in several ways. Mafite porphyry xenoliths and xenocrysts (plagioclase megacrysts) are found in small-to-trace amounts throughout the body, but are concentrated near mafite porphyry contacts and in the south-central portion (Plate 15B). Rare diorite xenoliths are found predominantly near the western margin.

Much of the constituent plagioclase and hornblende of the granophyre occurs in tiny (few mm) aggregates which have an appearance suggestive of relict diorite texture. On a larger scale, there are generally subtle fluctuations in hornblende and plagioclase content with a suggestion of an overall decrease in color index eastward and northward from the western margin north of Tonto Creek. The granophyre in the small exposure north of Bishop Nose fault (O-7) is least mafic and grades locally into exceedingly leucocratic material.

These field observations suggest that the tiny plagioclase and hornblende aggregates are micro-xenoliths of diorite and that the inhomogeneities in color index are due to incomplete mixing of a large volume of assimilated and almost totally disaggregated diorite.

CONTACT RELATIONS

Locally at the contact with mafite porphyry, an 8-10 m intrusive breccia zone has developed, in which a profusion of mafite porphyry fragments occur in a matrix of hornblende granophyre. Such breccias were not found along the diorite-granophyre contacts; in fact, no sharp contacts were found with diorite, but rather, there seemed to be a gradational zone of hybridization. At the extreme, within this ill-defined zone, a diorite of rather normal appearance contains pockets, or perhaps fingerlets of granophyre.

There was certainly no extensive assimilation of pendant rocks at the eastern contact of hornblende granophyre. However, a few felsic inclusions noted in eastern parts of the hornblende granophyre may have been derived from the eastern Gisela pendant.

Diorite was much more readily assimilated and disaggregated than was mafite porphyry or material of the eastern pendant. The position of the granophyre body, apparently along a roof contact of the diorite, and its ready reaction with diorite suggest that it was a late high-level differentiate of the Gibson Complex and that local diorite may have been hot when granophyre intruded. This hypothesis is developed elsewhere (page 298).

Granodiorite and Quartz Monzonite

On Oxbow Hill and north of Gisela several plutonic bodies, ranging from generally granodiorite to quartz monzonite, were noted. These rocks contain much more alkali feldspar and quartz than the most felsic diorite, or possibly quartz diorite, seen. Thus there is apparently a composition gap between these minor felsic rocks and the diorite.

The only unit demonstrated to be younger than the diorite is a distinctive, locally widespread leucogranodiorite occurring between

Bishop Nose fault and Tonto Creek at Gisela. This persistent lithology occurs as dikes and small irregular discordant bodies intruding the diorite. In some of the easternmost exposures it is locally agmatitic - containing abundant angular inclusions of the various diorite phases.

Some of the felsic bodies may be late differentiates of the Gibson Complex, but others might be older than the main gabbro-diorite mass. At station 2218 (P-6), near Gisela, medium-grained quartz monzonite, for which contact relations were not determined, is similar to the least modified portion of the buchite mass which occurs in contact with undifferentiated mafite. Petrographic characteristics of these rocks are compared on page 275 and it is inferred that the buchite mass may have been stoped by mafite porphyry from the rock type of this locality. If indeed buchite and this quartz monzonite are correlable, the latter is probably not a late differentiate of the Gibson Complex because mafite porphyry is apparently intruded by Gibson diorite.

PAYSON GRANITE

DISTRIBUTION, EXPOSURE AND GENERAL

The Payson Granite occurs in continuous exposure over about 60-70 square miles in the northern part of the mapped area. Minor connecting and isolated exposures extend up to 6-8 miles west and north of Payson, mostly along the East Verde River. Two major Tonto Creek tributaries, Houston Creek and Green Valley Creek, have deeply dissected the decomposed granite thus exposing it in low topographic pockets bounded by benches of Paleozoic strata to the north, the high-standing Gibson

Complex to the southwest, and resistant rhyolite and granophyre comprising King Ridge, Green Valley Hills and Gisela Mountain to the east and south.

The name Payson granite has apparently been used informally for many years and first appeared in print in a paper by Putman and Burnham (1963, p. 63). Inasmuch as the town of Payson is underlain by the granite, this name is very appropriate and it is proposed that it be given formal status. Brief lithologic descriptions of the Payson Granite given by Lausen and Wilson (1925), Gastil (1958), and by Putman and Burnham emphasize the granitic texture and mineralogy, the alteration of ferromagnesian phases and plagioclase, and the pervasive disintegration of the granite to form coarse soil and grus. Wilson (1939, p. 1150) very briefly described the granite and its contact relations along upper Tonto Creek (see page 114). Gastil examined the granite north of the Green Valley Hills and King Ridge and described what appeared in reconnaissance to be a textural gradation from the granite southward into granophyre, then rhyolite.

In this study, Payson Granite was examined in detail along its southern contacts. East of the Green Valley Creek fault detailed mapping was extended locally up to a mile north of the contact with granophyre. A reasonably successful effort was made to examine outcrops and collect samples throughout the body along highway 260 and along unpaved roads and jeep trails which provided relatively good access. The best-preserved samples were collected in a roadcut on highway 260 west of Star Valley (677, G-6), just southward toward Stewart Pocket, and at Houston Pocket (M-9).

The granite is massive and apparently devoid of primary internal structures. Obvious deformation is restricted to the vicinity of fault zones. Well-developed joint systems are in part related to the Precambrian and Tertiary fault systems but many are probably primary tensional cooling joints.

LITHOLOGY

Almost all of the Payson Granite body is coarse-grained to medium-grained, hypidiomorphic-granular granite. Average grain size is 4-8 mm. It is somewhat porphyritic only locally near southern margins and is occasionally strongly porphyritic right at intrusive contacts. The granite is characterized by a ubiquitous rapakivi-like mantling of alkali feldspar by plagioclase.

Most granite has an alkali feldspar/plagioclase ratio of about three, but locally plagioclase approaches alkali feldspar in abundance. The plagioclase-rich rocks are apparently mostly alkali granite (albite-bearing) rather than quartz monzonite (oligoclase-bearing). Hornblende and biotite, or biotite alone, are the ferromagnesian phases and generally constitute less than 5% of the rock.

West of the Green Valley Creek fault the granite lithology is monotonous. Occasional variants are aplite dikes, granite porphyry dikes (sometimes micrographic), rare, poorly developed pegmatites, and porphyritic phases usually occurring at contacts. Certainly the latter and probably the dikes and pegmatites are co-genetic with the main granite and are manifestations of varying local physical conditions in the crystallization history of the magma. Granite east of the Green

Valley Creek fault is more heterogeneous. In addition to the same variants described west of the fault, some quartz monzonite(?) occurs in the vicinity of Little Green Valley (E-13) and eastward to Bearhide Canyon (D-16). Minor fine-grained diorite or quartz diorite occur just west of Little Green Valley and at Bear Flat (D-17). The relation between the granite and the other plutonic rocks (undifferentiated from main granite on the map plates) is not known.

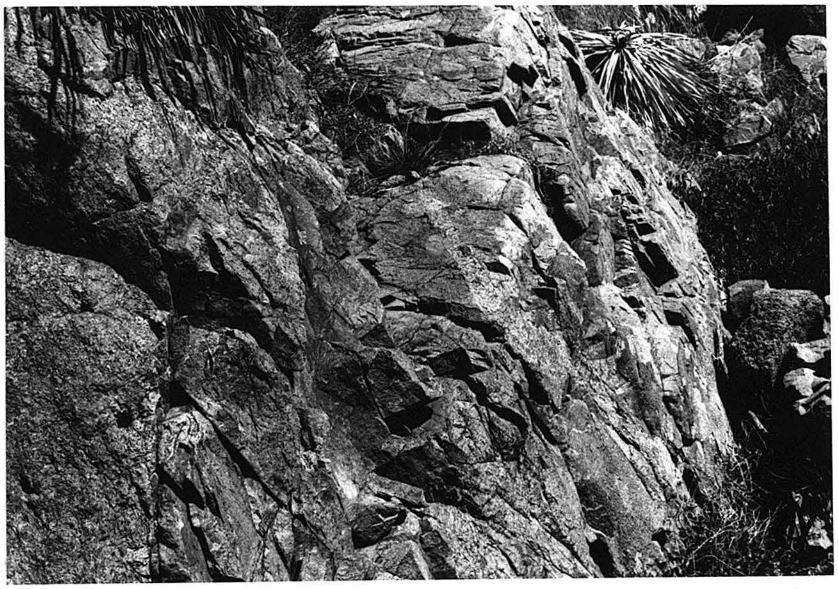
RELATION TO OTHER ROCKS

Other than in fault juxtaposition, Payson Granite is exposed in contact with no major Precambrian units except the Gisela pendants, phases of the Gibson Complex, Green Valley Granophyre, and alaskite along granite-granophyre contacts.

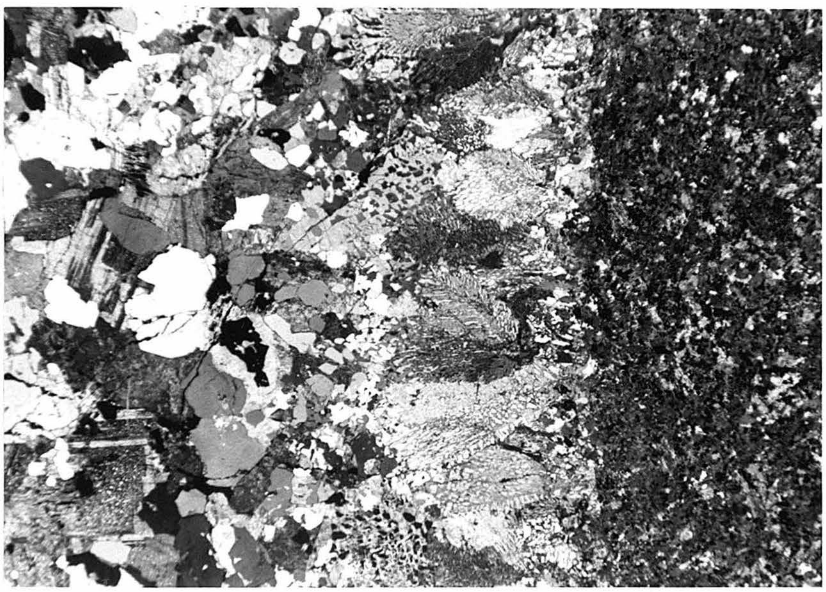
Gisela pendant. Exposure is so poor along the short length of Payson Granite-Gisela pendant contact (O-6,7; Figure 3) that no direct age relationship could be determined.

Gibson Complex and mafite porphyry. At station 1469, immediately east of the granite-pendant contact, a 5-cm wide dike in hornblende granophyre was traced in complete exposure to its source in Payson Granite (Plate 16A). For a mile westward from station 1469, a number of exposed intrusive contacts between Payson Granite and hornblende granophyre, mafite porphyry and diorite phases of the Gibson Complex were examined. Each phase is clearly intruded by granite. The granite transects the diorite-mafite porphyry contacts and the diorite-hornblende granophyre contact.

PLATE 16. PAYSON GRANITE INTRUSIVE CONTACTS



A. Dike of Payson Granite in hornblende granophyre of the Gibson Complex. The 5 cm-wide dike (center) is continuous with the main granite in the lower and left portions of the photo. (1469, 0-7)



B. Intrusive contact, Payson Granite left, mafite porphyry right. Quartz and feldspar in the micrographic margin of the granite have nucleated on the mafite porphyry surface and grown perpendicular to it. Cross-nicols, 10 x 15 mm. (2167, 0-6)

A thin-section of the intrusive granite-mafite porphyry contact at station 2167 reveals spectacular micrographic intergrowth in which quartz and feldspar of the granite have clearly nucleated on the mafite porphyry surface and grown perpendicular to it. The intergrowth grades over about 2 cm into nearly normal granite texture (Plate 16B). Near this station, weakly developed pegmatite and drusy cavities were found in granite at the contact with mafite porphyry and a small granite dikelet in mafite porphyry, of irregular but coarse texture, was probably derived from the granite less than a meter away.

In the vicinity of station 2168 Payson Granite expresses itself variously at contacts with diorite as normal coarse-grained granite, as granite porphyry, and as granite porphyry with a micrographic groundmass. Granite porphyry and the micrographic variant occur as a 10-30 meter-thick border phase at numerous places along the granite-Gibson Complex contact in the Gisela vicinity. At stations 2168 and 1435 probable inclusions of diorite were found in granite.

Border textural variants similar to those described above were found in granite along the Payson Granite-Gibson Complex contact on Gibson Rim from Gibson Peak west to Payson. However, no granite-diorite/gabbro contact exposures were found except in a roadcut at the south city limit of Payson (2203, I-2). Relationships are not clearcut in the deteriorated rock of the roadcut but diffuse mafic areas in granite near the contact might be partially digested diorite/gabbro fragments.

Felsic dikes, distinct from granophyre and rhyolite porphyry dikes also present, are common in northern parts, and particularly along the margin of the Gibson Complex. Coarser and more granitic than the granophyre and rhyolite, often sub-graphic, these dikes were likely injected from Payson Granite.

Rhyolite supposedly intruded by granite (Wilson, 1939). Wilson (1939, p. 1151) reported granite (Payson Granite as mapped in this report) intruding rhyolite east of upper Tonto Creek and southeast of Bear Flat (C,D,E - 17,18). The Bear Flat/upper Tonto Creek region was mapped by the author and the only granite-rhyolite relationship found was a juxtaposition on the Lost Camp fault. If Wilson's stated relationship were found to be true, however, it would support the hypothesis advanced in this study that Payson Granite is younger than the Haigler rhyolite.

AGE

Several years prior to the initiation of the present study, an apparent U-Pb zircon age of 1730 ± 15 m.y. was obtained for a sample of Payson Granite collected from a highway 260 roadcut in the vicinity of station 677 at the west end of Star Valley (L. T. Silver, personal communication). The sample dated is generally typical of the widespread and consistent main lithology but this age should not be indiscriminately assigned to all variants of the Payson Granite. The quartz monzonite and diorite/quartz diorite rocks east of the Green Valley Creek fault, for example, might be of a different age.

HELL'S GATE RHYOLITE

Gastil (1958, p. 1506) recognized that both intrusive and extrusive rhyolite were present "between Lost Camp Mountain and the granite of the Payson area." He called this mass 'rhyolite of the Hell's Gate area' and thought that the large portions displaying columnar jointing were extrusive because of pyroclastic textures (1958, p. 1506; 1954, p. 54).

It was found in the present study that indeed most of the rhyolite is columnar-jointed but that this rhyolite is intrusive. Extrusive rhyolite, rarely columnar-jointed, occurs only in the southwestern parts of the 'rhyolite of the Hell's Gate area,' and it is Haigler rhyolite undifferentiated. It would appear that Gastil found pyroclastic texture in some of the latter rhyolite which was columnar-jointed, although a rare type of flow structure in the intrusive rhyolite might have been seen and taken to be flattened pumice fragments.

It is proposed that the name Hell's Gate Rhyolite be formally applied to the columnar-jointed intrusive rhyolite initially described and partially mapped by Gastil. This mass is a composite sill composed of two distinctive phases, the Blue Dog phase and the Salt Lick phase.

LITHOLOGY

The Hell's Gate lithology is very persistent and the two phases are distinguished only by differences in xenolith content. Both consistently contain 5-10% 1-3 mm quartz and 5-10% 2-4 mm feldspar phenocrysts set in a homogeneously even-grained and generally very fine-grained (0.01 to 0.04 mm) groundmass.

Fine-grained mafic inclusions (0.5 cm to, rarely, a meter) occur throughout both bodies but are considerably more abundant in the Blue Dog phase in which they constitute one or two percent of the rock. Sparse, white-weathering plagioclase megacrysts (0.5-4 cm) are present in the Blue Dog body generally as free crystals but occasionally within the fine-grained mafic inclusions (Plate 17A). A second type of mafic inclusion is found only in the Blue Dog phase. Small (0.2-1 cm) clots of diorite (or gabbro) commonly make up several percent of the rock. It was virtually impossible to collect a Blue Dog specimen which was free of mafic inclusions. Most contain both types.

Though color varies considerably, mostly due to alteration, rocks of both members are typically dark red-brown with a few mm light brown weathering rind. Blue Dog rocks are nearly always somewhat darker, due to the higher quantity of assimilated mafic material. Alkali feldspar phenocrysts are usually reddened and conspicuous. They generally appear lighter than the groundmass on a fresh surface and darker on a weathered surface. Quartz phenocrysts are clear and vitreous. Both phenocryst phases, particularly the quartz, are seen in hand specimen to have been resorbed.

For the most part the rhyolite is very well preserved; alteration seems to be localized along faults and foliation zones. Alteration may extend from a few meters to a hundred meters out from a fault. On both large and small scales these alteration areas consist of zones of progressive bleaching. The rock first becomes lighter brown, then yellowish, greenish or occasionally white, and finally nearest the fault there is sometimes a light rusty zone. A weak to strong foliation is imposed locally on the rocks, especially near faults. Both prevalence and intensity of foliation increases markedly in the south near contacts with quartzite and extrusive rhyolite.

Salt Lick phase. Groundmass grain-size and phenocryst abundance and character vary only slightly throughout the Salt Lick phase. The only marked variations to the monotonous lithology are flow foliations and the very minor fine-grained mafic xenoliths.

A generally weak flow foliation was observed at many places throughout this member but was found to be pronounced only near margins. It is defined both by weak, regular parting surfaces in the groundmass and by orientation of platey mafic inclusions. The mafic inclusions are nearly always platey and often have fiamme-like terminations. They vary from a few cm to a few 10's of cm in length and appear to have undergone plastic deformation. A single probable plagioclase megacryst, altered to dark green in altered creamy-tan rock, was found in Salt Lick rhyolite.

Blue Dog phase. Blue Dog rhyolite has an interesting and systematic variation in groundmass grain size. In the lower parts (northwestern margin against granophyre) the groundmass is relatively coarse-grained (up to 0.3 mm). There is a gradational size reduction up into the body until about midway. Above that grain size is roughly constant and similar (0.01 to 0.03 mm) to that in the Salt Lick phase. Phenocryst and xenolith abundances show no change in relation to groundmass variation.

Only very occasionally in the upper (southern) parts of the body is flow foliation developed. As in the Salt Lick phase, it may be defined by orientation of platey fine-grained mafic xenoliths.

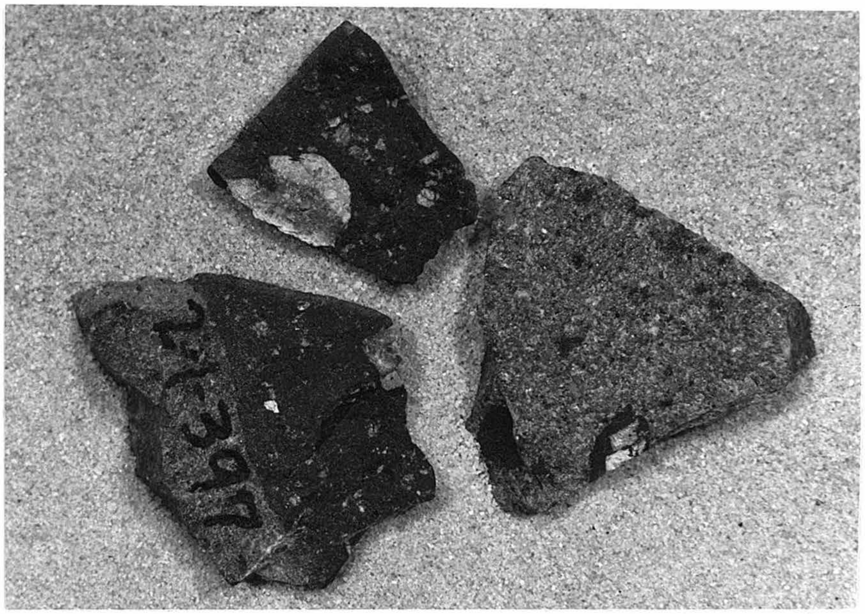
Fine-grained mafic xenoliths vary in size from less than a mm to nearly a meter, but those in the range 0.5-1 cm greatly predominate. Fragments larger than 3 or 4 cm constitute a negligible fraction of the rhyolite whereas those less than 1 cm make up a few percent of the rock nearly everywhere. With diminishing size the xenoliths lose their tabular character and those of the abundant 0.5-1 cm population are mostly equidimensional.

Though there is some variation in texture and mineralogy of the much coarser granitic inclusions, they are basically fine- to medium-grained diorite (or gabbro). They are very consistently about 5 mm in diameter; two much larger (0.3 m) spherical inclusions probably of the same lithology were found. The usual presence of these inclusions, along with the fineness and abundance of mafite inclusions, quite clearly distinguishes Blue Dog from Salt Lick rhyolite.

Plate 18A is a photograph of Blue Dog rhyolite in which most lithologic properties are portrayed. Present are both types of mafic xenoliths and at least three free plagioclase megacrysts. The small dioritic xenoliths can be seen with some difficulty throughout but are particularly evident on weathered surfaces. Alkali feldspar phenocrysts are lighter than usual and stand out very well.

<u>Source of mafic xenoliths</u>. The plagioclase megacryst-bearing xenoliths are identical to the unusual mafite porphyry mapped near

PLATE 17. HELL'S GATE RHYOLITE - MAFITE PORPHYRY INCLUSIONS



A. Mafite porphyry inclusions in Blue Dog rhyolite. Larger white crystals in each specimen are plagioclase; smaller crystals are alkali feldspar. Compare with Plate 14A. Rhyolite host is seen in two of the specimens. Largest plagioclase crystal is 1.5 x 2 cm. (390, 397, G-13)

B. An unusually large, fine-grained mafic inclusion in Blue Dog rhyolite. Unusual among the generally homogeneous fine-grained mafic inclusions, this type contains felsic interlayers. It may be equivalent to the mafite-felsite found in the mafite porphyry body near Gisela (see text). (1065, J-12)

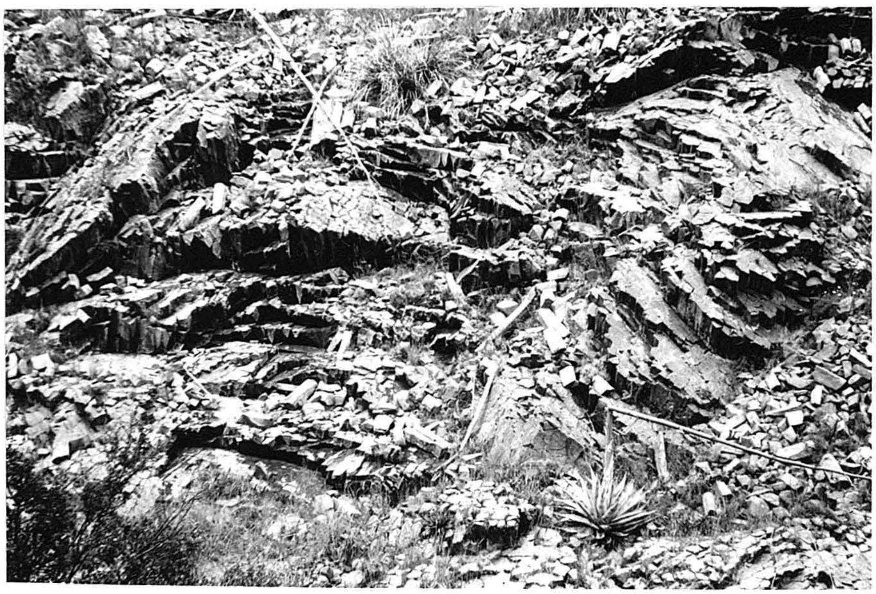
PLATE 18. HELL'S GATE RHYOLITE - LITHOLOGY, INCLUSIONS

A. Outcrop of Blue Dog rhyolite. Light-colored crystals throughout are alkali feldspar. Plagioclase megacrysts (two in upper left) and dark fist-size inclusions are disaggregated mafite porphyry. Small mafite and diorite xenoliths are visible throughout and are conspicuous on the weathered surface, lower left. (1173, G-14)

B. Rhyolite inclusions in Blue Dog phase. Two flow-banded inclusions on left are likely Haigler rhyolite. Third, light green altered massive inclusion may be Salt Lick rhyolite or Haigler rhyolite. (1048, K-10)

PLATE 19. HELL'S GATE RHYOLITE - COLUMNAR JOINTING

A. Columnar jointing in Blue Dog rhyolite. Columns plunge N 15° W at 55°. View is eastward into Salt Lick Canyon from near Station 1173. (G-14).



B. Columnar jointing in Salt Lick rhyolite. All columns have the same attitude (plunge to N at about 60°) independent of variations in the set of undulating fracture surfaces to which they are sub-perpendicular. (1065, J-12)

Gisela. There can be little doubt that the fine-grained mafic fragments and solitary plagioclase megacrysts are disaggregated mafite porphyry.

A comparison of mafite porphyry inclusions in hornblende granophyre with those in Hell's Gate Rhyolite is intriguing. In the former all are roughly equidimensional and internally homogeneous, whereas in the latter, though most are analogous, some are platey and often contain internal parallel layers of felsic material. A striking example of the latter is shown in Plate 17B and a small inclusion with a felsite layer is just to the right of the pencil in Plate 18A. Inasmuch as the mafite porphyry which crops out at Gisela has an isotropic texture and inasmuch as xenoliths of mafite porphyry in hornblende granophyre are not tabular and show no such planar interleaving with the host, one wonders why these planar features repeatedly show up in the xenoliths in the Hell's Gate body. A plausible explanation arises from a comparison of the xenolith texture in Plate 17B to that of the banded mafite-felsite block (Plate 13B) within mafite porphyry at Gisela. This block is interpreted (page 282) as being a stoped block of extrusive rhyolite intimately penetrated along foliation partings by the host mafic magma. If such a phenomenon was more widespread where mafite porphyry intimately invaded an older extrusive rhyolite mass, Hell's Gate Rhyolite, particularly the Blue Dog phase, could later have intruded and incorporated rhyolite pervaded by the mafite porphyry as well as normal rhyolite and mafite porphyry.

The most reasonable source for the small dioritic xenoliths in

Blue Dog rhyolite is the Gibson Complex. The grain size of these xenoliths is comparable to some of the finer Gibson diorite. Occurrence of both mafite porphyry and diorite as xenoliths in the Blue Dog body strongly suggest a recurrence or extension of the close spatial relationship between mafite porphyry and diorite at Gisela at depth beneath the Blue Dog exposures.

DISTRIBUTION

Hell's Gate Rhyolite underlies about 30 square miles in the center of the mapped area. In plan it is roughly a horseshoe-shaped body with the open end facing southwest and with most of the exposure area, including all the Blue Dog phase in the northwestern arm and arc. Both phases were extensively traversed and sampled and nearly all internal and external contacts other than some in Tonto gorge and those of the southern extension of the southeastern arm were walked out.

Dissected by the McDonald Mountain fault the eastern part of the Salt Lick mass lies in the Apache Ridge-Hell's Gate area while the remainder, to the west of the fault, is in the southern Green Valley Hills and Picket Pen Ridges area. The name for this phase is taken from Salt Lick Canyon which traverses the northern part of the eastern portion.

Essentially all rhyolite mapped as Salt Lick lithology is continuous (discounting fault offset) within the main Hell's Gate mass. However, some isolated minor areas of probable correlation are designated by the same map symbol on Plate 1. These are the small sills northwest of Diamond Bute (L,M-14,15), two small bodies in the Picket

Pen fault slice (N,O-10), a sheet occurring between Green Valley Granophyre and Haigler rhyolite on Gisela Mountain (Q-8), and a fourth occurrence between Horse Mountain and Big Ridge (H-19). Unmapped rhyolite porphyry of the same lithology also occurs as dikes in the Gibson Complex and at one spot along a diorite-granophyre contact of the complex.

Blue Dog rhyolite occurs essentially as a single mass 6 x 2½ miles in dimension trending northeast-southwest from the central Green Valley Hills to King Ridge. Exposure is continuous except for several small bodies isolated near margins within the Salt Lick phase. The Blue Dog phase is named for Blue Dog Ridge which runs north-south nearly the whole width of the body near its eastern end.

STRUCTURE

Internal structures, columnar jointing and flow foliation, are of great importance in understanding not only the Hell's Gate body itself, but in defining the Tonto Basin syncline containing it. Except in the coarse lower parts of the Blue Dog member, columnar jointing in the Hell's Gate Rhyolite is usually a salient and often spectacular feature (Plate 19). The rock columns defined by the jointing are 15-25 cm in diameter and are highly regular in orientation even where (rarely) intersected by randomly undulating fracture surfaces (Plate 19B).

The two members of the Hell's Gate Rhyolite seem to have behaved structurally as a single entity. This is emphasized by columnar jointing which, with one minor exception, shows no discontinuity at contacts between the two members.

Attitudes of plunge and trend of the rock columns (or intersections of joints which bound the columns) have a meaningful systematic distribution. In the Salt Lick and Blue Dog rocks of the northwestern limb and throughout most of the broad northern arc of the 'horseshoe' almost all joint intersections defining column elongations plunge north to northwest at 50° to 70°. There is a reversal of attitudes on the far eastern margin of the nose and in the southeastern limb. Here columns plunge 50° to 70° but northeast to southeast. Though the data on the axis is scarce there is a suggestion that plunges swing around the nose to the north so that columns usually trend toward basal contacts. Overall the trend of joint intersections in the Hell's Gate body is roughly perpendicular to contacts (upper and lower) and the plunge is semi-perpendicular to the layered elements of the Tonto Basin syncline. Thus the joints themselves, by this conformity, become an additional element in defining the syncline.

The regularity of attitudes would suggest that the sill itself is a generally conformable simple cooling sheet in the syncline. A detailed discussion of the implications of the columnar jointing with regard to the temporal relation between folding and intrusion is given on page 234.

Though less numerous and less consistent than jointing attitudes foliation attitudes in the Salt Lick phase are also consistent with the interpretation that the Hell's Gate body is a roughly conformable stratiform member of the syncline. Flow foliation generally is developed perpendicular to columnar joints (there are notable exceptions) and parallel to planar elements of the syncline discussed above.

Rather steep dips of flow foliation in the southern northwestern limb (L,M-10,11) are consistently to the northeast or southeast. A less coherent pattern of flow foliation is seen in the eastern mass of Salt Lick rhyolite. Attitudes tend to strike northeastward and may dip steeply northwest or southeast, but near contacts they tend to swing into parallelism. Along eastern margins and in the southeastern limb, foliations dip generally steeply northwestward.

It has been emphasized that the Hell's Gate body is synformal and essentially conformable. It would appear however that the body is emplaced lower in the section in the northwest limb. No extrusive rhyolite occurs below the sill (below Blue Dog phase) there, whereas there is a considerable thickness in the southeastern limb beneath Salt Lick rhyolite. Swinging eastward across the trough of the syncline the Hell's Gate Rhyolite apparently rises higher into the Haigler rhyolite. It may be that Hell's Gate Rhyolite is above nearly all the Haigler rhyolite in the southeastern limb and intrudes along the Haigler rhyolite-Christopher Mountain Quartzite contact. A preferred interpretation, however, is that reverse faulting along the eastern margin of the quartzite has cut out some Haigler rhyolite which may have been above the Hell's Gate sill (see structural profiles C-C' and D-D'). Regardless, the case is strong for the low angle discordance of the body approximately across the trough of the fold.

The much greater exposure area of Hell's Gate Rhyolite in the northwestern limb of the syncline is a proportional reflection of the much greater thickness in that limb rather than an indication of a much shallower dip than in the opposing limb. Numerical values of a given type of structural attitude in all units of the syncline are essentially symmetrical about the fold axis. It is difficult to estimate the thickness of Hell's Gate Rhyolite in the northwestern limb because of disruption of the structure by the Green Valley Creek and McDonald Mountain faults; a minimum estimate, assuming a dip of about 30°, is 2.5 km. Salt Lick rhyolite in the southeastern limb is calculated to be only about 0.5 km thick.

Salt Lick rhyolite is very extensive, occurring throughout the main synformal areas as defined above and also as small generally conformable bodies elsewhere. Blue Dog rhyolite apparently intruded in a more viscous state and is confined to a rather simple thick (1.5-2 km) lens which is responsible for most of the great thickness in the northeast limb. Columnar jointing in the Blue Dog body is remarkably uniform. Of 45 measurements made, only 9, usually near faults or contacts, were strongly anaomalous. For the other 36 measurements the mean of the plunge is 61° with an average deviation of 6°. Azimuthal trends for these vary from 300° to 10° but most are from 330° to 350°.

SALT LICK-BLUE DOG RELATIONSHIP

Most of the Salt Lick-Blue Dog contact was carefully mapped and was generally easily located. A few complete exposures revealed it to be a sharp simple contact and location of the contact within a few meters nearly everywhere indicates this is probably generally true. Unfortunately, relative ages could not be determined. At a few localities contact relations are very complex. The two units are mixed(?) in a complex irregular way over a few hundred meters. A similar relationship was noted at a few spots in the interior of the Blue Dog body; numerous small areas (few meters ?) were found to be entirely free of the mafic clots. In one instance, a sharp contact was found between mafic xenolith-free and xenolith-bearing phases (418, H-13). This sharp contact suggests that the mafic-free areas are inclusions of Salt Lick rhyolite rather than Blue Dog rhyolite into which xenoliths were not mixed. One would expect gradations if the phenomenon were due to incomplete mixing. Irregular geometry of the leucocratic areas argues against their being dikes of the Salt Lick phase.

In the Buttes area numerous felsite xenoliths in Blue Dog rhyolite (some localities indicated on Plate 1, I,J-10,11) are mostly extrusive rhyolite, but some massive blocks are possibly Salt Lick lithology (Plate 18B). Immediately south of the contact in this area are three large masses of Blue Dog rhyolite apparently isolated in the Salt Lick rhyolite. It is not known whether they are apophyses or inclusions, but it seems unlikely that such enormous blocks, particularly the southernmost, could be lifted up as inclusions into the Salt Lick Member which is stratigraphically higher than the Blue Dog.

Columnar jointing in the northwesternmost of the three blocks and in Salt Lick rhyolite on the east has a consistent shallow plunge to the northeast, much different than surrounding attitudes in both phases. It seems that here as elsewhere both phases of Hell's Gate Rhyolite experienced the same cooling history. In all likelihood the time interval separating times of intrusion was small compared to time for cooling.

The temporal relation between the two phases is not critical to the overall evolution of the study area, but it would appear that Blue Dog may be younger. It may be that an original single magma rose nearly to the final emplacement level and began to assimilate mafite porphyry (and Haigler rhyolite ?). Very little assimilation would have occurred before a portion of the magma (Salt Lick phase) rose to the present position. The deeper magma continued to assimilate, disaggregate, and mix mafite porphyry and diorite and possibly to engulf blocks of Haigler rhyolite. A final intrusive pulse (Blue Dog phase) then arose to the exposed position.

RELATIONS TO OTHER UNITS

Haigler rhyolite (and Board Cabin Formation). The mapped cross-cutting relationship of the Hell's Gate body as described above quite clearly reveals the intrusive relationship to Haigler Rhyolite. The identification of relatively small (5-20 m) sills interleaved with Haigler rhyolite, Board Cabin andesite and minor sedimentary rocks northwest of Diamond Butte as equivalent Salt Lick lithology further supports the intrusive interpretation.

It has been noted above that blocks of extrusive rhyolite occur in the Blue Dog phase in the Buttes area. Plate 18B shows three small inclusions from this area, at least two of which are flow-banded extrusive rhyolite. Much larger blocks (up to 10 meters) are common.

In the southern Green Valley Hills and Picket Pen Ridges a great deal of extrusive rhyolite is associated with the Salt Lick phase (undifferentiated on Plates 1 and 2). Locally small inclusions of various extrusive lithologies were found in the Salt Lick rock and it appears that large masses of Haigler rhyolite were complexly intruded by the Salt Lick phase.

The felsite xenoliths northward in the Blue Dog rhyolite are possibly in part both Haigler and Salt Lick blocks incorporated simultaneously as Blue Dog rhyolite intruded the region of mixed Haigler and Salt Lick rocks.

In contrast to the situation in the Green Valley Hills, extrusive rhyolite was not found intimately associated with the Salt Lick phase in the Apache Ridge vicinity, nor were stoped blocks of extrusive rhyolite recognized in upper parts of the Blue Dog sill. Blue Dog rhyolite may have stoped blocks of roof rock along its entire upper contact but these blocks would have been only Salt Lick rhyolite in the Apache Ridge area and would have included extrusive rhyolite only in the Green Valley Hills.

Two small occurrences of probable Salt Lick rhyolite also bear a relation to Haigler rhyolite which may be interpreted as intrusive. In the Picket Pen fault slice the two small bodies of massive rhyolite (M,O-10) appear from overall shape to be discordantly intrusive into the eastward dipping layers of extrusive rhyolite. Again, at Gisela Mountain the small sill along the extrusive rhyolite-granophyre interface (Q-7) appears (incompletely mapped) to diverge to the west up into the overlying rhyolite.

Christopher Mountain Quartzite. It was not determined whether Salt Lick rhyolite intruded Christopher Mountain Quartzite in the southeastern limb of the Tonto Basin syncline. The quartzite is apparently in fault contact with either Salt Lick rhyolite or Haigler rhyolite from Spring Creek (M-13) to McDonald Mountain (O-11). Just north of Spring Creek at station 1694 about 40 m of purplish, foliated rhyolite occurs between the fault and the quartzite, but this is apparently Haigler rhyolite conformably beneath the quartzite.

A small mass of rhyolite porphyry indistinguishable from typical Salt Lick rhyolite occurs south of Horse Mountain and has a clear-cut intrusive relation to Christopher Mountain Quartzite. The contact at station 1946 (H-19) is discordant to bedding. On trend with a bed which appears to project a few meters into the rhyolite are several few-meter-long blocks isolated in the rhyolite. The quartzite-rhyolite contact on one of the blocks was located to within 2 cm and no indications of shear nor other evidence of tectonic disruption in the immediate vicinity were observed. The blocks are undoubtedly xenolithic. Based on this relationship and the lithologic correlation of this rhyolite with the main Salt Lick mass, it is tentatively concluded that the Salt Lick phase is younger than Christopher Mountain Quartzite.

Gibson Complex. Arguments were presented earlier for the derivation of mafic xenoliths from the Gibson Complex. Within the Gibson diorite (2151, J-5) are porphyry dikes with a somewhat coarser groundmass but otherwise identical to Salt Lick lithology. Along the diorite-Green Valley Granophyre contact (2128, K-6) is a rhyolite similar to Salt Lick lithology but highly charged (~ 20%) with mafite porphyry inclusions. It was intruded by the granophyre sill and may itself have intruded along the Payson Granite-Gibson diorite contact.

MINOR INTRUSIVE RHYOLITE

Rhyolite of Hog Canyon

Intrusive rhyolite in Hog Canyon (H-20) was included by Gastil (1958, Plate 2) in the Oxbow Rhyolite. This rhyolite was examined only along its contact with Christopher Mountain Quartzite. It is consistent in character and quite distinct petrographically from Oxbow Rhyolite. Feldspar and quartz phenocrysts, particularly the latter, are only about half as abundant and are much smaller than those in Oxbow Rhyolite. Rhyolite of Hog Canyon is also much more leucocratic. Moreover, Oxbow Rhyolite is clearly overlain by the quartzite whereas the Hog Canyon rhyolite intrudes the quartzite. (It presumably intrudes the Oxbow Rhyolite also, just east of Hog Canyon, but mapping was not extended that far east.) The evidence for intrusion of quartzite by the rhyolite is that steeply dipping quartzite strikes into the contact at the southwestern limit of the rhyolite and that a few hundred meters to the east an arm of quartzite projects out into the rhyolite. The exact rhyolite-quartzite contact was not seen but there is no evidence of faulting near the contacts.

Quite different from the Hell's Gate Rhyolite, this rhyolite is exceedingly leucocratic and contains both plagioclase and perthite phenocrysts. It is light gray on a fresh surface and weathers white. Feldspar and quartz phenocrysts are 1-2 mm in diameter and, in roughly equal proportions, constitute about 10-15% of the rock. The groundmass is homogeneously fine-grained and featureless.

Melanocratic Rhyodacite(?) at Bull Mountain

A small mass of dark intrusive porphyry at Bull Mountain (L-15) has some similarities to Hell's Gate Rhyolite but the ground mass has a much higher mafic content. Quartz and alkali feldspar phenocrysts are fewer but otherwise similar to those in Hell's Gate Rhyolite. Small mafite inclusions are common. A few rather large (1 cm) plagioclase crystals were noted and some alkali feldspar phenocrysts are overgrown with plagioclase. The mafic character of the rock, the presence of the large plagioclase, and some alkali feldspar crystals with unusual internal striae and lacework (similar to fretted textures found in buchite, page 276) are strongly reminiscent of the vitreous black porphyry in the mafite undifferentiated unit at Gisela. It is possible that the mass at Bull Mountain is hybridized and may bear some relation to mafite porphyry.

Though no contact relations were observed the highly irregular outline of the body indicates it is intrusive in the Haigler rhyolite. Its relation to the Hell's Gate sills with which it is in apparent contact is not known. Probably the positioning of the body along the discordant(?) Haigler rhyolite-Board Cabin Formation contact where there is clearly some faulting was structurally controlled.

Sills East of Diamond Butte and Houden Mountain

The cluster of sills in Board Cabin Formation and along the Board-Cabin-Haigler contact one to two miles directly west of Diamond Butte and sills on the west face of Houden Mountain mapped by Gastil (1958, Plate 2) were not examined by the author. Gastil called them intrusive rhyolite and quartz porphyry. Whether they correlate with Hell's Gate rhyolite is unknown. The rhyolite mapped by Gastil as extrusive rhyolite unassigned on the north slope of Breadpan Mountain (S-14) was briefly examined and though modified by tectonic foliation was found to resemble Hell's Gate Rhyolite.

KING RIDGE RHYOLITE

King Ridge Rhyolite is a large tabular body of massive spherulitic rhyolite porphyry and granophyre. It was very extensively studied because it was thought initially that the spherulitic rhyolite might be extrusive and thus a member of the Haigler Group. Separated from Payson Granite only by Green Valley Granophyre sills, it suggested a pre-granophyre conformable relationship to the upper Payson Granite surface which would have been an important factor in the problem of the structural relationship between the granite and the extrusive rhyolite. Field and petrographic criteria seem to require, however, that the spherulitic rhyolite, and the granophyre into which it is texturally gradational at depth, comprise a sill intrusive into overlying Haigler rhyolite and Salt Like rhyolite.

LITHOLOGY

A most remarkable feature of the King Ridge body is the universal presence in upper parts of 1-2 mm spherulites. These closely-spaced or coalescing spherules nearly always comprise more than 50% of the rock. A few percent of 2-4 mm alkali feldspar crystals are nearly always obvious and persist in size and quantity as much as do the spherulites. Tiny quartz, alkali feldspar and plagioclase phenocrysts (rarely 1 mm), often forming cores of spherulites, are generally seen only in thin section.

In upper (southern) parts of the body the mesostasis is exceedingly fine-grained and is sharply delineated from the spherulites and phenocrysts (Plate 20A). With increasing depth the groundmass coarsens and the spherulites begin to lose their definition. In the lowest parts of the body the rock appears rather even-grained and the spherulites are megascopically unrecognizable (Plate 20B). The original form of the spherulites is reflected microscopically in micrographic domains. A feature of the gradational transition is that the interspherulitic areas can be recognized after the spherulites lose their definition as areas of vugginess and concentration of secondary quartz (Plate 20B). Throughout much of the transition these interspherulitic areas weather in negative relief.

In most places, particularly in lower parts of the body, the rocks are rather strongly weathered or altered. Most rocks are red-brown. Infrequently, in upper spherulitic parts, the rocks are much darker and more gray than red (Plate 21A). On a freshly-broken surface of well-preserved upper spherulitic rock both groundmass and spherulites are dark, but are readily distinguished texturally. In the few mm weathering rind the mesostasis weathers orange-tan in the reddish rocks and yellow in the dark gray rocks; the spherulites remain dark (Plate 21A). It is clear that the weathering is not entirely responsible for the internal color variations. This must reflect, in part, some earlier variation in oxidation state related perhaps to deuteric modification or low-grade hydrothermal metamorphism.

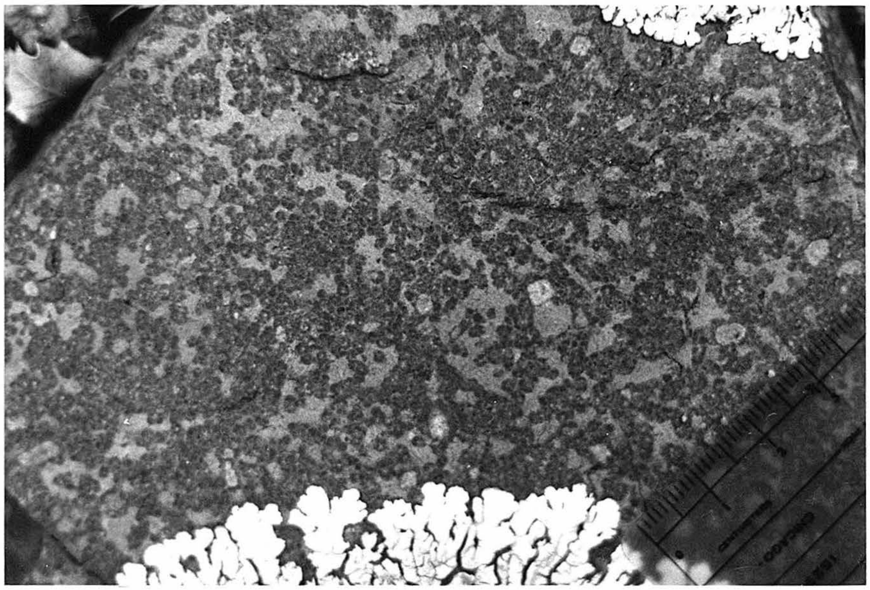
The spherulite-mesostasis texture is monotonous. Both spherulitic and granophyric portions of the body are practically devoid of anisotropic texture. Rare flow foliation occurs near upper contacts (439, G-15; 832, G-16) and a very subtle red-gray 2-3 cm layering is found in some lowermost granophyre. The latter at station 2053 (E-16) is parallel to the lower contact.

DISTRIBUTION AND STRUCTURE

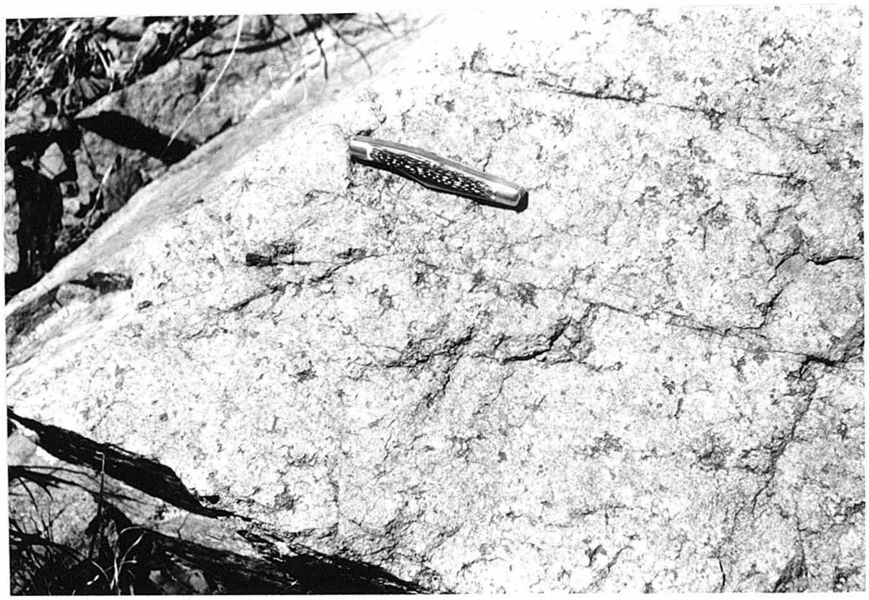
King Ridge Rhyolite is located almost entirely between McDonald Mountain fault and Bull Tank fault in King Ridge and Mescal Ridge. Tonto Creek gorge dissects the body between the ridges. Most of the unit lies within one large (6 square miles) continuous mass, disrupted only by a few small faults. A number of masses are mapped within Blue Dog and Salt Lick rhyolite along upper Salt Lick Canyon and a possible sheet within Mescal Ridge granophyre in Thompson Wash.

The King Ridge body is concordantly interlayered with other tabular units in the Tonto Basin syncline. This is shown by scarce internal

PLATE 20. KING RIDGE RHYOLITE



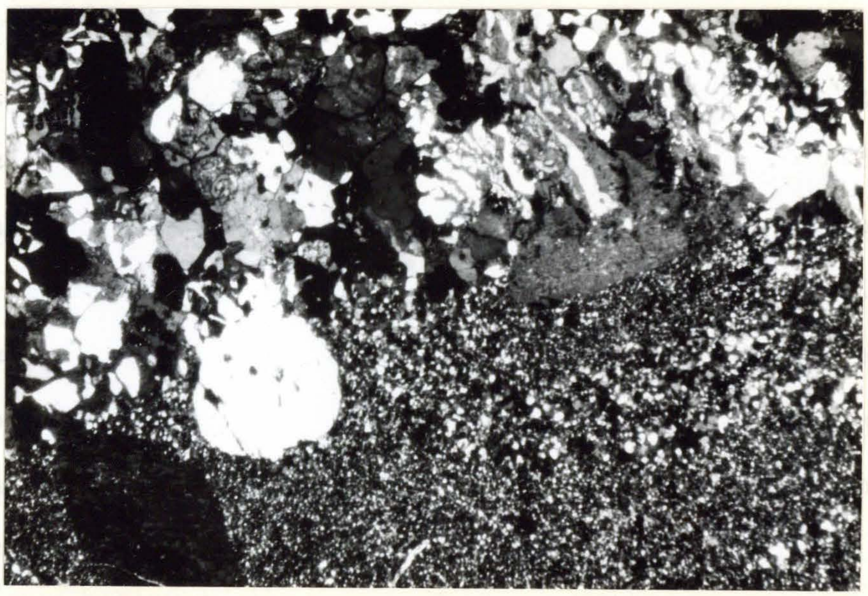
A. Spherulitic rhyolite porphyry from the upper part of the King Ridge sill. Light mesostasis surrounds dark coalescing spherulites. A dozen or more 2-4 mm alkali feldspar phenocrysts are conspicuous. Scale numbered in centimeters.



B. Vuggy granophyre from lower part of the sill. Dark vuggy areas are relict areas of interspherulitic mesostasis. There is a complete textural transition upward in the sill to the spherulitic texture shown above.

PLATE 21. KING RIDGE RHYOLITE

A. Interior and weathered surface of well preserved red-brown and rare dark brown-gray facies. Mesostasis weathers orange in red-brown rocks (left) and yellow in brown-gray rocks (right). Both samples from near station 435 (F-15). Specimens are 5 to 8 cm in length.



B. Intrusive contact, Salt Lick rhyolite below, granophyric apparent margin of King Ridge Rhyolite above (see text). Intricately intergrown quartz and feldspar in crystallographic continuity with a quartz and a feldspar phenocryst, respectively, of the rhyolite indicate that these phenocrysts were truncated by the King Ridge magma and then overgrown in the crystallization of the magma. Cross-polarized light, 7 x 4.7 mm. (443, F-15) structures, by contact configuration in relation to topography and by elongate distribution of the body parallel to the granophyre sills.

Both the sparse faint banding near the base and rare flow foliation in the upper part of the body dip southwestward. Weakly-developed columnar jointing plunging about 50°-60° northeastward was found at the base of the unit on King Ridge (F-16) and on south Mescal Ridge (G-16). Looking from the last locality across Tonto Creek at the opposite wall of the gorge one sees a weak suggestion of layers dipping southwestward at about 45° and of columnar jointing roughly perpendicular to the layering. Presumably the columnar jointing developed not only perpendicular to the apparent layering but to the external contacts of the tabular body as well.

Relationship to topography consistently indicates the lower contact is dipping southwestward and at one point the dip was geometrically estimated to be 24° SW. At the top of the unit contact configuration generally indicates a southwestward dip. At the south end of Mescal Ridge an estimate of dip is 49° SW. This agrees with the flow foliation attitudes in overlying Haigler rhyolite. It appears that the upper contact of the body may be steeper than the lower. Assuming the lower contact attitude is 30° and the upper, 50°, a calculated thickness is 1000 meters at the exposed position (see cross-sections F-F' and G-G').

Only minor amounts of the spherulitic rhyolite are exposed outboard of the two faults bounding the main mass and the sill apparently maintains its thickness right up to these faults. Westward across the McDonald Mountain fault only a small body bounded both by McDonald

Mountain fault and the southern branch of the Diamond Rim fault is exposed above the granophyre. Southward across the Diamond Rim fault no spherulitic rhyolite remains in contact with the granophyre and only the few blocks within the Blue Dog rhyolite are found (F-13,14). From the senses of displacement of the two faults it is seen that the spherulitic rhyolite body is thinning very rapidly both southward (downdip) and westward (along strike). Since there is little offset on the Bull Tank fault and because only little spherulitic rhyolite could be buried beneath the gravel blanket to the southwest it is apparent that the King Ridge body rapidly terminates southeastward along strike as well. The King Ridge body is thus a rather thick lens in the dimensions viewed, about 8-10 km long and about 1 km thick.

CONTACT RELATIONS

Haigler rhyolite. Much of the contact with Haigler rhyolite is of difficult access along Tonto Creek gorge and was not mapped. However, it was mapped for a way at the south end of Mescal Ridge where there is an unquestionable sharp change from massive spherulitic rhyolite to spherulite-free or spherulite-poor strongly flow-foliated rhyolite. Either it is an intrusive contact with spherulitic rhyolite intruding conformably below the flow-foliated rhyolite or it marks a change in character of effusive rock with more typical Haigler rhyolite being deposited on the massive spherulitic rhyolite. A possible inclusion of flow-banded rhyolite in spherulitic rhyolite at the contact station 840 (G-17) supports the first alternative.

At the two localities (page 136) near the upper contact where the rock is weakly flow-foliated, the quantity of spherulites locally drops to a few percent and the distribution of spherulites partially defines the weak flow banding. Such variations were not seen deeper in the mass and might be interpreted to be either indicative of transition into Haigler rhyolite or of near-contact intrusive phenomena.

Hell's Gate Rhyolite. Blue Dog rhyolite is not found in contact with the main mass of King Ridge Rhyolite, but near the Diamond Rim fault and near the contact with Mescal Ridge granophyre (F-13,14; G-13) are five bodies (100 to 500 meters in length) of massive spherulitic rhyolite which are quite clearly King Ridge lithology. Exact intrusive contacts gave no indication of relative age. A similar small body of the spherulitic rhyolite also was found within the Salt Lick phase one-third mile south of station 866.

The contact between the main mass of King Ridge Rhyolite and Salt Lick rhyolite was carefully walked out and the two lithologies were found in a number of places within a few cm of one another. The only relationship found which might support intrusion by the Salt Lick body was an apparent swinging of Salt Lick flow-banding in a distance of a few meters from a high angle to nearly parallel to the contact (station 443, F-15). Weak flow-foliations throughout the northern parts of the Salt Lick rhyolite, however, trend at a high angle toward the contact.

Other contact relations support intrusion by the King Ridge body.

At station 937 (G-16) a 0.7 m-wide dike was found only a few meters from the contact and running 10 meters into the Salt Lick rock. The dike has a micrographic interior with a 2-3 cm aplitic margin and it contains plagioclase, alkali feldspar and quartz phenocrysts. In a thin section of the dike contact a Hell's Gate quartz phenocryst is apparently truncated. Phenocryst mineralogy (plagioclase phenocrysts do not occur in Green Valley Granophyre) of the granophyre dike and proximity to the contact seem to require that King Ridge Rhyolite was its source.

At two contact stations (866, F-14; 443, F-15) the spherulitic texture was found to coarsen, over distances of 15 and 50 meters, respectively, into micrographic texture toward the contact. A series of samples across the transition zone at each station was thin-sectioned. Over these relatively short distances the textural transition is comparable to that which occurs at depth over much of the thickness of the whole King Ridge body. A thin section was cut of what appeared to be the exact contact at station 443 (the station at which Salt Lick flow-banding swings more nearly parallel to the contact). It clearly reveals (Plate 21B) that the Salt Lick rhyolite is intruded by a micrographic phase, but the latter is much coarser than the coarsest specimen of 'granophyric' spherulitic rhyolite examined only a few meters from the contact. No plagioclase phenocrysts were found in the intruding contact granophyre.

Either continuous and coarsened marginal granophyre of the King Ridge body intruded the Salt Lick body or a tiny amount of later granophyre intruded along the contact. In a careful examination of this contact area no evidence was found of any distinct third phase and the King Ridge lithology was found to be megascopically continuous over the gradation in several places to within a meter or two and at one spot within 5 cm of the contact. It seems unreasonable that a tiny quantity of granophyre unrelated to either the King Ridge or the Salt Lick body (the nearest other source would be the Thompson Wash granophyre about a mile distant) could intrude along the contact. If the intruding granophyre shown in Plate 21B did come in as a film along the contact its most reasonable source is the King Ridge body because it is the only body of the two with any grain size variation which might hint at a process (such as filtration of residual liquid from a volume interstitial to coalescing micrographic domains) which could give rise to a residual liquid.

If the King Ridge body intruded the Salt Lick rhyolite it developed (at least locally along the contact) instead of a chilled margin a coarse micrographic contact zone which became the very coarsest at the exact contact. One might imagine that a concentration of volatile constituents at the upper margin during intrusion could cause such a coarsening. Indeed, possibly analogous coarse, complex, sometimes pegmatitic layers were found at upper intrusive contacts of alaskite in the field area.

ORIGIN

Contact relations favor an intrusive origin for the King Ridge

Rhyolite. Were it not for the spherulites the author would early have concluded an intrusive origin, not only because of the contact relations but because of the great mass and homogeneity (notwithstanding the textural gradation) of the body. If extrusive, this enormous body (about 1 km thick and 10 km long, in plan) must either be a dome or a series of flows. The spherulites (if devitrification products) would be better explained in terms of a series of flows, but it is difficult to conceive of such an enormous pile of flows with no lithologic variation, flow foliating or evidence for internal contacts. A viscous dome origin is certainly reasonable in association with the great volume of viscous and pyroclastic flows, but one would expect a km-thick dome to quench to a glass only near the upper surface and so a non-devitrification origin would be required for deep spherulites.

Again, if the body were extrusive, and if spherulites somehow formed evenly throughout by devitrification, secondary events would be required to recrystallize the spherulites thus giving rise to the textural gradations into granophyre both at depth and in the narrow upper granophyre zones. These events feasibly could be the intrusion of the Payson Granite (not proven, of course, to intrude any extrusive rhyolite) or Green Valley Granophyre and Hell's Gate Rhyolite, respectively. This would be a remarkable effect considering the practically undiscernible contact effects at various hypabyssal contacts elsewhere in the area. The marginal granophyre at the upper contact would be coarser than the rock which intruded it. Such extensive recrystallization might be feasible if, because of textural instability of spherulites or because of high water content due to subaerial hydration of glass (Lipman, 1965), spherulites were highly susceptible to recrystallization. Still, it is difficult to accept the coarsening at the upper contact as a contact metamorphic effect because at exact contacts of spherulitic rhyolite in the small isolated masses surrounded by Blue Dog rhyolite there is no marked coarsening of the spherulite texture. If these blocks were large inclusions in Blue Dog rhyolite metamorphic recrystallization should have been as pronounced or more pronounced than at contacts between the main mass and Salt Lick rhyolite. A similar problem is that a granophyre zone appears to occur only locally along the King Ridge-Salt Lick contact. Because both bodies are very homogeneous the granophyre zone, if due to contact metamorphism, should have been a consistent characteristic of the contact. (On the other hand, coarsening at the upper margin of an intrusive body might be very local due to concentration of volatiles in favorable sites.)

A final argument against a contact metamorphic origin for the granophyre, both at depth and at the upper contact, arises from the fact that in the fine micrographic intergrowth the feldspar has precisely the same mesoperthitic hypersolvus character as does micrographic intergrowth in the intrusive Green Valley Granophyre. The indication is, in spite of the presence of both plagioclase and K-feldspar phenocrysts, that feldspar in the micrographic groundmass (more than 90% of the feldspar in the rock) crystallized as a single phase then later exsolved. This would have been impossible in contact metamorphism of a devitrified rock; under the relatively low-temperature sub-solvus conditions of metamorphism both K-feldspar and albite should have recrystallized as separate and distinct phases. Not only does this relationship contradict the idea of contact metamorphism, but it implies that the micrographic intergrowth, and hence the spherulites into which the latter grades, crystallized from a magma. A possible crystallization history, including an explanation for the change from subsolvus to hypersolvus character and for the origin of the textural transition is given on page 353.

In light of the evidence and implications cited above, an intrusive origin is preferred for the King Ridge Rhyolite. It would have intruded both phases of the Hell's Gate Rhyolite (the isolated masses in Blue Dog rhyolite would be small plugs) as well as Haigler rhyolite, essentially at the known base of each.

GREEN VALLEY GRANOPHYRE

All granophyre and related aplite along the upper border of the Payson Granite is here defined as belonging to the Green Valley Granophyre, named for excellent exposures in the northern Green Valley Hills. Unique structural position, common petrographic character, and consistent contact relations to other bodies argue for treating these sills as a geologic unit. In reconnaissance Gastil first noted the presence of granophyre between Payson Granite and rhyolite and concluded (1958, p. 1508) that "the contacts between granite and rhyolite are characterized by a fabric gradation." In this study sharp intrusive granite-granophyre and granophyre-rhyolite contacts have been found (page 160).

Two main granophyre phases occur in the extensively studied ten-mile segment east of the Green Valley Creek fault. The earlier phase, continuous over this whole length, is called the Mescal Ridge phase. The later Thompson Wash phase occurs only to the east. Other sill granophyre is incompletely mapped and undivided at present.

LITHOLOGY

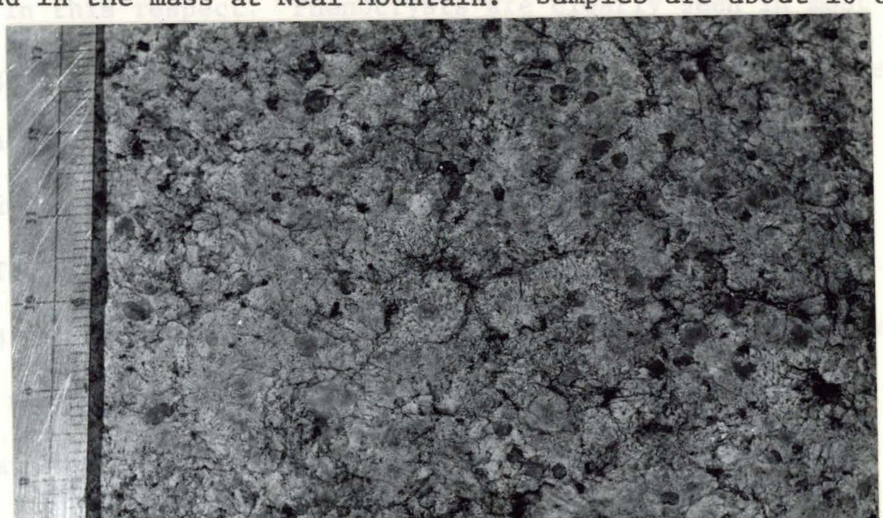
All rock (except aplite) of the Green Valley Granophyre is characterized by the presence of 0.5-3 mm quartz phenocrysts and 1-4 mm perthitic alkali feldspar phenocrysts. The former varies in abundance from perhaps 3 to 10% and the latter from about 5 to 15%. In all cases the phenocrysts are rounded and embayed and are overgrown with and surrounded by a mesostasis of micrographically intergrown quartz and perthitic alkali feldspar. Color index is consistently very low (about 2-3%) and uniform and the rarely-preserved mafic minerals are distinctive and peculiar to the granophyre.

Mescal Ridge granophyre contains about 10% each of 2-4 mm roundish quartz and alkali feldspar phenocrysts. Thompson Wash granophyre has alkali feldspar phenocrysts of similar size and quantity, but contains only a few percent of 0.5 mm quartz phenocrysts. Granophyre of Neal Mountain and Gibson Rim is variable in phenocryst character but appears to be generally similar to the Thompson Wash phase.

Granophyre at all occurrences is typically a medium red-brown. It is classical 'red-rock granophyre.' Mafic minerals are totally altered to hematite and the feldspar is brick-red due to hematite clouding. Occasional exposures possess degrees of grayness and there are

PLATE 22. GREEN VALLEY GRANOPHYRE

A. Typical Mescal Ridge red granophyre and a sample from the single gray block found of the Mescal Ridge phase. Note reddening of some alkali feldspar crystals in the gray sample. Rare outcrops of gray rock, often entirely free of reddening, occur in the Thompson Wash sill and in the mass at Neal Mountain. Samples are about 10 cm long.



B. Outcrop texture of Mescal Ridge granophyre. Dark 1-3 mm spots are quartz phenocrysts. Alkali feldspar phenocrysts are as abundant as the quartz but only a few lighter crystals can be made out. Pervasive micrographic intergrowth is clearly seen in the coarser areas. Scale is numbered in cm.

exceedingly rare light gray areas lacking redness. Original mafic minerals are preserved in varying degrees in the gray rocks. Red and gray facies of the Mescal Ridge phase are compared in Plate 22A.

Except for the effects of a pervasive hydrothermal event (presumably the cause of oxidation) the granophyre is everywhere very well-preserved; dynamic metamorphism has affected the granophyre only near major faults.

Mescal Ridge phase. The Mescal Ridge phase is quite distinct from other granophyre of the Green Valley Granophyre, or any other granophyre in the mapped area, in that it very consistently contains more and larger quartz phenocrysts. It also contains more and larger alkali feldspar phenocrysts than most but is very similar to the Thompson Wash phase in this respect. Phenocrysts are clearly seen in most outcrops. Micrographic domains are usually somewhat larger than the phenocrysts and the intricate quartz-feldspar intergrowth is easily seen with a hand lens and often with the unaided eye (Plate 22B).

The granophyre is commonly vuggy; the 0.5-2 cm cavities are drussy, or are completely filled, with quartz, dark oxides (mostly hematite), white mica and sometimes albite. Often entirely filled with quartz, they are conspicuous milky pods. Abundant muscovite in some pods has a dark greenish color. The vuggy character is particularly well-displayed in the high northern Green Valley Hills.

Lithologically the granophyre is very homogeneous, though some minor local variations occur. The only systematic variations noted were a slight upward coarsening(?) and an upward increase in the abundance of miarolitic cavities.

A single meter-long boulder of gray granophyre was found in the drainage at station 475 (G-11). Gray outcrop was not located.

A minor lithology included in the Mescal Ridge phase is aplite which occurs sporadically along the upper border of the granophyre (contact relations, page 158). The border aplite sometimes contains up to several percent phenocrysts but more often is non-porphyritic. It is usually micrographic (weakly to strongly developed intergrowth) and is thus properly fine-grained micrographic granite. Nevertheless in the field it looks like aplite and it is easier to use that term in text. It attains mappable thickness (> 30 m) in several different bodies along 2-3 miles of the upper contact and has a maximum thickness of about 150 meters. Along much of the contact it is common in thicknesses of fractions to several meters.

A similar aplite at the base of the granophyre is considered also to be a part of this phase; nowhere does it occur in mappable thickness. The lithology and field relations of this important phase are discussed in connection with the Payson Granite-Green Valley Granophyre-alaskite relationships (page 176).

Commonly Mescal Ridge granophyre has a low bouldery weathering style due to granular disintegration. The latter is particularly true where the rock is best preserved and in upper parts of the sill. Where more intensely fractured, it disintegrates into small, angular fragments. Angular fragmentation is more common in finger-grained rocks, particularly the aplite.

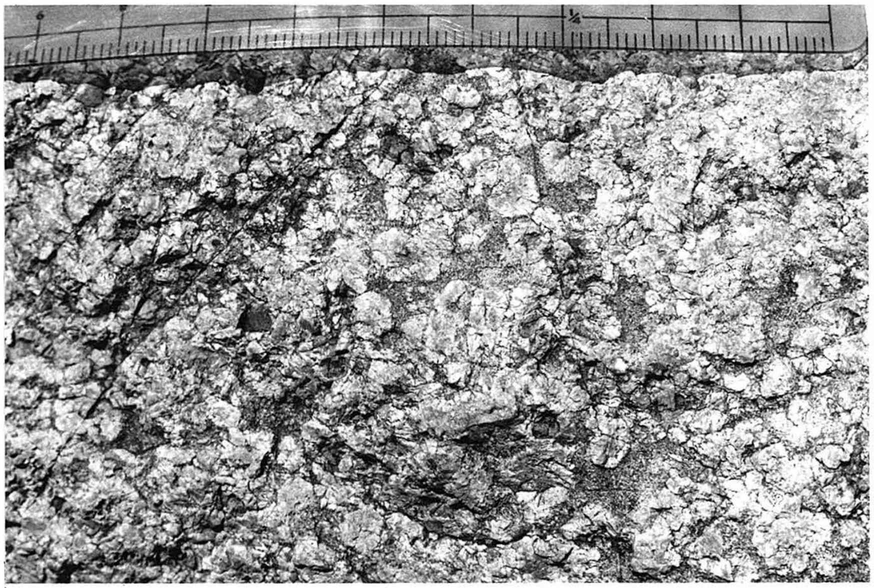
Thompson Wash phase. In most aspects the Thompson Wash lithology is very much like Mescal Ridge granophyre. Micrographic intergrowth is, however, somewhat finer in the Thompson Wash rocks and, in sharp contrast to Mescal Ridge granophyre, minor small (0.5 mm) quartz phenocrysts are quite inconspicuous. Sometimes it is difficult to distinguish the phenocrysts from the micrographic domains and the rock on irregular broken surfaces has a crystalline appearance somewhat analogous to syenite because of the abundant feldspar cleavage surfaces. Generally, however, phenocrysts are quite easily recognizable, especially on locally abundant planar (fracture) surfaces and small blocky fragments.

There seems to be a little more variation from the monotonous red-brown coloring in this body than that in Mescal Ridge granophyre. Very locally in a few areas the rock is brown-gray or, rarely, dark gray.

One to two centimeter vugs, generally filled with milky quartz, are locally common, particularly in upper parts of the body. They are neither as large or as prevalent as in the Mescal Ridge Member.

