STRUCTURE AND PETROLOGY OF THE EASTERN PORTION
OF THE SILVER BELL MOUNTAINS, PIMA COUNTY,
ARIZONA

by

Barry N. Watson

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STATEMENT BY AUTHOR

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ABSTRACT

The Silver Bell Mountains of Pima County, Arizona, are within a structural block bounded on the north by the Ragged Mountain normal fault and on the south by the Silver Bell fault zone—both deep-seated, west-northwest-trending structural breaks. The eastern portion of the range contains rocks ranging in age from Precambrian to mid-Tertiary.

Just north of the Ragged Mountain fault, Precambrian granite and diabase are nonconformably overlain by younger Precambrian Apache Group conglomerate and quartzites. Paleozoic sediments occur north of the Silver Bell fault zone and within the zone of alteration and copper mineralization.

Fine clastic sediments of pre-Laramide but Mesozoic age present in adjacent areas are missing in the eastern Silver Bell Mountains. It is thought that these sediments were deposited in the district
but eroded during the beginning of the Laramide Revolution.

Coarse clastic conglomerates and metasediments of the Claflin Ranch Formation formed by rapid sedimentation associated with the Laramide igneous upheaval. These sediments occur in seemingly ambiguous structural relationships with several of the volcanic units. Their deposition evidently continued in one place or another throughout much of the early Laramide volcanic activity.

The earliest of the Laramide igneous units was a dacite porphyry which moved up along the Silver Bell fault zone and spread laterally to the northeast between Paleozoic and Mesozoic sediments as a large sill several thousands of feet thick. Dikes and small sills of the porphyry invaded overlying Claflin Ranch sediments. An explosive and possibly fluidized origin is suspected for the dacite porphyry.

The Silver Bell complex which followed consists of andesite and dacite porphyries in the forms of flows, intrusions, hot lahars, cold lahars, intrusion breccias, and autoclastic breccias. Shallow intrusions of granodiorite porphyry with subsequent andesite porphyry dikes may well be associated with the Silver Bell complex but are distinctly later.

The Mount Lord Ignimbrite reflects the final expression of Laramide extrusive activity and includes: (1) a major body of extrusive ignimbrite, (2) a capping unit of lithic vitric tuff, and (3) sill-like and
dikelike intrusive ignimbrites closely related to the major extrusive body.

There followed a period of dike intrusion, with porphyritic syenodiorite, syenodiorite porphyry, and monzonite porphyry emplaced in that order. These dikes, related to the intrusion of Laramide monzonite plutons along the Silver Bell fault zone, were injected along northeast- to east-northeast-trending tensional fractures.

Miocene-Oligocene volcanic activity is manifested in northwest- trending pyroxene and hornblende andesite dikes and quartz latite porphyry dikes and by the invasion of a plutonic body of latite porphyry along the Ragged Mountain fault.

The eastern portion of the Silver Bell Mountains is a layered sequence of sedimentary, subvolcanic, and extrusive rocks—albeit often intruded—striking generally northwest and dipping 20° to 40° to the northeast. The northeast tilt of the Silver Bell structural block may be due in part to doming caused by the invading monzonite, subsidence following the eruption of the ignimbrites, or a combination of these hypothesized events.

Three directions of fracturing are evident: (1) the west-northwest trend, including the deep-seated structural breaks, and the fractures which controlled the emplacement of mid-Tertiary dikes; (2) the east-northeast direction of tensional breaks which controlled emplacement
of dikes related to the monzonite intrusions; and (3) north-northeast-trending normal faults.

Three periods of mineralization are evident: (1) an early, minor lead-copper mineralization apparently associated with the granodiorite porphyry, (2) the major period of copper mineralization controlled by the northeast fracture system, and (3) a final period of minor lead-silver(?)-copper mineralization evidenced as epithermal veins in north-northeast-trending fractures and faults.
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CHAPTER I
INTRODUCTION

The Problem

The Paleozoic and younger Precambrian stratigraphic sections of southern Arizona have received considerable attention from field and laboratory geologists. Not so favored, however, have been those areas in which are exposed Cretaceous and early to middle Tertiary volcanics and clastic sediments.

Many of these areas of Cretaceous-Tertiary rocks are structurally highly complex, and the origins of various of the rock units are in question. Because of a general lack of knowledge concerning volcanic processes and a lack of economic incentive, study of these areas has often been by-passed in favor of the less complex and better understood older rock sections.

In more recent years, however, two major factors have stimulated inquiry into these localities of Cretaceous-Tertiary volcanics and sediments. First, it has been realized that much of Arizona's copper was emplaced in Late Cretaceous-early Tertiary (Laramide) times, and that sizable economic deposits occur in Cretaceous-early Tertiary rocks. Examples of copper deposition in rocks of this age are found in the Pima mining district near Tucson, Arizona (e.g., the
Mission and Pima open-pit mines).

The second major factor results from the geographic position of the University of Arizona at Tucson in the heart of southern Arizona. Faculty and student members of the Geology Department have recently turned their studies more and more to the Cretaceous-Tertiary rocks for at least two reasons: (1) the accessibility of relatively unmapped areas of Cretaceous-Tertiary outcrops to university students for graduate theses, and (2) a heightening of worldwide interest in volcanic rocks and their associated sediments.

It is hoped that the investigation of the eastern portion of the Silver Bell Mountains with its Cretaceous-Tertiary volcanic and sedimentary complex will contribute significantly to knowledge of volcanic processes.

**Location and Accessibility**

The Silver Bell Mountains are situated in the north-central portion of Pima County, Arizona, 38 miles by highway west-northwest of Tucson. The mining community of Silver Bell, located on the south side of the range, can be reached either by the paved Avra Valley road—which joins Arizona Highway 84 and 93, 25 miles east of Silver Bell—or by a graded county road which intersects Arizona Highway 84 and 93 at Red Rock, approximately 25 miles north-northeast of Silver Bell.

Geologic mapping was conducted in all or part of secs. 22, 23,
Figure 1. Index map showing location of the Silver Bell Mountains.
The area mapped is skirted by graded county roads on the southwest, west, and north, a dirt pipeline road on the northeast, an unmaintained track road on the southeast, and the paved Avra Valley road on the south. Access into the mapped area by automobile is possible only with a 4-wheel drive vehicle. The American Smelting and Refining Co. maintains for service purposes one private dirt road into the area just north of Oxide pit and another private dirt track road from El Tiro pit to the top of Mount Mammoth. The deserted Belmont mine just north of Tin House well was reached by a sandy stream bed and remnants of an old jeep trail. The old Franco Riqueza claims on the northwest end of Ragged Top Mountain are accessible from the north by an infrequently used track road. A rugged powerline road through the Claflin Ranch bisects the mapped area from east to west between Ragged Top and Silver Bell Peak, but it can be used only by permission of the ranch owners.

Field and Laboratory Studies

The fieldwork was conducted between October 1962 and April 1963. Several trips to Silver Bell in the summer of 1963 served to check mapping. The mapping itself was done on enlarged aerial photographs 18" x 18" in size and of an approximate 1:6,500 scale. The
original 9" x 9" photographs (approximately 1:13,000) and a pocket stero­
eoscope were also carried in the field in order to determine accurate
location.

Because of a rather low flight altitude and the sharp relief of
the Silver Bell Mountains, the enlarged aerial photographs used for
mapping displayed considerable parallactic distortion. This distortion
made difficult compilation of the final map which was constructed in the
following manner: (1) The U. S. Geological Survey 7-1/2-minute quad­
rangle sheets "Tucson Mountains 2 NW" and "Silver Bell 1 NE"—each
containing a part of the area mapped—were spliced together and the
pertinent area enlarged three times to a 1:8,000 scale; (2) a number of
prominent points picked on the enlarged composite topographic sheet
were found and marked on the air photographs used for mapping—each
point marked on at least two overlapping photographs; (3) acetate over­
lay tracings were made from each of the large photographs, including
geology, reference points, and important drainage; (4) these overlay
sheets were pieced together by placing the reference points at approx­
imately correct distances and with correct angular relationships with
respect to one another; and (5) a composite overlay was made, "aver­
aging in" distortions, and this overlay reduced to the 1:8,000 scale of
the enlarged topographic sheet. To prevent cluttering of the geologic
map, no contour lines are placed upon the final map (although a few
elevations are given); however, a copy of the 1:8,000 scale topographic
map showing the mapped area is included in the map pocket for comparison purposes.

Two-hundred and twenty-four thin sections were made of the Silver Bell rocks and were individually studied. Petrographic study was quite sufficient for the purpose of rock correlations and allowed categorical classification of the various units. It was hoped that the U.S. Geological Survey’s method of rapid silica analysis (Shapiro and Brannock, 1962, p. 21-22 and 24) could be mastered in order to give additional information for the proper naming of the various fine-grained porphyry rocks from Silver Bell. However, 2-1/2 weeks of work in the geochemical laboratory showed that working conditions and equipment and/or knowledge of the technique were incapable of giving results with sufficient accuracy to be of any help.

Acknowledgments

The American Smelting and Refining Co. provided financial assistance, aerial photographs, a 4-wheel drive vehicle, room and board at Silver Bell during periods of geologic mapping, and access to all company land in the ore zone. ASARCO geologists Kenyon Richard and Harold Courtright made most of these arrangements, acquainted me with the geologic setting, and accompanied me into the field on several occasions. Needless to say, I am very grateful to ASARCO and to Messrs. Richard and Courtright.
Appreciation is due also to Silver Bell pit geologist Fred Graybeal for accomplishing numerous small tasks for me during and after mapping and for a number of valuable discussions on the geology of the ore zone. Mr. and Mrs. Steven Claflin allowed me access to all their land and very kindly offered the use of a guest cabin while I was mapping on their property over the Easter holidays.

My dissertation advisor Dr. Willard C. Lacy initially introduced me to the problem and to Messrs. Richard and Courtright. Dr. Lacy, who was in the field with me on several occasions, offered technical advice and was present with encouragement when it was needed most. Also indispensable was Dr. Robert L. DuBois who spent many hours with me discussing petrographic criteria and interpretations for numerous thin sections. Dr. Evans B. Mayo and Dr. Spencer R. Titley offered their time during various phases of the work for helpful discussions and technical advice, and Richard Mauger of the University of Arizona Geochronology Laboratory ran valuable age determinations on several of the Silver Bell rocks.

Finally, something that goes far beyond thanks is due my most ardent supporter and helper, my wife Jan.

Previous Work

Very little has been written directly concerning the volcanic
and sedimentary units of the Silver Bell Mountains which lie north and northeast of the ore zone. The ore zone itself, which arcs around the southern and southwestern flanks of the mountain range, has been studied in some detail, and various of the workers who have performed these studies have made occasional reference to the adjoining volcanic-sedimentary complex.

W. G. Barney in 1904 seems to be the first person to mention the geology of the Silver Bell Mountains. He wrote (1904, p. 755) of a "well-defined volcanic core" and stated that the mountains were "made up of tilted and altered sedimentaries with eruptive intrusions."

In 1912 C. A. Stewart wrote extensively on the geology and ore deposits of the Silver Bell mining district. He discussed the dacite porphyry which covers a large area just northeast of the ore zone and described some minor lead-silver mineralization found within it. In 1913 Stewart published an article on magmatic differentiation at Silver Bell.

The next significant paper on the area was a 1941 compilative report on the geology and ore deposits by H. M. Kingsbury, L. P. Entwistle, and Harrison Schmitt. These men included a discussion of the geologic setting of the ore zone and categorized the aforementioned dacite porphyry and some of the dikes found within it. The written thoughts of Schmitt in the introduction to this report are of interest. He felt that alternate hypotheses of the dynamics of structure at Silver Bell were more necessary than in the average mining district. "This is due
in part to the complex nature of the igneous geology and to the scarcity of regional information on this part of Arizona (Schmitt).

In 1951 Paul F. Kerr studied alteration features at Silver Bell. His discussion, like that of Kingsbury, Entwistle, and Schmitt, included the dacite porphyry and some of the dikes within it.

Thomas Mitcham has mapped structural features in the Silver Bell area, reporting privately to the American Smelting and Refining Co. In a brief article (1955, p. 300) he states that the "Silver Bell area is one of complex tectonic structure, and time and spatial relationships are by no means apparent."

Messrs. Harold Courtright and Kenyon Richard have been instrumental in recent years in calling attention to the volcanic-sedimentary complex. Brief discussions of various of these rock units in the Silver Bell Mountains proper are given by Richard and Courtright in 1954, Courtright in 1958, Richard and Courtright in 1960, and Richard and Courtright in an unpublished manuscript.

Some of the findings and concepts of these various field workers will be brought out in subsequent chapters.
CHAPTER II
GEOLOGIC SETTING

The Silver Bell Mountains are located in the eastern portion of the Sonoran Desert province—a region with many "Basin and Range" characteristics. Ranges in this region run north to northwest with basins between. The basins are broad alluvial outwash plains and pediment slopes and make up approximately 70 percent of the total area.

The mining community of Silver Bell is at an elevation of 2,628 feet. Total relief in the area mapped during this investigation is on the order of 1,820 feet. The highest point is Silver Bell Peak at 4,261 feet and the lowest approximately 2,440 feet near the Claflin Ranch buildings. Streams are intermittent, and drainage is radially out from the range.

Much of the geology of the country immediately surrounding the Silver Bell Mountains is imperfectly known. The Waterman Mountains a couple of miles southward and the ore zone on the southern and southwestern flanks of the Silver Bell range have been most closely studied.

The central and eastern portions of the Waterman Mountains were mapped by N. E. McClymonds (1957) and the northwestern portion by A. W. Ruff (1951). In the central and eastern portions of this range,
a probable Precambrian granite underlies 4,400+ feet of Paleozoic limestones, quartzites, siltstones, and shales. On the northeast these Paleozoic sediments are in fault contact with over 1,600 feet of clastic sediments which resemble the Cretaceous Amole Arkose of the Tucson Mountains described by Brown (1939, p. 715-718). McClymonds hypothesized that Laramide compressive stresses from the southwest uplifted the Waterman range and thrust wedges of Paleozoic strata through the overlying Cretaceous(?) sediments. Faulting is intense. Relatively older faults of compressive origin trend N. 45° W. and dip southwestward. Relatively younger faults of tensional origin trend N. 60°-70° E. and N. 85° W.

Ruff described several igneous intrusives. His oldest rock is a Precambrian alaskite intruded by the Precambrian granite. Rhyolite and porphyritic granite dikes cut the Cretaceous(?) sediments, and dacite in the form of dikes and irregular bodies intrudes the "Waterman Alaskite." Mineralization at the Indiana-Arizona mine is of the vein replacement type and occurs in east-northeast-trending faults and fractures.

The ore zone or "zone of alteration" at Silver Bell is comprehensively described by Richard and Courtright (1954), and a brief resume of their work is considered necessary here. This zone, trending west-northwest through most of its length, is thought to represent the position of a line of deep-seated structural weakness that existed in pre-Laramide times. Laramide intrusive activity obliterated this line or
"major structure," but the shapes and positions of the igneous bodies found here indicate that the major structure did exert a control on their emplacement.

The first igneous activity along the major structure was the intrusion of an elongate stock of alaskite whose northeast side conforms rather closely to the major structure. The Cretaceous(?) sediments described by McClymonds and Ruff are found in questionable contact with alaskite to the southwest. (Mr. Courtright and the author recently found the alaskite intruding Cretaceous(?) sediments of the Amole type not far southwest of the El Tiro pit.)

The next event was the intrusion of dacite porphyry into Paleozoic sediments to the northeast of the major structure. The porphyry was confined sharply on the southwest by the alaskite along the major structure.

Following an interval of erosion and subsequent volcanic activity, a series of small monzonite plutons and contemporaneous dikes were emplaced. The plutons are elongate parallel to the major structure line, while the dikes, although distributed along this line, trend across it with an average east-northeast strike. Next, systems of close-spaced parallel fractures with this same east-northeast strike developed along the line of major structure. Subsequent alteration and sulfide mineralization were controlled in detail by the cross-trending fractures.
Figure A
Aerial view of the Silver Bell district. Looking to the southeast, El Tiro pit is seen in the foreground and Oxide pit in the background. Silver Bell Peak is to the left of Oxide pit.

Figure B
View west from the northern flank of Mount Mammoth. El Tiro pit is on the far left and Union Hill, scarred by past mining activity, is to the right. The outcrop in the foreground is part of a large quartz latite porphyry dike intruding dacite porphyry in this vicinity.
Post-sulfide andesite dikes represent the last intrusive activity in the zone of alteration. These dikes parallel the major structure rather than occupy the tensional cross fractures—a fact which emphasizes the persisting and deep-seated nature of the major structure.

West of the Silver Bell range proper are the smaller West Silver Bell Mountains. Several hundred feet of Paleozoic limy and quartzitic sediments crop out in the southwestern portion of these mountains, and the section may be in part duplicated by imbricate thrusting from a southwestern source. Overlying the Paleozoic sediments with a nearly conformable but probably not depositional contact is roughly 5,000 feet of Cretaceous (?) Amole-type sediments (Craig Clarke, personal communication). These latter sediments strike north-northwest and dip with varying degree to the northeast.

To the northeast in the West Silver Bell Mountains, the Amole-type sediments give way to coarser clastic debris. Above an angular unconformity coarse sediments with interbedded tuffs strike west-northwest, dipping north to northeast. In the northeastern portion of this small range, a complex of coarse clastic sediments, tuffs, ignimbrites, and interspersed andesitic porphyry flows and/or intrusives are found. Overlying these unmapped and visibly highly complex Laramide rocks are Tertiary rhyolitic and then andesitic flow materials.

Both the Silver Bell and West Silver Bell ranges are bordered on the north by the major west-northwest-trending Ragged Mountain
normal fault (Mitcham, 1955, p. 300) which dips steeply south. North of this fault is Precambrian granite terrane that has been penetrated by Tertiary andesitic and Quaternary basaltic activity. Northeast of Wolcott Peak and the Silver Bell range, about 200 feet of younger Precambrian Apache Group sediments overlies the granite. One outcrop of Precambrian Pinal Schist is reported from this area (Harold Courtright, personal communication).

East of the Silver Bell Mountains and in the direction of the Avra Valley, a pediment surface exposes frequent outcrops of Cretaceous and Tertiary sediments and volcanics. Six miles east of the community of Silver Bell, an andesite flow overlying a conglomerate containing mineralized fragments has been geochemically age-dated at 27.9 ± 1.7 million years (Damon, et al., 1962, sec. A-III, p. 10).
CHAPTER III
PRECAMBRIAN AND PALEOZOIC ROCKS

Although the Silver Bell Mountains are composed predominantly of post-Paleozoic volcanics, intrusives, and sediments, Precambrian intrusives and sediments as well as Paleozoic sediments were included in the field investigation. The Precambrian rocks are found on the northeast edge of the mapped area, while Paleozoic sediments lie in and immediately to the northeast of the zone of alteration.

Precambrian Granite

A coarse-grained, often porphyritic granite is found extensively to the north of the Ragged Mountain fault. Megascopically, large and numerous quartz grains—frequently .25 inch in diameter—are set among pinkish crystals of feldspar and clumps and books of biotite. In many places orthoclase porphyroblasts up to an inch in length are common.

Near Ragged Top, which represents an elongate latitic pluton that has welled up along the Ragged Mountain fault, the granite is flooded with iron oxides after magnetite and pyrite, and it is invaded by several resistant quartz veins. In a few places the granite is so iron stained
that all that can be seen in hand specimen are quartz grains and a few biotite flakes set in a homogeneous red matrix. Sometimes the biotite is altogether absent.

Two thin sections from different localities show that this granite has a coarse hypidiomorphic-granular texture and consists of 25 percent quartz, 37 percent orthoclase, 20 percent oligoclase (with possibly some albite), and 10 percent biotite, with minor amounts of chlorite, epidote, oxidizing magnetite, apatite, and zircon. (If these percentages are indicative of the entire mass, this "granite" might more properly be called quartz monzonite.) The plagioclase is euhedral and well sericitized, while the biotite occurs as well-shaped laths and euhedral crystals. Both these minerals appear to be relict to an igneous rock. Extensive feldspathization has given rise to the large porphyroblasts of orthoclase which are mildly argillized. Near Ragged Top hydrothermal alteration is indicated by moderate argillization of orthoclase and heavy sericitization of plagioclase, the presence of sericite veinlets, and possibly by the breakdown of biotite to chlorite plus white opaque.

This granite, which is probably equivalent to—or the same as—the one underlying the Paleozoic section in the Waterman Mountains, was the oldest rock mapped during the field studies. Metasediments of the younger Precambrian Apache Group lie nonconformably on it. Pinal Schist, the most common Precambrian basement rock in southern Arizona, has been found in outcrop only once in the area, as previously
mentioned. However, the many fragments (ranging up to boulder size) of Pinal-like schist seen in the Cretaceous sediments just south of Ragged Top indicate the presence of that schist at the surface and in the near vicinity during the Laramide igneous activity.