Very minor amounts of aplite, for which no clear-cut field relations were determined, occur both at upper and lower contacts of the sill and very rare, tiny (few cm wide) aplite dikes were discovered within the granophyre. An uncommon feature, noted at five widely spaced stations (noted also, in one place, in Mescal Ridge granophyre), is the occurrence of coalescing 5-10 mm spherulitic/micrographic domains in irregular, 0.5-4 cm areas of aplitic mesostasis (Plate 23A). Only in these areas are the micrographic domains so large and only here does

PLATE 23. GREEN VALLEY GRANOPHYRE



A. Coalescing micrographic spherules in an aplitic mesostasis in Thompson Wash granophyre (2044, E-15). Found occasionally near contacts in Thompson Wash granophyre and at one locality in Mescal Ridge granophyre. Larger scale divisions are in cm.

B. Weakly porphyritic aplite dike intruding Blue Dog rhyolite a few meters from contact with Mescal Ridge granophyre (1986, I-11). Aplite phase along this contact is derived from the granophyre (see text) and is possibly an extracted interspherule phase as pictured in Plate A.

the textural discontinuity exist (discounting dikes). The aplitic mesostasis clearly represents residual magma, which could presumably have been tapped to form the aplite dikes and marginal aplite. Certainly in the case of this granophyre body the aplite dikes are autogenetic for some of the dikes are several miles from the nearest exposed intruding body, the alaskite at Cherry Spring which intrudes the far eastern end of the granophyre sill.

Granophyre undivided. Granophyre of Neal Mountain (P,Q-7,8) strongly resembles Thompson Wash granophyre, but may be more variable in grain size and texture and may contain slightly more and larger quartz phenocrysts and slightly fewer alkali feldspar phenocrysts. The rock seemed consistently finer-grained toward the margins and coarser toward the interior. This characteristic, not noticed in the Mescal Ridge and Thompson Wash sills, is probably due to the large size of the Neal Mountain mass.

Granophyre of Neal Mountain is predominantly red-brown, but red-gray and gray areas are more abundant than elsewhere in the Green Valley Granophyre. At station 32 in McDonald Pocket (O-9) a light area approximately 20-30 meters across contrasts sharply with surrounding red-brown rock into which it is apparently gradational. About one-half mile up Tonto Creek from the western edge of the mass is a large area (limits undefined) of unusually coarse, and remarkably light, gray granophyre. In several places elsewhere along the base of the sill the granophyre is red-gray or grayish. No systematic distribution or form of gray areas was observed. However, near the upper part of the sill

(2104, P-7) very well preserved medium gray granophyre appeared to occupy a layer or zone striking roughly east-west.

Granophyre of the fault slice along the Green Valley Creek fault (L,M-10) is similar to that examined in the Neal Mountain mass.

Granophyre of Gibson Rim is also similar to that of Neal Mountain except that it may be a little finer-grained and poorer in phenocrysts. Only the oxidized red-brown granophyre was seen.

A small dike of granophyre (1425, O-6) in Gibson Complex diorite just north of Gisela is phenocryst-rich and strongly resembles Mescal Ridge granophyre.

DISTRIBUTION AND STRUCTURE

The composite granophyre sill occurs everywhere along the exposed upper (southern) margin of the Payson Granite except along small portions of the Payson Granite-Gibson Complex contact north of Gisela (O-6,7) and on Gibson Rim (I-2,3,4; J-5,6). Even between the two large lenses of granophyre on Gibson Rim, the granite-gabbro contact is commonly occupied by granophyre sill too narrow to be shown at the scale of the map. The sill attains its greatest thickness of almost 2 km in the Neal Mountain area (Q-8) but in most places is 0.5 to 1 km thick. The sill consistently dips southeastward to southwestward at angles between 5° and 40°, usually about 20°.

The granophyre is very resistant to erosion and stands up in sharp relief above the plutonic rocks to the north. Contacts with Payson Granite are generally high on north slopes of granophyre-sustained ridges and hills (for example, the Green Valley Hills). Granophyre-rhyolite contacts, however, are not marked by conspicuous topographic expression.

Mescal Ridge phase. Mescal Ridge granophyre occurs as a fault-disrupted, convex-northward, 10-mile arc extending from the Green Valley Creek fault across the northern Green Valley Hills, King Ridge, and Mescal Ridge to the Lost Camp fault. It is in contact with Payson Granite or alaskite to the north and with Blue Dog rhyolite or Thompson Wash granophyre to the south. It is named for Mescal Ridge where good exposures are easily accessible by trail from Bear Flat (E-17).

Irregular topography and considerable local relief along the Mescal Ridge sill-Payson Granite contact provide excellent three-dimensional exposure of the contact. From its consistent behavior across topography (veering southward and downhill into drainages and veering northward and uphill on ridges) the contact is seen to be quite planar and to dip generally southward. Geometrically determined attitudes where contacts V northward or southward vary from shallow (5-25°) in the eastern parts to moderate (> 35°) in the western part near the Green Valley Creek fault. A few brunton compass attitudes on exact exposures of the contact are in good agreement.

Though not so consistent in trend across topography, the upper contact of the sill behaves in the same general manner as does the lower contact. This, and the quite consistent outcrop width of the sill (generally one-fourth to three-fourths mile) over its 10-mile length clearly indicates that the body is a sheet dipping shallowly southward. The sill varies in thickness from 100 to 1000 m averaging about 600-700 m.

Internally the granophyre is massive and homogeneous with only seldom detected columnar jointing at the base. Joint intersections plunge steeply (55-70°) northward. On the assumption that columnar joints developed perpendicularly to contacts, these attitudes indicate a lower granophyre surface dipping gently southward, in accord with the independently estimated dips.

Thompson Wash phase. Occurring only in the northern King Ridge/ Mescal Ridge area between McDonald Mountain fault and Bear Flat fault, the Thompson Wash sill is exposed almost continuously for a five-mile length along which its width is usually 0.3-0.6 miles. It is named for excellent exposures in the last 1.5 mile stretch of Thompson Wash before it empties into Tonto Creek (E,F-16).

The Thompson Wash phase is a tabular body dipping generally southwestward as evidenced by the relationship to topography of both upper and lower contacts. This is most clearly shown in the lower Thompson Wash area where geometrically estimated dips of the lower contact at two places are 24° and 16° and of the upper contact at one place, 24°. Along the south wall of lowermost Thompson Wash the upper contact with spherulitic rhyolite runs essentially on contour indicating again a very shallow southwestward dip. It is quite clear that upper and lower contacts of the body are quite regular in parallelism, except perhaps at the eastern end of the sill. The sill in the Thompson Wash area is about 300-400 m thick.

Westward the sill is much more limited in extent than the Mescal Ridge sill and is found nowhere west of the McDonald Mountain fault.

It appears to be lensing out approaching that fault from the east. Eastward it is apparently displaced, along with Mescal Ridge granophyre, downward and perhaps northward on the east side of the Lost Camp fault.

Granophyre undivided. The Neal Mountain mass is almost as thick as it is long because of its eastern truncation by the Green Valley Creek fault and its western abutment against the Gisela pendant. Nevertheless it is basically a shallow-dipping concordant body as far as northern and southern contacts are concerned. Three geometrically-estimated dips for the lower contact are 33°, 26°, and 20°, all southward. At the upper contact with rhyolite a number of contact attitudes and columnar jointing attitudes (in the rhyolite right at the contact), as well as geometric attitudes, require a southerly, shallow dip also.

At the western contact the style of intrusion is sharply discordant. At the southwest (P-7) a transition from discordance to concordance is marked by short, stubby projections of granophyre into the rhyolite just before the contact swings east. In this vicinity flow-banding attitudes, though striking parallel to the contact, dip discordantly northward into the southward dipping granophyre-rhyolite surface. Attitudes in rhyolite and dark graywacke of the Gisela pendant further north strike east-west perpendicular to the intrusive contact.

Granophyre along the Gibson Rim occurs as two mapped lenses about one and one-half by one-quarter miles in dimension and as unmapped thin sheets along much of the Payson Granite-Gibson Complex contact.

The granophyre was examined only for short distances along the southern margins of the lenses and locally along the thin sheets. A few measured contact attitudes and trends across topography indicate that the sill(s) dip shallowly southward.

INTERNAL CONTACT RELATIONS

Mescal Ridge granophyre-upper border aplite relationship. Contemporaneity of granophyre and upper border aplite is indicated by a gradational relationship at contact station 470 (I-10) where there is a smooth transition over a distance of one meter from granophyre into the aplite. The gradation is expressed by a gradual decrease in phenocryst content and size reduction of micrographic domains until 'aplite' essentially free of phenocrysts is reached. Only a very small amount (generally less than a meter) of fine-grained material occurs at and near this station along the contact with Blue Dog rhyolite. The relations suggest that granophyre did not simply chill against the intruded body but that a nearly phenocryst-free extract of the magma accumulated at the contact.

Only sharp intrusive contacts were found between granophyre and the larger mapped lenses of aplite. These larger masses of aplite are hypersolvus, as are all rocks in the Green Valley Granophyre, and are included in the Mescal Ridge Member because of their occurrence along the upper contact of the granophyre. This aplite might be derived from the granophyre and still exhibit intrusive relationships where it had moved along slightly cooled contacts.

Textures have been discussed (page 151) which indicate that a residual phenocryst-free or phenocryst-poor liquid developed at least locally in both the Mescal Ridge and Thompson Wash bodies. An aplite dike occurs only a few meters from aplitic mesostasis (analogous to that in Plate 23A) in Mescal Ridge granophyre at station 2051 (E-16). It seems quite plausible that upper border aplite was derived from the granophyre sill by filtration of such a residual liquid (see page 359).

Thompson Wash-Mescal Ridge contact. Relations at several excellent contact exposures indicate that the Thompson Wash phase intruded the Mescal Ridge granophyre. In a few instances some gradation, indicative of hybridization, was found but usually Mescal Ridge granophyre is homogeneous right up to a sharp contact with variably textured Thompson Wash phase. The latter, at two contacts observed, is somewhat coarser and very mildly pegmatitic within 3-4 meters of the contact. In one of these places, however, it has a 0.5 m fine border.

Contact exposures at station 788 on Mescal Ridge (F-17) have several features indicating intrusion by Thompson Wash granophyre. Isolated and somewhat diffuse quartz phenocryst-rich areas in Thompson Wash granophyre, within a few meters of the contact, are possibly inclusions of Mescal Ridge lithology. The exact contact was noted in a few places at this station and the Thompson Wash granophyre becomes somewhat finer-grained at the contact. Development of large spherulitic micrographic areas and accompanying aplitic mesostasis is abundant in the Thompson Wash phase along the contact and several small aplite dikes in Mescal Ridge granophyre right off the contact were possibly derived from the aplite-spherulite areas. At other stations aplite and aplite dikes along and near the contact may have been derived from either granophyre body.

EXTERNAL CONTACT RELATIONS

Diverse phases of the Green Valley Granophyre were consistently found to be younger than all units with which they are in contact except for alaskite.

Haigler rhyolite. At the extreme eastern end of the Thompson Wash sill the upper contact of the granophyre is exposed for 200-300 m in contact with dark flow-banded Haigler rhyolite. A thin section of the contact (1317, G-18) revealed sheaths of micrographic intergrowth in the granophyre perpendicular to the contact surface, confirming intrusion of rhyolite by granophyre.

Haigler rhyolite of Neal Mountain strikes generally east-west and is discordantly or concordantly intruded by granophyre depending on contact azimuth. General discordance of the rhyolite flow-banding and the apophyses of granophyre projecting semi-concordantly into rhyolite clearly show that granophyre intruded the rhyolite.

Gisela pendant. In the stratified rocks of the eastern Gisela pendant the discordance of planar features to the contact with Neal Mountain granophyre is evidence of intrusion by the granophyre. Moreover, at station 1447 granophyre contains numerous inclusions of the dark graywacke which strikes into the contact. Again, at superb exposures in Tonto Creek (1460, P-7), granophyre contains inclusions of, has a chilled margin (2 cm) against, and intrudes as a 25-cm wide dike 7 m into, pendant rhyolite which strikes into the contact.

Gibson Complex. A dike of granophyre essentially identical to the Mescal Ridge lithology intrudes Gibson diorite at station 1424 (O-6).

Payson Granite. Determination of the nature of the granite-granophyre contact was a primary important aim of this study. In the first instance it was important to evaluate whether, as Gastil (1958) had hypothesized, the granite was gradational into granophyre (see Figure 5). Fortuitously, a sharp contact was found between Payson Granite and granophyre in the Green Valley Hills (29, G-11; Figure 6) the third day in the field. This disproved the hypothesis of gradation but, unfortunately, no relative age determination could be made. As work progressed it was seen that such a determination would be important. Granophyre was found to intervene everywhere between the granite and the intrusive rhyolite and stratified rocks to the south. It seemed the only possible way to determine a relationship between the layered sequence and the Payson Granite would be to get relative ages at

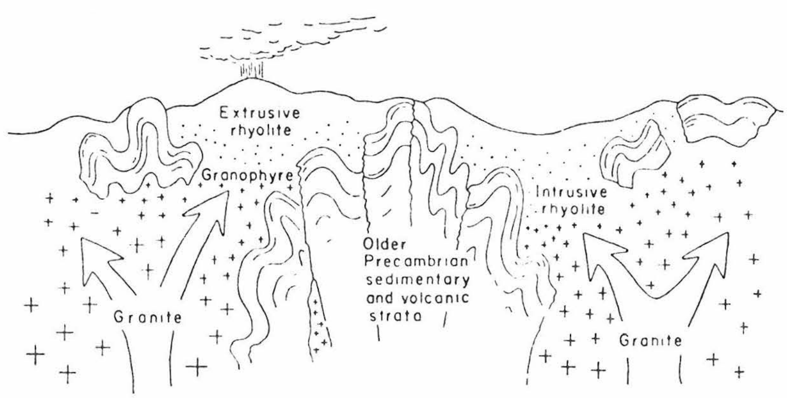


Figure 5. Hypothetical section across the Diamond Butte quadrangle at the time of granitic intrusion (from Gastil, 1958, Fig. 5). Relation as visualized by Gastil between older stratified rocks and major igneous masses conveying his hypothesis of gradation from granite through granophyre into intrusive and extrusive rhyolite.

contacts of all intervening intrusive rhyolite and granophyre. Even then the granite-layered rock relationship would remain undetermined if the granophyre was the youngest unit and, if upon its intrusion as a sill everywhere along a pre-existing contact, no evidence was preserved as to the nature of that pre-existing contact.

Granophyre-granite (including alaskite) contacts were intensively studied from the Green Valley Hills to Bear Flat and between Gisela and McDonald Pocket. The contact was also briefly examined between stations 2141 and 2146 (J-5) on Gibson Rim where, ironically, the only direct definitive relations were found.

In the vicinity of station 2141, at the upper part of a small alaskite sill on Gibson Rim, large areas of probable Payson Granite are mostly surrounded by alaskite but are locally in contact with granophyre. A few cm from a contact with this granite are coarse xenocrysts (?) in granophyre which are probably from the granite. At station 2146 an unmapped 10-15 m sheet of granophyre separates Payson Granite from gabbro/diorite of the Gibson Complex. Inclusions of granite were found in this granophyre. Because alaskite in this vicinity is clearly younger than the granophyre, Payson Granite is the only reasonable source of the xenocrysts and inclusions.

From Green Valley Hills to Bear Flat alaskite and/or aplite occurs along most of the contact and obscures the granite-granophyre relationship. The study of this contact is therefore primarily a study of the alaskite-aplite-granophyre relationships which are discussed in detail later (page 176). It is concluded that alaskite is younger than granophyre; consequent to this relationship several indirect arguments suggest that granophyre intruded Payson Granite (page 186).

No relative age criteria were obtained in the McDonald Pocket area. The study of the granite-granophyre contact sheds no light on the relationship between Payson Granite and the stratified sequence to the south.

Hell's Gate Rhyolite. Both granophyre and upper border aplite phases of Mescal Ridge granophyre were found in sharp intrusive contact with Blue Dog rhyolite. Gradations as described earlier of granophyre into aplite which is in sharp contact with the rhyolite are convincing evidence for the intrusion of rhyolite by granophyre. Other direct evidence is the presence of rare porphyritic aplite dikes in Blue Dog rhyolite found only very near the contact with the granophyre (Plate 23B). Phenocryst content in these dikes is low and quite variable, but the crystal size and morphology is comparable to that in the porphyritic marginal aplite.

In walking the contact a careful search was made for inclusions in both lithologies. Only one questionable inclusion of rhyolite in granophyre was found.

The data from this contact indicating that Mescal Ridge granophyre intrudes Blue Dog rhyolite is very important because it demonstrates that both main phases of the Green Valley Granophyre are younger than both phases of the Hell's Gate Rhyolite (Mescal Ridge granophyre is older than Thompson Wash granophyre and Blue Dog rhyolite is younger than Salt Lick rhyolite).

At several places the exact intrusive contact was observed between the granophyre of Neal Mountain and the small sheet of Salt Lick (?) rhyolite running through the saddle between Neal Mountain and Gisela Mountain. Granophyre has an apparent chilled margin against this rock at station 2191 (Q-8).

At station 2128 (K-6) on Gibson Rim a complete exposure was found of granophyre in contact with a small exposure of Hell's Gate Rhyolite (?) containing abundant inclusions of mafite porphyry. Inclusions of the rhyolite were found in the granophyre a few cm from the contact.

King Ridge Rhyolite. In early mapping it appeared that the two bodies now designated King Ridge Rhyolite and Thompson Wash granophyre were a single body in which a continuous textural gradation existed from granophyre northward to spherulitic rhyolite southward. This was bothersome because it appeared that this 'body' intruded Mescal Ridge granophyre on the north whereas the extensive development of spherulites to the south seemed to require an extrusive origin. Moreover, petrographic study to that point showed that the spherulitic rhyolite and near granophyre contained plagioclase phenocrysts whereas plagioclase was entirely absent in northernmost granophyre. Additionally, northern granophyre was found to contain 1.5-3 times the abundance of 2-3 mm alkali feldspar phenocrysts. It seemed that an internal contact might exist close to the northern limit of the mass. With additional field and petrographic work it was found that in spite of the transition into granophyre texture, subtle hints of the spherulitic texture could be found far northward into the granophyre. Familiarization with details and variability of field expression quickly led to the discovery of a contact.

It has since been concluded that the spherulitic rock, as well as the northern granophyre, is intrusive; ironically, an only apparent incompatibility partially prompted the successful search for the contact.

Once identified the contact was fairly easy to trace. The most helpful field criterion is the difference in alkali feldspar phenocryst content, but due to the granular appearance of the rock the phenocrysts are not always easy to identify. Rocks at the base of the King Ridge Rhyolite are also micrographic and granular, but generally slightly finer grained than the Thompson Wash rocks. In some instances a faint to fairly strong alternating reddish and grayish lamination (few cm layers) in the King Ridge granophyre serve to distinguish it from the Thompson Wash granophyre. The former also seems usually to have a more mottled appearance and to be more vuggy. All these criteria except phenocryst content break down from place to place where to be sure one is following the contact he must find outcrops where phenocrysts are recognizable. In some cases distinguishing between the two lithologies in the field is an arduous or impossible task and petrographic study is required to locate the contact.

The contact was found to be sharp and intrusive. It is particularly well defined by virtue of greater than usual lithologic contrast in the vicinity of station 2044 (E-15). At this station aplite was found along the contact, as a probable dike in King Ridge Rhyolite and as mesostasis for the large spherulitic micrographic domains in

Thompson Wash granophyre only a few meters from the contact. At this station and at one other spot probable inclusions of King Ridge lithology were found in the granophyre. It appears that the Thompson Wash phase intrudes the King Ridge body.

No age relations could be determined where Mescal Ridge granophyre is in contact with King Ridge Rhyolite in Salt Lick Canyon (F-14).

A tabular body of King Ridge Rhyolite(?) occurs in the upper part of the Mescal Ridge granophyre sill along Thompson Wash (D-16; see cross-section G-G'). This southward-dipping sheet is granophyre and it cannot presently be concluded that it is King Ridge and not Thompson Wash lithology. Relatively common local relict spherulitic texture seems to bear more resemblance to King Ridge spherulitic/micrographic texture, sometimes found in similar abundance near the base of the King Ridge sill, than to the rare spherule-aplite texture in Thompson Wash granophyre. Spherulitic/micrographic domains, however, are 3-5 mm, larger than those typically found in King Ridge Rhyolite. Identification of plagioclase phenocrysts in the body would confirm that it is King Ridge Rhyolite; none were found in a single thin-section sample.

If indeed the lens of granophyric rock is King Ridge lithology, it is a block engulfed by Mescal Ridge magma (prior to intrusion of overlying Thompson Wash phase), or it is a sill which has intruded Mescal Ridge granophyre.

King Ridge Rhyolite is permissively intermediate in age between the two granophyre phases. It is not included in the Green Valley Granophyre because of different lithology. Based on the relationships at the contact with the Thompson Wash phase it is probably older than Green Valley Granophyre.

GRANOPHYRIC PLUGS IN PAYSON GRANITE

A cluster of small leucocratic plugs, essentially equidimensional in outcrop and ranging from 20 to 200 meters in diameter, underlies small hilltops at Hole in the Ground Canyon (H-9). They are interpreted to intrude Payson Granite on the basis of numerous apparent granite inclusions in a few of the bodies. The limit of the cluster was not defined but knobby topography in the unmapped vicinity suggests that more such bodies exist.

At first appearance these rocks are strongly reminiscent of the Mescal Ridge granophyre. Quartz and feldspar phenocrysts are of about the same size and abundance, and the overall texture, color and low color index are about equivalent. Upon closer inspection one finds that the groundmass is coarser and less well-defined.

In order to make a critical comparison with Mescal Ridge granophyre thin sections were cut of samples from five of the plugs. In thin section the rocks are porphyritic to seriate porphyritic and in three samples the groundmass is weakly and coarsely micrographic. The others have a rather ragged granitic groundmass. All except one is clearly hypersolvus, though some marginal exsolution exists. Free plagioclase crystals in the one specimen might have originated by extensive granular exsolution or by assimilation of Payson Granite, or perhaps the small body (1 × 3 m) from which this sample came is actually a xenolith and not related to the granophyric plugs.

Magnetite, hematite, minor secondary biotite, and a trace amount of dark pseudomorphs made up the few percent of mafic components. The pseudomorphs are very much like those found in Green Valley Granophyre to be alteration products of pyroxene.

Remarkable lithologic similarity, particularly the hypersolvus character, strongly suggests that these plugs are correlative with Green Valley Granophyre and specifically the Mescal Ridge Member. It seems reasonable that these small granophyric bodies may have been feeders to the Mescal Ridge granophyre. The upper Payson Granite surface at Gibson Rim is some four miles from the plugs and the same surface at McDonald Pocket would be about the same distance given pre-Agate Mountain fault geometry. Projecting the dip (20° to 30°) of the upper granite surface northward into the air from a horizontal distance of 4-5 miles, it is seen that the perpendicular distance from the plugs to that surface would be only 1.5 to 2.5 miles. Considering that the texture of the Green Valley Granophyre sill itself changes very little in thicknesses of about half a mile to a mile, it seems that at depths 3-4 times that great the rock could still exhibit porphyritic and micrographic character, though it might be more granitic in texture.

MINOR GRANOPHYRE

Diamond Butte

A granophyre body mapped by Gastil (1958, Plate 2) on the south slope of Diamond Butte (0-15) was examined in Board Cabin Draw. This granophyre is shown in Gastil's cross-sections to intrude the adjacent strata. In confirmation of this the author found a dike of the granophyre intrusive into the middle slate member of the Houden Formation.

Petrographically this granophyre is very much like the phenocryst-poorer phases of the Green Valley Granophyre. Micrographic texture is very well developed, the color index is only 2-3% and the rock is hyper-solvus. Moreover, dark pseudomorphs are very much like those found to be after pyroxene in the Green Valley Granophyre.

Lost Camp Mountain

On the south slope of Lost Camp Mountain (K-17) a small mass of granophyre(?), also mapped by Gastil, was found to have a sharp intrusive contact with flow-banded Haigler rhyolite. The interior of this leucocratic body is a rather fine-grained porphyritic aplite/granophyre whereas the outer 50 m adjacent to the rhyolite is spherulitic. The ubiquitous, evenly-spaced, 2-3 mm spherulites are very well defined in the outer part of the border but gradually coalesce toward the interior. Finally, the spherulitic texture is so diffuse as to be unrecognizable and it apparently grades into the porphyritic aplite/granophyre interior.

Inasmuch as the rhyolite has unequivocal extrusive textures (flow-banding, pumice fragments) the exact intrusive contact indicates that the spherulite-bearing body intruded the rhyolite. Either the margin was quenched to a glass and then devitrified or the spherulites crystallized directly from the magma.

No petrographic examination was made of this body. Its highly leucocratic and granophyric(?) character suggests possible affinity to grossly similar rocks discussed in this section.

Salt Canyon

Another small leucocratic mass mapped by Gastil intrudes Haigler rhyolite in Salt Canyon (I-18). The rock is finer-grained near the margins (outer 30-60 m) and several dikes were noted running from the granophyric rock into the rhyolite. Although the texture, weakly porphyritic with occasional micrographic areas in the ragged granitic groundmass, is somewhat granophyric, this rock is petrographically more akin to alaskite of Cherry Spring, the main mass of which is only one-fourth mile to the north, than to Diamond Butte or Green Valley granophyre. It contains 2-5% biotite, apparently primary but altering to chlorite, and 5-20% euhedral-subhedral plagioclase. It is clearly subsolvus.

ALASKITE

Scattered small alaskite bodies are discussed together in this section primarily because of similar lithology and secondarily because field relations indicate several of these bodies are younger than Green Valley Granophyre. All are apparently younger than Payson Granite.

The alaskite stocks, sills, and plugs are fine-grained to medium-grained leucocratic granite characterized by sub-equal proportions of quartz, perthite, and albite (or less often, sodic oligoclase). Biotite is most commonly the primary ferromagnesian phase; hornblende is rarely present. The alaskite rocks are similar to upper parts of the Payson Granite. They are distinguished by a generally much finer grain size and by sparsity of rapakivi texture, which is prevalent in Payson Granite. Alaskite is more resistant to erosion than Payson Granite and, like granophyre, stands in relief against the Granite.

Though the alaskites are possibly identical compositionally, and from contact relations permissively time-correlative, petrographic differences among the bodies attest to varying crystallization and alteration histories. It seems preferable at present neither to apply a formal name to the alaskite group nor to name individual bodies.

Sills along Upper Payson Granite Contacts

LITHOLOGY

Sill alaskite generally is medium-grained (2-6 mm), slightly to markedly finer-grained than Payson Granite, and is characterized by a color index of 2-3%. Degree of preservation and consequent coloration varies remarkably. Rarely the rock is little modified biotite granite; more often the biotite is extensively or completely replaced by hematite and muscovite. In the latter case the rocks are drab red-gray with small dark red-brown splotches which are primarily pseudomorphs after biotite. Often, particularly near some granophyre contacts, biotite, or biotite pseudomorphs, are completely lacking and the mafic component of the rock occurs as fine-grained hematite disseminated along fractures and grain boundaries. Such alteration imparts a dark red-stained appearance to the entire rock. Rarely the granite is bleached to a creamy-tan; these rocks are generally muscovite-rich and occur in proximity to the red-stained rocks.

Texturally the granite is hypidiomorphic-granular and is quite homogeneous. Upper parts of the sheets tend locally to be slightly prophyritic and very coarsely micrographic.

Textures and alteration do vary enough so that a slightly porphyritic, altered (reddened) version is not always readily distinguished from Mescal Ridge granophyre. On the other hand a somewhat coarser, even-grained, and biotite-bearing variety bears much resemblance to Payson Granite.

Associated with the alaskite is porphyritic and non-porphyritic aplite. An apparently rather large mass occurs in McDonald Pocket (O-8), but was not carefully examined. An ubiquitous, but thin aplite selvage along contacts with granophyre is thought in part to be related to the alaskite. Its importance in understanding the alaskite-granophyre relationship is discussed on page 176.

DISTRIBUTION AND STRUCTURE

Alaskite occurs as discontinuous, lens-like sheets up to perhaps 600 m thick along about 6-7 miles of the 10 miles of Payson Granite-Green Valley Granophyre contact between Green Valley Creek fault and Lost Camp fault. There are three separate masses, one at the rim of Green Valley Creek (H-10), one at the head of Salt Lick Canyon (F-13, 14), and one in the Bear Flat/Bearhide Canyon area (E,F-17). Contacts with granophyre were carefully traced whereas contacts with Payson Granite were only crossed in a number of places. The western two masses were abundantly sampled and the location of their contacts with

Payson Granite is quite well controlled. The eastern body and its contact with the Payson Granite is less well known. Best preserved alaskite was found in the Salt Lick Canyon body and best contact exposures were located on the rim of Green Valley Creek.

A roughly elongate mass of alaskite lies between Payson Granite and Green Valley Granophyre in McDonald Pocket (O-7,8,9). Here the alaskite-granophyre contact was also traced carefully on foot, except for a one-half mile stretch where the contact crosses Tonto Creek. West of station 1445 the lithology in contact with granophyre (and with the Gibson Complex) is essentially all Payson Granite. Between that station and the Green Valley Creek fault most or all of the rock in contact with granophyre is the alaskite; locally much aplite is present. No attempt was made to map the contact between Payson Granite and alaskite but the area in which alaskite predominates is indicated on Plate 1.

On Gibson Rim (2141, J-5) a small body of alaskite was found between Payson Granite and Green Valley Granophyre. Its extension westward from station 2141 is hypothetical.

Exposed masses of alaskite are elongate and parallel to the granophyre sills. Both southern and northern contacts of the Bear Flat/ Bearhide Canyon mass run southward down into the Tonto Creek gorge. These overall relationships indicate that, like the granophyre sills, the alaskite bodies are roughly tabular and dip generally southward, conformable to the 'regional' upper Payson Granite surface.

Relation of Sills to Payson Granite and Green Valley Granophyre

Alaskite between the rim of Green Valley Creek and Bear Flat was early recognized as distinct from coarser rapakivi Payson Granite, but was nevertheless initially thought to be a late phase of the Payson Granite possibly intruding at the upper margin. The contact between the granite phases and the Mescal Ridge granophyre was intensively studied in an effort to determine the granophyre-granite relationship. This relationship was found to be initially obscured by a ubiquitous selvage of aplite along the contact. The few apparently definitive relations were confusing because some suggested intrusion by granite (alaskite) whereas others indicated that granophyre was the intruding phase (in some cases apparently into alaskite).

A study of the granite-granophyre contact between McDonald Pocket and Gisela met with similar frustration. On Gibson Rim, however, relatively simple relations indicated that alaskite intruded both Payson Granite and granophyre and that granophyre intruded Payson Granite. Careful re-evaluation of field relations and extensive study of the lithologies at the base of the Mescal Ridge granophyre leads also to the conclusions that alaskite intruded granophyre and that granophyre probably intruded Payson Granite.

Data and interpretive arguments supporting intrusion of Payson Granite and Green Valley Granophyre by the alaskite sills are considered for each area separately in the following pages. Field relations and arguments are such that integrated discussions of the relations to both granite and granophyre are necessary in some cases.

GIBSON RIM

At station 2141 (J-5) on Gibson Rim large areas (up to tens of meters) of Payson Granite are apparently surrounded by alaskite. Unusually large (5-8 mm) quartz and alkali feldspar crystals in the alaskite near contacts with the coarser granite appear to be xenocrysts from the granite. The coarse-grained blocks occur near the top of the alaskite sill and it appears, particularly because probable Payson Granite is nearby found in contact with granophyre, that alaskite intruded along a Payson Granite-granophyre contact, locally preserving and partially engulfing a Payson Granite selvage at its roof. The presence of apparent coarse granite xenocrysts(?) in granophyre a few centimeters from the contact suggest that granophyre intruded Payson Granite. At this station both fine- and medium-grained alaskite were found to clearly intrude granophyre. One contact in the field and both contacts in thin-section revealed gradational chill margins of the alaskite phase.

RIM OF GREEN VALLEY CREEK TO BEAR FLAT

Alaskite-Payson Granite Contacts

At seven stations Payson Granite and alaskite lithologies were found within 10-15 m of one another -- in two instances within 2-3 meters. The two phases are distinct and quite certainly in non-gradational contact. Occasionally, however, the lithologies are similar and location of the contact is somewhat difficult. At one of the best areas of exposure (285, G-11) there appeared to be a gradation over perhaps 30-40 m from one into the other. The gradation is characterized more by heterogeneity than by smooth transition. Grain size reversals were noted. At station 725 (E-17), south of Bear Flat, a rather large mass of coarse Payson Granite was found well within the alaskite, with similar medium-grained alaskite both above and below it.

The half dozen relatively sharp contacts and the lithology reversals suggest that the aslaskite is not continuous with the Payson Granite, but is a separate intrusive phase. A contact, as at station 285, might appear to be gradational because of hybridization, or gradations or variations within one or both phases near the contact. An unusual abundance of biotite aplite dikes in Payson Granite near the contact at station 520 (F-13) and an apparent increase in abundance of the dikes approaching the contact may suggest derivation of the aplite from alaskite.

Alaskite/Payson Granite-Granophyre Contacts

Contact relations between Mescal Ridge granophyre and underlying Payson Granite and alaskite are schematically shown in Figure 6. The granophyre is juxtaposed with alaskite along about two-thirds of the 10-mile length of contact and with Payson Granite along the remaining third. An aplite selvage (0.5-10 m thick) occurs nearly everywhere between granophyre and the granite phases. Notes were taken of contact relations at 32 stations and over 50 samples were collected of granite, granophyre or aplite at or near the contact. Petrographic study of thin sections from 24 of these samples proved indispensable in interpreting contact relations.

Contacts free of aplite. Payson Granite and granophyre were found in contact at only one station (587, D-15) at which an apparent hybridized zone indicates only that one intruded the other.

A meter-long float boulder of Mescal Ridge granophyre containing two small (4 cm and 2 cm) medium- to coarse-grained granite dikes was found at station 483 (F-11). These plagioclase-bearing dikes could not have been derived from the hypersolvus granophyre and almost certainly came from either Payson Granite or alaskite.

Alaskite at two stations (473, G-11; 490, F-12) appears to be chilled against granophyre, while the opposite is seemingly true at two other stations (495, F-12; 292, H-11). In the contact area of stations 490 and 495 (only 20-30 m apart) alaskite is quite heterogeneous whereas the granophyre textural variations are subtle. At station 490 the marginal meter of alaskite is slightly finer-grained. At station 495, where there is a weak suggestion of size reduction in granophyre at the contact, the alaskite is coarser than normal within 0.5 m of the contact and possess an unusual textural heterogeneity. The apparent chilling of granophyre at station 292 is very subtle. Both phases are perfectly normal in texture right up to the contact at station 473 except that a 1 cm border of alaskite is clearly somewhat finer-grained. The relationship at the latter station is most creditable in terms of a chill interpretation. Textural variations near 490 and 495 are most reasonably interpreted to mean that alaskite intruded granophyre, apparently chilling at one place, but coarsening elsewhere perhaps because of local volatile concentration.

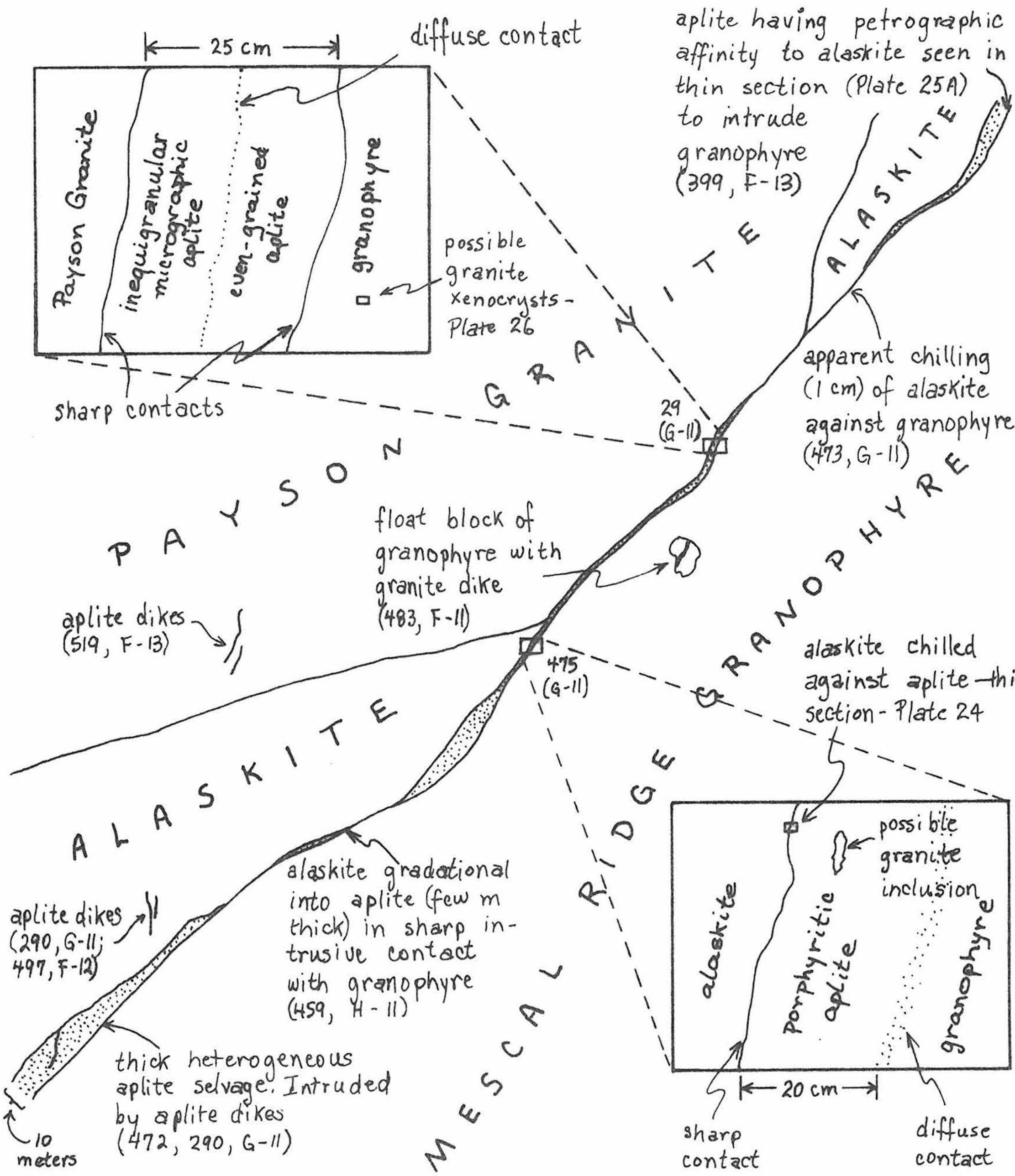


Figure 6. Schematic map portraying Payson Granite-alaskite-granophyre-aplite selvage (stipled) relations along the base of the Mescal Ridge granophyre from the rim of Green Valley Creek to Mescal Ridge. Aplite selvage was found to intervene between the granophyre and alaskite or Payson Granite at 23 of the 32 stations where contact relations could be observed.

Aplite selvage relations. For the most part the aplite selvage is fine- and even-grained aplite. It also contains micrographic aplite, porphyritic aplite, granophyre and granite. In some instances wide and unusually heterogeneous zones are apparently products of granite and perhaps granophyre assimilation. There is considerable variation in plagioclase and biotite content and character.

Aplite selvage is in sharp intrusive contact with the three major phases and aplite dikes in the contact zone intrude alaskite, Payson Granite, and the aplite selvage. Apparent inclusions of granophyre and both phases of granite are found in aplite. It would appear that at least some aplite is younger than all the three major phases. Relations at several stations strongly indicate that some aplite is gradational into alaskite. An origin then, for at least part of the aplite is differentiation, or segregation, from alaskite. At one station, however, alaskite apparently intrudes aplite which has a diffuse contact with granophyre and a sparse phenocryst population identical to that in the granophyre. It appears that the aplite selvage consists of at least two generations of aplite, one related to alaskite and the other to granophyre. These relations also suggest that alaskite is younger than granophyre.

Of 18 thin sections of aplite several were found which contain only exsolved (internally or marginally, but in optical continuity) plagioclase. Up to 15% 'free' euhedral-subhedral plagioclase crystals were found in others. Between the extremes a variety of amounts and textural types were found. All plagioclase is apparently albite.

Upper border aplite of the Mescal Ridge granophyre (page 158) is hypersolvus as is the granophyre itself. It seems probable that both the upper border aplite and the hypersolvus aplite of the lower aplite selvage are genetically related to the granophyre. The subsolvus aplite of the selvage is probably related to the alaskite. With increasing P_{H_2O} a subsolvus residual phase could feasibly differentiate from the granophyre or with increasing (Na + K)/Ca a hypersolvus residual phase might differentiate from the alaskite. It seems likely, however, that the effect of increasing P_{H_2O} would outweigh the effect of increasing alkali content in which case hypersolvus aplite could not form from alaskite.

At a few stations where certain petrographic criteria and/or field relations suggest affinity of aplite to granophyre the aplite contains a few percent 'free' plagioclase crystals. In these instances, feldspar of the presumably granophyre-derived aplite may have crystallized below the solvus crest because of increased P_{H_2O}, or originally hypersolvus aplite may have been metamorphically recrystallized when intruded by alaskite. These rocks also contain a little secondary biotite (usually replacing alkali feldspar) which may also be the result either of an increase in magmatic H_2O or contact metamorphism. There is no evidence of primary biotite. It is important to note in this connection that while neither primary biotite nor non-perthitic plagioclase occur in about 20 thin sections from the interior of the Mescal Ridge body, both secondary biotite and a little fine granular plagioclase were found in a few contact granophyre samples. Clearly the same process could have modified both granophyre-derived aplite and marginal granophyre.

Other petrographic criteria in the modified(?) hypersolvus aplite suggesting affinity to granophyre are clusters of dark, nearly opaque pseudomorphs (probably after pyroxene) and quartz and alkali feldspar phenocrysts virtually identical to counterparts in granophyre. Neither pyroxene nor anything resembling the pseudomorphs was found in alaskite or strongly subsolvus aplite.

Most aplite of the selvage, including that which is apparently gradational into alaskite, has a mineralogy very similar to alaskite, though generally poorer in plagioclase. Biotite and its alteration products constitute a few percent of the rock.

Specific field relations and petrographic characteristics at several key stations will now be described to support the multiple aplite thesis and the contention that alaskite intruded granophyre.

Relations at station 475 (G-11) are shown in an inset in Figure 6. A 20-cm zone of variably porphyritic aplite occurs in sharp contact with alaskite but has a diffuse contact with granophyre. A thin section of the sharp aplite-alaskite contact reveals an apparent 0.5-1 cm chilled alaskite margin (Plate 24). An extra thin section was cut to confirm this relation.

Both secondary biotite and a little non-perthitic plagioclase are present in this modified(?) hypersolvus aplite. Subhedral resorbed quartz and alkali feldspar phenocrysts are virtually identical to those of the granophyre. This aplite is very similar to the upper border aplite at station 470 (page 158) which is gradational into granophyre.

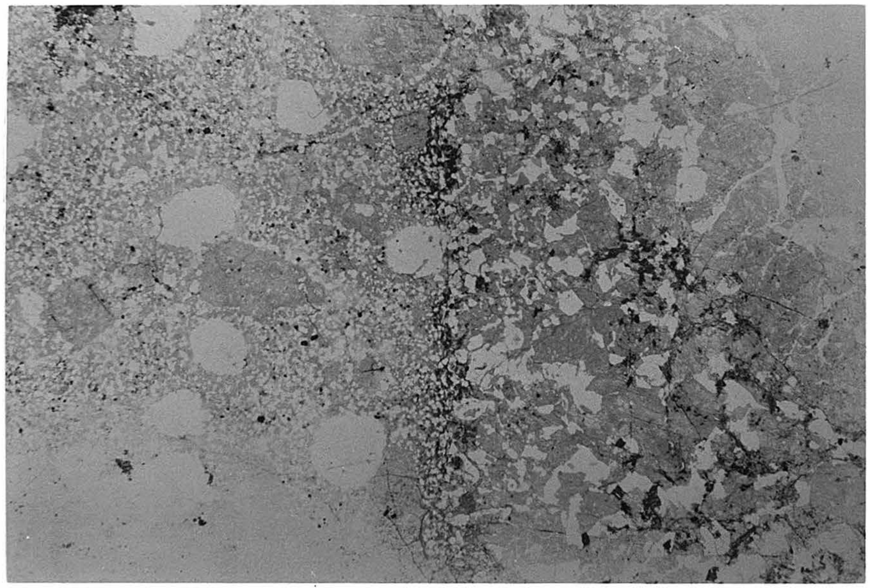
Within the aplite is a possible inclusion of granite, which cannot have been derived from alaskite, if, as the chilled margin indicates, alaskite intruded granophyre. At this station only 20 meters of alaskite intervenes between Mescal Ridge granophyre and Payson Granite. It seems highly likely that the granophyre had intruded Payson Granite, from whence the small inclusion came, and had developed the porphyritic aplite selvage against the Payson Granite. Later alaskite cleanly intruded the Payson Granite-aplite contact preserving the aplite selvage and chilling against it.

A 10-meter-wide aplite zone at station 399 (F-13, Figure 6) is somewhat heterogeneous but becomes distinctly finer-grained approaching the granophyre. The aplite was not traced directly into alaskite because of incomplete exposure, but is mineralogically similar to alaskite a few meters away. Distinct, subhedral biotite flakes oocur in the even-grained aplite and are prominent, and slightly phenocrystic, in mildly porphyritic portions. Elsewhere in the vicinity alaskite has developed porphyritic marginal rocks in which biotite is phenocrystic. There can be little doubt that this aplite is genetically related to alaskite.

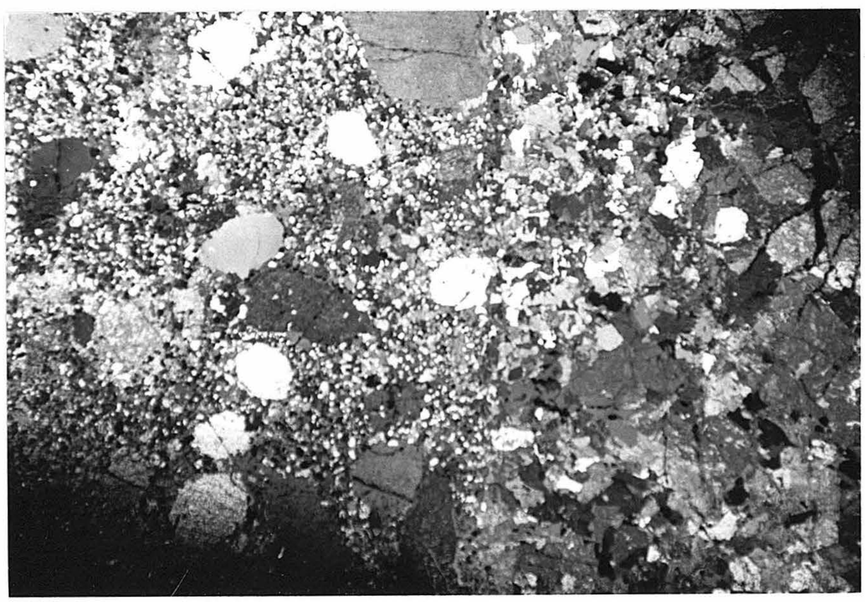
A thin section of the exact contact with granophyre (Plate 25A) shows that aplite is the intruding phase. Locally abundant 3-4 mm rounded quartz and alkali feldspar crystals in aplite a few meters from the contact are probably xenocrysts from the granophyre.

At station 459 (H-11, Figure 6) there is a clear-cut gradation over several meters from alaskite to fine-grained aplite which is in sharp intrusive contact with granophyre. The aplite is certainly

PLATE 24. ALASKITE-GREEN VALLEY GRANOPHYRE CONTACT

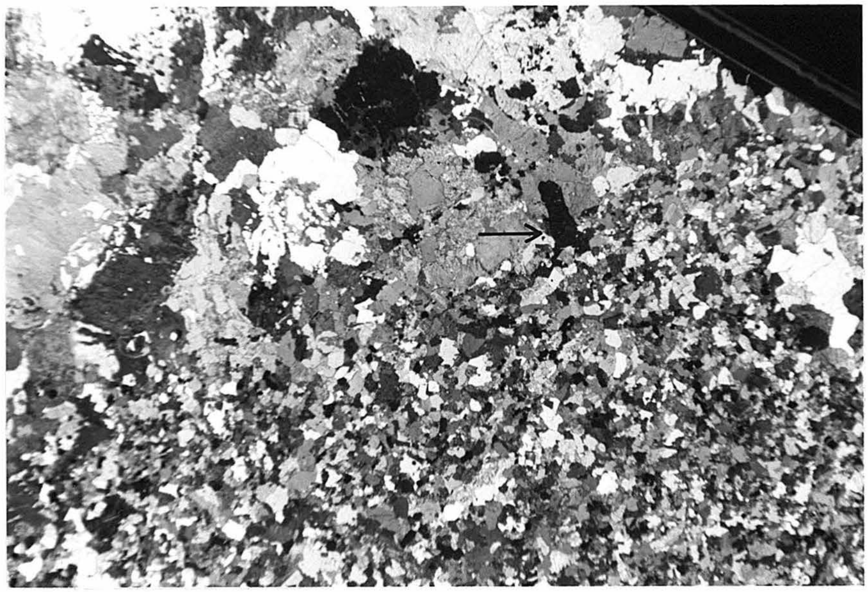


A. Sill alaskite (right) with an apparent gradationally chilled margin against porphyritic aplite having petrographic and field affinities to Mescal Ridge granophyre (see text). An alkali feldspar phenocryst (top center) and a quartz phenocryst (center) in the aplite are possibly barely truncated at the contact. Plane-polarized light, 25 × 17 mm. (475, G-11)



B. Same as A. Cross-polarized light.

PLATE 25. ALASKITE CONTACT RELATIONS

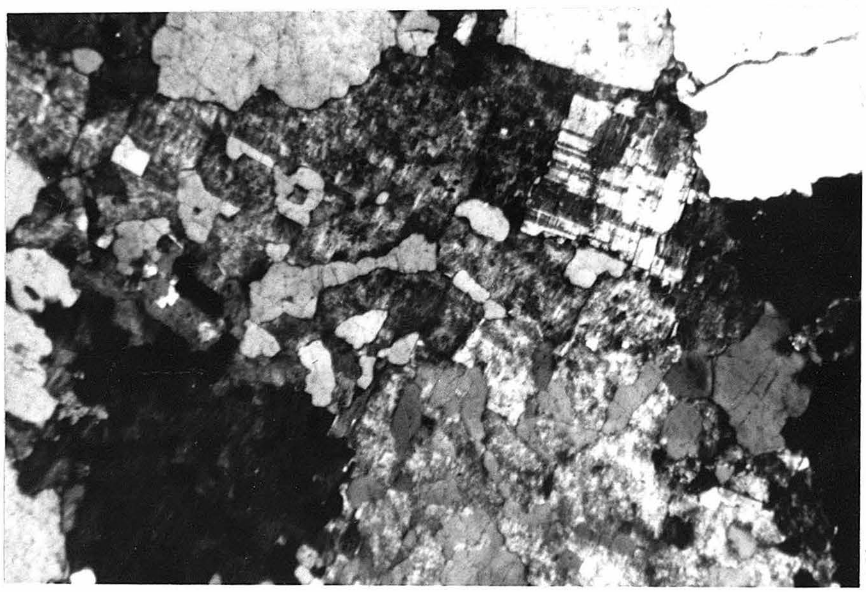


A. Aplite having petrographic and field affinities to sill alaskite (see text) in contact with and containing an apparent inclusion of Mescal Ridge granophyre. An elongate quartz crystal crossing the contact (arrow) was apparently truncated by the aplite then overgrown in crystallographic continuity by quartz crystallizing from the aplite magma. Cross-polarized light, 27 × 18 mm. (399, F-13).

B. Inclusions of Payson Granite in alaskite of a small plug in eastern Star Valley. (2012, G-6)

PLATE 26. GRANITE XENOCRYSTS(?) IN MESCAL RIDGE GRANOPHYRE

A. Plagioclase (somewhat altered) inset in alkali feldspar. This texture is common in Payson Granite (Plate 34) and alaskite. Its occurrence in only three contact samples of the granophyre suggests that the plagioclase-bearing alkali feldspar crystal is xenocrystic. Cross-polarized light, 2 × 3 mm. (29, G-11)



B. Plagioclase inset in alkali feldspar. Micrographic intergrowth in part of small host crystal may indicate it was broken upon assimilation, then overgrown in the granophyre melt. Alkali feldspar xenocrysts(?) are apparently from Payson Granite (see text). Cross-polarized light, 2 × 3 mm. (399, F-13) genetically related to the alaskite and appears to intrude granophyre.

Evidence for Intrusion of Payson Granite by Mescal Ridge Granophyre. Relations at station 475 were interpreted to mean that alaskite intruded granophyre and that, this being so, granophyre probably earlier intruded Payson Granite. Possible xenocrysts of granite at two contact stations also argues that granophyre intruded Payson Granite.

An inset in Figure 6 illustrates the relations at station 29 (G-11), which is only about 150 meters from station 475. Here a 25-cm aplite selvage is in sharp intrusive contact with Payson Granite and granophyre and contains an internal contact separating two distinct films of selvage material. One is very homogeneous classical aplite; the other is inequigranular with well-developed micrographic texture prevailing. Neither aplite phase is porphyritic; both contain secondary biotite and a trace amount of 'free' plagioclase. Probable pyroxene pseudomorphs were found in one aplite phase. The aplite at this station is interpreted to be slightly 'modified' hypersolvus aplite derived from the granophyre. There are no megascopic relations indicating which phase(s) are intrusive.

Thin sections of granophyre 10 cm and 5 m from the contact with aplite contain plagioclase crystals as insets in alkali feldspar crystals (Plate 26A). The plagioclase crystals are in optical discontinuity with exsolved albite lamellae of the host crystal. An identical feature was also found in granophyre a few cm from the contact with aplite at station 399 (Plate 26B).

These plagioclase insets appear to be inclusions incorporated during growth of the host. An identical texture is very common in both Payson Granite (Plate 34A) and alaskite, but has not been observed elsewhere in any phase of the hypersolvus Green Valley Granophyre. All other thin sections (22) of the Mescal Ridge granophyre, including 5 samples very close to the lower contact, were carefully examined for other such crystals. None were found.

Compositions of the few plagioclase insets is difficult to determine, but they are apparently albite. Plagioclase in both alaskite and most upper Payson Granite is albite. The plagioclase-bearing alkali feldspar crystals are apparently xenoliths which came from either Payson Granite or alaskite. If this is so, and if the previous arguments favoring intrusion of granophyre by alaskite are correct, then granophyre must have intruded Payson Granite.

Minor intergranular plagioclase in marginal granophyre might also be xenocrystic but other origins are possible as well (page 180).

McDONALD POCKET TO GISELA

Relations along the granophyre-granite/alaskite contacts between the Green Valley Creek fault and the eastern Gisela pendant are essentially like those just discussed. Aplite was found, apparently locally in very large masses and as typical thin selvage along the contact. At station 1445 (0-7) 3 meters of aplite selvage, then 5-10 meters of alaskite (in sharp contact with aplite) separate granophyre from Payson Granite. Alkali feldspar phenocrysts in the aplite are identical to those in granophyre. Granophyre may have intruded Payson Granite at which time marginal aplite would have formed. Alaskite then would have intruded the aplite-Payson Granite contact. (This is equivalent to the relationship at station 475 in the Green Valley Hills.)

East of station 1445 several clean contacts were observed between granophyre and alaskite, granophyre and aplite, and alaskite and aplite. No clear-cut Payson Granite was identified at or close to the contact. At station 1443 (O-7) granophyre is homogeneous right up to a sharp, exposed contact with alaskite which may be slightly finer-grained within 10 cm of the contact. It appears that alaskite was chilled against granophyre.

Near station 1575 (O-9) there are indications of assimilation of granitic material by granophyre and a decrease in granophyre grain size near the contact. Alaskite is locally homogeneous right up to the contact, but elsewhere is quite variable in texture near the contact and in one instance appears to be a dike in granophyre.

No firm conclusions could be drawn from the data on this contact segment. However, the suggestive observations are compatible with hypotheses developed in the previous section and the apparently contradictory relations can be easily explained by these hypotheses. Granophyre would have intruded Payson Granite, hence the indications of assimilation and chilling in the granophyre, then alaskite intruded the contact, as attested by its marginal variations and probable dikes.

Stocks at Cherry Spring

Near Cherry Spring (G,H-17,18) four isolated exposures of alaskite are situated on the flanks of a Tertiary gravel blanket. The localization of the bodies suggests that they may be continuous beneath the gravels, but petrographic differences suggest the presence of at least two similar, yet distinct phases. The two western bodies are lithologically similar and all alaskite to the east is similar. Gastil mapped these alaskite bodies as granophyre but did not describe them.

Eastern Exposures

Alaskite of the eastern stocks is leucocratic quartz-albite-perthite granite similar to that of the alaskite sills but richer in perthite (~ 50%) and poorer in albite (~ 5%). It is medium-grained and generally even-grained though rarely faintly porphyritic and micrographic. Minor biotite is strongly to completely altered to hematite and muscovite. In outcrop color may vary from penetrative red-brown to light tan, with fine-grained dark red-brown alteration products along fractures and grain boundaries.

No clear relative age relation was found between this alaskite and the Thompson Wash and Mescal Ridge granophyre phases, both of which are in intrusive contact with the alaskite. Along some of the contacts the alaskite is somewhat finer grained; this suggests intrusion into the granophyre.

At station 1994 (H-19), and again nearby, exact contacts of the alaskite with Haigler rhyolite were, in spite of some minor fracturing and deformation, identifiable as intrusive. The alaskite appears to have a 1-2 cm chilled margin and is unquestionably intrusive into the extrusive rhyolite.

Internally the alaskite is quite homogeneous and structurally unmodified except for a few minor shear zones clearly related to the northeast-southwest fault system. It has undergone extensive shearing along the Lost Camp fault. It would appear from the overall position of this alaskite that it has intruded somewhat discordantly along the Mescal Ridge granophyre-Thompson Wash granophyre contact to the north and discordantly into the Haigler rhyolite at and near its contact with the Thompson Wash phase east of station 1317 (G-18). Clearly, this alaskite is quite close to the Payson Granite upper surface (see structure sections A-A' and F-F') and may be continuous with alaskite which, though elsewhere restricted to the Payson Granite-Green Valley Granophyre interface, broke through the granophyre sheet here and up into the rhyolite.

Western Exposures

In both western exposures the alaskite is fine- to medium-grained and porphyritic, though groundmass grain-size and texture vary considerably (aplitic to weakly micrographic) and portions of the northern mass tend to be nearly even-grained. Quartz, alkali feldspar and plagioclase phenocrysts in all variants are a few mm in size and the finest groundmass (in the southern exposure) is a few tenths mm. Unifying characteristics, distinguishing this rock-type from other alaskite, are the presence of white to light green weathering plagioclase phenocrysts and the abundance ($\sim$ 5%) of megascopically well-preserved biotite variably chloritized. Plagioclase is three or four times as abundant as in the eastern alaskite. The rocks are characteristically gray or tan-gray and have a general appearance of being well-preserved.

It would appear that this body is less oxidized than the other alaskite at Cherry Spring and elsewhere. Chemical and modal analyses (page 363) quantify some of the distinguishing characteristics pointed out above and indicate other distinguishing properties.

Another feature distinguishes this alaskite from the eastern phase. Small (2-3 cm) fine-grained mafic inclusions consistently make up a minor fraction of the rock. At the northwestern margin of the northern exposure near station 1288 much larger (blocks up to 1-2 m) inclusions of the same rock type are quite abundant. Right at station 1288 an elongate mass (30 by 10 m) of fine-grained porphyritic mafic rock occurs along the contact with King Ridge Rhyolite. It hosts dikes from the alaskite and was clearly dragged up along the margin of the intruding alaskite body. Plagioclase phenocrysts in this rock are very similar in abundance and habit to those in some of the finer phases of andesite porphyry in the Board Cabin Formation. Gastil (1958, Plate 2) mapped this little block as Board Cabin porphyritic basic flow and the author concurs in this interpretation.

Assimilation of mafic rock might feasibly have had bearing on the petrographic character of the granite.

At station 2209 in the small northern mass excellent exposures of the contact in the drainage bottom revealed several dikes of the alaskite (bearing mafic inclusions) cutting Thompson Wash granophyre. Near the contact about 150 m westward apparently isolated blocks of granophyre occur in the alaskite.

The anomalous petrographic character and unusual lack of oxidation in western Cherry Spring alaskite suggest that it is of different affinity and perhaps younger than the other alaskites (see page 380). It appears, however, that it is older than the northeast-southwest Precambrian fault system. Brecciation and shearing at station 1191 in the easternmost part of the southern exposure are probably indicative of the presence of the Bull Tank fault which is covered by Tertiary gravel for a half-mile to both north and south.

Alaskite Bodies in Payson Granite

Sill at Mud Spring

A body of medium-grained tourmaline pod-bearing alaskite underlies an area two by one-quarter miles in dimension at Mud Spring (G-10,11). The rock is a leucocratic biotite granite, similar in overall composition to other alaskites, but different by generally finer grain size, common pea-green weathering of plagioclase, and common, but unevenly dispersed, 2-4 cm black tourmaline pods and irregular stringers.

Contact relations clearly indicate that this alaskite intruded Payson Granite. At station 306 a 2-6 meter-wide dike intruded 30 meters into the coarser granite along a joint. One hundred meters to the north an inclusion of probable Payson Granite was found in the alaskite near the contact.

The tabular Mud Spring body occurs wholly within Payson Granite but very near the Payson Granite contact with Mescal Ridge granophyre (as close as 150 meters). The tabular form and attitude are indicated by: 1) elongate exposure subparallel to the granite-granophyre contact, 2) 35° southeasterly dip measured at one exposure of the upper contact, and 3) a sense of displacement across the Mud Spring fault identical to that of the nearby southeastward-dipping granite-granophyre contact and of the granophyre sill.

The alaskite at Mud Spring was the only body delineated within the rather heterogeneous Payson Granite terrain east of Green Valley Creek fault. Certainly others could be mapped.

Plugs near Star Valley

Alaskite similar to the Mud Spring alaskite in grain size and mineralogy (lacking tourmaline), but in more nearly equidimensional bodies was found to comprise a small hill in western Star Valley (2012, G-6) and Yerba Senta Butte 1.5 miles to the southwest. These bodies stand in sharp relief against the coarse Payson granite which they intrude. Abundance of uninvestigated knobby topography in Payson Granite, particularly between Star Valley and Gibson Rim, suggests the presence of numerous other such bodies.

The alaskite at station 2012 contains numerous inclusions of Payson Granite (Plate 25B), quartz diorite and dark fine-grained metasedimentary or metavolcanic rocks. The latter two inclusion types suggest the presence of Gibson Complex rocks and stratified rocks perhaps of the same generation as the Gisela pendants either as floor beneath, or blocks within, Payson Granite. It is interesting in this connection that Raymond Cline of Star Valley, in drilling water wells into Payson Granite north of Payson, penetrated mafic rocks which he thought were perhaps diorite like that of the Gibson Complex.

Affinity

Although the alaskite bodies within Payson Granite might be genetically related to the Payson Granite, two factors suggest that they were not differentiated internally from the Payson Granite. First, it seems highly unlikely that a minor phase derived by internal differentiation should contain inclusions from lithologies foreign to the parent granite body. Secondly, the styles of intrusion are similar to that of other phases clearly or apparently intruded after the Payson Granite had solidified and cooled. The bodies near Star Valley have the same form and expression as the Tertiary(?) lamprophyre of Monument Peak (H-6) and the cluster of granophyre bodies and Tertiary(?) mafic plugs at Hole in the Ground Canyon (H-9). These all possess a plug or necklike form, presumably a consequence of the consistent manner in which Payson Granite yielded with non-planar control to intrusion. The intrusion of the Mud Spring body, on the other hand, was strongly controlled by planar structure, presumably by a fracture system near and parallel to the upper margin of the Payson Granite. Intrusion of the much more abundant sill alaskite right at the Payson Granite-granophyre contact (and perhaps of other unmapped bodies near the contact) would have been controlled in a similar way.

The distinction between the minor alaskite bodies of this discussion and the more abundant alaskite which occurs as sheets between Payson Granite and granophyre is primarily the field occurrence, rather than differences in petrographic character. Except for a somewhat finer grain size of the former (which may be due simply to the smallness of the bodies) and the occurrence of tourmaline in the Mud Spring lithology, they are very similar (see modes, Table 14, and page 365). Though close genetic affinity to Payson Granite cannot be ruled out, the minor alaskite bodies are more likely genetically related to the alaskite contact sills.

It seems likely that the plug-like bodies near Star Valley were feeders to the higher 'conformable' sheets at or near the upper Payson Granite margin. This plug/sill relationship is analogous to that also proposed for the granophyre plugs at Hole in the Ground Canyon and the Green Valley Granophyre sills.

From field relations it is not required, of course, that the plugs are Precambrian. It is only assumed from lithologic similarity that they are. The Mud Spring sill is Precambrian because it is cut by the Green Valley Creek fault.

MISCELLANEOUS INTRUSIVE ROCKS

Several very minor intrusive rock types occur in the study area and are shown on Plate 1. Most crop out in the area southwest of Diamond Butte and were not examined by the author. The distribution of unclassified intrusive rock and fine-grained mafic intrusive rock in this area is taken from Gastil's Plate 2. Fine-grained mafic rock shown in Mayfield Canyon north of Star Valley was also uninvestigated and is taken from Titley (1962). Fine-grained mafic rock was found in very small bodies at various other places in the study area, notably along the Green Valley Creek fault, which it apparently intruded, in lower Green Valley Creek.

Just north of Diamond Butte two small intrusive bodies are shown on Plate 1 as albite diorite and as ultramafic rock. The latter was not examined and is taken directly from Gastil's map. The former, mapped as mylonitized ultramafic rock by Gastil, was found to be a tectonically unmodified fine-grained albite-chlorite plutonite, essentially an albite diorite.

SUMMARY OF KEY SEQUENTIAL AND SPATIAL RELATIONS AMONG THE MAJOR PRECAMBRIAN UNITS

A complete section of the Alder Group is exposed in Spring Creek and Board Cabin Draw south of Diamond Butte. Upper units in the Alder Group are exposed between Diamond Butte and McDonald Mountain and trend southwestward out of the map area. Best exposures of possible pre-Breadpan rocks are found in Spring Creek and tributaries above the Flying W ranch. The base of the section is not exposed.

A complete section of the Haigler Group is exposed only in the tightly-folded area between Houden Mountain and Oxbow Mountain. At the base the conformable relationship between Winter Camp Formation of the Haigler Group and underlying Board Cabin Formation was observed at Winter Camp. Exposures of conformable contacts between Haigler rhyolite undivided or Oxbow Rhyolite and overlying Christopher Mountain Quartzite of the Mazatzal Group were examined in many places in this region. Haigler Group in the southeastern limb of the Tonto Basin syncline is sub-conformably intruded by a large sill of Hell's Gate Rhyolite and uppermost Haigler rocks are in fault contact with Christopher Mountain

Quartzite. A conformable basal relationship between Haigler rhyolite and the Board Cabin Formation was found in this limb of the syncline. Across the syncline upper conformable contacts with Christopher Mountain Quartzite are well-exposed in several places.

The rhyolites of Gisela Mountain are correlated with other Haigler Group exposures because of similar lithology and a sequential and spatial relationship to underlying intrusive rhyolite granophyre, and Payson Granite similar to that in the northwestern limb and trough of the Tonto Basin syncline. Neither stratigraphic top nor base of these rhyolites is exposed.

Christopher Mountain Quartzite occurs only in the axes of the Tonto Basin and Big Ridge synclines where it rests in slight(?) unconformity on Haigler Group rhyolite. The top of the quartzite has been removed by erosion.

Gisela pendants and mafite porphyry may bear an important intermediate relationship between the Gibson Complex and Payson Granite and the stratified rocks. Metarhyolite and metasedimentary pendant rocks are intruded by the Gibson Complex. Lithologic similarity and structural relations suggest these rocks may be from the Haigler and Alder groups. Mafite porphyry contacts suggest intrusion by Gibson diorite and clearly reveal intrusion by Payson Granite. A small exposure of mafite porphyry at a contact with Haigler rhyolite of Gisela Mountain contains inclusions of the latter. It is hypothesized that scattered mafite porphyry occurrences are correlative, that mafite porphyry is intrusive, and that its relationship to the plutonic rocks and Haigler rhyolite suggest that Gibson Complex and Payson Granite are younger than Haigler rhyolite.

The main Hell's Gate Rhyolite mass is an enormous, semi-conformable compound sill in the Tonto Basin syncline intruded primarily into Haigler rhyolite. Small masses of probable Salt Lick lithology apparently intruded Haigler rhyolite also at Gisela Mountain and in the Picket Pen fault slice. In the Big Ridge syncline probable Salt Lick rhyolite intruded Christopher Mountain Quartzite. Dikes of Salt Lick lithology occur in Gibson diorite and a probable sill occurs along the Gibson Complex-Green Valley Granophyre contact near Gibson Peak. Inclusions of probable Gibson diorite are prevalent in Blue Dog rhyolite.

King Ridge Rhyolite occurs as a simple, thick sill in the trough of the Tonto Basin syncline where it has intruded the base of the Salt Lick phase of the Hell's Gate Rhyolite.

Beneath the King Ridge Rhyolite are the Thompson Wash phase, then the Mescal Ridge phase of the Green Valley Granophyre composite sill. Each appears to have intruded the unit above it. Westward in the syncline limb the Mescal Ridge granophyre lies beneath and has intruded the Blue Dog phase of the Hell's Gate Rhyolite. At Neal Mountain and on Gibson Rim Green Valley Granophyre undivided intruded small overlying bodies of probable Hell's Gate Rhyolite.

At its base the widespread Green Valley Granophyre is in contact with Payson Granite or with local alaskite sills. On Gibson Rim the granophyre intruded Payson Granite and was intruded by alaskite. Detailed study of Payson Granite-alaskite-Mescal Ridge granophyre relations, complicated by a ubiquitous aplite contact selvage, also indicates that granophyre intruded Payson Granite and was intruded by alaskite in the Tonto Basin syncline. At McDonald Pocket granite-alaskite-granophyre relations are permissively the same.

One and possibly both alaskite phases at Cherry Spring discordantly intrude Green Valley Granophyre and Haigler rhyolite.

Hell's Gate Rhyolite is the oldest of the hypabyssal intrusive bodies. The main Hell's Gate mass intruded Haigler rhyolite; a smaller rhyolite exposure, almost certainly correlative, intruded Christopher Mountain Quartzite. Thus all felsic hypabyssal rocks are younger than the stratified sequence. Hell's Gate Rhyolite intruded the Gibson Complex but no relationship to Payson Granite could be determined. The next younger widespread hypabyssal unit, Green Valley Granophyre, was shown to intrude Payson Granite. Thus, from direct field relations all widespread felsic hypabyssal units except Hell's Gate Rhyolite are younger than Payson Granite and all of them are younger than the Gibson Complex.

It appears from indirect relations that Hell's Gate Rhyolite also is younger than Payson Granite. The same relations support correlations of scattered intrusive rhyolite, granophyre and alaskite exposures. These relations are as follows.

The upper Payson Granite surface dips shallowly southward. Alaskite, granophyre, and intrusive rhyolite sills above this surface are roughly conformable. In the three segments of the upper granite region -- from the rim of Green Valley Creek to Bear Flat, from McDonald Pocket to Gisela, and on Gibson Rim -- the intrusive sheets were successively intruded, each beneath the previous, in the order intrusive rhyolite, granophyre, then alaskite. The scales are drastically different but it is significant that both spatial and sequential orderings are the same. Only at Cherry Spring is the spatial order violated. Here alaskite is apparently located partially above the granophyre.

These relations strongly argue for correlation of similar phases in the respective areas and for the successive sequence of intrusion of Hell's Gate Rhyolite, Green Valley Granophyre, and alaskite, each beneath the last, along a pre-existing sub-planar contact (or contacts) between Payson Granite below and the stratified sequence or Gibson Complex above. Some of the hypabyssal magma, particularly the Hell's Gate Rhyolite magma, also intruded sub-concordantly into the stratified rocks away from the Payson Granite contact region.

STRUCTURE

INTRODUCTION

Tonto Basin Precambrian rocks constitute two major structural blocks, a northern, structurally lower block of massive plutonic rocks and a southern, upper block of stratified sedimentary and volcanic rocks and hypabyssal sills. Basically the southern block rests upon the northern with the gently southward-dipping upper Payson Granite surface as the boundary over most of the region. The widespread felsic hypabyssal sills invaded along the interface between Payson Granite and the stratified rocks and intruded subconformably into the strata of the upper block.

Impressed upon this fundamental structure are systems of generally NE-SW-trending faults and shallow folds which traverse the entire study area affecting all major geologic units. The plutonic block seems to have had a buttressing effect during the early folding stage of the deformational episode.

Thrust and reverse faulting succeeded and perhaps partially accompanied folding, apparently as a late manifestation of the regional NW-SE compressional event in which folding occurred. Thrust and reverse faults are truncated by NE-SW to N-S trending faults having both left-lateral strike-slip and normal (east side down) displacement. These faults reflect a change from a regional compressional tectonic regime to one of lateral translation, perhaps under a counter-clockwise NE-SW couple. Finally, perhaps NE-SW to E-W tension prevailed during which normal faulting occurred.

Tonto Basin was apparently a site of foreland folding and thrusting as the southeastward geosynclinal crustal block moved northwestward toward the high-standing proto-cratonic block composed of deformed rocks of the slightly older orogenic cycle. This tectonic regime gave way to one in which the geosynclinal block was apparently translated northeast relative to the proto-cratonic mass. In terms of plate tectonics theory, the proto-cratonic and geosynclinal blocks may have been crustal plates having a SW-NE trending boundary. The tectonic sequence in Tonto Basin may have been analogous to certain more modern plate interactions in which plate collisions resulted initially in the formation of magmatic arcs (above subduction zones) and foreland folds and thrust faults then, with a change in plate motion, gave rise to strike-slip or transform faults parallel to and near the plate boundary.

The overall deformational fabric in Tonto Basin is similar to that found regionally in Precambrian rocks of both provinces and there are direct correlations with certain structures in the Mazatzal Mountains.

Cooling surface orientations in Hell's Gate Rhyolite, as inferred from columnar joint attitudes, suggest that the rhyolite intruded after some folding of the Tonto Basin syncline. It is suggested that this was a proto-Tonto Basin syncline formed during intrusion of the Payson Granite.

Structural arguments support the hypothesis advanced from contact data at Gisela that Payson Granite intruded Haigler rhyolite. The southward-dipping upper Payson Granite surface along which the hypabyssal sills intruded would have been the roof of the pluton and not an erosional surface or a thrust fault plane.

This is the first report of a field relationship between units (Payson Granite and Haigler rhyolite, respectively) of the northern, older and southern, younger regional geochronologic provinces and implies an overlap in magmatism. Payson Granite would be co-magmatic with Haigler rhyolite and the hypabyssal sills and together these plutonic and volcanic silicic alkali rocks might be an anorogenic suite along the two-province boundary.

Both Payson Granite and the felsic sills were emplaced at shallow depths and may have vented to form volcanoes. The enormous volume and thickness of the sills and intrusion of some into the highest unit in the stratigraphy (Christopher Mountain Quartzite) is particularly strong evidence that Tonto Basin was the locus of a volcanic construct since totally removed by erosion.

Tonto Basin may also have been near the center of the great volcanic field extensively preserved as Haigler Group rhyolite. It seems to have been topographically high and there is permissive evidence for the existence of a caldera. Minor unconformities above Haigler rhyolite and in the Alder Group are probably effects of magmatic activity on the local environment of deposition rather than effects of regional deformation.

DEFORMATIONAL STRUCTURES

Folds

On a regional scale the entire map area is an asymmetrical synclinorium with the Tonto Basin syncline as the major synclinal element. The Alder Group strata are exposed in the southeastern limb of the synclinorium but do not appear in the opposing limb. Instead, plutonic rocks appear in approximately the same structural position with the upper Payson Granite surface as a planar element in the northeastern limb of the Tonto Basin syncline. Christopher Mountain Quartzite, the highest unit in the stratigraphy, occurs only in the central Tonto Basin and Big Ridge synclines.

The fold structures of Tonto Basin are dominated by a great fault-bounded segment of the Tonto Basin syncline, which occupies a large central portion of the area. It appears that two major anticlines and two major synclines lie to the southeast; all are more tightly folded than the Tonto Basin syncline. The Tonto Basin syncline and apparently the adjoining anticline truncated by the Lost Camp fault plunge southwestward at about 10-20°. The other folds, which lie across the Lost Camp fault, plunge gently northeastward. All fold axial planes are nearly vertical and trend NE-SW with the exception that northward the Big Ridge syncline swings to trend NW-SE where it is overturned to the northeast. Amplitudes of the major folds are probably more than a km or two and that of the Tonto Basin syncline may be 4-5 km.

Major Folds

The Tonto Basin syncline is a large broad open fold unique from the other major folds because it is constituted of concordant hypabyssal sheets and the upper Payson Granite surface in addition to sedimentary and volcanic strata. The granite surface and by far most of the intrusive sheets occur in the northwestern limb. Exposed over a large central portion of the area the syncline is actually a fault-bounded segment of a much more extensive structure. The fold is truncated on the west at a low angle to the axis by the Green Valley Creek fault and on the east by the northern portion of the Lost Camp fault.

The syncline is a relatively simple, open fold (Plate 11A) although there is some smaller-scale local internal folding generally near the axis (see cross-section E-E'). The syncline plunges southwestward at perhaps 10-15° but may reverse its plunge at the south end of McDonald Mountain in the southwestern part of the structural block. A small offset portion of the Tonto Basin syncline is probably represented by the upper Payson Granite surface, by alaskite, granophyre, and rhyolite sills, and by Haigler rhyolite in the Gisela Mountain area.

In the Lost Camp Mountain and Bull Mountain areas the strata in the southeastern limb of the Tonto Basin syncline may also belong to the northeastern limb of an anticline the axis of which is sub-parallel to and perhaps truncated by the Lost Camp fault. This is inferred more because of the great width of steeply-dipping Board Cabin strata in the belt just northeast of Diamond Butte than because of observed structures. Board Cabin Formation would have to be more than 1200 m thick if there is no duplication by folding and its greatest measured thickness elsewhere is only 600 m. A tiny mass of gray quartzite at Bull Mountain (L-15) may be Houden quartzite at the base of the Board Cabin Formation in the core (possibly boudinaged) of this very tight fold. The abrupt northeastward termination at this point of the Board Cabin belt appears to be due primarily to faulting transcurrent to the fold axis which has dropped down on the northeast a higher part of the anticline where rhyolite occupies the hinge of the fold.

East and south of the Lost Camp fault the same folding style predominates but with some modification. Several large folds also trend NE-SW but their axes plunge gently northeastward. The major fold is the Big Ridge syncline which trends NE in the Lost Camp Canyon and Big Ridge areas but swings around to the north then northwest roughly paralleling the pronounced bend in the Lost Camp fault. In swinging northwestward the axial plane of the syncline becomes overturned to the northeast and the axis plunges more steeply as the structure swings almost westward and is truncated by the Bear Flat fault in the vicinity of Christopher Mountain. Though the fold axis swings northward apparently beneath Horse Mountain, the southeastern limb continues to trend northeastward. At about the position where the fold swings and becomes overturned the southeastern limb is intruded by rhyolite of Hog Canyon.

Paralleling the southern part of the Big Ridge syncline and lying to the southeast of it are an anticline and another syncline. These are much less clearly defined than the Big Ridge syncline, but nevertheless, from the mapping of Gastil, appear to be present.

The three large folds southeast of the Lost Camp fault are tighter than the Tonto Basin syncline but are similar in trend and have shallow fold axes. Axial foliation is more intensely developed than in the Tonto Basin syncline and there is much more small-scale internal folding. Just southwest of Colcord Mesa (O-16) axes of many of these folds plunge 20°-30° to the northeast. In the vicinity of Diamond Butte, however, both folding and foliation are mild and the strata are very well-preserved and exposed. This is essentially the area shown in Gastil's Plate 1.

Minor Steep Folds

Steeply plunging folds were found only in the less competent sedimentary rocks in the deeper part of the section in Spring Creek and just west of Houden Mountain. They were found to be relatively small features (amplitudes less than 100 m) with their axes parallel to a set of lineations and stretched pebbles, all of which generally plunge steeply to the northeast. Gastil (1954, p. 68) found both steep and shallow folds in Tonto Basin and thought that with increasing tightness folds plunged at steeper angles. He also noted that the more open folds are the larger folds.

It appears to the writer that the major folds, including some internal sub-folds, vary greatly in degree of tightness but all seem to retain shallow plunge. It is possible that fold plunge is correlated not so much with fold tightness as with fold size. There seem to be two distinct fold sets with the minor steeply-plunging folds occurring in the limbs of the large shallow folds.

It is difficult to understand how the two fold sets can be contemporaneous. If they are contemporaneous the small folds may have somehow developed in response to an effective decoupling of the Alder Group strata from the more competent overlying rhyolite and quartzite and/or to the buttressing effect of the northern plutonic block so that the deeper, less competent strata were more complexly and intensely deformed. This seems incompatible, however, with the apparent continuity of the major folding style going down-section into the southeast limb of the synclinorium, and with the occurrence of the steep structures (fold axes and lineations) in rocks which are also folded on the large shallow axes.

It seems more reasonable that the minor folds, which may be termed incongruous drag folds (Badgely, 1965, p. 307), developed under a different, later stress field than did the large shallow folds. They may have developed following folding and thrusting and concomitantly with NE-SW strike-slip faults of Stages II and/or III. An observed steep right-lateral fold of a thin quartzite bed in the Breadpan Canyon Formation is compatible under this hypothesis with Stage III right-lateral faulting.

Faults

Three categories of faults in Tonto Basin (Figure 7) reflect three general stages in the Precambrian faulting history. Early southeastward-dipping thrust and reverse faults are classed together as Stage I faults. High-angle reverse faults apparently truncate fold axes in the Tonto

Basin syncline and the Oxbow Mountain anticline.

Stage II faults are very steep to vertical and have both left-lateral and normal (east side down) components of displacement and are subdivided into apparently earlier NE-SW faults (Subset I) with greater left-lateral offset and later arcuate NE-SW to N-S faults (Subset II) with greater vertical offset. They truncate Stage I faults and major fold axes. The single Stage III fault is steep, trends NE-SW, and has apparent right-lateral offset. It truncates a Stage II Subset II fault.

Thrust and Reverse Faults - Stage I

The main thrust fault is the Agate Mountain fault which dips southeastward at about 15°-20° and offsets the Payson Granite-Gibson Complex contact an apparent distance of about three miles. Actual offset cannot be determined because there is no direct evidence for the direction of thrusting. From geometrical analysis (Figure 8), using 30° and 15° dips for the upper granite surface and the fault, respectively, minimum offset is just less than 3 miles (thrusting to the SW along $A-A_1$). If thrusting was to the west ($A-A_2$) there is about 4 miles of displacement, and if motion was WNW ($A-A_3$, perpendicular to the trace of the fault) the throw is 7 miles. Distances are less if the upper granite contact is shallower, if its overall trace is arcuate southward, or if the fault is steeper. Because folds, thrust faults and reverse faults in the area all trend NE to N the most likely direction of thrusting is NW to W, in which case there may have been, considering uncertainties in attitudes, 4-10 miles of displacement on the Agate Mountain fault.

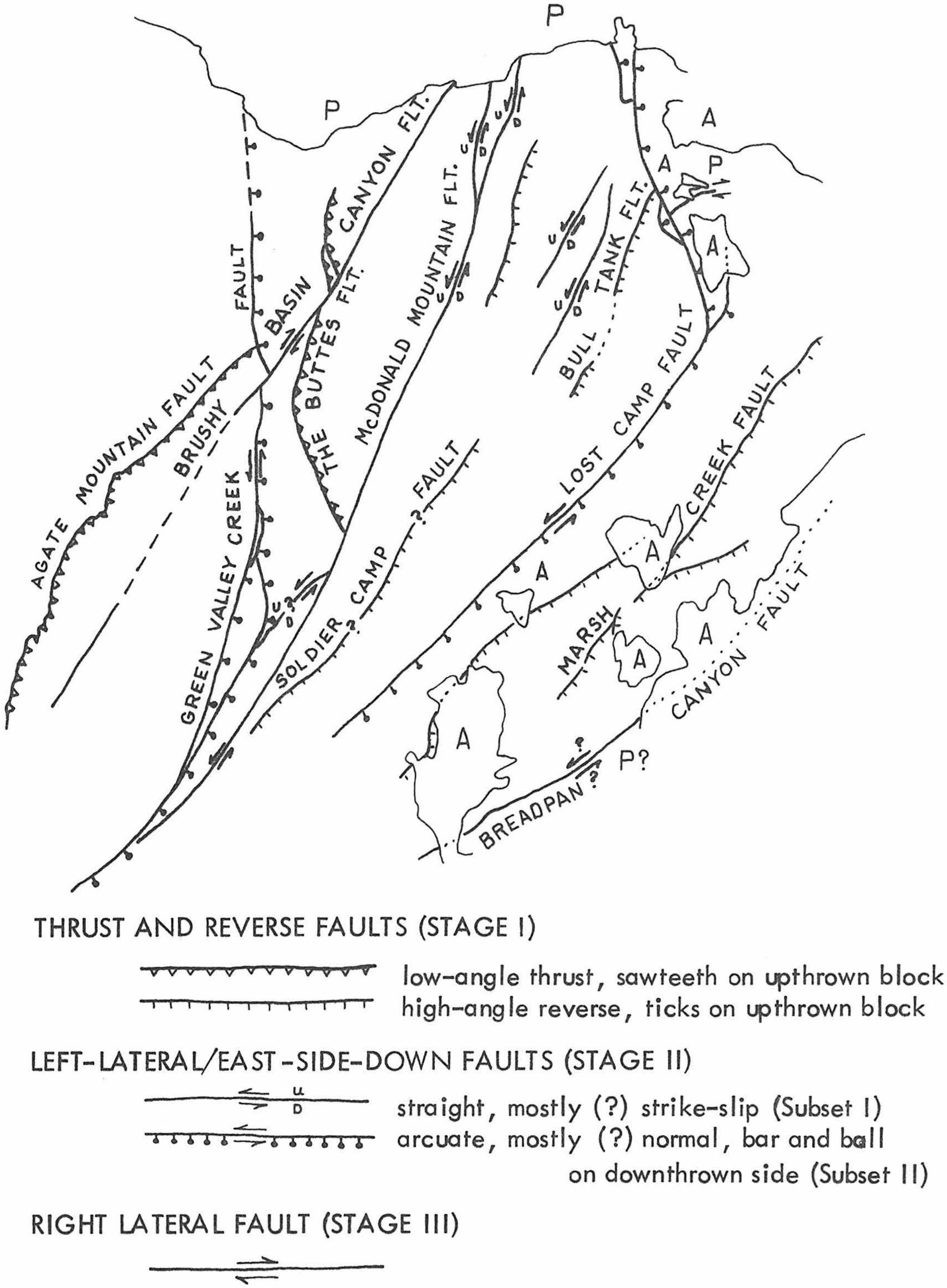


Figure 7. Major Precambrian faults in Tonto Basin.

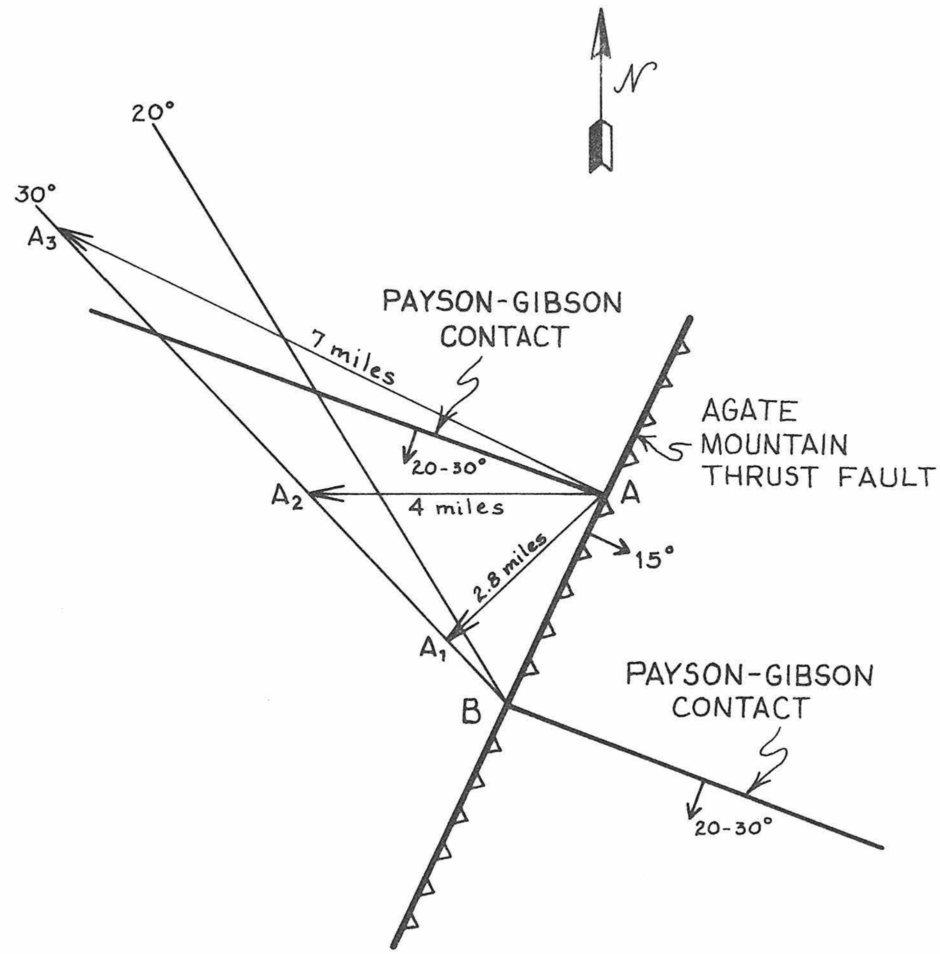


Figure 8. Idealized map showing apparent offset of Payson Granite-Gibson Complex contact on the Agate Mountain thrust fault and the relationship between actual amount of displacement and direction of motion. The lines labeled 20-B and 30-B are the lines of intersection (determined by stereonet plot) of the fault plane (dipping 15° at S 65° E) and the contact in the upper thrust plate (dipping 20° or 30° at S 20° W) projected onto the horizontal plane. Any vector $A\text{-}A_i$ to the line 30-B is the path of motion on the fault plane, projected onto the horizontal plane, of the 30° contact being offset in the direction of the vector from A to A_i. The length of the vector gives the approximate distance of offset (actual distance is slightly greater on the unprojected fault plane). The family of vectors $A\text{-}A_i$ gives distances of offset for all possible directions of thrusting. See text for evaluation of most likely thrust direction.

The northeastward extension of the Agate Mountain fault is probably offset northward along the Green Valley Creek fault and now is covered by the Paleozoic sedimentary rocks of Diamond Rim. The trace of the fault is profoundly marked by extensive brecciation, silicification and alteration of host rock, particularly Payson Granite. Agate Mountain (K-7), from which the name is taken, is a hill on the trace of the fault which is almost entirely underlain on its southeast cap and slope by spectacular agate which formed during multiple stages of fracture and silicification during the active history of the fault. The evidence for recurrent movement is quite clear from the repetitively disrupted and rehealed character of the agate layers. Specular hematite is quite abundant in the agate and hematitization of the granite for tens of meters into the granite all along the fault zone is prevalent

The Buttes fault is similar to the Agate Mountain fault. It is a low-angle thrust fault dipping eastward at perhaps 30° in the Green Valley Hills. It has no more than a few hundred meters of cumulative offset. Minor silicification occurs in the several breaks of the fault.

Disposition of the thrust faults precludes a determination of their relationship to major shallow folds.

High-angle reverse faults mapped both in the Tonto Basin syncline by the author and in the Diamond Butte-Haigler Creek area by Gastil are interpreted to be of the same generation as the two low-angle thrust faults simply because of the common implication for NW-SE compression. Apparent offsets and/or fault traces across topography indicate that these faults dip southeastward at moderate to steep angles and are up to the southeast. Interesting members of this steeply dipping system are the Bull Tank fault and the Soldier Camp fault near the axis of the Tonto Basin syncline.* Complex low to moderate angle faulting in the immediate vicinity of Hell's Gate, which was incompletely mapped, may relate to and connect these two faults. This fault system may represent renewed movement along a very early and cryptic disruption along which Hell's Gate Rhyolite, to the south, and alaskite and possibly granophyre, to the north, rose higher into this limb of the syncline. The western alaskite at Cherry Spring is probably cut by the Bull Tank fault and it is inferred that Hell's Gate Rhyolite is cut by the southern fault (see cross-sections). However, it is possible that Hell's Gate Rhyolite intruded an older fault there with no subsequent motion on that fault.

A small anticline in the southeastern limb of the Tonto Basin syncline at McDonald Mountain (O-11) is truncated by the Soldier Camp fault. The Oxbow Mountain anticline is transected at a low angle by the Marsh Creek fault (K,L-19).

Left-Lateral/East-Side-Down Faults - Stage II

Most and perhaps all faults of a second major group are younger than those of the thrust/reverse fault set and have both left-lateral strike-slip and east-side-down vertical components of offset. These faults are vertical or very steep and frequently have wide (1-20 m)

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*The existence of the Soldier Camp fault is inferred throughout most of its length but it must be present at the south end of McDonald Mountain.

brecciation and silicification zones. Massive white quartz veins in these faults often weather in sharp positive relief and are particularly prominent on segments of the McDonald Mountain (I-13) and Lost Camp (H-19) faults. Brecciation and mineralization are not so prevalent in faults of this system as in the low-angle thrust faults.

Some Stage II faults are splayed from a roughly common focus just south of Gisela Mountain.

There is a possible subdivision of these faults on the basis of sequence and partially of geometry. An early subset (Subset I) may consist of faults that are more or less straight and trend northeast. None are positively shown to offset a thrust or reverse fault although such might be demonstrated at the intersection of The Buttes fault (thrust) and the McDonald Mountain fault (Subset I). The major fault of this subset is the McDonald Mountain fault which has about two miles of apparent left-lateral offset (offset of the Green Valley Granophyre sill) but which must have a considerable component of vertical offset because many lithology patterns and contacts intersected by the fault do not have matching equivalents across the fault.

Subset II faults are very distinct faults which trend NE-SW at their south ends but turn and trend N-S to NNW-SSE at their northern ends. These are the Green Valley Creek and Lost Camp faults. The latter is a complex fault with a branching and a sharp deflection point just south of Horse Mountain (H-17), the nature of which is not clearly understood.

These two faults unquestionably offset Stage I faults and possibly two faults of Subset I. The Agate Mountain thrust fault is offset by the Green Valley Creek fault and the Bull Tank reverse fault by the Lost Camp fault. The Lost Camp fault cuts a small fault of Subset I in upper Bull Tank Canyon (F-18), and it is possible that the Picket Pen fault branch of the Green Valley Creek fault system cuts the small fault branching southwestward from the McDonald Mountain fault just north of McDonald Mountain (O-10).

The Green Valley Creek fault has the greatest apparent offset of all the steep Precambrian faults. The Green Valley Granophyre sill has been apparently left-laterally offset about 6 miles by the fault. It is clear, however, from the greatly contrasting thicknesses and lithology changes of both Hell's Gate Rhyolite and Green Valley Granophyre across the fault that there may have been a fairly large component of vertical motion. Assuming an average 25° dip of the upper Payson Granite surface the maximum vertical component (no strike-slip component) of offset would be almost three miles. This is probably an unreasonably large dip-slip displacement and there certainly must have been a considerable amount of strike-slip motion on this fault.

The Lost Camp Fault is a major fault which is the common boundary for two structural blocks containing large folds of opposite plunge. Because of opposite trends of the folds in the two blocks and because of the lack of distinct elements to correlate across the fault it is difficult to estimate the offset. An apparent four-mile right-lateral offset of the Haigler rhyolite-Board Cabin Formation contact from northwest of Houden Mountain to just north of Diamond Butte cannot be taken to indicate actual right-lateral offset. Rather the offset is compatible with much vertical displacement down to the southeast thus exposing higher units in the southern block and displacing contacts southwestward. Offset is apparently greatest in the Christopher Mountain area where the widely exposed Christopher Mountain Quartzite, the uppermost unit in the area, is juxtaposed with Payson Granite which is at the base of the structural sequence in its position in the Tonto Basin syncline. If present in the eastern block Payson Granite is at least three miles deep beneath Christopher Mountain (see section F-F').

Great vertical separations (at Christopher Mountain and elsewhere) need not all be attributed simply to amount of displacement on the fault. Some of the anticline which apparently existed between the Big Ridge and Tonto Basin synclines has been cut out by the faulting. This is clearly seen just north and northeast of Diamond Butte where the Lost Camp fault occurs in the southeast limb but near the crest of the probable anticline of Bull Mountain and in the northwest limb but near the trough of the Big Ridge syncline. The common limb of these two folds is cut out because the fault transected the fold structures at a very small angle. If all the structure were present the stratigraphic throw would not be so great. Nevertheless, there was a great deal of vertical motion on the Lost Camp fault and there is no evidence for lateral translation.

It is significant that both the Green Valley Creek and Lost Camp faults have associated irregular or smooth and arcuate satellite faults which define fault slices. No other faults in the area have such features. Attention is particularly drawn to the granophyre fault sliver on the Green Valley Creek fault and the northern rhyolite slice on the Lost Camp fault. The bounding satellite fault of each slice is somewhat irregular and intersects the main fault at a rather high angle. This configuration may be evidence of primarily vertical motion on these faults. In the vertical dimension these bounding faults would presumably intersect the main fault at very small angles.

The two faults of Subset II in their northern parts offset the thrust/reverse faults at rather high angles, but they do not appear to be contemporaneous tear faults. They swing southward into near parallelism with the reverse faults and Subset I faults and are there downdropped to the southeast. This orientation and sense of motion seems to preclude a tear fault relationship.

Right Lateral Fault - Stage III

The near vertical Green Valley Creek fault of Subset II is offset about 400 meters in a right-lateral sense along the Brushy Basin Canyon fault which also is near vertical. This amount of offset is very puzzling because elsewhere shallow contacts or faults, though having a similar sense of displacement along the Brushy Basin Canyon fault, are offset much smaller distances.

It appears that this single fault is unique in its sense of displacement and perhaps represents the latest episode of Precambrian faulting in the area. It is speculated on the basis of trends and suggestive lineations on aerial photographs that this fault connects with the minor highly silicified fault at Gisela. The latter appears to have only a very small component of east side down motion.

Breadpan Canyon Fault

The Breadpan Canyon fault, mapped by Gastil, is a major fault in the Tonto Basin area, but the author is unable at present to assign it to one of the above stages. It exposes to the south strata (pre(?)-Breadpan Formation) which Gastil suggested might be the oldest exposed rocks in his map area. The appearance south across the fault of rocks possibly lower in the section may be explained by vertical motion with the southeast side up or by left-lateral strike-slip motion, for in the opposing block strata dip roughly northeastward and successively lower beds are exposed to the southwest. This fault is probably related to the Stage II faults but could be a Stage I reverse fault.

Relation of Faults to Folds

No evidence was found that any fault had been folded. It is certain that most, if not all, faulting followed the folding on the shallow axes. However, the intriguing sub-parallel relationship between the Big Ridge syncline axis and the Lost Camp fault, wherein they turn northward nearly together, suggests the possibility that they may have been folded together. If the Lost Camp fault was folded the possibility also arises, particularly in consideration of the irregular geometry of the accompanying fault slices, that it was originally a low-angle thrust fault. If warped and tilted in the same manner as was the axial plane of the syncline, the now near-vertical fault would originally have dipped southeastward or southward at perhaps 45° or less.

This hypothesis does not seem reasonable because only structures in the Christopher Mountain block are deformed in the manner described. If the fault were so folded, so also should be the nearby structures of the Tonto Basin syncline in the western block; they are not.

A better explanation for the relationship may be that the Big Ridge syncline axis was deformed during Stage II faulting under the hypothesized (page 223) NE-SW counter-clockwise couple. The arcuate portion of the syncline axis now exposed may be one half of a great dextral fold the opposite portion of which was cut out by east-side-down normal faulting on the Lost Camp fault (Figure 9). This folding and much left-lateral strike-slip faulting would have occurred in early Stage II time, followed by large-scale normal faulting, particularly on N-S faults, late in Stage II history.

Earlier it was suggested (page 208) that minor steep folds of sinstral orientation might be related to Stage III right-lateral faulting.

Nature of Deformation

The structural data obtained in this study fall short of that necessary to fully understand the structural characteristics of the area. It appears, however, that the deformation occurred at relatively shallow depths and that the intensity of deformation was a function of rock type and nearness to the massive plutonic rocks in the north.

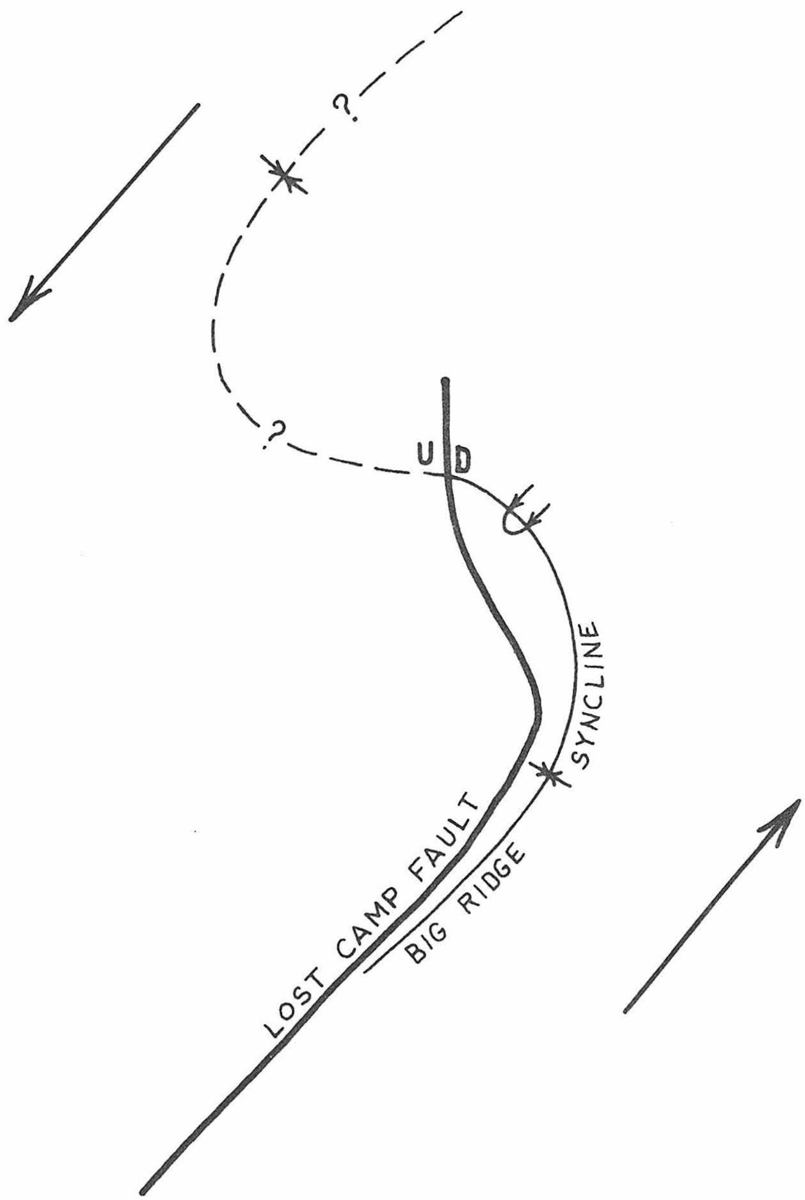

Figure 9. Relationship between the Lost Camp fault and the Big Ridge syncline. The folded syncline axis may define part of a great dextral drag fold which developed in response to a regional NE-SW couple. The symmetrical counterpart is missing because of large vertical offset on the Lost Camp fault.

Penetrative deformational structures (tectonic foliation and lineation) are prevalent only in the sedimentary units in the southern part of the area; they are locally very pronounced. Foliations are much more intense in the immediate vicinity of faults and in areas of tightest folding. In areas of little folding, such as near Board Cabin Draw, internal deformation is practically absent and the original structures are very well preserved. Northward into the areas underlain mostly by massive rocks - quartzite, rhyolite, granite - tectonic foliation is generally restricted to narrow zones along faults. Here folds are open and rupture was brittle. Faults of all stages are characterized by brecciation and filling of pore spaces by silica and, infrequently, hematite.

Deformational response is clearly related to rock type, that is quartzite and massive silicic volcanic rock are always much better preserved than slate, wacke or mafic volcanic rock in the same vicinity. On a much larger scale, however, metamorphic fabric is also a function of distance from the Payson Granite and the Gibson Complex. Rhyolite within a few miles of the Payson Granite is exceedingly well preserved and free of foliation zones which locally develop only east of the axis of the Tonto Basin syncline, or south of the Green Valley Creek fault in the Gisela Mountain area, or east of the Lost Camp fault. Rocks of all types near the plutonic bodies appear more or less sheltered from internal deformation. South of the Breadpan fault a general marked increase in penetrative deformation may simply be due to the increase in the proportion of less competent rocks. Alternatively, or in conjunction, this might mark the approximate southern limit of the buttressing and sheltering effect of the Payson Granite. Would this imply that the granite terminates at depth somewhere in this vicinity?

Southward increase in deformation intensity cannot be taken to indicate greater depth of deformation. Rather the opposite might be true because the major structural blocks are dropped successively downward from northwest to southeast. On the other hand, the possibility is not denied that some deformation might have occurred at greater depths in these stratigraphically lower rocks prior to the development of the great shallowly-plunging folds. Brittle fracture characteristics of the northern faulting and paucity or absence of mylonite zones associated with any of the faults in the area are indicative of relatively shallow deformation. This is particularly evidenced by the sustaining of large pore spaces in the fault zones into which silica was precipitated.

Age of Deformation

From the work done in this study the age of deformation can only be said to predate the pre-Apache Group erosional episode. The minimum age of the Apache Group is 1125 ± 25 m.y. (L. T. Silver, pers. comm.)

Gastil found in the eastern Diamond Butte quadrangle that the Young granite is intrusive into Alder Group rocks. Silver (pers. comm.) obtained an age of 1650 ± 15 m.y. for the Young granite. It is assumed, though not yet demonstrated from field relations, that the Young granite is post-tectonic and thus the folding and faulting in Tonto Basin would have occurred prior to 1650 ± 15 m.y. ago and after 1715 ± 15 m.y. ago, the latter being the age of the Flying W rhyolite and of the Haigler Group. Silver (1968, and pers. comm.) has found that many plutons in southern Arizona are about 1650 m.y. old and appear to be post-tectonic. A post-deformational relation was clearly shown for the Johnny Lyon granodiorite (1655 ± 20 m.y.) in the Johnny Lyon Hills, Cochise County (Silver, 1955; Silver and Deutsch, 1963). The possibility remains, nevertheless, that while some deformation may have preceded the intrusion of the Young granite, some, perhaps late-stage faulting, may have been later.

Interpretation and Implication of Deformational Structures

The fold-fault sequencing suggests a period of regional compression with a general NW-SE principal axis of stress,* followed by a period of relaxation. It does not appear, however, to be a simple change from compression to tension along the same lines of force.

The pattern and sense of motion on the Stage II faults suggests a change or rotation of tectonic stresses at an indeterminate time following the compressional episode. A N-S to NE-SW counter-clockwise couple developed in which there was a strike-slip motion along NE-SW lines (Subset I faults) and tensional faulting along N-S lines (Subset II faults).

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*Stage I low-angle faults may be more E-W in compressional direction.

This model has support in experiment. Mead (1920) found that in deformation under a couple vertical tensional fractures developed at about 45° to the stress direction, followed by shear fractures developed parallel to stress direction (Figure 10). The N-S portions of Subset II faults would be the 45° tensional faults and the NE-SW Subset I faults and portions of Subset II faults would be the shear fractures parallel to stress direction. Subset II faults would be complex faults having characteristics of both tensional and shear faults, probably having arisen by intersection of the two types.*

According to the suggestion of sequence presented earlier the left-lateral strike-slip motion would have been initiated first followed by vertical east-side-down motion. However, if there was a finite time in which the regional tectonic stress rotated continuously from NW-SE to NE-SW, the earliest strike-slip motion may have been on the N-S Stage II faults when compression was N-S. With continued rotation of the stress field NE-SW strike-slip motion may have prevailed and steep drag folds may have formed. With increased tension vertical faulting then predominated on the earlier N-S fault lines. Thus continuity of N-S to NE-SW arcuate faults on which left-lateral motion occurred might be due to the rotation of the stress field. Alternatively, it might be the result of displacement of fault blocks northeastward along the southern margin of

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*There is no reason, of course, why all the tensional faults should be down to the east or that Subset II faults should always be concave north to the northwest, as is the case in Tonto Basin. One might expect grabens and west-side-down faults along the N-S tensional lines as well as compound arcuate faults with radii of curvature to the southeast.

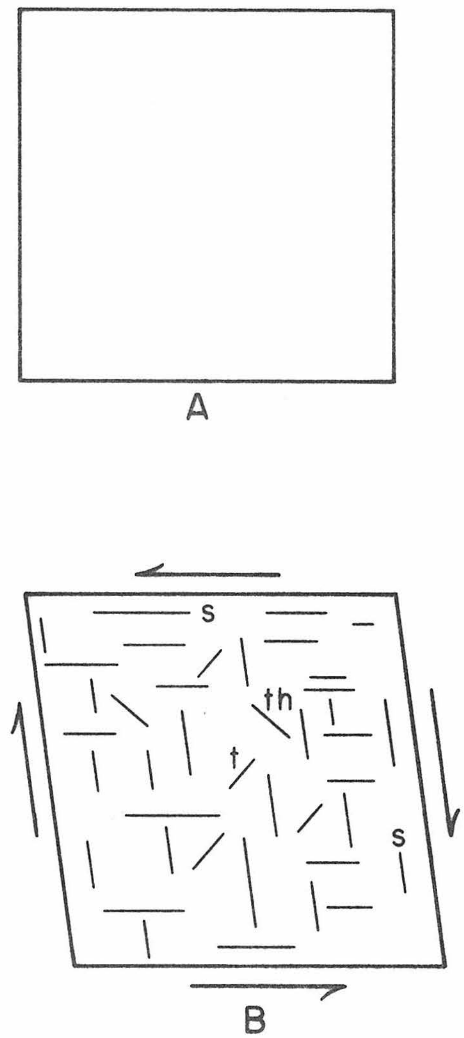

Figure 10. Ruptures due to a couple (after Mead, 1920). *A*. Square frame that is covered by a sheet of rubber, on which is a layer of paraffin. *B*. Fractures that develop because of a couple: *t* = tension fractures (perpendicular to plane of paper); *s* = shear fractures (perpendicular to plane of paper); *th* = thrust faults (inclined to plane of paper).

the plutonic block and then northward into a pressure shadow (?) of the rigid plutonic mass.

Vertical motion was not restricted to N-S lines and it may be that the vertical motion was continuous in rigid blocks around intersections of N-S and NE-SW faults (e.g., the Lost Camp fault) so that vertical motion was added to the strike-slip component of the NE-SW faults. Alternatively, the vertical motion on the NE-SW faults may have been late and consequent to a further change in tectonic stress in which NW-SE tension was attained. There is no evidence, however, that the vertical motion on these faults occurred later than the vertical motion on the N-S faults.

The present structural picture and interpretation is exciting in indicating that there may have been a shift from regional compression to regional left-lateral motion in the major orogenic episode of which the effects in Tonto Basin are a local, but possibly representative, manifestation.

Such a tectonic history in Tonto Basin may have analogy in better understood younger systems. For example, it is hypothesized that the right-lateral San Andreas system developed on the western margin of the North American continent following a long period of compressional tectonics in which oceanic crust (hypothetical Farallon Plate) was impinging from the west and being subducted beneath the continental crust (Atwater, 1970). In this case the change in tectonic regime presumably occurred when (about 30 m.y. ago) the spreading center bounding the Farallon plate to the west reached the continental

(American) plate. There are other examples. The association of strike-slip faults (or transform faults) with parallel or sub-parallel fold belts and magmatic arcs is now widely recognized (e.g., Alpine fault of New Zealand, Atacama fault of Chile, Philippine fault). Silver and Anderson (1974) now raise the possibility that a major left-lateral strike-slip disruption occurred in southwestern North America in mid-Triassic to Mid-Jurassic time which would have had coincidence with mid-Mesozoic magmatic arcs.

In each of the above instances the major fault zones are temporally and spatially associated with magmatic arcs and fold belts and closely parallel the same. In modern plate tectonics theory the folding, thrusting and magmatism would have occurred in consequence to collision of two crustal plates and the subduction of one beneath the other. Presumably in most instances this activity was culminated by a change of relative plate motion which also initiated strike-slip or transform faulting approximately parallel to and near the plate boundaries.

Whether plate tectonics, as now being discussed in these more modern systems, was operative in the Precambrian of the southwest is an intriguing and unanswered question. Numerous field studies in the Precambrian of the southwest, notably those of Wilson (1939) in central Arizona, of Silver (1955) and Cooper and Silver (1964) in southeastern Arizona, of Anderson (1951, 1972), Anderson and colleagues (1958, 1971, 1972, 1974), Blacet _et al._, (1971), and Kreiger (1965) in Yavapai County, of Gastil (1958) in Gila County, and of Ludwig (1973) in the

Mazatzal Mountains, have demonstrated the classical elements of the orogenic cycle, thick eugeosynclinal accumulations, folding and uplift and invasion by batholithic rocks. Geochronologic studies (Silver, 1964, 1966, 1967, 1968; Silver and Deutsch, 1963) have more recently shown that these elements are distributed in great belts, the products of at least two closely-timed events. The structure of the Tonto Basin terrain, underlain by rocks of the younger belt but close to the boundary of the two belts, provides insight into the tectonic history of the second of the two orogenic pulses.

It is important in the current study that volcanism is demonstrated to have been succeeded by folding, then thrusting, and finally by strike-slip and normal faulting. The volcanic rocks are possibly part of a magmatic arc which developed approximately along a craton* margin, the craton being comprised of the products to the northwest of the prior orogenic event. Following volcanism there was thrusting onto or toward the craton. Lastly, the geosynclinal block to the southeast may have moved laterally northeastward relative to the cratonic block. Further evidence for this final event must be sought; it is hypothetical at this point. Would the motion have been evenly distributed in a broad belt along Stage II-type faults, or would there have been a major shear, perhaps to the south of Tonto Basin?

The implied occurrence of the major left-lateral event, in connection with the structural data clarifying the developmental stages of

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*The word craton is used here with the understanding that this new highland was not yet completely stabilized and constituted a protocratonic mass.

classical orogenic cycle (presumably culminated by a plutonic event represented in the Tonto Basin area by the Young Granite) suggests great differential crustal movements which may be analogous to those more recent events being explained in terms of plate tectonics.

Alternative mechanisms for causing such large-scale regional deformation are plausible but considered less tenable. For example, intrusion of the great mass of Ruin granite (1450 m.y., L. T. Silver, pers. comm.) in the southern Mazatzal Mountains and Salt River area, northern parts of which are only 10-15 miles south of Gisela, may have caused the Tonto Basin southern structural blocks to be shoved northeastward. Stage II faults would have formed at this time - much later than the folding and thrusting event.

Relation to Regional Structures

Mazatzal Mountains

A stratigraphic correlation was made between Precambrian stratified rocks in Tonto Basin and in the Mazatzal Mountains (page 29). It appears there is a good correlation between general, and perhaps some specific, structural features as well.

Faults and folds in the Mazatzal Mountains are basically NE-SW (Wilson, 1939, Plates 10 and 11; Ludwig, 1973). The Red Rock syncline is the major fold of the central Mazatzal Mountains (Ludwig, 1973) and is of appropriate stratigraphic composition, size, and trend to be correlative with the Tonto Basin syncline. Haigler Group rhyolite occupies the core of the syncline in both areas and upper Alder Group rocks are apparently mutually continuous, or transitional, (page 29) in the southeastern limbs.

A major contribution of Wilson was the identification of thrust faulting in the northern Mazatzal Mountains. He interpreted associated low angle to steep reverse faults as branching up from the sole of the major Mazatzal thrust (Wilson, 1939, p. 1132). These reverse faults have the same sense of offset and NE-SW trend as those in Tonto Basin; both the Mazatzal thrust and the thrusts in Tonto Basin dip eastward to southeastward.

Thrust faults in the northern Mazatzal Mountains are offset both by NE-SW normal faults and by a NW-SE 'tear fault'. The so-called tear fault (Wilson, 1939, p. 1132) cannot be a true tear fault genetically related to thrusting because it is continuous northwestward into the underlying plate. Lineations on Skylab photos examined by the author indicate that this fault (in South Fork, a tributary to Deadman Creek) is continuous with a lineation that runs northeastward and flanks the Verde River valley on the southwest. It is probably a member of the prominent NW-SE Tertiary fault system.

Normal faulting occurs primarily as several breaks along a Deadman Creek/City Creek lineament. In the northernmost part of Wilson's Plate 10 these faults are shown to offset thrust faults and to form a graben. Wilson shows faults only in the northern part of the Deadman Creek drainage but on Skylab photos the drainage is a pronounced, regular arcuate feature extending southwestward to the Verde River. Its course is no doubt structurally controlled and probably follows a large arcuate fault which trends NE-SW at its southern extension and to the north trends more northerly and may run due north across the East Verde River and up Pine Creek.

Some characteristics of the hypothetical Deadman Creek fault correlate with Stage II Subset II faults of Tonto Basin. Common qualities are: 1) offsetting of thrust faults, 2) concave northwestward arcuity, and 3) origin at least partially due to E-W tension (east-side down-faults in Tonto Basin; graben in Mazatzal Mountains). A field objective should be to determine whether there is left-lateral offset on the southwestern part of the Deadman Creek fault.

Direct determination of Precambrian age for the structures in the northern Mazatzal Mountains has not been made, but a Precambrian age is probable in view of correlations of trends, patterns and sequence with those in Tonto Basin. There can be little question that the structural features of the Precambrian rocks in both areas are continuous and that they manifest the same sequence of regional tectonic evolution. The intervening Rye Creek valley reflects Tertiary faulting and erosion, but the several hundred meters of vertical offset has little or no noticeable effect on the continuity of Precambrian structure.

An important question is whether the large expanse of granite bounded on the east by the Deadman Creek fault is only in fault contact with Haigler Group rhyolite and Mazatzal Group rocks or whether an unconformable or intrusive relationship is somewhere exposed. This is a potential area for determination of a granite-rhyolite relationship which might correlate with the Tonto Basin pre-hypabyssal rocks Payson Granite-Haigler rhyolite relationship.

General

The overall NE-SW structural grain in Tonto Basin is consistent with that generally found throughout the Precambrian of Arizona (Wilson, 1962, p. 12) both in the northern, older province and the younger, southern province. Folds and faults in the Precambrian of Arizona generally trend NE-SW as does the boundary between the two age-provinces. These are salient features observed on the Geologic Map of Arizona (Wilson and others, 1969) in the central mountainous belt and in the Grand Canyon. These trends are practically indiscernible in terms of physiographic expression in the Basin and Range area of Arizona, though locally in evidence. Nevertheless, where completely obscured from ready observation, original structure can be discerned by careful structural analysis. For example, in the Johnny Lyons Hills where the Precambrian X fold structures were disrupted both by intrusion of the post-tectonic Precambrian X Johnny Lyon Granodiorite and again by Tertiary block faulting, Silver (1955) was able to demonstrate in reconstruction that the structures were originally NE-SW.

In the northern plateau country of the state Tertiary faulting of Paleozoic and younger rocks has been shown in some cases to reflect a NE-SW structural grain of the Precambrian basement (Shoemaker and others, 1974; Huntoon, 1974). Structures of this trend are salient features of Precambrian rocks exposed in the Grand Canyon.

In the near vicinity of Tonto Basin strata either are folded on NE-SW axes or strike NE-SW in the northern and central Mazatzal Mountains, at Four Peaks in the southern Mazatzal Mountains, and at White Ledges along the Salt River. In many other places mapping is not yet sufficient to discern the grain of the main masses of Precambrian rock.

Departure of faulting from the dominant NE-SW grain to approximately N-S occurs at other places than in Tonto Basin and Mazatzal Mountains. Most notable of such N-S faults is the Shylock fault (Anderson, 1967) of the Black Hills-Bradshaw Mountains area in Yavapai County. It appears from ERTS imagery and Skylab photography examined that the Shylock fault zone may swing southwestward at its southern end and that perhaps several NE-SW lineaments, including the Chaparral fault, may swing into coincidence with the Shylock zone. These features are very similar to the arcuate faults described earlier in Tonto Basin. An interesting speculation is that the Shylock fault may connect northward with a Precambrian fault ancestral to the NE-SW Tertiary Mesa Butte fault (Shoemaker and others, 1974) and thus effectively swing northeastward. This would define an arcuate fault of opposite disposition to those described in Tonto Basin and would provide support for the left-lateral couple model earlier presented to explain Tonto Basin structures.

There are two possible obstacles to the correlation of origin of the Shylock fault system and Subset II faults in Tonto Basin: 1) The Shylock system is in the northern, older province and may have formed during a deformation which preceded the deposition of the southern province rocks; 2) The Shylock fault has right-lateral strike-slip offset (at least 5 miles, Anderson, 1967), opposite the translational sense of Tonto Basin faults.

Anderson (1967, p. C 64) made the argument that a great fault slice of Texas Gulch Formation in the Shylock fault zone is of piercement origin, squeezed upward in the zone. The Texas Gulch rocks are juxtaposed against rocks originally interpreted to be higher in the section; hence, the argument for piercement. The original stratigraphic assignment of the Texas Gulch Formation is now believed to be in error (Anderson and others, 1971) and the formation is considered the youngest stratigraphic unit in the area. The presence of Texas Gulch rocks as a fault slice in the Shylock fault zone may possibly indicate down-faulting into a graben, thus implying E-W tension.

Evidence at present does not support a genetic correlation of the Shylock system with the Tonto Basin Subset II faults. Nevertheless, the similar trends and common evidence for tensional faulting are intriguing and further comparative studies are in order. In preliminary study of regional structure utilizing Skylab photography there are suggestions of other arcuate features in Precambrian terrains of Arizona which may be of the same generation as those in Tonto Basin and/or the Shylock system.

RELATION OF FELSIC HYPABYSSAL SILLS TO FOLD STRUCTURES

There is an apparent systematic deviation of columnar joint orientations in Hell's Gate Rhyolite sheets in the Tonto Basin syncline from perpendicularity to the planar elements in the syncline. It appears that in rhyolite of both limbs the joint intersections plunge about 60-65°. Planar elements, if perpendicular, would dip at 25-30°, but quartzite beds dip 40-50° and flow-banding in the extrusive Haigler rhyolite is generally even steeper. Figure 11 schematically illustrates this apparent relationship both in the present position and in an unfolded geometry. Also shown in this figure are hypothetical cooling surfaces inferred to have been perpendicular to the joints.* Joint and cooling surface configuration about the syncline axis is symmetrical.

If rhyolite intruded prior to folding there must have been a linear heat source below the sill which caused an upward bulge of the isothermal surfaces. This might be feasible. For example, the linear heat source may have been a wide feeder dike for the sill. Later the syncline axis would coincide with the linear heat source.

Alternatively, the magma may have intruded folded strata and a significant component of vertical heat loss, due to nearness to the earth's surface, caused a deflection of the isotherms away from parallelism to contacts and toward parallelism with the surface.

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*Jaeger (1961) concludes that in irregularly-shaped bodies columnar jointing is not necessarily perpendicular to isothermal cooling surfaces. It is implicit from his discussion, however, that in simple sheet-like bodies where isothermal surfaces are roughly parallel to the margins of the sheets that columnar jointing should be roughly perpendicular to the cooling surfaces and hence the contacts. Numerous observations by geologists over the years indicate that indeed columnar joints tend to be oriented perpendicular to sheet surfaces.

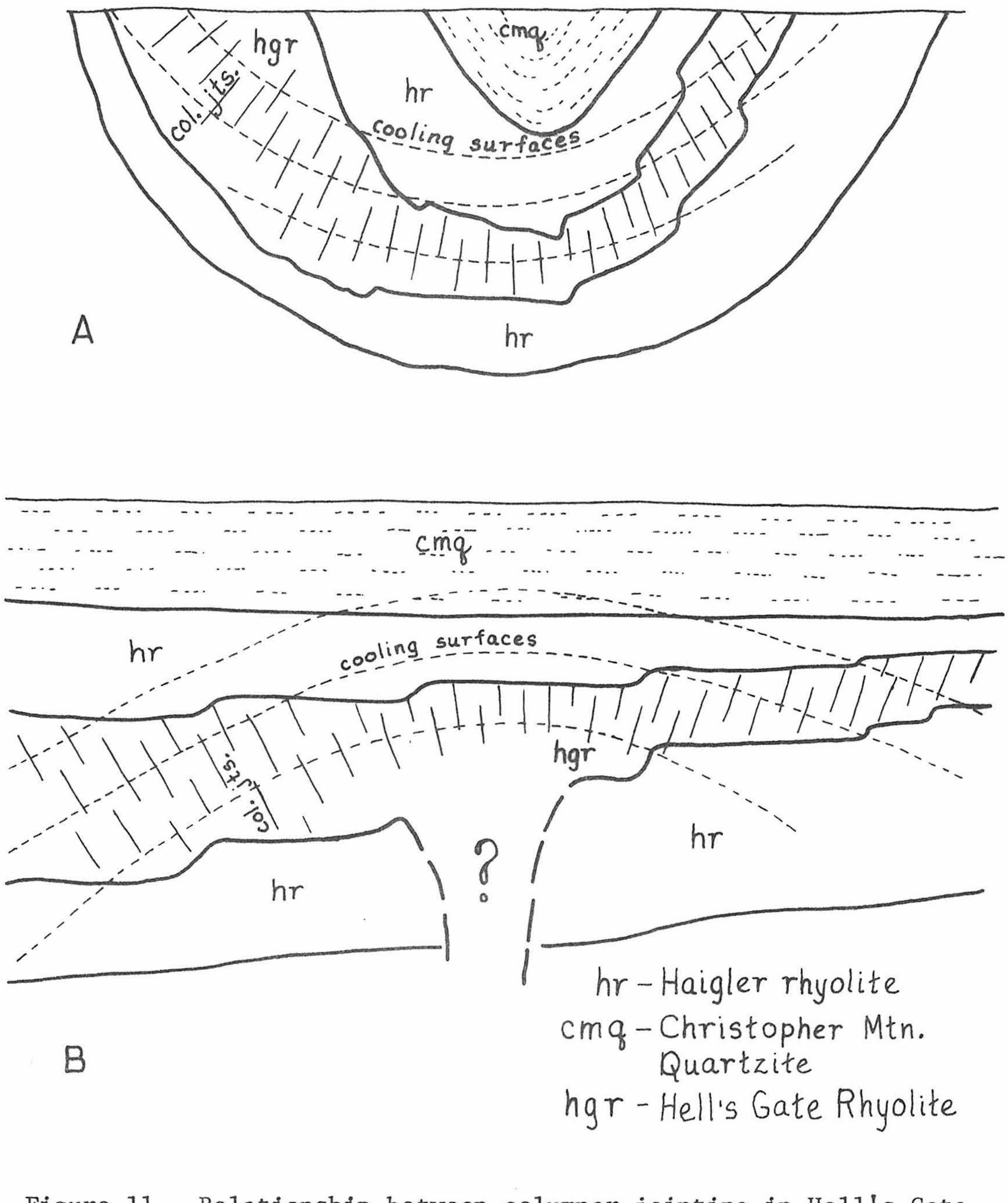

Figure 11. Relationship between columnar jointing in Hell's Gate Rhyolite and attitudes of stratified rock in the Tonto Basin syncline. A. Schematic cross-section illustrating the apparent divergence of joint plunge from perpendicularity to layering of strata and a hypothetical perpendicular relationship to isothermal cooling surfaces. B. Same relationships in an unfolded geometry.

Although no strong arguments can be presented to support either alternative, the second is preferred because a linear heat source is hypothetical and its coincidence with a later fold axis would probably be fortuitous.

If Hell's Gate Rhyolite intruded a fold, so also did the younger granophyre and alaskite sills. All these hypabyssal units are silicic alkali rocks. Modern compositional analogs are thought to form in regions of crustal extension (page 427). If this is true also for the Tonto Basin rocks, the hypabyssal sills could not have intruded after the onset of regional compression event in which the major folds were formed. This would not preclude the presence of a fold, however, at the time of intrusion. A proto-Tonto Basin syncline* may have been formed during local deformation associated with intrusion of the Payson Granite. There is no direct evidence for such a deformation and, indeed, intrusion of Payson Granite into Haigler rhyolite is hypothetical, but such deformation would almost certainly accompany intrusion of such a large body.

Whether or not a fold existed when the sills were emplaced, it seems quite probable that magmatic activity was not restricted to shallow intrusion. Hell's Gate Rhyolite rose quite high into the southeastern limb of the Tonto Basin syncline. To the northeast at Cherry Spring, at an equivalent position in the syncline, alaskite

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*This syncline would have been more tightly folded in the later regional compression. The upper contact of the Payson Granite is apparently folded in the trough of the syncline between Little Green Valley and Bear Flat.

which elsewhere persists at the upper contact of the Payson Granite departed from the granite and intruded discordantly up into Haigler rhyolite. This suggests a zone of weakness existed in the southeastern limb of the syncline into which various hypabyssal bodies could rise. These magmas may have fed surface vents along this or other fractures.

Hell's Gate Rhyolite and particularly rhyolite of Hog Canyon intrude Christopher Mountain Quartzite stratigraphically high in the Big Ridge syncline.

UPPER PAYSON GRANITE SURFACE

Some of the most intriguing and profound problems in understanding the Precambrian history of Tonto Basin relate to the nature of the relatively smooth, generally southward shallow-dipping upper Payson Granite surface. The two fundamental questions are:

1) What was the nature of the upper granite contact prior to pervasive intrusion by hypabyssal rocks?

2) Is the upper granite surface beneath the Gibson Complex continuous eastward with that which dips beneath granophyre and which constitutes the lowermost surface which is apparently part of the Tonto Basin syncline?

There are three major alternative explanations for the character of the upper Payson Granite surface (Figure 12):

Hypothesis A is that Payson Granite intruded the stratified sequence with its upper intrusive contact roughly conforming to the base of the Haigler Group. In this hypothesis (intrusive hypothesis) the

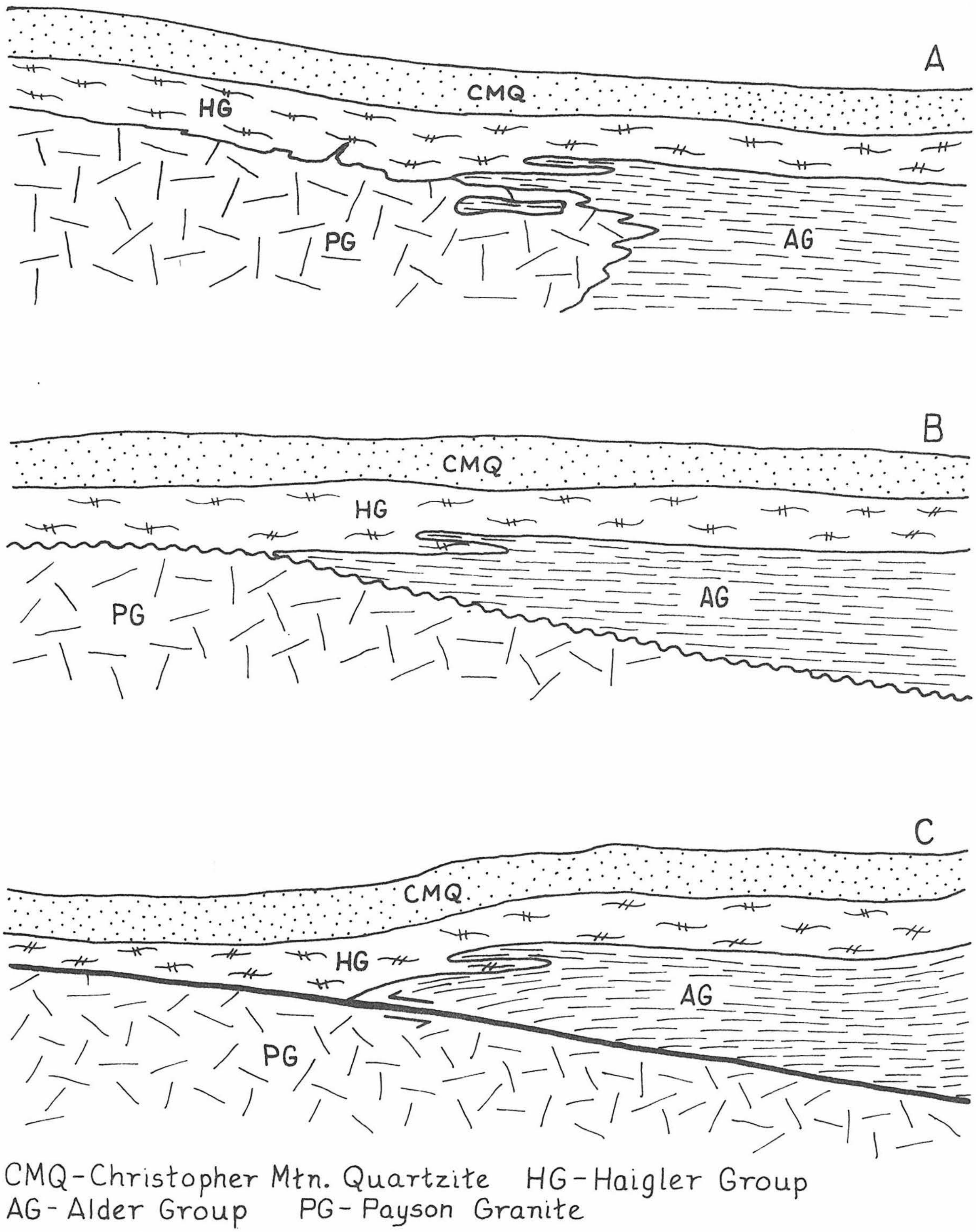


Figure 12. Schematic cross-sections across Tonto Basin illustrating alternative hypotheses for the pre-hypabyssal sill relationship between Payson Granite and the stratified rocks. In each case the axis of the Tonto Basin syncline would develop at about the middle of the cross-section and the hypabyssal rocks would intrude along the upper granite surface mostly to the left of that axis.

apparent concordance at the roof might be taken to indicate that the granite is an enormous sill-like or laccolith-like body and semi-concordant at its base as well. Alternatively, of course, it might be discordant at depth.

Hypothesis B (basement hypothesis) is that Payson Granite was exposed and eroded (essentially peneplained) prior to deposition of the stratified rocks. The granite and other rocks (possibly including lower Alder Group strata) would presumably unconformably underlie strata of the southern block. Alder Group rocks were either never deposited on Payson Granite in the northern part of the area or they were deposited but subsequently removed by erosion prior to the deposition of Haigler rhyolite.

In hypothesis C the absence of Alder Group to the north would be explained by thrusting which would have occurred after deposition of the Haigler rhyolite but prior to intrusion of the hypabyssal sills. This concept is amply conveyed in the figure.

There is no direct evidence bearing on the nature of the contact between Payson Granite and the Haigler Group as it existed before emplacement of the hypabyssal rocks. In fact, it has been exceedingly difficult to establish the age relationships (see earlier sections) between the various hypabyssal units and granite and rhyolite from which to speculate about the earlier, more cryptic relation. It can only be inferred from the general structural relationships that the Haigler rhyolite would have been in contact and generally conformable with Payson Granite. This is conveyed in each of the three models.

From his early field work the author (Conway, 1973) preferred the second model which seemed structurally sound and which was compatible with U-Pb zircon apparent ages (L. T. Silver, pers. comm.) of 1730 ± 15 m.y. and 1715 ± 15 m.y. for Payson Granite and rhyolite of the Flying W Formation, respectively. Moreover, it was thought at that time that erosion was the only reasonable means to produce the extensive planar surface on the granite. Further field investigations have led to preference for the intrusive hypothesis.

It appears from detailed mapping in the Gisela area that the upper Payson Granite surface dipping southward beneath both the Gibson Complex and the Green Valley Granophyre is one continuous surface. One would infer from this that the granite surface dipping beneath alaskite or granophyre, and presumably once in contact with the Haigler rhyolite, is of the same nature and origin as that beneath the Gibson Complex. It would be the original intrusive roof contact of the granite. Support for this is found in the nature of the Payson Granite itself. Granite near the upper contact may be a slightly differentiated roof phase.

The basement hypothesis is weakened by the absence of granite detritus in the strata of the southern structural block, by the lack of evidence for weathering and erosion on the granite surface, and by the absence of Alder Group rocks in the northwestern limb of the Tonto Basin syncline.

The thrusting hypothesis is not supported by deformation of Payson Granite or faulting where the thrust plane should project into the Gibson Complex. The hypothetical thrusting would have occurred during the alkali rhyolite event contrary to the implication from continuing silicic alkali magmatism of non-compressional tectonics.

Payson Granite intruded the Gibson Complex at a high angle to layering in the gabbro. It may have sub-concordantly intruded the stratified sequence approximately at the Alder Group-Haigler Group interface. Intrusion into the Gibson Complex may have been controlled by fracture(s) propagating out from a zone of weakness in the stratified rocks approximately at the base of the rhyolite. This deformation probably accompanied intrusion of the granite.

Basically from structural considerations it is argued in this section that the intrusive hypothesis is much more plausible than either the basement or thrusting hypothesis. It is intended that this discussion be independent of the arguments based on mafite porphyry and Gisela pendant contact relations and lithology correlations that Payson Granite and probably Gibson diorite are younger than Haigler rhyolite (page 95). It should now be made clear that these latter independent and more direct arguments are the main basis for the hypothesis that the plutonic rocks are younger than the stratified rocks. These arguments would make the basement hypothesis impossible but would permit the thrusting hypothesis; the plutonic rocks might have intruded the stratified rocks and then been overthrust by them. However, the mafite porphyry/Gisela pendant arguments in connection with arguments of this section require that the intrusive hypothesis stand as the single preferred hypothesis.

Intrusive Hypothesis

East of point X north of Gisela (O-7) Green Valley Granophyre overlies Payson Granite. West of that point the granite dips beneath rocks of the Gibson Complex. The granite-granophyre interface has essentially the same strike and dip as does the granite-Gibson Complex interface. Either they are continuous and the surface east of point X is an upper intrusive contact of the granite, subsequently intruded by rhyolite, granophyre, and alaskite sills, or they are two distinct surfaces intersecting at a low angle.

In the two-surface alternative Payson Granite would first have intruded the Gibson Complex, then both plutonic bodies would have been either eroded (basement hypothesis) or overthrust (thrusting hypothesis) in such a way that the new sub-planar surface would nearly coincide with, and truncate at a very low angle, the granite-Gibson Complex interface.

The strongest argument against the two-surface alternative is that there is no reason to call on this peculiar complexity to explain the structures in this area. On the contrary, careful mapping of the excellent exposures of the Payson Granite contacts north of Gisela reveal an apparent continuity of the contact in the transition from granite-granophyre to granite-Gibson Complex. The two steep intersecting faults have somewhat obscured the relation, but the upper granite surface maintains its orientational characteristics as emphasized by the strong relief in the area. The simplest and most reasonable explanation of the observed relationship is that the granite intruded both the Gibson Complex and Haigler rhyolite and that the felsic sills later intruded primarily the granite-rhyolite portion of that contact.

The presence, sequence of intrusion, and positioning of hypabyssal rocks at the upper granite surface throughout the area - at Gibson Rim, north of Gisela, and in the Green Valley Hills - is in itself an argument for continuity of character of the upper granite interface. This contact in each area was the site for intrusion of rhyolite, then granophyre, and finally alaskite; each succeeding sill (or sill set) in each area occurs just beneath the earlier.