**Precambrian Diabase**

A well-altered Precambrian diabase irregularly intrudes the granite on the northern slopes of Ragged Top. In one outcrop a good subophitic texture is visible, but elsewhere this rock is nondescript because of extensive alteration.

Petrographic study of the apparent diabase shows that 60 percent of the rock consists of small altered laths of plagioclase, probably andesine-labradorite, of an average length of .75 mm. About 20 percent of the rock is pyroxene in an advanced state of breakdown to biotite, chlorite, and relatively fine muscovite. The plagioclase and the altered pyroxene occur in subophitic intergrowth. A high amount of quartz (ca. 8 percent) occurring mostly as interstitial blebs is thought to be due in part to silica release with the breakdown of pyroxene and minor calcification of plagioclase and may be due in part to quartz introduction. Quartz, calcite, and a secondary iron oxide fill several veinlets. Titaniferous magnetite is present at about 8 percent.

A thin section of one of the highly altered outcrops thought to be diabase disclosed a much coarser grained material, with laths of
zoned and twinned andesine (An$_{37-40}$) up to 6 mm in length arranged roughly to give what could be considered a subophitic texture. Calcite, quartz, and feldspar vein the rock and occur as local concentrations which may indicate mobilization. A considerable amount of fine reddish iron oxide (probably hematite) is present. The distinct textural differences between these two specimens of supposed diabase, especially with respect to the grain size of involved constituents, suggest two periods of diabase injection.

The diabase is found only in granite. It is in contact with the overlying Apache Group sediments in at least one locality (outside of the area mapped) but never enters them. It is therefore considered most probably to be intermediate in age between the granite and the younger Precambrian sediments.

**Younger Precambrian Apache Group**

On the southern edge of the granite terrane and lying conformably on the granite, there is a sequence of metasediments thought to belong to the younger Precambrian Apache Group. These metasediments are cut off sharply on the south by the Ragged Top intrusion and the Ragged Mountain fault. They are first encountered as a wedge of bedded quartzites only 25 feet thick high on the northern flank of Ragged Top, all but removed by the intrusion of latite and subsequent erosion. This wedge of Apache material increases in volume to the east where a
thickness of at least 200 feet is found outside the area of investigation. The metasediments are warped, no doubt in part due to the nearby intrusion, but retain a quite consistent east-west strike and dip of 35° S. Immediately overlying the granite and directly below the summit of Ragged Top is a 2- to 3-foot thickness of a rounded pebble conglomerate. The pebbles are generally cherty, with bright-red and orange hues common. The matrix is white and very siliceous. Above the conglomerate there is approximately 50 feet of interbedded white quartzite and tan silty quartzite. Over this lies a 20-foot thickness of bedded silty metasediments which is colored a deep red by hematite. A couple of prospect pits show nothing but hematite. A final 30 feet of granular light-tan quartzite is seen before the contact of the latite intrusive is encountered. As the sequence thickens to the east, an increasing number of thin to moderately thick bedded quartzites are detected, including a few interbedded layers of metamorphosed silty sediments.

These metasediments where found farther to the east have been mapped as Apache Group on the 1960 Composite Geologic Map of Arizona Counties. The basal bright pebble conglomerate could well be the Barnes Conglomerate accompanied by an overlying sequence of the Dripping Spring Quartzite. It is of interest to note that both Schmitt (Kingsbury, et al., 1941, p. 14) and McClymonds (1957, Introduction) found that sediments of the Apache Group were missing in the Waterman Mountains.
There, a quartzite thought to be Cambrian Bolsa conformably overlies the basement granite.

**Paleozoic Sediments**

The Paleozoic section, which is widely exposed along the north-eastern side of the zone of alteration, is intricately faulted and intruded by alaskite, dacite porphyry, and monzonite. Kingsbury and Entwistle (1941, p. 15-20) have conducted the most detailed study of these sediments to date, and their breakdown of units with thickness estimates is presented briefly below:

- Permian quartzites, limestones, shales ...... 550 ft. approx.
- Pennsylvanian Naco (Horquilla Limestone) .... 220 ft. max.
- Mississippian Escabrosa Limestone .......... 275 ft. max.
- Devonian Martin Formation .................. 300 ft. max.
- Cambrian Abrigo Formation ................... 430 ft. max.
- Cambrian Bolsa Quartzite ................... thickness unknown (faulting)

Total ................1,775± ft.

The Paleozoic sediments mapped in this investigation were not studied in any great detail for other than structural information. These sediments, mostly altered limestones with some interbedded quartzites and shales, strike generally from east-west to N. 30° W. and dip from 25° to 40° north and northeast. They closely match Kingsbury and Entwistle's description of undifferentiated Permian sediments, and their stratigraphic position as the uppermost Paleozoic sediments east of the
El Tiro area would seem also to indicate a Permian age for most of them. Unfortunately, metamorphism has destroyed any obvious fossil evidence.

Most of those Paleozoic sediments shown on the geologic map (pl. 1) have been either recrystallized to marble or converted to hornfels, and in places near igneous intrusives metasomatic activity has produced tactites. These tactites are much more apparent in the vicinity of dikes related to the monzonite plutons than they are near intruding dacite porphyry.

The dacite porphyry, however, has had some metasomatizing effect on adjacent limy sediments. A thin section cut from an altered limy sediment some 2,500 feet southeast of the old Union mine and just a few feet from the dacite porphyry contact showed that diopside, grossularite garnet, and calcite made up over 90 percent of the rock. Minor hedenbergite, quartz, and oxidized magnetite or hematite comprised the remainder. This hornfelsic assemblage falls within Turner and Verhoogen's ACF diagram for the hornblende hornfels facies rocks with excess silica and potash (1960, p. 512-514). As this rock was originally a limy sediment, the suggestion is strong that silica has been introduced from the dacite porphyry.

A separate study of the various mineral assemblages found in the altered Paleozoic sediments with emphasis on causative factors and chemical changes might prove to be highly interesting and beneficial.
CHAPTER IV
CRETACEOUS AND TERTIARY IGNEOUS ROCKS

Igneous rocks of the Cretaceous and Tertiary periods make up, by far, the greatest bulk of the eastern portion of the Silver Bell Mountains. Because they are the principal interest of this study, and because a knowledge of them is essential to the understanding of the post-Jurassic sedimentation history of the range, they will be discussed prior to the description of the sediments belonging to the same two geologic periods. The term "Claflin Ranch Formation" or "sediments" will crop up frequently during this igneous rock discussion, however, and it is considered advisable to give here a brief account of these sediments which will, in turn, be dealt with more thoroughly in the following chapter.

Sediments of the Cretaceous Claflin Ranch Formation are found in various localities throughout the range—their most continuous sequence of approximately 1,800 feet existing about 1.5 miles west of the Claflin Ranch buildings. The sediments from the various locations strike in the northwest quadrant anywhere from east-west to north-south, dipping north, northeast, or east at 25°-45°.

The rocks of this formation include massive to thin-bedded
conglomerates, silty and arkosic sandstones, dacitic-appearing metasediments, and possibly a few large landslide blocks. The metasediments have been created by igneous intrusion into existing sediments. All of the sediments and metasediments of the Claflin Ranch Formation have aspects of an origin related to volcanic activity.

As will be seen, the Claflin Ranch Formation is not restricted to any one portion of the period of Laramide volcanic and intrusive activity. Its relations with the various igneous units to be described are manifold.

Alaskite

The alaskite does not crop out anywhere within the area mapped. However, because it is an important rock in the ore zone and since some information pertaining to its age and relationships with other units was found in the investigation, it is discussed here.

Kingsbury, et al. (1941, p. 26) describe the alaskite as coarsely granitoid with quartz phenocrysts 0.1 to 0.2 inch in diameter. Biotite ranges from scarce to 1 percent and is plentiful on one lead claim. These authors (p. 31) list the alaskite as containing 45 percent orthoclase, 5 percent perthite, 5 percent albite, and 40 percent quartz, with no accessories. Kerr (1951, p. 462) agrees with the mineral identification but seems to indicate the presence of a larger albite percentage.

Similarity between certain portions of the alaskite and the
Precambrian granite found in the Waterman Mountains as well as north of the Ragged Mountain fault caused earlier writers to consider the alaskite most likely Precambrian in age. It is now known that the alaskite in the El Tiro area intrudes both Paleozoic limestone and, as recently discovered by Mr. Courtright and the author, Cretaceous (?) Amole-type sediments. The possibility that both Precambrian and Cretaceous granitoid rocks of similar appearance exist in the region west of the El Tiro pit will remain until that region is finally mapped in some detail.

Pebble, cobble, and boulder-size xenoliths of granitoid rock resembling at the same time both the granite and the alaskite were found in all of the various types of dikes related to the ore zone monzonite, in middle Tertiary quartz latite dikes, in one flow related to the Silver Bell complex, and in the Mount Lord Ignimbrite.

A thin section was made from one of the many such cobbles found in a pebble dike which parallels and then joins a dike of quartz monzonite porphyry. Quartz composed 24 percent of the cobble, orthoclase 40 percent, albite 35 percent, and muscovite after biotite 1 percent. Orthoclase and albite occur as large, equally well-altered, subhedral plates, while the quartz is, for the most part, interstitial. This description would seem to fit the alaskite rather than the granite, particularly with respect to the minor amount of biotite present and the lack of twinned oligoclase. Most of the chunks of granitoid rock found in the
various units contained only a minor amount of biotite, and thus the opinion that they are alaskite is favored. There is a very close similarity to portions of the altered granite near Ragged Top, however, and it may be that fragments of both granite and alaskite have been picked up by the various Cretaceous and Tertiary igneous bodies.

Fragments of a porphyritic igneous rock are found within areas of the dacite porphyry, notably on the eastern slopes of Mount Mammoth. These fragments, up to 4 inches in diameter, superficially resemble a porphyritic phase of the alaskite seen west of the El Tiro pit. No specimens of this phase of the alaskite were collected at the time, and therefore no real correlation can be made with the porphyry fragments in the dacite. Even if this correlation were to be made, it would be merely supporting evidence for the established fact that dacite is younger than alaskite, as previously mentioned (see Richard and Courtright, 1954, p. 1095 and map on p. 1098; Richard and Courtright, 1955, p. 300).

Evidence will be advanced in the discussion of the age of the Mount Lord Ignimbrite to show that the alaskite is older than 70 million years. The author agrees with Richard and Courtright (1954, p. 1095) that intrusion of alaskite marks the beginning of the Laramide igneous activity.

**Dacite Porphyry**

The dacite porphyry, in the past also called the "dacite" or
"quartz porphyry," is exposed over large areas in the southern, southwestern, and western portions of the Silver Bell range. It is apparently underlain by the Paleozoic sediments on the southwest and overlain variously by Claflin Ranch sediments, breccias, and flows of the Silver Bell complex, and ignimbrites to the north and northwest.

Field Description

The most distinctive feature of the dacite porphyry is the presence of numerous small, rounded to subrounded quartz "eyes" (.04 to .15 inch in diameter) which, along with small white feldspar phenocrysts and a few biotite flakes, are set in an aphanitic matrix. This matrix is very dark in some locations and light gray in others, but all shades between the two extremes can be found.

Also distinctive of much of the dacite porphyry are rather numerous fragments of foreign material frequently up to an inch in diameter. Pieces of quartzite, a bedded or banded shaly material, a homogeneous silty material, and limestone are common to all areas of xenolith-bearing dacite porphyry. Fragments of a porphyritic igneous rock are most numerous on the east slope of Mount Mammoth, in a draw just north of the Oxide pit, and in a dacite porphyry sill in Paleozoic limestone and quartzite in the southeast corner of section 3. \(^1/\) Schist

\(^1/\) There are no duplicate section numbers in the area mapped. Thus, in indicating specific locations with the aid of section numbers, township and range designations will be omitted.
fragments are often found in the uppermost 10 to 100 feet of the porphyry, and a few such fragments were seen in the dacite within Paleozoic sediments and also in the dacite near the main contact with these sediments.

There are places in the central portion of the dacite porphyry where xenoliths are megascopically few to absent. Thin-section study of specimens taken from these areas usually shows a few small fragments, recognizable only with the microscope.

Flow structure within the upper portion of this unit is suggested by a platy layering which is brought out by weathering. This layering consistently strikes west-northwest to northwest and dips between 20° and 35° to the north-northeast and northeast. A visible foliation, as shown by alignment of fragments and phenocrysts, was seen in three places near the base of the main body of dacite porphyry. Strikes and dips were similar to those given for the platy layering.

These indications of a consistent flow structure allow thickness computations of the main body of dacite porphyry. North of the Oxide pit and east of the prominent north-south-trending Mount Mammoth fault, the porphyry is approximately 1,940 feet thick. West of this fault, the porphyry thickens to almost 3,400 feet. On the geologic map (pl. 1) it would appear that the northeastward-dipping dacite west of the Mount Mammoth fault is on the order of three times thicker than that to the east. This exaggeration is due to the north-dipping slope of the
country west of the fault as opposed to the reverse situation east of the fault.

Jointing within the dacite porphyry shows a lack of consistent orientation, as mentioned by Richard and Courtright (1954, p. 1096). Locally, strong sets of joints cannot be traced over 50 feet, and often less than that. Orientation of many fine fractures and small faults in the dacite is also random.

Near the base of the dacite porphyry, the jointing often is closely spaced (approximately an inch between breaks) and is best described as a vertical-to-oblique sheeting. In several localities this sheeting has been strongly folded, evincing post-jointing mechanical deformation.

Petrographic Description

Twenty-seven thin sections were made from the different areas of dacite porphyry outcrop in order to study the various aspects of this unusual rock. The features considered pertinent were found to be present in most of the thin sections.

A representative dacite porphyry specimen taken in the Oxide pit area about 220 feet above the contact with Paleozoic sediments was found to contain the following minerals and percentages: quartz, 20 percent; plagioclase (An30), 15 percent; chlorite and muscovite after biotite, 10 percent; sanidine (also orthoclase?), 3 percent; intergrown magnetite
and ilmenite, 2 percent; calcite, 3 percent; apatite, 1 percent; xenoliths, 20 percent; minor epidote, zircon, sphene and leucocene; and cryptocrystalline matrix, 24 percent.

The quartz ranges from rounded to fragmental and from minute in size to 2 mm along the greatest dimension. It is frequently embayed. Tiny quartz or devitrified glass shards are recognizable in the matrix. Oligoclase-andesine is generally subhedral to euhedral, twinned, moderately sericitized, and up to 2.5 mm in length with an average length of 0.5 mm. Chlorite and muscovite are after biotite, and these grains, up to 2 mm in length, are generally bent and sometimes broken. The sanidine occurs as subhedral phenocrysts up to 1.5 mm in length, contains considerable sericite around the borders and in cleavage cracks, and is mildly argillized. Opaques are mostly euhedral.

Calcite is found as stringers in the cleavages of the altered biotites and as small patches in the matrix. The apatite is a fairly common accessory in the form of prismatic crystals up to 0.5 mm in length, while sphene and its alteration product leucocene are very minor. Epidote occurs as small growths within plagioclase crystals. (Epidote is also commonly found as stringers in the lower and central portions of the dacite porphyry but is rarely seen in the upper portions.) The xenoliths make up one-fifth of the slide and include an alaskite or granite fragment 5 mm across, a quartzite fragment, drawnout pieces of a volcanic rock that look like they might be the dacite porphyry itself,
PLATE 6

Figure A
Photomicrograph of dacite porphyry, showing fragmental quartz, embayed quartz phenocrysts, sericitized plagioclase crystals, chloritized biotite, and magnetite. A phenocryst of slightly argillized sanidine (s) and a fragment of quartzite (q) are also present. Matrix is partially devitrified glass. (X 15.)

Figure B
Same field as figure A (crossed nicols). Flow structure is seen in the outcrop from which this thin section was cut, but the foliation is not obvious under the microscope. (X 15.)
and numerous fragments of a recrystallized silty material. The matrix is still somewhat glassy and rather dark, but devitrification has proceeded to the point where much of the matrix is cryptocrystalline.

This slide was stained with cobaltinitrite solution to determine potash feldspar content, and the sanidine along with much of the matrix reacted positively. This same reaction indicating a rather high potash feldspar content was encountered in the staining of several of the other dacite porphyry thin sections. If an appreciable number of sanidine and/or orthoclase phenocrysts are found in an aphanitic porphyry rock, it might well be expected that the generally late crystallizing potash feldspar will be rather plentiful in the groundmass. Thus, this dacite porphyry gives every indication of being more truly a quartz latite porphyry, a point which will assume more significance later on in the discussion of its origin. The rock has been called a dacite for so long, however, that it is felt that changing its designation now would achieve nothing more than confusion.

Alteration observed in the slide of the representative dacite porphyry could well be both deuteric and hydrothermal. The biotite alteration and a certain amount of the feldspar alteration may be deuteric. A sericite veinlet and occasionally heavy sericitization of feldspar phenocrysts are suggestive of hydrothermal activity. Calcite and epidote might be considered deuteric to the dacite; however, these two minerals are found in increasing quantities when any of the dikes that
cut the dacite porphyry are approached, particularly if limestone is nearby or many limestone fragments are found in the rock. Thus, a hydrothermal alteration may have contributed in the formation of these two constituents.

A few additional minerals have been identified from elsewhere in the dacite porphyry. Orthoclase in place of, or in addition to, sanidine is common. Minor hornblende was seen in a thin section taken from an outcrop near Union Hill, and rutile and monazite are present on rare occasions. Pyrite is sometimes found in the vicinity of dikes related to the ore zone monzonite. In a few localities relatively fresh biotite still exists. Finally, Kerr (1951, p. 460) reports that the clay mineral produced by alteration of the dacite porphyry is hydromica, as confirmed by refractive indices, X-ray diffraction patterns, and thermal analysis curves.

Two separate factors were found to be responsible for the variation in color of the matrix. First, it was noted that in some localities containing "dark" dacite porphyry, a considerable amount of finely divided opaque material was scattered throughout the matrix, lending a dark tone to the rock. This effect was encountered in "dark" porphyry both on Mount Mammoth and north of Union Hill. A probably more important reason for tone variation, however, concerns the amount of devitrification and recrystallization that has taken place within the matrix. The more glassy and less devitrified the matrix, the darker it
appears. This is brought out in one thin section cut from a dacite porphyry sill in limestone northwest of the Oxide pit. Here, large fragments of light-colored dacite porphyry with a devitrified and recrystallized matrix are engulfed in "dark" dacite porphyry whose matrix is barely devitrified and exhibits flow lines about the fragments.

A few of the other thin sections also seem to contain fragments of dacite porphyry within dacite porphyry. The numerous porphyry fragments on the eastern slope of Mount Mammoth, mentioned earlier as possibly being fragments from a porphyritic phase of the alaskite, could also conceivably belong to an earlier phase of dacite porphyry which was later broken and carried upward in the main entry of the porphyry.

About two-thirds of the thin sections of dacite porphyry evinced flow structure, as shown by alinement of quartz phenocrysts, shards and biotite phenocrysts, swirl structures in the matrix, and occasional drawnout lenses of fine-grained material which might once have been molten glass. Metamorphism tends to accentuate this flow structure when it is present in the matrix. Carefully oriented hand specimens were not taken from the field, but it is almost certain that this flow structure corresponds to the flow indicated in places at the base of the dacite porphyry body and to the orientation of the platy layering in the upper portions of the porphyry.

One further feature of the dacite porphyry suggested by
PLATE 7

Figure A
Photomicrograph of dacite porphyry, showing flow structure. Biotite laths, slivers of quartz, and a stretched lapillus indicate flow east-west across the photograph. (X 15.)

Figure B
Same field as figure A (crossed nicols). Polarized light accentuates the extended lapillus and the moderate amount of quartz present. (X 15.)
petrographic study is of note. The ratio of phenocrysts to matrix appears to decrease upward in the unit. In the basal portions of the porphyry, phenocrysts constitute 65 to 75 percent of the rock (not including xenoliths). Near the top of the porphyry, most thin sections show about 50 percent of the rock to be matrix. The quantity of xenoliths contained, however, does not reflect such a pattern. Fragments are most numerous near the base of the dacite porphyry, least numerous in the central portions, and of considerable number in the upper portions.

In summary, the most significant petrographic features of the dacite porphyry are the presence of rounded and embayed quartz phenocrysts, large fragments of quartz, distinct shards in the matrix, sanidine and/or orthoclase phenocrysts indicating a less basic rock than previously thought, numerous xenoliths of varied types of material, and a generally consistent flow structure.

Structural Relationships

Stewart (1912, p. 260) stated that the dacite porphyry could be taken for a surface flow, since it forms the higher hills to the north­east of the El Tiro area and because it contains a large amount of devitrifying glassy groundmass. The lack of gas cavities and the fact it sends dikes into the Paleozoic limestones brought him to regard it, however, as "an intrusive which came in considerably later than the alaskite series, after erosion had removed much of the overlying rock,
so that it solidified under smaller pressure."