The character of the Payson Granite body itself may indicate that present upper levels of the granite are original, high-level differentiated parts of that body. This is documented elsewhere (page 307). This is clearly compatible with the intrusive hypothesis though it may not argue strongly against the basement hypothesis because the hypothetical erosional surface could feasibly have barely penetrated the roof of the body. The latter, nevertheless, would involve a considerable degree of fortuitousness considering that the exposed granite contact is so extensive and that the erosional surface would have been developed in a deformed orogenic terrain. Whether or not the apparent occurrence of more differentiated granite near the upper contacts can be adduced in argument against the basement hypothesis, it is extremely important in supporting the notion that the great Payson Granite body could have had a rather regular planar upper contact over a great distance.

Basement Hypothesis

The basic concept of this hypothesis is that an erosion surface on older Payson Granite dipped southward at the time of Alder Group deposition and was high to the north where it did not receive Alder Group sedimentation. As the basin to the south filled with sediments and volcanic rock the higher units would have lapped progressively northward onto the granite until finally rhyolite of the Haigler Group would have completely covered the granite, at least in the region of the mapped upper granite contact.

A serious objection to this hypothesis is the absence in Alder Group strata of either granite clasts or a significant component of alkali feldspar detritus which could be attributed to a Payson Granite source. Another argument against the hypothesis is the complete northward lap-out required of the 3800± m-thick Alder Group over a stratigraphic distance of less than 8 miles (see sections B-B' and C-C'). This might be no problem in itself because buttress unconformities are well known. However, from this thickness and lap-out distance the granite slope would have had a regional gradient of 15°. It is difficult to see how such a steep erosional surface could be so lacking in local relief. Even given the possibility that Payson Granite was peneplained, tilted, and submerged prior to receiving the onlapping Alder Group sedimentation one might expect some submarine erosion of the granite.

A variation on this hypothesis is that some Alder Group sediments were deposited on the granite and then, following southward tilting, stripped away to the north, thus exposing the granite again prior to Haigler rhyolite volcanism. This seems improbable because there is no evidence of an angular unconformity beneath Haigler Group rhyolite. It conformably overlies Board Cabin Formation throughout the area mapped by Gastil and to the southwest several miles in the area south of McDonald Mountain. Absence of granite clasts as well as reworked sedimentary detritus argues against this variation, also. Conspicuously absent are quartzite clasts which would have been derived from the Houden Formation. The abundance of conglomerate in the upper Alder Group might be taken to indicate such a deformation and erosion, but the conglomerate clasts are entirely volcanic and were most reasonably derived by erosion of local volcanic edifices.

Two arguments against this hypothesis arise from field observations in the region of the granite contact.

West of point X at Gisela the hypothetical erosional surface would have been on the rocks of the Gibson Complex and Gisela pendants. This plausibility was earlier discussed in connection with the origin of the Gisela pendants (page 84). It is argued that the high angle Haigler rhyolite flow foliation makes to the contact with the Gibson Complex is evidence for intrusion by, rather than deposition on, the Gibson Complex rocks.

Finally, granite in the contact region was carefully examined for evidence of weathering and erosion. None was found.

Thrusting Hypothesis

The thrusting hypothesis is not supported by any positive evidence for faulting. Nowhere along the upper Payson Granite surface was deformation of the granite observed and north of Gisela there is no sign of faulting where the hypothetical thrust should occur in the Gibson Complex.

East of point X at Gisela the upper granite surface would have been the thrust plane. West of that point the fault should pass (roughly projecting the attitude) into rocks of the Gibson Complex just above the granite-Gibson Complex interface. This fault would have been a major feature supporting a great deal of offset of the contacts which it would necessarily truncate at a high angle. Detailed mapping in this area demonstrates that no such fault exists.

The timing assigned to the hypothetical thrust would have it follow the extrusion of the Haigler rhyolite and precede emplacement of the Hell's Gate Rhyolite and other silicic alkali sill rocks. This is inconsistent with the hypothesis (page 427) that the continuing silicic alkali magmatism reflects a prevailing non-compressional tectonic environment.

A Structural Analysis Based on the Intrusive Hypothesis

Assuming the intrusive hypothesis an evaluation will now be made of the possible and probable structural controls and effects of intrusion by the Gibson Complex and the Payson Granite.

It is intriguing that Payson Granite maintains its upper surface sub-planar geometry beneath the Gibson Complex. This geometry beneath the Haigler rhyolite presumably reflects the control of layering during intrusion, but intruded Gibson rocks are structureless except for subordinate gabbro which is truncated at a high angle by the granite. Primary igneous lamination has been crinkled in the gabbro near the contact with granite at station 2147 (J-5). Just to the west layering attitudes in gabbro locally strike nearly parallel to the contact and are thus strongly divergent from 'normal' attitudes elsewhere. Apparent deformation of gabbro layering near the planar contact with granite suggests that a fault in the Gibson Complex controlled intrusion by granite.

An objection raised earlier against thrust faulting during the interval of silicic alkali magmatism also applies here.

It is speculated that perhaps the primary control for the intrusion of the Payson Granite was the Haigler Group-Alder Group interface and that during deformational adjustment which must have taken place during the emplacement of this enormous granite body a zone of weakness propagated out approximately from the Haigler Group-Alder Group contact into the Gibson Complex. This assumes that the Gibson Complex had intruded both of the rock-stratigraphic groups and was discordant to their mutual contact. Some support for this derives from the fact that a rhyolite-sedimentary rock contact occurs very near the Payson Granite upper surface in the eastern Gisela pendant. It was earlier suggested (page 84) that this might be the Haigler Group-Alder Group contact. Thus at depth in the Tonto Basin syncline the Alder Group might occur beneath, or foundered within, the Payson Granite and the same would be true for the northern missing part of the Gibson Complex. A single 5-meter block of quartzite in Payson Granite (Q#1, H-9) is the only evidence, however, for stoping by that body.

It is not necessary according to this model to call on thrusting or other low-angle faulting unrelated to the intrusion of the Payson Granite for the deformation observed in the layered gabbro. Considerable other deformation may have accompanied the intrusion.

Probable Haigler Group rhyolite and overlying Mazatzal Group quartzite dip northwestward away from the Payson Granite/Gibson Complex mass (no contact is known) at Natural Bridge almost 20 miles to the northeast of the Payson Granite upper contact in Tonto Basin. Strata at Natural Bridge and in Tonto Basin may be tilted and deformed approximately marginal remnants of a broad dome formed by sub-concordant intrusion of the Payson Granite. Shouldering aside of the strata would have resulted in the formation of the proto-Tonto Basin syncline. Intrusion of hypabyssal rocks on the southeastern flank of this hypothetical dome would have been controlled by ruptures in the stratified rocks and by the easily penetrated upper conformable contact of the granite body.

Implications for Regional Structure

Plutonic rocks in the northern and older of the two Precambrian provinces in Arizona range in apparent age from 1725 to 1770 m.y. (page 23). Payson Granite, at the southern margin of the province, is one of the younger bodies (1730 ± 15 m.y.) but rocks of similar age also occur much further north. Haigler rhyolite (1715 ± 15 m.y.) is a northern member of the younger province 1700-1715 m.y. suite of volcanic rocks.

The intrusive hypothesis above would have Payson Granite of the northern, older province intruding Haigler rhyolite of the southern, younger province. Nowhere else in Arizona has a structural or relative age relationship been found between representatives of the two geochronologic provinces. For the broad purpose of this discussion Payson Granite, though intrusive into Haigler rhyolite, is essentially the same age as the rhyolite; they are products of the same magmatic episode (page 409).

The important implication from the intrusive hypothesis is that there was an overlap of magmatism on the margins of the two provinces. Volcanism apparently associated with latest plutonism of the northern province is (possibly earliest) younger province volcanism. Volcanic and sedimentary rocks contemporaneous with the youngest plutons elsewhere in the province have not yet been identified, though there are a few candidate terranes.

Most plutonic rocks of the northern province are 1750-1770 m.y. old and their intrusion closely followed volcanism in the orogenic cycle of that province. It seems possible that the later plutonic bodies approximately of Payson Granite age are of a post-orogenic suite. The silicic alkali composition of the extrusive and hypabyssal rocks in Tonto Basin and of Payson Granite itself, possibly indicative of non-compressional or extensional tectonics, is compatible with this idea. The relatively brief anorogenic period would have been interrupted by orogenic magmatism and deformation in the southern province. There is some suggestion that volcanism in the southern province away from the contact region was slightly later than that in Tonto Basin and that the rocks are more calc-alkaline.

If magmatic activity in Tonto Basin was synchronous with volcanism throughout the southern province Tonto Basin may have been a site of back-arc extension.

VOLCANIC AND CONTEMPORARY STRUCTURES

Haigler and Alder Groups

Haigler Group rhyolite averages perhaps 2 km in thickness in Tonto Basin; a little more than a km is exposed in the Mazatzal Mountains. Mazatzal Group quartzite unconformably overlies the rhyolite in Tonto Basin with very little basal conglomerate. At Natural Bridge (see page 34) and in the Mazatzal Mountains the quartzite has a thick basal conglomerate of rhyolite fragments. These factors suggest that the highest parts of the rhyolite field were in Tonto Basin. There was undoubtedly much local relief as well, due perhaps to both numerous eruption centers and to caldera formation. Erosion of the high areas may account for local unconformable characteristics. Rhyolite interbedded at the base of the quartzite at Natural Bridge (page 26) and quartzite interbedded with rhyolite at Christopher Mountain (page 54) suggest a continuation of volcanism as deposition of the quartzite began.

Large recent rhyolite centers have almost invariably been found to contain one or more calderas. Positive evidence for caldera structures, such as ring fractures or ring dikes, were not found in Tonto Basin. However, characteristics of the massive Oxbow Rhyolite and immediately underlying conglomerate, slate, wacke, and pillow lava (page 67) suggest that the Oxbow mass may have been a viscous dome extruded into a depressed area which may have been a cauldron. There is a close analogy with modern caldera structures where domes have erupted during resurgence along ring fractures in the moat region.

Gastil (1958) reported an unconformity at the base of the Houden Formation. He suggested that the Breadpan Formation was deposited in a stable, quiet-water environment and that conglomerate in the overlying Flying W Formation indicated subsequent uplift. "Continued uplift," he states "exposed the area to erosion and produced the unconformity at the base of the Houden Formation."

This unconformity is not pronounced. Its position immediately above volcanic rocks and volcanogenic conglomerate of the Flying W Formation may reflect a relationship between the unconformity and the volcanism possibly analogous to the Haigler rhyolite-Mazatzal quartzite relationship.

Two factors associated with extensive magmatic activity may profoundly affect regional elevation and relief and hence the depositional environment. The first is the volcanic construct itself and the second is the epeirogenic movements which may be associated with the rise, emplacement, and venting of large bodies beneath the construct.

Alone or in combination these factors were probably responsible for the fluctuations in environment of deposition and the formation of the minor unconformities in the Tonto Basin strata. It seems unnecessary to call on regional deformation associated with major external crustal movements.

Post-Haigler Volcanism

The parent magma of the Payson Granite apparently intruded beneath a relatively thin cover of stratified rocks and it is certainly reasonable that it may have fed a volcanic system developing above fractures in the domed region.

The probability that the later sill magmas, particularly Hell's Gate Rhyolite, vented to the surface seems particularly strong. Hell's Gate magma and rhyolite of Hog Canyon intruded Christopher Mountain Quartzite, the highest stratigraphic unit exposed. Structural disruption caused by intrusion of the Payson Granite and possible erosion of the uplifted region are both factors which may have enhanced accessibility to the surface of the sill magmas. These voluminous sills are almost certainly the roots of a volcanic system.

It seems unlikely that Christopher Mountain Quartzite was the highest stratigraphic unit to be deposited in Tonto Basin in Precambrian X time. Much superjacent rhyolite and reworked volcanic debris may have been completely eroded from the region. Evidence for these volcanic strata might be found in the detritus of the Apache Group rocks, but it would be difficult indeed to distinguish Haigler and post-Haigler rhyolite fragments.

PETROGRAPHY AND CHEMISTRY

INTRODUCTION

The stratified rocks of Tonto Basin were recrystallized in the greenschist facies. Large plutonic bodies are unmodified except by deuteric alteration at higher levels. Marked alkali exchange has affected some rocks very near the Apache Group unconformity.

Petrographic criteria support the possible Alder/Haigler Group parentage of the Gisela pendants and igneous intrusive origin of mafite porphyry thus enforcing the hypothesis that the Payson Granite and probably the Gibson Complex are younger than Alder and Haigler Group rocks.

The calcic Gibson Complex differentiated from a basaltic parent magma. Upper parts of the alkali Payson Granite body may be a slightly differentiated roof zone. Minor mafic Alder Group volcanic rocks, mafic hypabyssal rocks, Haigler alkali rhyodacite, and the voluminous, compositionally identical silicic alkali bodies, Haigler rhyolite, Hell's Gate Rhyolite, King Ridge Rhyolite, Green Valley Granophyre, and alaskite, are all characterized by high alkali/lime and iron/magnesium ratios.

All silicic alkali bodies were hydrothermally oxidized; mafic mineralogies and pristine chemistries are preserved only in rare gray facies. Alkali exchange possibly occurred between Green Valley Granophyre magma and Haigler rhyolite. Extreme exsolution in Haigler rhyolite feldspar phenocrysts may have been facilitated by hydrothermal solutions.

Certain feldspar characteristics in both porphyritic and equigranular silicic alkali rocks have important implications for histories and conditions of crystallization.

STATE OF PRESERVATION

Nowhere in the Precambrian of the southwest is there a known suite of rocks so well preserved in terms of textures, mineralogies, and chemical compositions as that of Tonto Basin. Nevertheless, processes of modification have operated on these rocks. Effects of several different processes have been recognized, but primary mineralogic, textural, and chemical data relating to primary igneous characteristics are readily obtainable.

Metamorphism

Pyroxene, hornblende and biotite are not preseved in the volcanic rocks of the Alder Group or Haigler Group. Mafic and intermediate rocks of the Alder Group in the vicinity of Diamond Butte contain abundant chlorite, epidote, and minor calcite. Opaque minerals are very abundant in these iron-rich rocks. Gastil (1958, p. 1504) stated that these rocks contain albite, but the writer found remnants of more calcic plagioclase in highly sericitized and saussuritized phenocrysts. It would appear that these strata passed through conditions of lower greenschist facies metamorphism but that equilibrium was not attained.

Excellent preservation of layered pyroxene gabbro and ferrohastingsite granite at depth in the Gibson Complex and Payson Granite, respectively, may suggest that the regional event in which the volcanic rocks were apparently metamorphosed occurred before or during intrusion of these plutonic bodies. It seems more likely, however, that the massive plutonic bodies passed through the metamorphic event, which probably accompanied regional deformation, but were virtually unaffected by it. Metamorphic reactions perhaps failed to occur because of low water content and/or lack of internal deformation.

Upper parts of the Gibson Complex are moderately to strongly altered and this is attributed to late stage deuteric activity. Alteration in upper Payson Granite is probably due to both late stage reactions in the cooling of that body and to hydrothermal activity accompanying intrusion of the hypabyssal rocks.

Pervasive hydrothermal modification of the hypabyssal rocks, particularly Green Valley Granophyre, and to a degree of intruded rocks, is pronounced. Alkali feldspar is strongly clouded and shows evidence of extreme exsolution and perhaps alkali exchange. Preserved primary mafic minerals in the hypabyssal rocks are rare, except that biotite is common in places in alaskite. Iron in these rocks occurs almost entirely in hematite pseudomorphous after primary mafic minerals and disseminated along grain boundaries and in feldspar. Fluorite is an abundant accessory phase in the hypabyssal rocks and is common probably as a secondary mineral in Haigler rhyolite and various other rock types.

The greatest variable in the extrusive rhyolites is oxidation state, though most is strongly oxidized. This oxidation may be due not only to hydrothermal activity, but to vapor phase reaction occurring at the time of extrusion. An outstanding example of preservation is the presence of probable primary glass in an ash-flow cooling unit (page 58). It is difficult to conceive that this glass(?) could have survived any but the very lowest temperature regional thermal event. In the structure section were described tectonite phases of those rocks which have locally been deformed in the major deformational episodes of regional tectonic activity. It is not possible at present to make any certain connection between the deformation and thermal metamorphic event(s).

Gisela pendant rocks were mildly to extensively recrystallized and metamorphosed in the hornblende hornfels (?) facies by the intrusion of the Gibson Complex. Pronounced contact metamorphic effects were nowhere else found. Payson Granite caused no observable modification of Gibson Complex rocks at exact contacts (e.g., within a thin section). At numerous contacts of felsic rock intruded by felsic rock, including extrusive rhyolite intruded by alaskite, no megascopic effects were seen.

Open System Chemical Exchange

A sample of Young granite collected by L. T. Silver a few miles to the east of the study area was analyzed for bulk chemistry. This sample containing K-feldspathized and sericitized plagioclase has a remarkably high K_2O content and extremely low Na_2O and CaO contents (Table 4). Inasmuch as the analyzed sample was collected only 5 - 15 m below the unconformable contact with Apache Group and inasmuch as earlier investigations (Smith and Silver, 1975; Smith, 1969; Granger and Raup, 1964; Williams, 1957) had shown that Apache Group rocks are extremely rich in K_2O, it was reasonable to suspect that K_2O enrichment in the Young granite was related to proximity to the erosional surface. Chemical

TABLE 4. CHEMICAL COMPOSITIONS OF ROCKS WITH PRONOUNCED MODIFICATION OF ALKALI AND LIME CONTENT

	Young granite Ar-Gi-Young gr #1		Haigler rhyolite 5-1-1252	Spherulitic rock, Apache Ridge
	1	2	3	4
SiO_2	73.45	74.34	76.99	
TiO_2	0.15	0.15	0.14	
Al_2O_3	13.62	13.35	12.50	
Fe_2O_3	1.11	*	*	
FeO	0.08	0.97	2.06	
MnO	0.00			
MgO	0.25	0.19	0.14	
CaO	0.18	0.11	0.07	
Na_2O	0.39	0.48	0.27	0.82
K_2O	9.88	10.38	7.81	9.21
$H_2O(+)$	0.65			
$H_2O(-)$	0.39			
P_2O_5	0.02	0.03	0.01	
CO_2	0.00			
F	0.05			
Total	100.22	100.00	100.00	

*All Fe as FeO

Analysts:

1. Japan Analytical Chemistry Research Institute.

2,3. C. M. Conway, electron microprobe.

4. W. H. Herdsman; Gastil, 1958, Table 5.

analyses from the Dripping Spring Quartzite of the Apache Group (Smith, 1969, Tables 1 and 4) average 10.7% K_2O, 0.4% Na_2O, and 1.1% CaO. One K_2O analysis (11.4%) was given for Pioneer Shale. Both Pioneer Shale and overlying Dripping Spring Quartzite can locally be found resting directly on the Precambrian X rocks of Tonto Basin (Gastil, 1958, Plate 2).

To confirm a non-coincidental relationship between K_2O enrichment and proximity to the unconformity, an altered sample of Haigler rhyolite collected about 10 meters beneath the Apache Group contact (1252, F-18) was analyzed. It clearly is also enriched in K_2O and depleted in Na_2O and CaO (Table 4). Also given in Table 4 is a partial chemical analysis consisting of alkali contents for a 'spherulitic rock, Apache Ridge' from Gastil, 1958. Apache Ridge is not underlain by spherulitic rhyolite but nearby Mescal Ridge and King Ridge both have extensive exposures of the spherulitic King Ridge Rhyolite. In none of these areas is Apache Group now exposed but the alkali content of this rock may indicate that Apache Group strata extended this far northwestward and were probably not far above the present level of exposure. Certainly the most reasonable explanation for the anomalous alkali and lime values is exchange during or following deposition of the Apache Group.

Smith (1969, p. 28-31) concludes that the extremely rich potash content in the Apache Group rocks is due to formation of authigenic feldspar in a highly saline brine. If this is so then the most likely medium for alkali exchange in the Precambrian X rocks would be this same brine which would have percolated down into the bedrock floor of the Apache Group sedimentation basin. In the Young granite the added K_2O is in secondary K-feldspar and less abundant sericite which have replaced granular plagioclase and plagioclase lamellae in perthite, suggesting that the exchange occurred contemporaneously with the K_2O enrichment of the Apache Group sediments.

Near Apache Group remnants east of the Lost Camp fault, maximum depth of erosion below the old surface (in Haigler Creek and Spring Creek) is about 300 meters. Erosion depth may be considerably greater west of the Lost Camp fault, but the possibility must nevertheless be considered that any rock sampled might have exchanged with a fluid penetrating deeply along fractures. A careful examination of other chemical analyses of the felsic rocks, however, reveals no clear-cut alkali exchange effects in this direction. There is no suggestion of systematic lowering of Na_2O in samples perhaps slightly high in K_2O and in fact some rocks possibly depleted in K_2O are either depleted or enriched in Na_2O. This may indicate the operation of an alteration process entirely apart from the Apache Group effect. Low CaO contents in two of the Haigler rhyolite samples may however be depletions caused by the Apache Group effect.

Haigler rhyolite analyses show more scatter, particularly in alkali and lime values, than do the hypabyssal rocks. This might be explained by one or more of the following possibilities: 1) The volcanic rocks represent numerous separate magmatic pulses and are thus more likely to have primary variations than the hypabyssal units derived from relatively few pulses. 2) Volcanic rocks were susceptible immediately following formation to sub-aerial weathering and possible exchange with ground water. 3) Analyzed Haigler Group rocks are from more easterly parts of the area and may have been closer to the Apache Group surface.

The analyzed Flying W basalt and Board Cabin andesite samples are suspect of K_2O enrichment. However, though the andesite might be depleted in Na_2O (thus permitting the Apache Group effect), the basalt is unusually rich in Na_2O and has somewhat of a spilitic character. Exchange with sea water in the extrusive environment may also have modified original chemistries.

GISELA PENDANTS

A cursory petrographic survey of pendant lithologies was undertaken to determine approximate compositions and parentages of the rocks. Visually estimated modes of the rocks examined are listed in Table 5. This group includes most rock types seen. Texturally they are essentially granoblastic, possess a weak to moderate foliation and are slightly to extensively recrystallized. Original lithologies are graywacke, rhyolite, mafic volcanic rock, and quartzite(?), which are petrographically equivalent or similar to rock types in the Haigler and Alder groups.

Graywacke

In the western pendant in the vicinity of station 1899 (P-5) are interlayered a variety of generally gray-brown to black, apparently

TABLE 5. MODES OF GISELA PENDANT ROCKS

	Western Pendant						Eastern Pendant		
	1	2	3	4	5	6	7	8	9
quartz	40	40	35	35	30	35	30	35	>5
plagioclase	30	40	55	30	30	40	35	20	45
An content	25	25	25?	5	5	5	5	5	25?
K-feldspar[a]	pr?	?	?	20pe	40pe	15	25pe	40pe	-
muscovite	-	-	-	8	<1	-	1	-	15[b]
biotite	-	15	8	-	tr?	-	5	tr?	10
chlorite	20	1	tr	3	1	8	-	-	tr
epidote	3	-	-	1	<1	1	-	-	5
hematite	-	-	-	tr	tr	tr?	-	tr?	-
opaque[c]	5py	3py	<1	2	<1	trpy	tr	3	2
apatite	tr	tr	tr	-	-	-	-	-	tr
fluorite	-	-	-	-	-	-	tr	tr	-

Modes are by visual inspection, numbers are in percentage.

pe - perthitic
pr - present - indeterminate amount probably more than a few %.
tr - trace amount
a - orthoclase; very minor microcline present in Nos. 4,5,6.
b - sericite, which with epidote constitutes pseudomorphs of plagioclase phenocrysts
c - probably magnetite unless indicated pyrite (py).

1. Sample 8-1-1899A, feldspathic graywacke (1899, P-5)
2. Sample 8-1-1899B, feldspathic graywacke (1899, P-5)
3. Sample 8-1-1890, rhyodacite (?) (1899, P-5)
4. Sample 8-1-1906A, rhyolite (1906, O-5)
5. Sample 8-1-1909, rhyolite (1909, O-5)
6. Sample 6-3-1459, gneiss (rhyolite ?) (1459, N-6)
7. Sample #1c, rhyolite breccia (#1, P-7)
8. Sample #1e, rhyolite (#1, P-7)
9. Sample 1-1-50c, andesite porphyry (50, O-6)

metasedimentary, rocks. Sample 8-1-1899A is a variety which is black, very fine-grained (0.1 mm) and even-grained with evenly-dispersed chlorite defining a moderate foliation. Sample 8-1-1899B is characterized by the presence of 25% of 1 mm subhedral-anhedral plagioclase grains in a 0.1 mm matrix of quartz, feldspar and biotite (Plate 27A). Poorly-defined clusters and lenses of 0.3 mm biotite define a weak foliation. The latter sample comes from an interlayered sub-unit of a generally fine-grained gray unit which is elsewhere free of the large (1 mm) plagioclase crystals. The concentration of these large grains in layers appears to be a sedimentary effect. A nearby rhyodacite(?) porphyry (1890) possibly interbedded with graywacke is a possible source for the plagioclase crystals.

Round apatite is abundant in both rocks and is probably clastic in origin. Pyrite, identified megascopically, appears as perfect cubes in thin section and is certainly metamorphic. Biotite is a metamorphic phase representing an original mafic mineral-clay mineral fraction. Chlorite after biotite typically has interleaving lenslets of epidote and possibly leucoxene.

Feldspar is almost totally altered to very fine-grained sericite or clay minerals. Trace plagioclase remnants are probably calcic oligoclase. A trace amount of alkali feldspar was identified in one sample.

On the basis of mineralogy and compositon (Pettijohn, 1957, p. 304) and bedding characteristics these samples and abundant similar rocks in both pendants are probably metagraywacke. They are potentially equivalent to graywackes in the Alder Group.

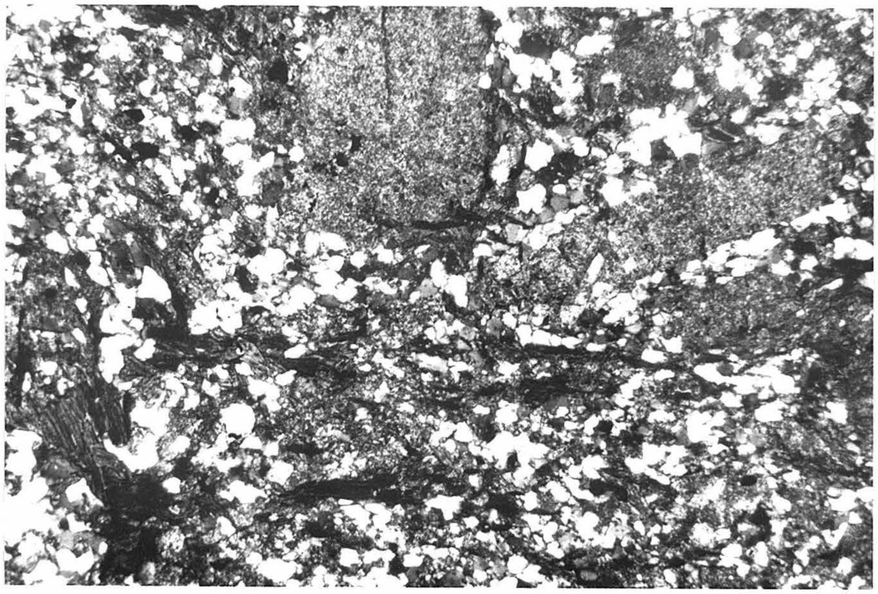
Rhyolite

Samples of moderately to extensively metamorphosed rhyolite were collected from outcrops near station 1901 in the western pendant. In specimen 8-1-1909, 15% of 2 mm feldspar phenocrysts are fairly well defined megascopically and in thin section are seen to be mostly granoblastic aggregates of albite (Plate 27B). The groundmass, composed mainly of alkali feldspar and quartz with minor albite, is quite homogeneous in mineral distribution and grain size (0.03 mm, locally up to 0.1 mm). If untwinned, albite may be more abundant in the groundmass than estimated. Alkali feldspar is orthoclase (2V $\sim$ 60°), but locally exhibits incipient microcline twinning.

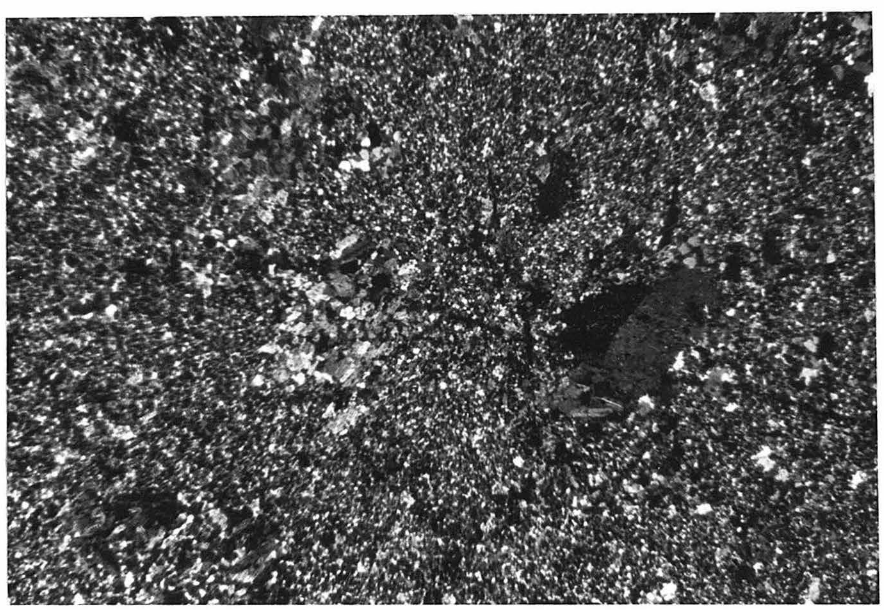
In contrast, sample 1906A has a foliation, poorly defined remnant phenocrysts and a rather inhomogeneous groundmass. Megascopically the foliation is defined by a smearing out of phenocrysts and of larger (0.2 x 3 cm) lenses which may be pumice fragments. Foliation is also defined in thin section by roughly lenticular plagioclase-rich and alkali-feldspar-rich areas and by a crude layering defined by finer and coarser areas in the groundmass. Grain size varies from about 0.05 to 0.5 mm; the coarsest areas usually being quartz-rich lenses.

A few solitary albite phenocrysts in both rhyolite samples are fairly well-preserved morphologically and contrast with the pseudomorph albite clusters. Some albite clusters have partially replaced extensively altered original phenocrysts which are highly clouded with fine-grained material. These relationships suggest the albite aggregates may be replacing alkali feldspar phenocrysts.

PLATE 27. GISELA PENDANTS



A. Metamorphosed graywacke. Sericitized plagioclase grains in a quartz-feldspar-biotite (chloritized) groundmass. Large plagioclase grains are concentrated in sedimentary lenses. Biotite defines foliation. Cross polarized light, 2 x 3 mm.



B. Metamorphosed rhyolite. Clusters of small albite crystals (left) are probably pseudomorphous after K-feldspar phenocrysts. Albite phenocryst (right) is apparently unmodified. The rock contains no calcium-bearing phase other than albite and only a percent or two of Fe-Mg-bearing phases (opaque oxides). Cross-polarized light, 6 x 9 mm.

Muscovite in both rhyolites occurs in the groundmass and partially replaces feldspar phenocrysts.

Northward in the pendant at a contact with diorite (1459, N-6) a gneissic felsic rock may be highly metamorphosed rhyolite. Sample 8-1-1459 is comprised of about 80% 1-3 cm gray albite-quartz layers and about 20% 0.5-1 cm flesh-colored orthoclase-quartz layers. Orthoclase- and plagioclase-rich lenses in sample 1906A are evidence of metamorphic differentiation producing lamellar segregations. An end-product of this differentiation might be a hornfelsic gneiss like sample 8-1-1459.

Metamorphic modification of rhyolite samples (#1C, #1E; 1460, P-7) from the isolated southern tip of the eastern pendant is similar but less extensive than that of rhyolite in the western pendant. Sample #1C is a tuff or volcanic breccia in which about 30% of highly felsic 1-4 cm (pumice?) fragments and a few percent of quartz and alkali feldspar phenocrysts occur in a 0.02-0.2 mm quartz-feldspar matrix. Secondary biotite crystals occur throughout this groundmass but tend to be concentrated in 1-2 mm areas which may have been either breccia fragments or a primary mafic phase. Imposed on the primary pyroclastic heterogeneity is a moderate development of albite- and orthoclase-rich domains. This is interpreted to be a metamorphic effect like that already described for rhyolite 1906A in the western pendant. Alkali feldspar is orthoclase and slightly perthitic.

Rhyolite #1E contains about 2-3% of 1-3 mm quartz and albite phenocrysts and 30% modified spherulites in a homogeneous (.05-.1 mm) quartz-feldspar matrix. Concentric-radial features (1-2 mm) defined generally by finer quartz-feldspar intergrowth near the center and a coarser, outer feldspar-rich ring are interpreted to be recrystallized spherulites. They are often cored with quartz or feldspar crystals. Another texture peculiar to this rock is an intimate association of orthoclase and albite wherein the latter is found only as paired bars (slabs) on opposite sides of most orthoclase grains. This may be a unique type of granular exsolution and suggests that the rhyolite was hypersolvus. These recrystallization textures are ascribed to contact metamorphism. Dikes from both Green Valley Granophyre and probably hornblende granophyre intrude the rhyolite at station 1460 and do not possess the subtle textural modifications of samples #1C and #1E. This logically ties the metamorphic event to the intrusion of the hornblende granophyre and/or diorite.

Rhyolite #1E is the least recrystallized of the rhyolite samples. It is also the most oxidized; most iron is in opaque minerals and orthoclase is hematite clouded. More biotite and the absence of clouding in other samples may be the result of reduction in the contact metamorphic environment. Pyrite in the wackes is evidence of a reducing environment.

By virtue of its high opaque/Fe-Mg silicate ratio, red feldspar clouding, presence of fluorite, and more importantly because of its highly felsic and alkaline character, rhyolite #1E is very much like characteristic Haigler rhyolite. The other rhyolites do not share all these characteristics but they too are highly felsic and alkaline. It is apparent from mineralogies that alkali/lime and Fe/Mg ratios are very high and that the rocks have a very high differentiation index. The strong similarities to Haigler lithology support the hypothesis that the pendants were derived from Haigler rhyolite.

Andesite Porphyry

Sample 1-1-50B, an andesite porphyry from the eastern pendant (50, 0-6), has well-preserved porphyritic and vesicular textures. Pseudomorphic euhedral plagioclase phenocrysts, totally replaced by epidote and serecite, constitute about 20% of the rock. The groundmass is a very fine-grained (0.01 mm) mosaic of anhedral oligoclase(?) in which is disseminated even finer opaque dust, biotite, and hornblende and occasional 0.1-0.2 apatite and opaque grains.

Prismatic to acicular amphibole (α = pale green-yellow, β = dark yellow-green, γ = deep blue-green) in both groundmass and amygdules is clearly of metamorphic origin. The seriate grain size distribution of both amphibole and biotite, from anhedral sub-microscopic crystallites to 0.02-0.04 mm subhedrons, and the hornfelsic mosaic of plagioclase are due to metamorphic recrystallization.

Andesite porphyry of the eastern pendant is of appropriate composition to correlate with Board Cabin andesite, but its simple, blocky plagioclase phenocrysts contrast sharply with the complex, platey, multiple phenocrysts observed in the latter.

MAFITE PORPHYRY AND ASSOCIATED ROCKS

Texture and mineralogy of mafite porphyry and associated gabbroic pods suggests that these rocks are igneous in origin and supports correlation of scattered mafite porphyry occurrences. It is suggested that mafite porphyry provided the heat for partial melting of the buchite body. Petrographic characteristics of vitreous black 'porphyry,' a sub-unit of mafite undifferentiated in contact with both buchite and mafite porphyry, suggest that it is hybridized mafite porphyry which has assimilated large quantities of buchite and probably Haigler rhyolite. Analogous features in the laminated mafite-felsite block within the main mass of mafite porphyry suggest this block is a xenolith of extrusive rhyolite which was partially melted and digested by the mafic magma.

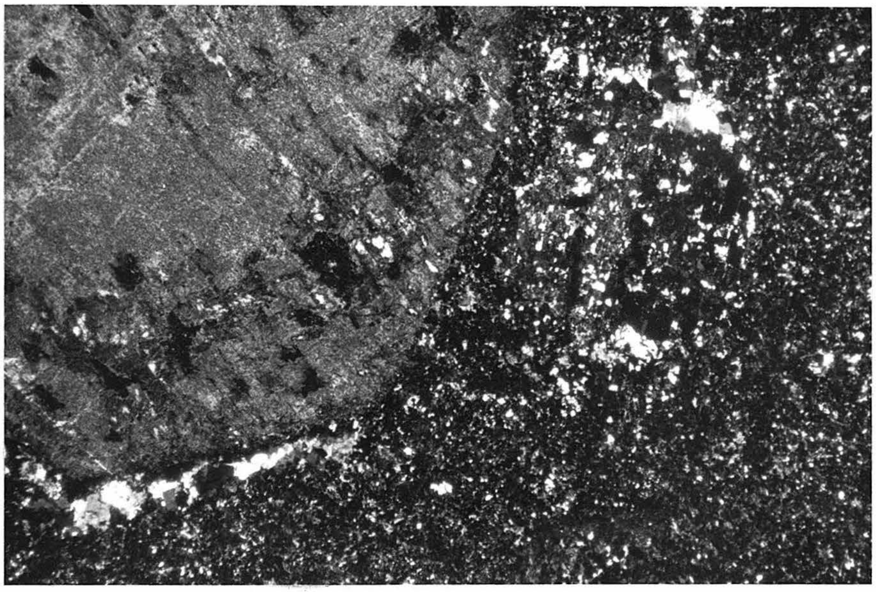
Field stations referred to are located on Plate 1 and in Figure 3.

Mafite Porphyry

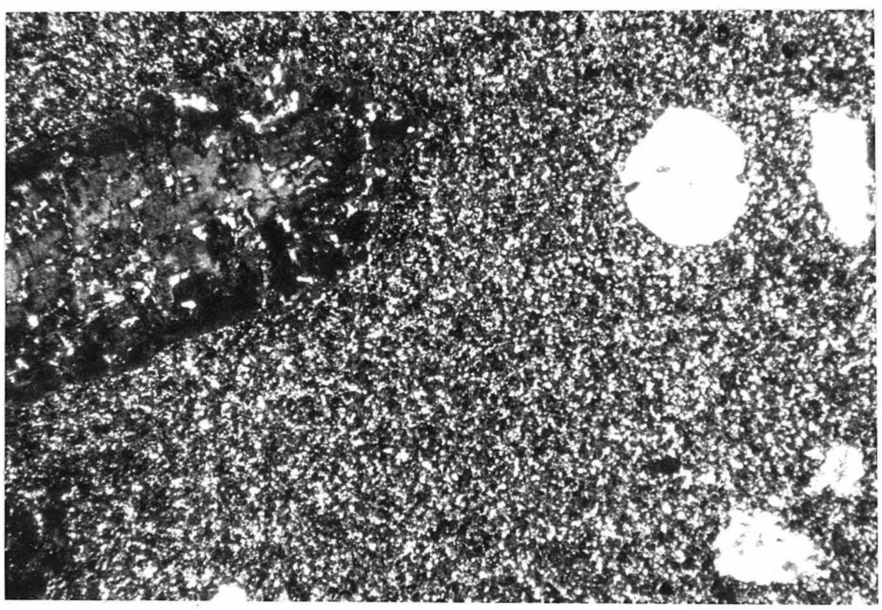
MINERALOGY AND TEXTURE

Table 6, page 285, presents a mode for a mafite porphyry sample from the main mass (2166, 0-6). Plagioclase and alkali feldspar megacryst amounts were estimated megascopically to be about 3% and 1%, respectively, and the groundmass count was normalized to 96%. A photomicrograph (Plate 28A) of this sample shows a portion of a 1 x 2.5 cm plagioclase megacryst and a 3 mm anhedral alkali feldspar crystal set in the amphibole-plagioclase-(opaque oxide-quartz-alkali feldspar-apatite) groundmass. Plagioclase megacrysts are euhedral and the 1-10 mm alkali feldspar crystals have anhedral to euhedral external forms. All alkali feldspar crystals have complex internal structures which may be due to a combination of exsolution, replacement and, probably primarily,

PLATE 28. MAFITE PORPHYRY



A. Part of a sericitized plagioclase megacryst and a blocky, castellated alkali feldspar phenocryst (?) (with Cb twin and internal quartz blocks) in a fine-grained amphibole-plagioclase matrix. Cross polarized light, 6 x 9 mm. (Main mass; 2166, O-6)



B. Blocky alkali feldspar phenocryst(?) (internal quartz blocks) and quartz phenocrysts(?) in amphibole-plagioclase groundmass. Cross polarized light, 6 x 9 mm. (Occurrence intruding Haigler rhyolite south of Tonto Creek; 2174, P-7) resorption. The most common internal texture is the block and castellate form shown in Plate 28A. Intergrown in the interior of the feldspar is quartz, plagioclase, and some amphibole and apatite.

Marginal tiny preserved portions of the plagioclase megacryst in Plate 28A give extinction angles indicating a minimum An content of 35 to 40. Indices of refraction of the groundmass plagioclase laths suggest a composition of about An_{30-35}. Interstitial alkali feldspar in the groundmass is very well preserved and is weakly to moderately perthitic, whereas the megacryst alkali feldspar is generally strongly clouded and altered.

Amphibole in the groundmass is exceedingly well-preserved and has the pleochroic scheme: α brown-yellow, β deep brown-green, and γ bright (bluish) green. Minute (0.005 x 0.1 mm) apatite needles are ubiquitous and remarkably abundant; rarely apatite occurs as subhedral, stout prisms with cross-sections of 0.1-0.2 mm. Quartz and alkali feldspar are interstitial to subhedral plagioclase and amphibole grains.

Quartz insets (0.5-2 mm) occur in trace amounts throughout most of the main mass of mafite porphyry but do not occur in this thin section.

The above description applies also to mafite porphyry which intrudes rhyolite at station 2174 (P-6) with the following minor exceptions. The latter may be slightly less mafic, its groundmass slightly finer-grained and it contains a few 0.5 mm hornblende phenocrysts and one strongly altered 0.5 mm pyroxene phenocryst. It also contains alkali feldspar insets with latticework texture typical of buchite (page 276) in addition to the large block and castellate alkali feldspars (Plate 28B). The few 1-2 mm quartz crystals present are rounded to subhedral.

Mafite porphyry in the Picket Pen fault slice is similar to that from the main mass, but has latticework alkali feldspars and no block and castellate forms. Groundmass plagioclase laths are coarser, the rock is less mafic, and the mafic component is all chlorite and opaque oxides.

Textures in mafite porphyry near diorite at station 168 may indicate contact metamorphic recrystallization. Groundmass plagioclase is relatively coarse, is bladed, and poikilitically encloses hornblende and opaques. Quartz insets are extensively recrystallized and heavily armored with hornblende. Amphibole mantled quartz is similar to amphibole-quartz amygdules of the andesite porphyry from the eastern Gisela pendant. They differ in having opposite concentric distributions of the two phases, but may both manifest a reaction between quartz and mafic groundmass in the same metamorphic environment.

COARSE GABBROIC PODS

Plagioclase of the gabbroic pods is much less extensively sericitized than are the megacrysts in mafite porphyry. Extinction angles on a Cb-Ab twin combination in a well-preserved, weakly zoned portion give a composition of An_{60}. The matrix is about 40% chlorite, 10% opaque oxides, 15% calcite and 35% unidentified exceedingly fine-grained, high-index material (some may be leucoxene). The oxides are quite coarse (2-3 mm skeletal network) and the other phases clearly have replaced mafic crystals perhaps half as large as the 3-5 cm plagioclase crystals.

CORRELATION AND ORIGIN

Mafite porphyry has an igneous porphyritic texture. The sericitized plagioclase megacrysts, the peculiar alkali feldspar crystals, the resorbed quartz phenocrysts and the distinctive hornblende-apatite-rich groundmass characterize each occurrence. On this basis alone the isolated occurrences seem to be equivalent and would be igneous because at station 2174 mafite porphyry intrudes rhyolite.

In addition to these positive criteria of correlation and igneous origin there are arguments against a metasomatic origin (page 283) which seems to be the only possible alternative origin. The first argument is that the mafite porphyry near diorite shows evidence of a metamorphic recrystallization but elsewhere is texturally homogeneous. If the whole mass were formed by metasomatic modification of rhyolite one might expect textural variations throughout.

A more powerful argument arises from the nature of the megacrystic alkali feldspar in the mafite porphyry. Many of these crystals are much too large (up to 1 cm) to simply be remnant from modified rhyolite and therefore they would have to be metasomatic. This is unreasonable because their texture indicates that they were unstable and were being reacted or resorbed, rather than growing in the mafic groundmass. The block and castellate textures might be the result of resorption along (001) and (010) cleavages thus allowing magma to intricately penetrate the crystals. The great variation from anhedral to euhedral external form indicates also that these crystals did not grow together in a metersomatic environment.

A further argument against a metasomatic origin for mafite porphyry is the nature of the coarse gabbroic pods and their relationship to mafite porphyry. There can be no doubt that the large plagioclase crystals in both occurrences are of the same origin because they are alike in shape, size, composition and alteration character. It seems unreasonable that there should be such a profound change across the sharp boundary between mafite porphyry and pod (page 92) if both were formed in the same metasomatic process. Moreover, the preferred orientation of plagioclase crystals in the pods (Plate 14B) argues for accumulation; random orientation and more interference would be expected if the crystals had grown statically in a pendant.

For the reasons enumerated above, because mafite porphyry probably provided the heat necessary to form the buchite, and because of the evidence that laminated mafite-felsite and vitreous black 'porphyry' are the result of intrusion and partial melting of rhyolite and quartz monzonite(?) by mafite porphyry, it is believed that all mafite porphyry occurrences are magmatic in origin. The gabbro pods are probably cognate xenoliths of cumulates carried up by the magma from depth, but it is not certain whether the megacrysts in the porphyry have been fragmented from the pods or were dispersed crystals in the magma. The latter is suspected because the coarse mafic minerals of the pods are not found associated with any 'free' megacrysts. The very coarse mafic matrix in the pods argues against formation of the gabbro by accumulation of megacrysts at the present emplacement level.

Mafite porphyry is an alkali-rich basaltic rock, very different in composition from the rocks of the Gibson Complex (see modes, Table 6). Because of the unknown extent of modification by assimilation it cannot be said whether the magma was genetically related to the parent magma of the Gibson Complex. Demonstration that the large alkali feldspar crystals are phenocrysts rather than xenocrysts would suggest that the rock is not related to the Gibson Complex.

Buchite

Devitrification and/or incipient micrographic texture in coalescing intergranular films in buchite clearly indicates these areas were liquid and were possibly quenched to a glass (Plate 29A). They were the result of a grain boundary eutectic melting phenomenon. The degree of partial melting varies from a few percent to about 75%.

Quartz monzonite possibly a parent rock to the buchite (page 87) is a medium to fine-grained seriate porphyritic rock. Phenocrysts are 0.5-2 mm plagioclase, usually mantled by perthitic alkali feldspar, and 0.5-1 mm perthite and quartz crystals. Biotite (mostly altered to chlorite), quartz, and euhedral, bladey alkalifeldspar constitute a 0.2-0.5 mm groundmass. The groundmass texture borders on being micrographic. In the buchite, remnant crystals are plagioclase, often mantled with alkali feldspar, alkali feldspar and quartz; grain sizes are in the range of the seriate phenocrysts of the quartz monzonite and have a similar pattern of distribution. No remnant mafic crystals larger than about 0.3 mm exist in the buchite and much of the mafic component apparently was in the melt phase and now exists as tiny altered amphibole(?) needles in the devitrified(?) glassy areas. If quartz monzonite was the parent rock, it appears that the groundmass area including much biotite was melted initially, then the larger crystals began to be resorbed into the melt.

Alkali feldspar in buchite often has a rather regular internal latticework of very fine quartz or quartz and feldspar. Shown in Plate 29B is alkali feldspar which is partially clear and homogeneous and partially cloudy and converted to this latticework. The clear 'preserved' portion is not perthitic and indicates, if quartz monzonite was the parent rock, that the perthite of the latter was homogenized in the high temperature melting event. Following homogenization the alkali feldspar was marginally resorbed (along with quartz and plagioclase) and was either internally resorbed or replaced to give rise to the lattice texture. Whatever the exact nature of the intricate intergrowth it is the result of instability at high temperatures, possibly requiring the presence of melt.

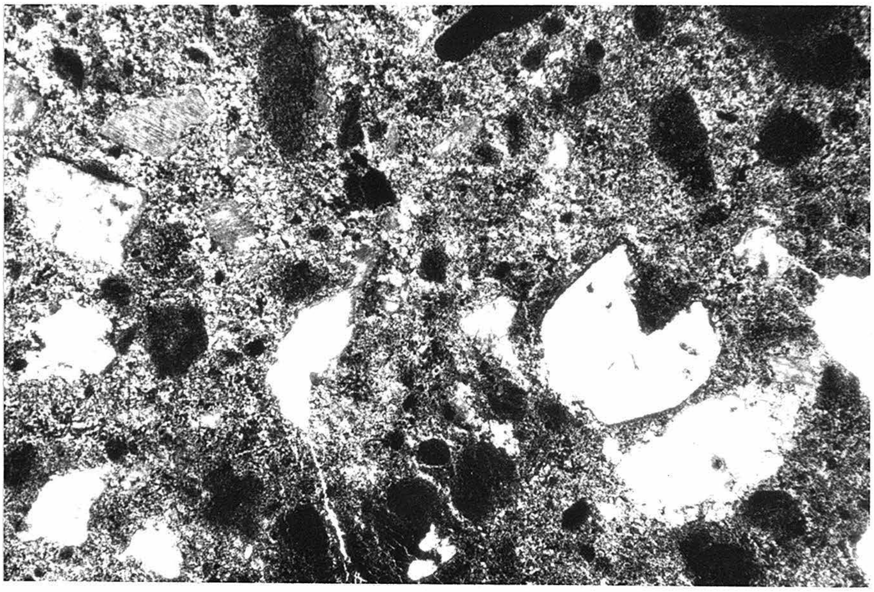
The main buchite mass is in contact with vitreous black 'porphyry' which is possibly transitional into mafite porphyry. Hornblende granophyre crops out near the buchite body and contains xenoliths of buchite. Diorite crops out a mile away and has apparently not modified the nearby parent(?) quartz monzonite. Mafite porphyry was no doubt much hotter than either diorite (by 100-200°C) or hornblende granophyre

PLATE 29. BUCHITE

A. Strongly resorbed feldspar (mostly dark) and quartz (light) crystals enveloped in coalescing films of axially devitrified(?) partial melt (about 70-80%) groundmass. Quartz, feldspar and amphibole(?) or opaque oxide needles are sub-parallel in the finely crystallized melt portion. Plane-polarized light, 6 x 9 mm.

B. Fretted alkali feldspar crystal from upper part of Plate A. Upper part of the grain is partly clear and unexsolved. Lower portion has delicate lacework typical of buchite alkali feldspar. Cross-polarized light, 2 x 3 mm.

PLATE 30. VITREOUS BLACK 'PORPHYRY'



A. Clear resorbed quartz and feldspar crystals in a heterogeneous groundmass of vitreous black 'porphyry.' The fine-grained dark areas are mafite porphyry sometimes containing large or fragmented plagioclase megacrysts. Note similarity to laminated mafite-felsite, Plate 31B. Plane-polarized light, 6 x 9 mm.

B. Two alkali feldspar crystals from left central portion of Plate A. The one on the left is entirely fretted in the same manner as alkali feldspar in buchite (Plate 29 B). Lacework has developed only on the margin of the resorbed grain to the right. Textures suggest mixing of buchite (and possibly rhyolite) and mafite porphyry (see text). Cross-polarized light, 2 x 3 mm.

PLATE 31. LAMINATED MAFITE-FELSITE

A. Mafic and felsic laminae of least mixed laminated mafite-felsite. Dark material is fine hornblende-rich mafite porphyry. Light layers with subhedral quartz and alkali feldspar crystals are probably rhyolite. Large central alkali feldspar crystal was apparently marginally brecciated as it was engulfed by the mafic magma and rotated against passageway walls. Plane-polarized light, 6 x 9 mm.

B. Indistinct mafic and felsic laminae from a portion of the mafite-felsite block in which mixing of the two phases has been very extensive. Plane-polarized light, 6 x 9 mm.

(by 200-300°C) and is not only by field relations but by this fact the most reasonable source of heat for melting of the quartz monzonite(?) to form buchite. Highly silicic rocks of the Gisela pendants near contacts with diorite were metamorphically recrystallized (page 266), but not melted as was the large buchite mass.

Vitreous Black 'Porphyry' and Laminated Mafite-Felsite

A thin section of vitreous black 'porphyry' (2120, P-6) has a very fine-grained and heterogeneous groundmass in which are set about 5-10% each of 0.5-2 mm variously resorbed alkali feldspar and quartz phenocrysts and a few 2-10 mm altered plagioclase crystals (Plate 30A). The latter in mafic-rich areas quite clearly indicates that one component of this hybrid rock is mafite porphyry. The other component is very felsic and in it are concentrated the alkali feldspar and quartz xenocrysts(?). Concentrations of 0.01-0.05 mm hornblende and opaque oxides indicate that about one-third to one-half of the rock is mafite porphyry.

Some alkali feldspar crystals have a fretted or latticework texture (Plate 30B) like those in buchite. Plagioclase mantled with alkali feldspar is also analogous to a buchite feature.

In the vicinity from which the sample was taken are xenoliths of buchite and Haigler rhyolite. The xenocrysts(?) of the felsic portion of the sample are exceedingly similar to remnant crystals of the buchite and may be too abundant to have been derived by mixing with the nearby crystal-poor Haigler rhyolite.

It is hypothesized that the vitreous black 'porphyry' is largely the result of a mixing of mafite porphyry and partially melted buchite. The fragmented character would be either a result of the predominance of the felsic magma and/or of earlier solidification of the mafic magma (because of its higher solidus temperature) which may then have been fragmented in continued movement of the hybrid mush. The latter is suggested and would also explain strung out areas of mafite porphyry surrounded by more felsic material in a transitional area from mafite porphyry to vitreous black 'porphyry' (page 97).

An alternative origin for vitreous black porphyry is that mafite porphyry was extensively assimilated by intrusive rhyolite. This is less likely because of the similarity of the phenocrysts to those in buchite, especially the fretted alkali feldspar. Such a texture was not observed in the major felsic hypabyssal units of Tonto Basin. Moreover, gradations from vitreous black 'porphyry' are into mafite porphyry and not into rhyolite.

Laminated mafite-felsite (168, O-6) is composed of fine-grained hornblende-rich and quartz/feldspar-rich layers (Plate 31). Occasional large (few mm to few cm) sericitized plagioclase crystals occur in the former and 0.5-2 mm quartz, alkali feldspar and plagioclase crystals occur in both, though only rarely in the mafic layers. The mafic layers are clearly mafite porphyry and are continuous with mafite porphyry which surrounds the block of laminated mafite-felsite rock. Hornblende is considerably coarser than in the vitreous black porphyry, possibly because of metamorphism by the diorite. Felsic layers are either even-grained or very finely micrographic and vermicular.

In portions of the mafite-felsite where laminae contacts are sharp (Plate 31A) felsic phenocrysts do not occur in the mafic areas. Alkali feldspar is perthitic, somewhat clouded, and sometimes strongly resorbed though commonly very euhedral. Euhedral form of phenocrysts suggests that the felsic portion of the rock is rhyolite. Elsewhere contacts between mafic and felsic portions are diffuse or not definable (Plate 31B) and quartz and alkali feldspar phenocrysts are fairly common in the most mafic areas. Alkali feldspar phenocrysts seem to be more strongly resorbed and many are quite clear and homogeneous ($2V_{\alpha}$ = 40-50°). Margins and occasionally interiors of these crystals have a fretwork distinct from micrographic or vermicular intergrowth in the groundmass. This fretwork, though a little different, may be akin to the ribbony latticework of feldspar in buchite and vitreous black 'porphyry.'

It appears that the laminated mafite-felsite rock is the result of penetrative intrusion of stoped rhyolite by mafite porphyry. The through-going, small-scale interlayering would have resulted by penetration of the mafic magma along closely-spaced flow partings in the extrusive rhyolite. The micrographic intergrowth suggests that extensive melting of the rhyolite occurred. In regions where cooling was slower, more melting, more phenocryst resorption, and more mixing of the two magmas occurred. Perthitic(?) alkali feldspar phenocrysts were homogenized and then began to react or to be resorbed in such a way as to give rise to the peculiar intergrowth texture possibly analogous to that in buchite.

An alternative explanation for the felsite-mafite layering is amphibolitization of a felsic pendant in diorite magma. A metasomatic fluid would have penetrated rhyolite along flow partings and precipitated amphibole and plagioclase. This would require all the main mass of mafite porphyry to be of metasomatic origin with the laminated mafite-felsite block an incompletely reacted area. This alternative is not given much credence because some mafite porphyry intruded rhyolite (2174, P-7) and all the scattered occurrences have a similar 'igneous' texture. Moreover, mafite porphyry is the only reasonable candidate in the area to have provided the heat to form buchite.

It seems unreasonable that rhyolite could intrude texturally isotropic mafite porphyry in such a way as to give rise to the intricate interlayering.

GIBSON COMPLEX

This work represents an incomplete examination of the petrography and petrology of the Gibson Complex, although hornblende granophyre at Gisela was studied in detail. A preliminary understanding of the complex is important in considering the petrogenesis of the volcanic rocks in relation to the plutonic rocks of the study area (page 421).

The major Gibson phases are considered to be a series differentiated from a parent basalt magma within the confines of the complex. Layered gabbro is an early cumulate phase. Most of the magma crystallized statically as massive diorite. Hornblende granophyre, and possibly other small felsic bodies are late differentiates emplaced at high levels. Hornblende granophyre apparently assimilated a high proportion of diorite as it coalesced (?) and rose to the roof.

Mineralogical and chemical compositions of the various phases are similar to those of comparable plutonic rocks of calc-alkaline batholiths. In overall character the complex is strikingly similar to the Guadalupe Complex (Best, 1963) of the western Sierra Nevada foothills.

Gabbro

MINERALOGY AND TEXTURE

Two gabbro samples from Round Valley were modally analyzed (Table 6). Sample 10-1-2154, from a rather homogeneously mafic-rich area within the layered gabbro, is a two-pyroxene gabbro. Sample 10-1-2155, collected a mile to the southeast about where the layering dies out, is a hornblende gabbro.

Both gabbros contain the same phases, except that pyroxene gabbro lacks quartz. Hornblende gabbro has more plagioclase, a lower color index, much less clinopyroxene and much more hornblende. Orthopyroxene contents are similar.

Euhedral to subhedral 1-2 mm plagioclase crystals are very well-preserved in the pyroxene gabbro and only slightly sericitized in the hornblende gabbro. Zoning is from An_{70} to An_{60} and from An_{60} to An_{50} in the respective rocks. Hornblende is also well-preserved and has a pleochroic scheme α = yellow-brown, β = dark golden-brown, and γ = dark brown with a hint of green.

Generally anhedral clinopyroxene (0.5-1 mm) has sharp, clean reaction contacts with hornblende and is well-preserved internally. Subhedral to anhedral orthopyroxene (1-2 mm) is considerably corroded

TABLE 6. MODAL ANALYSES, GIBSON COMPLEX AND MAFITE PORPHYRY

	1	2	3	4	5	6	7	8	9
quartz	-	1.0	8.9	6.8	18.7	27.2	21.2	31.8	5.5
orthoclase	-	-	-	-	15.4	10.5	32.0	43.6	6.9[b]
plagioclase	53.0	58.9	57.4	46.3	41.9	55.1[a]	28.2	20.7	43.6[b]
An content	70	60	47	alt	~30	alt	text	text	text
clinopyroxene	27.9	2.0	1.3	tr	-	-	-	-	-
orthopyroxene	4.4	3.4	-	-	-	-	-	-	-
hornblende	6.1	27.0	24.3	40.2	15.4	-	14.0	tr	38.6
biotite	0.2	0.7	-	6.0	-	4.6	0.3	1.7	-
chlorite	-	-	2.8	-	4.0	1.6	1.3	1.1	-
opaques	2.9	6.1	1.3	0.6	0.9	0.8	2.2	1.1	5.4
(olivine)[c]	(5.2)	(tr)	-	-	-	-	-	-	-
apatite	tr	0.7	0.2	tr	0.5	0.1	tr	tr	tr
epidote	-	0.2	0.4	-	2.8	tr	0.8	tr	-
color index	47.0	39.2	33.1	46.8	20.3	7.0	17.8	3.9	44.1
points	1741	1654	1522	665	702	1597	675	711	860
area (mm^2)	627	595	548	665	702	575	675	711	860
grain size (mm)	1.5	1.5	2	1	3	1	text	text	0.1

alt - altered, tr - trace, text - see text.
a -includes some altered orthoclase.
b -include orthoclase and plagioclase megacrysts, 1% and 3%, respectively.
c -chlorite-serpentine-opaque-mica(?) pseudomorphs probably after olivine.

1. Pyroxene gabbro 10-1-2154, Round Valley (2154, K-3).
2. Hornblende gabbro 10-1-2155, Round Valley (2155, K-4).
3. Biorite 9-3-2084A, Oxbow Hill (2084, M-2).
4. Meladiorite 6-3-1427, Gisela (1427, O-6).
5. Granodiorite 8-1-1898, Gisela (1898, P-5).
6. Leucogranodiorite 6-3-1431, Gisela (1431, O-6).
7. Hornblende granophyre 1-2-164, Gisela (164, P-6).
8. Leucocratic hornblende granophyre 10-1-2157, Gisela (2157, O-7).
9. Mafite porphyry 10-1-2166, Gisela (2166, O-6).

and altered to fine-grained material along grain boundaries and fractures. In neither pyroxene phase could exsolution lamellae be positively identified.

Opaque minerals occur in the olivine(?) pseudomorphs, as 0.5-1 mm irregular, anhedral grains, and, in the pyroxene gabbro, in symplectitic intergrowth with clinopyroxene. Anhedral, subequant 0.5 mm apatite occurs in both gabbros, but is much more abundant in the hornblende gabbro. Scarce 0.2 mm euhedral biotite plates also occur in both gabbros. Tiny amounts of secondary epidote, chlorite and calcite occur mostly in plagioclase.

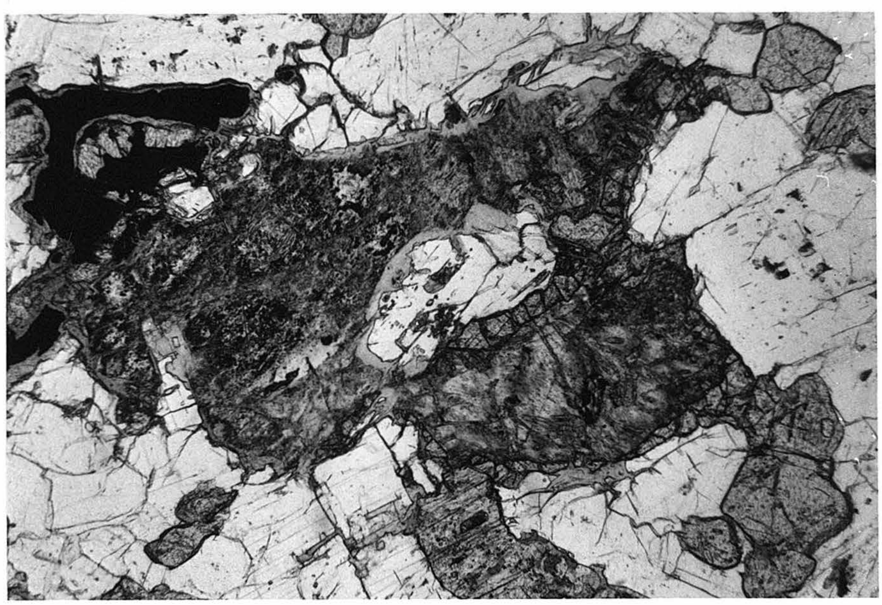
The lamination of the pyroxene gabbro is weakly defined in thin section by sub-parallel plagioclase crystals tabular on (010) (Plate 32A). A striking feature of both rocks is the network of poikilitic and skeletal hornblende. Between the large poikiloblasts of hornblende (up to 2 cm) the texture is hypidiomorphic-granular and the grain size is about 1-2 mm.

Hornblende forms reaction mantles around all opaque minerals and much of the clinopyroxene and internally replaces the latter in discrete patches. In these modes it is secondary, whereas the large ophitic crystals may be primary and intercumulous in the pyroxene gabbro.

Aggregates of chlorite, serpentine, fine opaques, and white mica (?), rimmed discontinuously with orthopyroxene, are interpreted as pseudomorphs after olivine (Plate 32B). The orthopyroxene mantled the olivine as a product of incongruent reaction with magma.

PLATE 32. PYROXENE GABBRO

A. Layering in pyroxene gabbro defined by sub-parallel orientation of plagioclase tablets. Note poikilitic hornblende, bottom right-center. Most small, splotchy or straiated grains are clinopyroxene. Pseudomorphs after olivine(?) occur in lower left and upper right. Cross-polarized light, 6 x 9 mm.



B. Pseudomorphs of olivine(?) from lower left of Plate A. Internal fibrous material is chlorite, serpentine, and white mica(?) with fine opaque oxide. Note thin discontinuous rims of orthopyroxene, particularly around the lower right pseudomorph. Plane-polarized light, 2 x 3 mm.

PYROXENE COMPOSITION

Utilizing the mode and chemical analysis of the pyroxene gabbro, assigning mineral densities from Deer, Howie, and Zussman (1963), and assigning minimum and maximum CaO contents of 14 and 15% to plagioclase, of 2 and 3% to orthopyroxene, and of 11 and 13% to hornblende, a mass balance calculation requires that the clinopyroxene contains between 20% and 23% CaO. The augite thus appears to be unusually calcium-rich for a two-pyroxene gabbro. This, in conjunction with the lack of exsolution, may suggest that, due to high water pressure and consequent extreme depression of the solidus, the pyroxenes crystallized at low temperatures far out on the limbs of the augite-hypersthene solvus. The late-stage alteration of olivine and crystallization of hornblende (and rarely, biotite) also suggest high P_{H_2O}.

Alternatively, the absence of exsolution lamellae in the pyroxenes might mean that total granular exsolution occurred under sub-solidus conditions.

Diorite

Diorite sample 9-3-2084A (Table 6) is probably typical of a great deal of the medium-grained diorite in the east-central part of the Gisela Complex. Weakly to moderately zoned calcic andesine is extensively altered to very fine-grained epidote and sericite. Scarce clinopyroxene is found as remnant cores in hornblende. Clusters of 0.2 mm pale green amphibole are possibly pseudomorphous after hypersthene. Hornblende is 1-3 mm, anhedral to subhedral and pleochroic in the scheme:

α = yellow, β = yellow green, and γ = yellow green.

Quartz is interstitial and forms recrystallization mosaics. Epidote in 0.2 mm crystals may in some cases be primary. Anhedral, subequant opaques and euhedral, stubby apatite are generally associated and in the 0.1-0.3 mm size range. Chlorite is apparently after biotite.

Strained plagioclase grains attest to some post-crystallization deformation.

Sample 6-3-1427 may be representative of the finer-grained diorite near Gisela. It is similar to the diorite just described but is more mafic. Plagioclase is totally sericitized and saussuritized. Hornblende may be somewhat recrystallized as it occurs in 0.1-1.5 mm disseminated and clustered anhedral to subhedral crystals as well as 1 mm subhedral poikilitic crystals. Pleochroism is α = very light yellow, β = yellow green, γ = medium blue-green. Biotite is recrystallized and strongly altered to white mica and to an unidentified dark, clouded phase. Another alteration mineral, probably pectolite, occurs usually in tiny veinlets.

Alkali feldspar was not identified in any of the half-dozen diorite samples thin-sectioned.

Granodiorite and Quartz Monzonite

Granodiorite 8-1-1898 and leucogranodiorite 6-3-1431 (Table 6) are variants in a range of intermediate rocks found in the southern part of the complex which generally appear to contain 10-25% alkali feldspar and 15-30% quartz. Field relations were not determined for the granodiorite but the leucogranodiorite sample is from the ubiquitous dikes which cut diorite in the area NW of the Connolly Ranch.

Granodiorite 8-1-1898 is hypidiomorphic-granular and texturally similar to the medium-grained diorite. Euhedral oligoclase/andesine grains are pervasively speckled with epidote and sericite. Subhedral, weakly perthitic orthoclase ($2V_{\alpha}$ = 30-40°) is quite well-preserved. Hornblende is considerably altered; quartz and biotite are found internally along the cleavages. Pleochroism is α = medium gold-yellow, β = dark brown-green, and γ = medium blue-green. Mosaic quartz is interstitial. Chlorite sheaths are at least partly after biotite.

Leucogranodiorite 6-3-1431 is allotriomorphic-granular and very weakly porphyritic with subhedral plagioclase. Weakly antiperthitic plagioclase is nearly all saussuritized and sericitized and frequently has clear albite(?) rims. Orthoclase ($2V_{\alpha}$ = 50-60°) contains 10-15% well-developed patch and string perthite and is also strongly altered. The disparity between modal (10.5%) and normative (20.0%) alkali feldspar may be partly due to misidentification of altered orthoclase as plagioclase. Biotite, mostly altered to chlorite, occurs in clusters of 0.1 to 0.5 mm grains which are suggestive of recrystallization. Only a trace of amphibole was noted.

A number of small quartz monzonite and possibly granite bodies were noted in the Gisela area and on Oxbow Hill. None were examined petrographically except the hornblende granophyre discussed separately in the next section and the small outcrop of quartz monzonite tentatively correlated with buchite.

Hornblende Granophyre

Hornblende granophyre contains plagioclase and hornblende xenocrysts, sometimes occurring with opaque minerals and apatite as incompletely disaggregated microxenoliths, and plagioclase, orthoclase, and quartz phenocrysts in a micrographic to vermicular groundmass of quartz and alkali feldspar. The parent magma, assumed to have the approximate composition of most leucocratic northern exposures, would have assimilated and disaggregated a quantity of diorite nearly equivalent to half its own volume to produce common hornblende granophyre. It is hypothesized that the granitic magma was a differentiate of the Gibson diorite and was able to assimilate a large quantity of high-level diorite as it rose to the roof of the complex because the diorite was hot.

MINERALOGY AND TEXTURE

Modally a quartz monzonite (sample 1-2-164, Table 6), common hornblende granophyre contains about 10-15% hornblende and about 25-30% plagioclase in a micrographic to vermicular groundmass of quartz and perthitic orthoclase. There are also a few percent each of 0.2-0.5 mm euhedral-subhedral quartz and orthoclase phenocrysts. Orthoclase also commonly mantles plagioclase. All orthoclase is perthitic (film to patch); both host and lamellae may be clear but the former is more commonly clouded. Plagioclase and hornblende vary considerably in grain size (0.5-4 mm), grain morphology and overall texture, though plagioclase is usually subhedral, and hornblende anhedral and ragged.

Chlorite occurs extensively as an alteration product of hornblende. Biotite, rarely an alteration mineral after hornblende is uncommon. Most rocks contain a few percent epidote mainly as an alteration product of plagioclase, occasionally as 1-2 mm aggregates of stacked, bifurcating platelets, and as a minor alteration product of hornblende.

Euhedral to subhedral opaque minerals (0.1-0.3 mm) and acicular apatite (0.02 x 0.1 mm) constitute a few percent and a trace, respectively, of most samples. Anhedral sphene is common in some sections. Fluorite and zircon are usually present in trace amounts.

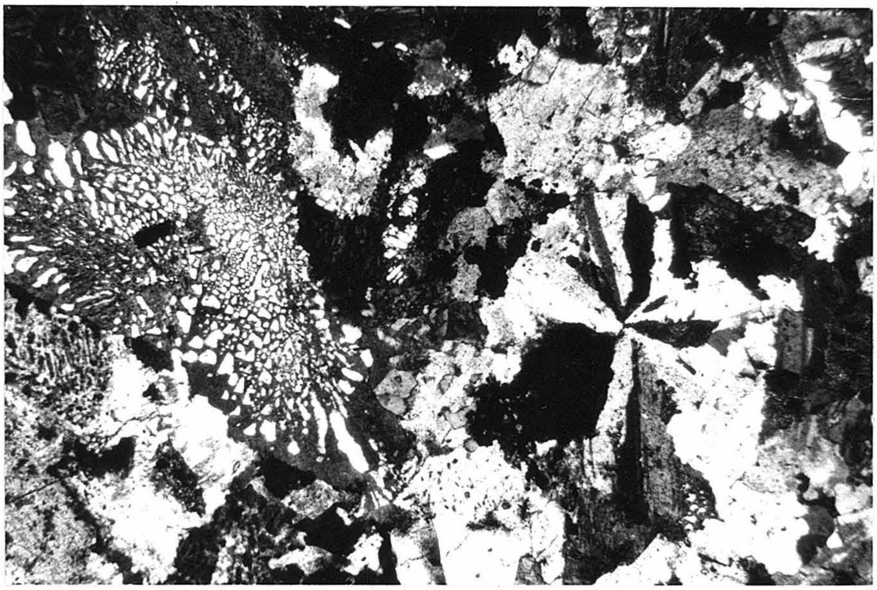
North of Bishop Nose fault mafic content is quite variable, but generally low. Biotite is sometimes more abundant than hornblende. In the most leucocratic specimen (10-1-2157, Table 6) hornblende is absent and the color index is only 3.9.

Amount and perhaps coarseness of micrographic intergrowth are roughly inversely proportional to hornblende plus plagioclase content. In the highly leucocratic specimen (10-1-2157) about 70% of the rock is a mosaic of alkali feldspar and quartz texturally transitional between micrographic and granular. In common hornblende granophyre, micrographic intergrowth is very fine and intricate and comprises 20-50% of the rock.

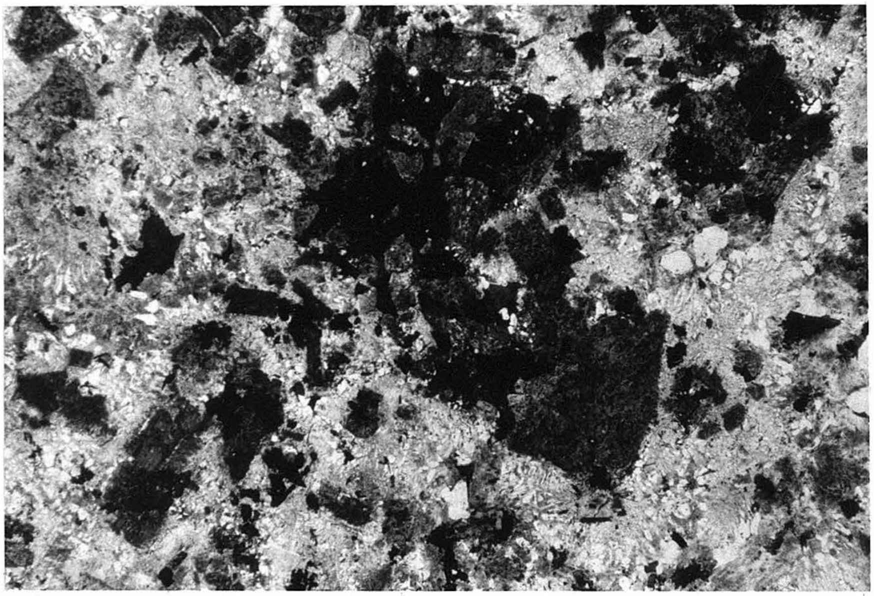
Shown in Plate 33A is typical micrographic texture in which are seen small (0.2-0.4 mm) euhedral quartz and alkali feldspar and plagioclase phenocrysts which are generally core crystals to the 0.5-3 mm micrographic domains.

A continuous size distribution of diorite fragments exists from fist-sized inclusions observed in outcrop down to clusters of a dozen crystals in thin-section. There can be little doubt that the best

PLATE 33. HORNBLENDE GRANOPHYRE



A. Micrographic texture (quartz and alkali feldspar) in hornblende granophyre groundmass. Radial intergrowth on the right (a rare feature) is composed of albite and blue-green amphibole. Cross-polarized light, 2 x 3 mm.



B. Microxenolith of diorite (saussuritized plagioclase, amphibole, opaqe oxides, apatite) and isolated xenocrystic(?) plagioclase and amphibole in the micrographic groundmass. Small less-clouded plagioclase grains are phenocrysts. Small euhedral quartz and alkali feldspar phenocrysts are also present. Plane-polarized light, 6 x 9 mm.

defined of the smaller clots (Plate 33B) are microxenoliths of diorite. However, the clusters vary from relatively large and discrete to small (less than a half-dozen grains) and ill-defined. A small fraction of the total hornblende and plagioclase in the rocks clearly belongs to discrete microxenoliths but most hornblende and much plagioclase may nevertheless be xenocrystic (following discussion).

PLAGIOCLASE

Plagioclase is weakly bi-modal in size and also bi-modal or possibly tri-modal in composition.

Generally small (0.5-3 mm) crystals are closely associated and often overgrown with micrographic quartz and orthoclase. Larger 2-4 mm crystals (cluster-plagioclase) are most often associated with hornblende, opaques and apatite (sometimes clearly microxenoliths of diorite). Cluster-plagioclase is one-half to one-third as abundant as the groundmass plagioclase.

The smaller crystals are almost invariably unzoned, well-twinned albite ($\sim An_5$) with minor sericite and rare epidote alteration. The cluster-plagioclase is usually totally altered to sericite and epidote, appearing very dark in plane polarized light. However, some small crystals are dark and saussuritized and in a few thin sections plagioclase of all textural and size variations is lightly sericitized albite.

Exceedingly rare unclouded zoned plagioclase was also found, usually as grain margin remnants. Nearly all of these grains are small groundmass grains; a few may be cluster-plagioclase. In one grain a reversal of the sign of extinction at the extreme crystal edge denotes zonation through the approximate composition An_{20}.

Complete albitization in some thin sections suggests that the albite in hornblende granophyre is a product of late-stage alteration or a subsequent metamorphic event. Moreover, it seems unreasonable that albite could be a liquidus phase in a magma as calcic as hornblende granophyre.

A granophyre in the Guadalupe igneous complex (Best, 1963, pp. 234, 242) is almost identical in composition to the least-contaminated hornblende granophyre:

	10-1-2157	Guadalupe gphr 95
SiO_2	73.36	73.81
TiO_2	0.28	0.29
Al_2O_3	13.52	13.60
Fe_2O_3	as FeO	1.25
FeO	2.15	0.72
CaO	1.46	0.79
MgO	0.42	0.40
Na_2O	4.19	4.09
K_2O	4.57	4.49
TOTAL	99.95	99.44

Plagioclase of the Guadalupe granophyre zones from An_{25} to An_{10}. One would expect plagioclase in hornblende granophyre to be as calcic or more calcic because compositions, textures, mineralogies, and physical settings of these two bodies are similar and because uncontaminated hornblende granophyre contains more CaO (any effect from assimilation would be in the same direction). From the normative feldspar composition and modal plagioclase and perthite abundances of sample 10-1-2157, it is calculated that ideal original plagioclase and alkali feldspar compositions would have been An_{22} and Or_{59}, respectively. (The reliability of this method for approximating actual primary compositions is demonstrated in Figure 13. Certainly all albite in the hornblende granophyre body is secondary.

The zoned oligoclase remnants may be preserved liquidus plagioclase of the granophyre magma. Virtually all of this plagioclase was albitized. Saussuritized cluster-associated plagioclase may be xenocrystic andesine from the diorite. Though locally albitized it was altered primarily to sericite and epidote. The presence of andesine might be confirmed by further petrographic or microprobe study of zoned remnants.

HORNBLENDE

The mafic content (5-20%) of hornblende granophyre is almost completely a measure of the amount of hornblende and its alteration products, mainly chlorite. Chloritization, negligible to almost complete, probably occurred in response to the same conditions which caused albitization.

Hornblende, like plagioclase, displays a heterogeneity in grain geometry and composition. Pleochroism is generally γ = bright blue-green, β = yellow-green and α = light yellow-green, but ranges from this blue-green scheme to γ = brown-green, β = green-brown and α = yellow-brown, the browns being very soft. The brown-green variety is usually more nearly euhedral, a little larger (1-2 mm) and tends to be cluster-hornblende (usage analogous to cluster-plagioclase). Blue-green hornblende is generally smaller (0.2-1 mm) and somewhat ragged; it is sometimes found as acicular spray-aggregates and often as disseminated 0.2 mm crystals. It is also common in the clusters. Blue-green hornblende, by far the most abundant, was found in all samples, while brown-green was found in minor amounts in perhaps half. The brown-green variety is most abundant in the mafic xenolith-rich area south of Tonto Creek.

Brown-green hornblende is interpreted to most nearly preserve the original chemistry and grain geometry of xenolithic hornblende. Amphibole in all intermediate aspects between subhedral, clustered, brown-green hornblende and small, disseminated, ragged blue-green hornblende is presumably evidence of the xenolith-magma exchange reaction and recrystallization which were operating to bring the exotic hornblende into equilibrium.

Scarce radiating intergrowths of hornblende and plagioclase (Plate 33B) in a few thin sections are basically analogous to micrographic quartz-orthoclase intergrowths and may be evidence that blue-green hornblende crystallized from the granophyre melt. Blue-green hornblende, therefore, may have been in equilibrium with the magma, and may have formed both by crystallization from the magma and by reconstitution of exotic hornblende. The absence of hornblende and the very low color index in 'uncontaminated' sample 10-1-2157 suggests, however, that a large proportion of the total hornblende in the main part of the body is xenocrystic.

Assimilation of Diorite

Much plagioclase and hornblende appears to be exotic but because of reconstitution or alteration it is difficult to estimate directly the quantity assimilated. It is assumed that the parent magma had approximately the composition of the northern leucocratic granophyre and that it assimilated Gibson diorite. To test this assumption and to estimate the quantity assimilated, mixtures of the modal quantities (Table 6) of meladiorite (6-3-1427) and leucocratic hornblende granophyre (10-1-2157) were calculated in an attempt to duplicate the common hornblende granophyre composition (1-2-164). A hypothetical mode of 30% meladiorite and 70% leucocratic granophyre is remarkably like the actual hornblende granophyre mode:

	hornblende granophyre	70% leucocratic gphr 30% meladiorite
quartz	21.2	24.3
orthoclase	32.0	30.5
plagioclase	28.2	28.4
hornblende	15.6	15.6
opaques	2.2	1.0

For less mafic diorite the best hypothetical mode is more divergent but is also about a 3:7 mixture. It is concluded that a fourth to a third of typical hornblende granophyre is assimilated diorite.

Assimilated diorite was apparently thoroughly disaggregated and disseminated in the magma prior to intrusion at its present level because locally assimilated mafite porphyry is not at all well mixed. This suggests that assimilation occurred at some depth in the diorite.

The remarkably degraded and disseminated diorite fragments undoubtedly reached magma temperature prior to the high-level intrusion but failed to withdraw enough heat from the magma to quench it (though this may have caused formation of the 15-20% phenocrysts). Preliminary calculations involving heat exchange between magma and assimilated diorite show that the diorite in the source region must have been very hot when it was incorporated in the magma. If it had been cooler than 300-400°C it would have totally quenched the magma before dissemination of the fragments and hence before the high-level emplacement. If the diorite caused only the phenocryst crystallization its pre-assimilation temperature would have been no lower than 600-700°C.

It is hypothesized that the parent hornblende granophyre magma was a late granitic differentiate within the Gibson diorite. Assimilation occurred as the magma rose from its site of accumulation through hot diorite to be emplaced essentially at the roof contact.

Nature and Evolution of the Complex

Gabbro, diorite, and minor leucocratic rocks of the Gibson Complex are considered to be co-magmatic phases formed from a parent basaltic magma differentiated *in situ*. The gradation from gabbro into diorite and the prevalence of diorite in the complex is taken to be evidence that the magma evolved to a diorite composition. There are indications that the small felsic bodies represent minor late differentiation:
1) These bodies occur in the southern or upper part of the complex consistent with ascendancy from a source area internal to the mass.
2) A deuteric alteration similar to that of adjacent diorite is

possessed by the felsic rocks. 3) Some of the felsic units intrude diorite. 4) Hornblende granophyre is thought to have intruded hot diorite, indicating contemporaneity in origin.

The Gibson Complex is similar in many aspects to the Guadalupe Complex, western Sierra Nevada foothills (Best, 1963). Common characteristics are steeply-dipping layered gabbro gradational into massive diorite, essential absence of intermediate rocks, and granite and granophyre cap rocks. Agmatite in the Guadalupe Complex, formed by pervasive intrusion of granite magma upward into shattered(?) diorite roof rock, suggests a mechanism for the profound assimilation by hornblende granophyre in the Gibson Complex. The parent granite magma of the hornblende granophyre may have acquired its enormous charge of diorite by passing in the same way through a pervasively fractured hot diorite roof zone. Initially, some magma may have risen through the agmatite zone essentially uncontaminated to be emplaced as the northern leucocratic portion. Later magma would completely digest the small fracture-bounded(?) fragments of diorite as it rose to its final emplacement level.

The Gibson and Guadalupe bodies share a calc-alkaline character indicated by the early appearance of iron-titanium oxides and hydrous mafic minerals, by the predominance of hornblende and biotite over pyroxene in all except lower gabbros, and by the presence of much calcic plagioclase. The compositions of the four analyzed Gibson rocks (Plate 4) are similar to those of comparable plutonic rocks from many calc-alkaline batholithic terranes. A tentative AFM curve (Figure 21) is typical of calc-alkaline trends and the limited data apparently define a calcic or calc-alkalic alkali-lime index (Figure 24).

PAYSON GRANITE

Apparently systematic mineralogical variations suggest that high-level Payson Granite is biotite alkali granite and that ferro-hastingsite alkali granite occurs at depth. This implies that the body is slightly differentiated and supports the hypothesis that the upper granite surface is the original roof contact.

The silicic and alkalic nature of Payson Granite strongly implies a genetic relationship to Haigler rhyolite and the felsic hypabyssal sills. The biotite alkali phase of the Payson Granite is virtually identical in composition to alaskite sills.

MINERALOGY AND TEXTURE

Payson Granite is consistently hypidiomorphic-granular, medium- to coarse-grained, and very leucocratic. Frequently aggregated (5-15 mm) anhedral quartz comprises about one-third of the rock. Most of the remaining two-thirds is subhedral-euhedral 2-6 mm plagioclase and 5-10 mm perthitic K-feldspar. The few percent mafic minerals are 0.5-1 mm subhedral biotite, 0.5 mm anhedral opaques, and less commonly 0.5 mm subhedral-euhedral amphibole. These phases are commonly clustered. Accessory minerals are zircon, apatite, allanite, and occasionally fluorite.

Plagioclase commonly occurs in both as euhedral inclusions in alkali feldspar (Plate 34A) and as rapakivi mantles around alkali feldspar.

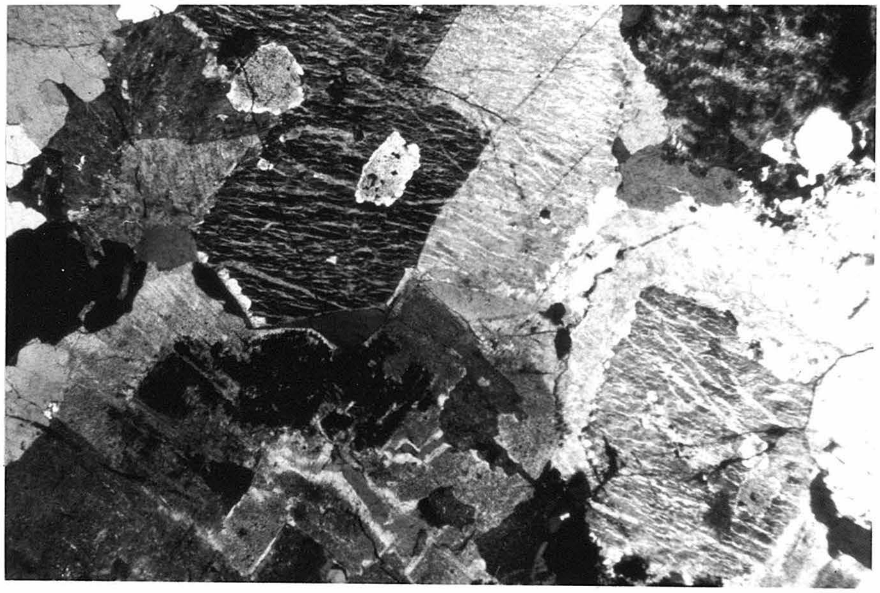
Scarce porphyritic marginal (Gibson Complex contacts) rocks and generally high-level syngenetic dikes contain quartz phenocrysts that are sometimes euhedral and bipyramidal. Associated alkali feldspar and plagioclase phenocrysts are euhedral to subhedral and rapakivi texture is common. Micrographic texture is sometimes weakly to moderately developed.

Modes in Table 7 probably reflect the major and possibly extreme mineralogical variations in the granite body. Biotite alkali granite and ferrohastingsite granite are the idealized end members of a continuum in which there are variations in shared characteristics.

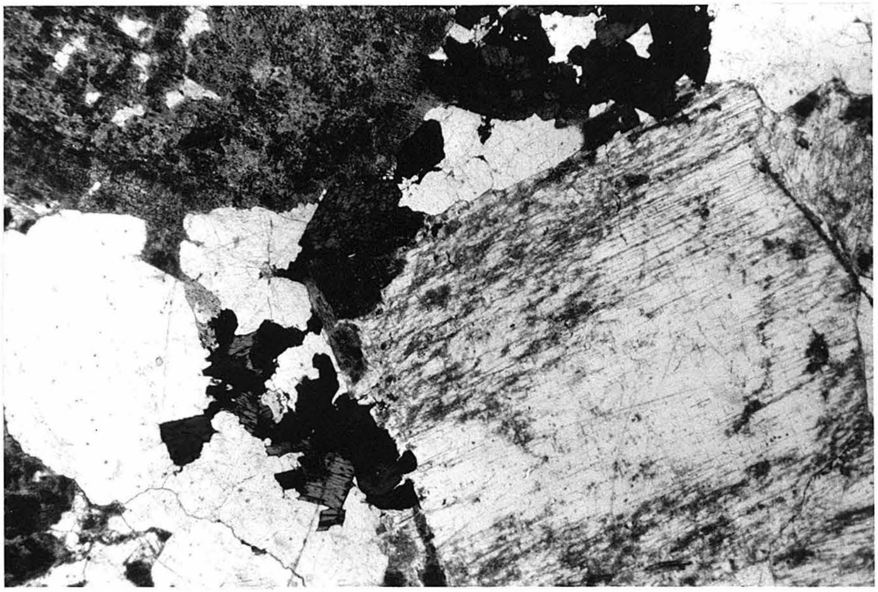
In biotite alkali granite plagioclase is albite to sodic oligoclase. Orthoclase may be present but K-feldspar is usually coarsely perthitic (patch or vein) microcline. Poorly preserved biotite is sometimes altered to chlorite, but more commonly, particularly in upper parts of the body, to hematite and muscovite. Strongly exsolved K-feldspar (Plate 34A), usually with a faint mottled microcline twinning, is often heavily clouded with hematite. Albite is unzoned to weakly zoned and speckled with sericite.

Ferrohastingsite alkali granite (Plate 34B) contains sodic to intermediate oligoclase with ferrohastingsitic amphibole as the major mafic phase. Coarsely perthitic clouded microcline or orthoclase is present, usually on grain margins, but is subordinate to clear, untwinned, more weakly exsolved (film perthite) orthoclase.

PLATE 34. PAYSON GRANITE



A. Biotite alkali feldspar granite with strongly exsolved vein perthite, clouded plagioclase, and dark concentrations of fine hematite partly pseudomorphous after biotite. Plagioclase insets in alkali feldspar (upper left) and plagioclase mantling (not seen) are common in all phases of Payson Granite. Cross-polarized light, 6 x 9 mm.



B. Ferrohastingsite alkali granite. Clusters of fine (0.5-1 mm) euhedral amphibole, biotite, and opaque oxides and much coarser plagioclase (saussuritized grain in upper left), alkali feldspar, and quartz. The large alkali feldspar grain has a clear, homogeneous interior with clouded, exsolved margins. Plane-polarized light, 6 x 9 mm.

TABLE 7. MODAL ANALYSES OF PAYSON GRANITE (AND ALASKITE AVERAGE)

	Ferrohosingsite alkali granite		Biotite alkali granite						
Number (see Table 8)	17	18	4	6	10	11	14		average of 12
Sample No.	3-1-677	10-1-2221	3-1-570	1-1-81A	1-1-60	1-1-57A	2-1-356	aver-age	alaskites (Table 14)
Location	G-6	F-3	E-15	E-17	E-13	E-12	L-9		
quartz	21.0	34.6	39.3	54.1	44.6	28.9	32.8	39.9	35.7
perthite	50.8	49.7	29.4	28.3	39.8	46.3	46.4	38.0	44.1
host	40.8	35.5	23.9	23.5	28.1	37.6	38.9		
lamellae	10.0*	14.2*	5.5	4.8	11.7	8.7	7.5*		
plagioclase	19.0	11.4	26.1	16.1	12.2	21.1	16.8	18.5	16.1
biotite	2.9	0.5	4.1	0.9	2.2	3.1	2.0	2.5	0.7
amphibole	5.4	3.6	0	0	0	0	0.1		0.9
mgt/ilm	1.0	0.3	0	0.2	0.3	0.5	0.8	0.4	1.1
hematite	0	0	0.9	tr.	0.8	0.2	0	0.4	0.8
other			0.2	0.4	0	0	1.0	0.3	0.2
counts	1891	788	440	540	623	577	732		
area (mm^2)	1891	788	440	540	623	577	732		
I.C.$^{\pm}$	14	13	~15	17	19	13	18		
$\sqrt{\bar{v}}$	3	7	~7	5	5	7	5		

Modal values are in percentage.

*These values include 0.1, 1.3, 2.4 myrmekite, respectively.

±I.C. numbers (identity change - measure of coarseness; the smaller the number the coarser the rock) and $\sqrt{\bar{v}}$ (analytical error, i.e., uncertainly in absolute amount) are parameters developed by Chayes (1956) for modal analysis of granitic rocks comprised almost entirely, and in roughly equal proportions, of three phases. Thus, the $\sqrt{\bar{v}}$ value given applies only to quartz, plagioclase and perthite and is less meaningful the further the proportions vary from 1:1:1. Validity of $\sqrt{\bar{v}}$ also rests on the assumption that the outcrop is homogeneous and truly represented by the thin section.

TABLE 8. PETROGRAPHIC VARIATIONS IN PAYSON GRANITE AS A FUNCTION OF DISTANCE FROM THE UPPER CONTACT

Number[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No. (suffix)	29A	154	154B	570	114	81A	88	517A	52	60	57A	2078A	296	356	gr. #3	665D	677	2221
Distance from upper contact (meters)	0.3	6	50	200	200	500	600	1300	1400	1600	1900	2600	3800	4000	4300	4300	4400	5000
Alkali feldspar[2]	0	M	M	M	M	M	M	M	M	M	M	0	0	0	0	MO	0	0
2V			65			55	70					55		60			50	
perthite[3]	p	pv	pv	v	pv	v	v	pvb	vb	pb	bv	pf	vf	vf	bv	pb	bf	bf
Plagioclase[4]	6	Ab?	5	Ab	Ab?	2	14	Ab	7-13	?	01?	15-23	Ab	17-23	01	Ab	01	01
zoning[5]	no	no	no	v wk	no	wk	no	mod	wk	mod	wk	str	wk	str	mod	v wk	mod	str
Amphibole (%)	0	0	0	0	0	0	0	0	0	0	0	~1	0	0.1	0	0	5.4	3.6
Biotite (%)	~1	tr	0	4.1	~1	0.9	~2	~3	~2	2.2	3.1	~4	~1	2.7	~2	~4	2.9	0.5
Hematite (%)	~1	~2	~3	~1	~1	tr	~1	~2	~1	0.8	0.2	0	tr	0	0	tr	0	0
Color Index (%)	~2	~2	~3	~5	~2	1.5	~3	~5	~4	3.3	3.8	~6	~2	3.6	~2	~5	9.3	4.4
Muscovite (%)	tr	~1	~2	tr	0	0	0	0	tr	0	0	0	0	0	0	0	0	0

1. Sample locations indicated by these numbers are given in Figure 12.
2. O - orthoclase predominating, M - microcline predominating.
3. P - patch, v - vein, b - braid, f - film; p v b f is generally the order of decreasing coarseness and less abundant lamellae.
4. numbers are An content, Ab - albite, 01 - oligoclase.
5. no - none, v wk - very weak, mod - moderate, str - strong.

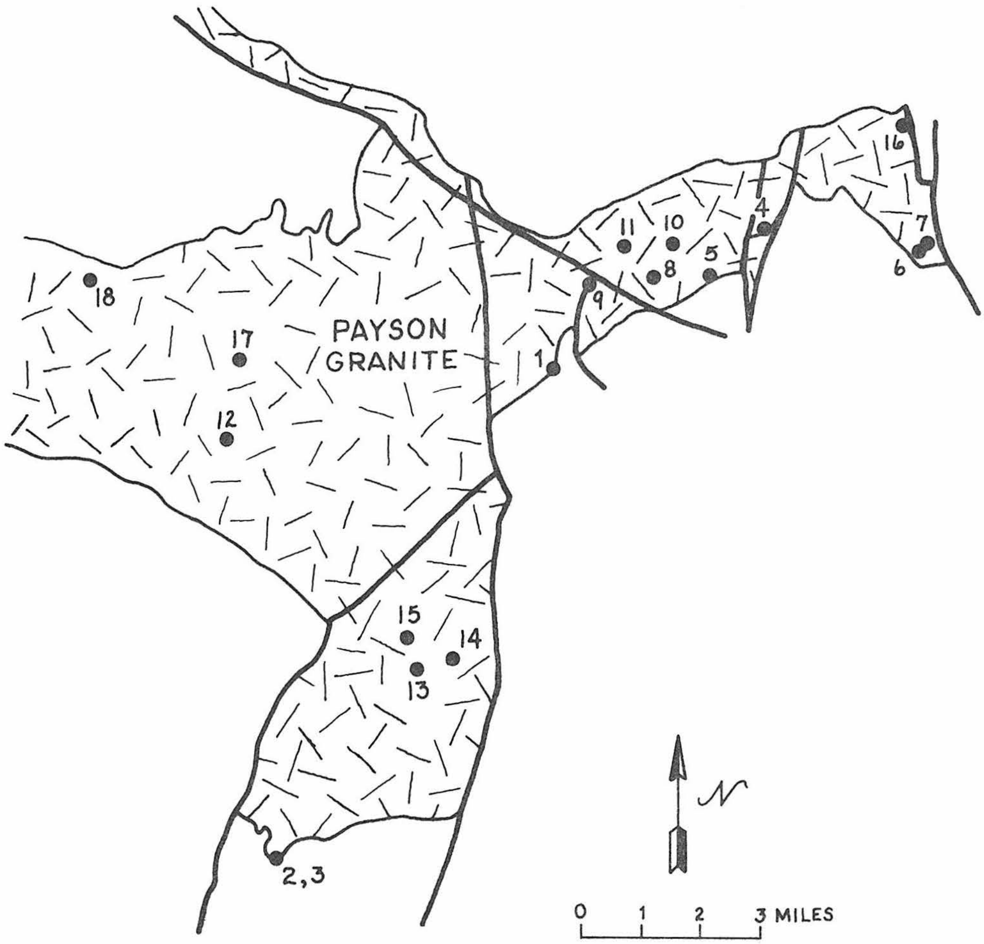


Figure 13. Locations of Payson Granite samples listed in Table 8.

Small 2V and deep blue-green and olive-green colors identify the moderately zoned amphibole as ferrohastingsite. Optic angle varies from less than 10° to about 50° but is generally between 10° and 30°. In plane-polarized light α is brown-yellow or yellow-brown, β is dark olive-green, olive-brown-green, or deep olive-green-brown, and γ is deep emerald-green, deep olive-green or deep olive-brown-green. Absorption for γ is occasionally so strong, particularly if there is some alteration, that the grains are almost opaque. Other optical properties are: γ:z'=18-24°, dispersion = $r<v$ (for high optic angle?) and $r<v$ (for low optic angle?), and δ=.020-.025.

Ferrohastingsite is occasionally slightly replaced by biotite but is not in a general reaction relationship.

INTERNAL VARIATIONS

Ferrohastingsite alkali granite was found only in the northwestern part of the map area in the most deeply exposed part of the Payson Granite. There is apparently a subtle gradation into biotite alkali granite toward the upper contact. From reconnaissance petrography throughout the predominating biotite alkali granite it appears that mineralogical variations are compatible with a systematic, universal downward change toward a ferrohastingsite alkali granite composition. Systematic studies on traverses parallel to the contact would be necessary to establish this relationship.

Selected petrographic characteristics of 19 granite samples possibly varying as a function of distance from the upper granite contact are shown in Table 8. Only the two most distant samples are ferrohastingsite alkali granite. Intermediate samples share characteristics of both granite types.

Only unzoned albite was found in the nearer contact rocks. It is usually quite heavily shot with discrete sericite flakes. In rocks more distant from the contact moderately zoned oligoclase is increasingly prevalent and saussuritization and sericitization are extensive. In the field it appeared that rapakivi plagioclase mantles are less abundant nearer the contact.

Microcline occurs preferentially nearer the contact, orthoclase further away. Even though the more distant orthoclase rocks seem to have as much exsolved plagioclase as the microcline rocks (Table 7) they have much K-feldspar, particularly in cores, that contains a relatively small amount of fine lamellae. If these feldspars were as completely exsolved as the microcline in the nearer contact rocks they would contain a much higher proportion of exsolved albite to host K-feldspar. This indicates that K-feldspar of the distant granites contained a higher proportion of Na-feldspar in solution. The presence of much more myrmekite in the marginally exsolved albite of the orthoclase granites indicates a greater component also of dissolved Ca-feldspar.*

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*This is based on the presence of 'excess silica' (Carstens, 1966) in the alkali feldspar structure when calcium substitutes on a charge for charge basis rather than an ion for ion basis into the lattice, thus leaving vacant one ion site for each calcium ion present.

A few of the more distant biotite alkali granite samples contain a little hornblende. Biotite and its alteration products may be slightly more abundant near the contact and nearer contact rocks may be slightly more leucocratic.

Biotite is increasingly replaced by hematite and muscovite nearer the contact. There can be no doubt that alteration, unrelated to weathering, and expressed by decomposition of biotite and perhaps by some albitization, is much more severe near upper contacts. The hydrothermal event accompanying intrusion of the Green Valley Granophyre (page 381) may in part be responsible for these changes. However, the lack of secondary calcium-bearing minerals in the albite-bearing rocks argues that albite is generally a primary mineral. Evidence for greater solid solution in distant orthoclase also argues that K-feldspar variations are not due entirely to hydrothermal modification near the granophyre.

It is hypothesized that the variations in Payson Granite are due to a slight differentiation wherein alkalies and water were preferentially fractionated to higher parts of the body. Upward, plagioclase became more sodic and lower-temperature, more water-rich phases crystallized. Biotite crystallized in place of hornblende, and K-feldspar crystallized lower on the solvus limb.

Alteration of biotite to hematite and muscovite and clouding of feldspar at the highest levels may have been a result of deuteric activity. Alternatively, the somewhat deeper alteration of biotite to chlorite may have been deuteric, but the hematite and muscovite alteration may have accompanied intrusion of the Green Valley Granophyre. Amphibole occurs in several relatively high-level dikes (not listed in Table 8). These dikes were probably late stage derivatives from deeper parts of the granite where amphibole was still crystallizing after solidification had occurred at higher levels. Preservation of this amphibole argues against pervasive hydrothermal activity accompanying intrusion of the granophyre.

The distribution of mineral variations would suggest that the upper granite surface was the original roof of the differentiating magma. This supports the preferred hypothesis (page 247) that Payson Granite semi-concordantly intruded the Haigler rhyolite, perhaps near its base. The upper Payson Granite intrusive contact would have been a relatively smooth surface over a great area. The present southward dip of the contact would have resulted at least partially in the regional deformation, but perhaps partly also because of broad doming of the strata upon intrusion of the granite.

The roof of the granite may have been as shallow as 3-4 kilometers if no great thickness of rock accumulated above the Christopher Mountain Quartzite. Upper parts of the Payson Granite would be no less hypabyssal than some of the granophyre and rhyolite sills. Porphyritic and micrographic textures in dikes and marginal phases support the concept of shallow intrusion. The overall coarse grain size of the body is attributable to slow cooling because of the great mass of the body.

COMPOSITION

No chemical analyses were obtained for alkali biotite granite but modally it is practically identical to alaskites (compare averages, Table 7) for which there are three chemical analyses. An average of these chemical analyses is exceedingly similar to Nockold's (1954) average alkali biotite granite (Table 9). In fourteen partial chemical analyses (X-ray fluorescence) of amphibole-free granite from the Payson body (Putman and Burnham, 1963), SiO_2 ranges from 72.0% to 78.0% and averages 75.2%. K_2O varies from 4.6% to 5.8%, averaging 5.1%, and CaO values between 0.13% to 1.0% average 0.47%.

An important conclusion based on the modal comparisons and supported by the partial chemical analyses is that most of the exposed Payson Granite is approximately of the same composition as the alaskite which is chemically equivalent to other hypabyssal silicic alkali rocks and to Haigler rhyolite (Table 15).

The chemistry of samples 3-1-677 has similarities to Nockold's average biotite-hornblende calc-alkali granite and to average ferrohastingsite alkali granite. On the basis of the high sodium content and the presence of sodic amphibole it is called ferrohastingsite alkali granite. The analyzed sample 3-1-677 may be anomolous in its low quartz content and high color index (see Table 7). Sample 10-1-2221 may be more representative of the ferrohastingsite alkali granite in which case the granite would contain more SiO_2 and less MgO, FeO, and Fe_2O_3 than the analysis indicates. It would also contain less CaO because the plagioclase content is lower in sample 10-1-2224.

TABLE 9. CHEMICAL COMPOSITIONS OF PAYSON GRANITE, SOME AVERAGE GRANITES, AND AVERAGE ALASKITE

	Payson Granite		Nockolds' (1954) Average Granites			Alaskite Average
	1	2	3	4	5	6
SiO_2	70.73	72.67	70.56	70.46	75.01	75.29
TiO_2	0.29	0.17	0.40	0.34	0.17	0.09
Al_2O_3	14.11	13.78	14.00	14.37	13.16	12.75
Fe_2O_3	1.03	1.26	0.91	1.09	0.94	*
FeO	1.86	0.68	2.41	2.48	0.88	1.40
MnO	0.03	0.01	0.06	0.05	0.07	--
MgO	0.46	0.35	0.48	0.22	0.24	0.23
CaO	1.58	1.06	1.63	1.19	0.56	0.64
Na_2O	4.13	3.64	3.56	4.19	3.48	3.55
K_2O	5.11	5.07	5.39	5.18	5.01	5.22
$H_2O(+)$	0.60	0.77	0.50	0.37	0.37	--
$H_2O(-)$	0.25	0.37				
P_2O_5	0.03	0.02	0.10	0.06	0.11	
CO_2	0.10	0.03				
S	0.01	0.02				
F	0.06	0.13				
Total	100.38	100.03				

*All Fe as FeO

1. Sample 3-1-677, ferrohastingsite alkali granite (677, G-6).
2. Sample 2-1-327A, porphyritic granite dike (327, F-11).
3. Average biotite-hornblende calc-alkali granite.
4. Average ferrohastingsite alkali granite
5. Average biotite alkali granite.
6. Average of three alaskite analyses (Nos. 29, 30, 31, Plate 4).

Analyzed sample 2-1-327A is from an amphibole-bearing high-level dike and may be somewhat intermediate in composition between biotite alkali granite and ferrohastingsite alkali granite.

The characterization of the Payson Granite in its several aspects as an alkali granite is exceedingly important. It provides a strong genetic tie to the alkali rhyolite and hypabyssal rocks and thus supports the intrusive hypothesis of the Payson Granite which would have the granite intermediate in age between Haigler rhyolite and the hypabyssal rocks.

MAFIC VOLCANIC AND HYPABYSSAL ROCKS

Mafic volcanic rocks occur in minor quantity in the Haigler Group and Flying W Formation and predominate in the Board Cabin Formation. Many of the pre(?)-Breadpan rocks are mafic volcanic rocks. Fine-grained mafic rocks intrude the upper Alder Group and lower Haigler Group in the Board Cabin Draw area. The pre(?)-Breadpan and intrusive rocks were not examined petrographically.

Though the Board Cabin Formation may contain some basalt, it is predominantly andesite. A mafic flow in the Flying W Formation is altered basalt(?) which has compositional similarities to a hypabyssal basalt sample analyzed by Gastil. High iron, low magnesium, and high alkali(?) contents in Board Cabin andesite, Flying W basalt(?), and hypabyssal basalt are perhaps primary characteristics genetically linking these mafic rocks to the felsic rocks in Tonto Basin.

Flying W Basalt(?) and Intrusive Basalt

The analyzed basalt(?) sample (7-1-1617A) from the single mafic flow in the Flying W type section is a fine-grained, weakly porphyritic, amygdaloidal rock. Although original minerals are not preserved, the rock retains a moderately well preserved pilotaxitic texture. The mineralogy is about 60% sericitized plagioclase (probably albite) microlites and rare albite phenocrysts, 30% very finely divided epidote and opaque minerals and 10% quartz amygdules. Unzoned and strongly sericitized sodic plagioclase is undoubtedly pseudomorphic after original more calcic plagioclase.

The analysis is high in silica, alkalis and iron and is low in lime and exceedingly low in magnesia. In spite of its strongly altered character the analysis has a remarkable similarity to that of a fine-grained mafic rock (Gastil, 1954, p. 63) which intrudes upper Alder Group rocks in the vicinity of the Board Cabin Draw. A recalculated analysis, with 9% SiO_2 removed for secondary amygdule quartz emphasizes the similarities (Table 10).

Gastil (1954) noted the spilitic character of the intrusive basalt analysis (see comparison with spilite analyses, Table 10). Carmichael, Turner, and Verhoogen (1974, p. 560) state that most recent spilite studies favor a metasomatic origin for the spilite composition. Clearly both the Apache Group effect (page 259) and 'spilitic alteration' may have affected the basalt compositions. Sample 7-1-1617A, for example, may have been secondarily enriched in K_2O; it was collected only 70 meters beneath the Apache Group unconformity. Nevertheless,

TABLE 10. CHEMICAL COMPOSITIONS OF FLYING W BASALT(?), INTRUSIVE BASALT, AND SOME SPILITES

	Flying W basalt		Intrusive basalt	Spilites	
	1	2	3	4	5
SiO_2	59.06	50.0	49.80	51.22	48.6
TiO_2	1.96	2.4	2.56	3.32	1.94
Al_2O_3	15.35	18.7	15.70	13.66	16.1
Fe_2O_3	*	*	10.65	2.84	7.6
FeO	12.75	15.6	3.58	9.20	4.0
MnO			0.24	0.25	0.34
MgO	0.79	1.0	4.28	4.55	3.6
CaO	3.79	4.6	5.12	6.89	6.2
Na_2O	4.38	5.3	4.96	4.93	4.5
K_2O	1.35	1.6	0.29	0.75	1.76
$H_2O(+)$			2.72	1.88 (H₂O+ and H₂O−)	2.9
$H_2O(-)$			0.24		0.22
P_2O_5	0.58	0.7	0.61		0.34
CO_2			tr.	0.94	1.45
Total	100.01	99.9	100.75	100.72	99.6

*All Fe as FeO.

1. Sample 7-1-1617A, Flying W basalt(?) (1617, P-17).
2. Same as 1, normalized to 50.0% SiO_2 (see text).
3. Fine-grained mafic rock intrusive into Alder Group (Gastil, 1954, p. 63).
4. Average spilite (Turner and Verhoogen, 1960, p. 271).
5. Potassic spilite (Turner and Verhoogen, 1960, p. 271).

the high iron and sodium contents and the low magnesium and calcium contents suggest an affinity between the two rocks and may provide a genetic tie with more leucocratic rocks in Tonto Basin also having high Fe/Mg and alkali/lime ratios.

Board Cabin Andesite

The analyzed andesite sample (7-1-1600) contains about 20% 1-6 mm plagioclase phenocrysts in a fine-grained weakly pilotaxitic groundmass. Plagioclase phenocrysts (Plate 35) are almost totally altered to sericite and epidote (about equal proportions) and the preserved portion is unzoned and slightly mottled. Gastil (1958, p. 1504) found that phenocrysts are albite. Plagioclase laths in the groundmass appear to be totally sericitized. Other phases in the groundmass are chlorite, epidote, opaque oxides and a trace amount of calcite. A very few amygdules(?) are composed of chlorite and epidote. Petrographic characteristics in the few other thin sections examined do not differ significantly.

Board Cabin andesite is unlike any of McBirney's (1969) average andesite compositions (Table 11). It is considerably lower in SiO_2 than all. It is similar to the average iron-rich 'andesite' in high iron and alkali content, but like the more calcic averages in high aluminum and calcium. Like the basalts (Table 10) the most striking characteristic is the high iron content. Like the basalts it is alkali-rich, but in contrast is rather low in sodium.

The andesite sample does not seem to have been strongly altered.

TABLE 11. CHEMICAL COMPOSITION OF BOARD CABIN ANDESITE AND SOME AVERAGE ANDESITES

	Board Cabin Andes.	McBirney's (1969) Average Andesites			
	1	2	3	4	5
SiO_2	53.87	58.68	58.65	58.05	58.31
TiO_2	1.11	0.81	0.79	1.10	1.71
Al_2O_3	17.84	17.29	17.43	17.15	13.77
Fe_2O_3	6.34	2.97	3.21	3.30	3.37
FeO	3.32	3.96	3.48	2.54	6.48
MnO	0.08	0.12	0.10	0.13	0.23
MgO	2.48	3.14	3.28	2.16	2.27
CaO	6.81	7.13	6.26	5.13	5.58
Na_2O	2.96	3.24	3.82	4.57	3.91
K_2O	2.35	1.27	1.99	3.60	1.88
$H_2O(+)$	2.40	1.20*	1.06*	1.64*	1.01*
$H_2O(-)$	0.39				
P_2O_5	0.42	0.17	0.18	0.43	0.46
CO_2	0.14				
F	0.08				
Total	100.59	99.98	100.25	99.80	99.98

*Total H_2O.

1. Sample 7-1-1600, Board Cabin Andesite (1600, 0-16).
2. Average of 89 calcic andesites from island arcs.
3. Average of 29 calc-alkaline andesites from continental margins.
4. Average of 13 alkali-calcic andesites from continental interior regions.
5. Average of 22 iron-rich andesites, icelandites, craignurites, etc., from oceanic and non-orogenic regions of continents.

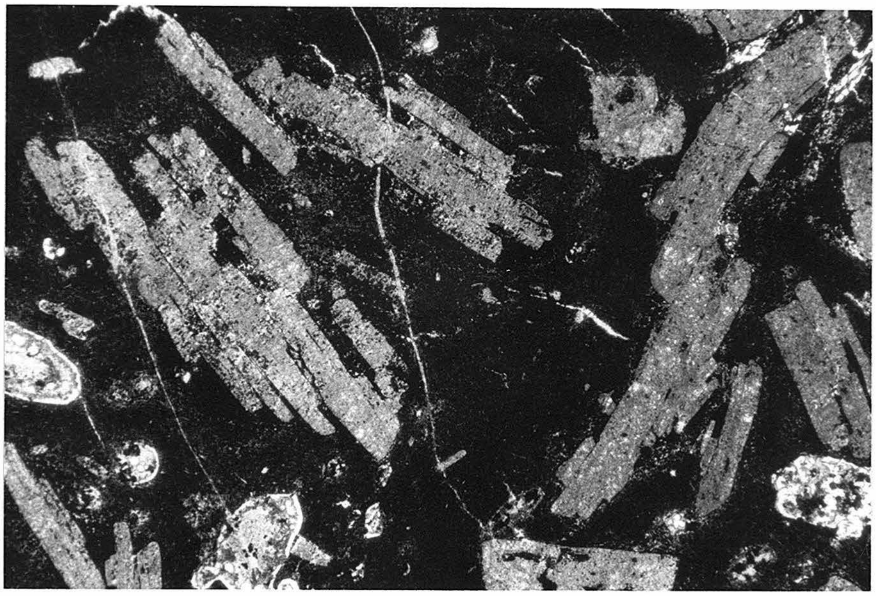


PLATE 35. BOARD CABIN ANDESITE PORPHYRY. Distinctive plagioclase phenocryst texture. Saussuritized compound phenocrysts are composed of irregularly stacked parallel to sub-parallel (010) plates. Groundmass is very dark due to high opaque oxide content. Note quartz-chlorite amygdules. Plane-polarized light, 6 x 9 mm.

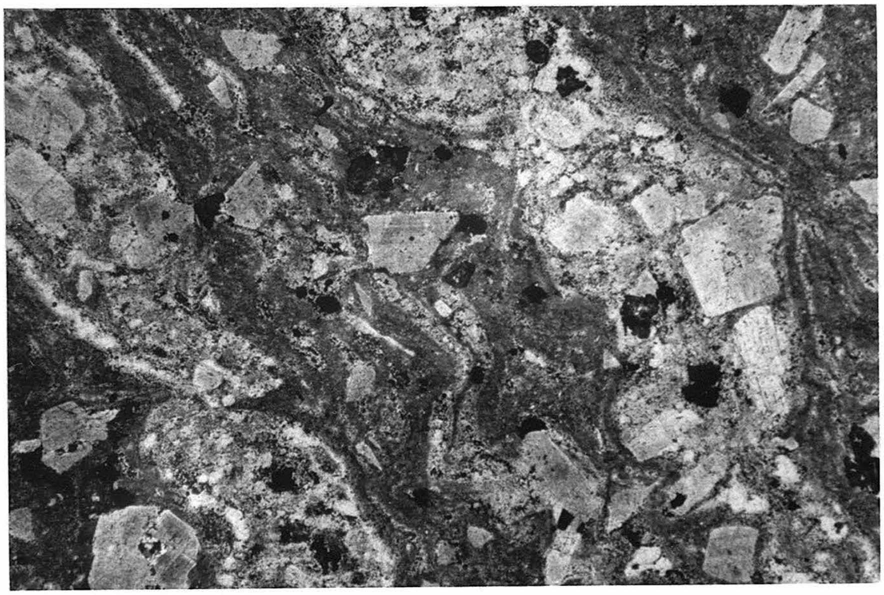


PLATE 36. WINTER CAMP ALKALI RHYODACITE. Contorted pumiceous(?) layers (light, coarse) are possibly indicative of an ash-flow tuff origin for this sample from the upper rhyodacite member. Phenocrysts are albitized plagioclase. Small dark grains are opaque oxides and clusters of epidote pseudomorphous after pyroxene(?). Note the euhedral form of the epidote grain at top center. Plane-polarized light, 6 x 9 mm.

It does not have the spilite-like character of the basalts. Its high K_2O might suggest enrichment by the Apache Group effect but the high CaO argues against much exchange by that mechanism.

ALKALI RHYODACITE

The only felsic volcanic rocks in the Alder Group are two minor units in the Flying W Formation. All volcanic rocks of the Winter Camp Formation are rhyodacitic flows and ash-flows similar in composition to the Flying W rocks. High alkali and iron contents and low magnesium and calcium contents identify these rocks as alkali rhyodacite and suggest genetic affinity to the voluminous silicic alkali rocks of the Haigler Group and hypabyssal sills which have the same characteristics.

Flying W Formation

In the Flying W Formation are two minor units called keratophyre and rhyolite by Gastil (1958). One new sample from each of these units was thin-sectioned and a chemical analysis was obtained of a sample (Ar-Gi-W rhy #1) of the rhyolite previously collected by L. T. Silver for radiometric dating.

Both samples from the rhyolite unit contain 10-15% 1-3 mm albite phenocrysts in a flow-foliated recrystallized groundmass of feldspar, quartz and hematite. Well-preserved, weakly-zoned albite phenocrysts are very lightly speckled with sericite flakes. A single K-feldspar phenocryst was found; quartz is not phenocrystic. Hematite is common as disseminated dust in the groundmass, and as large aggregates which in some cases may be pseudomorphs after ferromagnesian silicates, but in the type section are 0.5 x 3 cm platey inclusions of iron-rich slate(?). Abundant topaz was found (L. T. Silver, pers. comm.) in the heavy mineral fraction of sample Ar-Gi-W rhy #1. No fluorite was identified and the unusually high fluorine content (0.34%) is undoubtedly due to the topaz.

Texture of the rhyolite is somewhat chaotic and many phenocrysts are broken. Small euhedral quartz and alkali feldspar crystals project into areas of massive quartz which were originally drussy cavities. Patterns of localization of relic drussy cavities may define nearly obliterated pumice fragments. The fine-grained groundmass texture is continuous through 0.5 mm 'seive' grains of recrystallized quartz. Megascopic and microscopic textures are evidence for a pyroclastic origin for this unit.

Albite phenocrysts in the keratophyre unit are similar in size and abundance to those in the rhyolite, but are heavily sericitized. Aggregated and fine-grained epidote along the borders of the phenocrysts indicates that original higher-calcium plagioclase has been albitized. Quartz and alkali feldspar phenocrysts are not present. The groundmass is composed predominantly of sericitized plagioclase microlites and subordinately of fine-grained opaque oxides, epidote and calcite.

The Flying W 'rhyolite', though quite silicic and alkali-rich, is here somewhat arbitrarily called alkali rhyodacite because of its similarity to Winter Camp alkali rhyodacites (Table 12). It may be a soda rhyolite. The 'keratophyre' is more mafic and apparently more calcium-rich and is probably a rhyodacite.

Winter Camp Formation

Volcanic rocks in the Winter Camp Formation of the Haigler Group appear to be predominantly rhyodacite. Gastil (1958) describes these rocks and gives a chemical analysis of a sample from the rhyodacite II member.

Analyzed sample 7-1-1604A from the upper rhyodacite member contains 10-15% unzoned albite phenocrysts which are clear, well-preserved and strongly twinned. Pseudomorphs of pyroxene(?) (0.5-2 mm) having well-preserved external forms are entirely composed of clusters comprised mostly of epidote blades and prisms and of opaques and phengitic (?) mica (Plate 36). Original textures are very well-preserved in spite of rather extensive recrystallization of groundmass quartz and of the formation of 0.1 mm booklets of white mica in the groundmass. Alkali feldspar occurs in the groundmass as tiny euhedral crystals projecting into quartz-filled cavities. Coarser-grained areas define lamellae (Plate 36) which are probably flattened pumice fragments. These indicate a probable ash-flow origin.

Two samples from the rhyodacite II member were thin-sectioned. Analyzed sample 7-1-1611 is similar in mineralogy to 7-1-1604A but the plagioclase phenocrysts are strongly sericitized and saussuritized and the few pseudomorphs after pyroxene(?) are comprised primarily of opaque oxide and rather deep green phengite(?) with only minor epidote. Plagioclase is apparently albite or oligoclase no more calcic than about An_{12}. Epidote in this rock is perhaps more abundant than in sample 7-1-1604A but is finer-grained, generally anhedral, and much more disseminated - both in the groundmass and in the plagioclase phenocrysts. Very fine opaque oxides thoroughly disseminated in the groundmass make the rock, even in thin section, very dark. Rare quartz phenocrysts are strongly absorbed; anhedral mosaic quartz making up perhaps 5-10% of the rock occurs in very elongate lenses which may be highly compressed vesicles. The exceedingly fine groundmass lacks any textural detail other than a quasi-polygonal fracture pattern. It appears that the groundmass was once glass and that the rock was a simple flow. The other sample is like the upper rhyodacite in phenocryst character, texture, and color index, but the plagioclase is sericitized and saussuritized and epidote is considerably disseminated.

METAMORPHISM

Outcrop from which sample 7-1-1604A was taken is only a few tens of meters from sills, both above and beneath, of intrusive basalt. The clean texture and highly segregated character of the epidote is attributed to contact metamorphism which preceded the regional metamorphism. The same phases are present as in the other rhyodacite rocks but epidote, an alteration product of the plagioclase, is strongly concentrated and well-crystallized, mostly in pyroxene(?) pseudomorphs, rather than disseminated in the feldspar phenocrysts and groundmass.

Some cations were apparently very mobile under the influence of heat from the mafic intrusive rock, yet of the felsic minerals only groundmass quartz was strongly recrystallized and the albitized plagioclase phenocrysts retain perfect form. Lack of textural modification in the face of substantial chemical and mineralogical reconstitution is remarkable.

Chemistry

Winter Camp and Flying W felsic volcanic rocks are considerably less silicic and potassic and more aluminum-, calcium-, and iron-rich than Tonto Basin intrusive and extrusive alkali rhyolite (Plate 4). Samples 7-1-1611 and 7-1-1604A are similar to Nockolds' average rhyodacite (Table 12) but are richer in iron and alkalis and poorer in CaO and MgO. Though somewhat intermediate between the other two samples and alkali rhyolite, Winter Camp sample V and the Flying W sample have more affinity to the former because of similarities in Al_2O_3, total Fe, MgO, and alkali contents. The Flying W sample may have been enriched somewhat in SiO_2 by quartz infilling of cavities. These two samples are similar to the dellenite (a rhyodacite also, for present usage) in SiO_2 and Al_2O_3, but are considerably richer in total Fe and Na_2O and poorer in MgO, CaO, and K_2O.

Tonto Basin rhyodacites seem to bear the same relation to Nockolds' dellenite and rhyodacite as Tonto Basin alkali rhyolites do to calc-alkali rhyolite. They are comparatively iron-rich, magnesium-poor, calcium-poor, and alkali-rich. It seems preferable to call them alkali rhyodacites or soda rhyodacites. Clearly they have affinity to the more felsic (and possibly the more mafic) rocks of Tonto Basin.

In the Flying W and Winter Camp sample V analyses Na_2O is significantly greater than K_2O, which is opposite the relationship in the similar dellenite average. This may point up an important characteristic of the rocks of the Tonto Basin volcanic series. They are sodium rich. For the silica-oversaturated rocks (excluding the peralkaline rocks) in Nockolds' tables the reversal in K_2O or Na_2O predominance occurs at the adamellite/dellenite-granodiorite/rhyodacite boundary. For the rocks in Tonto Basin this transition appears to be shifted toward the more leucocratic end of the spectrum.

Strong chemical similarities among the alkali rhyodacites and distinctive chemical characteristics in common with more felsic rocks indicate that the Winter Camp rocks are either not strongly or not differentially altered. The small amounts of normative corundum may indicate some loss of alkalis or lime. Consistent high Na_2O/K_2O argues against any significant operation of the Apache Group effect. It seems unlikely that the high Na_2O contents are due to alkali exchange with saline water in the environment of deposition. The abundance of conglomerate in the Winter Camp Formation and the textural evidence for ash-flow origin of rock 7-1-1604A favor a subaerial environment.

TABLE 12. CHEMICAL COMPOSITIONS OF FLYING W AND WINTER CAMP ALKALI RHYODACITE, AVERAGE RHYODACITE AND AVERAGE DELLENITE

	Flying W	Winter Camp Formation			Nockolds' (1954) Averages	
	1	2	3	4	5	6
SiO_2	72.62	71.04	66.85	69.19	66.27	70.15
TiO_2	0.17	0.26	0.78	0.41	0.66	0.42
Al_2O_3	13.50	14.63	15.47	14.01	15.39	14.41
Fe_2O_3	3.63	2.72		3.92	2.14	1.68
FeO	0.10	2.05	5.52	1.27	2.23	1.55
MnO	0.03	0.13		0.11	0.07	0.06
MgO	0.22	0.14	0.70	0.30	1.57	0.63
CaO	0.83	0.81	1.83	1.82	3.68	2.15
Na_2O	4.40	4.48	4.49	4.82	4.13	3.65
K_2O	3.19	3.74	4.16	3.36	3.01	4.50
$H_2O(+)$	0.51	0.09		0.36	0.68	0.68
$H_2O(-)$	0.23	0.06		0.28		
P_2O_5	0.04		0.21	0.04	0.17	0.12
CO_2	0.01			0.02		
F	0.34			0.12		
Total	99.82	100.15	100.01	100.03		

1. Sample Ar-Gi-W rhy #1A, Flying W Formation (0-16).
2. Sample V, rhyodacite II, Winter Camp Formation (Gastil, 1958, Table 3).
3. Sample 7-1-1611, rhyodacite II, Winter Camp Formation (1611, N-16).
4. Sample 7-1-1604A, upper rhyodacite, Winter Camp Formation (1604, N-17).
5. Average rhyodacite plus rhyodacite obsidian.
6. Average dellenite plus dellenite obsidian.

ALKALI RHYOLITE, GRANOPHYRE, AND ALASKITE

Haigler Rhyolite Undivided

All outcrop areas of Haigler rhyolite undivided, except the type area mapped by Gastil, were extensively sampled. Thirty-eight of the forty-two thin sections examined are alkali rhyolite, characterized by 1-5% quartz phenocrysts, 1-5% feldspar (K-feldspar or Na-feldspar, or both) phenocrysts, Fe-Ti-oxides as the only mafic phases, and a color index of 1-4. The minor rocks, lacking quartz and K-feldspar phenocrysts, may be similar to Winter Camp rhyodacite, but two are breccias containing lithic fragments and one may have inclusions of diorite(?). More than 95% of the volcanic rock in undivided Haigler rhyolite is the distinctive, consistent alkali rhyolite. Only alkali rhyolite is considered in the following discussion

TEXTURES AND TEXTURAL TYPES

Flattened pumice texture (Plate 37A), suggestive of ash-flow origin, is microscopically visible in almost half the samples, including many thought to be simple flow rocks. Pumice layers are typically coarsely devitrified (often spherulitic) and recrystallized. Very occasionally a trace of the primary filament texture (walls of collapsed vesicles) in the flattened pumice fragments is preserved. In strong contrast to the coarse pumice layers, interpumiceous areas in these rocks are often very finely devitrified and in one instance (see Plate 38 and discussion of ash-flow cooling unit, page 59) is possibly partially devitrified glass. Devitrification is common as fine crystal growth perpendicular to flow lamination lines. Axiolitic devitrification of shards was noticed in a few samples.

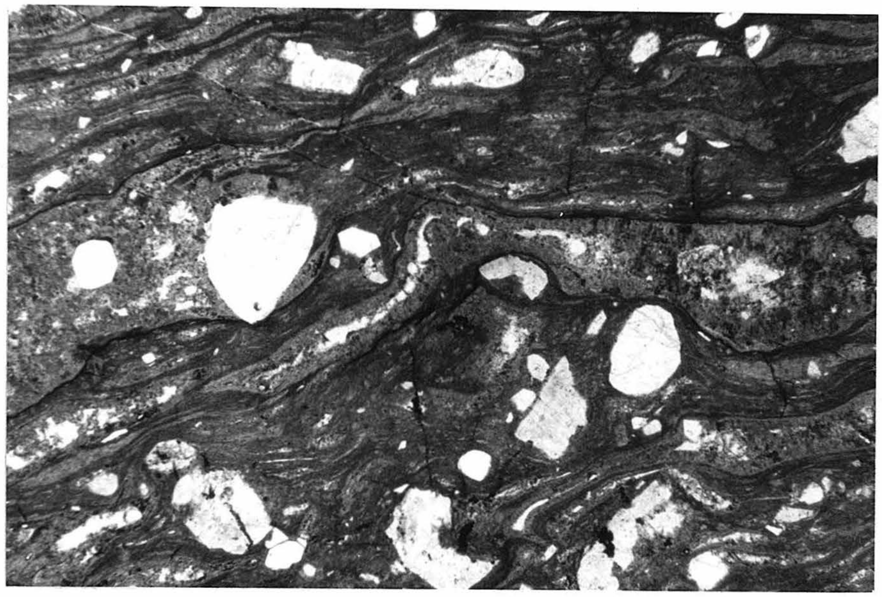
Well-preserved shard texture is seldom a salient feature in the flattened pumice rocks (Plate 37B). The apparent absence of shards in most of the flattened pumice rocks can only be due to recrystallization of the groundmass, or in some cases, thorough welding of the rock.

Spherulites, as small (0.1-1.0 mm) radial features with ill-defined margins, are rather uncommon. These are nowhere as pervasive and well-developed as in the intrusive King Ridge Rhyolite body. Spherulites of another variety, locally extensively developed, are much larger (0.5-2 cm), sharply bounded, and have both radial and concentric internal structure. The internal texture is often obscured because of recrystallization but it appears that the concentric banding is more pronounced than the radial character. These bulbous features apparently grade upward in size into lithophysae which are hollow.

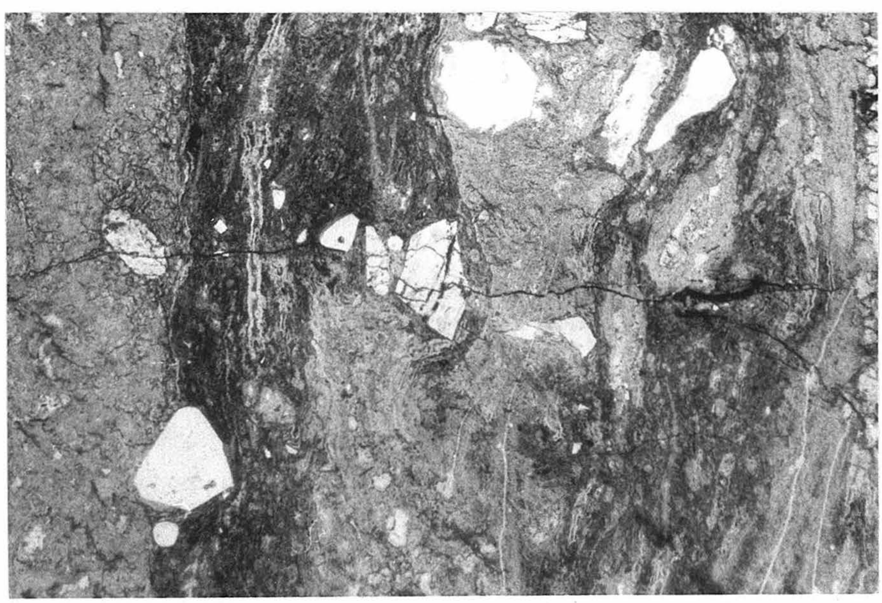
Rocks with simple laminar flow texture are generally very fine and even-grained, though devitrification textures are present. Many of the massive rocks have coarse devitrification textures which have in some cases obscured original flow textures.

In the breccia and tuff samples shard texture is usually present in the groundmass, and both unflattened pumice fragments and lithic fragments (virtually all rhyolite) are present. These rocks best preserve original vesicular and shard textures (Plate 39A) because individual fragments of the rock cooled rapidly and were then deposited together.

PLATE 37. HAIGLER RHYOLITE

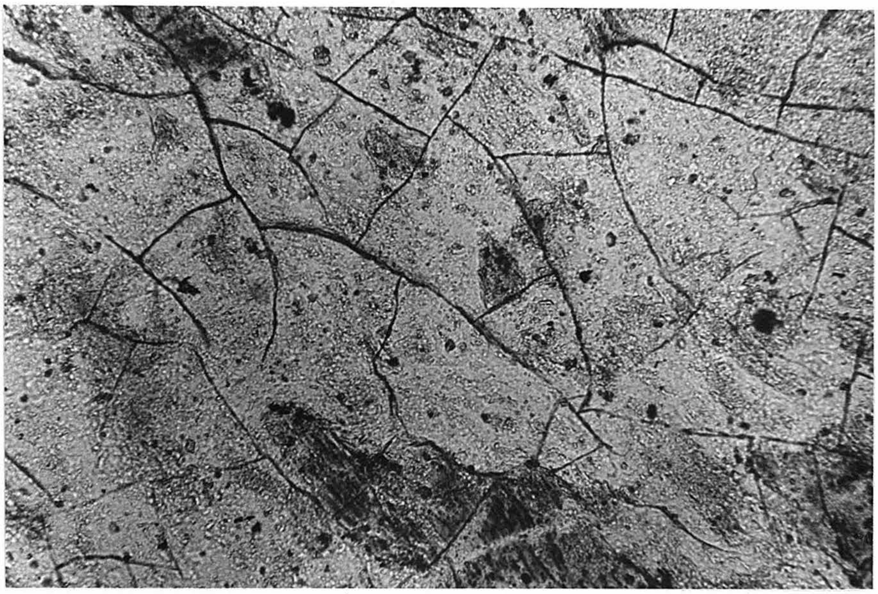


A. Flattened pumice texture in ash-flow tuff. More coarsely recrystallized lamellae are flattened pumice fragments. Phenocrysts are quartz and patch antiperthite. Plane polarized light, 6 x 9 mm.

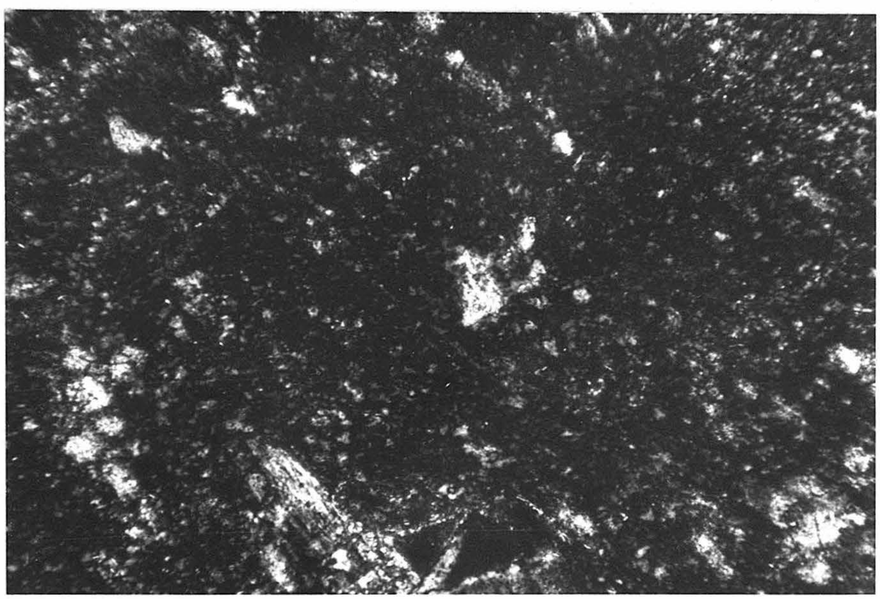


B. Flattened pumice texture. Light areas are coarser pumice fragments. Shard texture is poorly preserved in the dark fine-grained groundmass. Plane polarized light, 3 x 4.5 mm.

PLATE 38. HAIGLER RHYOLITE

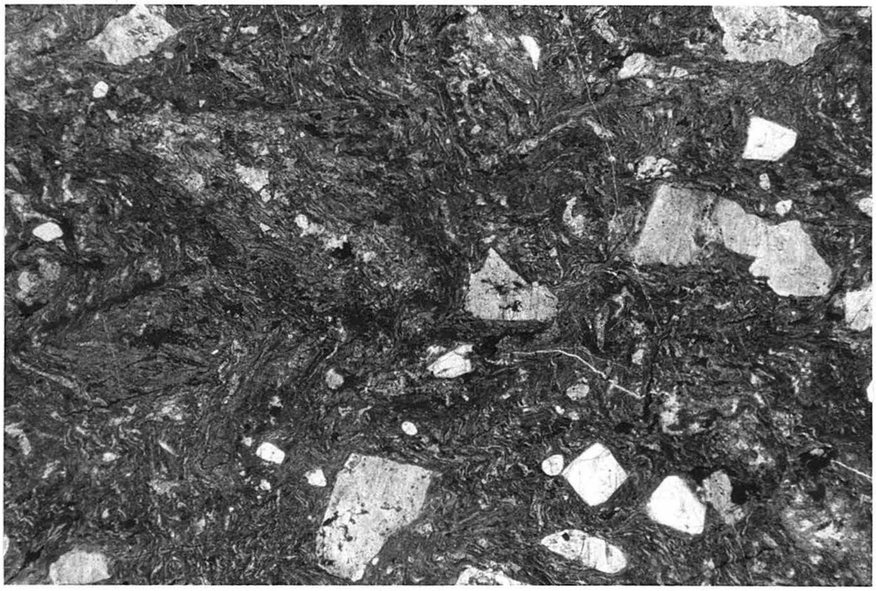


A. Polygonally fractured, incompletely(?) devitrified glass from an ash-flow cooling unit. Fractures appear to be primary tensional cooling features. Glassy polygons are heavily clouded with tiny crystallites. Weakly laminated dark areas are pumice bits. Plane polarized light, 0.7 x 1 mm.