Richard and Courtright (1954, p. 1095; 1960, p. 1), although recognizing the intrusive nature of the dacite porphyry with regard to the Paleozoic sediments, have felt that the porphyry surfaced and was later eroded to contribute material to the Cretaceous Claflin Ranch Formation. They based their collective opinion in good part on the presence of dacitic-appearing pebbles and cobbles in the overlying Claflin Ranch conglomerates. These authors have recently modified their opinion in the light of new evidence turned up in this investigation and now refer to the dacite porphyry as an intrusion of a large stock or sill (unpublished manuscript).

There is no doubt that the dacite porphyry invades the broken Paleozoic sediments in the form of sills and dikes. What is of particular interest here is the intrusive nature of the contact between the sediments and the overlying main body of porphyry. Reference to the geologic map (pl. 1) shows the dacite porphyry to deeply embay the limy sediments and to intrude them forceably along parallel bedding planes east of Union Hill and north of Oxide pit. In a few places intact beds of limestone up to 15 feet long are engulfed in porphyry 5 to 10 feet out from the contact.

In the northwestern portion of the area mapped and also to the east of Silver Bell Peak, the dacite porphyry is overlain by sediments of the Claflin Ranch Formation. Only one sharp contact between these
two units has been found—apparently conformable and exposed over a distance of 25 feet in the southwest corner of section 27. Elsewhere the contact is gradational over a distance of 6 or more feet.

Four locations along the dacite porphyry-Claflin Ranch Formation contact present evidence for an intrusive nature to the porphyry: (1) on a steep slope east of Silver Bell Peak, the underlying dacite porphyry apparently crosscuts the overlying sediments at a low angle (the contact is gradational); (2) west-northwest of Silver Bell Peak in the center of section 2, a wedge of dacitic material pokes upward into a narrow band of metasediments left along the dacite porphyry-Silver Bell complex contact; (3) farther northwest along this same contact, an isolated block of sediment has apparently foundered in the top of the dacite porphyry; and (4) in the northwest corner of section 35 between two small north-trending faults, a single exposure in the vicinity of a dacite porphyry-Claflin Ranch Formation contact shows porphyry invading cracks and surrounding pebbles in a conglomerate.

The best evidence for the intrusive nature of the porphyry, however, is in the form of irregular crosscutting dikes of dacitic porphyry material found at several points within the Claflin Ranch sediments north of the main body of porphyry. Petrographic study of two of these dikes shows them to be nearly identical with the dacite porphyry. The metasediments near the dacite porphyry contact may contain more dacite dikes and sills than have been mapped, but these dikes and
PLATE 8

Figure A
Small pebble dike in dacite porphyry half a mile north of Oxide pit. The included pebbles are all of dacite porphyry, but the dike is probably related to the emplacement of the ore zone monzonite.

Figure B
Dacite porphyry (light) intrusive into massive Claflin Ranch conglomerate (dark) in the southwest corner of section 26. Scale is shown by the wrist-watch.
sills often are so similar in outward appearance to some of the meta-
sediments that tracing them in the field would be contingent upon petro-
graphic identification. The similarity between dacite porphyry and
metasediments will be dealt with further in the discussion of the Claflin
Ranch Formation, as will the appearance of dacitic fragments in this
formation. It is felt, nevertheless, that the present investigation has
proven conclusively that the dacite porphyry did intrude some of the
overlying Claflin Ranch sediments.

The relationship between dacite porphyry and the andesitic
breccias, flows, and intrusions of the Silver Bell complex is not quite
so clear. This contact, where it is occasionally exposed, presents
nothing conclusive in the way of evidence. The dacite porphyry, howev-
er, is never found invading the massive andesitic breccia, which often
immediately or closely overlies it. This evidence, albeit negative,
coupled with the presence of a few almost certain dacite porphyry cob-
bles seen near the base of the massive andesitic breccia and just above
dacite porphyry are felt sufficient to justify the opinion that the Silver
Bell complex was a later occurrence.

Two field situations were found that might have argued for a
later advent of the dacite porphyry. First, the massive andesitic brecc-
cia was found both directly overlying and indirectly below the porphyry
on the steep southern slopes of Silver Bell Peak. This is thought to be
explained by normal faulting of Cretaceous age which dropped the
breccia several hundred feet on the south. The Mount Lord Ignimbrite
is found roughly 500 feet lower on the south side of this old fault (just
outside the mapped area) than it is on top of the Silver Bell range, lend­
ing additional evidence for faulting. This fault was intruded by dikes
during the later emplacement of monzonite and consequently has been
obliterated except for the trace of these dikes.

The second situation involves dacite porphyry exposed among
Silver Bell complex flows and dikes in the southwest-central portion of
section 35. The porphyry here is thought to be a topographic high left
after erosion, against which lapped andesitic flows and into which were
intruded dikes associated with the complex.

With the exception of the alaskite, the dacite porphyry is un­
questionably older than the remaining Cretaceous and Tertiary igneous
rocks. It is intruded by the Cretaceous granodiorite porphyry southeast
of Silver Bell Peak. In the south-central portion of section 2, it is cut
by a feeder dike directly associated with the Cretaceous Mount Lord
Ignimbrite. It is cut also by all the dike types related to the ore zone
monzonite and by later quartz latite and andesite Tertiary dikes.

Summary

The combined evidence presents a picture of the dacite porphyry
as a large sill or laccolithic body, with a source in the zone of altera­
tion. The main body of this sill was generally floored by Paleozoic
sediments and roofed by sediments of the Claflin Ranch Formation and is earlier in age than the Silver Bell complex. The porphyry may have surfaced somewhere in the district, possibly northwest of the area mapped. Discussion of the method of emplacement of the porphyry is left until later.

Reasons for considering the dacite porphyry, like the alaskite, to be of an age greater than 70 million years will be presented in the discussion of the age of the Mount Lord Ignimbrite.

Silver Bell Complex

The term "Silver Bell Formation" (Courtright, 1958, p. 7; Richard and Courtright, 1960, p. 1) has been used in the past to refer to massive andesitic breccias of hypothesized laharic origin found overlying either Claflin Ranch sediments or dacite porphyry. During the present field investigation, the stratigraphic interval occupied by the "Silver Bell Formation" was found to contain not only the massive breccias but also andesitic to dacitic flows, andesitic intrusions, and various andesitic to dacitic breccias of origins other than laharic. These various materials are herein referred to collectively as the "Silver Bell complex."
Massive Breccias

Field description

The massive breccias of the Silver Bell complex are prominently exposed high on the southern and southwestern flanks of the range and to the northwest in the western portion of section 27. Also belonging to the massive breccias are the breccia outliers perched on Claflin Ranch sediments in the southwestern corner of section 26.

This unit is composed mainly of subrounded fragments of dark-gray to purplish-hued andesite and dacite porphyry enclosed in a gritty reddish-purple matrix. The fragments are usually less than 6 inches in diameter, but large fragments several feet in diameter are occasionally present. The breccias are heterolithologic in the sense that two or three texturally different types of porphyry are commonly present at any one point, although one type is usually predominant. Fragments of anything other than andesite or dacite porphyry are scarce.

Stratification was seen in only two places, both in the massive breccias of section 27. One contact between breccia flows, striking north-northwest and dipping 50° east-northeast, is probably disturbed by nearby faulting. The other breccia flow contact with northwest strike and northeast dip of 20° conforms closely to bedding in sediments that both underlie and overlie this thickness of massive breccias. On the steep southwest flank of the range, the massive breccias also strike
northwest and dip $20^\circ$ to $35^\circ$ northeast, as shown by the basal contact with dacite porphyry or Claflin Ranch sediments and by the upper contact with ignimbrite. The only indication of stratification in these breccias is the presence of a few narrow, sill-like andesite and dacite porphyry intrusions which are roughly parallel to the basal and upper contacts and which may mark bedding planes between breccia flow units.

A wide variation is seen in the apparent thicknesses of these massive breccias. In section 27 to the northwest a thickness of 600 feet is estimated. On the southwest flank of the range, the breccias are but a few feet thick in the west-central portion of section 2, but they thicken to approximately 1,100 feet less than a mile to the southeast. Evidence is strong that these breccias flowed out over a locally rugged, erosion-carved topography.

**Petrographic description**

A study of 9 thin sections from different portions of the breccias showed a considerable variance in the textures of the porphyry fragments. As an example of this variance, two common textures—not necessarily extremes—are briefly described here: (1) phenocrysts up to 2.5 mm long and constituting 60 percent of the rock are set in a reddish-brown, partly glassy, partly devitrified matrix which includes a few tiny, nearly equidimensional grains of feldspar; and (2) a hyalopilitic texture is evident—large phenocrysts frequently over 3 mm and
### Table: Petrographic Summary of Silver Bell Rocks

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Winchysite (percent)</th>
<th>Groundmass (percent)</th>
<th>Quartz (percent)</th>
<th>Pyroxene (percent)</th>
<th>Hornblende (percent)</th>
<th>Magnetite (percent)</th>
<th>Felspar (percent)</th>
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<th>Minerals</th>
<th>Occurrence</th>
<th>Alteration</th>
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<td>Deuterite, Hydrothermal</td>
<td>Clay, sericite, calcite, chloride, potassium, iron.</td>
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</tbody>
</table>

**Note:** Percentages represent the proportion of each mineral or component in the rock. Alteration minerals indicate the types of minerals that form due to alteration processes within the rock.
up to 5 mm in length make up 40 percent of the rock, while small, slender laths of plagioclase and blebs of quartz set in a devitrifying dark-gray glass constitute the remainder.

Quartz varies from 2 percent to 10 percent in the fragments examined. Subangular to angular phenocrysts up to 3 mm in diameter are deeply embayed. Quartz blebs in the matrix are evidently a sign of hydrothermal alteration.

All determinable feldspar is plagioclase, frequently twinned, and sometimes cross twinned when both albite and pericline types are present. The anorthite content varies from An$_{28}$ to An$_{38}$ with sodic andesine prevalent. Large plagioclase phenocrysts are euhedral to subhedral, moderately sericitized, and mildly argillized and calcitized. Smaller laths and equidimensional crystals of feldspar in the matrix are similarly altered.

The ferromagnesian minerals, representing 8 to 15 percent of the volume, have been totally or partially replaced by iron oxides and now exist as opaque masses of magnetite, hematite, and limonite. This phenomenon, which indicates hydrothermal alteration, is common to all fragments within the massive breccias. Remnant crystal forms indicate that biotite was slightly more prevalent than hornblende. Recognizable biotite remains in a few slides, but the books are altering to chlorite plus white opaques. Only one thin section exhibited andesitic fragments containing pyroxene.
Figure A
Photomicrograph of Silver Bell complex laharic massive breccia. The brecciated rock is a quartz-bearing andesite porphyry sprinkled with magnetite. Alignment of fragmental material in the fine matrix indicates flow. (X 10.)

Figure B
Photomicrograph of an essentially monolithic laharic massive breccia. Quartz is absent from this brecciated andesite porphyry. Like all the massive breccias, the altered and oxidized breccia matrix—originally a mud—is a fiery red under reflected light due to its high iron content. (X 10.)
Five to seven percent of oxidized magnetite is present in all 9 slides. Anywhere from 3 percent to 20 percent calcite is found as patches in the matrix, as fillings in biotite cleavages, and as an alteration product of plagioclase. Very minor epidote, apatite, and zircon were also recognized.

The matrix surrounding the andesite and dacite porphyry fragments is composed of chunks of quartz, tiny pieces of the different porphyries, and a fine-grained, reddish, iron-rich "mud"—a rock flour now well indurated—which shows lines of flowage. The amount of quartz in the breccia matrix is usually greater than that amount seen in the fragments. The reason for this phenomenon is not known, unless it is the resistance of quartz to comminution during flowage.

The heterolithologic nature of the massive breccias coupled with the uniform iron-oxide alteration throughout fragments and breccia matrix are strongly suggestive of a hot laharic origin.

Flows and Intrusions

Field description

Andesitic to dacitic porphyry flows and andesite porphyry intrusions of the Silver Bell complex are very common north of Silver Bell Peak, where, with breccias of the complex, they floor almost the entire valley between the main range and Ragged Top. These flows and
intrusions are found also within and on top of the massive breccias. All these igneous rocks are porphyritic with light-gray, dark-gray, bluish-gray, green, red (iron-staining), and purple colors of matrices.

Relations between Silver Bell flows, intrusions, and breccias in the valley between the main range and Ragged Top are complex. At least seven different rock variations were seen in a quarter-mile length of the draw south of the Claflin Ranch guest cabin near Mesquiti well. Such complexity over an area greater than 2 square miles defied detailing in the time allotted for this investigation. About the only mapping distinction made in this portion of the Silver Bell complex is that between areas of breccia and areas of unbrecciated flow and intrusive rocks combined.

The distinction between extrusive units and subintrusive units is difficult. The only certain intrusive was apparent from visibly steep-dipping to vertical flow structures found in two elliptical to elongate plugs or dikes north of Mesquiti well.

**Petrographic description**

Six of the more prominent unbrecciated flows and intrusives found in the complex are petrographically described in the Appendix. Table 1 (p. 45) presents a brief petrographic summary of five of these Silver Bell complex rocks, all of which are porphyries in the andesite to dacite compositional range.
Other Breccias

Breccias of origins other than laharic are also found in the Silver Bell complex.

The greenish-gray dacite porphyry described in the Appendix and summarized in table 1 as Silver Bell porphyry No. 1 is found in one place as a breccia. This breccia, however, does not exhibit the pervasive iron replacement of fragments and iron-rich flourlike matrix material seen in the massive breccias. The fragments have been torn apart, and in several places small pieces of the porphyry can be matched up with the larger fragments from which they have become separated. The "matrix" (that space between larger fragments) is cluttered with broken particles of porphyry. A fine-grained matrix material filling minute spaces between particles is a finely comminuted porphyry flour which lacks iron staining.

Any evidence of alteration during brecciation is absent, although post-brecciation hydrothermal alteration has taken place. All evidence points to autoclastic brecciation of a surface flow by differential movement in the plastic state.

Several breccias near the Claflin Ranch appear to have an origin by autoclastic brecciation, and certain other very local breccias in that area have evidently formed with the intrusion of nearby porphyries. These latter intrusion breccias show a post-consolidation breaking or
crushing with subsequent invasion of iron-rich fluids along some of the cracks.

A rather unusual form of brecciation was seen in a thin section taken from a 20-foot thickness of reddish-purple andesite porphyry within Mount Lord Ignimbrite. (The origins of these intraignimbritic andesite porphyries and breccias will be discussed later.) This porphyry has undergone some autoclastic brecciation, and then has been intruded along the breaks by some of the parent porphyry magma. The original porphyry and the intruding porphyry are identical except for a slight difference in the matrices, which allows the petrographic distinction between the two materials. The matrix of the original porphyry is a slightly devitrified brown glass, while the intruding porphyry matrix is cryptocrystalline and a lighter brown in color.

Finally, it should be noted that heterolithologic laharian breccias other than the reddish-purple massive breccias already discussed are found in the Claflin Ranch area. Some of these breccias are distinctively different in outward appearance from the massive breccias and may more closely fit the conception of cold lahars. 1/

1/ Fisher (1960, p. 978) distinguishes eruption-type (hot) lahars from regular (cold) lahars. These latter, Fisher states, "may form by mudflow carrying, dispersing, and depositing coarse- and fine-grained volcanic particles and/or admixed non-volcanic material."
Figure A
Andesite breccia in wash south of Mesquiti well.
This breccia is nearly monolithologic, and a hot laharc origin is indicated.

Figure B
The same breccia as that of figure A but in a more indurated outcrop.
PLATE 11

Figure A
Photomicrograph of a Silver Bell complex quartz andesite porphyry. Rounded quartz grains, sericitized andesine plagioclase phenocrysts, and chloritized crystals of hornblende and biotite are set in a microcrystalline matrix. The altered ferromagnesian minerals all possess iron oxide (hematite and magnetite) rims. (X 10.)

Figure B
Photomicrograph of an autobrecciated Silver Bell complex dacite porphyry. The amount of fine-grained breccia matrix is small, and no evidence of post-brecciation flow is seen.
Structural Relationships

As previously indicated, the massive breccias have flowed out upon an eroded terrane somewhat deeply carved, at least locally, into sediments of the Claflin Ranch Formation and dacite porphyry. Claflin Ranch sediments, however, also overlie the massive breccias in the center of section 27. Thus it is seen that sediments referred to the Claflin Ranch Formation were deposited both before and after the laharic avalanches of andesitic porphyry. Indeed, as will be later discussed, a gradation between laharic breccia and volcanic sediment is indicated by field evidence.

The Mount Lord Ignimbrite overlies the complex and intrudes it in the form of sills and dikes. Reference to the geologic map (pl. 1) will show that there is a discontinuous band of ignimbrite high on the southwest flank of the range separated from the main body of ignimbrite by 20 to 75 feet of breccias and flows of the Silver Bell complex. In the discussion of the Mount Lord Ignimbrite, conclusive evidence will be presented to show that these lower ignimbrites are intrusive into the complex in a sill-like form.

Proof of andesitic activity concurrent with the emplacement of the ignimbrites is seen in the far southwest corner of section 35. A flow of reddish-brown andesite porphyry breccia much like the massive breccias of the Silver Bell complex is found interbedded with ignimbrites
a couple of hundred feet up in the Mount Lord sequence. On the geologic map (pl. 1) these breccias are shown as belonging to the Silver Bell complex in order to call attention to their existence. Although similar to the massive breccias, more properly they are a part of the Mount Lord Ignimbrite sequence.

The granodiorite porphyry closely resembles a dacite porphyry from the complex a mile west of the Claflin Ranch buildings. It also resembles in hand specimen many of the fragments found in the massive breccias on the southern slopes of Silver Bell Peak. There is felt to be a fairly close time as well as spatial relationship between the complex and the granodiorite porphyry, but as the latter is everywhere seen to be post-complex and since it is a mappable unit of itself, it has been given an identity separate from the Silver Bell complex.

All of the various dikes related to the ore zone monzonite intrude the Silver Bell complex, as do the Tertiary quartz latite and andesite dikes.

The Silver Bell complex is thought to be approximately 70 million years old for reasons to be advanced in the discussion of the Mount Lord Ignimbrite.

**Granodiorite Porphyry and Associated Andesite Dikes**

The granodiorite porphyry might more properly be called a dacite porphyry. Petrographically the groundmass, which is about half
of the rock, is microcrystalline. This rock has been given a name implying a phaneritic texture so that it will not be constantly confused with the already described dacite porphyry northeast of the ore zone. The phaneritic implication is felt to be partly justified by the fact that the granodiorite porphyry as mapped is everywhere intrusive, that its largest area of outcrop has all the aspects of a near-surface stock, and that at times in the field it does appear to be a phaneritic rock.

A number of andesite dikes are spatially very closely associated with the granodiorite porphyry. They are all later than this porphyry, and therefore they are not included within the Silver Bell complex as defined in the preceding section. Megascopically and microscopically these andesite dikes differ considerably from the andesites of the Silver Bell complex.

It is thought that the rocks of the complex, the granodiorite porphyry, and the andesite dikes associated with the porphyry are all a part of the same period of igneous activity. Quite possibly the Mount Lord Ignimbrite should be included in this period also.

Granodiorite Porphyry

Field description

The granodiorite porphyry is found as three different plutonic bodies. In the field and under the microscope the rocks from these
three plutons are nearly identical, and as far as can be determined, they all have the same relationship with other units in the range. A granodiorite porphyry stock, whose exposure in the area mapped exceeds 1 square mile, exists to the west of Ragged Top. More of the porphyry is seen east of Wolcott Peak and southeast of Silver Bell Peak. The full exposure of these three plutonic bodies has not been mapped. Granodiorite porphyry also occurs as dikes in the proximity of the stock, in the area around Mesquiti well, and at places within the massive breccias on the southern and southwestern slopes of Silver Bell Peak.

In hand specimen the granodiorite porphyry exhibits subangular to rounded quartz phenocrysts (average diameter of .05 inch, maximum diameter of .2 inch), subhedral to euhedral pink and white feldspar phenocrysts (average diameter of .1 inch, maximum diameter of .3 inch), chloritized laths and books of biotite, and an occasional hornblende phenocryst set in a fine-grained gray groundmass. Oxidizing grains of magnetite are sometimes visible.

**Petrographic description**

The granodiorite porphyry from the stock west of Ragged Top consists of 50 percent phenocrysts and 50 percent microcrystalline quartzo-feldspathic groundmass. Averaging seven thin sections from this stock gives the following mineral percentages: quartz, 8 percent;
plagioclase (An$_{30}$), 20 percent; chlorite and epidote after ferromagnesian minerals, 15 percent; calcite, 4 percent; apatite, 1 percent; ilmenitic magnetite, 2 percent; minor zircon and leucocene; and matrix, 50 percent.

The quartz occurs in the matrix and as subrounded to rounded, slightly corroded phenocrysts up to 2.5 mm in diameter. Plagioclase content varies from An$_{27}$ to An$_{32}$ with an An$_{30}$ average. This oligoclase-andesine is found as euhedral to subhedral phenocrysts up to 3 mm in length, most of which have been well sericitized and argillized and replaced by calcite and some epidote. No orthoclase phenocrysts were found, although the groundmass appears to contain an appreciable amount of argillized potash feldspar. The ratio of biotite to hornblende seems to have been about 2:1, but both minerals are now completely altered to chlorite and epidote. Euhedral apatite and euhedral to subhedral magnetite are scattered evenly through the rock.

Rather extensive hydrothermal activity (or a pervasive deuteric stage) is suggested by the strong alteration of most plagioclase phenocrysts and all ferromagnesian minerals. A minor amount of copper and lead mineralization seems to have been associated with the emplacement of the granodiorite porphyry.

The porphyry to the east of Wolcott Peak is identical to that of the stock just described. The granodiorite porphyry southeast of Silver Bell Peak and the northeast-trending porphyry dikes near Mesquiti well
PLATE 12

Figure A
Photomicrograph of granodiorite porphyry from the near-surface stock west of Ragged Top. Somewhat rounded and embayed quartz grains, sericitized and argillized plagioclase (An$_{30}$) phenocrysts, and chloritized crystals of biotite and hornblende are set in a rather fine-grained hypidiomorphic-granular matrix. Secondary crystals of epidote are sprinkled throughout the slide. (X 10.)

Figure B
Photomicrograph of granodiorite porphyry from southeast of Silver Bell Peak (crossed nicols). The mineralogy is the same as in figure A. A considerable amount of epidote replaces plagioclase and ferromagnesian phenocrysts and the matrix. (X 10.)
contain only 4 to 5 percent quartz but otherwise are the same as the stock porphyry. A little sphene was found in one thin section from the porphyry southeast of Silver Bell Peak.

Structural relationships

The granodiorite porphyry stock intrudes Claflin Ranch sediments and the Silver Bell complex massive breccias, and its dikes cut dacite porphyry and Silver Bell complex porphyry to the south and southeast. The porphyry east of Wolcott Peak and the dikes near Mesquiti well slice the Silver Bell complex. The granodiorite porphyry invading the southeast flanks of Silver Bell Peak intrudes the dacite porphyry and the Silver Bell complex, but its upward extent is limited sharply by the base of the Mount Lord Ignimbrite. Neither the granodiorite porphyry nor the associated andesite dikes are found intruding ignimbrites anywhere within the area mapped.

Further evidence for a post-complex but pre-ignimbrite porphyry comes from Guillermo Barba (personal communication) who is mapping an adjoining area to the northwest. Barba, in mapping the western edge of the granodiorite porphyry stock, has seen good exposures showing the porphyry steeply cutting Silver Bell complex massive breccias but has not found the porphyry or its associated andesite dikes intruding the Mount Lord Ignimbrite which overlies the massive breccias in his area.
The granodiorite porphyry intrusion as exposed is thought to have been very near the ground surface. Inliers of Claflin Ranch sediment are found in the stock in two places, and a large patch of Claflin-like metasediments may be roofing the porphyry just west of the northwest end of Ragged Top. Likewise, a Silver Bell complex breccia overlying the porphyry high on the western flank of Ragged Top may represent a part of the stock roof. If such a large volume of granodiorite porphyry was so near the surface, the chances are certainly good that it reached the surface in one or more places.

Dikes related to the ore zone monzonite flood the granodiorite porphyry southeast of Silver Bell Peak and cut the andesite dikes associated with the porphyry south of the stock. The Tertiary quartz latite dikes and the Ragged Top latite porphyry both intrude the granodiorite porphyry.

Like the Silver Bell complex, the granodiorite porphyry is thought to be approximately 70 million years old.

Associated Andesite Dikes

Field description

Several porphyry dikes of andesitic composition are spatially associated with the granodiorite porphyry stock and are thought to be a late phase of the stock magma. Most of these dikes intrude the stock
porphyry. The dikes have various trends, but north-south and northeast trends are prevalent.

In hand specimen these dike rocks are dark gray to light gray and greenish gray in color. Three dikes which bear a close resemblance to the granodiorite porphyry that they intrude are half phenocrysts, half groundmass. The rest of the dikes have notably more groundmass, containing as few as 15 percent of phenocrysts.

Petrographic description

Those dikes bearing a close field resemblance to the granodiorite porphyry are petrographically like the material they intrude with the exception of their darker colors and lesser amounts of quartz. They contain only 2 to 3 percent quartz, which is more severely corroded than that of the granodiorite porphyry. One of these dikes has a fairly coarse matrix and is thus more truly a syenodiorite porphyry.

One of the dikes of lesser phenocryst quantity is briefly described here for comparison purposes: phenocrysts, 20 percent; groundmass, 80 percent (microcrystalline feldspar); phenocrysts consist of quartz, 3 percent (rounded to subangular, corroded, up to 1.5 mm in diameter); plagioclase, 7 percent (An?, euhedral to subhedral, up to 4 mm long, strongly altered to sericite, clay, and calcite); biotite and hornblende, 3 percent (completely altered to chlorite and calcite); ilmenitic magnetite and leucocene, 6 percent; and minor apatite.
Hydrothermal alteration is shown by highly altered phenocrysts and a quartz veinlet.

A fair amount of potash feldspar in the matrices of the various dikes is indicated by indices of refraction. Thus, these andesite porphyry dikes may be chemically close to latite in composition.

Structural relationships

The andesite porphyry dikes intrude granodiorite porphyry, Silver Bell complex, Claflin Ranch sediments, and dacite porphyry. They are in turn cut by dikes related to the ore zone monzonite.

Mount Lord Ignimbrite

According to Mr. Steven Claflin (personal communication), Silver Bell Peak was formerly known to residents of the area as Mount Lord. Thus the name "Mount Lord Ignimbrite" is given here to the pyroclastic flow breccia which caps the range and comprises the upper portion of the present-day Silver Bell Peak. This welded ignimbrite\(^1\) appears to be lithologically similar to, and stratigraphically a near time equivalent of, the Cat Mountain Rhyolite (ignimbrite) of the Tucson

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\(^1\) The term "ignimbrite" as used herein is felt to be more descriptive of origin than the term "welded tuff." These two terms are commonly used in the western United States for rocks of the same type. (See Fisher, 1960, p. 976-977.)
Mountains as described by Bikerman (1962) and Kinnison (1958).

The following description of the Mount Lord Ignimbrite is divided into three parts: First, the main body of extrusive ignimbrite; second, the capping unit of lithic vitric tuff; third, the sill- and dikelike intrusive ignimbrites related to the main body of the Mount Lord Ignimbrite.

**Ignimbrite**

**Field description**

The ignimbrite overlies the Silver Bell complex at the top of the range. It strikes generally northwest to north-northwest with an average northeasterly dip of 30°—as shown by the well-developed eutaxitic structure—but diverse orientations are common. Minor faulting is seen everywhere in these pyroclastics, but the diversity in the orientation of the ignimbrite is thought to be due mostly to the topographic relief of the terrane over which the flows were poured.

The average dip of 30° as shown by the ignimbrite foliation is certainly indicative of post-ignimbrite tectonic activity, since such pyroclastic material is thought to be unstable on slopes greater than 5° to 6° (Dolgoff, 1963, p. 878). In fact, later regional tilting is indicated not only by the Mount Lord Ignimbrite but also by the Paleozoic sediments, the Claflin Ranch sediments, the dacite porphyry, and the Silver
Bell complex.

The thickest continuous sequence of ignimbrite—between 750 and 800 feet—is encountered at Silver Bell Peak. This thickness decreases northeastward in the direction of dip. Unknown thicknesses of ignimbrite exist on a mountain just northwest of the mapped area and in the West Silver Bell Mountains. Pyroclastics also extend southeast of the mapped area to a point 4 miles east of Silver Bell, where, along the Avra Valley road, a small amount of ignimbrite showing only very weak flow structure is found. This outcrop may mark the outer limits of flow. As Enlows (1955, p. 1242) has pointed out, the farther the material travels, the less welding and less eutaxitic structure are seen because of cooling.

It is almost certain that the Mount Lord Ignimbrite has been emitted from a series of fissures with a general northwest-southeast arrangement. One probable point of emission in the Silver Bell Peak locality will be indicated shortly.

No detailed study of jointing was undertaken in the extensively faulted and fractured ignimbrite. Some joint measurements were made, and they indicate what is generally seen in the field—that no one specific set of joints is prominent in the ignimbrite. Most of the joints are perpendicular to the eutaxitic structure. Columns are developed in several places and are characteristically either rectangular or nearly square in shape. This is a feature typical of many of the ignimbrites of the western
United States (Ross and Smith, 1960, p. 29), and the joints are evidently tensional cooling phenomena. Lack of a consistent set of joints over any significant area eliminates the possibility of tectonic jointing caused by a regional couple, as suggested by Enlows (1955, p. 1237-1238) for the Chiricahua Welded Tuffs.

The ignimbrite is a very resistant cliff-forming rock that almost everywhere rings under the hammer. This consistent degree of induration is not very often seen in Tertiary ignimbrites (Ross and Smith, 1960; Enlows, 1955; Gilbert, 1938; etc.) or in the Laramide ignimbrites of south-central Arizona. Induration as a result of strong welding is thought to be caused by a high degree of heat during eruption and by a thick sequence which produces considerable compression. Petrographic study indicates that strong welding may not have produced the intense lithification seen in most of the Mount Lord Ignimbrite, but as will be shown it does bring to light factors that help account for this induration.

No attempt was made to map individual cooling units within the ignimbrite. Several such units are believed to exist, but the divisions are not obvious in the field or on aerial photographs. A more intimate study of the ignimbrite than was undertaken here would be necessary for the delimitation of these units.

Xenoliths are common, although not really abundant, in the Mount Lord Ignimbrite. Pebbles, cobbles, and boulders of various
andesite porphyries, alaskite and/or granite, dacite porphyry, quartzite, limestone, shale, siltstone, schist, and possibly granodiorite porphyry are visible in the field. Numerous tiny chips and pieces of foreign materials are seen under the microscope. Fragments of a purple andesite porphyry with lath-shaped plagioclase phenocrysts up to .75 inch long are found throughout the ignimbrite—including one boulder 6 feet in diameter. These andesite porphyry fragments are a diagnostic feature of the ignimbrite since no such porphyry, or fragments thereof, is found in the area mapped.

Of some interest are two small pebbles of altered rock containing malachite and cryscolla which were plucked from the base of the ignimbrite. These were the only mineralized fragments found in the pyroclastics, but nevertheless they hint of an early period of mineralization in the area.

The large number of xenoliths within these pyroclastics and the fact that many of them are over a foot in diameter distinguish the Mount Lord Ignimbrite from certain other ignimbrites seen in the field and described in the literature. The Chiricahua Welded Tuffs exposed in the Chiricahua National Monument contain very few fragments with respect to their great thickness. Likewise, Gilbert (1938, p. 1851) states that the Bishop Tuff in eastern California contains only sparse fragments of older rock.

The base of the Mount Lord Ignimbrite has a very coarse rubbly
zone of material up to 12 feet thick. This basal zone, which locally contains a plentiful number of broken xenoliths and extended pieces of a green chloritic material, seems to have been sheared by the overlying ignimbrite which moved or flowed in a plastic state. Such a sheared and rubbly base—although somewhat contrary to Enlows' statement (1955, p. 1243) that a brecciated base is generally lacking in welded tuffs—is consistent with certain petrographic data to be advanced shortly.

Above this basal zone, brownish-colored stretched pumice fragments and flattened lapilli and volcanic bombs give a prominent eutaxitic structure to the rock. The ignimbrite matrix is gray in color, and euhedral to subhedral pink and white feldspar crystals speckle the matrix as the drawn-out magmatic material. Quartz is always visible, as are flow lines which enclose crystals and xenoliths. A large number of incipient fractures are seen throughout much of this well-indurated ignimbrite.

The eutaxitic structure varies greatly in appearance. On the eastern side of the range in the east-central portion of section 1, a locality was seen where the ignimbrite appeared to be banded. Inclusions were stretched out to a thickness of but .25 inch and with a length of over a foot. Elsewhere the eutaxitic structure is apparent only to close scrutiny. Two zones containing a minute but definite flow structure are overlain in turn by zones of plentiful xenoliths—a change which very
possibly may mark a transition between cooling units.

Occasionally, lenses of altered andesite porphyry or reddish-purple andesite breccia are found well above the base of the ignimbrite, indicating andesitic activity concurrent with the ignimbrite emplacement.

Petrographic description

A representative specimen for thin-section study was taken from outcrop about 30 feet above the base of the Mount Lord sequence. Typical of much of the ignimbrite, it shows a vitric-crystal tuff of probable quartz latite composition. The crystals, which constitute 25 percent of the slide, include quartz (15 percent, subrounded to angular with many slivers, up to 2 mm, embayed and corroded), sanidine (4 percent, subhedral, .3 to 1.5 mm, 2V ≈ 0° to 5°, strongly argillized), plagioclase (sodic andesine) (5 percent, subhedral, up to 2.2 mm, sometimes twinned, considerable clay and fine sericite), and magnetite (1 percent, euhedral to anhedral, up to .5 mm, oxidizing). Several of the sanidine crystals are well argillized about the borders, but the primary material remains in the center. Good optic figures of sanidine were obtained from such crystals.

Xenolithic material constitutes 10 percent of the slide, including fragments of a quartz-rich sediment, several different andesites, and several igneous porphyries. In two of these porphyry xenoliths, biotite has been epidotized.
A number of brown flattened pumice fragments up to 6 mm in length have devitrified, with feldspar spherulites forming in large quantities. Blebs of quartz and feldspar and euhedral to subhedral untwinned plagioclase crystals are found in these devitrified pumice fragments. Vapor-phase crystallization probably accounts for the late plagioclase crystals and may be in part responsible for the quartz and feldspar blebs. No tridymite could be conclusively identified.

A considerably large amount of incipiently devitrified brown glass is left in the slide, and flattened and nearly planar devitrified glass shards are visible. Unfortunately, alteration of the matrix masks the degree of welding of these shards. A rigorous orientation of shards is apparent, however, which could well be explained by differential flowage of the pyroclastic material. Some shards are considerably drawn out, flexing around small crystals and xenoliths. The indications of plastic-state differential flowage in this specimen would be consistent with the sheared base of the ignimbrite and with the extreme stretching of included lapilli and volcanic bombs seen in various portions of this pyroclastic sequence.

Hydrothermal alteration in the exemplary thin section is shown by the aforementioned strong feldspar alteration and the presence of quartz, sericite, and calcite in veinlets. A strange phenomenon—maybe also a result of hydrothermal activity—is the presence of stylolitic veinlets or cracks filled with sericite. Golding and Conolly (1962) report
Figure A
Photomicrograph of Mount Lord Ignimbrite. Present are several crystals of sanidine (argillized around the edges), fragmental and embayed quartz, and an andesitic xenolith (dark). Both the devitrified matrix and the recrystallized drawn-out lapilli evince flowage. (X 15.)

Figure B
Photomicrograph of Mount Lord Ignimbrite, showing stylolitic sericite veinlets. These "stylolites," along with a quartz veinlet, probably indicate post-solidification hydrothermal activity. The two large fragments in the upper portion of the photograph are xenoliths. (X 15.)
the only other known occurrence of volcanic sericite stylolites from a New South Wales rhyolitic lava. These authors, feeling that a highly siliceous felsitic rock is favored for the formation of such stylolites, suggest a number of factors which might be responsible for their origin (p. 536-537).

Each thin section of welded tuff that was made for study shows a vitric or vitric-crystal tuff with 10 to 30 percent of crystals and a probable quartz latite composition. Each slide shows evidence of a period of vapor-phase crystallization, and each displays hydrothermal alteration with introduction and mobilization of quartz. Quartz veinlets are most commonly parallel the eutaxitic structure and frequently occupy the axes of stretched pumice fragments. Sanidine is the most common potash feldspar, but orthoclase was found in several slides. Any biotite primary to the ignimbrite has been destroyed by alteration.

The high ratio of now devitrified, glassy magmatic material to crystals and xenoliths suggests a relatively high temperature of final emplacement for the ignimbrite. Assuming that a high percentage of molten material would contain a great quantity of heat, the instigation of an extensive crystallization from a vapor phase might be suspected. In the same light, a great quantity of heat insulated by its position within a thick pyroclastic sequence would lead to a relatively slow rate of cooling—a factor which could be important in accounting for differential plastic flow.
The extensive induration of the Mount Lord Ignimbrite is probably due to a combination of a considerable thickness of flows (causing compression and giving heat insulation), a fairly high heat of emplacement, differential flowage after emplacement, an extensive vapor-phase crystallization, and a pervasive hydrothermal alteration. The hydrothermal alteration, probably associated with the period of copper mineralization in the ore zone, may have been the most important single factor.

Lithic Vitric Tuff

An 80-foot thickness of resistant tuff lacking eutaxitic structure caps the ignimbrite in the north-central portion of section 1. This tuff stands out in the field from the underlying gray ignimbrite because of its light-pinkish-gray color. Small xenolithic fragments, tiny euhedral to subhedral crystals of feldspar, and scattered quartz phenocrysts dot a tuffaceous matrix which occasionally exhibits flow lines.

Under the microscope this material is seen to be a lithic vitric tuff of the type frequently found atop an ignimbrite sequence (Enlows, 1955, p. 1243; Gilbert, 1938, p. 1840). Eighty percent of the rock is composed of generally crescentic shards with diverse orientations. Fragments and crystals of quartz, sanidine, sodic andesine plagioclase, and magnetite are never over 2 mm in size. Xenoliths of andesite and latite porphyry up to 3.5 mm in diameter constitute 5 percent of the
PLATE 14

Figure A
Photomicrograph of Mount Lord Ignimbrite, showing a portion of a large pumice fragment (dark). Embayed and broken quartz phenocrysts and several extended lapilli are set in a partially devitrified matrix. (X 15.)

Figure B
Photomicrograph of the lithic vitric tuff which caps the Mount Lord sequence. An argillized sanidine phenocryst and several pieces of quartz are scattered through a matrix composed of devitrifying crescentic-shaped shards. (X 60.)
slide. Enough quartz is present to place this tuff in the quartz latite compositional range.

It would appear that this lithic vitric tuff represents the termination of pyroclastic activity in the Silver Bell Peak vicinity. Erosion has removed any overlying material; however, the vitroclastic texture indicates a lack of overburden during, and for a while after, the emplacement of the tuff. The thickness of ignimbrite, including the tuff, on the eastern side of the range is 400 to 450 feet. Projection of the lithic vitric tuff horizon to Silver Bell Peak a mile southwestward suggests a maximum total thickness of 950 to 1,000 feet at that point. The decrease in thickness of the Mount Lord sequence by half over a distance of a mile is indicative of proximity to a vent.

Intrusive Ignimbrites

Field description

Intrusive ignimbrites directly related to the Mount Lord welded ignimbrite manifest themselves southwest of Silver Bell Peak in several dikes and sills.

Dikelike zones of light-gray ignimbrite exhibiting vertical eutaxitic structure were seen in two places within the main body of gray ignimbrite. Both are in the northwest portion of section 2. No visual difference other than shade of color is seen to exist between these
possible feeder dikes and the flows, and no petrographic distinction between the two could be made.

A sill of ignimbrite with a 200-foot maximum thickness is found several hundred feet below the extrusive welded ignimbrite along the dacite porphyry-Silver Bell complex contact northeast of Oxide pit. Well-developed eutaxitic structure in the central and upper portions of this sill indicates some turbulence, but a northwest strike and northeast dip of about 40° comprise an average orientation.

Xenoliths are common within the sill, and the big phenocryst andesite porphyry fragments so characteristic of the welded ignimbrite are present. One zone midway in the sill contains numerous rounded cobbles and boulders of quartzite up to a foot in diameter.

The upper contact of the sill with well-indurated massive breccia of the Silver Bell complex is fairly sharp. The basal contact with dacite porphyry is, in one place, a 30-foot zone of intrusion breccia, whose character as a breccia is indistinct in the field but recognizable under the microscope.

This sill tapers in both directions. In a deep gully 1,100 feet to the east of the maximum thickness, the sill is but a few-inch thickness of tuffaceous material along the massive breccia-dacite porphyry contact. Some 2,000 feet northwest of the maximum thickness, the sill narrows to 25 feet, then gradually rolls over to become a cross-cutting, steeply dipping, 20-foot thick dike. This feeder dike, which shows flow
structure but contains none of the stretched pumice fragments seen in the sill, is soon lost under cover. On the geologic map (pl. 1), this ignimbrite dike appears to cut a quartz latite dike. In the field, however, close study of the dike intersection shows that the quartz latite was later, welled up along both sides of the resistant ignimbrite dike, yet could penetrate it only with a few wispy fingers of magma.

A 200-foot long segment of ignimbrite dike striking in a northeasterly direction is encountered not far west of the aforementioned feeder dike.