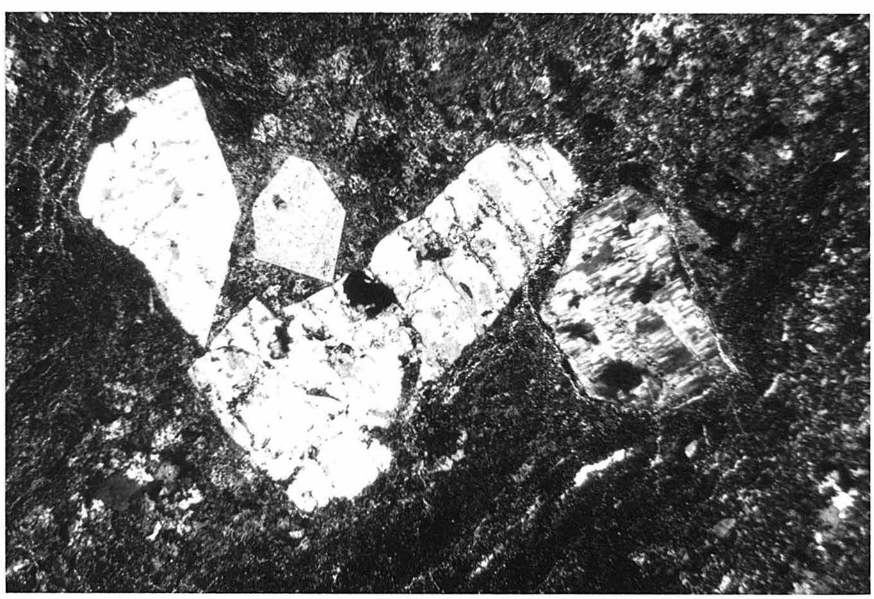


B. Same as A, cross polarized light. Though minute crystals are ubiquitous, a small portion (5-10%) of the groundmass appears to be isotropic suggesting the presence of glass. Tiny areas remaining black with stage rotation are the clearest in plane polarized light.

PLATE 39. HAIGLER RHYOLITE



A. Pumice breccia. Pumice fragments and phenocrysts in a deformed groundmass of pumice bits and shards. Plane polarized light, 6 x 9 mm.



B. Perthitic alkali feldspar phenocrysts exhibiting extreme exsolution(?) texture typical of Haigler rhyolite. Three larger crystals are patch antiperthite (0.2 K-feldspar component), the smaller is quartz. Phenocryst to the right displays pericline/albite twinning in the albite host. Cross polarized light, 2 x 3 mm.

MINERALOGY

Quartz phenocrysts in all the samples are moderately to strongly resorbed and embayed but usually reflect original euhedral bipyramidal form. In the groundmass quartz is sometimes recrystallized into irregular poikilitic domains up to 0.5 mm in diameter. It is the only massive pore filling mineral in the rocks and as such forms a coarse mosaic in lithophysael cavities, vesicular areas, central portions of some flattened pumice fragments, and other cavities.

Weakly to moderately resorbed feldspar phenocrysts are albite and antiperthitic and perthitic alkali feldspar. Perthite textures are usually very coarse and irregular; most is patch perthite (Plate 39B). Perthite formation along or near (100) gives a coarse bladed appearance to some perthite intergrowth. Twinning in albite in both albite and perthite phenocrysts is usually simple albite twinning, but in some antiperthite is a weakly developed patchwork on both albite and pericline laws. K-feldspar in the phenocrysts is seldom twinned but may occasionally have a fine mottled microcline appearance. Optic angles are 30(?)-60° indicating that the feldspar is generally preserved in the orthoclase structural state.

Albite phenocrysts or albite portions of perthitic grains are usually lightly speckled with sericite flakes and are seldom extensively sericitized. Absence of calcium-bearing secondary minerals, except for traces of epidote and calcite in a few rocks, indicates that the albite is primary. The alternative that the rocks were all albitized and equally depleted in calcium is unreasonable in view of the fact that about half of the exposed Precambrian rock in Tonto Basin, including intrusive and extrusive rhyolite and granophyre, is similar low-calcium rock with very little epidote and calcite.

Hematite occurs in the reddish oxidized rocks (most of the samples) as 'dust' in the groundmass, but only occasionally within feldspar phenocrysts. The latter is in contrast to granophyre and much intrusive rhyolite in which feldspar is heavily clouded with fine hematite. The finely-divided groundmass hematite is generally strongly localized, sometimes in the cores and sometimes outside of small radial spherulites, always outside the larger concentric-radial spherulites, and always outside the pumice layers. Somewhat larger opaque oxide grains, mostly magnetite but presumably hematite also, are found disseminated (up to 0.1 mm) usually throughout the rock and as 0.2-1 mm pseudomorphs(?) after minor mafic silicate phenocrysts. Subhedral blades (0.1-0.5 mm) of hematite(?) are commonly found replacing feldspar phenocrysts usually in the more strongly sericitized rocks.

Biotite and chlorite are virtually absent and not a trace of original ferromagnesian silicate was found.

Zircon is remarkably abundant as 0.1-1 mm prisms in many samples and is very well preserved. In several instances a dozen crystals were counted in a 1-2 mm area clustered with opaque minerals.

Abundant sericite replaces both groundmass minerals and sodic portions of perthitic phenocrysts in the few most badly altered rocks. Rarely does it replace K-feldspar. Calcite is present in trace amounts in only a few samples, but constitutes almost a percent of the chemically analyzed sample 8-1-1850A. Fluorite was found in trace amounts in perhaps one-fourth of the samples and appears to be secondary.

ORIGIN OF PATCH PERTHITE

The patch character of the perthite, and particularly the great variation among the different samples in proportion of the two phases in perthitic phenocrysts, raised the possibility that the perthites are replacement perthites and, if so, that alkali and lime mobilization may also have modified bulk compositions.

In a careful examination of feldspar phenocrysts in all samples it was found, in spite of the great overall variation in perthite proportions, that in all except two thin sections little variation exists and certain associations recur. Feldspar phenocryst types, along with quartz and feldspar phenocryst amounts, are given in Table 13. Perthite proportions were estimated in tenths of K-feldspar component which for most thin sections seemed to vary only over about two tenths. Quantities visually estimated in Table 13 are, of course, not very accurate but quite reliably reflect phenocryst proportions within a thin section and proportional differences from sample to sample. All the estimates were made during two consecutive days.

Thirteen of the rocks contain a single feldspar, albite in two, 0.2-0.4 antiperthite (Plate 39B) in five, 0.5-0.7 perthite in three, and a perthitic phase (partially altered) of uncertain proportions in three. Nineteen of the samples contain two feldspars, albite and

TABLE 13. COMPOSITION AND PROPORTION OF PHENOCRYSTS IN HAIGLER RHYOLITE

One-Feldspar Rocks				Two-Feldspar Rocks					
albite		perthite or antiperthite*		albite and perthite*			antiperthite and perthite*		
vol % Albite	vol % quartz	vol % feld	vol % quartz	vol % albite	vol % perth	vol % quartz	vol % antiper	vol % perth	vol % quartz
		0.2-0.4			0.5-0.9		0.1	0.5-0.9	
3	2	a 5	5	<1	3	5	<1	3	2
4	2	3	2	<1	1	<1	<1	<1	2
4	1	4	4	1	4	2			
		1	1	<1	1	1			
		5	1	c 3	1	2	0.2-0.3	0.5-0.8	
				<1	4	3	<1	2	2
				<1	2	2	$1?^{\pm}$	$1?^{\pm}$	2
		0.5-0.7		3	5	5	$2?^{\pm}$	$2?^{\pm}$	3
		5	2	2	3	2			
		b 2	3	<1	2	4			
		1	4	<1	4	1			
		altered		altered					
		d 3	4	<1?	3	3			
		4	4	<1?	3	tr.			
		<1	5	<1?	3	4			

*Amounts of K-feldspar component in perthite and antiperthite are given in sub-headings, e.g. 0.2-0.4 indicates antiperthite in the range 0.2 to 0.4 K-feldspar component.
±Perthite appears to range continuously from 0.2 to 0.8 and from 0.3 to 0.6 in the respective samples but two feldspars are probably present in each.

a. Chemically analyzed sample 6-3-1531.
b. Chemically analyzed sample 8-1-1819.
c. Chemically analyzed sample 8-1-1850A.
d. Chemically analyzed sample 5-1-1252.

0.5-0.9 perthite in fourteen and 0.1-0.3 antiperthite and 0.5-0.9 perthite in five. The significant points to be made with regard to perthite origin are: 1) In a given rock perthite proportion is quite constant. 2) Perthite character and associations recur so that the samples all fall into one of only a few groupings. 3) Albite and antiperthite are mutually exclusive. Feldspar bulk compositions (as inferred from perthite proportions) and associations are consistent with the crystallization of feldspars according to the principles of alkali feldspar crystallization as understood from studies over the years in experimental systems and of natural systems. It is concluded that the patch perthites are the products of extreme exsolution rather than replacement.

In most of the rocks albite and a potassium feldspar crystallized low enough on the solvus that upon cooling no exsolution occurred in the sodic phase. A few samples crystallized two feldspars somewhat higher on the solvus so that both potassic and sodic perthitic phases exsolved. The remainder of the rocks crystallized a single hypersolvus feldspar phase.

It is interesting to note the overall consistency of feldspar and quartz phenocryst contents and the tendency for certain proportions to prevail. Quartz content is about the same or a little greater than the total feldspar amount and in the two-feldspar rocks perthite is generally 2-3 times more abundant than albite. Notwithstanding the variations in phenocryst type in the single feldspar rocks all the rocks may be very similar in composition. Bulk compositional differences required to explain this variation need not be great because rocks of very similar composition but on either side of the feldspar minimum trough or cotectic, as the case may be, can crystallize feldspars differing greatly in composition even under hypersolvus conditions.

Oxbow Rhyolite

Generally massive, homogeneous Oxbow Rhyolite is alkali rhyolite very similar to Haigler rhyolite undivided but much more phenocryst rich.

Among the thin-sectioned samples is a specimen with well-defined pumiceous lenses, one with poorly outlined lenses, and two that are massive and texturally homogeneous. Clastic texture was recognized in thin section in all these samples although it is very weak in the latter two. The groundmass is generally very fine grained, though recrystallized to varying degrees, and the pumice fragments are always more coarsely crystalline with occasional weakly-developed spherulite forms.

Phenocrysts are quartz, antiperthite, plagioclase, perthite and a mafic silicate(?) replaced by opaque oxides. The unusual abundance ($\sim$ 15%) and large size of quartz phenocrysts is the most distinctive feature of the Oxbow Rhyolite. The phenocrysts have an apparent seriate size distribution from 1 to 5 mm and are only moderately resorbed.

Moderately to strongly resorbed alkali feldspar phenocrysts

(1-3 mm) are also markedly abundant (~ 10%). Nearly all this feldspar is patch antiperthite consistently containing about 30-40% K-feldspar component. A trace amount of perthitic K-feldspar contains less than 10% exsolved albite lamellae.

A half-dozen 0.5-1 mm anhedral-subhedral crystals of albite were found in the least sericitized sample. Sharply bounded fine-grained aggregates of sericite in the other rocks are apparently pseudomorphs after plagioclase.

The groundmass is composed of fine quartz and feldspar and reddening is due to very finely disseminated hematite. Fine opaque grains (~ 0.1 mm) are sometimes quite abundant in the flattened pumice layers. A few zircon crystals in some thin-sections are associated with clusters of opaque minerals. A trace of fluorite was also noted.

Sericite is disseminated in the groundmass in all samples and occurs as 0.1-0.2 mm subhedral booklets. It constitutes from a few percent to perhaps 10% of the rocks.

The presence of three feldspar phenocryst types is probably due to an early period of subsolvus crystallization at depth and later hypersolvus crystallization at a shallow crustal level (see page 407). A relatively small amount of early crystallizing plagioclase, K-rich alkali feldspar, and quartz remained in the melt as a much larger proportion of hypersolvus sodic sanidine and quartz crystallized in a high-level chamber. No other extrusive rhyolite, and no intrusive rhyolite* examined in Tonto Basin had a similar crystallization history.

The unique history of phenocryst formation is compatible in a very specific way with the hypothesis (page 67) that Oxbow Rhyolite extruded as a dome in a cauldron. The magma with its initial low phenocryst content would have occupied a chamber beneath a cauldron. It may earlier have been the source of a final voluminous ash-flow, the eruption of which led to subsidence and caldera formation. In a long period of quiescence nearly a fourth of the magma crystallized to form hypersolvus alkali feldspar and quartz phenocrysts. Finally resurgence of the magma would have led to doming in the cauldron (Smith and Bailey, 1969) and eruption of the crystal-rich, viscous magma above ring fractures in the moat.

Hell's Gate Rhyolite

The two units of the Hell's Gate Rhyolite, the Salt Lick phase and the xenolith-rich Blue Dog phase, will not be distinguished in the following discussion except where noted. Extensive petrographic study (38 thin sections) of both leucocratic phases reveals remarkable internal homogeneities and, except for inclusions, identical mineralogical compositions. The two phases no doubt represent two pulses from the same reservoir of silicic alkali magma.

In addition to a few percent each of quartz and alkali feldspar (probably a single sodic sanidine) phenocrysts, the magma apparently

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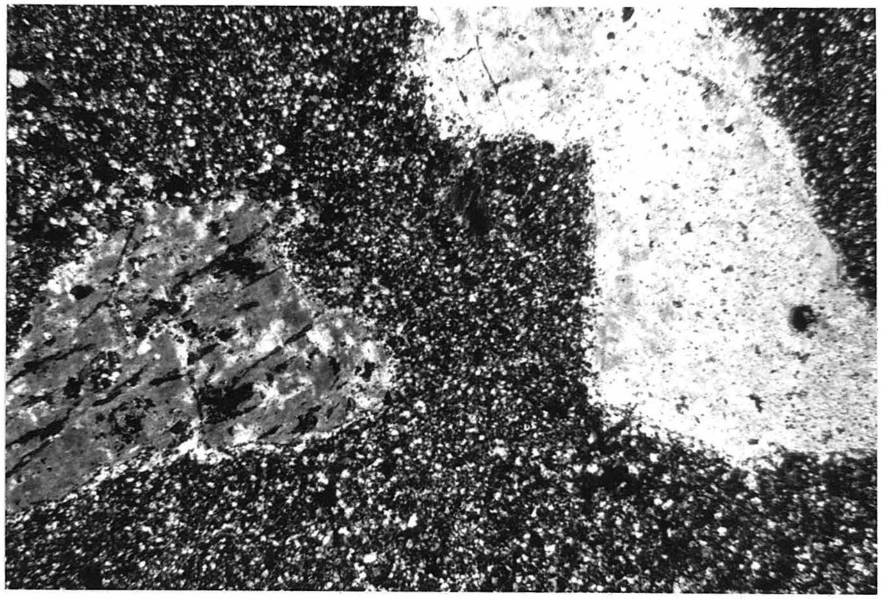
*King Ridge Rhyolite also crystallized in early subsolvus and later hypersolvus stages, but phenocrysts formed in the earlier and micrographic groundmass in the latter.

intruded with a little sodic(?) pyroxene, as suggested by the preservation in one exceptionally well-preserved sample of resorbed pale green clinopyroxene.

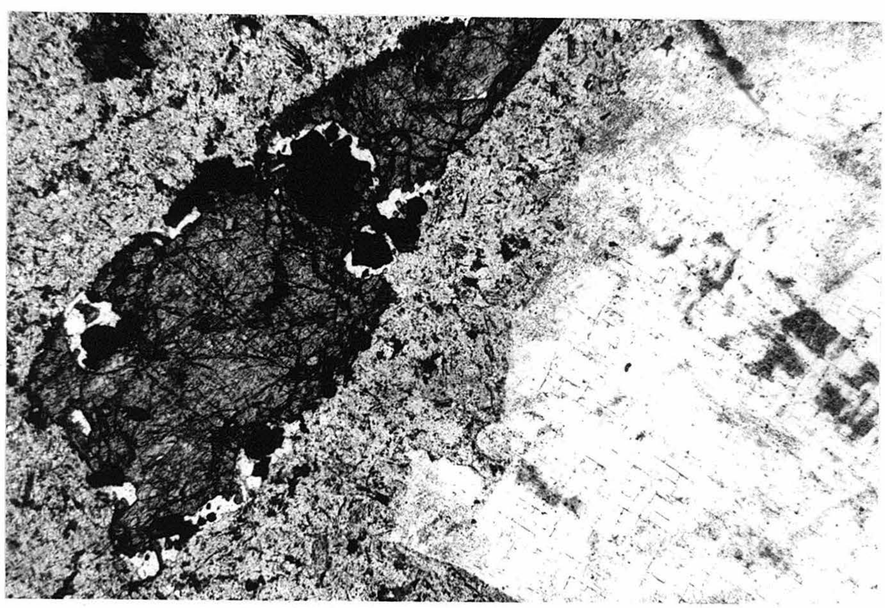
TEXTURE AND THE BLUE DOG TEXTURAL GRADATION

A lamellar texture due to flow foliation is present in a few samples. With this exception there is no variation on the simple porphyritic texture. Groundmass grain size is practically invariant in a given thin section but varies a little throughout the Salt Lick body and markedly with depth in the Blue Dog body. Groundmass grain-size varies from 0.01 to 0.03 mm in the Salt Lick phase and from 0.01 to 0.3 mm in the Blue Dog phase. In the Salt Lick phase most samples are about 0.010-0.015 mm (Plate 40A) and there seems to be no systematic relationship between grain size and depth in the body. With increasing depth in the thick Blue Dog sill, however, there is a pronounced gradation into a much coarser groundmass which becomes micrographic to vermicular at depth (Plate 41B). This transition is somewhat analogous to that in the King Ridge Rhyolite except that distinct, well-developed spherulites are the initial phase in the succession of textural stages culminating in micrographic intergrowth in the latter. This no doubt accounts for the fact that in the King Ridge body the final micrographic texture is more pervasive, more spectacular, more regular and fine, and the domains are larger. At perhaps a third of the depth in the Blue Dog body, however, fine quartz-feldspar intergrowths appear in the fine, granular groundmass. Lacking internal and

PLATE 40. HELL'S GATE RHYOLITE

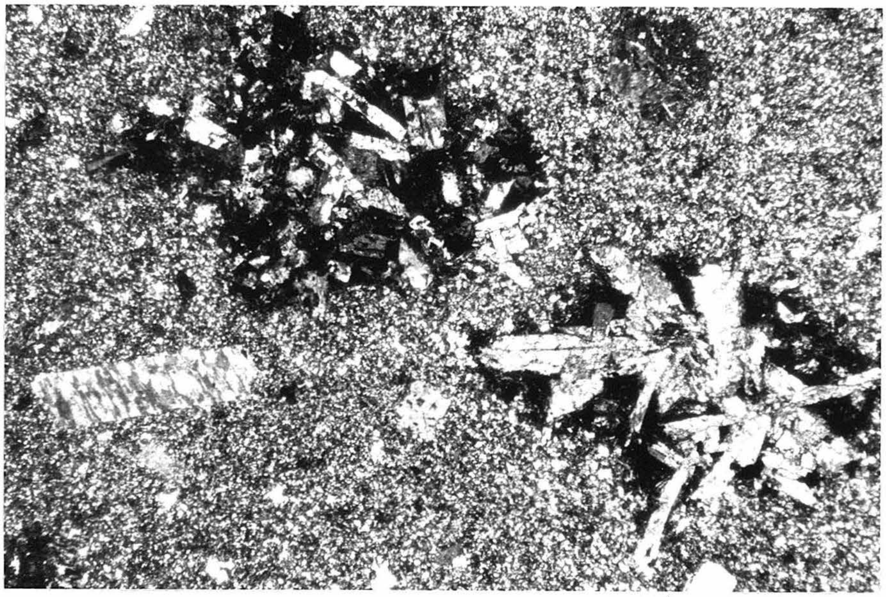


A. Resorbed perthite (left) and antiperthite phenocrysts in a very fine, even groundmass; Salt Lick phase. Dark specks and bars in phenocrysts are opaque oxides. Cross polarized light, 2 x 3 mm.

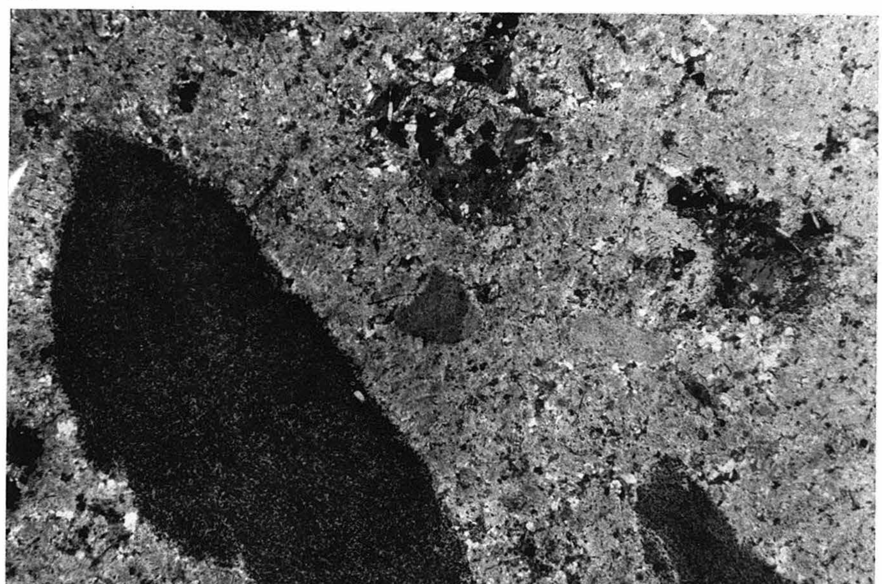


B. Marginally corroded clinopyroxene and orthoclase phenocrysts of an exceptionally well preserved Blue Dog specimen. The pale green sodic(?) pyroxene is preserved in no other sample examined. The feldspar, in contrast to typical clouded patch perthite of Hell's Gate Rhyolite, has clear, unexsolved(?) interior areas preserving a high temperature character. Plane polarized light, 2 x 3 mm.

PLATE 41. HELL'S GATE RHYOLITE



A. Texturally well preserved diorite(?) microxenoliths in upper Blue Dog rhyolite. Xenoliths are composed of sericitized and saussuritized plagioclase, chlorite (after amphibole), opaque oxides, and apatite. Coarse vein antiperthite (0.4 dark K-feldspar component) phenocryst to the left is typical of Hell's Gate Rhyolite. Cross polarized light, 6 x 9 mm.



B. Diorite(?) and mafite porphyry microxenoliths from lower Blue Dog rhyolite. The former are somewhat recrystallized; note apatite prisms. The groundmass, with finely intergrown quartz and clouded alkali feldspar, is much coarser than in Plate A. Plane polarized light, 6 x 9 mm.

external regularity, these tiny intergrowths are nevertheless basically like spherulites and also contain needles composed of chlorite(?) or trails of opaque grains like those in King Ridge Rhyolite. With increasing depth the areas of fine intergrowth coarsen gradually into domains of micrographic texture. In most of the deep samples there remains a considerable quantity of even grained groundmass between the micrographic areas. Feldspar in the micrographic intergrowth is a fine mesoperthite.

The coarsening with depth in the Blue Dog phase is a primary crystallization phenomenon. This is reasonable in view of the great thickness of the body, and the hypersolvus character of the micrographic intergrowth requires a magmatic origin (this argument is developed for the King Ridge Rhyolite, page 353). Absence of a systematic coarsening with depth in the Salt Lick phase is due to shallower intrusion, a lesser thickness (see cross-sections), and earlier intrusion. On the other hand, the presence of the probably still hot Salt Lick phase above would retard the cooling rate of the Blue Dog sill, thus enhancing its tendency to coarsen at depth.

MINERALOGY

Minerals thought to be exclusive to mafic inclusions are not discussed in this section.

The basic persistent mineralogy of the Hell's Gate Rhyolite is 1-3 mm phenocrysts of both quartz and alkali feldspar, each consistently making up 3-5% of the rock, in a groundmass of quartz, feldspar and minor amphibole and/or chlorite(?) and opaque minerals. A few crystals of zircon are present in most slides, and sericite, calcite, fluorite, and rarely biotite and epidote are present as alteration products. Resorbed phenocrysts of pyroxene were found in one sample and the few pseudomorphic clots composed of opaque minerals, chlorite(?) and calcite found in most thin sections are probably after pyroxene.

Feldspar phenocrysts are all perthitic or antiperthitic alkali feldspar. Solitary plagioclase crystals were found only in those samples with xenoliths and are unquestionably derived by breakup of the xenolith clusters. The feldspar phenocrysts are generally moderately to strongly clouded and coarsely exsolved, but there is much variation. In a few samples from the upper part of the Blue Dog body clouding and exsolution are restricted mostly to the margins of the grains and some interiors are clear and lamellae-free, apparently preserving high-temperature character ($2V_{\alpha}=40°$) (Plate 40B). At the opposite extreme, feldspar is intensely clouded with finely divided hematite and is an evenly exsolved lamellar mesoperthite. The latter type predominates in both phenocryst and groundmass in the granophyric lower part of the Blue Dog mass and is identical to that found in the Green Valley Granophyre. In the finer-grained upper rocks of the Blue Dog body and throughout the Salt Lick phase both antiperthitic and perthitic feldspars occur, often in the same rock (Plate 40A). These are generally patchy or coarsely lamellar but much variation in form and coarseness exists.

Because of variations in perthite texture and proportion it is uncertain whether two phenocryst feldspars or a single hypersolvus phase crystallized. Incomplete exsolution and possibly replacement complicate the problem. The prevalence of antiperthite ($\sim$ 0.4) in most samples and a continuum of perthite proportions in those containing perthite suggests that primary feldspar was a single sodic sanidine.

Pyroxene was found in one sample, a rare dark brown-black specimen from the Blue Dog phase (21, J-12), both as moderately eroded phenocrysts and in xenolithic diorite(?). The internally well-preserved pale green slightly pleochroic phenocrysts ($2V_{\gamma}$=40-50°) (Plate 40B) are clearly distinguished from the smaller yellow-brown alteration-clouded crystals ($2V_{\gamma}$=50-60°) of the diorite(?) clots. Arguments for an intratelluric origin for the pale green pyroxene are: 1) The prismatic and subhedral form is analogous to pseudomorphic forms seen in many thin sections of xenolith-free Salt Lick rhyolite. 2) Zircon crystals, along with opaque grains, are enclosed in the pyroxene. Zircon was not found in the microxenolithic clots. 3) The pale green color of the pyroxene is compatible with an origin in a silicic alkali magma. Sodic pyroxenes are typically greenish; those in the Green Valley Granophyre, which is more alkaline than the Hell's Gate Rhyolite, are a deeper green.

In the predominant red-brown rocks mafic minerals are amphibole, chlorite(?), and opaque oxides. In much of the upper Blue Dog sill and in the Salt Lick body fine-grained pleochroic bright green amphibole and/or chlorite(?) is disseminated through the groundmass, is the major alteration product of the pyroxene(?) pseudomorphs, and is a minor replacement phase in alkali feldspar. In a few instances larger and better formed grains were identified as amphibole. Most of the greenish component, however, is exceedingly fine-grained, often fibrous and sheeted. It appears to be chlorite and is probably an alteration product of the amphibole. In the deeper parts of the Blue Dog body some coarser amphibole is preserved, mostly in the xenoliths, and the very fine chlorite(?) is much less abundant. The more oxidized the rock the less abundant is the chlorite(?); it is altered to opaque oxides. This is the case in the deep granophyric portions of the Blue Dog body.

Sericite and calcite are present in trace amounts in the groundmass of most rocks and in the few most altered rocks may constitute 10% of the rocks, with sericite predominating. Sericite also replaces the Na-feldspar phase of the perthitic alkali feldspar phenocrysts in the more strongly altered samples. Calcite is secondary after both pyroxene(?) and alkali feldspar. Fluorite is present in essentially all the samples and commonly occurs as blebs in both the groundmass and in the feldspar phenocrysts.

INCLUSIONS

In upper parts of the Blue Dog sill, texture of the diorite(?) fragments is very well preserved (Plate 41A) and in the least altered rocks original(?) slightly zoned plagioclase is partially preserved. It was noted earlier that clinopyroxene was found in one sample. Sericitized and saussuritized plagioclase constitutes more than one-half of the typical xenolith, and chlorite(?) like that in the groundmass makes up almost one-third. Opaque minerals make up 5-10% and acicular apatite needles are remarkably abundant. Calcite and less abundant epidote are alteration products in these clusters.

With increasing depth the diorite(?) inclusions become albitized and recrystallized (Plate 41B). In the lower granophyric zone rather coarse amphibole is intergrown with the albite. Amphibole is only locally and poorly preserved, usually in the coarser grains or aggregates. It is altered to opaque minerals, chlorite(?) and to a lesser degree to biotite(?). Epidote is an abundant alteration product in the albitized xenoliths and sphene is occasionally present.

The fine-grained mafite porphyry inclusions have essentially the same mineralogy as the diorite(?) clots but plagioclase is less abundant. They are only slightly recrystallized at depth.

Rhyolite of Hog Canyon

Rhyolite which intrudes Christopher Mountain Quartzite in the Big Ridge syncline was examined only along its contact with the quartzite and only one sample (8-1-1912) was thin-sectioned.

Phenocryst content (about 20%) is higher than in any other alkali rhyolite body except the Oxbow Rhyolite. Quartz ($\sim$ 5%), albite ($\sim$ 5%), and K-feldspar ($\sim$ 10%) phenocrysts are all 0.5-2 mm, are subhedral to euhedral, and are little resorbed. Unzoned albite is twinned on both albite and pericline laws and is lightly speckled with sericite flakes. K-feldspar is an irregularly exsolved 0.8-0.9

perthite. It has a fine intricate pattern of strain birefringence and contains inclusions of albite.

The thin-section contains about a dozen muscovite tablets a few tenths mm thick and 1-2 mm in diameter. Some of these contain minor interlayers of leucoxene(?) and hematite which suggests they are secondary after biotite. Less than a percent of tiny opaque mineral clusters may be pseudomorphs after pyroxene(?), a few crystals of which are preserved in one cluster. Fluorite is unusually abundant both as a secondary (small anhedral grains, some replacing feldspar) and perhaps as a primary (0.5 mm subhedral-euhedral grains) phase.

The groundmass is evenly fine-grained (0.05 mm) and contains in addition to quartz and feldspar about 20% sericite. Disseminated hematite is virtually absent in the groundmass and in the feldspars.

King Ridge Rhyolite

From study of several dozen thin sections it was possible to verify a textural gradation in the King Ridge body from upper spherulitic rhyolite to granophyre at depth. A unique phenocryst mineralogy of two generations of alkali feldspar, plagioclase, and quartz persists unchanged through the coarsening and coalescing of the spherulites.

Mesoperthitic feldspar in the granophyre micrographic groundmass seems to require hypersolvus magmatic crystallization. Spherulites gradational into the micrographic intergrowth must also be magmatic in origin. This is compatible with an intrusive emplacement of the body as hypothesized from contact relations.

TEXTURE AND THE TEXTURAL GRADATION

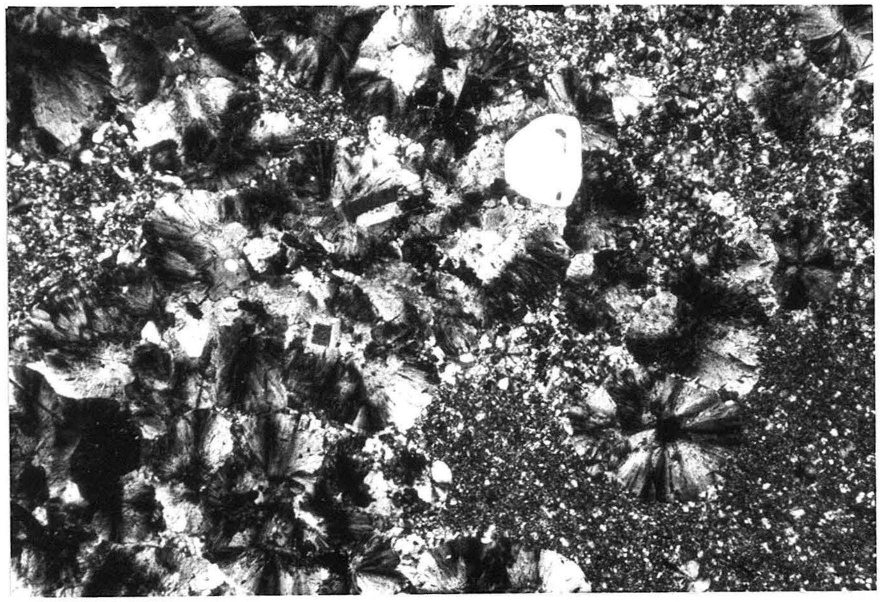
In upper parts of the body classical 1-2 mm spherulites are sharply delineated from a fine-grained groundmass (Plate 42A). A generation of tiny spherulites is sometimes present in the groundmass. Phenocrysts seldom occur in the granular groundmass, rather all three phenocryst phases are nucleation centers around which the spherulites have grown. Nearly every phenocryst of the small generation (0.2-0.7 mm) occupies the core of a single spherulite. Most larger crystals (2-3 mm) generally provide a substrate for a number of partial spherulite forms.

With increasing depth fibers of the spherulites coarsen, domains begin to develop, and spherulites gradually lose their smooth, spherical outline. The amount of interspherulitic groundmass is diminished as the crudely sectored spherulites begin to coalesce (Plate 42B). Crystallographic domains then become irregular fan-like or feather-like sectors with fine but distinct micrographic texture. Finally the distinction between groundmass areas and spherulitic areas is mostly lost and recognition of 'spherulite' areas is seldom possible. Micrographic texture becomes rather coarse and is very well developed (Plate 43A).

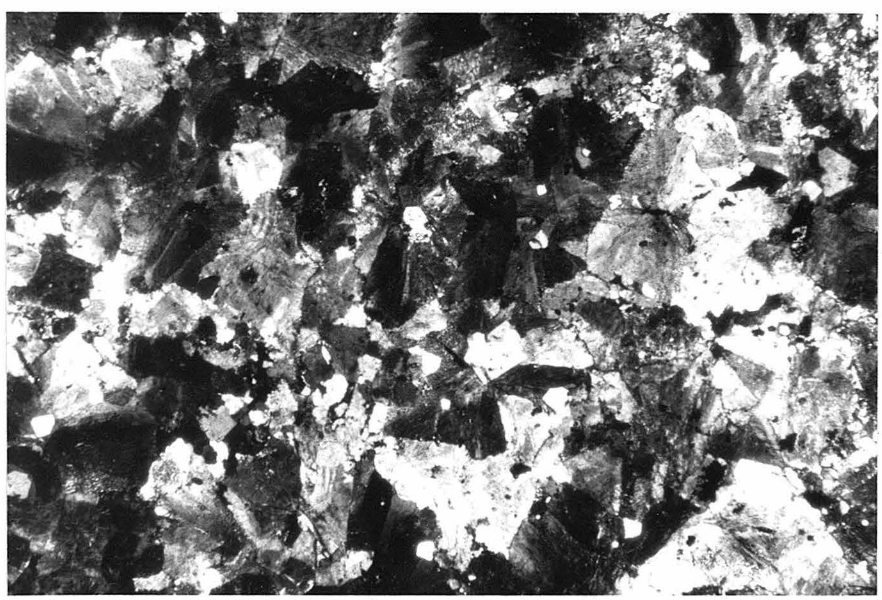
MINERALOGY

In a typical thin section one finds a half-dozen 2-3 mm perthitic alkali feldspar phenocrysts and a few 1-2 mm plagioclase and quartz phenocrysts. All have euhedral to subhedral form more or less modified by resorption. Rarely plagioclase either mantles or exists as euhedral inclusions within alkali feldspar phenocrysts. The small generation

PLATE 42. KING RIDGE RHYOLITE

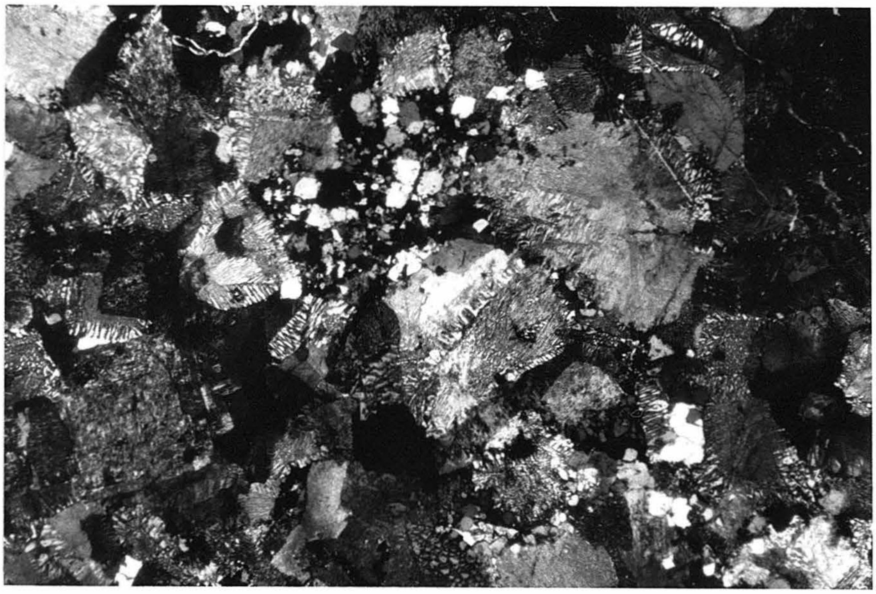


A. Spherulite texture in upper King Ridge Rhyolite. Coalescing spherules lie in a fine, even-grained groundmass. Note quartz, plagioclase, and alkali feldspar phenocrysts central to some spherules. Cross polarized light, 6 x 9 mm.

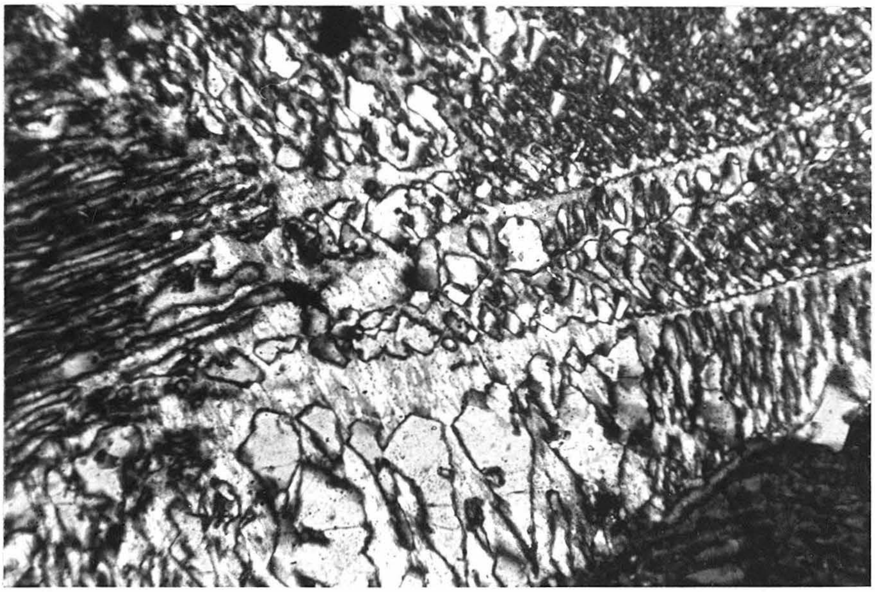


B. Intermediate texture in central part of King Ridge sill. Spherules have recrystallized into fan and feather sectors crudely centro-symmetric to core phenocrysts. Very little even-grained mesostasis remains. Cross polarized light, 6 x 9 mm.

PLATE 43. KING RIDGE RHYOLITE



A. Well developed fine micrographic texture at depth in the King Ridge body. Vestiges of spherule morphology are rare though phenocrysts are usually central to micrographic domains. Granular areas (upper center) are rare. Cross polarized light, 6 x 9 mm.



B. Mesoperthitic alkali feldspar in fine micrographic intergrowth of deep granophyre of the King Ridge body. Most of the feldspar in the rock crystallized in the groundmass apparently as a single hypersolvus phase. Cross polarized light, 0.7 x 1 mm.

of unresorbed phenocrysts consists of euhedral plagioclase and alkali feldspar (both usually rectangular or nearly square in outline) and euhedral quartz. These constitute no more than a few percent of the rock.

Alkali feldspar is patch perthite in which the K-feldspar fraction varies from 0.4 to 0.7. Plagioclase (albite?) is often complexly twinned on both albite and pericline laws and sometimes contains minor patches of apparently exsolved K-feldspar. Complex twinning and antiperthitic character are evidence that these crystals were probably anorthoclase. Feldspars of both generations are similar in composition.

Both even-grained groundmass and spherulites consist of quartz, feldspar, and minor mafic minerals. In the upper level rocks the mafic minerals are generally concentrated in the groundmass. In the typical red-brown rocks mafic minerals are almost universally opaque oxide, mostly hematite. The hematite occurs as dust in the feldspar and along grain boundaries and as larger anhedral grains usually associated with magnetite. The iron oxides also occur as needles or in trails defining the needles. Opaque minerals of both needles and larger more equant grains are pseudomorphic after a mafic silicate mineral. Biotite and chlorite(?)[*] are exceedingly rare and are fine-grained alteration products.

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[*]Aggregates of this variably pleochroic yellow to deep green mineral appear usually to have low first-order interference colors, but often exhibit second-order colors. Perhaps it is oxidized chlorite or some complex intergrowth of white mica and chlorite. Optic angle is less than 10°.

Deeper granophyric rocks are the most extensively altered. Plagioclase is strongly sericitized and hematite is more abundant and reddening of the feldspars by disseminated hematite is pronounced. Muscovite, uncommon or absent in upper level spherulitic rocks, commonly constitutes a few percent of the granophyre.

Gray rocks, containing little or no hematite, were found only in upper parts of the body. In the chemically analyzed gray sample, 2-1-435A, there is no hematite and the acicular and sub-equant pseudomorphs are composed of chlorite(?) with only minor magnetite. There may be a trace of amphibole as well. No positive trace of the original mafic silicate(?) was found but identical alteration products in both needles and larger sub-equant forms indicate that it crystallized from the magma in two stages as did the felsic phenocrysts.

Zircon is unusually abundant in King Ridge Rhyolite and fluorite is present in many thin sections.

In the coarsest granophyre, micrographic feldspar consists of a very fine lamellar or patchy intergrowth of both sodic and potassic phases in approximately equal proportion (Plate 43B). The texture is identical to that in the groundmass and also the phenocrysts of the hypersolvus Green Valley Granophyre. It appears that whereas both plagioclase and K-feldspar crystallized as phenocrysts in King Ridge Rhyolite, only a single intermediate phase crystallized in the groundmass.

HYPERSOLVUS CRYSTALLIZATION OF THE GROUNDMASS AND INTRUSIVE ORIGIN OF SPHERULITES

Preservation of the basic spherulite morphology throughout most of the textural gradation into granophyre attests to an origin of micrographic texture by recrystallization of spherulites. Either the spherulite crystallization and recrystallization to micrographic intergrowth were magmatic and the textural transition a function of depth, or cooling rate, or the spherulites formed by devitrification and the recrystallization and textural transition resulted from metamorphism. The latter was originally considered plausible because the spherulites suggested an extrusive origin for the body. Payson Granite might have provided heat for the metamorphic recrystallization.

Because of the mesoperthite character of the micrographic feldspar it is concluded that the feldspar and hence the quartz-feldspar intergrowth formed at hypersolvus or very near hypersolvus temperature. It is more reasonable therefore to think that the recrystallization leading to micrographic intergrowth occurred in a magmatic environment rather than in a contact metamorphic environment. This would require that the precursory spherulites be magmatic in origin.

This conclusion is compatible with field relations indicating an intrusive origin for the King Ridge body. Two generations of subsolvus feldspar phenocrysts formed at depth. Upon intrusion as a shallow sill, crystallization in the form of spherulite growth commenced throughout the magma. In faster-cooling upper parts of the body spherulite growth ceased as the residual interspherulitic magma quenched to a fine granular groundmass. With slower cooling at increasing depths spherulites grew larger, coalesced, and recrystallized to form the micrographic texture. These processes occurred throughout the body under hypersolvus conditions.

The change from solvus to hypersolvus feldspar crystallization is possible because with pressure decrease the feldspar critical temperature is reduced (Figure 19). Even with no increase in temperature or decrease in water content a silicic alkali magma rising in the crust can thus change from subsolvus to hypersolvus feldspar crystallization.

Green Valley Granophyre

Throughout all phases of the Green Valley Granophyre significant basic variations occur only in amount and size of phenocrysts and coarseness of micrographic texture. Quartz and mesoperthitic feldspar phenocrysts are set in a micrographic groundmass of the same phases. With one possible exception, the nearly fifty samples examined from all outcrop areas are hypersolvus. Rare albite occurs only in vugs. The leucocratic rocks contain a few percent mafic minerals and accessories. Most granophyre is strongly oxidized and has a red-brown color due to hematite disseminated in feldspar and along grain boundaries and fractures. Only in scarce gray samples is primary sodic pyroxene (and amphibole?) preserved.

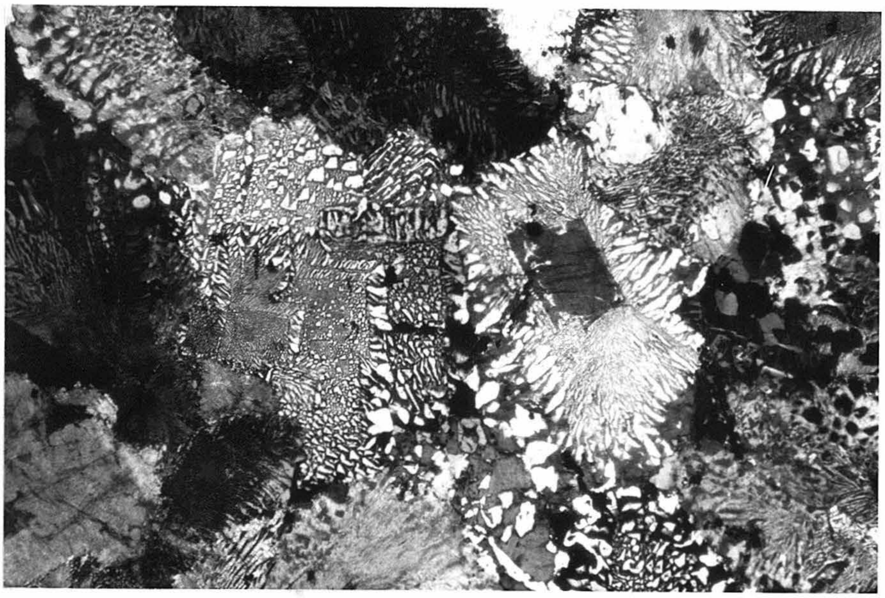
Rare globular, radiating micrographic forms are similar to spherule forms in the King Ridge rhyolite-granophyre transition and suggest that Green Valley Granophyre may also have passed through a spherulite stage. Abundant aplite sills and dikes attending granophyre may have been filtered from the granophyre at an intermediate stage of spherule recrystallization and coalescence.

TEXTURE

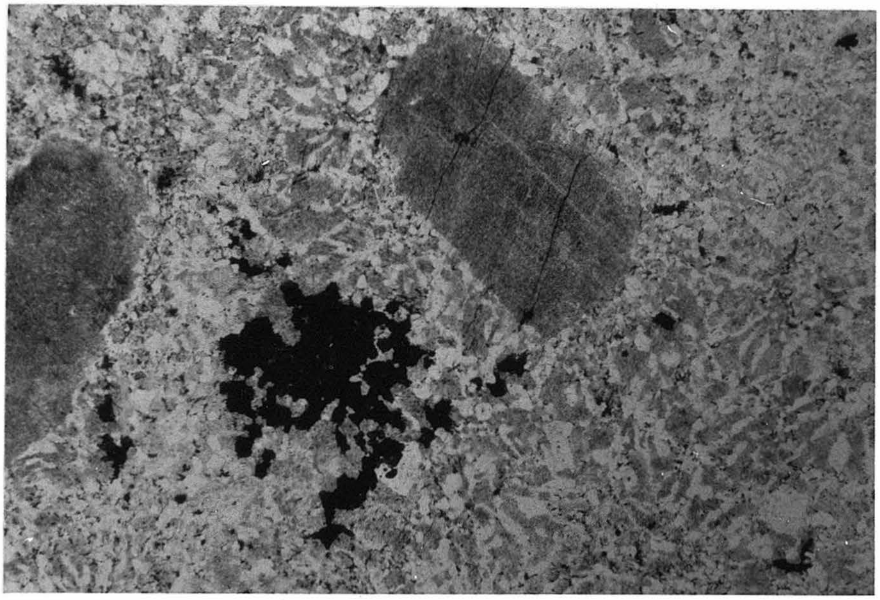
Rocks of the Green Valley Granophyre possess the classical porphyritic-micrographic texture (Plate 44A) which defines the rock as granophyre (Johannsen, 1939, vol. 1, p. 214). Euhedral to subhedral somewhat resorbed quartz and perthitic alkali feldspar phenocrysts are set in a micrographic groundmass of fascinating variety and beauty. There are infinite variations on the basic textural theme of a mosaic of domains consisting of intricately intergrown quartz and perthitic alkali feldspar. The domains may be defined by either crystallographically continuous alkali feldspar or quartz in which there may be several sub-domains of the other phase. Where a domain is adjacent to or completely surrounds a phenocryst the phase common to both phenocryst and domain is usually crystallographically continuous. Quartz in the domains usually forms more or less regular rods, elongate along the c-axis, which may be cuneiform in cross-section (Plate 44A). Less idiomorphic alkali feldspar has the appearance of being poured around quartz rods.

Micrographic intergrowth is coarsest in the Mescal Ridge body where less well-defined quartz rods may be a few tenths mm in diameter. It is finest in some marginal portions of the Thompson Wash phase where clusters of fan-like radiating domains are similar to recrystallized

PLATE 44. GREEN VALLEY GRANOPHYRE



A. Micrographic texture typical of finer portions in all phases of Green Valley Granophyre. Resorbed alkali feldspar core crystal (right center) is in optical continuity with alkali feldspar of enveloping micrographic domain. All feldspar is mesoperthitic with K-feldspar lamellae possibly slightly more abundant. Cross polarized light, 6 x 9 mm.



B. Rare pyroxene-bearing gray granophyre. Deep green (almost opaque) aegirine-augite (center) is apparently partially intergrown with vermicular quartz and alkali feldspar indicating all crystallized together. Feldspar clouding is due primarily to a disseminated phase other than hematite. Plane polarized light, 6 x 9 mm.

spherulite forms in King Ridge Rhyolite. There is a general tendency for intergrowth to be coarser with depth in the sills.

Micrographic intergrowth constitutes all the groundmass in the rocks except in rare instances where there is a small amount of generally aplitic material interstitial to 1-2 mm micrographic domains.

Miarolitic cavities are presently locally in much of the granophyre, particularly in the Mescal Ridge phase. The 'cavities', a few mm to a few cm in dimension, are filled mostly with coarse quartz, but also contain albite, muscovite and opaque minerals.

MINERALOGY

Mescal Ridge granophyre is characterized by 5-10% each of 2-3 mm roundish quartz and alkali feldspar phenocrysts. Quartz crystals are more extensively resorbed. Thompson Wash granophyre contains 5-10% of 1-3 mm alkali feldspar phenocrysts but contains only a few percent of quartz phenocrysts which are generally less than a mm in diameter. Granophyre at Neal Mountain and Gibson Rim has a quartz phenocryst content about like that of the Thompson Wash phase, and may have a lesser (3-6%) and more variable alkali feldspar phenocryst content. Local variations were encountered in each phase.

The feldspar and quartz mineralogy in all rocks is very simple. Almost two-thirds of the rock is finely to coarsely exsolved lamellar or patch perthite and nearly one-third is quartz. The perthitic character of the feldspar is consistent whether in phenocryst or micrographic intergrowth. It is 0.4-0.5 antiperthite or mesoperthite which is more coarsely and evenly lamellar when more strongly clouded and more patchy, finely exsolved, and often less completely exsolved where more clear.

In the brick-red granophyre typical of each exposure area hematite, magnetite, white mica, zircon, and rarely biotite are present in addition to quartz and feldspar. Perthite is moderately to heavily clouded with hematite dust; the albite portion tends to be much less clouded than the K-feldspar. Hematite is also disseminated along grain boundaries and fractures, and occurs in clots with magnetite.

Muscovite and sericite make up a percent or two of some rocks, mainly those with miarolitic cavities. Rare albite crystals occur only in miarolitic cavities. Biotite occurs as an extremely rare alteration product in some of the mafic clots and is strongly oxidized.

Alkali feldspar in the scarce gray rocks is clear to strongly clouded (usually milky rather than red) and exsolution is sometimes incomplete. One sample (1-0-32) contains a few percent albite which may be a liquidus phase. Other samples, like red granophyre, are entirely hypersolvus. The gray samples contain 1-2% of fine-grained green pleochroic mineral(s) and less than 1% of sphene. Traces of allanite(?), garnet(?), zircon and unidentified phases are also present. Fluorite is common in both these and the brick-red granophyres.

The green phase ($\sim$ 1%) in one gray sample is apparently all pyroxene (α=β= medium green, γ=medium yellowish green; $2V\gamma$=60-70°; α:z=30-35°) which is resorbed and marginally corroded to a reddish-brown. This pyroxene is apparently a low-Na aegirine-augite. Similar, more strongly altered grains occur in other gray samples, but most of the green phase, particularly in the reddish-gray rocks, is a much deeper green. Because of fine grain size, strong absorption, and alteration optical properties were very difficult to determine. A large (70-80°) negative 2V was obtained on one deep green grain. Extinction angles are about 10°. Some of the dark green phase may be amphibole but the large negative 2V suggests a sodic pyroxene (aegirine?) rather than sodic amphibole. The latter should have a considerably smaller 2V, and more bluish in its pleochroic scheme.

Some larger (1 mm) partially altered pyroxene(?) grains are apparently phenocrysts. Opaque clusters throughout the red granophyre are no doubt pseudomorphous after this phase. Most pyroxene (and amphibole?) is fine-grained, however, and may be acicular or intergrown with micrographic quartz and feldspar (Plate 44B). It apparently crystallized from the magma along with groundmass quartz and feldspar.

Sphene occurs in the gray rocks as tiny grains in the amphibole (?) clusters, as rims apparently replacing opaque grains, and less frequently as comparatively large (0.2-0.5 mm) subhedral solitary grains. Opaque (magnetite?) minerals in the gray and red-gray rocks are about as abundant as the green minerals.

ORIGIN OF MICROGRAPHIC TEXTURE AND OF APLITE ASSOCIATED WITH THE GRANOPHYRE

The scarce micrographic spherules, particularly when found with very fine interstitial granular material, are reminiscent of the spherulitic and finer granophyric portions of the King Ridge Rhyolite. This prompts two suggestions. 1) Micrographic intergrowth of the Green Valley Granophyre may itself have passed through the spherulite stage. 2) The fine granular phase, essentially free of phenocrysts, represents a magma residuum which was extracted to form aplite sills, dikes, and gradational margins associated with the granophyre.

Though generally much coarser, Green Valley granophyre is very similar to granophyre of the King Ridge body. Phenocrysts in both bodies apparently were loci for crystallization of the groundmass intergrowth. Micrographic domains commonly radiate crudely away from phenocrysts and coarsen outward. Crystallographic continuity of phenocrysts and the comparable phase in the surrounding intergrowth is very common. In the King Ridge body the regularity of texture and its relation to phenocrysts is clearly inherited from the precursory spherulites. Analogous textures in Green Valley Granophyre suggest the same origin and the rare spherulitic forms in the more quickly cooled border areas seem to confirm it.

Barker (1970) points out that intergrowth textures in granophyre vary considerably (spherulitic, plumose, radiating fringe, vermicular, cuneiform, and insular) and suggests that the term micrographic not be used because it implies more regularity than is usually found. Several origins of granophyre may be reflected in the different textures. Striking regularity of texture and the prevalence of graphic or cuneiform intergrowth in Green Valley and King Ridge granophyre warrants the application of the term micrographic to this groundmass.

It may be taken as a working hypothesis that granophyre with the distinctive micrographic texture analogous to that of the intrusive sheets in Tonto Basin is descended from spherulitic intrusive porphyry.

Origin of aplite by extraction from the granophyre was proposed from megascopic relations (page 159 and Plate 23A). From the present discussion it becomes clear how such large quantities of aplite (relative to tiny amounts of interstitial aplite found) were derived and why it is so phenocryst-poor. Early in the crystallization of the groundmass most phenocrysts were enveloped by spherulites. As the spherulites grew, coalesced, and began to recrystallize, much interstitial crystal-free, spherulite-free melt was filtered from the semirigid framework of crystalline material. Remaining interstitial liquid, except in rare instances, was eventually consumed in the continuing formation of the micrographic intergrowth.

Alaskite

Alaskite from all exposures is biotite alkali granite identical to much of the Payson Granite.

In red-brown alaskite of the sills and Cherry Spring east exposures biotite is strongly altered to hematite and plagioclase is albitized. Biotite of Cherry Spring west alaskite is strongly altered to chlorite and plagioclase to sericite and epidote. Original minerals are relatively well-preserved in the Star Valley plug.

Systematic differences in plagioclase and perthite content and perthite bulk composition imply widely varying crystallization for the various bodies. Feldspar of Cherry Spring west alaskite crystallized lowest on the solvus indicating lowest temperature and highest water pressure. Sill alaskite crystallized at a little higher temperature and the Star Valley plug higher still. With feldspars indicating the greatest solid solution, eastern Cherry Spring alaskite crystallized at the highest temperature and lowest water pressure relatively near the solvus crest.

TEXTURE AND MINERALOGY

Most alaskite is medium-grained (1-5 mm) and basically hypidiomorphic. The western Cherry Spring alaskite is variably fine-grained and weakly to strongly porphyritic. Faintly porphyritic textures and rare subhedral quartz crystals present locally in most of the bodies are evidence that phenocrysts existed in the magma when it was emplaced. Sub-graphic and cuneiform textures are not uncommon and coarse micrographic domains occur sporadically near margins. Upon intrusion the magmas may have been very similar in phenocryst character to the rhyolite and granophyre.

Patch and vein perthite is nearly always coarsely and extensively exsolved and varies from about 0.5 to 0.8 in K-feldspar component. Granular plagioclase in most units is only slightly more calcic or of about the same composition as exsolved albite lamellae in perthite. The proportion of plagioclase to perthite (Table 14) varies considerably from unit to unit and in one instance within the same unit (Mud Spring body).

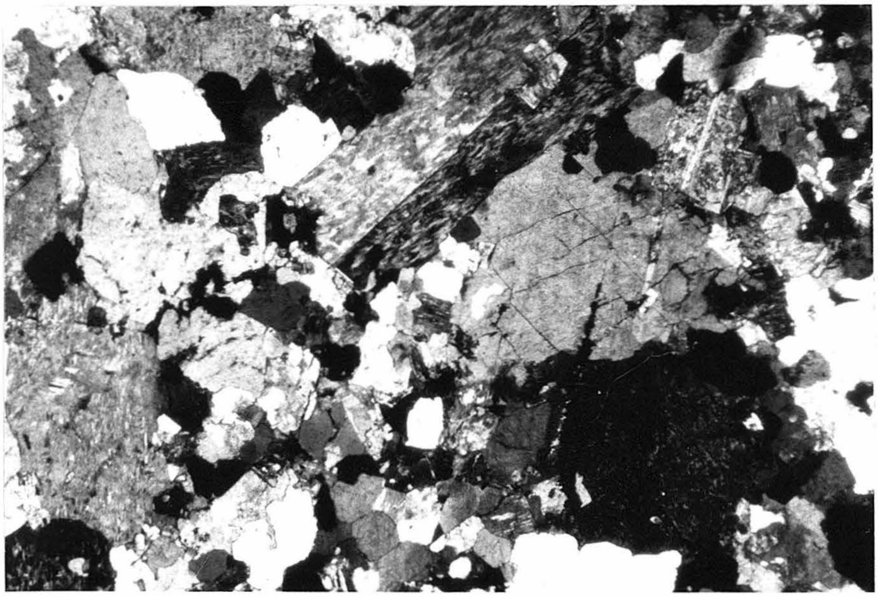
TABLE 14. MODAL ANALYSES OF ALASKITE

	Cherry Spring Stocks				Sills Beneath Mescal Ridge Granophyre						Mud Spring Sill			Star Valley Plug	
	west		east												
Sample Number	5-1-1192	5-1-1290[1]	5-1-1273	9-1-1993	1-1-112	2-1-346	2-1-383[1]	2-1-453	1-2-249	1-2-256	1-0-1B	2-1-310A	2-1-314	9-3-2012A[1]	Average
Location	H-17	G-17	G-18	H-19	F-13	F-13	E-14	E-14	I-10	H-10	F-11	G-11	H-10	G-6	
quartz	27.0	30.8	32.1	40.6	32.2	38.1	40.6	28.5	47.5	39.3	37.3	37.3	37.1	36.7	35.7
perthite (pe)	40.2	41.2	58.2	48.1	41.7	45.7	35.8	52.0	38.0	43.4	28.0	44.1	48.2	40.2	44.1
host (h)		33.3	37.4	34.0			25.3							26.5	
lamellae (1)		7.9	20.8	14.1			10.5							13.7[2]	
plagioclase (pl)	25.8	24.2	5.7	5.9	23.3	9.0	20.4	17.3	9.9	14.4	30.2	15.7	12.1	21.5	16.1
biotite			0.1		2.9		3.1	1.8			2.5	0.8	0.4	0.6	0.7
muscovite				2.9		4.1			3.3	0.8	1.6	0.2	0.6		1.1
chlorite	4.5	2.8													0.9
hematite		0.3	3.3 (hematite + mgt/ilm)	2.1 (hematite + mgt/ilm)	0.1	0.3		0.3	1.1 (hematite + mgt/ilm)	1.9 (hematite + mgt/ilm)	0.3	1.8 (chlorite + hematite)	1.5 (hematite + mgt/ilm)		1.1 (hematite + mgt/ilm)
mgt/ilm	0.9	0.6				0.2		0.2				0.1		0.6	
epidote	0.8		0.4												
fluorite			0.1	0.4			0.1		0.2	0.2			0.1		0.2 (epidote + fluorite + other)
other	0.8								0.1		0.2			0.3	
pe/(pl + pe)	.61	.63	.91	.89	.64	.83	.64	.75	.79	.75	.48	.79	.80	.35	.27
(pl + 1)/(pl + pe)		.49	.41	.37			.55							.57	
1/(1 + h)		.19	.36	.29			.29							.34	
An in pl[3]						4		8	3	2	4	5	3		
color index	6.2	3.7	3.7	2.1	3.0	0.5	3.1	2.3	1.1	1.9	3.6	2.7	1.9	1.5	2.7
counts	648	836	756	700	948	1009	986	1128	1000	1000	1209	1000	1000	859	
area (mm^2)	525	677	612	700	768	817	799	914	810	810	979	810	810	696	
I.C.[4]	200	44	35-40	35-40	30-35	25-30	20-25	20-25	30-35	20-25	35-40	35-40	35-40	35-40	
$\sqrt{v}$[4]	~1	2.7	~3.0	~2.9	~3.2	~3.4	~4.0	~3.9	~3.2	~4.0	~2.7	~2.8	~2.8	~2.9	

1. Chemically analyzed samples
2. Includes 5.9% myrmekite
3. Determined by dispersion method (Morse, 1968); index of refraction on (001) cleavage flakes using monochrometer.
4. See Table 7 for meaning of these parameters.

PLATE 45. ALASKITE

A. Cherry Spring west lithology. Subhedral, zoned plagioclase, more strongly altered in the cores, makes up about 20% of the rock. Perthite contains about 20% fine albite lamellae. Cross polarized light, 4.5 x 6 mm.



B. Cherry Spring east lithology. Coarsely exsolved perthite contains about 40% albite component. Unzoned albite crystals (not seen in photo) constitute about 5% of the rock. Cross polarized light, 4.5 x 6 mm.

Modal color indices for the 12 samples in Table 14 average 2.7. Normative color indices are 1.3, 3.2, and 3.3 for the three chemically analyzed rock samples. Biotite is present in all alaskite bodies but is seldom well-preserved; it was either the major or only mafic silicate in all exposures. It is strongly to completely altered to hematite and muscovite or chlorite. Well-preserved amphibole (0.2%) was found in the Star Valley plug and a trace of badly altered amphibole(?) was found in one of the Cherry Spring east samples.

Alaskite of the sills and the Cherry Spring east body is strongly reddened by disseminated hematite. Chlorite is virtually absent in these rocks. Muscovite and sericite are generally present and are most abundant in the most strongly altered rocks. Muscovite books in some areas (particularly in Cherry Spring east exposures) are pseudomorphic after biotite. Trace amounts of epidote occur occasionally with opaque clusters.

In gray-brown Cherry Spring west alaskite biotite is altered to chlorite. Alkali feldspar is clear but zoned plagioclase phenocrysts are clouded, more strongly in cores, with sericite and epidote.

All minerals are relatively well-preserved in the Star Valley plug.

Accessory minerals in all phases are opaque oxides and zircon; fluorite occurs in all except the Cherry Spring west stock(s).

Despite variations in feldspar proportions and alteration style alaskite from all areas is of remarkably uniform composition. Characterized by nearly equal proportions of quartz, K-feldspar, and very sodic plagioclase (including lamellae in perthite) and a small amount of biotite or its alteration products, all alaskite is biotite alkali granite like much of Payson Granite (see Table 7).

IMPLICATIONS OF FELDSPAR VARIATIONS

Feldspar crystallization in alaskites was entirely subsolvus but there is great variation in plagioclase and perthite content and in perthite host/lamellae proportions. Perthite in most rocks is coarse and exsolution appears to be essentially complete. Those rocks with less plagioclase and more perthite have a higher proportion of albite lamellae in perthite. For five samples with widely ranging granular plagioclase contents, modal values of total plagioclase (granular plagioclase plus lamellae in perthite) are similar (Table 14).* These considerations and the similar chemical compositions (Plate 4, Analyses 29, 30, and 31) imply that the varying feldspar proportions are simply the result of crystallization over a relatively wide temperature range at higher and lower positions on the feldspar solvus.

Cherry Spring east alaskite, with about 6% granular plagioclase and about 50% coarse intermediate perthite, seems to have crystallized at the highest temperature nearer the solvus crest. The western Cherry

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*That perthite may be extensively exsolved and that the modal determination of the amount of albite lamellae is reasonably accurate is shown by the close agreement between normative and modal quartz, K-feldspar, and albite (granular and lamellae) in sample 5-1-1290 (Cherry Spring west):

	normative	modal
quartz	30.2	30.8±2.7
K-feldspar	33.1	33.3±2.7
albite	32.7	32.1±2.7

Spring rocks have the highest plagioclase content (about 25%), the lowest perthite lamellae/host ratio, and therefore crystallized low on the feldspar solvus at the lowest temperature. Other alaskites are of intermediate character.

This attempt to understand the relative crystallization conditions from feldspar character and composition is hindered because of albitization of the plagioclase and because of incomplete or fine exsolution of perthite in some grains or in some rocks. However, original bulk feldspar compositions can be calculated from normative feldspar compositions and modally determined plagioclase and perthite amounts. The reliability of this approach is shown in Figure 14A. Core and rim feldspar compositions determined by microprobe (Piwinskii, 1968; Piwinskii and Wyllie, 1970) for two granite samples compare favorably with feldspar compositions calculated by the author from modal and normative values given by Piwinskii and Wyllie.

Calculated and adjusted feldspar compositions for four Tonto Basin alaskites are shown in Figure 14B.* Tie lines between the calculated compositions (ticks on the sidelines) would pass through the respective normative compositions, the relative distances from the normative points giving the proportions modally determined. These proportional distances and hence the proportional amounts are maintained for respective

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*The normative bulk value of sill sample 2-1-383 was arbitrarily used in the calculation for the Cherry Spring east sample (5-1-1273). Average plagioclase and perthite proportions from all sill samples were used in the calculation for sample 2-1-383 because its low modal perthite content would give a calculated alkali feldspar composition (Or_{78}) much too poor in albite component for the lamellae proportion measured (0.29).