More sill-like intrusive ignimbrite is found in the Silver Bell complex not far below the main body of extrusive ignimbrite. Segments of a 1- to 50-foot thick sill are seen in many places along the southwestern flank of the range, separated from the main Mount Lord sequence by from 20 to 150 feet of Silver Bell complex breccias and flows. Small stretched pumice fragments within these sill segments give a measurable eutaxitic structure, which shows the intrusive ignimbrites to be striking and dipping in close conformity with the basal contact of the overlying main ignimbrite body.

Five pieces of evidence are advanced here in support of the assertion that these "sill" segments are intrusive:

1. The sill segment northeast of Mount Mammoth seems to follow no single bedding horizon, as it turns quite sharply from the Silver Bell complex-dacite porphyry contact into massive breccias.
(It is conceivable, however, that this could be explained by the topography existing at the time of emplacement.)

2. One tapering end of a sill segment was seen to give way to homogeneous breccia. In fact, several of these segments are overlain and underlain by identical breccias.

3. Atop one 40-foot thickness of sill-like ignimbrite in the center of section 2, a hunk of andesite breccia a foot in diameter was found partially immersed in ignimbrite, with ignimbrite welling up around its edges.

4. A thin section cut from the upper contact of the sill-like ignimbrite with andesite breccia in the center of section 2 indicates that the ignimbrite is later. Good flow structure in the ignimbrite parallels the somewhat wavy but abrupt contact, and a couple of small andesite porphyry xenoliths are seen in the ignimbrite below the contact.

5. A number of narrow, interconnecting dikes and sills of ignimbrite are found in the Silver Bell complex between the large sill-like segment and the main body of ignimbrite in the center of section 2.

A substitute hypothesis of alternation of breccia and ignimbrite flows could explain some of these observations, but the compilation of evidence is felt to exclude all possibilities other than that of an intrusive ignimbrite.

A number of xenoliths and also evidence of shearing are found at the base of most of these sill-like segments of ignimbrite. The basal
PLATE 15

Figure A
View northeast from Silver Bell Peak toward the Claflin Ranch buildings (arrow). Wolcott Peak—part of the Ragged Top Latite Porphyry intrusion—and adjacent low hills composed of younger Precambrian Apache Group sediments stand behind the ranch. The ridge in the foreground is made up entirely of Mount Lord Ignimbrite.

Figure B
A chunk of Silver Bell complex massive breccia embedded in the top of an ignimbrite sill. Dip of the massive breccia-ignimbrite contact is to the lower right. This outcrop is in the center of section 2.
contact where exposed is usually somewhat jagged, and no evidence of soil formation is seen.

The Silver Bell Peak locality was evidently a point of emission of ignimbrite material, as shown by the feeder dikes northeast of Oxide pit. Proximity to a point of emission meant that the flows were stacked higher here than elsewhere and had more of an opportunity to become indurated. Toward the end of the pyroclastic activity, one or more of the feeder vents evidently became choked with solidifying ignimbrite, forcing the magmatic and gas-charged material still rising to spread out beneath the thick ignimbrite sequence already deposited. In most places these surging intrusive ignimbrites took advantage of flow contacts existing within the Silver Bell complex.

**Petrographic description**

The petrography of the sill ignimbrite just northeast of Oxide pit is like that of the previously described extrusive welded ignimbrite with but a few exceptions. Closer to the zone of alteration it is more highly altered, with epidote partially replacing drawn-out lapilli and volcanic bombs. Devitrification has progressed to a greater extent, and a slightly larger percentage of crystals is present.

Higher up, the sill ignimbrite closely underlying the main ignimbrite sequence appears no different under the microscope than the extrusive material.
Figure A
Photomicrograph from a sill of intrusive Mount Lord Ignimbrite (crossed nicols). Extended lapilli, now recrystallized, show the direction of flow (north-south in this photograph). The rock is fairly well altered. (X 8.)

Figure B
Photomicrograph from a sill of Mount Lord Ignimbrite (crossed nicols). Drawn-out lapilli give the rock a strong eutaxitic structure. Note the spherulite (arrow). (X 8.)
A thin section of the northeast-trending feeder dike northeast of Oxide pit shows the same mineral composition and xenolith content seen in the extrusive ignimbrite but lacks flow structure. The matrix is devitrified, and epidote has partially replaced many of the crystals and xenoliths.

The narrow ignimbrite dikes and sills in the center of section 2 lack the extended pumice fragments of the extrusive ignimbrite but contain a definite microscopic flow structure. Mineral composition, xenolith content, and percent of crystals are the same as that described for the overlying Mount Lord Ignimbrite.

Structural Relationships

The Mount Lord Ignimbrite intrudes the dacite porphyry and the Silver Bell complex, terminates the upward extent of granodiorite porphyry southeast of Silver Bell Peak, and most certainly post-dates the Claflin Ranch sediments found in the area of investigation. Within the pyroclastic sequence are found fragments of alaskite and/or granite and possibly of granodiorite porphyry, as well as fragments of the other aforementioned rock units.

Some question exists as to the overall relationship between ignimbrite and sediments ascribed to the Claflin Ranch Formation. In the West Silver Bell Mountains, ignimbrites are found in one locality interbedded with coarse clastic sediments of Claflin-like appearance.
Not far northwest of the area of investigation, bedded sediments overlie a thickness of ignimbrite. The so-called Claflin Ranch Formation obviously presents a great many problems.

All the dike types related to the ore zone monzonite intrude the Mount Lord Ignimbrite, as do dikes of Tertiary quartz latite and andesite.

**Age**

The Geochronology Laboratory at the University of Arizona has geochemically dated several specimens from the Cat Mountain Rhyolite of the Tucson Mountains—a volcanic sequence which appears to be lithologically similar to, and stratigraphically a near time equivalent of, the Mount Lord Ignimbrite. A potassium-argon date on feldspar giving an age of 70.3±2.2 million years is accepted as the age of the Cat Mountain Rhyolite (Dr. Paul E. Damon, personal communication).

An attempt was made recently to date the Mount Lord Ignimbrite, but results indicated that the ignimbrite was younger than some of the dikes intruding it—an obvious fallacy. It is very possible that the monzonite intrusion and subsequent hydrothermal alteration and mineralization at Silver Bell has affected the argon content of the ignimbrite.

It is apparent that the Mount Lord Ignimbrite cannot be absolutely correlated with the Cat Mountain Rhyolite or with other of the Laramide ignimbrites of south-central Arizona. The ignimbrite at Silver
Bell has a local source(s), and geochemical methods so far have been unable to obtain a date on the emplacement of these pyroclastics. The writer feels quite strongly, however, that lithologic and stratigraphic similarities between the ignimbrites of the Silver Bell and Tucson Mountains indicate that the age of the Mount Lord Ignimbrite is approximately 70 million years.

Information already presented herein and some yet to be presented indicate a fairly close time as well as spatial relationship between the Silver Bell complex and the Mount Lord Ignimbrite. If this be the case, and assuming an age of approximately 70 million years for the ignimbrite, the Silver Bell complex and the granodiorite porphyry with its associated andesite dikes should not be much older. In the same light, the alaskite and the dacite porphyry should then be somewhat older than 70 million years. These rocks are all Cretaceous in age if the date of 63 million years (Folinsbee, Baadsgaard, and Lipson, 1961, p. 358) is accepted for the ending of the Cretaceous period.

**Monzonite of the Ore Zone and Related Dikes**

**Monzonite**

The monzonite of the ore zone does not occur in the area of investigation, but it does send numerous porphyry and porphyritic dikes into the volcanic-sedimentary complex. The emplacement of the
monzonite (often quartz monzonite) and related dikes coupled with subsequent hydrothermal alteration and mineralization have had a profound effect upon most of the rocks of the Silver Bell range.

Evidence of this statement comes from the geochemical age dates derived from Silver Bell rocks by the University of Arizona Geochronology Laboratory. Reference to table 2 (p. 86) shows that dates on unaltered (quartz) monzonite of $67.1^{\pm}2.0$ m.y. and El Tiro pit (quartz) monzonite of $63.4^{\pm}2.0$ m.y. agree within limits of error that the monzonite is of an age a little over 65 million years. Of course, the pit monzonite had solidified previous to the mineralization, but the time span between the two events was not great enough to be detected by the potassium-argon dating method. The emplacement of the ore, then, occurred at the end of the Cretaceous period.

From table 2, however, the dates of $64.6^{\pm}2.5$ m.y. on alaskite, $57.5^{\pm}3.0$ m.y. and $55$ m.y. on dacite porphyry, and $59.7^{\pm}2.0$ m.y. on Mount Lord Ignimbrite show that these rocks have been affected by the pervasive alteration that followed the monzonite emplacement. In explanation of these dates, which are obviously younger than the primary solidification of the rocks they represent, the Geochronology Laboratory states that "younger igneous or hydrothermal events can exert perturbing influences on the accumulation and retention of argon in all neighboring older rocks" (Damon, et al., 1963, part A-III, p. 9).

In hindsight, the inability of geochemical age-dating methods
<table>
<thead>
<tr>
<th>Geological Unit</th>
<th>Age (Million years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat Mountain Rhyolite, Tucson Mountains (feldspar)</td>
<td>70.3±2.2</td>
</tr>
<tr>
<td>Quartz monzonite, Silver Bell (&quot;unaltered,&quot; biotite)</td>
<td>67.1±2.0</td>
</tr>
<tr>
<td>Quartz monzonite, Silver Bell (El Tiro pit, biotite)</td>
<td>63.4±2.0</td>
</tr>
<tr>
<td>Alaskite, Silver Bell (biotite)</td>
<td>64.6±2.5</td>
</tr>
<tr>
<td>Dacite porphyry, Silver Bell (biotite)</td>
<td>57.5±3.0</td>
</tr>
<tr>
<td>Mount Lord Ignimbrite, Silver Bell (sanidine)</td>
<td>59.7±2.0</td>
</tr>
<tr>
<td>Petroglyph Hill Andesite, east of Silver Bell (biotite)</td>
<td>27.9±1.7</td>
</tr>
<tr>
<td>Dacite porphyry, east of Silver Bell Peak (biotite)</td>
<td>55</td>
</tr>
<tr>
<td>Ragged Top Latite Porphyry, Ragged Top Mountain (biotite)</td>
<td>24</td>
</tr>
</tbody>
</table>

All dates were determined by the Geochronology Laboratory of the University of Arizona. The first seven dates are taken from Damon, et al. (1963, p. 8 and part A-III, p. 12). The last two dates are yet unpublished and subject to final correction.
to obtain primary dates on the older Silver Bell rocks might have been forecast by noting the hydrothermal alteration evinced in many of the thin sections of these older rocks made during this investigation. This opinion is substantiated by Richard Mauger of the Geochronology Laboratory (personal communication).

As noted previously, a regional tilting is shown by Paleozoic sediments, Claflin Ranch sediments, dacite porphyry, Silver Bell complex, and Mount Lord Ignimbrite—all of which dip generally to the northeast. It is possible that the rise of a large, only partially exposed, plutonic body of monzonite in the ore zone could have had a doming or up-punching effect on the Silver Bell area, with the structural block between the axis of the zone of alteration and the Ragged Mountain fault tilting 20° to 30° to the northeast. It is also possible that this regional tilting might be in part due to subsidence following the emission of the ignimbrites.

Related Dikes

Numerous dikes related to the ore zone monzonite are found in the volcanic-sedimentary complex. These dikes almost without exception trend northeast to east-northeast. A great majority of the dikes, particularly those in the Oxide pit area, dip steeply to the southeast.

In general the dikes are most prevalent near the zone of alteration and decrease in number to the northeast away from this zone. The
eastern border of the area mapped, except in the southernmost portion, seems to coincide fairly closely with the farthest northeastward penetration of these dikes. Two great concentrations of dikes exist—one swarm heading east-northeast from the vicinity of Oxide pit and the other trending northeast from the vicinity of El Tiro pit. The intersections of these two dike swarms with the zone of alteration nicely pinpoint the location of the two open-pit copper mines.

The dikes related to the ore zone monzonite are grouped into three categories according to field aspect and to petrographic correlation. The earliest and least common are the fine-grained porphyritic syenodiorite dikes. Next come the rather unusual pyroxene- and quartz-bearing syenodiorite porphyry dikes, followed by monzonite porphyry dikes. Field relationships and petrographic study of dike contacts have confirmed the order of emplacement of these three dike groups.

The dikes related to the monzonite intrude Paleozoic sediments, Claflin Ranch sediments, alaskite (outside of the area mapped), dacite porphyry, Silver Bell complex, granodiorite porphyry and associated andesite dikes, and Mount Lord Ignimbrite. They are in turn cut by Tertiary quartz latite and andesite dikes.

A few pebble dikes and quartz veins are related to the period of hydrothermal alteration and mineralization.
Porphyritic syenodiorite dikes

The porphyritic syenodiorites, oldest group of dikes related to the monzonite, are few in number. Six such dikes exist in dacite porphyry—one north of Oxide pit, one west of Mount Mammoth, two more three-quarters of a mile northwest of Mount Mammoth, and the final two northeast of the old Belmont mine. One porphyritic syenodiorite dike is found associated with minor lead mineralization in the southern portion of the granodiorite porphyry stock, and one dike is located in Claflin Ranch sediments just southeast of the stock. Most of these dikes trend northeast, but the two dikes to the north of the dacite porphyry trend northwest. All of the dikes are less than 6 feet thick.

Very little can be seen in the hand specimen of this dike type. The rock is quite fine grained, and only an occasional tiny feldspar phenocryst can be seen. Freshly broken rock is greenish gray in color, while weathered surfaces are either a faded gray or iron stained.

Petrographically, the rock is found to consist of quartz, 4 percent; feldspar, 65 percent; chlorite (pennine), 10 percent; calcite, 10 percent; ilmenitic magnetite and leucocene, 10 percent; and minor apatite. The dike north of Oxide pit locally contains pods and veinlets of calcite and hematite—the latter mineral as cubes with modified corners, evidently pseudomorphous after magnetite or pyrite. The dike west of Mount Mammoth has up to 2 percent of sphene.
Phenocrysts comprise only 2 to 5 percent of the rock. For the most part, they are sericitized and argillized twinned plagioclase \((\text{An}_{29-31})\) phenocrysts up to 1.25 mm in length. A few ferromagnesian phenocrysts are completely altered to pennine chlorite, calcite, quartz, and white opaque. The fact that quartz is always present in the sites of these altered phenocrysts suggests that the ferromagnesian mineral might have been pyroxene.

The groundmass is holocrystalline and felted. Interstitial potash feldspar and opaques are seen in an interwoven mesh of altered plagioclase laths of an average length of 0.2 mm. Blebs of quartz are scattered throughout the matrix, and secondary chlorite and calcite abound. Hydrothermal alteration, seen in all of the dikes from which thin sections were made, has destroyed all ferromagnesian minerals, altered somewhat extensively all feldspar, created veinlets of calcite and quartz, and possibly concentrated quartz in the matrix. This hydrothermal activity has masked any deuteric effects.

**Pyroxene- and quartz-bearing syenodiorite porphyry dikes**

A syenodiorite porphyry with lamprophyric tendencies forms a great many dikes northeast and north of Oxide pit and a few dikes northeast of the El Tiro area. These dikes are frequently found running side by side with later monzonite porphyry dikes. In hand specimen numerous lath-shaped plagioclase phenocrysts of an average length of 0.1 inch
PLATE 17

Figure A
Photomicrograph of porphyritic syenodiorite. A cavity in the felted feldspathic matrix is filled with calcite and crystals of hematite, pseudomorphous after pyrite or magnetite. An argillized phenocryst of plagioclase is seen in the lower right corner. (X 15.)

Figure B
Photomicrograph of syenodiorite porphyry, showing abundant phenocrysts of diopsidic augite and slightly sericitized plagioclase (An₃₁). Pennine chlorite and magnetite are common. The matrix—which contains about 2 percent of quartz—is fine grained hypidiomorphic granular. (X 15.)
and plentiful crystals of pyroxene surficially altered to a dark-brown color are set in a fine-grained gray matrix.

Petrographically, the rock contains feldspar, 75 percent; pyroxene, 5 percent; hornblende, 1 percent; quartz, 4 percent; chlorite (pennine), 5 percent; calcite, 2 percent; apatite, 1 percent; ilmenitic magnetite and leucocene, 6 percent; and occasional zircon and epidote. In a few dikes north of Oxide pit, pyrite and chalcopyrite are present in minor amounts. Phenocrysts and groundmass each constitute 50 percent of the rock.

The phenocrysts are predominantly a sodic andesine plagioclase (An$_{32-38}$), often twinned and moderately sericitized. These plagioclase phenocrysts are euhedral to subhedral and frequently up to 2 mm in length. The pyroxene is diopsidic augite with an extinction angle (c $\wedge$ Z) of 45°. Subhedral to euhedral, these pyroxene phenocrysts up to 1 mm in diameter are partially altered to pennine chlorite, calcite, white opaque, and sometimes epidote. Hornblende is occasionally found relatively fresh but is usually altered to pennine chlorite and white opaque.

The groundmass is hypidiomorphic granular fine grained. It is composed of small sericitized plagioclase laths and altered pyroxene crystals accompanied by considerable amounts of interstitial argillized potash feldspar and quartz. Potash feldspar is indicated by refractive index and by staining with cobaltinitrite. The quartz in places has been
mobilized and concentrated into patches up to .5 mm in diameter.

All of the syenodiorite porphyry dikes have undergone strong deuteric alteration with partial breakdown of pyroxene and moderate alteration of feldspar. Many were hydrothermally altered during the subsequent invasion of monzonite porphyry dikes. Sure signs of hydrothermal activity occasionally seen are quartz mobilization in the matrix and the presence of disseminated grains of pyrite and chalcopyrite.

**Monzonite porphyry dikes**

The monzonite porphyry dikes are by far the most prevalent of the dikes related to the ore zone monzonite. They are quite resistant to erosion and frequently form ridges. Often they run alongside of pyroxene-bearing syenodiorite porphyry dikes and occasionally are found obliquely crosscutting them. The monzonite porphyry dikes have been subdivided into five types on the basis of field relationships and appearances, as well as petrographic criteria. Three of these types are gradational, one to another. The other two are distinct types with distinct field relationships. The porphyry listed in table 1 (p. 45) as monzonite porphyry No. 1 is discussed in the paragraph below, while the other four porphyry dike types are described in the Appendix. Monzonite porphyries Nos. 3, 4, and 5 are also summarized in table 1.

The very common type of monzonite porphyry chosen for description here is brownish gray in color and contains about 30 percent
Figure A
Photomicrograph of monzonite porphyry. Phenocrysts of sericitized sodic andesine plagioclase and a book of biotite (dark) are set in a felted, fine-grained, hypidiomorphic-granular matrix. Calcite and chlorite make up the patchwork mass in the upper left corner. Staining with cobaltinitrite indicates the presence of a large amount of potash feldspar in the matrix. (X 10.)

Figure B
Photomicrograph of a contact between monzonite porphyry (top) and syenodiorite porphyry (bottom). The monzonite porphyry is visibly later. (X 15.)
PLATE 19

Figure A
Photomicrograph of monzonite porphyry, showing a large biotite book, numerous phenocrysts of argillized plagioclase (An29), and several cubes of pyrite. The biotite is altering to calcite and pennine chlorite, and a few pieces of epidote are present in the field of view. (X 15.)

Figure B
Same field as figure A (crossed nicols). Polarized light emphasizes the allotriomorphic-granular matrix. (X 15.)
of phenocrysts, with white plagioclase laths up to .3 inch in length, chloritized biotite books, and occasionally altered hornblende crystals conspicuous in hand specimen. Mineral percentages as determined petrographically are as follows: quartz, 4 percent; feldspar, 80 percent; chlorite after biotite, 5 percent; chlorite after hornblende, 1 percent; calcite, 4 percent; apatite, 1 percent; ilmenitic magnetite and leucocene, 4 percent; and minor epidote and zircon. Sodic andesine plagioclase (An32-34) occurs as frequently twinned, euhedral to subhedral phenocrysts up to 5 mm in length which are moderately sericitized. Biotite books up to 4 mm in size are completely chloritized, with calcite and sericite along cleavages and white opaques scattered throughout. Hornblende has altered to pennine chlorite and calcite. The groundmass is hypidiomorphic granular fine grained, felted with small plagioclase laths, and containing large amounts of interstitial argillized potash feldspar as shown by refractive indices and staining with cobaltinitrite. The composition is close to that of syenodiorite, but it is thought that enough potash feldspar is in the matrix to place the rock in the monzonite category. Quartz is interstitial in the groundmass. Hydrothermal alteration is frequently indicated in these dikes by veinlets of quartz and calcite, heavy calcification of the matrix, and the occasional presence of pyrite. Signs of a fairly strong deuteric alteration are always present.
Late pebble dikes and quartz veins

Several short segments of pebble dikes were encountered on the southwestern slopes of the range. All trend northeast and are thus probably related to the major period of ore deposition. One of these dikes, mentioned earlier in the description of the alaskite, contains numerous alaskite fragments set in a tuffaceous matrix. This dike parallels then joins an older monzonite porphyry dike north of Oxide pit.