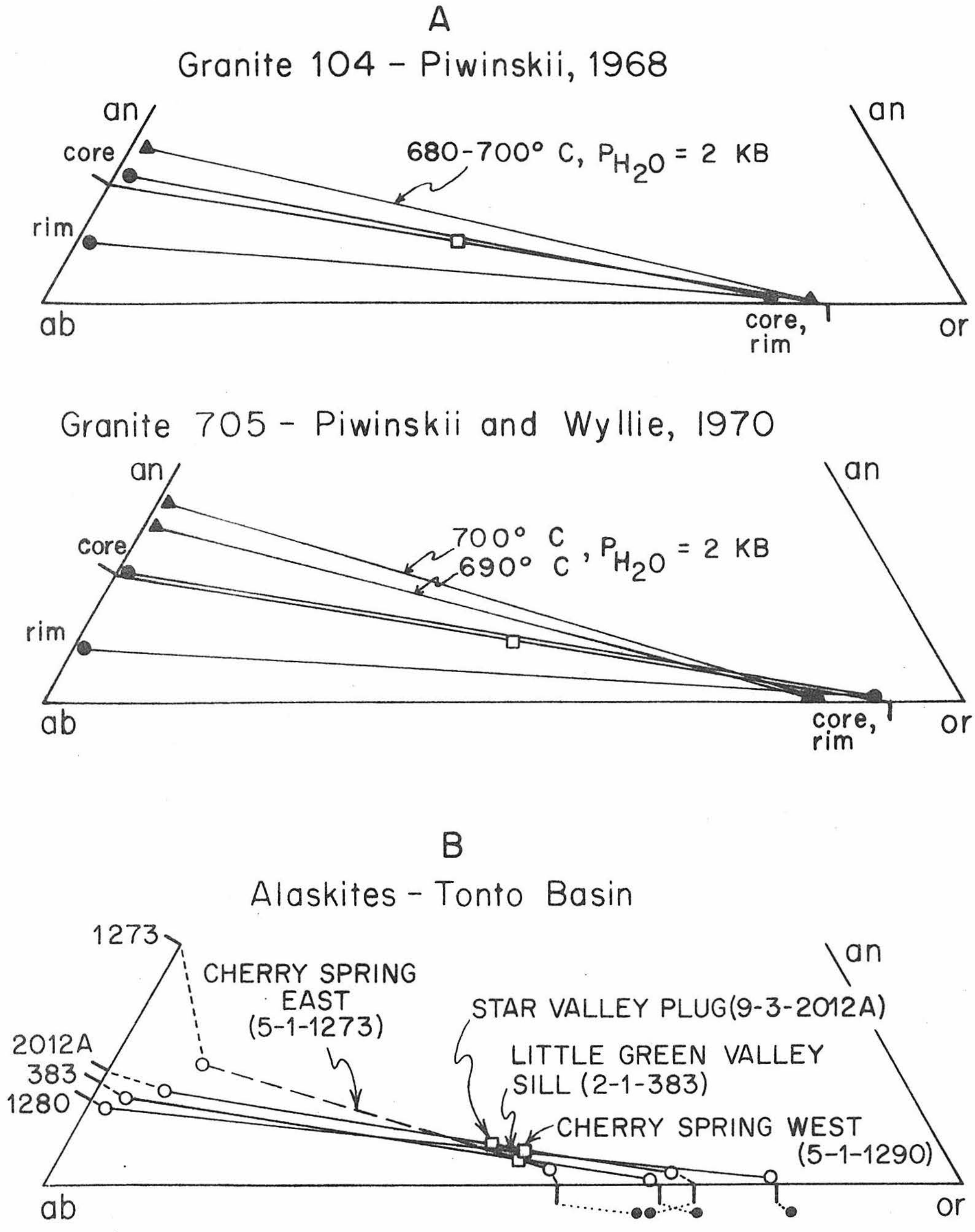

Figure 14. (A) Comparison of actual, calculated, and experimentally crystallized feldspar compositions from two granite samples. (B) Approximated compositions of primary feldspars in Tonto Basin alaskites. Calculated values adjusted for approximate amount of ternary solid solution.

Triangles - synthetic compositions; filled circles - actual compositions; squares - normative bulk compositions; sideline ticks - calculated compositions; open circles - approximated compositions; dots tied to sideline ticks - modal bulk perthite compositions.

adjusted compositions indicated by open circles.

The adjustments are made because of petrographic indication of ternary solid solution. Plagioclase in sample 5-1-1290 is unexsolved and extensively exsolved perthite was clearly albite-poor. In sample 2-1-383 and other sill samples plagioclase generally contains a few percent K-feldspar blebs. In the Star Valley sample plagioclase contains 5-10% exsolved K-feldspar. Granular albite of the Cherry Spring east sample, however, is not anitperthitic and its arbitrary adjusted plagioclase composition arises from allowing solid solution of Ca-feldspar in perthite. Perthites in the Cherry Spring east and Star Valley samples have the most exsolved albite component and the most associated myrmekite* suggesting solution of more anorthite component. The presence of amphibole in only these rocks also supports the contention of more ternary solid solution because it implies higher temperatures.

Calculated compositions can be compared with original compositions only in the relatively well-preserved Star Valley sample. The measured plagioclase composition (An_{15-20}) and lamellae content (0.34) in incompletely exsolved alkali feldspar indicate that the calculated compositions are a little low in An content and Ab content, respectively. Adjustments would give this rock a slightly steeper tie line and a

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*Myremekite is considered (Hubbard, 1966, 1967; Phillips and Carr, 1973; Carstens, 1967) to be exsolved from alkali feldspar which has excess SiO_2 due to substitution of one Ca for two alkali ions thus leaving a vacant ion site. Observations in this study, including discovery of some myrmekite internal to alkali feldspar (sample 9-3-2012A), supports this hypothesis.

clear-cut intermediate position between the Cherry Spring east and sill samples.

It has been noted by many petrologists (e.g., Rahman and MacKenzie, 1969) that for a given bulk composition steeper plagioclase-alkali feldspar tie lines in the ternary feldspar diagram indicate higher crystallization temperatures and hence lower water pressure. The progressive steepening of tie lines supports the other evidence indicating increasing temperature of crystallization and clearly indicates the temperature sequence, Cherry Spring west, sills, plug, Cherry Spring east.

The sills beneath Mescal Ridge granophyre and the Mud Spring sill seem to have about the same feldspar character (Table 14). Mud Spring sample 1-0-1B is anomalous. Its high granular plagioclase content may be due to local high water content at its position along the upper contact of the sill.

Extensive reconstitution of feldspars in some alaskite rocks has occurred with little or no modification of original texture and plagioclase-alkali feldspar proportions. Textural preservation was suspected from textural relations alone (plagioclase inclusions in perthite, subhedral feldspar forms, apparent paucity of granular exsolution) and is confirmed by the demonstrated capacity of the rocks to yield data pertinent to crystallization histories. Original plagioclase in the alaskites was sodic to intermediate oligoclase which has been, except in the Star Valley plug and possibly in the Cherry Spring west body, almost universally altered to intermediate albite. The absence of epidote in the rock means that calcium must have migrated into the albite lamellae of the perthite. It would appear that the albite lamellae and granular plagioclase have exchanged Na and Ca practically to the point of equilibration. This effect is most pronounced in the Cherry Spring east body. Primary plagioclase was by calculation An_{30} and by adjustment about An_{18} with perhaps 10% dissolved $KAlSi_3O_8$. It is now intermediate albite with no trace of exsolved K-feldspar. Granular plagioclase was apparently depleted in Ca and K and enriched in Na; albite lamellae were enriched in Ca. The site of deposition of the K-feldspar component is not recognized, but this is not surprising because it constitutes only about 1% of the K-feldspar in the rock.

Because albitized plagioclase is prevalent in the reddened rocks (sills and Cherry Spring east) both oxidation and albitization may have occurred during hydrothermal activity (page 381). Extent of exsolution in alkali feldspar however seems to be unrelated to reddening of the rock. In the Cherry Spring west rocks, which are not oxidized and in which plagioclase is not albitized, alkali feldspar exsolution was essentially complete (page 366).

Chemistry

Extrusive rhyolite and intrusive rhyolite, granophyre, and alaskite (and possibly part of Payson Granite), constituting more than half of the Precambrian exposure in Tonto Basin, are exceedingly similar leucocratic silicic alkali rocks. Multiple analyses within units indicate a high degree of homogeneity and a general absence of marked alteration.

Inconsistent and somewhat low alkali oxide contents and moderate amounts of normative corundum in Haigler rhyolite are evidence of mobilization and possibly some loss of alkalis. In Green Valley Granophyre a correlation of alkali variation with oxidation state suggests alkali (mainly potassium) addition during alteration. Alkali metasomatism may have occurred during hydrothermal activity initiated by intrusion of the granophyre sills. Certain petrographic characteristics in granophyre suggest the possibility that the alkali variations are inherited from the magma and therefore that the hydrothermal alkali enrichment(?) occurred prior to complete crystallization.

GENERAL

Average chemical compositions for the hypabyssal and volcanic silicic alkali rocks of Tonto Basin are compared in Table 15 with those of other silicic alkali and calc-alkali rocks. Included in the Tonto Basin averages are all analyses determined for this study except analyses 17 and 23, which have, respectively, strong and moderate alkali alteration. Remarkable similarities of the averages and of the analyses within units argue that the rocks are generally well preserved.

Similarity of the Tonto Basin and Mazatzal Mountains extrusive rhyolite averages supports the proposed correlation (page 29) of these Haigler Group rocks.

The Tonto Basin averages are similar to Nockolds' average alkali rhyolite and biotite alkali granite analyses and to the average extrusive rhyolite from the Yellowstone-Island Park area. Tonto Basin

TABLE 15. AVERAGE COMPOSITIONS OF TONTO BASIN SILICIC ALKALI ROCKS AND OTHER AVERAGES OF SILICIC ALKALI AND CALC-ALKALI ROCKS

	Tonto Basin					Maz. Mtns.	Yellow-stone	Nockolds' (1954)			Cascades
	Extr. rhyo.	Intr. rhyo.	Grano-phyre	Alas-kite	Grand Avg.	Extr. rhyo.	Extr. rhyo.	Alkali rhyo.	Biotite Alkali gran.	Calc-Alkali rhyo.	Calc-Alkali rhyo.
	1	2	3	4	5	6	7	8	9	10	11
SiO_2	75.67	75.28	75.78	74.29	75.45	74.97	76.3	74.57	75.01	73.66	73.23
TiO_2	0.13	0.17	0.10	0.09	0.12	0.23	0.15	0.17	0.17	0.22	0.24
Al_2O_3	12.56	12.20	12.34	12.75	12.44	12.58	12.3	12.58	13.16	13.45	14.03
Fe_2O_3	*	*	*	*	*	*	1.1	1.30	0.94	1.25	0.60
FeO	1.65	1.89	1.69	1.40	1.67	2.41	0.5	1.02	0.88	0.75	1.70
MnO	0.02	0.02	0.01		0.01	0.03		0.05	0.07	0.03	0.02
MgO	0.03	0.05	0.05	0.23	0.08	0.06	0.10	0.11	0.24	0.32	0.35
CaO	0.55	0.74	0.60	0.64	0.63	0.65	0.5	0.61	0.56	1.13	1.32
Na_2O	3.51	3.59	3.89	3.55	3.63	3.63	3.3	4.13	3.48	2.99	3.94
K_2O	4.40	5.00	5.19	5.22	4.94	5.00	5.0	4.73	5.01	5.35	4.08
P_2O_5	0.00	0.01	0.00	0.02	0.01	0.02		0.07	0.11	0.07	0.05

*All Fe as FeO

1. Average of analyses 14, 15, 16 & 18, Plate 4.
2. Average of analyses 20, 21, 22 & 24, Plate 4.
3. Average of analyses 25, 26, 27 & 28, Plate 4.
4. Average of analyses 29, 30, 31, Plate 4.
5. Grand average of 15 analyses, columns 1-4.
6. Average of extrusive rhyolite analyses V and VII (Table III, Ludwig, 1973), Red Rock Rhyolite and rhyolite sub-unit of Telephone Canyon Formation, Mazatzal Mountains.
7. Average of 15 rhyolite analyses, Yellowstone-Island Park complex (Hamilton, 1963, 1965).
8. Average of 21 alkali rhyolite analyses.
9. Average of 12 biotite alkali granite analyses.
10. Average of 22 calc-alkali rhyolite analyses.
11. Average of 9 rhyolite analyses, Cascades (Carmichael, 1964, Table 8).

and Yellowstone-Island Park rocks are remarkably homogeneous and alike and differ slightly from Nockolds' average alkali rhyolite in having less Na_2O, perhaps a little more K_2O, and less iron. Tonto Basin may be distinctive in its very low MgO content.

Calc-alkali rhyolite averages are markedly different from the silicic alkali rocks of Tonto Basin in containing less SiO_2, more Al_2O_3, and in having lower alkali/lime and Fe/Mg ratios.

Perhaps the singular most impressive characteristic of the Tonto Basin Precambrian province is the distinctive composition and homogeneity of the enormous volume of hypabyssal and extrusive rocks. Approximately half (more if biotite alkali granite of the Payson body is included) the mapped area is underlain by rocks of this singular composition. The quantitatively minor, more mafic volcanic rocks in Tonto Basin also possess high alkali/lime and Fe/Mg properties indicating genetic affinity to the predominant leucocratic rocks.

EXTRUSIVE RHYOLITE

Analysis 17, of a sample strongly altered by the Apache Group effect (page 257), is strongly enriched in K_2O and strongly depleted in Na_2O and CaO. Overall alkali and lime depletion is reflected in the large amount of corundum (3.50%) in the norm. Moderate amounts of corundum in analyses 16 and 18 also suggest alkali loss. Soda (and lime in anal. 16) has apparently been depleted, but the alteration may not be due to the Apache Group effect inasmuch as K_2O is not increased and in fact appears to be depleted in analysis 18.

Low corundum contents in analyses 14 and 15 suggest no significant alkali loss but analysis 15 has unusually high and low Na_2O and K_2O values, respectively. The only other analyzed silicic alkali rock with similar alkali contents (analysis 23) has only albite phenocrysts whereas analysis 15 is of a one-feldspar rock perthite rock. It appears that alkali exchange has occurred or that the analysis is in error.

Analysis 14 is of a black, flow-banded rock from a strongly welded zone(?) (Plate 8A) of an ash-flow cooling unit. Partially(?) devitrified glass (Plate 39) is present in the same flow. This relatively unoxidized rock seems to be very well-preserved and is unusual only in high CaO and CO_2 contents which reflect the presence of almost 1% secondary calcite. The high CaO content may be primary, however, because the sample is the only two-feldspar rock in which plagioclase is more abundant than perthite (Table 13).

It is concluded in spite of alkali variations that there is little inhomogeneity in the primary composition of the extrusive alkali rhyolite of the Haigler Group and that its composition is very similar to that of the hypabyssal units. The alkali variations may suggest an alkali depletion in the prevalent oxidized rocks unrelated to the Apache Group effect. The oxidation and depletion may have occurred by interaction with meteoric water shortly after extrusion, or possibly during a hydrothermal event (page 381) associated with intrusion of the hypabyssal rocks.

INTRUSIVE RHYOLITE

Three analyses of Hell's Gate Rhyolite* and one of King Ridge Rhyolite are all very similar and consistent. Their average (Table 15) is probably a good estimate of the composition of these intrusive bodies. The only noteworthy deviations from the average are that CaO is a little high in analysis 20 and that K_2O is perhaps a little low in analysis 22. Analyses 21 and 24 are of dark gray rocks, 20 is of a red-gray sample, and 22 is of a more typical red-brown rock. Except for tiny amounts of calcite and sericite in rocks 20 and 21 only chlorite or hematite is present as a secondary mineral in the samples.

As expected, $FeO/(FeO+Fe_2O_3)$ is highest for the gray rocks and lowest for the red sample. Highest K_2O content in a gray rock and the lowest in the red rock may suggest a correlation also between coloration and K_2O content. Lack or dearth of corundum in the norms argues against alkali depletion.

The Hog Canyon rhyolite sample (analysis 23) has an anomalously high Al_2O_3 content reflected in the norm by 2.57% corundum. The groundmass is moderately sericitized (20%). The high Na_2O/K_2O ratio may be primary because only plagioclase feldspar phenocrysts are present. It appears (alteration aside) that the Hog Canyon mass may be compositionally anomalous in comparison with other Tonto Basin silicic alkali bodies.

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*Two of the Hell's Gate samples are from the Salt Lick phase and one (analysis 22) is from a rare mafic xenolith-free exposure in the Blue Dog phase. The possibility cannot be ruled out that the latter is from a xenolithic block of the Salt Lick phase.

GRANOPHYRE

Granophyre analyses are very similar except for an unusual dispersion in alkali values which apparently correlates with oxidation state of the rock. The high K_2O values of analyses 25 and 26, of typical red samples from the Mescal Ridge and Thompson Wash phases, respectively, and of analysis 27, of a red-gray sample from the Neal Mountain mass, suggest that Green Valley Granophyre as a whole contains significantly more K_2O than does Haigler rhyolite and Hell's Gate Rhyolite (though not necessarily more than King Ridge Rhyolite). It may be a little more soda-rich also. Much lower alkali contents in a gray sample (anal. 28) from the Neal Mountain mass suggest that scarce gray granophyre has a composition more like rocks analyzed from other bodies. (The red-gray sample may have a somewhat intermediate K_2O content.) Analysis 28 has a little corundum in the norm whereas the red and red-gray granophyres, in contrast to all other Tonto Basin rocks, are nearly peralkaline as shown by the tiny amounts of normative anorthite (alumina/alkali oxide ratios are only slightly greater than unity).

The apparent correlation between oxidation state and alkali content would suggest that alkali exchange occurred during a relatively low-temperature hydrothermal event which presumably caused the pervasive hematite reddening. Taylor (1974) and Wenner and Taylor (1975) infer from stable isotope studies of Precambrian 'red-rock' granophyre, granite, and rhyolite in other localities that the oxidized rocks may have equilibrated with hydrothermal, meteoric water at temperatures as low as 50-100°C. There is evidence, however, that the alkali differences in Green Valley Granophyre may reflect primary alkali variations in magma: 1) Any secondary Na_2O and K_2O enrichment must be accounted for in secondary alkali feldspar; there is no other alkali bearing phase in the analyzed red granophyre samples. However, all feldspar is mesoperthitic, implying magmatic formation. Moreover, perfect preservation of intricate micrographic texture argues against sub-solidus replacement of quartz (the only candidate for replacement) by alkali feldspar. 2) Pyroxene (and amphibole?) in the more reddened rocks is deeper green. This could possibly be due to alteration, but instead might reflect primary alkali variation in the magma. In the more alkali-rich magma the pyroxene and amphibole would have formed with more aegirine and ferrohastingsite component, respectively. 3) the analyzed gray sample (anal. 28) is different from all other granophyre examined in that it contains a small amount (<1%) of discrete albite. These subhedral, unzoned crystals, in contrast to scarce vuggy albite in many parts of Green Valley Granophyre, are apparently magmatic in origin because part of one grain is micrographically intergrown with quartz and because amphibole(?) is molded around the corner of a subhedral albite crystal. The minor albite may indicate a change with increasing P_{H_2O} late in the crystallization history from hypersolvus to subsolvus crystallization. This would have happened only in magma crystallizing very near the ternary solvus because of lower alkali/lime ratio. (This argument is weakened by the fact that the albite is not antiperthitic.)

Alkali inhomogeneity in the granophyre magmas (even within a single large magma body) would not be too surprising, but the apparent correlation of gray lithology and low alkali content is remarkable. The correlation is not likely fortuitous and implies, if alkali variations were magmatic, that high alkali rocks were preferentially altered in the hydrothermal event. It further implies, since slight alkali variation in itself cannot possibly determine whether a rock is affected by hydrothermal alteration, that variations in alkali content and alteration are both the result of a process initiated during the magmatic history of the granophyre. This raises the possibility that alkali exchange occurred between the magma and a hydrothermal fluid, probably meteoric water. Potash and probably soda were added to the granophyre magma. Portions (nearly all) thus affected were also subject to the oxidizing influence of the hydrothermal medium. That magma may interact with meteoric water has been shown by stable isotope studies indicating O^{18}/O^{16} exchange (Forester and Taylor, 1972; Friedman et al., 1974). Relatively easy, rapid penetration of hydrothermal water into incompletely crystallized Green Valley Granophyre may have occurred along grain boundaries in coalescing spherulite/micrographic domains (see page 360).

An obstacle to this hypothesis is that with continued circulation of hydrothermal fluids during sub-solidus cooling one would expect eventual penetration and alteration of the scarce pockets preserving low-alkali content.

ALASKITE

Alaskite analyses 29, 30, and 31, respectively, are of samples from a sill along the upper Payson Granite surface, from the Cherry Spring west stock(s), and from a plug in Payson Granite. The sill sample has a composition most like granophyre and rhyolite, and probably closely represents the composition of all sill alaskite and the eastern Cherry Spring stock. Though biotite is partially altered and 0.83% corundum in the norm may indicate some alkali loss, this sample is comparatively well preserved. The well-preserved alaskite plug sample differs only slightly in higher Al_2O_3 and MgO contents.

The Cherry Spring west sample in comparison with most silicic alkali rocks of Tonto Basin is a little high in Al_2O_3 and K_2O, a little low in SiO_2, but is strongly anomalous only in its very high MgO content. The differences might be partially accounted for by assimilation of mafic volcanic rock of the Board Cabin Formation (page 191), but this certainly cannot account for the MgO anomaly. The $FeO/(FeO+Fe_2O_3)$ ratio of this sample reflects the relatively reduced character of all Cherry Spring west lithology. This contrasts with other alaskite, granophyre, and rhyolite bodies in which gray, reduced rock is scarce or absent. Though a similar overall bulk composition suggests affinity to other silicic alkali rocks, the unusual petrographic and chemical characteristics of the Cherry Spring west alaskite indicate a detached history if not an unrelated origin. It may have intruded late, after cessation of the hydrothermal activity during which the strong oxidation of the other bodies presumably occurred.

The Hydrothermal Event

Most alteration in the silicic alkali rocks is attributed to hydrothermal activity. Mafic minerals may have generally been totally altered - mostly to hematite and muscovite - and feldspars except in much of Haigler rhyolite are heavily clouded with hematite dust. Fluorite is a primary mineral in some bodies, but apparently has been extensively redistributed by the hydrothermal activity.

Alteration is much more extensive and the oxidation more extreme in the Green Valley Granophyre sills. Alteration of the same style in other bodies, including Payson Granite, seems to be generally more pronounced near the granophyre. These overall relations strongly suggest that the Green Valley Granophyre was central to and probably provided energy for a major hydrothermal event. This, of course, does not preclude initiation of hydrothermal activity by other intrusive bodies as part of the overall hydrothermal activity. The possibility that alteration of each intrusive body was simply deuteric and that none initiated any external hydrothermal activity is discounted by several lines of evidence.

In the first place, the volcanic rocks seem to have been affected by more than vapor phase activity and other processes attendant to subaerial deposition. The patch perthite character of the feldspar may be indicative of hydrothermal activity. Feldspar phenocrysts in strongly oxidized Tertiary volcanic rocks generally retain their homogeneous character but the occasional occurrence of patch perthite (Ratte and Steven, 1967, Figure 5C) in rhyolite from the Creede caldera may be an effect of hydrothermal activity known to have been locally intense in that region. It was demonstrated that the patch perthite in the Haigler rocks (page 333) is the result primarily of exsolution and not replacement, but it may be that hydrothermal solutions promoted the exsolution.

Possible depletion and enrichment in alkalis, of volcanic rocks (page 375) and granophyre (page 377), respectively, may be further evidence of hydrothermal activity. It seems possible that there was a alkali transfer via convecting hydrothermal solutions from Haigler rhyolite to granophyre.

Finally, there is evidence that the strong oxidation of the rocks could not have occurred by simple deuteric alteration involving only juvenile water. Deuteric alteration in the western Cherry Spring alaskite is of an entirely different character. Mafic minerals are altered to chlorite rather than hematite and muscovite. If alteration in all bodies is deuteric, the much more reduced character of the Cherry Spring west alaskite, in comparison with other alaskites, could only be attributed to its higher magmatic P_{H_2O} (page 370). It seems more reasonable that oxidizing meteoric waters were involved in alteration of the red rocks and that the Cherry Spring west body intruded after hydrothermal activity and was affected only by deuteric alteration.

Oxidation of the extrusive rhyolite need not be attributed to the hydrothermal event because extreme oxidation of volcanic rocks commonly occurs during subaerial exposure. Participation of the large mass of oxidized rhyolite in the hydrothermal regime may have been a factor in causing oxidation of the intrusive bodies.

The stable isotope work of Taylor (1973, 1968, 1971), Taylor and Forester (1971), Forester and Taylor (1972), and Wenner and Taylor (1975) has demonstrated that meteoric water is involved in hydrothermal cells in which water circulates through shallow cooling igneous bodies and adjacent country rock. Taylor has found that the optimum conditions for the development of a hydrothermal system in which isotope exchange occurs are met where shallow stocks intrude into volcanic rocks which are highly permeable due to pervasive jointing and fracturing. By these criteria conditions were ideal for initiation of a hydrothermal event in the Tonto Basin rocks. Hell's Gate Rhyolite may have initiated little hydrothermal activity itself, but it is significant that this rhyolite is pervasively fractured by closely-spaced columnar joints. If the joints were filled with meteoric water at the time the Green Valley Granophyre intruded conditions would have been ideal for convective circulation. Not all the granophyre intruded at the base of the jointed rhyolite, however, and one is led to speculate that perhaps the general region of the upper Payson Granite contact was highly permeable and water-rich. Thus it is visualized that upon intrusion and during cooling of the granophyre hydrothermal activity was at its zenith. Local later intrusion of alaskite may have 'pumped up' the system.

PETROGENESIS

EVOLUTION OF SILICIC ALKALI MAGMAS

This section will deal primarily with alkali rhyolite, granophyre, and alaskite, for convenience referred to here as the silicic alkali rocks of Tonto Basin. Many analyzed silicic alkali rocks have a well-preserved chemistry; others have only slightly modified alkali contents (pages 271-381). It is proposed to treat these near pristine petrogeny's residua bulk compositions (differentiation indices range from 92.2 to 97.2, Plate 4) in terms of phase equilibria data available in the low-An region of the system An-Ab-Or-Q-H_2O. This treatment in connection with implications from phenocryst abundances and character indicates that the magmas possibly originated by partial melting and were initially water-undersaturated.

Phenocrysts in the porphyritic rocks are hypothesized to have formed in intermediate-level (~ 10-20 km ?) magma chambers. From experimental data, estimated depths of emplacement and feldspar (phenocryst, groundmass, or total) character, P-T conditions are estimated for hypabyssal magmas rising from the intermediate level to their levels of hypabyssal emplacement. Spherulitic and micrographic texture are hypothesized to be the result of water exsolution in intrusive rhyolite and possibly granophyre. From this hypothesis combined with the other criteria Hell's Gate Rhyolite is thought to have been hottest and to have become water-saturated only at its highest emplacement levels. Cooler, more water-rich Green Valley Granophyre and King Ridge Rhyolite magmas were emplaced just high enough to exsolve water. Lowest temperature alaskites were water-saturated at considerably greater depths. Payson Granite may have been the highest of the intermediate-level magma bodies. Alaskites may have differentiated from a deeper analogous body.

The An-Ab-Or-Q- Tetrahedron

Carmichael (1963) introduced a schematic quaternary diagram (Figure 15) to facilitate understanding of crystallization in the experimentally undetermined system $CaAl_2Si_2O_8$- $NaAlSi_3O_8$-SiO_2. From the experimental work of Tuttle and Bowen (1958) and Luth et al. (1964) the ternary system $NaAlSi_3O_8$- $KAlSi_3O_8$-SiO_2 is fairly well-understood under water-saturated conditions from 0.5 to 10 kb. Recently James and Hamilton (1969) determined the water-saturated liquidus temperatures at 1 kb for joins at 3, 5, 7.5, and 10 weight percent anorthite in the An-Ab-Or-Q tetrahedron. These experimental data in the low-An region of the tetrahedron are extremely helpful in a preliminary attempt to understand the origin and evolution of the Tonto Basin silicic alkali magmas.

In Figure 15 the dot-dash lines illustrate the position of two constant An joins in the tetrahedron. Intersection of these planes with the quartz-feldspar surface (abcd) and with the two-feldspar surface (defg) define boundary curves (ut and sr in the lower join) in a pseudo-ternary system. Such systems are not truly ternary because neither the crystallizing phases nor the liquids with which they are in equilibrium need be in the constant An plane. The point defined by the intersections

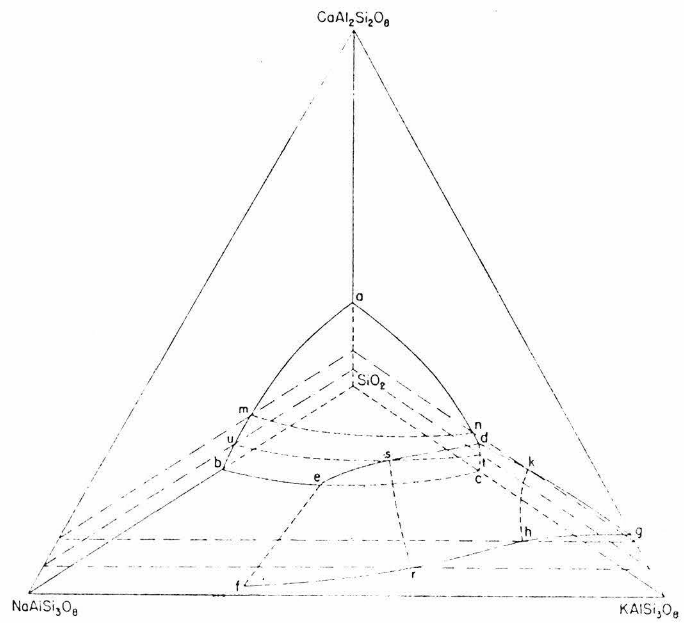

Figure 15. System An-Ab-Or-Q (at low P_{H_2O}) showing intersections of planes of constant An content with quartz-feldspar and two-feldspar surfaces. (From James and Hamilton, 1969, modified after Carmichael, 1963.)

of these boundary curves (point s in the lower join) is a piercing point of the quaternary univariant line (de) and marks the lowest temperature liquid or the isothermal first melt composition for most bulk compositions[1] in the constant An plane.

The liquidus topologies determined by James and Hamilton for the 3, 5, and 7.5 percent An joins at 1 kb are similar to those determined by Tuttle and Bowen for the Ab-Or-Q system at 1 kb except that they have piercing-point (pseudo-eutectic) relationships rather than a minimum trough. The An_3, An_5, and $An_{7.5}$ boundary curves, piercing points, and the 1 kb water-saturated univariant line which they define are shown in Figure 16 projected onto the Ab-Or-Q basal plane. Also shown are the An-free minimum points determined by Tuttle and Bowen at 0.5, 1, 2, and 3 kb[2] and the An-free eutectic points determined by Luth et al. at 5 and 10 kb. Note that the univariant curve is shown to terminate about mid-way between the 1 kb-An_0 and 1 kb-An_3 points because, according to James and Hamilton, the 1 kb univariant curve terminates within 1.5% An of the Ab-Or-Q plane. Constant An joints below the univariant terminus have pseudo-ternary minimum troughs. Liquids on the univariant curve are in equilibrium with two feldspars whereas those in the minimum troughs are in equilibrium with a single hypersolvus feldspar.

Also shown in Figure 16 are hypothetical positions for An_3

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[1] Very near the Ab-Q and Or-Q sidelines systems would be effectively binary with higher-temperature first melts also very near the sideline.

[2] According to Figure 7 of Morse (1970) the 3 kb minimum point of Tuttle and Bowen should actually be a eutectic point.

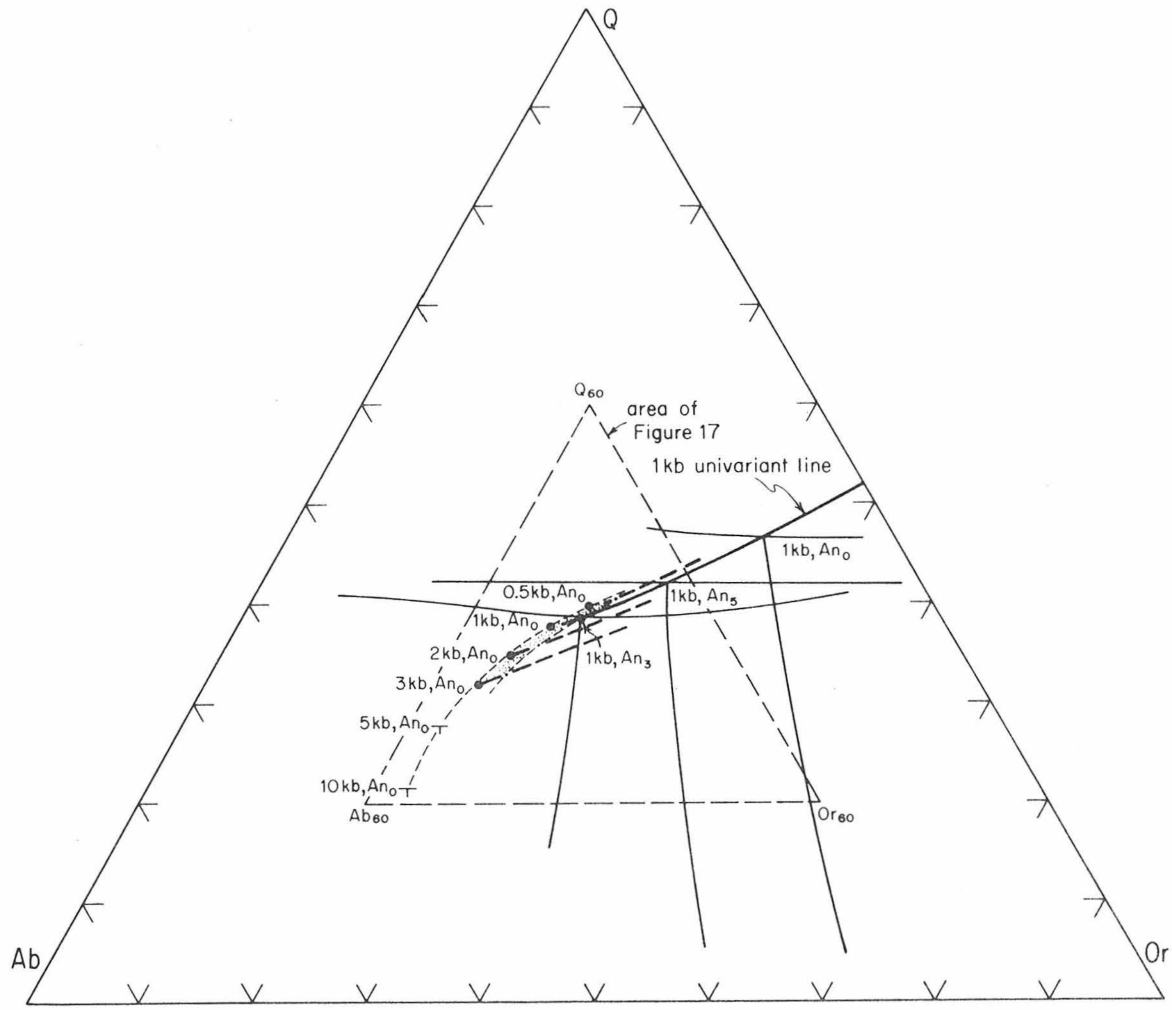

Figure 16. Ab-Or-Q face of the An-Ab-Or-Q tetrahedron onto which are projected the 1 kb water-saturated boundary curves and piercing points of constant An joins of 3, 5, and 7.5 weight percent An (James and Hamilton, 1969). Also shown are water-saturated minimum and eutectic points for the Ab-Or-Q system at 0.5, 1, 2, and 3 kb (minimum, Tuttle and Bowen, 1958) and at 5 and 10 kb (eutectic, Luth _et al_., 1964). The 1 kb univariant curve is defined by the $An_{7.5}$, An_5, and An_3 piercing points and terminates about midway between the latter and the 1 kb-An minimum. Hypothetical 0.5, 2, and 3 kb univariant curves (dashed lines) are drawn to parallel the 1 kb curve and to terminate at or near the respective An_0 minima. The locus of An_3 piercing points is drawn through the 1 kb point sub-parallel to the locus of An_0 minimum points. The shaded field represents the compositions of all water-saturated An_0-An_3 pseudo-minima or piercing point liquids between 0.5 and 3 kb.

piercing points at 0.5, 2, and 3 kb. These points are positioned on the assumptions that the An_3 piercing point will shift with pressure in the same manner as does the minimum of the Ab-Or-Q system and that the univariant curves at the different pressures will have about the same trend as does the 1 kb univariant curve. Short dashed portions of the resulting isobaric univariant curves at 0.5, 2, and 3 kb are shown. The hypothetical points and limited portions of the univariant curves are considered to be reasonably realistic as shown and the deviations from actual topologies, yet to be determined, will probably not be large enough to alter any of the conclusions to be drawn about the Tonto Basin rocks.

No topologies have been determined in this system for water-under-saturated melts. However, from specific gravities of phases crystallizing in the low-An region (quartz - 2.65; K-feldspar - 2.56; An_0-An_{20} - 2.63-2.65) one would expect that for a given water content the quartz field would expand with increasing pressure.

The shaded field of Figure 16 is the loci of all pseudo-minimum points or piercing points for all constant An planes between 0 and 3 weight percent An in the water-saturated pressure range 0.5 - 3 kb. In that water-saturated pressure range any liquid in the An_0-An_3 joins, if in equilibrium with quartz and two feldspars or with quartz and a hypersolvus feldspar, must project into the shaded field. All such liquids are the piercing-point liquids or the minimum liquids in that portion of the An-Ab-Or-Q tetrahedron which is of direct interest in considering the magmas from which the silicic alkali rocks of Tonto

Basin crystallized.

Normative Data and Petrographic Criteria

Normative tetrahedral An contents (An/(An+Ab+Or+Q) x 100) for the 18 analyses (nos. 14-31, Plate 4) of silicic alkali rocks ranges from 0.04% to 3.8% and average 1.5%. The average for the best 11 analyses (no pronounced depletion of CaO or enrichment(?) in alkalis) is 2.3%. A considerable amount of the CaO in some of the norms occurs in fluorite and lesser quantities occur in carbonate. Whether some of the CaO should actually belong to anorthite for the purpose of considering crystallization in the quaternary system is not known. However, the norms of several well-preserved probe-analyzed rocks (no fluorine determination) have about 3% normative An and it is probably safe to say that the effective An contents of the magmas ranged from about 1% to no more than about 3%.

The purpose in directing the previous discussion to the An_0-An_3 portion of the tetrahedron is now obvious, but some important petrographic criteria must be presented before the normative data can be interpreted. Presentation of these criteria will be integrated with reference to the quaternary normative data which are projected onto the Ab-Or-Q (Figure 17) and An-Ab-Or (Figure 18) faces of the tetrahedron. The silicic alkali rock data are the solid symbols in these plots; other Tonto Basin data are the open symbols.

From the phenocryst populations in the porphyritic extrusive and hypabyssal rocks (alaskites cannot be evaluated in the present discussion) we learn that most of these rocks were crystallizing, prior to

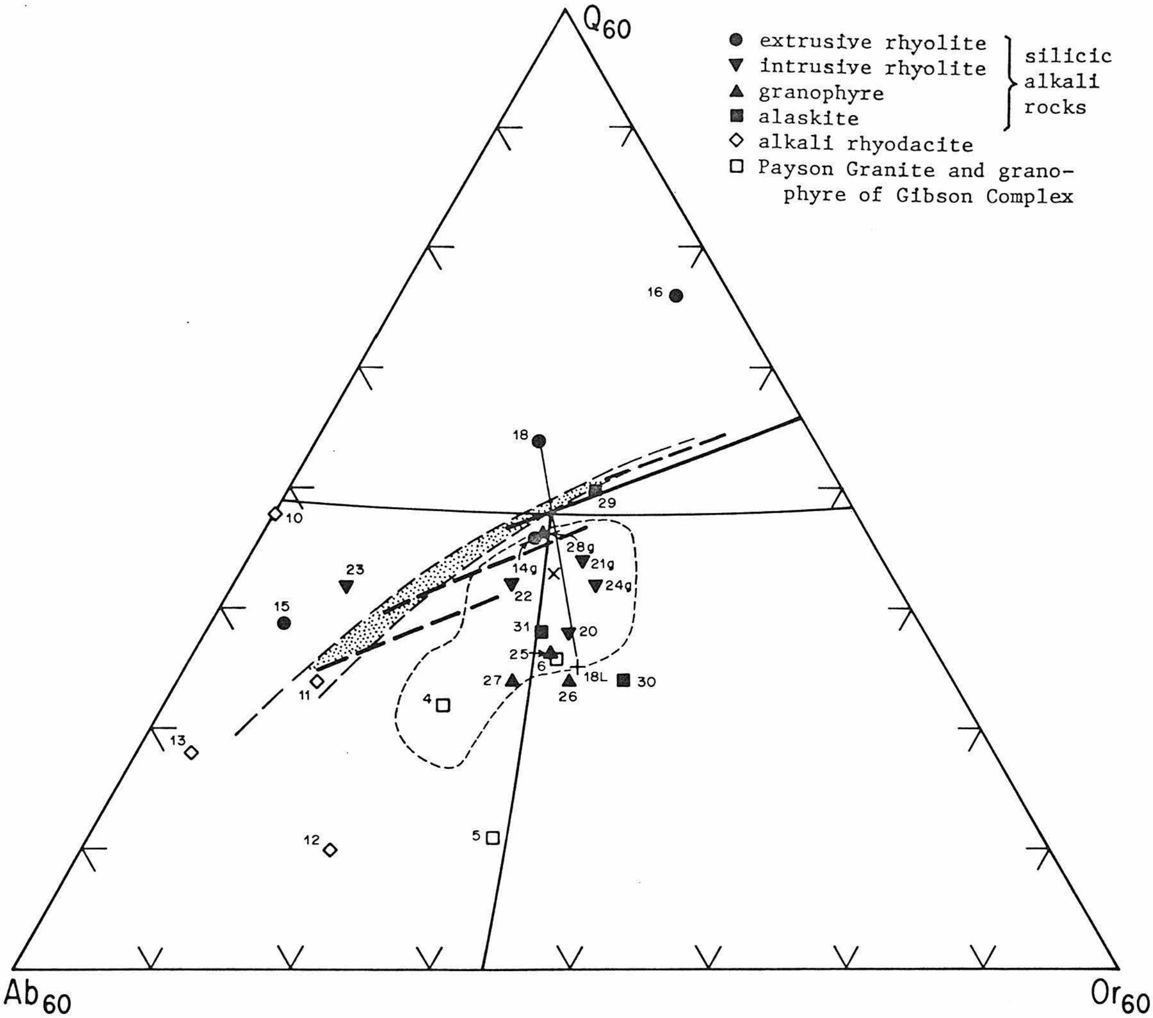

Figure 17. Tonto Basin normative data projected onto the expanded central portion of the Ab-Or-Q diagram as shown in Figure 16. Water-saturated topologies are the 1 kb-An_3 boundary curves, the 1 kb univariant curve, the hypothetical 0.5, 2, and 3 kb univariant curves, and the shaded field of An_0-An_3 pseudo-minimum and piercing point liquids in the pressure range 0.5 to 3 kb.

Data point numbers correspond to analysis numbers of Plate 4. Point X is an average of 6 analyses (14, 28, 21, 24, 20, 22) thought to best preserve original compositions and may closely represent compositions of univariant or divariant liquids with which the small sub-equal amounts of quartz and feldspar phenocrysts in these rocks were in equilibrium. The cross labeled 18L is a calculated groundmass composition (tie line to bulk composition) of the strongly porphyritic, quartz phenocryst-poor Oxbow Rhyolite and may approximate the composition of the liquid in equilibrium with the phenocrysts. 'Gray facies' samples, essentially free of hydrothermal oxidation and alteration, are indicated by g accompanying the analysis number.

The short-dashed line is the maximum contour (Tuttle and Bowen, 1958, Fig. 63) for normative Ab-Or-Q from 1269 rocks containing 80 percent or more Ab + Or + Q.

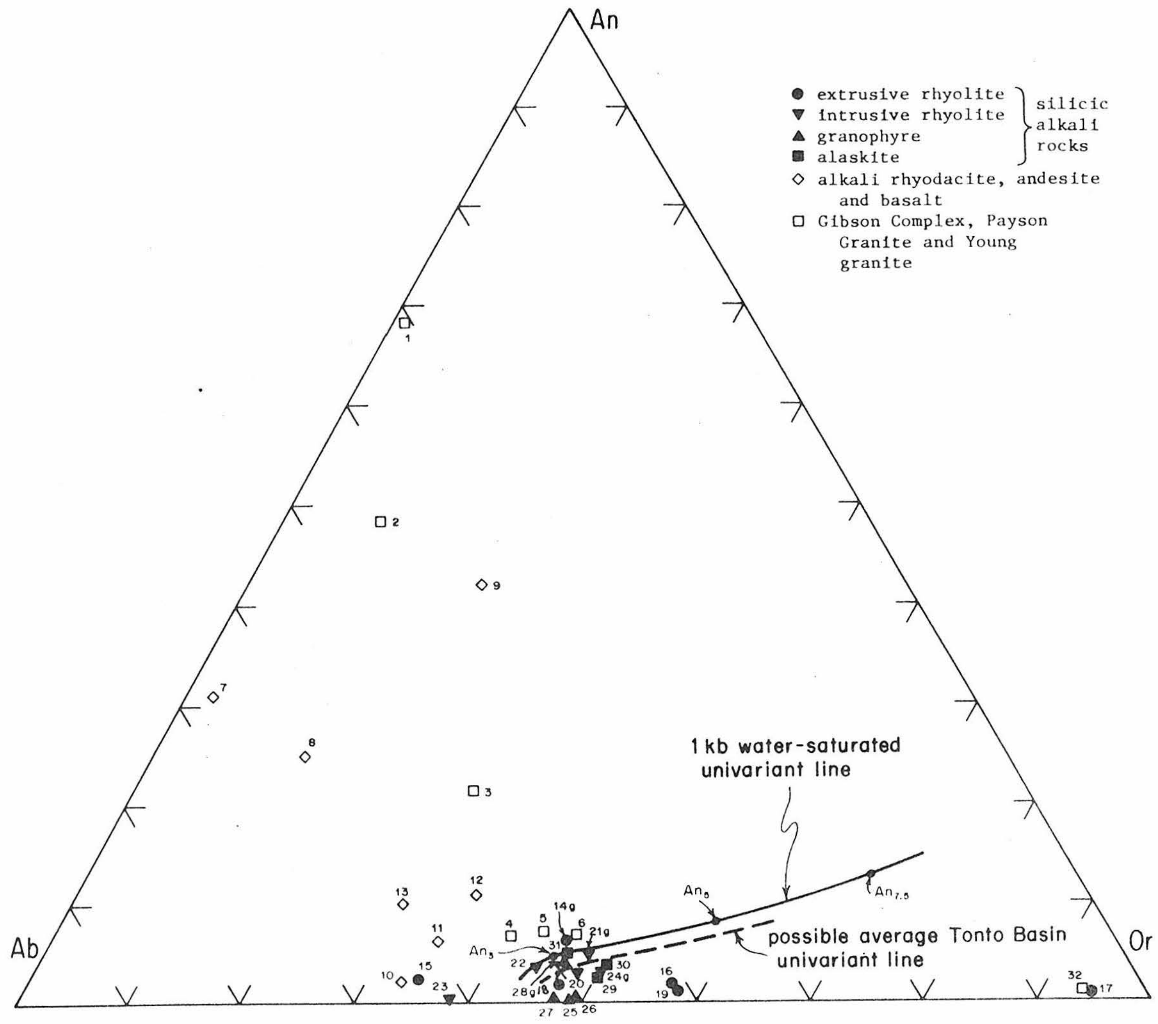

Figure 18. Tonto Basin normative data and the 1 kb water-saturated univariant curve projected onto the An-Ab-Or face of the An-Ab-Or-Q tetrahedron. The possible average Tonto Basin univariant line is drawn parallel to the 1 kb line to pass through the cluster of silicic alkali data points nearer the 'gray facies' points (labeled g). The average hypothetical univariant silicic alkali magma composition (point X, from Figure 17) is projected onto this line.

extrusion or hypabyssal emplacement, from univariant liquids or from liquids very near the univariant line on the quartz-feldspar surface. Some possibly were crystallizing in pseudo-ternary minima. Quartz, plagioclase, and alkali feldspar phenocrysts occur in more than half of the thin-sectioned Haigler rhyolite samples (Table 13, page 334) in the Oxbow Rhyolite, and in the King Ridge and Hog Canyon intrusive bodies. The other extrusive rhyolites and Hell's Gate Rhyolite and Green Valley Granophyre contain intermediate to somewhat sodic hypersolvus feldspars. Liquids in the two-feldspar rocks reached the quaternary univariant line(s). Magmas with the hypersolvus feldspar were either on the quartz-alkali feldspar surface below the quaternary univariant line of they were 'beyond' the terminus of the univariant line. In the former case they would, upon crystallization of alkali feldspar, move onto the univariant line and begin to crystallize plagioclase. In the latter they would continue to crystallize only a single feldspar under pseudo-ternary minimum conditions. Either case is plausible because the rocks are so low in CaO, and because hypersolvus alkali feldspar phenocrysts are intermediate in composition.

Univariant or near univariant equilibrium crystallization apparently prevailed in the Tonto Basin porphyritic rocks prior to extrusion or hypabyssal emplacement. With extensive modal analyses (planned in further investigation) one could determine and subtract out phenocryst amounts to arrive at approximate quenched liquid compositions. Because phenocryst contents are generally low (< 10%) and because quartz and feldspar phenocrysts are of sub-equal abundance, it is assumed that the bulk compositions are essentially liquid compositions. The bulk compositions are so considered in the Ab-Or-Q diagram of Figure 17. A major exception to this is Oxbow Rhyolite (anal. 18) which contains about 20% quartz and 10% $Or_{40(?)}$ alkali feldspar phenocrysts. Subtraction of phenocrysts in these amounts gives a hypothetical liquid composition at the cross labeled 18L in Figure 17.

On the assumption that the liquids would be quite near bulk composition (except for Oxbow Rhyolite) it appears from Figure 17 that liquid compositions are considerably scattered. This brings up the problem of alteration which may be the cause for part of the scatter in the data. Analyses 15 and 16 (Haigler rhyolite), and 23 (Hog Canyon intrusive rhyolite) clearly have modified alkali contents (pages 374-376) and granophyre analyses 25, 26, and 27 are suspect of being enriched in alkalis (page 379). It is inferred that Haigler rhyolite 14, intrusive rhyolites 20, 21, 22, and 24 and granophyre 28 are perhaps the only analyses with unmodified alkali contents. It is probably significant that four of these six rocks are 'gray facies' rocks (Figure 17) which have apparently escaped hydrothermal effects. The point X represents an approximate average of these six rocks. It is suggested that the univariant or near univariant silicic alkali liquids were approximately of this composition. If the high alkali contents of red granophyre are primary, rather than secondary as hypothesized, univariant or divariant granophyre magmas were more alkali-rich than composition X.

The normative data of Figure 18, especially for the gray rocks,* suggests that the closely-spaced family of univariant lines is somewhat nearer the Ab-Or sideline than the 1 kb water-saturated line. The projected position of X onto a hypothetical Tonto Basin univariant line would correspond approximately to an An_2 piercing-point liquid.

Pre-hypabyssal History of the Magmas

On the basis of the foregoing discussion it is tentatively suggested that the Tonto Basin magmas were crystallizing on or near univariant lines which passed through the vicinity of X in Figure 17. Thus some or most of these magmas were An_1-An_3 piercing-point or possibly pseudo-minimum liquids. The liquid compositions would be near but for the most part outside the shaded field. This would suggest that most liquids were not water-saturated at the site of phenocryst formation.

The apparent displacement of Tonto Basin An_1-An_3 piercing-point liquids toward the Ab-Or sideline from the shaded field supports the argument (page 389) that the quartz field would expand with increasing pressure and a given water content. It appears that the shaded field may migrate toward the Or-Ab sideline with increasing disparity between P_{total} and P_{H_2O}. If so, water pressure in the water-saturated piercing-point magmas, less than P_{total} by an undetermined amount, would have been about 1 kb. (No real meaning in the sense of the present discussion can be attached to the Tuttle and Bowen (1958) maximum contour (Figure 17) because of the wide variation in CaO content in the

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*Analysis 14 is of a gray extrusive rhyolite which is comparatively plagioclase-rich; its liquid point would be less An-rich than the whole-rock point as shown in Figure 18.

granitic rocks and because one cannot infer primary magma compositions.)

The probable displacement of the hypothetical Oxbow Rhyolite liquid (18L, Figure 17) from its bulk composition toward and possibly beyond X may suggest that magmas (liquids plus crystals) of varying bulk compositions were crystallizing under similar conditions and hence their liquids were differentiating toward the same univariant region. The discussion will return to the idea that the magma compositions may have converged toward a common $P_{H_2O}<P_{total}$ univariant region, but a digression will first be made to consider implications of the bulk compositions and phenocryst character for origin of the magmas.

Carmichael (1963) and Barth (1965) propose that any porphyritic rock containing only quartz or K-feldspar phenocrysts began to crystallize in the quartz or K-feldspar regions of the An-Ab-Or-Q tetrahedron (Figure 15) and thus must have originated by partial melting rather than be fractional crystallization. The argument is that more calcic potential parent magmas would lie in the plagioclase region and could not differentiate across the quartz-feldspar or two-feldspar surfaces. This seems valid as long as conditions and hence topologies remain constant or change slowly and continuously allowing equilibrium. However, sudden topological change due to rapid rise of magma in the crust is a potential means of causing a cross-over. From specific gravities of quartz, plagioclase (An_0-An_{20}), and K-feldspar (page 389), one would expect that with decreasing pressure the plagioclase field would expand (the reverse would be true for more calcic plagioclase) relative to the quartz field but contract relative to the K-feldspar field. If this is so, a liquid in equilibrium with sodic oligoclase near the quartz-feldspar surface would be effectively displaced away from the quartz region but one near the two-feldspar surface might be effectively displaced into the K-feldspar region. In the latter case plagioclase crystals might be entirely resorbed as K-feldspar began to crystallize.

No Tonto Basin silicic porphyritic rocks contain only a single phenocryst phase but there is evidence that first crystallization in some magmas may have been in either the quartz or K-feldspar fields. An important phenomenon in quaternary crystallization is that once liquids of the Tonto Basin general composition intersect the quartz-feldspar surface they move only slightly and sub-parallel to the Ab-Or sideline as they continue to crystallize. Such liquids in the vicinity of X ($\sim Q_{40}Or_{30}Ab_{30}$) would continually crystallize quartz and feldspar in a 4:6 ratio. If a porphyritic rock contains considerably more quartz than feldspar one can readily conclude that crystallization initiated in the quartz field and that much of the quartz crystallized prior to intersection of the quartz-feldspar surface. The opposite relation is also true. The same general principle applies to the two-feldspar surface but because of large fluctuations in the two-feldspar boundary with small variations in An and because of variations in feldspar solid solution it is very difficult to determine from feldspar proportions which phase began to crystallize first.

From these considerations it would appear that the quartz phenocryst-rich Oxbow Rhyolite crystallized a rather large amount of quartz before reaching the quartz-feldspar surface. This is compatible with the bulk composition (point 18, Figure 17) which, given its low An content (1%), would have begun crystallization in the quartz region regardless of water pressure. According to the Carmichael-Barth argument the Oxbow Rhyolite magma formed by partial melting.

A few silicic alkali units contain 2-3 times as much phenocrystic alkali feldspar as quartz or quartz plus plagioclase. They may have begun crystallization in the K-feldspar field. Most other rocks have nearly equal amounts of quartz and feldspar but many are lacking plagioclase. It seems probable some magmas of these rocks were crystallizing on the quartz-K-feldspar surface; the first liquidus phase may have been either quartz or alkali feldspar. Magmas with intermediate hypersolvus feldspar may have begun crystallization in either the plagioclase or K-feldspar regions. Whether the liquid migrated into the low-temperature trough and subsequently into the pseudo-ternary minimum from the plagioclase or the K-feldspar side could feasibly be demonstrated by determination of direction of zoning in the feldspar.

If Oxbow Rhyolite formed by partial melting as argued, it seems reasonable that earlier (Haigler rhyolite undivided) and later (hypabyssal bodies) silicic alkali rocks of the same general composition formed in the same manner. The great volume of rocks of this composition and the dearth of intermediate rocks in Tonto Basin argues against an origin by differentiation. The nature of the source region for partial melting is an important general problem in the derivation of great volumes of such highly silicic magma, but is not dealt with in this study.

The preferred hypothesis that melts of slightly varying composition formed by partial melting can now be coupled with the earlier hypothesis that liquids all differentiated toward a common $P_{H_2O} < P_{total}$ univariant region to form a model for a two-stage pre-hypabyssal history for the Tonto Basin silicic alkali rocks. It is assumed that partial melting occurred at considerable depth in the crust or upper mantle and that the liquids coalesced and rose to form magma chambers at higher levels in the crust where crystallization began. These magma chambers must have been deeper than about 4-5 km, the depth of the deepest hypabyssal bodies, and are arbitrarily considered to have been at ~10-20 km. Whatever the actual depth it is suggested that conditions were about the same in all bodies so that compositions of liquids migrated as phenocrysts formed toward the common water-undersaturated univariant or piercing-point area. Perhaps some fundamental structural break in the crust, such as an unconformity between the older Precambrian province to the north and the southern province to which the Tonto Basin strata belong, served to localize the intermediate level magma bodies. Partial melts may have continued to rise to the region of magma chambers and the magma bodies would have been tapped over the interval of time it took to extrude the Haigler Group rhyolite and to emplace the hypabyssal rhyolite, granophyre, and alaskite.

This model of partial melting at great depth, of intermediate magma chambers, and of high-level sills is compatible with interpretations of the nature of the region beneath the Yellowstone rhyolite plateau (Eaton et al., 1975). New gological and geophysical data indicate that a silicic magma body a few km thick exists at a few km depth. Beneath that the mechanically and thermally disturbed crust and mantle to a total depth of 100 km are interpreted to contain pods of silicic and basaltic magma.

Extrusive and Hypabyssal Emplacement

Figure 19, taken from Morse (1970), shows the relative positions of the water saturated melting curves of Ab-Or-Q and Ab-Or and the Ab-Or critical line. Added to this figure are the 1 kb water-saturated first melting points (piercing points) for the An_3, An_5, and $An_{7.5}$ joins in the An-Ab-Or-Q system (James and Hamilton, 1969). Portions of hypothetical An_3, An_5, and $An_{7.5}$ first melting curves are drawn through these points so as to trend sub-parallel to the determined melting curves. Hypothetical ternary feldspar critical lines corresponding to these An-poor systems are not drawn parallel to the Ab-Or critical line because of constraints in positioning magma bodies in Figure 20 relative to topologies (see page 407). Note that the critical lines corresponding to respective melting curves are of higher An content in the ternary feldspar system than the An value indicated for the quaternary system (e.g., the critical line for the An_3 quaternary system is actually at about An_5 in the feldspar system).

The positions of the critical lines in Figure 19 are highly speculative but there can be no doubt that the temperature of the solvus crest rises very rapidly from the Ab-Or sideline of the ternary feldspar system with only slightly increasing An content. This must be so

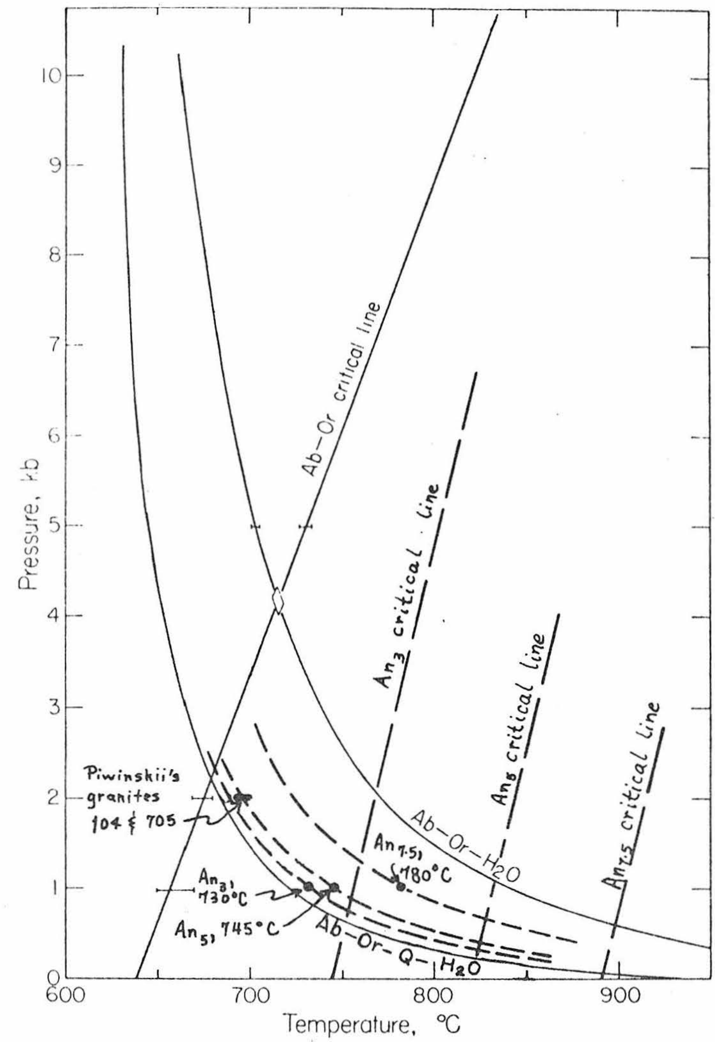

Figure 19. Critical line of the alkali feldspar solvus compared with beginning of melting curves of Ab-Or-H_2O and Ab-Or-Q-H_2O from Morse (1970). Beginning of melting points for planes of constant An (3, 5, and 7.5 percent) in the An-Ab-Or-Q tetrahedron at 1 kb under water-saturated conditions (James and Hamilton, 1969) are also shown. The dashed lines drawn through the An_3, An_5, and $An_{7.5}$ piercing point positions are hypothetical first melting curves for the respective constant An compositions. See text for details and for explanation of hypothetical critical lines and Piwinskii's melting of granites.

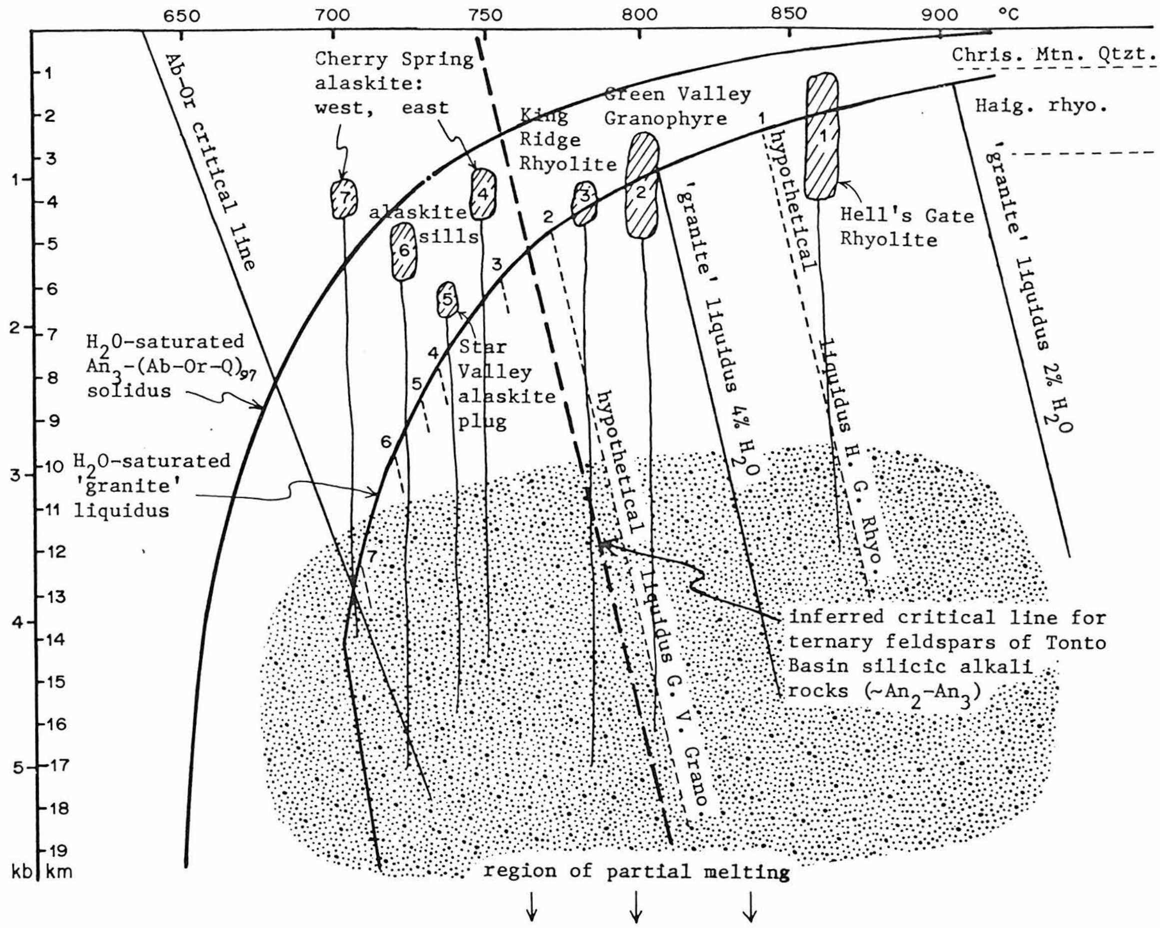

Figure 20. Water-saturated An_3-(Ab-Or-Q)$_{97}$ solidus (Figure 19) and water-saturated, 4% H_2O, and 2% H_2O 'granite' liquidus curves (Harris et al. 1970) in relation to speculative comparative P-T conditions for Tonto Basin hypabyssal silicic alkali magmas and the hypothetical intermediate-level magma chambers (stipled region) from which they were derived. The water-saturated liquidus is based on Tuttle and Bowen (1958), Boyd and England (1963), Luth et al. (1964), Green and Ringwood (1966), and Piwinskii (1968). The water-undersaturated liquidus curves were calculated from solubility data from Burnham and Jahns (1962) and are parallel to the dry liquidus.

Depth ranges as shown for the hypabyssal bodies are estimated from stratigraphic relations and the relative positions on the temperature axis are primarily from implications of feldspar character for subsolvus or hypersolvus crystallization. Intersections with the saturated liquidus of hypothetical water-undersaturated liquidus curves for each of the hypabyssal magma types are indicated by corresponding number. A magma rising above its liquidus interception would become water-saturated. Constraints for positions relative to topologies of the magma bodies and their paths of ascent are discussed in detail in the text.

because the most calcium-rich hypersolvus alkali feldspars contain no more than 15% An (Tuttle and Bowen, 1958, Figure 64) and are found only in rocks such as trachytes which have crystallized at very high temperatures (greater than 1000°C). In other words the critical point region for An_{15} is probably over 1000°C. Pseudo-eutectic melting relations for the An_3, An_5, and $An_{7.5}$ joins require that solvus crests for these systems be displaced to temperatures higher than those at the respective 1 kb first melting points shown in Figure 19. Thus the critical line for the An_3 system, which is presently of interest, is to the right of 730°C at 1 kb. This line is placed in this figure to correspond to the critical line ($\sim An_3$) for the silicic alkali rocks as deduced in Figure 20 (discussion to follow).

A final point with respect to both the critical lines and melting curves comes from the fact that two-feldspar assemblages with relatively little feldspar solid solution were crystallized from two natural leucocratic An_5 granites (nos. 104, 705) at 2 kb and 680-700°C under water-saturated conditions (Piwinskii, 1968; Piwinskii and Wyllie, 1970). The solvus crest for feldspar of these granites must, by crude analogy with the Ab-Or solvus, be at a much higher temperature, perhaps 100-200°C higher.

An An_5 water-saturated melting curve is drawn from the 1 kb experimental point through the granite 104 and 705 first melt temperature at 2 kb. The two types of experimental data at 1 and 2 kb clearly require that the An_3 solidus is very close to the Ab-Or-Q melting curve. This solidus is also shown in Figure 20 along with a water-saturated 'granite' liquidus (deduced by Harris et al., 1970, from published experimental crystallization data for the Ab-Or-Q system and for natural granite) which must closely approach the actual liquidus corresponding to the An_3 solidus. Water-undersaturated liquidus curves from Harris et al. at 2 and 4 percent H_2O are also shown. Controls for the relative placement of the inferred critical line are that alaskites crystallized entirely below it, King Ridge Rhyolite magma rose above it, and Green Valley Granophyre magma crystallized entirely above it. A fairly broad family of critical lines may actually exist because critical temperature is extremely sensitive to slight changes in composition.

Depths of intrusion as shown in Figure 20 are based on estimated thickness of overlying rocks. Depth ranges for individual units are derived from sill thicknesses and variations from place to place of overburden height. These are minimum estimates. The bodies were intruded at greater depth if more strata existed atop the known Christopher Mountain Quartzite or if antecedent deformation had effectively increased the height of the rock columns.

The relative positions of the hypabyssal magmas on the temperature axis partially reflect petrographic interpretation developed in earlier sections based principally upon the hypersolvus or subsolvus natures of the phenocryst, groundmass, or total feldspars. Subsolvus feldspars in biotite-bearing alaskites crystallized successively higher on the feldspar solvus in the alaskite sequence 7, 6, 5, 4 (numbers in Figure 20). Intrusive rhyolite and granophyre magmas were hotter than alaskite magmas because they crystallized pyroxene, amphibole, and hypersolvus feldspars (phenocrysts, groundmass, or both) but their relative temperature positions come from arguments to be presented shortly.

It was concluded earlier (page 395) that the porphyritic silicic rocks were undersaturated at the depths (~ 10-20 km ?) in which the phenocrysts formed. An additional argument arises from constraints seen in Figure 20. Hypersolvus phenocrysts in some magmas formed at depths greater than 4-5 km (depth of hypabyssal emplacement) and at temperatures above the critical line (certainly no less than 50° higher than Ab-Or critical temperatures) - almost certainly in the field of water-undersaturation. If the critical temperature in this depth region is as high as shown in Figure 20 the magmas with hypersolvus feldspars could not possibly have been water-saturated.

Water-undersaturation (for the porphyritic magmas) at depth is assumed in the following discussion in which histories of the magmas are considered in the order of their emplacement. Specific positions of these bodies along the temperature axis will be explained in terms of water-saturation or undersaturation at hypabyssal emplacement levels.

An undersaturated magma rising from depth, as depicted in Figure 20, would become saturated above the level at which its liquidus intersects the saturated liquidus curve. This occurred with many Haigler Group rhyolite magmas causing vesiculation prior to extrusion and resulting in the formation of gas-rich ash-flow tuffs. Two-feldspar and one-feldspar extrusive rhyolites indicate that the magmas occurred at depth both above and below critical temperatures in the same region from which the shallow porphyritic rocks were later derived. Oxbow Rhyolite magma began to crystallize subsolvus, rose above the critical line, and may have crystallized extensively at shallow depths (see page 338) before eruption. Non-ash-flow rhyolites may have contained much less water and therefore have been much hotter magmas.

Figure 20 depicts relations following deposition of rhyolite and quartzite when the hypabyssal magmas were emplaced. Hypothetical liquidus curves whose intersections with the water-saturated liquidus are numbered are shown for each of the correspondingly numbered hypabyssal magmas. Divergence of ascent paths of the magmas from their liquidus curves are compatible with resorption of phenocrysts. (Magmas need not actually rise above the liquidus for resorption to occur, however.) Higher-level Hell's Gate magma and all other magma types are shown above the intersections of their respective liquidus curves. All except deeper Hell's Gate magma is thought to have become or have originally been (possibly alaskites) water-saturated.