A 20-foot long segment of pebble dike 3 feet wide trends N. 62° E. about a third of a mile northwest of the summit of Mount Mammoth. Here, chunks of quartzite, limestone, dacite porphyry, and monzonite porphyry are cemented by tuffaceous material.

Two other small pebble dikes were seen. A 6-inch dike in dacite porphyry containing fragments of the same dacite porphyry was found a half a mile north of Oxide pit, while a 6-inch dike in Silver Bell complex massive breccia containing andesite porphyry fragments was encountered northeast of Mount Mammoth.

Several quartz veins, usually associated with dikes related to the monzonite, trend northeast and are shown on the mineralization map (pl. 2). The most prominent of these is a vertical quartz vein up to 12 feet thick which runs almost due east from Oxide pit. This vein penetrates an adjoining dike of pyroxene-bearing syenodiorite porphyry.
A mid-Tertiary period of igneous activity is demonstrated in the area of investigation by the presence of pyroxene and hornblende andesite dikes, quartz latite porphyry dikes, and the Ragged Top Latite Porphyry. The latite porphyry has been referred to herein as a pluton for want of a better term. However, since latite magma was in transit to the surface, welling up along a portion of the Ragged Mountain fault, this irregularly shaped but elongate body might be thought of more specifically as a massive dike.

The age relationships among these three rock units are not made clear in the area mapped. Nowhere do these units visibly intersect one another. The Geochronology Laboratory of the University of Arizona has derived an early Miocene date of 24 million years (unpublished and subject to final correction) on fresh biotite from the Ragged Top Latite Porphyry. When compared to the date of 27.9±1.7 m.y. for the Petroglyph Hill Andesite 6 miles east of Silver Bell (Damon, et al., 1963, part A-III, p. 12), it is apparent that andesitic activity preceded the emplacement of the Ragged Top Latite Porphyry.

However, as previously mentioned, Tertiary andesite flows are found overlying Tertiary rhyolitic flows in the West Silver Bell Mountains. Here, andesitic extrusions have clearly post-dated the more acid volcanic activity. The conclusion must be that in the mid-
Tertiary, just as in the Late Cretaceous, andesitic activity was a continuing phenomenon over an extended period of time.

The quartz latite porphyry and the Ragged Top Latite Porphyry would be nearly identical rocks but for the lack of quartz in the latter. These two units are probably very closely related in time and genesis. Tertiary andesite dikes are seen to approach the Ragged Top Latite Porphyry but they never enter it. On the basis of this admittedly inconclusive evidence, the andesitic activity seen within the area of investigation is tentatively assigned to an age older than the latite and quartz latite intrusions.

**Pyroxene and Hornblende Andesite Dikes**

The late pyroxene and hornblende andesite dikes, like the late andesite dikes found in the zone of alteration, trend northwest to west-northwest. In so doing, they frequently cut dikes related to the ore zone monzonite. The dike andesites—various shades of gray, green, and purple—are sometimes aphanitic and sometimes porphyritic with small phenocrysts of pyroxene, hornblende, and plagioclase visible. Moderately susceptible to erosion, these dikes are late Oligocene or early Miocene in age.

The andesite porphyry dikes are most common in section 34 where they occur, often as a swarm, in a northwest-trending belt. Short segments of andesite porphyry dikes are also found in the northwest
and east-central portions of section 2, in the southwest corner of section 1, and in the south-central portion of section 36. Aphanitic andesite rock is encountered in dikes northeast and southwest of Wolcott Peak, in the northwest corner of section 36, and in the northwest and north-central portions of section 35. A small elongate pluglike body of moderately resistant andesite stands out as a small hill within the Silver Bell complex in the northeast corner of section 35.

Petrographically, the late andesites are of several types. A hornblende andesite, a pyroxene andesite, and the andesite plug rock of section 35 will be described briefly below.

The hornblende andesite porphyry dike in the east-central portion of section 2 contains 20 percent of phenocrysts set in a pilotaxitic matrix of andesine microlites accompanied by interstitial "cryptofelsite" and specks of magnetite, chlorite, and augite. The phenocrysts are, for the most part, laths of plagioclase up to 1.5 mm long and crystals of euhedral to subhedral oxyhornblende (z C = 10°) up to 2.5 mm in size. Augite pyroxene constitutes less than 1 percent of the phenocrysts. Minor apatite is found as prismatic crystals, and several percent of euhedral to subhedral, slightly oxidized magnetite is scattered about as grains up to .5 mm in size. Calcite replacement of feldspar and chlorite in the matrix is probably a sign of deuteritic alteration.

Two pyroxene andesite dikes are found side by side northeast of Wolcott Peak. The later and relatively unaltered dike (the other is
PLATE 20

Figure A
Photomicrograph of hornblende andesite porphyry. Phenocrysts of oxyhornblende and andesine plagioclase are prominent. The groundmass is pilotaxitic, with specks of magnetite and augite liberally sprinkled among the plagioclase microlites. (X 15.)

Figure B
Photomicrograph of pyroxene andesite porphyry. Texture is pilotaxitic with phenocrysts of diopsidic augite set in a groundmass of andesine plagioclase microlites and interstitial felsite. (X 15.)
quite iron stained) shows a pilotaxitic texture and contains 15 percent of phenocrysts, all euhedral to subhedral diopsidic augite less than 1 mm in size. The groundmass is predominantly made up of andesine laths with interstitial bits of pyroxene and magnetite. Some clay in the groundmass is due either to weathering or to minor deuteric alteration.

The plug of andesite in the northeast corner of section 35 carries only 3 to 4 percent of phenocrysts. A few yellowish subhedral crystals up to 3 mm long have an extinction angle of 2° to 3° and were identified by X-ray diffraction patterns as oxyhornblende. Euhedral to subhedral phenocrysts of slightly sericitized andesine plagioclase up to 2 mm in size are also present. Several oxyhornblende and plagioclase laths less than .25 mm long have a common orientation and as such are the only good indication of flow structure to be seen. The matrix shows a ghostlike crystallization of plagioclase crystals superimposed on a mat of very tiny plagioclase microlites and bits of magnetite.

Quartz Latite Porphyry Dikes

Resistant northwest-trending quartz latite porphyry dikes are prominent ridge formers on the southwestern side of the range. These dikes, which can be up to 200 feet in thickness, have a strangely discontinuous line of outcrop which is caused not by faulting, as has been previously suggested (Kingsbury, Entwistle, and Schmitt, 1941, p. 24), but by intrusion into a very broken and faulted terrane.
The rock contains, on the average, 15 percent of phenocrysts with rounded quartz grains and euhedral to subhedral crystals of sanidine and plagioclase dotting a light-gray matrix. Fine-grained selvages are occasionally seen along the dike borders, and dikelets of very fine grained material apparently related to the quartz latite are found in the proximity of certain of these porphyry dikes.

An origin by other than quiet flow is indicated by a large area of breccia within a quartz latite porphyry dike located north of a left-lateral fault in the southeast portion of section 2. This breccia contains large chunks of the quartz latite porphyry firmly cemented by a fine-grained latitic matrix.

Petrographically, the rock is composed of quartz, 20 percent; feldspar, 75 percent; biotite, 1 percent; magnetite, 1 percent; and minor quantities of sphene, calcite, epidote, ilmenite, and leucocene. Quartz occurs as rounded to subrounded embayed phenocrysts up to 2 mm in diameter. Sanidine is seen as large euhedral to subhedral phenocrysts up to 5 mm in size. Rarely, smaller subhedral, slightly altered crystals of orthoclase are present. The plagioclase is calcic oligoclase (An$_{28}$) and is found as argillized and calcitized laths, frequently twinned and up to 2.5 mm long. Biotite is the only ferromagnesian mineral and exists as small crystals never over 0.5 mm long. A few bits of epidote were seen in two thin sections.

The groundmass contains about equal amounts of plagioclase
and potash feldspar with minor quartz. In places it is microcrystalline, and only staining with cobaltinitrite solution can bring out the differences between the two feldspars. For this reason it is easy to see why the rock, when found with a fine-grained matrix, has been called a rhyolite (Kingsbury, Entwistle, and Schmitt, 1941, p. 23). In other places, however, the matrix has had more of an opportunity to crystallize, and a large number of plagioclase laths can be seen. In one unusual thin section, the matrix is nearly granophyric, indicating simultaneous crystallization of quartz and feldspar. Several small quartz spherulites are also present in this particular slide.

Minor deuteric alteration was observed in all of the quartz latite porphyry thin sections. Biotite is still brown but occasionally has been replaced in the center by calcite. The very minor epidote is no doubt deuteric. All feldspar has been lightly argillized and the plagioclase has also been mildly sericitized.

The dikelets of fine-grained material found in proximity to certain of the quartz latite dikes contain bits of quartz, feldspar, and iron oxide up to .2 mm in size in a very fine grained feldspathic matrix. These dikelets, never over an inch thick, are strongly banded parallel to the contacts—some bands carrying the coarse grains, some totally fine grained, some showing a streaky sericite or clay alteration, etc. A fluidized origin seems assured.
PLATE 21

Figure A
Photomicrograph of the matrix of a fine-grained quartz latite porphyry dike (crossed nicols). A small quartz phenocryst and a dark blade of biotite are present. Some recrystallization has occurred within this quartzofeldspathic groundmass. (X 60.)

Figure B
Photomicrograph of the matrix of a trachytic-textured quartz latite porphyry dike (crossed nicols). Fine-grained potassic feldspar and tiny blebs of quartz are interstitial among numerous small laths of plagioclase. The coarsened matrix of this porphyry dike may be due to a late vapor phase crystallization. (X 60.)
Figure A
Photomicrograph of a quartz latite porphyry dike (crossed nicols). Rounded quartz phenocrysts are set in a quartzofeldspathic matrix whose tiny interlocking crystals evince primary crystallization. Some recrystallization has also occurred. The spherulites apparently consist entirely of quartz. (X 15.)

Figure B
Photomicrograph of a dikelet of fluidized material (crossed nicols), probably associated with the intrusion of a nearby quartz latite porphyry dike. The vein contact with dacite porphyry is barely visible at the bottom of the photograph. (X 10.)
Ragged Top Latite Porphyry

The early Miocene Ragged Top Latite Porphyry is found only along the Ragged Mountain fault. Resistant to erosion, it forms the spectacular spine of rock along which Ragged Top Mountain and Wolcott Peak are situated.

A vertical flow structure parallel to the contact walls is common, but often indications of turbulent flow can be seen in the latite cliffs. This "massive dike" or pluton could show much concerning the fluid mechanics of a rising body of magma under hypabyssal conditions were it not so treacherous to climb.

The Ragged Top Latite Porphyry is light gray in color and exhibits phenocrysts of sanidine and plagioclase and flakes of black biotite. Flow structure can often be seen in the hand specimen. A bleached zone within the porphyry, evidently caused by argillization, is found on the southwest flank of Ragged Top, while two supergene iron-stained zones are seen on the northeast flank.

Petrographically, the rock has a hyalopilitic texture with 20 percent of phenocrysts. The matrix contains small plagioclase laths of a common orientation, patches of potash feldspar, and considerable interstitial brown glass. Over half of the phenocrysts are euhedral to subhedral sanidine crystals up to 5 mm in diameter. Plagioclase phenocrysts are laths of oligoclase-andesine (An$_{29-32}$), frequently twinned.
Figure A
Mount Mammoth flanked by a large quartz latite porphyry dike on the right and Paleozoic limestones on the far left. The mountain and much of the terrane in the foreground are composed of dacite porphyry. View is toward the west.

Figure B
View north from Silver Bell Peak to Ragged Top Mountain (left) and Wolcott Peak (right). Both are composed of Ragged Top Latite Porphyry.
Figure A
Photomicrograph of Ragged Top Latite Porphyry (crossed nicols). The fine-grained matrix photographs very dark because of strong iron oxidation, but large sanidine phenocrysts and smaller plagioclase crystals remain quite fresh. (X 15.)

Figure B
Photomicrograph showing flow structure in Ragged Top Latite Porphyry. Sanidine and oligoclase-andesine phenocrysts, along with numerous plagioclase microlites, are present in a devitrifying glassy matrix. (X 10.)
and up to 2 mm in length. Dark-brown biotite laths compose 2 percent of the rock, and euhedral to anhedral crystals of magnetite make up 1 percent. Deuteric alteration is suggested by minor alteration of feldspar phenocrysts and biotite flakes and clay alteration of the matrix.
CHAPTER V
CRETACEOUS AND CENOZOIC SEDIMENTARY ROCKS

Amole-Type Clastic Sediments

The Cretaceous (?) Amole-type clastic sediments which are found south of the zone of alteration and which overlie Paleozoic sediments in the West Silver Bell Mountains are conspicuously absent in the eastern portion of the Silver Bell range. The interval they would occupy—between Paleozoic sediments and Claflin Ranch sediments—is filled with dacite porphyry. However, a sequence of the Amole-type sediments must have existed in the range sometime prior to the intrusion of the dacite porphyry.

Claflin Ranch Formation

The name "Claflin Ranch Formation" was given by Richard and Courtright (1960, p. 1) initially to a thick series of clastic beds which lie about 1.5 miles west of the Claflin Ranch buildings. Unfortunately, this formation is ill-defined in the Silver Bell range, and consequently it serves as a catchall classification for any coarse clastic sediments of "Laramide aspect." It has been so used in this investigation.

Careful mapping of these Cretaceous-Laramide sediments
found in the western portion of the Silver Bell Mountains and in the West Silver Bell range would shed some light on the situation. (Some mapping is presently being accomplished in these areas.) Quite possibly the ultimate conclusion will be that the present catchall aspect of the "Claflin Ranch Formation" is not so far from the truth—for this formation is certainly unique in comparison with the "standard" formation of geologic literature.

Field Description

Sediments ascribed to the Claflin Ranch Formation are found principally in the northwest portion of the area mapped but exist also east of Silver Bell Peak and in three localities on the southwest flank of the range. The thickest continuous sequence of approximately 1,800 feet occurs on the southeastern side of the granodiorite porphyry stock in section 26.

The orientation of the Claflin Ranch sediments differs from one locality to the next. As mentioned in the beginning of the preceding chapter, the sediments from these various localities strike in the northwest quadrant anywhere from east-west to north-south while dipping north, northeast, or east at 25° to 45°. These orientations are undoubtedly affected by faulting and intrusion. It is also probable that the primary orientations differed somewhat because the sediments were deposited at different places and at different times.
The Claflin Ranch Formation almost everywhere exhibits coarse volcanic sediments which were deposited rather rapidly. In a few places fairly clean sandstone is found. Many of the sediments have been metamorphosed by the dacite porphyry and granodiorite porphyry intrusions as well as by later igneous and hydrothermal activity. A few of the sediment types seen in the field are described below.

A massive conglomerate of greenish-gray color is exposed for over 1,300 feet in a north-trending wash southeast of the granodiorite porphyry stock. Angular pebbles and cobbles of arkose are very common, as are fragments of siltstone, sandstone, shale, limestone, and conglomerate. Small blocks of sandy bedded sediment up to 4 feet in size are occasionally seen. A dike of dacite porphyry knifes through the upper portion of the conglomerate.

South of the stock a coarse rubbly conglomerate contains numerous chunks of Pinal-like schist. Such schist fragments are absent from many of the sediments, yet are characteristic of certain conglomerates.

Also south of the stock, one of the infrequent fine-grained beds—an argillaceous sandstone under the microscope—is found to be a favored site for minor lead and copper mineralization. This bluish-gray bed about 5 feet thick strikes northeast on the eastern side of the Barite fault. Another fine-grained bed—a metasediment near the granodiorite porphyry contact southwest of the Franco Riqueza mine—is well
pyritized.

A very common type of metasediment which can be either thin or thick bedded has an appearance similar to the dacite porphyry. Quartz "eyes" dot a brownish-gray matrix, and small rock fragments are visible. A freshly broken surface, however, is liable to show more crystalline material than is seen in the dacite porphyry. That these rocks are metasediments, and not dacite porphyry with platy layering due to flow structure, is shown by occasional graded bedded and by minor changes in grain size from bed to bed.

However, in places to the south and southeast of the granodiorite porphyry stock, zones of massive quartz-eye material exist between bedded metasediments. Occasionally these unbedded zones seem to obliquely crosscut the bedded metasediments. Such zones may well be sill-like intrusions of dacite porphyry, but to map them would require tedious fieldwork accompanied by numerous petrographic checks.

Nearly 2,000 feet south of the Franco Riqueza mine, a horizon within the Claflin Ranch Formation is found to include several large blocks of foreign material set among bedded sediments. A couple of blocks of "andesite-schist conglomerate" over 50 feet in length and 25 feet thick have been mentioned by Richard and Courtright (1960, p. 1). Another even larger block at this horizon contains either laharcic or intrusion breccia with highly altered andesitic fragments cemented by a recrystallized quartzofeldspathic matrix. The emplacement of these
Figure A
An isolated block of Claflin Ranch sediments at the dacite porphyry-Silver Bell complex contact. The sediments grade into dacite porphyry in the immediate foreground. This outcrop is in the west-central portion of section 2.

Figure B
Massive quartzofeldspathic material within well-bedded Claflin Ranch sediments in the south-central portion of section 27. This lens of material, quite possibly a sill of dacite porphyry, is quickly lost in alluvium.
blocks by gravity sliding is suspected. Their positions are indicated on the geologic map (pl. 1) by dotted lines.

East of Silver Bell Peak, about 500 feet of Claflin Ranch sediments cap an east-dipping slope. As elsewhere, bedded metasediments of dacitic appearance directly overlie the dacite porphyry. Progressing downhill, but gradually up the sedimentary column, various coarse arkosic conglomerates and conglomeratic mudflows are found to give way to andesite-bearing conglomerates. At the furthest extent downhill and at the top of the sedimentary sequence as exposed, a massive conglomerate is seen to contain cobbles of material which are identical to the dacite porphyry. No fragments of ignimbrite were found, and it is assumed that structural implications in the area correctly indicate a pre-ignimbrite origin for this sequence of sediments.

Just east of the Mount Mammoth fault in the northeast corner of section 3, nearly 200 feet of petrographically proven Claflin Ranch metasediments underlies Silver Bell complex massive breccia by an erosional contact. The metasediments are massive in places and in the field would be indistinguishable from dacite porphyry were it not for occasional patches of bedded material which grade perceptibly into the massive rock.

Of final note is a locality along the southwest flank of Ragged Top where a breccia with andesitic matrix is seen to contain large numbers of the arkosic fragments so typical of Claflin Ranch sediments.
Nearby, the Claflin Ranch sediments are full of andesite porphyry fragments similar to those in an andesite breccia in the vicinity. Furthermore, on the southern flank of Wolcott Peak, a few layers of arkosic sandstone are interbedded with laharic andesite breccia. The indications are certainly present that transitions between volcanic sediment deposition and laharic andesite breccia deposition exist.

**Petrographic Description**

There is no difficulty in recognizing a strictly sedimentary mode of deposition for the various massive dark conglomerates. The matrix of these conglomerates, a mud at the time of deposition, is composed of fine sand- to silt-size particles of quartz, feldspar, and other miscellaneous fragments set in a commonly sericitized indurated filler. Quartz is very plentiful in the matrix and much of it is fragmental.

The major petrographic problem concerns the distinction between metasediments and dacite porphyry. All transitional phases between the two seem to exist, and the final decision on any one rock can be very subjective. Certain criteria were worked out during the petrographic study of these rocks to help in distinguishing between the quartzofeldspathic metasediments and the quartzofeldspathic igneous rock which caused the metamorphism (and at times, metasomatism).

Several aspects of the quartz always present in these rocks can be helpful in this distinction. Whereas the dacite porphyry never exceeds
25 percent of quartz, many of the metasediments will contain 30 percent of quartz or more. Another criteria concerns the fact that the dacite porphyry shows an even distribution of quartz "eyes" and quartz fragments. Often, the metasediments will show a linear distribution of a certain particle size of quartz which is quite indicative of bedding. If a dacitic-appearing rock contains very few large quartz phenocrysts but very numerous tiny pieces of quartz scattered throughout, it is most likely a metasediment.

The matrix can be of help, also. In the dacite porphyry a flow structure is usually shown in the fine matrix and by alinement of small crystal laths. If no indication of flow is seen, the rock is suspect of being a metasediment. Also, the dacite porphyry usually has a considerable amount of a glassy or devitrified matrix not too greatly cluttered by crystals and fragments. If very little fine matrix can be seen, the rock is again suspect as a metasediment.

Occasionally a thin section from a bed of material will show fragmental quartz and a tuffaceous matrix. The possibility is very real that some layers of igneous tuff are interbedded among the Claflin Ranch sediments. There is also a good chance that the dacite porphyry surfaced in the vicinity and gave rise to thin flows or tuffs which covered the sediments existing at that time.
Figure A
Photomicrograph of a Claflin Ranch metasediment.
Well bedded in the field, this rock shows only a faint bedding in the photograph, striking into the northwest quadrant. Quartz fragments are generally smaller and the total percentage of quartz higher than in the similar-appearing dacite porphyry. (X 15.)

Figure B
Same field as figure A (crossed nicols). The tiny veinlet is filled with calcite. (X 15.)
Figure A
Photomicrograph of a Claflin Ranch sediment (crossed nicols) adjacent to the Mount Mammoth fault. Cut parallel to the bedding, this thin section contains a high percentage of quartz—some shown to be volcanic by its fragmental nature. (X 10.)

Figure B
Photomicrograph of a tuff (crossed nicols) laterally continuous with a sill of Mount Lord Ignimbrite. A very crude bedding or flow structure is evinced, but the distribution of quartz shows no particular pattern. The matrix consists of devitrified glass. Igneous tuffs petrographically similar to this one appear to exist in places within the Claflin Ranch Formation. (X 10.)
Structural Relationships

At first glance the relationships between the Claflin Ranch Formation and the Laramide igneous units of the range appear nebulous. The sediments both post-date and pre-date the dacite porphyry. They overlie and underlie the Silver Bell complex massive breccia. A transition between volcanic sediment and andesite breccias is indicated near Ragged Top, and Claflin-like beds lie within laharic breccias south of Wolcott Peak. In the area of investigation, the sediments probably pre-date the granodiorite porphyry; however, it must be remembered that Claflin-like sediments are found interbedded with tuffs in the West Silver Bell range and overlie welded ignimbrite in the northwest portion of the Silver Bell Mountains.

The explanation for these profuse relationships seems to be quite simple. The Silver Bell district, with its cover of Amole-type sediments, was undergoing volcanic upheaval throughout much of the Laramide Revolution. It is not difficult to conceive of continual erosion giving rise to the deposition of coarse volcanic sediments in various portions of the district at various different times. Any one locality would be likely to receive sediments intermittently, with areas of maximum deposition shifting according to the train of volcanic events.

Most of the sediments deposited in such a setting would be of a coarse, clastic nature. Fragments of the various igneous rocks in
the district would be anticipated. The question, then, becomes one of definition. If these coarse volcanic sediments are to be named, should they be given a single name to cover the entire period of essentially similar type of deposition, or should a separate name be given to each continuous sequence in a given locality? It is felt that the term "Claflin Ranch Formation" is satisfactory to refer to all coarse clastic sediments in the area deposited during the Laramide Revolution.

The Claflin Ranch Formation as now known in the Silver Bell Mountains is Late Cretaceous in age, as determined from its structural relationships.

**Recent Sediments**

No definable sequence of post-Claflin Ranch sediments exists in the area mapped. During the Quaternary—and probably a good portion of the Tertiary—the Silver Bell Mountains have undergone erosion; and, consequently, the only sedimentary deposits belonging to the Cenozoic Era are talus accumulations and a frequent but thin alluvial cover. These deposits are shown as "Quaternary alluvium" on the geologic map (pl. 1). Recent manmade fills are separately designated.
CHAPTER VI
STRUCTURAL GEOLOGY

The structural elements of the individual rock units have been discussed in the descriptions of these units. It remains now to summarily integrate the various structural elements already mentioned and to add to the picture the ingredients of folding and faulting.

General Structure

The integral structural picture of the eastern portion of the Silver Bell Mountains is that of a layered sequence of sedimentary, subvolcanic, and extrusive rocks striking generally northwest and dipping 20° to 40° to the northeast (see cross sections, pl. 4). This sequence is a part of a structural block located between the Ragged Mountain fault on the northeast and the major structure of the zone of alteration on the southwest. The layered sequence is ruptured by andesitic volcanism, massive granodioritic intrusive bodies, and ignimbrite feeder dikes. This complex, in turn, is sliced by numerous northeast-trending syenodioritic to monzonitic dikes and later northwest-trending quartz latitic, latitic, and andesitic dikes.

The strikes of the layered units actually vary from
east-northeast clockwise to nearly north-south. This variance is a result of somewhat different orientations of initial emplacement and of subsequent intrusive activity and faulting. The moderate dips to the north, northeast, and east are a result of regional northeasterly tilting.

A single widespread pattern of jointing—or even consistency of jointing in individual units—is conspicuously absent. This may be a result, in part, of the intense faulting and fracturing that the area has undergone since the beginning of the Laramide intrusive activity. A careful and complete jointing study of the mapped area (which was not undertaken in this investigation) might possibly hint of an organized system of jointing and also might give some information concerning the structural deformation that the area has undergone.

The highly fractured and faulted state of the rock terrane is clearly shown by the paths of intrusion of the Tertiary quartz latite porphyry dikes. These dikes are found always as a series of oddly shaped disconnected segments and nearly equidimensional patches. At first glance the dikes would appear to be highly faulted, but such is not seen to be the case in the field. These quartz latite porphyry dikes, as also the Tertiary andesite dikes and many of the smaller dikes related to the ore zone monzonite, have been injected into broken ground and have made their way up along already existent fractures, no matter how discontinuous these fractures might be. One of many examples of this
phenomenon is seen .75 mile north of Oxide pit where two segments of a Tertiary quartz latite porphyry dike appear to be offset from each other a distance of 150 feet by a north-south fault. The illusion of faulting is shattered, however, by a Cretaceous monzonite porphyry dike which knifes directly and continuously through the gap representing the "offset."

**Folds**

The Claflin Ranch sediments and the distinguishable flow units of the Silver Bell complex massive breccias are warped. The only folding seen in the mapped area was to the southwest where the Paleozoic sediments have undergone various stages of flexuring and where the dacite porphyry occasionally evinces a post-jointing period of folding.

It has been previously suggested herein that a plutonic body of monzonite welling up along the major structure of the zone of alteration, might have domed that area and caused the structural block between the major structure and the Ragged Mountain fault to tilt to the northeast. The rise of the monzonite might have also effected the folding seen near the zone of alteration.

No other evidence of doming is seen in the area of investigation. The Mount Lord Ignimbrite was evidently erupted through feeder dikes, and indications are of possible collapse rather than doming. The dacite porphyry intruded Cretaceous sediments in a sill-like fashion—yet
nowhere seemed to cause any great buckling of the sediments. The ex-
planation here may well lie in the mode of emplacement of the dacite
porphyry, as will be discussed later.

Faults

The eastern portion of the Silver Bell Mountains is severely
faulted, and no attempt was made to record all of the faults seen during
the fieldwork. Only those faults which noticeably offset dikes or con-
tacts between rock units were mapped.

Faults with all orientations are present, but three directions
are prevalent—west-northwest, east-northeast, and north-northeast.
The age of the faulting varies from pre-Laramide to late Tertiary, with
intermittent movement common along many of the breaks. All of the
faults mapped were either high angle normal, strike slip, or some
combination thereof. Although reverse faulting has been recognized in
the Waterman Mountains (McClymonds, 1957; Ruff, 1951), in the West
Silver Bell Mountains (Craig Clarke, personal communication), and in
the El Tiro-Atlas mine area (Kingsbury, Entwistle, and Schmitt, 1941;
Agenbroad, 1962), no such faulting was encountered in the area of in-
vestigation except for very minor amounts of thrusting occasionally seen
in the Paleozoic sediments.
West-Northwest-Trending Faults

A pronounced west-northwest trend of regional faulting exists in the Silver Bell area (Richard and Courtright, 1954, p. 1098). The structural block that constitutes the Silver Bell range is bounded by such faulting—the Ragged Mountain fault to the north-northeast and the Silver Bell fault zone (the "major structure" of the zone of alteration) on the south-southwest.

The Ragged Mountain fault is high angle normal, dipping steeply to the south. It brings Precambrian granite and younger Precambrian Apache Group sediments on the north against Cretaceous Claflin Ranch sediments and the Silver Bell complex on the south. Total displacement thus may be in the range of 5,000 to 7,000 feet. Intruded by the middle Tertiary Ragged Top Latite Porphyry, this fault best fits the broad classification of "Laramide."

The Silver Bell fault zone has been previously discussed herein. It lies just south and southwest of the area mapped where it is intruded by the various Laramide igneous rocks. According to Richard and Courtright (1954, p. 1095), this zone contains high-angle faulting with a stratigraphic separation on the order of several thousand feet. A probable offshoot or strand of this fault zone is found in the southeastern portion of the area mapped where Silver Bell complex massive breccia and Mount Lord Ignimbrite have been dropped several hundred feet on
the south.

Between these two major structures and within the area of investigation, a few minor west-northwest-trending faults have been mapped. Quite possibly such faulting has controlled, at least in part, the emplacement of the late andesite and quartz latite porphyry dikes—although a few of the faults are apparently late enough to offset these dikes (i.e., northwest corner of section 2).

The west-northwest direction was evidently one of shear during the emplacement of the ore zone monzonite. Any faults formed in this direction during the monzonite intrusion and subsequent mineralization remained tight to the completion of the igneous activity. Relaxation during the Tertiary could have then opened some of these breaks, which were later invaded by the andesite and quartz latite porphyry dikes.

East-Northeast-Trending Faults

Emplacement of the dikes related to the ore zone monzonite was very strongly controlled by the east-northeast to northeast fracture system. Also guided to a certain extent by this system of faulting and fracturing are many of the granodiorite porphyry dikes and related andesite porphyry dikes.

East-northeast-trending faults are not long, nor do they show any great amount of offset. They represent tensional stresses existing prior to—as well as during—the emplacement of the monzonite and
consequently are mainly pre-monzonite intrusion with some occasionally post-monzonite intrusion. Most of these faults, like the dikes that invade them, dip 70° to 80° to the south.

North-Northeast-Trending Faults

Several minor and two major faults follow a north-northeast direction. The larger breaks are named herein the Barite and Mount Mammoth faults.

The Barite fault is located in the northwestern portion of the area of investigation where it cuts the granodiorite porphyry stock, Claflin Ranch sediments, Silver Bell complex massive breccia, and dacite porphyry. It forks at its southern end. This high-angle normal fault dips approximately 85° W. and has a displacement of more than 100 feet. Probably Laramide in age, the fault is mineralized by an appreciable amount of barite (hence, its name) plus calcite, quartz, galena, fluorite, copper (only secondary copper minerals were seen), and possibly silver over much of its length.

The Mount Mammoth fault is located in the west-central portion of the area where Mount Lord Ignimbrite is dropped several hundred feet into contact with dacite porphyry. The fault is normal with a dip of 70° to 80° E. Movement along it has been both pre- and post-monzonite intrusion. Calcite stringers parallel the fault in dacite porphyry in the southwest corner of section 35, while the fault zone in the northeast
corner of section 3 has been silicified.

These north-northeast-trending faults apparently have been relatively tight throughout periods of igneous activity, for very few dikes with such an orientation exist in the area. It is conceivable that these faults are a result of the collapse of subterranean areas drained by the eruptions of the Mount Lord Ignimbrite. The downthrown block of the Mount Mammoth fault contains the major remaining portions of the ignimbrite, including the feeder dikes previously described. The western or downthrown block of the Barite fault includes a thickness of ignimbrite and at least one dike related to the ignimbrite not far northwest of the area of investigation.

West-northwest and north-northeast shear directions and an east-northeast tensi­onal direction within the area mapped agree closely with the fracture pattern which controls mineralization in the El Tiro pit area.
CHAPTER VII
ECONOMIC GEOLOGY

The eastern portion of the Silver Bell range, although immediately adjacent to the ore zone, shows very little potential with regard to any kind of an economic mineral deposit. Numerous prospectors' pits, tunnels, and shafts dot the area, but only two mines have had any sort of production.

Reference to the mineralization map (pl. 2) shows that zones of alteration, almost invariably containing pyrite and/or hematite, are located throughout the area. The alteration indicated along the southern and southwestern edges of the map marks the approach to the ore zone; and, in fact, almost all of the alteration seen in the southern two-thirds of the area is related to the emplacement of the monzonitic and syenodioritic dikes and to the subsequent hydrothermal activity. One curious feature is a north-northeast-trending zone of pyritized ignimbrite found in the northeastern portion of section 2. Here, the oxidizing cubes of pyrite up to .2 inch in diameter are probably also related to the main period of mineralization.

Much of the iron mineralization in the northwest portion of the area is found within and adjacent to the granodiorite porphyry stock and
is probably related to the emplacement of that body. Strong iron staining associated with pyritization northwest of the Franco Riqueza claims may be associated with the granodiorite porphyry or possibly may be connected in some way with igneous activity along the nearby Ragged Mountain fault. Unfortunately, most of the country just north of the area mapped is covered by alluvium.

The Precambrian rocks immediately north of the Ragged Mountain fault are flooded in many places with iron oxides after magnetite and pyrite, but the granite becomes progressively less stained on to the north. The Silver Bell complex breccias and flows on the southern slopes of Ragged Top and Wolcott Peak are also stained by iron oxides. The intrusion of the Ragged Top Latite Porphyry may have given rise to some of the iron metasomatism manifested in adjacent rocks, but Laramide activity in the vicinity of the fault has probably also contributed to this metasomatism, especially within the Precambrian metasediments and intrusives.

Three periods of mineralization—two of which may be closely related in time—are recognized in the area of investigation. The earliest is a period of copper-lead mineralization related to the granodiorite porphyry. The major period of mineralization associated with the ore zone monzonite has given rise to scattered showings of copper values throughout the range, while a final period of lead, silver(?), and copper mineralization occurred sometime between the major period of
copper deposition and the mid-Tertiary intrusion of andesitic and latitic rocks.

**Early Copper-Lead Mineralization**

The earliest mineralization seen in the area is associated with the granodiorite porphyry stock. Small amounts of lead, copper, and possibly zinc minerals are found within the stock and associated with the granodiorite porphyry dikes about the stock margins. This mineralization is always found in northeast-trending fissures and shears. As will be pointed out shortly, the later major copper mineralization associated with the ore zone monzonite was also quite strongly controlled by the northeast fracture system. Either there is a much closer association between the granodiorite porphyry and the ore zone monzonite than is advocated herein or else the dynamic forces acting upon the region at the time of the monzonite emplacement were not peculiar to the monzonite alone. The opinion favored is that the dynamics of the region were fairly consistent throughout the Laramide igneous activity.

The Franco Riqueza claims on the western slope of Ragged Top exploit the best showing of lead and copper minerals associated with this early period of mineralization. According to Mr. Steven Claflin (personal communication), these claims, worked principally for lead, have also been the subject of mine promotions. The claims have been staked on a mineralized fissure vein in granodiorite porphyry which
trends N. 75° E. and dips 50° S. Several pits and short adits on the surface outcrop of the vein show galena, chalcocite, and pyrite. A winding 300-foot adit has been driven from downhill on the west to intersect the vein far below the surface outcrop. Vein minerals from depth include galena, chalcopyrite, pyrite (sometimes thinly coated with chalcocite), and possibly minor sphalerite, with a calcite-quartz gangue. The granodiorite porphyry wallrock near the vein is relatively fresh but contains finely disseminated pyrite and chalcopyrite. It is said that a carload or two of ore have been shipped from this fissure deposit.

The only other lead minerals seen in the field associated with this period of mineralization came from a 20-foot shaft south of the granodiorite porphyry stock. This shaft is located along a bluish-colored bed of Claflin Ranch argillaceous sandstone which shows staining by malachite, azurite, and crysocolla in several places along its strike length. Granodiorite porphyry dikes are always near.

The copper showings along this favored sandy bed and elsewhere south and southwest of the stock are always in the form of the secondary minerals crysocolla, malachite, and azurite. They are accompanied by various iron oxides—usually hematite with some goethite-limonite.

The two rock fragments containing copper minerals previously mentioned as being found in the base of the Mount Lord Ignimbrite might
have belonged to this period of mineralization.

**Major Copper Mineralization**

The major period of copper mineralization is very probably associated with the ore zone monzonite. In the El Tiro and Oxide pits, the primary sulfides—mainly pyrite and chalcopyrite—occur both as disseminations and in thin seams predominantly oriented in the northeast quadrant (Richard and Courtright, 1954, p. 1096). The age of this mineralization, as has been previously shown, is approximately 65 million years.

The northeasterly control over the sulfide deposition is very apparent in the area of investigation. In the well-broken dacite porphyry just east of Union Hill, the strongest copper staining is on nearly east-west fractures. A mile to the north, pyritized monzonite porphyry dikes and copper-stained fissures in dacite porphyry trend generally N. 50° E. Northeast of the zone of alteration, copper occurs as disseminated pyrite and chalcopyrite within a few of the dikes related to the monzonite and as crysocolla, malachite, and azurite in fissures. Dikes and fissures alike possess east to northeast trends.

The copper values of this period of mineralization occur in Paleozoic sediments, dacite porphyry, Silver Bell complex, and Mount Lord Ignimbrite as well as the various dikes related to the monzonite. No significance is attached to the fact that these values are not found in
the more distant Claflin Ranch sediments and granodiorite porphyry.

**Late Lead-Silver(?) Mineralization**

Epithermal vein deposits carrying lead, silver(?), and very minor copper mineralization are found in the northwestern portion of the area. They may represent a late stage of the major period of copper mineral deposition, but they have a separate entity. According to Silver Bell pit geologist Fred Graybeal (personal communication), these galena-bearing deposits—where found in the zone of alteration—are distinctly later than the copper mineralization and contain none of the sphalerite sometimes associated with the copper minerals. On the other hand, late lead mineralization along the trace of the Barite fault is cut in one place by a mid-Tertiary quartz latite porphyry dike, thus establishing a minimum age for these epithermal deposits.

The Belmont mine and a number of prospects are located along a nearly north-south fissure zone which dips $80^\circ$ W. just north of the Tin House well. A large dump at the Belmont shaft shows a limited amount of galena, cerrusite, and anglesite with copious amounts of the gangue minerals barite, calcite, quartz, and fluorite. It is reported that the mine has been worked for ornamental calcite in more recent years, but the workings are inaccessible at the present time.

Stewart in 1912 visited a mine which fits well the description of the Belmont. From his report (1912, p. 287) the shaft on the vein is
about 100 feet deep, and over 500 feet of drifts has been driven along strike. The ore was galena, but native silver and cerargyrite were said to have been found by prospectors. A few green stains of copper carbonate were seen at depth. Stewart goes on to state that the deposit occurs in a fault-fissure, as shown at depth where the ore is a cementing of a 5-foot wide breccia zone and where some post-mineral movement is seen to have taken place.

The Belmont mine may well be located on a fault-fissure, but the "fault" is impossible to trace north or south of the various workings. Short veins carrying barite, calcite, and quartz parallel the main fissure to the west, to the east, and to the southwest at the Tin House well. The fact that the main fissure vein "cuts off" one of the erratic quartz latite porphyry dikes means very little except that this mineralization is pre-quartz latite (as seen elsewhere).

Many small pits and shafts explore galena-barite showings along the Barite fault. Recent prospecting has been conducted in two places along the fault, but all efforts have apparently been abandoned. Quartz, calcite, and fluorite are seen frequently along the trace of the fault, and minor copper staining was found at one working.

A very minor amount of galena was encountered in the hanging wall of a well-altered porphyritic syenodiorite(?) dike within grano-diorite porphyry west of the Barite fault. It is assumed that this trace of lead also belongs to the late period of mineralization.
PLATE 28

Figure A
Oxide pit with the community of Silver Bell in the background. View is to the southwest.

Figure B
A recent prospect along the Barite fault. Minor galena and secondary copper minerals are found here in a gangue of quartz, barite, calcite, and fluorite. The outcrop of the vein, which marks the location of the fault, is seen in the background.
CHAPTER VIII
INTERPRETATION OF VOLCANIC PHENOMENA

The various volcanic units of the Silver Bell Mountains have been described and their relative positions in the sequence of time discussed. With this factual information in hand, it is now possible to delve into the somewhat theoretical aspects of origin of the volcanic materials and methods of their emplacement.

Dacite Porphyry

The character of the dacite porphyry, with its rounded quartz phenocrysts and numerous xenolithic fragments set in a glassy matrix, is unique. Schmitt (Kingsbury, Entwistle, and Schmitt, 1941, p. 41) concluded that the porphyry was certainly intrusive and possibly extrusive and was moved to comment that "the dacite volcanism may have been explosive" (p. 83). Kerr (1951, p. 465) recognized the possible significance of the rounded quartz phenocrysts when he stated that "the grains have a rounding or a subangularity of a type frequently associated with sedimentary rocks."

This investigation has shown the dacite porphyry to be an intrusive—sill-like in form. An explosive nature is strongly suggested.
by the numerous xenoliths, the large fragments of quartz, and the shards of former glass in the matrix. Thus, the quartz phenocrysts need not be necessarily sedimentary but can be interpreted as volcanic, with rounding produced by gas action. Some of the quartz, however, is probably of sedimentary origin.

The dacite porphyry has some of the characteristics of an intrusive breccia or a tuffisitic breccia but certainly does not fit the type of rock implied by these terms (Wright and Bowes, 1963, p. 82-83). Nevertheless, gas action has played an important role in the evolution of the porphyry, and it is believed that the nature of the rock reflects an emplacement by fluidization. The writer visualizes the intrusion of fluidized dacite porphyry in the manner explained below.