Shard texture found in a small apophysis(?) of Hell's Gate Rhyolite (1360, M-10) is evidence that magma was vesiculating and moving rapidly upward at a depth of 2 km or more. Extremely rapid quenching probably occurred in this rock disallowing the growth of coarse crystals in spite of the presence of a vapor phase. Hell's Gate magma probably became water-saturated at highest levels and vented to form ash-flow tuffs. At depth, however, the groundmass is fine-grained and even, suggesting rapid crystallization and low water content. It is hypothesized that if water-saturation had occurred in the thick static sills, spherulitic or micrographic texture would have formed.

Water-saturation is suggested as the condition promoting formation of spherulites and micrographic texture in King Ridge Rhyolite and Green Valley Granophyre. Exsolution of water may have occurred preferentially along phenocryst-melt interfaces. Growth of spherulites around the phenocrysts may have resulted from rapid material transfer in the interface vapor phase. This is highly speculative, of course, but whether or not exsolution occurred to cause formation of spherulites and micrographic texture, differences in water content seem to be the only possible factor to explain the profound textural differences between granophyre and porphyritic intrusive rhyolite.

Both phenocryst and groundmass feldspars in granophyre are hypersolvus. Groundmass feldspar in deep granophyre of the King Ridge body is similarly hypersolvus. The King Ridge magma is placed below the granophyre on the temperature axis because it contains both plagioclase and K-feldspar phenocrysts; it crystallized at depth below the critical line and after shallow emplacement above the critical line (page 353). The inferred critical line in Figure 20 is drawn steeper than the Ab-Or critical line to accord with these feldspar crystallization histories and the hypothesized exsolution of water in both bodies without further crowding the alaskites toward the water-saturated solidus. It may be just as reasonable to place the ciritical line parallel and closer to the Ab-Or line.

Different water-undersaturated liquidus curves are shown for the different alaskite magmas. This seems reasonable considering the different crystallization temperatures, but the magmas were possibly all water-saturated and derived from varying depths. Coarse granular crystallization is attributed to high water content and exsolution far below emplacement levels. Cherry Spring west alaskite is the only strongly porphyritic alaskite; this might be explained, as indicated in Figure 20, by a temperature just below the saturated solidus at the site of emplacement causing quenching.

For the hypabyssal bodies correlations exist between sequence of emplacement, temperature of emplacement, and textural variations which indicate the possibility that the magmas were successively derived from differentiating (with increasing H_2O content) and cooling intermediate-level magmas. The succession of emplacement was Hell's Gate Rhyolite, King Ridge Rhyolite, Green Valley Granophyre, Cherry Spring east alaskite and sill alaskite (and possibly Star Valley alaskite), and finally Cherry Spring west alaskite. This coincides with the general interpreted temperature sequence from hottest to coolest. Hell's Gate Rhyolite is only permissively the hottest, and there is a reversal between King Ridge Rhyolite and Green Valley Granophyre. The textural correlation is that from earliest to latest the hypabyssal rocks become coarser and less porphyritic.

Relations as illustrated in Figure 20 provide a plausible, internally consistent scheme of petrogenesis. Aspects lacking a strong basis for support, particularly the existence of an intermediate region of magma chambers and exsolution of water as the cause of spherulite formation, are obvious. Relative temperature and pressure positions for the hypabyssal bodies must be approximately correct, however, and the absolute pressures and temperatures may be close to those implied. The magma positions and the hypothetical critical line are crowded about as closely as possible on the temperature axis to the water-saturated solidus. If the overall temperature interval is greater than that shown and if water-saturation did not occur in granophyre, the critical line might be placed at a higher temperature.

Payson Granite

Payson Granite varies in petrographic composition from alkali ferrohastingsite granite to alkali biotite granite; the latter is essentially identifical to the late hypabyssal alaskite bodies. Not only does the composition suggest a genetic relationship to the silicic alkali hypabyssal and extrusive rocks but the petrographic variations upward in the body (pages 307-310) suggest that the upper regions of granite beneath the southward-dipping sub-planar contact is a differentiated roof phase of the body. This is compatible with the favored hypothesis based on field relations at Gisela (page 95) that Payson Granite intruded Haigler rhyolite.

If Payson Granite intruded Haigler rhyolite and belongs to the silicic alkali event it could be considered to have been the highest member of the intermediate-level magma masses as envisioned in the model developed above for the evolution of the magmas. Haigler rhyolite magmas have been tapped from older, deeper magma bodies. Volcanism may have ceased and these magmas may have crystallized during the time that the Christopher Mountain Quartzite was deposited. The Payson Granite magma would then have risen above the older solidified bodies and have intruded sub-conformably along its roof into the presumably flat-lying strata. The Payson Granite magma chamber probably was at least 4-5 km deep and upper parts may have been as shallow as 3 km -- a depth comparable to that at which later hypabyssal bodies would intrude. In the slight differentiation which is visualized to have occurred as the magma cooled, alkalis were fractionated upward in relation to lime, and silica (?) and iron (?) in relation to alumina and magnesia. Water was concentrated upward also. In consideration of the earlier discussion of water-saturation in the hypabyssal bodies it certainly seems possible that the Payson Granite magma might have exsolved H_2O. Biotite was stabilized relative to hornblende in the water-rich, cooler upper portions of the body.

The upper Payson magma became essentially identical to that which later would have risen from depth up through solidified Payson Granite and crystallized as alaskite sills and plugs. Payson Granite magma may have been an early high-level analog to later, deeper bodies from which the relatively minor alaskite magmas were derived. In bulk composition the Payson Granite body seems too mafic, calcic, and water-rich to have been before its differentiation a magma similar to intrusive rhyolite or granophyre magmas.

The relative importance of partial melting and differentiation in the origin and evolution of the silicic alkali magmas remains to be determined. It is necessary before considering that problem in greater depth to determine conclusively whether Payson Granite intruded Haigler rhyolite -- to determine whether Payson Granite actually was emplaced as part of the silicic alkali event.

If Payson Granite is older than the rhyolite and part of a basement upon which the Tonto Basin strata were deposited, it cannot, of course, be directly integrated into the petrogenesis. This would be important in another way, however, because it would attest to the presence of a unique source area, or uniquely located tectonic control, so that similar high-silica, high-alkali rocks were produced in Tonto Basin in two temporally distinct events. Plutonic rocks of approximate Payson Granite age (1725-1740±15 m.y.) elsewhere in the older, northern Precambrian province are intermediate calc-alkaline rocks, and volcanic rocks of approximate Haigler rhyolite age (1715±15 m.y.) elsewhere in the southern, younger province are more calc-alkaline and generally more rhyodacitic in composition (L. T. Silver, pers. comm.).

It is interesting to note that if Payson Granite intruded the rhyolite it may be supportive to a specific and limited degree of the proposal of Hamilton and Myers (1967) that batholithic rocks intrude sub-conformably as enormous sheets into the base of their own volcanic ejecta. It is supportive in that Payson Granite would be related genetically (although it did not serve as the direct source) to the rhyolite and that it would have intruded with such a remarkably conformable roof. There is no evidence that the Payson Granite is sheetlike and conformably floored, though it is possible that Alder

Group rocks might lie beneath the granite. The situation may have been ideal for intrusion of Payson Granite as a great sill approximately along the Haigler Group-Alder Group interface because the strata were probably near horizontal and because the thick rigid rhyolite above that interface would have provided a barrier to the rising magma. Subjacent, predominantly sedimentary strata may have been more easily deformed and penetrated by the magma. Such ideal conditions would not likely exist in orogenic belts where the magma might be rising through strongly deformed and folded strata.

Relation to Intermediate and Mafic Volcanic Rocks

It is plausible to assume that the silicic alkali rocks, as defined above, have a genetic relationship to the alkali rhyodacites. The common characteristics, notably high alkali/lime and iron/magnesium ratios, were discussed earlier (pages 314-316). Although the available analyses for the mafic rocks are limited in number and quality it appears that the same characteristics may be common to these rocks. The high iron/magnesium character of all volcanic and hypabyssal rocks is illustrated in the AFM diagram (Figure 21).

The possible continuous AFM trend for all Tonto Basin volcanic and hypabyssal rocks is intermediate between Fe-enrichment differentiation trends of some mafic intrusions (represented by the Skaergaard trend) and the calc-alkaline trend of the orogenic magmatic belts (represented by the Cascade trend). It is apparently similar to the trend for the Iceland Thingmuli volcano (Carmichael, 1964).

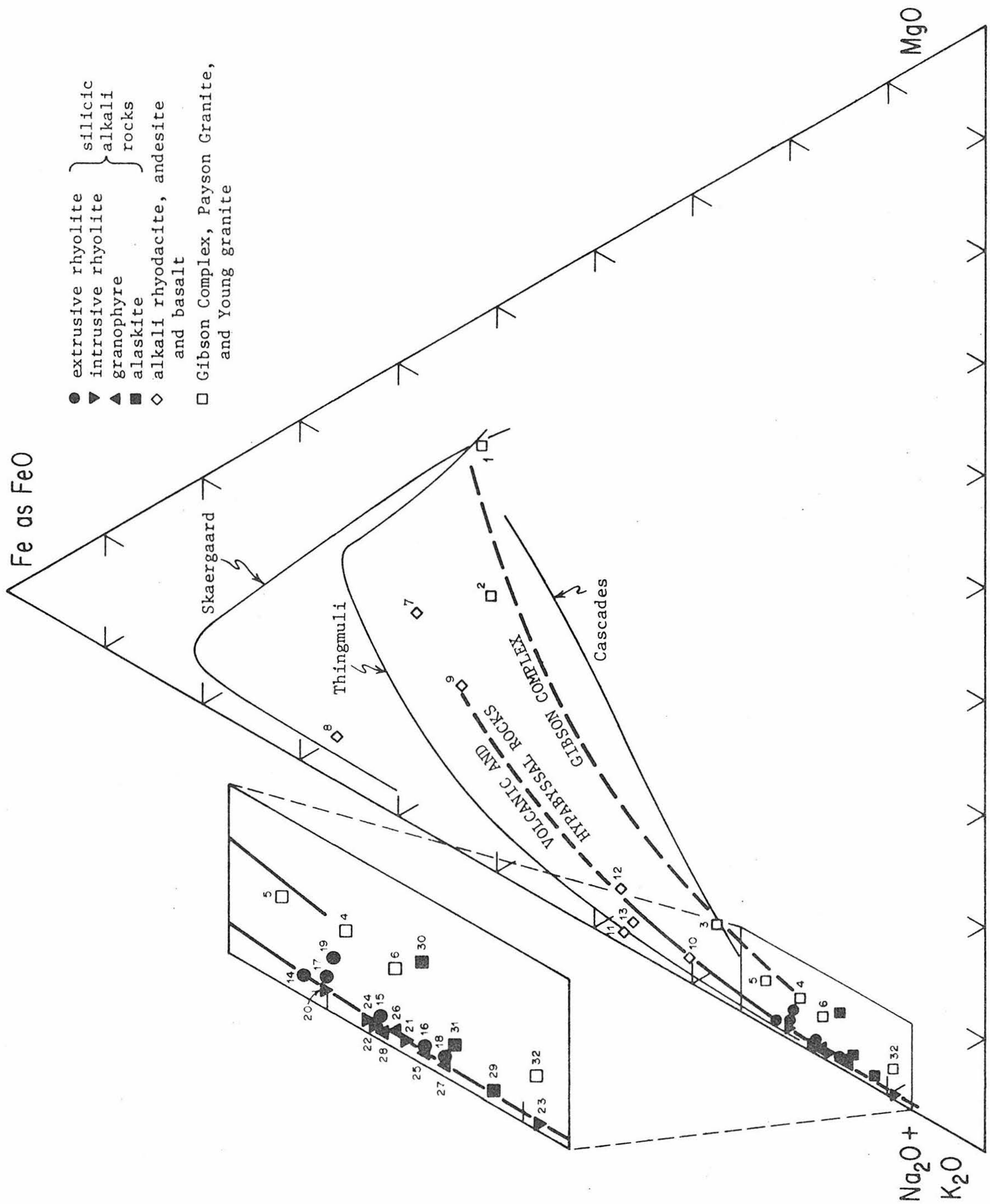

Figure 21. AFM variation diagram for all Tonto Basin rocks showing distinctly different trends for the Gibson Complex and the volcanic and hypabyssal rocks. Payson Granite lies on the Gibson trend in this figure, but on the volcanic-hypabyssal trend in the alkali-lime variation diagram (Figure 23).

To what degree magmatic differentiation might be involved in the apparent Tonto Basin trend is unknown, but it is unreasonable because of volume that the silicic alkali rocks were derived by continuous differentiation from a mafic parent magma along the AFM line. Alkali rhyodacite may have formed by a greater degree of partial melting than did the more silicic rocks, and perhaps from a slightly different source area. On the other hand, perhaps rhyodacite magmas were differentiated from the more mafic rocks along the apparent AFM trend or formed by mixing of rhyolite and mafic magma or assimilation of rhyolite by mafic magma.

THE TONTO BASIN SILICIC ALKALI PROVINCE

The extrusive rhyolite field of the Tonto Basin region is comparable in size and character to some of the largest pyroclastic ash-flow fields associated with calderas, and is remarkably similar in all aspects, notably in chemical composition, to the Yellowstone rhyolite plateau. Relations of the intrusive rocks to the extrusive rhyolite as determined in this study add to our understanding of deep processes associated with formation of ash-flow fields.

Like Yellowstone and most other silicic alkali rhyolite terranes the Tonto Basin province has a bimodal rhyolite-basalt association. Large volumes of silicic alkali granite, granophyre, and rhyolite in some provinces are associated bimodally with tholeiitic layered gabbro complexes. Except for its calcic character the mafic Gibson Complex suggests analogy also with these terranes. If the Gibson Complex is contemporaneous with silicic alkali magmatism, as inferred from field relations, the anomolous association might be explained by initially dry tholeiitic Gibson parent magma developing a 'calc-alkaline' differentiation trend due to assimilation of water upon intrusion into water-rich Alder Group sediments.

The consistent occurrence elsewhere of large volumes of silicic rocks only in regions of extensional anorogenic tectonics suggests a similar tectonic setting for the Tonto Basin province.

Definition, Magnitude, Summary of Characteristics

Included in the Tonto Basin silicic alkali province as here defined are the extrusive and hypabyssal rocks and also the alkali rhyodacites and other related rocks (probably including Payson Granite) which were a result of the enormous volume of silicic alkali magma that was extruded or emplaced at shallow levels in the Tonto Basin region. These rocks were all emplaced in what will be called the Tonto Basin alkali rhyolite event, which began as early as the extrusion of the Flying W alkali rhyodacite and continued intermittently as late as the time of emplacement of the Cherry Spring west alaskite.

The province extends at least as far as 30 miles westward into the Mazatzal Mountains to include Red Rock Rhyolite and related hypabyssal rocks and silicic volcanic rocks in the Alder Group (Ludwig, 1973). Undoubtedly much of the province lies buried beneath the Paleozoic strata of the Mogollon Rim. Rocks of the province appear to be distributed in a northeast-southwest trending belt. This may partially be the result of folding of the province into a synclinorium and erosion of much strata on the flanks, but on the other hand volcanic centers may have been strung out on a NE-SW axis. Tonto Basin was probably at or near a center of volcanic and intrusive activity.

The type Red Rock Rhyolite has a minimum thickness of about 1 km (Ludwig, 1973). In Tonto Basin the Haigler Group may average about 2 km in thickness. On the assumption that the original volcanic field had an average thickness of 1 km over a diameter of 50 km (the distance from eastern exposures in Tonto Basin to western exposures in the Mazatzal Mountains) a conservative volume for the extrusive magma is about 2000 km^3. According to estimates of volumes of younger pyroclastic flow fields by Smith (1960) (Figure 22) the Tonto Basin field would be larger than all others except the San Juan field in Colorado, the Taupo field in New Zealand, and the Elkhorn field in Montana. There are probably larger, older fields not included by Smith, e.g. the Precambrian St. Francois Mountains ash-flow rhyolite field in Missouri. Hypabyssal bodies (rhyolite, granophyre, alaskite) in the map area are estimated to have a total volume of 200 km^3 - which is probably comparable to the volume of extrusive rhyolite exposed in the same area.

The Tonto Basin rhyolite field is in large part an ash-flow tuff field and contains all the lithologic representatives of the classical ash-flow suite. More modern undeformed or little deformed ash-flow fields of comparable volume and lithology are invariably associated with caldera structures (Smith, 1960; Smith and Bailey, 1969). Viscous domes are commonly found along cauldron ring fractures, particularly if resurgence has occurred. Although it may be possible that some Tonto Basin

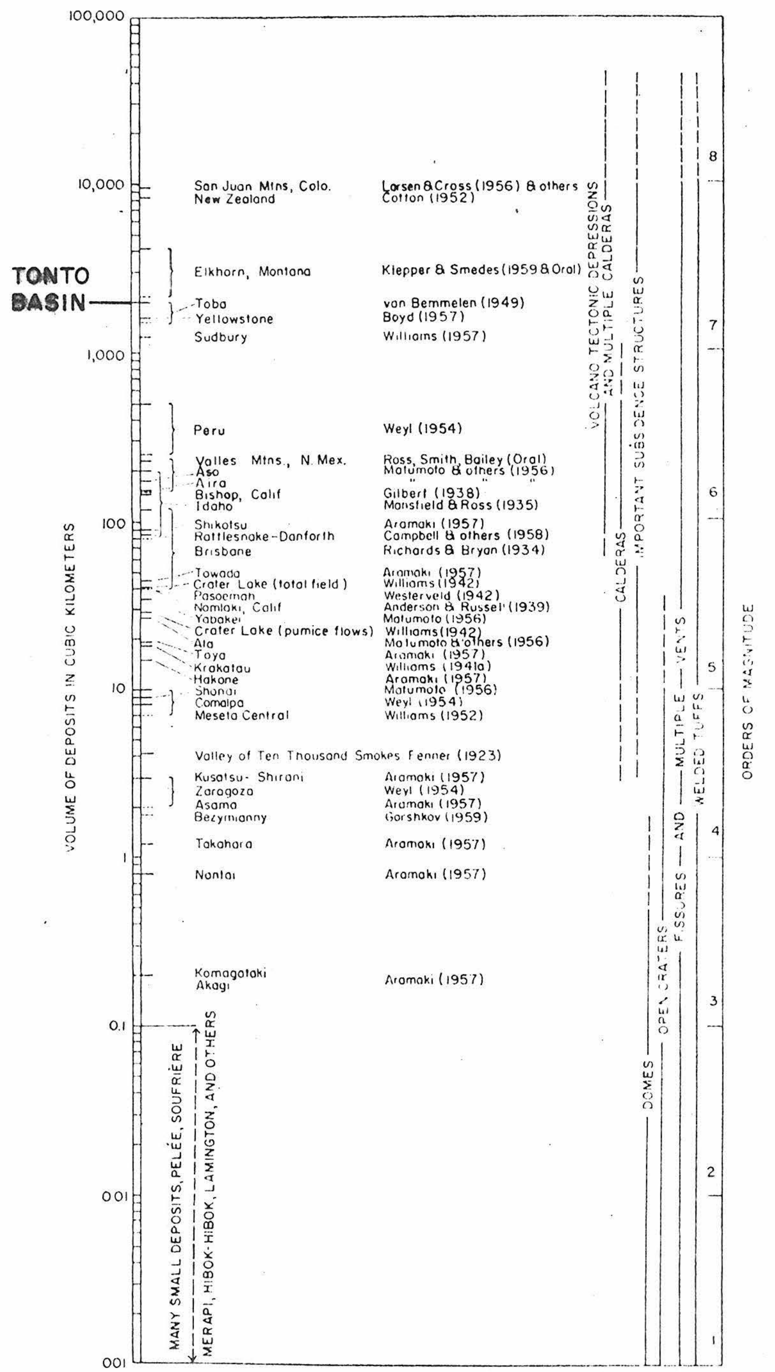

Figure 22. Estimated minimum volume of Haigler Group rhyolite compared with volumes of younger pyroclastic flow fields from Smith (1960, Fig. 3).

units were extrusive domes associated with ring fractures of caldera collapse, a notable candidate being Oxbow Rhyolite, the features of the caldera(s) which were surely at the heart of the complex have not yet been identified.

To the knowledge of the author the Tonto Basin ash-flow field is unparalleled among similar provinces in its superb exposure and preservation of the compositionally equivalent hypabyssal rocks in the roots of the system. These hypabyssal rocks, though apparently separated in time from the Haigler rhyolite by the interval in which Christopher Mountain Quartzite was deposited are chemically persuasive of a comagmatic origin. The earlier discussion of the history of the magmas and conditions of hypabyssal emplacement adds to our understanding of the classical ash-flow field. For students of ash-flow fields, particularly of the modern complexes, the deep and superb exposures in Tonto Basin provide an important comparative case in which the deep phenomena of ash-flow tuff caldera complexes can be studied. This may be of special interest to those who are involved in current studies of hydrothermal potential.

Comparison with other Silicic Alkali Provinces

Most of the larger fields listed by Smith in Figure 22 are calc-alkaline and are not composed predominantly of rhyolite. Yellowstone, however, is strikingly similar to Tonto Basin in the size of the volcanic field and particularly in its identical, limited rhyolite composition (Table 15). Magma bodies existing beneath Yellowstone (see page 399) extend the analogy because these magmas in part may crystallize to form plutonic and hypabyssal rocks similar to those in Tonto Basin. The Yellowstone rhyolite plateau may be an incredibly close modern analog of the Tonto Basin alkali rhyolite province.

Associated with the voluminous alkali rhyolite of Yellowstone is a little basalt. Tonto Basin volcanic rocks seem to have a similar skewed bimodality, but the composition gap is less pronounced. A little basalt occurs in Haigler rhyolite undivided and in the Flying W Formation, but the greatest volume of mafic rock is (basaltic) andesite of the Board Cabin Formation. Except for the minor alkali rhyodacite, no rocks intermediate between the andesite and rhyolite have been found in Tonto Basin, although dacitic rocks do occur in the Alder Group of the Mazatzal Mountains (Ludwig, 1973).

The common bimodal association basalt-rhyolite has long been noted by geologists and Hamilton (1960, p. 66) points out that rhyolites in the bimodal terranes, Precambrian Keweenawan series of the Lake Superior region, Yellowstone-Snake River province of Idaho and Wyoming, and British-Artic Teriary region, are alkali rhyolites.

Christiansen and Lipman (1972) include middle to late Cenocoic basalt-rhyolite fields in their 'fundamentally basaltic' continental volcanism of the western United States. They state (p. 254) that rhyolite of these bimodal associations is quite distinct from rhyolite of the calc-alkaline predominantly andesitic fields in being more silica-rich, and in having higher alkali/lime and Na/K ratios. They make no mention of Fe/Mg ratio but state that ferroaugite and fayalite (which minerals probably indicate high iron relative to magnesium) are found in these rocks but not in calc-alkaline rhyolites. In examination of some of the literature reporting analyses of rhyolite from these bimodal areas the author finds that many analyses are exceedingly similar to those of the Tonto Basin alkali rocks.

An enormous Precambrian complex containing mostly silicic alkali rocks but also minor mafic rocks underlies the St. Francois Mountains of Missouri (Bickford and Mose, 1975; Kisvarsanyi, 1972; Anderson, 1970).

Much literature dealing with basalt-rhyolite associations has not been examined but no instance has yet been found where the rhyolite is not alkali rhyolite.

Hamilton (1959a, 1959b, 1960) in concluding a study of the gabbro and associated granophyre, granite, and rhyolite of the Wichita lopolith, Oklahoma, and in initiating study of the Yellowstone rocks, noted the similarities in the silicic rock chemistries of these two areas. He further pointed out that similar silicic to intermediate alkali rocks (granophyre, granite, and rhyolite) also cap the Bushveld, Sudbury, and Duluth layered gabbro bodies.

Nesbitt (1966) described high-K alkali rhyolite in association with ultramafic and mafic layered intrusions of the Giles Complex, Australia, and suggested a possible analogy with the lopoliths studied by Hamilton.

It is remarkable that silicic alkali rocks occur bimodally again and again with basalt or with layered mafic intrusions or minor intrusive mafic rock. There is, no doubt, in many of these instances a genetic relationship between mafic and felsic rock, but the great predominance of the latter in many provinces argues strongly against an origin by differentiation from the mafic magmas. Christiansen and Lipman state (1972, p. 254): "We believe that even in bimodal fields where rhyolite is the greatly predominant erupted magma type, basalts represent the fundamental expression of deep-seated processes and that the rhyolites are related directly to the rise of basaltic magmas in the earth's crust." Although in some cases the silicic cap rocks of mafic layered intrusions and diabase sills may be due to differentiation, and in some cases to melting of country rock (e.g. granophyre associated with the Sierra Ancha diabase, Smith and Silver, 1974), their commonly huge volume and strong compositional similarity to alkali rhyolites of the bimodal rhyolite-basalt provinces compel the consideration that there is basically little difference between the basalt-rhyolite and the gabbro-granophyre/granite/rhyolite associations. In the case of the former the rocks observed are all extrusive, whereas in the latter the intrusive equivalents, often with extrusive rhyolite also, are found.

Layered intrusive bodies 'capped' by silicic alkali rocks are generally considered to be of tholeiitic basalt parentage, but from descriptions of 'fundamentally basaltic' fields by Christiansen and Lipman (1972) it appears that basalts of the bimodal basalt-rhyolite fields may be either tholeiitic or alkalic. A more extensive literature survey is needed to determine the nature and variation of basalt and other mafic bodies in association with silicic alkali rock.

Relation to the Gibson Complex

In considering the volcanic and hypabyssal rocks of Tonto Basin we see a strongly skewed bimodality of rock type. When all igneous rocks are considered together the same bimodality remains but is not so strongly skewed because of the very large Gibson Complex which consists primarily of diorite and is considered to have differentiated from a basalt magma (page 299). It is intriguing that the Tonto Basin province apparently falls into the bimodal pattern outlined above both in its association with mafic volcanic rocks and with mafic plutonic rocks. This is to be considered cautiously, however, because the temporal relationships are not yet conclusively demonstrated, and because the Gibson Complex is not a tholeiitic layered gabbro body. If the Gibson Complex was emplaced during the alkali rhyolite event there is almost certainly a genetic relation, but if it is part of an older terrane the bimodality may have no meaning in a comparison with other bimodal provinces.

Whereas other mafic intrusive bodies associated with alkali rhyolite are layered throughout and exhibit a pronounced iron enrichment in differentiation (like the Skaergaard trend, Figure 21; see also Hess, 1960, Plate 11), the Gibson Complex is layered only at its base(?) and has a calc-alkaline differentiation trend (Figure 21). It has a calcic alkali-lime index (Peacock, 1931) of about 63 (Figure 23). The calcic nature of the Gibson Complex is compatible with the alternative that is is part of an older basement to the Tonto Basin stratified rocks. Voluminous volcanic and plutonic rocks (including gabbro) in the Jerome-Prescott area are of the same character. Chemical data from that re-

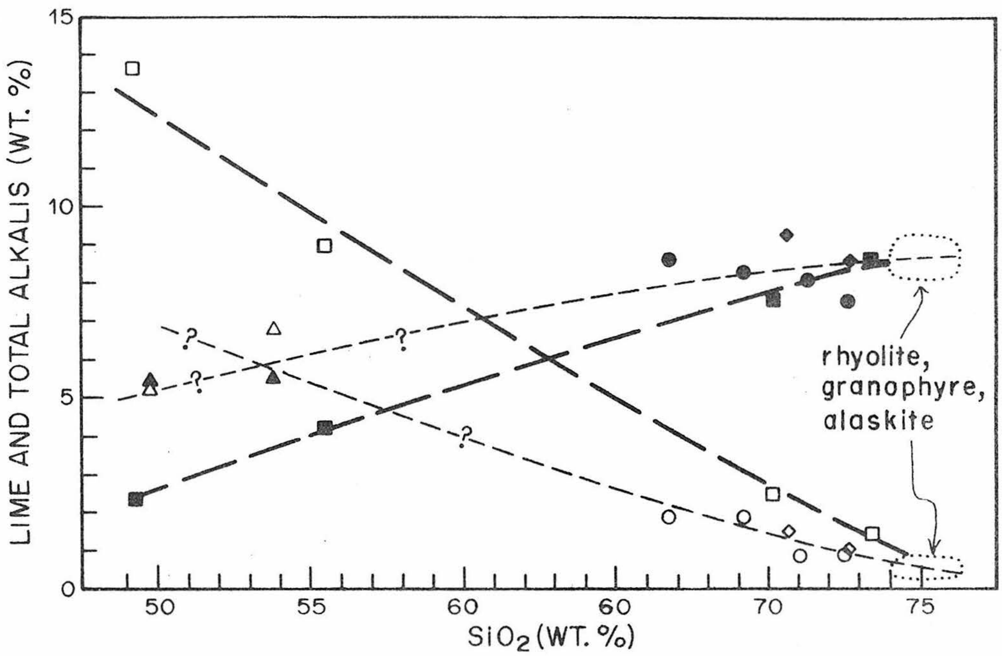

Figure 23. Alkali-lime variation diagram for all Tonto Basin rocks. Heavy dashed-line trends for the Gibson Complex (square symbols) intersect at 63% SiO_2 - a calcic alkali-lime index (Peacock, 1931). Silicic alkali rocks (rhyolite, granophyre, and alaskite) along with alkali rhyodacite (circles), Payson Granite (diamonds), and Board Cabin andesite and intrusive basalt (triangles), may(?) define curves with an alkali-calcic intersection. Open symbols are K_2O + Na_2O; solid symbols are CaO.

gion (Anderson and Creasey, 1958; Anderson, et. al, 1971; Anderson and Blacet, 1972) yields alkali-lime indexes of about 58 and 62 for the volcanic and plutonic rocks, respectively, and AFM curves essentially identical to that of the Gibson body (L. T. Silver, pers. comm.).

The preferred hypothesis of this study, that the Gibson body intrudes Haigler rhyolite and is thus contemporaneous with the rhyolite event meets with objection because of the possible incompatibility of alkali rhyolite and the calcic plutonic body. It is difficult to understand why the silicic alkali rocks (like typically anorogenic rocks elsewhere) in Tonto Basin should be contemporaneous with a differentiated calcic pluton (like typically orogenic bodies elsewhere), especially considering the numerous instances of contrasting associations and lack of mutual association.

It may be significant, however, that the differentiation trend for the Gibson Complex is wholly internal. It is not shared by the Payson Granite and no other 'calc-alkaline' intrusive bodies have been found in Tonto Basin. The solution to the problem might lie in the uniqueness of the geological situation at the time of the hypothetical intrusion of the parent Gibson magma. The alkali rhyolite volcanic field was constructed upon and intertongued with the margin of a eugeosynclinal sequence (Alder Group). The sedimentary strata were essentially undeformed and perhaps still in the diagenetic stage when intruded by the basaltic magma. No doubt the rocks were very rich in connate water. The relatively dry magma would have intruded into the water-rich environment and have engulfed blocks of the sedimentary and volcanic rock (Gisela Pendants).

With this hypothetical situation in mind let us briefly review some interesting and controversial ideas about the role of water in the differentiation of basaltic magma. Osborn (1962) concluded that an iron-enrichment trend in fractional crystallization occurs under low-P_{O_2} conditions but that under high P_{O_2} the magma is enrich in silica (iron is removed early by early precipitation of magnetite) thus giving rise to the calc-alkaline trend. Kuno (1968, pp. 680-686) found that hypersthenic (calc-alkaline) rocks seem to be associated with and genetically related to tholeiitic, high-alumina, and alkali basalts in the major volcanic arcs of Japan. He suggested that the mineralogy of the hypersthenic rocks indicated a high water content in the magmas. Considering Osborn's conclusions and assuming that a high water content favors a high oxygen pressure Kuno hypothesized that the calc-alkaline series in the Japanese belts arose from differentiation of basalts of each type which somehow attained high water content. He concluded:

> The most likely process of the formation of the hypersthenic rock series is fractional crystallization of any of the three basalt magmas enriched in water. The high water content of the magma can explain almost all features characteristic of this series : no iron concentration during fractionation, lower crystallization temperature, and appearance of hydrous silicate minerals.
>
> Whether such concentration of water in the magma is connected in some way with contamination by sialic materials, as suggested previously (Kuno, 1950), or is caused merely by some geological environment characteristic of orogenic belts is a question to which we have no answer yet.

Osborn (1969) supports the contention that high water content is responsible for the calc-alkaline trend. He hypothesized that a basalt magma intruded into a 'wet' geosyncline environment would "during fractional crystallization experience an exchange with the surrounding country rock of water flowing in to the magma to a total amount of probably 2 or 3 percent and hydrogen flowing out." Osborn cites experimental and natural evidence to support his thesis and argues that orogenic andesite results when basaltic magma crystallizes in a wet geosynclinal environment as settling crystals accumulate to form alpine peridotite.

The mainline of petrologic thought has long held that water cannot migrate into magma, at least at a sufficient rate to cause appreciable or pervasive water enrichment before crystallization could occur. Nevertheless, oxygen isotope studies (Friedman, et al., 1974; Forester and Taylor, 1972) show that certain magmas have in some way incorporated significant meteoric water. Evidence was presented in this work (page 379) that magma from which Green Valley Granophyre crystallized may have been enriched in alkalies, presumably by interaction with meteoric water.

The possibility should perhaps be considered that the Gibson Complex is calcic because it incorporated water upon intrusion into the Alder Group. Initial stages of crystallization were perhaps similar to those of tholeiitic layered gabbro intrusions, but as water content increased the trend reversed. Upon precipitation of magnetite, SiO_2 content began to rise, viscosity went up and crystal settling ceased. Most of the magma then crystallized as calc-alkaline diorite and only minor late silicic differentiates formed. The near absence of alteration in layered gabbro and the rather pronounced deuteric alteration upward in the diorite and more felsic rocks may reflect the hypothesized increase in water content by influx from the country rock as crystallization proceeded. Under this notion, the implication is that had the Tonto Basin complex developed in a cratonic environment where high-level rocks were relatively dry (presumably the case for the typical layered mafic intrusion/silicic alkali rock complex) the Gibson magma would have had an iron-enriching differentiation history and been layered throughout.

Implications for Tectonic Regime

Great rhyolite volcanic centers are virtually absent in calc-alkaline magmatic arcs and the relatively minor rhyolite generated in association with the great volumes of intermediate rock are chemically distinct from alkali rhyolite. Alkali rhyolite terranes are apparently generally restricted to anorogenic environments and all or nearly all may be associated with gabbro or basalt and little or no intermediate rock. To the knowledge of the author all the various bimodal provinces earlier discussed are anorogenic.

According to Christiansen and Lipman (1972, p. 255) the 'fundamentally basaltic' volcanic fields of the western United States, of which the bimodal basalt-alkali rhyolite associations are a part, are of extensional tectonic setting and are similar to volcanic assemblages associated with continental extension in other parts of the world. The great layered gabbro-granophyre/rhyolite complexes if not developed in regions of extension are certainly not associated with orogenic belts.

The St. Francois Mountains silicic alkali complex developed during a Precambrian anorogenic event for which magmatic activity is recorded in the interval 1400-1500 m.y. in Missouri (Bickford and Mose, 1975) and throughout the southwest (Silver, 1968, and pers. comm.).

That the Tonto Basin silicic alkali province developed in an extensional or anorogenic tectonic environment is a tenable working hypothesis. Possible conciliations of this hypothesis with what is now understood about the Precambrian tectonic framework is discussed on pages 250-251. Silicic alkali magmatism would have occurred in a brief post-orogenic episode following calc-alkaline magmatism and deformation in the northern part of the state and prior to the southern orogenic episode, or possibly in a site of back-arc extension during the latter. No volcanic magmatic arc has yet been defined for the southern province, however. During the interval in which the alkali rhyolite event occurred the minor tectonic disturbances recorded in the stratigraphy can all be attributed to crustal disturbance related to the magmatism (pages 252-253). Presumably as a (late) part of the orogenic paroxysm to the south the Tonto Basin region became the site of foreland folding and thrusting (pages 223-229). Silicic alkali magmatism may have been terminated by the onset of this tectonic activity.

In opposition to the suggestion of an anorogenic or extensional tectonic environment, which invokes to a degree plate tectonics not demonstrated to have been operative at that time or in that place*, are alternatives which must not be dismissed. It may be that the Tonto Basin province developed in an orogenic environment along with calc-alkaline rocks (Gibson Complex and possibly other rocks nearby to the south). This would have great implications indeed for a Precambrian tectonic-petrogenetic environment contrasting sharply with those of other Precambrian and more modern calc-alkaline magmatic arc systems.

*The argument may be turned around, however, for if plate tectonics is demonstrated to have been operative, such a demonstration will lie partly in the implications of petrologic characteristics such as those of the Tonto Basin terrane.

APPENDIX I

PREPARATION AND ANALYSIS OF ROCKS

Thirty samples were prepared for chemical analysis by crushing with a hammer and a steel mortar and pestle to fragments less than 3 mm. The total amount crushed varied from 0.5 kg for the coarse granitic samples to 0.1 kg for the finest rocks. Samples were then split 1 to 3 times with a riffle splitter to obtain a 50-60 gram portion of each sample which was pulverized, in two or three parts for 60-90 seconds each, in a tungsten carbide Shatterbox (Spex Industries, Inc.). Powders were homogenized by shaking in a glass jar.

From twenty of the samples 15-20 grams of powder were removed by coring with a glass tube and shipped to the Japan Analytical Chemistry Research Institute, Tokyo, Japan, for wet chemical analysis. These were sent in two shipments; one set was analyzed by Shiro Imai and the other by Tadashi Asari.

Bulk chemical analysis for 10 samples were made by the author with Caltech's MAC electron microprobe using a procedure developed by two fellow graduate students, Raymond Joesten and Jay Murray. Approximately equal portions (about 1.5 grams) of powdered sample and a fluxing agent ($Li_2B_4O_7$) were thoroughly mixed and fused in carbon crucibles at 1150°C. Homogeneity of the glass sample was greatly increased by crushing, powdering and refusing the glass bead. The bead was crushed again and about a dozen 1 mm grains were mounted for microprobe analysis.

One minute count-rates were determined on a 50 micron spot for each of 8 grains and averaged. Calculation of the chemical analysis from these averaged count-rates was based both on a standard matrix of correction factors and on empirical factors for the flux-rock oxide interactions. The latter factors were those necessary to correct microprobe analyses of fluxed USGS rock standards G-2 and BCR-1 to the wet chemically determined values (Flanagan, 1969).

Results by the microprobe method are compared with those by the wet chemical method (recalculated anhydrous) for one Tonto Basin sample and for four tonalite samples from the San Jose pluton, Baja California, Mexico in Table I-1. Agreement is good except for slightly higher probe Na_2O and SiO_2 and slightly lower probe Al_2O_3. Discrepancies in SiO_2 and Al_2O_3 may be due to errors inherent in the wet chemical procedure rather than microprobe error (Stevens and Chodos, 1960; Fairbairn, 1953).

TABLE I-1. COMPARISON OF MICROPROBE AND WET CHEMICAL ANALYSES

	1		2		3		4		5	
	a	b	a	b	a	b	a	b	a	b
SiO_2	61.18	60.65	61.55	61.66	65.67	64.81	65.22	64.49	74.52	74.18
TiO_2	0.78	0.80	0.70	0.74	0.55	0.60	0.58	0.61	0.19	0.15
Al_2O_3	18.15	18.13	18.52	18.31	16.66	17.55	17.10	17.49	13.26	13.75
FeO	4.92	5.12	4.63	4.55	3.86	3.92	3.78	3.95	0.98	1.09
MgO	2.74	2.89	2.54	2.64	1.81	1.87	1.93	2.02	0.20	0.25
CaO	6.47	6.80	6.42	6.55	5.38	5.40	5.38	5.51	0.10	0.18
Na_2O	4.85	4.71	4.82	4.74	4.94	4.75	4.91	4.85	0.46	0.39
K_2O	0.71	0.72	0.64	0.65	0.95	0.95	0.95	0.94	10.26	9.98
P_2O_5	0.20	0.17	0.19	0.15	0.17	0.14	0.16	0.13	0.02	0.02
TOTAL	100.00	99.99	100.01	99.99	99.99	99.99	100.01	99.99	99.99	99.99

1-4. Tonalite samples Ba-JM-25a, Ba-JM-240-52, Ba-JM-93, Ba-JM-46a, respectively. Microprobe analyses by J. D. Murray, wet chemical analyses by Tadashi Asari.

5. Granite sample Ar-Gi- Young gr #1A. Microprobe analysis by C. M. Conway, wet chemical analysis by Shiro Imai.

a. Microprobe analyses.

b. Wet chemical analyses, Japan Analytical Chemistry Research Institute, Tokyo, Japan.

APPENDIX II

PETROGRAPHIC DESCRIPTIONS OF ANALYZED SAMPLES

(keyed by analysis number to Plate 4;
abbreviations at conclusion of appendix)

Analysis 1
Sample 10-1-2154: pyroxene gabbro (Gibson Complex)
photomicrograph: Plate 32, p. 287
described, p. 284, 286; mode, Table 6, p. 285

Analysis 2
Sample 9-3-2084A: diorite (Gibson Complex)
described, p. 288-289, Table 6, p. 285

Analysis 3
Sample 6-3-1431: leucogranodiorite (Gibson Complex)
described, p. 290; mode, Table 6, p. 285

Analysis 4
Sample 10-1-2157: leucocratic hornblende granophyre (Gibson Complex)
described, p. 292; mode, Table 6, p. 285

Analysis 5
Sample 3-1-677: ferrohastingsite granite (Payson Granite)
texture: hyp gran (7-8 mm), rapakivi plag, myrmekite along per margins, eu plag inclusions in per, bio occ rpl amph, amph, bio, & opaq clus
mineralogy: mode, Table 7, p. 304
21.0 quartz: an, clus
50.8 perthite: an-sub, most is clear ortho ($2V_\alpha$ 50-60°) with fine lam; clouded portions (hem, ser) usually micro with coarser, braid lam
19.0 plagioclase: sub-eu, wk zoned and mod twinned Na oligoclase, str epi and wk ser alt
5.4 amphibole: sub-eu, 0.2-1.0 mm. $2V_\alpha$ 10-30°, $r<v$ wk, α yellow-brown, β dark brown-green, γ deep olive-green
2.9 biotite: sub-eu, 0.2-1.0 mm
1.0 opaques: an, 0.1-0.5 mm
acc zircon, fluorite, apatite
an excellent road-cut specimen, unusually free of weathering affects

Analysis 6
Sample 2-1-327A: porphyritic dike granite (Payson Granite)
texture: porph, hyp gran gdms, rapakivi plag, scarce migr, eu plag inclusions in per, bio and opaq clus
mineralogy:
<u>phenocrysts</u> (3-8 mm)
10 quartz: sub
20 perthite: sub fn to cs vein & patch ortho and micro, minor hem clouding
10 plagioclase: sub-eu, sometimes clustered Na olig, mod ser and epi alteration
tr amphibole: eu, prisms seen only megascopically
<u>groundmass</u> (0.5-1 mm)
20 quartz: an
20 perthite: an-sub, as above
15 plagioclase: sub-eu, as above
4 biotite: sub, partially rxll then partially alt to chl and leu
1 opaque oxide: an, associated with bio
tr amphibole (?): deep green absorption, similar to ferrohastingsite of sample 3-1-677
from 5 m-wide dike in upper part of Payson Granite, well pres grayish specimen; phenocrysts of same size and character as grains in equigranular Payson Granite

Analysis 7
Sample Gastil, 1954, Table 5: hypabyssal basalt
The following description is taken from Gastil, 1954, p. 62.
texture: relict pilotaxitic fabric, cut by a stock work of fn veinlets consisting of epi and leu with a little chl, cal and qtz
mineralogy:
chlorite is predominant mineral
microlites are alb (An_{0-7})
quartz
leucoxene
opaque oxide
apatite

Analysis 8
Sample 7-1-1617A: basalt? (Flying W Formation)
described, p. 314

Analysis 9
Sample 7-1-1600: andesite (Board Cabin Formation)
described, p. 316

Analysis 10
Sample Ar-Gi-W rhy #1A: alkali rhyodacite (Flying W Formation)
described, p. 319-320

Analysis 11
Sample V, Gastil, 1958, Table 3: alkali rhyodacite (Winter Camp Formation)

The following (from Gastil, 1954, p. 46) is a general description of the unit, rhyolite II, from which the analyzed sample was taken.

texture: flow foliation defined by lam composed of qtz, alb, & epi

mineralogy:

phenocrysts
albite: An_{0-7}, well pres
pseudomorphs (?): crystal skeletons filled with epi, chl, & unidentified green mineral of moderate birefringence

groundmass
quartz
feldspar
sericite
iron oxide dust (giving the rock a dark color)
apatite (unusually abundant)

Analysis 12
Sample 7-1-1611: alkali rhyodacite (Winter Camp Formation)
described, p. 321-322

Analysis 13
Sample 7-1-1604A: alkali rhyodacite (Winter Camp Formation)
photomicrograph: Plate 36, p. 318
described, p. 321

Analysis 14
Sample 8-1-1850A: extrusive alkali rhyolite (Haigler rhyolite)

texture: porph, aph gdms, fn contorted flow/compaction foliation; 25% 0.2-5 mm-thick opaq-free rxll pumice lam, 75% fn opaq-bearing gdms with occ pres shard texture; phenos more abdt in dark gdms; foliation warped around 2-5 mm sub-equant lithic inclusions

mineralogy:

phenocrysts (0.3-0.7 mm) (see Table 13, p. 334)
2 quartz: an-sub, rsbd, bipyr
1 alkali feldspar: sub-eu, cs vein per (0.8 ortho), 25% rpl by cal, 5 rpl by fluor
3 plagioclase: an-sub, unzoned wk twinned alb, str rsbd, 10% rpl by cal, 10% rpl by ser, tr rpl by fluor
tr cs opaque oxide: skeletal, possibly pseudo after mafic silicate

groundmass (0.01-0.3 mm in pumice lam, 0.003-0.02 mm in dark gdms)
30 quartz: an, to 0.3 mm in pumice lam

Analysis 14 (cont.)

50 feldspar: plag laths in cs K-feld in pumice lam; an, v fn in dark gdms
10 sericite: flakes diss through gdms
4 calcite: an, diss and clus
2 opaque oxide: equant grains (probably mgt) diss in gdms exclusive of pumice lam
tr fluorite: an, clus

hand specimen has appearance of black banded obsidian; it is apparently strongly welded ash-flow tuff; 1% 1-10 mm diss lithic inclusions are slightly coarser, slightly more mafic rhyolite

Analysis 15

Sample 8-1-1819: extrusive alkali rhyolite (Haigler rhyolite)

texture: porph, aph gdms, faint flow foliation defined by 0.5-2 mm coarser, more opaq-rich and finer, opaq-poor lam whose boundaries are difficult to discern; v wk spher (0.3 mm) occ in both lam but primarily in coarser; 'glassy' polygonal fracture pattern pervasive

mineralogy:

phenocrysts (0.5-2 mm) (see Table 13, p. 334)

3 quartz: an-sub, mod rsbd
2 alkali feldspar: an-sub, cs patch/vein per (0.6 ortho & micro), mod-str rsbd, 20% rpl by hem blades, 10% rpl by agg ser, tr rpl by cal

groundmass (0.001-0.3 mm)

40 quasi-spherulite quartz-feldspar domains: 0.02-0.1 mm, submicroscopic intergrowths of qtz & feld, sometimes semiradial, generally constitute opaq-poor lam
45 quartz-alkali feldspar aggregates: granular, an-sub, 0.1-0.3 mm, generally contitute more opaq-rich lam
5 sericite: minute flakes diss & agg
3 opaque oxide: an-sub, 0.03-0.3 mm, diss & agg in gdms & in fractures
tr calcite: an, diss, occ equant 0.1-0.3 mm xll
tr zircon: eu, 0.01 mm prisms

hand-specimen gray-brown & massive, foliation difficult to discern, v wk fracture system

Analysis 16

Sample 6-3-1531: extrusive alkali rhyolite (Haigler rhyolite)

photomicrograph: Plate 37A, p. 328

texture: porph, aph gdms, 40% 0.1-5 mm-thick rxll pumice lenses in fn foliated gdms, marginal axiolitic and internal spher devitrification textures in pumice lenses, filamentous collapsed vesicle texture locally present at pumice margins, phenos of same character and abdce in both pumice & fn gdms

mineralogy:

phenocrysts (0.5-2 mm) (see Table 13, p. 334)

5 quartz: an-eu, bipyr, mod rsbd

Analysis 16 (cont.)

5 alkali feldspar: sub-eu, patch/vein (100) antiper (0.3-0.4 ortho), few % rpl by cal & ser

groundmass (0.005-0.02 mm in fn portion, spher & qtz up to 0.3 mm in pumice lenses)

83 quartz-feldspar: intergrown in v fn granular gdms or in spher

5 sericite: minute flakes diss throughout

2 opaque oxide: mostly hematite dust concentrated in pumice lam

tr zircon: eu, 0.01 mm prisms

red-brown ash-flow tuff with excellent megascopic and microscopic definition of flattened pumice fragments

Analysis 17

Sample 5-1-1252: extrusive alkali rhyolite (Haigler rhyolite)

texture: porph, aph gdms, 35% 0.1-3 mm-thick pumice lenses in fn foliated gdms, extensively rxll pumice lenses contain relatively cs eu feld prisms (semi-radiating and axiolitic) in very cs qtz

mineralogy:

phenocrysts (1-3 mm) (see Table 13, p. 334)

4 quartz: an-sub, rsbd

3 alkali feldspar: an-sub, rsbd, 40% rpl by fn ser, 5% rpl by hem blades and platelets, remainder heavily clouded with fn hem, areas of ser concentration may have been plag lam

groundmass (0.005-0.02 mm in fn portion, up to 1 mm in pumice lenses)

60 quartz and feldspar: granular mosaic in fn gdms; eu 0.1-0.3 mm K-feld prisms poikilitic within mosaic of 0.3-1 mm qtz in pumice lenses

30 sericite: minute diss flakes

3 opaque oxide: minute equant diss hem grains, occ 0.2 mm grain or cluster possibly pseudo after mafic silicate

extensively alt ash-flow tuff, all feld heavily clouded with fn hem, no plag lam clearly identified - apparently rpl by K-feld and ser

Analysis 18

Sample 8-1-1976: extrusive alkali rhyolite (Oxbow Rhyolite)

texture: porph, aph gdms, 10% wk to mod defined pumice lenses, wk flow foliation throughout defined partly by laminar concentration of tiny opaq grains, polygonal 'glassy' fracture system

mineralogy:

phenocrysts

20 quartz: 2-5 mm, an-sub, mod-str rsbd

10 antiperthitic alkali feldspar: 1-3 mm, an-sub, cs patch antiper (0.3-0.4 ortho), clear alb, hem clouded

Analysis 18 (cont.)

ortho, few % rpl by cal, ser, & opaq

tr perthitic alkali feldspar: 1 mm, sub, patch/vein per (0.8 ortho), str hem clouding

tr sericite: 1 mm blocky agg possibly pseudo after plag

tr opaque oxide: clus & skeletal, probably pseudo after silicate

groundmass

50 quartz-feldspar: 0.002-0.2 mm granular mosaic

10 quartz-feldspar: 0.01-0.2 mm agg in pumice lenses, much is quasi-spher intergrowth domains

8 sericite: minute diss flakes, concentrations in pumice lenses

2 opaque oxide: minute equant diss grains

tr fluorite: an, diss

tr zircon: eu

relatively well-preserved specimen, red-brown and massive in appearance, pumice lam wk visible, probably not ash-flow tuff

Analysis 19

Sample III, Gastil, 1958, Table 3: extrusive alkali rhyolite (Oxbow Rhyolite)

The following (from Gastil, 1958, p. 1506, and 1954, p. 52) is a general description of the Oxbow Rhyolite.

texture: Welded rhyolite tuff forms the lower part of the unit and grades upward into massive quartz porphyry. The tuff consists of coarse phenoclasts, welded glass shards, and contrastingly dark, flattened, welded glass shards (pumice). Except for lack of pyroclastic texture, the quartz porphyry resembles the tuff.

mineralogy:

phenocrysts (up to 4 mm)

quartz

perthite: largest and most abundant of the phenocrysts

albite: An_5, chessboard or other twinning

tuff is grayish-white, quartz prophyry rocks are commonly pinkish-orange to grayish-red; alt of feld is restricted to diss of iron dust; chl, musc, and iron oxide are present as secondary minerals; some zircon is partially rpl by iron oxide

Analysis 20

Sample 5-1-1212: intrusive alkali rhyolite (Hell's Gate Rhyolite, Salt Lick phase)

photomicrograph: Plate 40A, p. 340

texture: porph, aph gdms, massive even-textured all gran gdms, very local flow laminations defined by concentration of opaq

mineralogy:

phenocrysts (0.5-2 mm)

5 quartz: an-eu, mod-str rsbd, deeply embayed

5 alkali feldspar: an-sub, patch/vein (100) per-antiper

Analysis 20 (cont)

(0.4-0.7 orth, $2V_{\alpha}$ 50°), mod rsbd, alb lam clear, ortho lam slightly reddened with hem dust, 10% rpl by cal, 5% rpl by chl, 5% rpl by fluor & ser

tr blacky opaque oxide-quartz-chlorite clusters: 0.5 mm, probably pseudo after mafic silicate phenos

groundmass (0.005-0.03 mm)

75 quartz-feldspar: an, granular mosaic
5 calcite: an, diss
3 chlorite: an-sub, diss
2 opaque oxide: an, equant, diss (probably mostly mgt)
2 sericite: flakes, diss
tr amphibole ?: sub, scattered xlls up to 0.2 mm, tiny prisms
tr fluorite: an, diss
tr zircon: eu, clus with opaq

dark red-brown sample, 1% 0.1-5 cm lithic inclusions have same minerals as gdms but are composed mostly of plag, & chl

Analysis 21

Sample 1-1-94: intrusive alkali rhyolite (Hell's Gate Rhyolite, Salt Lick phase)

texture: porph, aph gdms, massive, texturally very homogeneous

mineralogy:

phenocrysts (0.3-3 mm)

3 quartz: an, sub, rsbd
3 alkali feldspar: an-sub, rsbd, cs patch/vein (100) antiper (0.2-0.4 ortho, unclouded, 15% rpl by cal, 5% rpl by amph & chl (?), tr rpl by fluor
tr chlorite-opaque oxide clots: regular from suggests pseudo after px

groundmass (0.01-0.02 mm)

85 quartz-feldspar: an, very even granular mosaic
4 amphibole and chlorite (?): an-sub, diss equant and prismatic grains, some clus of larger (0.1 mm) grains
2 opaque oxide: an, diss & clus with amph and chl; mostly mgt
3 calcite: an, diss, occ larger (0.1 mm) patch
tr fluorite: an, diss
tr sphene: an, clus & trails exceedingly fine grains
tr zircon: eu, 0.1 prisms

dark brown-black specimen, comparatively very well-preserved

Analysis 22

Sample 2-1-418A: intrusive alkali rhyolite (Hell's Gate Rhyolite, Blue Dog phase)

texture: porph, aph gdms, massive homogeneous

mineralogy:

Analysis 22 (cont.)

phenocrysts (1-3 mm)
4 quartz: sub, rsbd
4 alkali feldspar: sub, rsbd, cs patch/vein mesoper, str clouded with hem dust
groundmass (0.03-0.04 mm)
90 quartz-feldspar: an, even granular mosaic
3 opaque oxide: an, diss, most is hem
tr zircon: eu

red-brown specimen typical of the prevalent oxidized facies of both Blue Dog and Salt Lake phases

Analysis 23

Sample 8-1-1912: intrusive alkali rhyolite (rhyolite of Hog Canyon) described, p. 346-347

Analysis 24

Sample 2-1-435A: intrusive alkali rhyolite(King Ridge Rhyolite)

photomicrograph: Plate 42A, p. 349

texture: porph, spher, massive, 60% 1.5-2 mm coalescing spher, 40% aph gdms mostly in 2-15 mm pockets, phenos occur only in spher portion as cores or substrate to one or more spher domains

mineralogy:

phenocrysts
tr quartz: 1-1.5 mm, an-sub, rsbd
<1 quartz: 0.2-0.4 mm, eu, bipyr
1 alkali feldspar: 1.5-2 mm, sub-eu, sl rsbd, patch/vein per (0.6 K-feld), 5-10% rpl by amph, chl, & ser, tr rpl by cal & fluor
1 alkali feldspar: 0.3-0.6 mm, eu, as above
tr plagioclase: 1.5-2 mm, sub-eu, unzoned mod twinned alb, 10-20% rpl by ser, few % rpl by cal, fluor, & chl
<1 plagioclase: 0.3-0.6 mm, eu, as above
tr chlorite aggregates: 0.3-0.5 mm, blocky to prismatic form suggests pseudo after mafic silicate pheno
groundmass (1.5-2 mm spher, 0.001-0.05 mm fn gdms)
90 quartz-feldspar: exceedingly fine fibers of large spher and 0.001-0.02 mm grains and tiny spher of fn granular gdms
5 amphibole/chlorite: needles and sub-equant grains originally amph largely alt to chl, needles (0.004 x 0.1 mm to 0.04 x 1 mm) are mostly radially distributed in spher, an-sub sub-equant grains (0.01-0.05 mm) diss in fn gdms
tr opaque oxide: 0.2 mm equant grains (mgt); diss dust (hem)
tr sericite: diss flakes
tr fluorite: an, concentrations in central coarser areas of fn gdms
tr sphene: an, small agg of exceedingly tiny xlls, usually rpl amph

Analysis 24 (cont.)

tr sphene: an, small agg of exceedingly tiny xlls, usually rpl amph
tr calcite: an, diss
tr zircon: 0.1 mm, eu, comparatively abdt

excellent gray-brown specimen, comparatively very well preserved

Analysis 25

Sample 3-2-701: alkali granophyre (Green Valley Granophyre, Mescal Ridge phase)

texture: porph, migr, qtz or feld of cs cuneiform domains usually optically continuous with a central pheno, distinction between phenos and gdms locally obscure because of rxll

mineralogy:

phenocrysts (2-4 mm)

15 quartz: an-sub, rsbd, deeply embayed, cs migr overgrowth
15 alkali feldspar: sub, cs migr overgrowth, mod-cs patch/vein per (0.5-0.6 K-feld), str clouded with hem dust & fn diss flour, fractures filled with hem, tr rpl by fn green-brown bio
2 biotite(?) aggregates: 0.5-2 mm, str oxidized (hem?), clus with opaq and zir, pseudo after pleochroic blue-green silicate (amph or px), a trace of which remains in a few clusters

groundmass

65 quartz-feldspar (~1:2): fn (0.01 mm) to generally cs (0.5 mm) migr intergrowth, feld identical in character to phenos
2 opaque oxide: 0.05-0.2 mm, equant grains (prob mgt) generally ass with bio(?) agg; fn hem diss and agg in fractures
tr fluorite: 0.1-0.4 mm, an, equant, usually ass with opaq
tr biotite: fn, diss, str oxidized
tr sphene(?): v fn agg
tr zircon: 0.1-0.2 mm, eu, comparatively abdt, ass with opaq

'red-rock' granophyre, perhaps slightly coarser and slightly less oxidized than typical Mescal Ridge lithology

Analysis 26

Sample 5-1-1299: alkali granophyre (Green Valley Granophyre, Thompson Wash phase)

photomicrograph: Plate 44A, p. 356

texture: porph, migr, qtz-feld intergrowth domains radiating from central qtz or feld phenos with which the corresponding phase is in crystallographic continuity

mineralogy:

phenocrysts

4 quartz: 0.5-1.5 mm, an-sub, rsbd
7 alkali feldspar: 0.5-3 mm, sub-eu, fn film/vein mesoper, mod-str clouded with hem dust, tr rpl by fn diss fluor, fn agg of yellow-green chl, and blades and veinlets of

Analysis 26 (cont.)

opaq (probably hem)

2 opaque oxide aggregates: most are 0.2-1 mm long clusters pseudo after acicular mafic silicate, some are 0.2-1 mm equant clusters, both have a little ass chl, sph & zir

groundmass

85 quartz-feldspar (~1:2): fn delicate 'fan and feather' to migr intergrowth, alk feld of some character as phenos

2 opaque oxide: an, 0.1 mm (mgt ?) and hem dust diss along fractures and grain boundaries

tr fluorite: 0.1-0.5 mm, an, sub-equant, usually ass with opaq

tr chlorite: an, fn agg, yellow-green, ass with opaq

tr sphene: an, agg of v fn xlls, also as rims around opaq

tr zircon: 0.05-0.02 mm, eu, with opaq

'red-rock' granophyre typical of prevalent Thompson Wash lithology except a little less oxidized and with slightly finer migr intergrowth

Analysis 27

Sample 9-3-2104: alkali granophyre (Green Valley Granophyre, Neal Mountain mass)

texture: porph, migr, intergrowth domains coarsen outward from central qtz of feld phenos, px locally wk migr, 10% fn-cs vermicular-granular qtz-feld intergrowth in interconnecting areas between cs migr domains

mineralogy:

phenocrysts

3 quartz: 0.5-1 mm, an-sub, rsbd

7 alkali feldspar: 1-4 mm, sub-eu, fn-cs patch-film per (0.5-0.6 K-feld), most str clouded with opaq dust, occ clear areas wk exsolved, all is poikilitic with few % 0.01 mm fluor blebs

tr plagioclase: 0.5-1 mm, sub, mod zoned & twinned intermediate olig, 10% rpl by ser, few % rpl by epi & cal (xenocrystic ?)

groundmass

85 quartz-alkali feldspar (~1:2): fn-med migr intergrowth, alkali feld internally identical to phenos

3 aegirine-augite: 0.05-0.3 mm, an-eu, equant to prismatic, some grains possibly phenos, $2V_\alpha$ 80-110°, α:z >10°, α deep green, β brown-green(?), γ green-yellow, locally altered to hem(?)

1 opaque oxide: 0.1 mm equant mgt; some hem dust

tr fluorite: 0.05-0.3 mm, equant

tr sphene: 0.01 mm, an, clus, reactions rims on opaq

tr zircon: 0.1 mm, eu, clus with px & opaq, comparatively abdt

red-gray granophyre, variable oxidation on microscopic scale, but generally unoxidized and well-preserved

Analysis 28
Sample 1-0-32: alkali granophyre (Green Valley Granophyre, Neal Mountain mass)

texture: porph, migr, central qtz or feld phenos in comparatively cs (0.05 mm lam or bars) highly regular cuneiform and graphic intergrowth, 5% granular areas (0.5-1 mm)

mineralogy:

phenocrysts

5 quartz: 0.5-2 mm, sub-eu, sl rsbd

10 alkali feldspar: 1-5 mm, sub-eu, sl rsbd, fn-mod patch-film-braid per (0.5-0.6 K-feld), partially clear, partially clouded with hem(?), much speckled with 0.01 mm fluor blebs

tr aegirine-augite: 0.5 mm, an-sub, few grains possibly phenos, same phase as in gdms (see below)

groundmass

80 quartz-alkali feldspar (∿1:2): migr intergrowth, feld internally identical to phenos, few % granular areas with alb

3 aegirine-augite: 0.05-0.3 mm, an-sub, equant usually clus and acicular usually solitary, ragged, large 2V, length-fast, α deep green, β brown-green, γ pale golden-brown, locally alt deep red-brown (hem ?) particularly in cores

1 plagioclase: 0.5 mm, an-sub, unzoned str twinned alb, some sl antiper or continuous with per grains, clear, no alt products

tr sphene: 0.2-0.4 mm, sub-eu, few discrete grains; 0.01-0.05 mm, an, clus

tr fluorite: 0.1-0.2 mm, an, diss

tr garnet(?): 0.2 mm, an, yellow-brown, isotropic

tr allanite(?): 0.05 mm, eu, 2V >70°, extinction angle >5°, deep golden-brown

tr zircon: 0.1 mm, eu, prisms ass with opaq & px

gray granophyre, virtually free from feld clouding and oxidation

Analysis 29
Sample 2-1-383: biotite alkali granite (alaskite sill)

mode, Table 14, p. 363

texture: all gran, biotite clus - apparently rxll, abdt fn plag along per margins is result of granular exsolution, sub plag inclusions in per; bio, fluor, opaq & zir clus

mineralogy:

40.6 quartz: 2-5 mm, an

35.8 perthite: 3-6 mm, occ xll up to 10 mm, an, cs vein/patch per (0.71 micro), sl hem clouding, sl bio rpl along fractures

20.4 plagioclase: 1-5 mm, an-sub, unzoned to v wk zoned str twinned alb-Na olig, some clus suggests rxll, 15% rpl by ser flakes up to 0.1 mm, few % rpl by bio,

Analysis 29 (cont.)

tr rpl by fluor & epi, sl antiper locally

3.1 biotite: 1-2 mm agg of sub xlls, partially alt to opaq, leu & qtz(?) lenslets

tr muscovite: 0.1 mm, an

tr fluorite: 0.1-1 mm, an, large xlls heavily clouded with fn opaq

tr zircon: 0.05-0.1 mm, eu

tr amphibole(?): 0.1 mm heavily altered patches in cores of biotite

tr opaque oxide: 0.2 mm, an, ass with biotite

tannish hand specimen, relatively free from oxidation, biotite comparatively well-preserved

Analysis 30

Sample 5-1-1290: (biotite) alkali granite (western alaskite of Cherry Spring)

photomicrograph: Plate 45A, p. 364

mode, Table 14, p. 363

texture: hyp gran, sl porph, local fn per (or qtz) interstitial to sub qtz (or sub per) and sub-eu plag, tr granular (sawtooth) exsolved plag at per-per and per-plag contacts

mineralogy:

30.8 quartz: 0.5-2 mm, an-sub

41.2 perthite: 2-4 mm, an-sub, fn-cs patch/vein/braid per (0.81 ortho or micro), mostly clear, locally sl clouded with opaq dust, tr rpl by ser, bio, & opaq

24.2 plagioclase: 0.5-2 mm, sub-eu, wk zoned Na-olig(?), heavily clouded with fn ser, epi, & hem

2.8 chlorite: 0.3-0.8 mm, sub, clus & solitary, contains 10% opaq & leu, is clearly secondary after bio only a str alt tr of which remains

0.9 opaque oxides: mostly mgt/ilm, 0.1-0.3 mm, an; some hem clus with mgt/ilm and as fracture fillings

tr zircon: 0.05 mm prisms

tr apatite: minute prisms

gray-brown specimen typical of 'unoxidized' Cherry Spring west alaskite

Analysis 31

Sample 9-3-2012A: alkali granite (alaskite plug at Star Valley)

mode, Table 14, p. 363

texture: all gran, plag inclusions in per, granular (sawtooth) exsolved myrmekitic plag along per-per & per-plag contacts, opaq, sph, & apa clus - sometimes with chl & amph

mineralogy:

36.7 quartz: 1-3 mm, an

40.2 perthite: 1-2 mm, an, fn-med film/braid per (0.66 micro), clear to wk clouded with opaq dust, plag lam often str clouded

Analysis 31 (cont.)

21.5 plagioclase: 1-2 mm, an-sub, mod zoned & twinned intermediate olig, 75% clear & well-pres, 25% str clouded (patches and cores) with opaq dust & fn ser & epi, 5-10% exsolved K-feld lam & blebs

0.6 chlorite/biotite: 0.1-0.2 mm, an, mostly chl after bio, sometimes clus with amph or opaq

0.6 opaque oxide: 0.1-0.7 mm, an, sub-equant

~0.3 amphibole: 0.1-0.2 mm, an-sub, pleo in pea-green, olive-green, & yellow-green, $2V_{\alpha}$ 60-70°

tr apatite: prisms up to 0.2 mm long

tr zircon: 0.1-0.2 mm

tr sphene(?): 0.05-0.3 mm, an-sub, clus, deep yellow-brown

tannish well-pres sample

Analysis 32

Sample Ar-Gi-Young gr #1A: granite (granite of Young)

texture: all gran, no modification of original texture and grain shape despite K-feldspathization of plagioclase (see below & text, p. 257), opaque oxide clots probably pseudo after bio or amph

mineralogy:

29.2 quartz: 1-2 mm, an, in 3-6 mm clus - app rxll from larger xlls

40.8 perthite: 3-8 mm, an, cs patch/vein per (0.6-0.8 micro), clear to mod clouded with hem dust, 5% rpl by musc & ser, plag lam like plag pseudo

28.4 plagioclase pseudomorphs: 3-6 mm, an-sub, no polysynthetic twinning or zoning, has xll domains or patchy twinning, $2V_{\alpha}\sim70°$(?), n < qtz, appears to be secondary K-feldspar, v str clouded with hem, 20-30% rpl by fn-cs ser flakes & occ musc book

1.2 opaque oxide: 0.1-0.5 mm, an-sub, equant & bladed, in clus up to 1 mm with ser, feld, & qtz

tr tourmaline(?): fn acicular spray agg, blue-green pleochroism

tr zircon: 0.1-0.2 mm sub prisms

str oxidixed red-brown specimen, mod weathered, easily broken

Abbreviations

textural terms and other:

abdt	abundant
acc	accessories
agg	aggregated, aggregated
all gran	allotriomorphic-granular
alt	altered, alteration
an	anhedral
aph	aphanitic
ass	associated
bipy	bipyramidal
clus	cluster, clustered
cs	coarse, coarse-grained
diss	disseminated
eu	euhedral
fn	fine, fine-grained
gdms	groundmass
hyp gran	hypidiomorphic-granular
incl	inclusion
lam	lamellae, lamination
migr	micrographic
med	medium, medium-grained
mod	moderate, moderately
occ	occasional
pheno	phenocryst
pleo	pleochroic, pleochroism
porph	porphyry, porphyritic
pres	preserved
pseudo	pseudomorph, pseudomorphic
rpl	replaced, replacement
rsbd	resorbed
rsp	respectively
rxll	recrystallized
sphe	spherulite, spherulitic
str	strong, strongly
sub	subhedral
tr	trace
wk	weak, weakly
xll	crystal

minerals:

alb	albite
amph	amphibole
apa	apatite
bio	biotite
cal	calcite
chl	chlorite
epi	epidote
fluor	fluorite
hem	hematite
ilm	ilmenite
leu	leucoxene
mgt	magnetite
micro	microcline
musc	muscovite
olig	oligoclase
opaq	opaque oxide
ortho	orthoclase
per	perthite
plag	plagioclase
px	pyroxene
qtz	quartz
ser	sericite
sph	sphene
zir	zircon

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