The gas- and fragment-charged dacite porphyry magma (actually quartz latite in composition, suggesting greater viscosity and more explosive potential) rose along the Silver Bell fault zone into Paleozoic sediments. The higher the porphyry magma ascended, the more the confining pressure decreased, causing exsolution of gases and thus lending an explosive and dilative nature to the intrusive material.

Its extension to the southwest blocked by the large body of solidified alaskite, the dacite porphyry welled upward, sending small dikes and sills northeastward into the fairly resistant Paleozoic limestones, quartzites, and shales. Damp Amole-type Cretaceous (?) sediments were reached and more gas evolved. The porphyry material,
expanding constantly, spread laterally to the northeast in the weak Cretaceous(?) sediments. Dilation occurred, as did the incorporation of fragments broken by churning gas action.

The dacite porphyry probably surfaced in one or more places, venting forth gases as it did. Gas also escaped laterally through the just-formed sill and vertically into overriding Amole-type and Claflin Ranch sediments. The heat and vapor action caused an induration of the immediately overlying quartzofeldspathic clastic sediments, making them somewhat similar in appearance to the porphyry just intruded.

As the intrusive material cooled, differential movement within the newly formed sill gave rise to the flow structure seen in many places and the platy layering found in the upper portions. Such a platy parting within quartz latite sills is seen also near Pando, Colorado (Tweto, 1951, p. 507).

There are at least three ways in which the absence of the Cretaceous(?) Amole-type sediments in the eastern portion of the Silver Bell Mountains can be explained. First, the early Laramide intrusion of the alaskite probably domed up the existing thickness of Amole-type material, giving rise to rapid erosion of these sediments. Thus, by the time of the dacite porphyry intrusion, the Amole-type thickness could have been considerably reduced and even partially covered with coarse eroded material—material which would represent the earliest of the Claflin Ranch sediments.
The gas-charged intrusion of dacite porphyry offers a second way of disposing of some of the Amole-type sediments. The idea of the breaking up of some of the beds by gas action and the subsequent incorporation of the fragments into the hot material is quite reasonable and is supported by the numerous clastic rock fragments seen in the porphyry today. The Pinal-like schist fragments frequently found in the uppermost portions of the porphyry are thought to be derived from the pre-existing Cretaceous (probably early Claflin Ranch) sediments.

Finally, it can be argued that some of the well-metamorphosed and finer grained clastic sediments immediately overlying the dacite porphyry in certain portions of the range are actually remnants of the uppermost Amole-type sediments.

A combination of all three of these possibilities is believed to sufficiently account for the absence of the Cretaceous (?) Amole-type sediments northeast of the zone of alteration.

An alternate hypothesis of dacite porphyry deposition which would make the Claflin Ranch Formation entirely post-porphyry is suggested in a situation described by Hay (1954, p. 605-620) from the Absaroka range of Wyoming. Here, the idea of a laccolithic injection of andesitic tuff-breccia into detrital sediments is discussed and abandoned. Instead, Hay proposes that the tuff-breccia was deposited on the surface, later to be buried by detrital sediments. The fact that the tuff-breccia intrudes the overlying sediments is explained by late
injection due to "gravity and doming" (Hay, 1954, p. 618-619).

Several arguments can be advanced against the idea of such a sequence of events happening in the Silver Bell Mountains—the most decisive of which is the apparently intrusive contact seen in several places between the dacite porphyry and the beds of the overlying Claflin Ranch Formation. It is much easier to conceive of a remobilized intrusion or even diapiric intrusion of a tuff-breccia than it is the remobilization of a glassy dacite porphyry exhibiting flow structure.

Silver Bell Complex

The Silver Bell complex reflects a period of many diverse types of andesitic and dacitic activity. Nothing resembling a volcanic crater from which these rocks could have erupted has been found in the area, and consequently it is assumed that the andesites were poured out through fissure vents.

Indeed, it was discovered during the investigation that andesitic extrusion had probably taken place from small vents in the area south of Mesquiti well. Another possible source area is the zone of alteration, suggested by the occurrence of andesite porphyry in the Oxide pit. Furthermore, there is the prospect that vents exist unmapped but covered by ignimbrite. And finally, vents could have been obliterated by intrusion of later rocks.

Andesitic intrusions, extrusive flows, and intrusion breccias
are to be expected in such a complex as that found at Silver Bell. Auto-
clastic brecciation of the type seen in the range can be attributed to a
sudden viscosity increase in a moving flow due to lowering of tempera-
ture, loss of volatiles, and/or crystallization (Curtis, 1954, p. 467-
469). Cold lahars would be normal for a rugged andesitic terrane, with
water supplied by snows or by the thunderstorms that invariably accom-
pany volcanic activity. Even the finding of laharian breccias interbedded
with volcanic sandstones (as on the southern flank of Wolcott Peak) is not
unparalleled (Fisher, 1960, p. 128). The only truly unique portion of
the complex is the massive breccia, whose unusual character demands
more of an explanation than simply the term "hot laharian."

The most commonly mentioned types of "hot" lahars involve (1)
volcanic eruptions through crater lakes, (2) eruptions accompanying the
melting of snow and ice, (3) eruptions following heavy rains, and (4)
eruptions accompanied by heavy rains (Anderson, 1933, p. 246). Such
lahars, including hot volcanic injecta, commonly contain a large amount
of old accidental material (Gilbert, 1938, p. 1851). The Silver Bell
complex massive breccias, however, contain only a very small amount
of accidental material—a feature somewhat at discordance with the
standard conception of a hot lahar. Furthermore, if these breccias
have emanated from fissure vents rather than from a volcanic crater or
cone, the four "typical" laharian types mentioned above—which are gen-
ernally thought of as implying a crater origin—become somewhat
meaningless at Silver Bell.

A similar situation exists in the Sierra Nevada near Blairsden, California. Here, Durrell (1944, p. 255-272) has encountered large areas of andesitic breccias that contain but little foreign material and that have no known adequate source. However, eight andesite dikes found in the area were composed of the same brecciated material as was scattered over the countryside. Durrell proposes that violent escape of volatiles caused disruption of a rising but nearly crystallized andesitic magma. The brecciation by volatile escape was triggered by a lowering of external pressures and a rapid cooling of the magma as cold, wet wallrocks were encountered. Durrell concludes: "The fact that andesite breccia with a mud matrix has been intruded to form these dikes, and the fact that identical material has been extruded in the immediate vicinity, indicate that surface mudflows may originate in this way" (Durrell, 1944, p. 272).

Such an outpouring of brecciated andesite from fissure dikes is at least one plausible way of explaining the emplacement of the unusual Silver Bell complex massive breccias.

Mount Lord Ignimbrite

The emplacement of the Mount Lord Ignimbrite has already been discussed. The deposit was apparently initiated by a low pressure upwelling of effervescing magma through fissures. Its temperature
of emplacement was probably fairly high, and its greatest thickness at Silver Bell is explained by the proximity of fissure vents.

Two factors set this Cretaceous ignimbrite apart from the many Tertiary ignimbrites of the western United States discussed in literature. Its greater age has allowed time for considerable erosion, and consequently source vents have been uncovered. Neither Enlows in the Chiricahua Mountains (1955, p. 1242) nor Gilbert on the eastern side of the Sierra Nevada (1938, p. 1830) are certain of the source for the welded tuffs they describe. The greater age of the Mount Lord Ignimbrite has also permitted time for a major period of metamorphism to occur. This metamorphism—most probably associated with the emplacement of the monzonite and its associated dikes and subsequent hydrothermal activity—has given to the ignimbrite at Silver Bell a far more consistent degree of induration than seen in most similar rocks.

The Mount Lord Ignimbrite has two features that deserve some further discussion—the concurrency of andesitic activity with the emplacement of the pyroclastics and the intrusive ignimbrites.

The numerous andesitic xenoliths in the ignimbrite and the apparently close genetic relation between ignimbrite and Silver Bell complex are not unexpected. Indeed, Ross and Smith (1960, p. 35), with reference to the xenoliths found in such pyroclastic materials, state that:
Most commonly these foreign materials are those of andesitic rocks; andesitic minerals and rock fragments are so ubiquitous in tuffs from the United States and other countries that their absence seems to be a rare exception. Andesitic eruptions have commonly preceded explosive rhyolitic ones, a long recognized, almost normal geologic sequence, and so an abundance of andesitic materials in welded tuffs is to be expected.

The few andesite flow and breccia layers found well up into the ignimbrite sequence bespeak of concurrent andesite and ignimbrite activity. This phenomenon is not unusual either. Curtis (1954, p. 453-454) in the Sierra Nevada describes a welded tuff outpouring followed by some erosion and then andesite breccias. He feels that there is little age difference between these two materials and strongly suspects a genetic relation, a single cycle of volcanism interrupted by intervals of quiet and erosion.

Within the ignimbrite at Silver Bell, evidence is great for a cessation of ignimbritic activity just prior to andesite and andesite breccia outpourings. No erosional intervals during the alternating activity are indicated, however. If both the ignimbrite and the andesite were related to the same near-surface pluton, a cessation in activity of the one might in some way trigger a period of activity of the other. The thought of vents tapping different portions of the same pluton to give rise to andesites and ignimbrites is not farfetched when it is realized that these vents are close to one another and that andesitic and ignimbritic activity were concurrent. The chemical differences between the
two materials can be in part explained if the emplacement of the ignimbrite is envisioned in terms of a gas-charged pyroclastic material that was being quite heavily contaminated by the rocks through which it passed enroute to the surface.

It is certainly possible in areas of ignimbrite flows for erosion to have uncovered some of the dikelike vents which gave rise to the flows. Likewise, it is not unreasonable to suppose that the ignimbritic material in its gas-charged and dilative state, rising in the vents, could have spread laterally along weak planes and contacts in the rock in the form of sills. Such a phenomenon is seen not only at Silver Bell but also in the Piedmontite Hills section of the Tucson Mountains where Mayo (unpublished manuscript) has seen parts of a large body of ignimbrite which appear to have been intruded sill-like, or laccolithlike, into stratified fragmental volcanics.
The geologic history of the Silver Bell Mountains is imperfectly known. The findings of this investigation, however, establish with some certainty the sequence of emplacement of the various rock units, thereby permitting a certain amount of conjecture concerning the dynamical forces which have been operative in the district. This investigation has dealt primarily with Cretaceous-Tertiary geology, and consequently the events of these two periods will be stressed in the following summary.

The Precambrian basement in the Silver Bell region consists of a porphyroblastic granite intruded by diabase. The Pinal Schist, a frequent basement rock in southern Arizona, is seen in outcrop in one locality, and its existence in the region is further evidenced by the many schist fragments in the Late Cretaceous Claflin Ranch sediments. Overlying these basement rocks on an erosional contact are conglomerates and quartzites of the younger Precambrian Apache Group.

Paleozoic limestones, quartzites, and shales were deposited in shallow seas during the Cambrian, Devonian, Mississippian, Pennsylvanian and Permian periods. Erosion occurred in the earlier portions
of the Mesozoic Era, followed by the deposition of several thousands of feet of Amole-type arkosic sediments. These clastic sediments probably began forming in the early Cretaceous but may have extended back into the Jurassic.

At the beginning of the Laramide Revolution, igneous activity developed along deep-seated west-northwest-trending regional faults. This activity was reflected in the Silver Bell area by the intrusion of a body of alaskite up the Silver Bell fault zone. The alaskite worked its way slowly through Paleozoic sediments and penetrated at least the lower portion of the thick Amole-type sequence, causing a doming or general upheaval and thus giving rise to rapid erosion at the surface.

A consequence of this early orogenic activity was the formation of a series of coarse, clastic sediments to the north. These earliest Claflin Ranch deposits were fed in great part on the eroding Amole-type sediments but also received material from Paleozoic sediments, a schistose basement, and various forms of igneous activity already manifesting themselves throughout the region. Some airborne tuffs may have incremented the thickness of the growing Claflin Ranch Formation.

As these sediments were forming, a gas- and fragment-charged dacite porphyry invaded the northeastern side of the Silver Bell fault zone. Blocked by the alaskite on the southwest, the dilative porphyry expanded into Paleozoic and Cretaceous sediments on the northeast. The favored plane of entry was the contact between Paleozoic limestones
and the remaining Amole-type sediments, now overlapped by the coarser Claflin Ranch beds. As the dacite porphyry surged northeastward dilating and incorporating sediments, it formed a large sill-like or laccolith-like body. The porphyry intruded Claflin Ranch sediments to the north in the form of small dikes and sills and may have surfaced in one or more locations giving rise to flows and/or tuffs.

The invasion of the dacite porphyry again domed the country just northeast of the Silver Bell fault zone. Another period of erosion ensued, and the Claflin Ranch sediments and remaining Amole-type sediments were stripped from the roof of the just-formed sill and transported to the northeast, north, and northwest. In at least one location—the vicinity of Silver Bell Peak—the dacite porphyry was unroofed and eroded, supplying material to the continually forming Claflin Ranch Formation.

Approximately 70 million years ago another large plutonic body forged into the Silver Bell area. Fissures opened up in several locations and spewed forth andesitic and dacitic breccias. These massive breccias filled topographic lows in the eroded terrane near the present-day Silver Bell Peak and poured out over the areas to the north where clastic sediments were still being formed. Soon a whole entanglement of andesitic and dacitic activity broke out. Andesitic flows, tuffs, lahars, and intrusions—which, along with the massive breccias, compose the Silver Bell complex—flooded much of the area between the
present-day Ragged Top Mountain and the town of Silver Bell. In places a little farther to the west, Claflin Ranch sediments were being deposited upon the recently formed massive breccias.

Another surge of igneous activity soon followed. A granodiorite porphyry with a relatively fine-grained matrix intruded the area in several localities. East of Silver Bell this porphyry invaded the massive andesitic breccias and may have surfaced to give rise to some of the materials attributed herein to the Silver Bell complex. Granodiorite porphyry also rose in places near the Ragged Mountain fault—another profound west-northwest-trending break—forming a fair-sized stock west of the present-day Ragged Top Mountain. The porphyry may have surfaced in this area too.

Both a minor period of copper-lead mineralization and a stage of andesite dike invasion closely followed the intrusion of the granodiorite porphyry stock. Tensional openings striking northeast controlled the emplacement of all of the mineralization and most of the dikes.

Probably the same subterranean igneous mass which gave rise to the Silver Bell complex and the granodiorite porphyry now yielded a period of pyroclastic activity. Ignimbrites welled up in fissure-dikes along a west-northwest trend and flowed out onto a somewhat rugged andesitic terrane. Several units were deposited—their continuity occasionally interrupted by minor andesite and andesite breccia flows. With a solidifying of the pyroclastic material in some of the fissure
vents, intrusive ignimbrites formed sills by spreading laterally along contacts in the rocks below the main ignimbrite sequence. The climax of the Mount Lord Ignimbrite activity (and also of the cycle of volcanic action which started with the massive breccias) came with the emplacement of a lithic vitric tuff.

It is probable that deposition of coarse, clastic Claflin-like sediments continued through the conclusion of the ignimbritic activity in the country west of the eastern Silver Bell Mountains. No Claflin Ranch sediments of a post-granodiorite porphyry age could be positively identified in the area of investigation.

Approximately 65 million years ago—near the close of the Cretaceous period—a final stage of Laramide igneous activity began in the Silver Bell fault zone. Dikes of porphyritic syenodiorite and pyroxene- and quartz-bearing syenodiorite porphyry controlled by the east to northeast direction of tension fractures intruded the volcanic complex. Shortly thereafter monzonite and quartz monzonite invaded the upper portions of the Silver Bell fault zone, sending monzonite porphyry dikes again to the east and northeast into the volcanic complex. It is possible that the monzonite intrusion was partially responsible for the 30° northeast tilting of the structural block between the Silver Bell fault zone and the Ragged Mountain fault.

The subsequent major period of hydrothermal alteration and copper mineralization had a profound effect in a metamorphic capacity
on all the rocks of the volcanic complex. Alteration and mineralization were again controlled by the northeast direction of tension fractures. The major copper deposition occurred in the west-northwest-trending zone occupied by the large monzonite plutons, and only very minor mineralization was associated with the dikes which swarmed to the northeast.

A final period of lead-silver(?)—barite mineralization possibly related to the formation of the major copper deposits occurred along north-northeast-trending faults and fissures north of the zone of alteration. These breaks—two of which show over 100 feet of normal movement—may have been caused by subsidence following the emission of the Mount Lord Ignimbrite.

The final igneous activity in the area of investigation occurred in late Oligocene—early Miocene times. The injection of pyroxene and hornblende andesite dikes probably preceded the emplacement of quartz latite porphyry dikes. At any rate, all of these dikes intruded highly fractured ground, as shown by their broken traces, and were oriented in the northwest direction—evidently a direction of relaxation following the Laramide activity. At roughly the same time the Ragged Top Latite Porphyry welled up along the major Ragged Mountain fault.

Table 1 (p. 45), which has summarized the petrography of the Cretaceous and Tertiary igneous rocks of the district, shows no particular trend (or trends) of changing chemical composition with the passing
of time. This lack of consistent change within the igneous rocks of the Silver Bell Mountains is significant. It indicates that the classical sequence of rock emplacement representing a body (or bodies) of continually differentiating magma need not be evinced in an area of great volcanic-intrusive complexity.

The Silver Bell Mountains have been undergoing erosion since some unknown time in the Tertiary. This erosion, which has revealed so much of the geology of the range, has also stripped away many of the rocks needed to complete the picture of the geologic history of the district.
CHAPTER X
APPENDIX
SUPPLEMENTARY PETROGRAPHIC DESCRIPTIONS
Silver Bell Complex Flows and Intrusions—Supplement

Six of the more prominent Silver Bell complex unbrecciated flows and intrusives are described in the following pages.

(1) A greenish-gray dacite porphyry is found frequently overlying and sometimes intruding the massive breccias on the southwestern flank of the range. This porphyry, half phenocryst and half groundmass, contains quartz, 20 percent; feldspar, 55 percent; altered biotite, 7 percent; calcite, 15 percent; and minor amounts of apatite and oxidizing magnetite.

The quartz occurs as small subangular to rounded phenocrysts up to .5 mm in diameter and as large subrounded to rounded, deeply embayed phenocrysts up to 6 mm in diameter. Feldspar exhibiting both albite and pericline twinning is present as well-sericitized, argillized, and calcitized phenocrysts (An₃₀?) up to 9 mm long. The devitrified and recrystallized groundmass is almost entirely composed of feldspar, with index of refraction indicating a moderate amount of orthoclase. Plates of biotite up to 2 mm long are altered to chlorite, muscovite, and white opaque (possibly clay and/or leucocene) and contain most of the euhedral apatite. Calcite in veinlets and as patches in plagioclase phenocrysts, biotite phenocrysts, and feldspathic matrix indicates hydrothermal activity—as does the rather heavy sericitization of plagioclase phenocrysts.
This particular porphyry appears to be on the borderline between quartz latite and dacite in composition.

(2) A gray porphyry, well-altered in appearance, overlies the above-described porphyry in one place near the center of section 2 and crops out again to the northeast in the bottom of a large canyon (northwest corner, section 3). It is overlain by ignimbrites in both localities and intruded by narrow ignimbrite dikes and sills in section 2.

An alinement indicating subhorizontal flow is shown in the phenocrysts which compose 50 percent of this rock. Euhedral and subhedral andesine plagioclase constitute the majority of the phenocrysts, while minor amounts of magnetite, biotite, hornblende, and quartz make up the rest. The andesine with phenocrysts up to 2 mm in length is frequently twinned and occasionally zoned. The devitrified groundmass shows much microcrystalline feldspar.

Hydrothermal alteration is strong, as might be expected of a material intruded by and immediately overlain by ignimbrites. Quartz, sericite, calcite, and epidote appear in veinlets. What little quartz was present in the original rock has been mobilized and concentrated in the groundmass. Both plagioclase and ferromagnesian phenocrysts are well altered.

(3) A dark-gray porphyry liberally speckled with white feldspar phenocrysts covers a considerable area in the southeastern portion of section 26 and the northeastern portion of section 35. Flow structure
is indicated by parallel alinement of some plagioclase laths and a few biotite and hornblende phenocrysts. The rock consists of quartz, 5 percent; plagioclase (An\textsubscript{35-40}), 28 percent; altered ferromagnesian minerals (biotite and hornblende), 15 percent; magnetite, 3 percent; cryptocrystalline feldspathic groundmass, 45 percent; and minor sphene, leucocene, apatite, epidote, zircon, calcite, and chlorite.

Quartz is subangular to rounded and frequently embayed, with phenocrysts up to 2 mm in diameter. The andesine occurs as euhedral to subhedral, moderately sericitized phenocrysts up to 3.5 mm in length. Carlsbad twinning is common, but albite twinning is frequently obliterated by alteration. Approximately equal amounts of biotite and hornblende have altered to chlorite, muscovite, and white opaque. The iron metasomatism so prominent in the ferromagnesian minerals of the massive breccias is incipient here, as shown by thin shells of hematite, limonite, and magnetite that rim all ferromagnesian phenocrysts.

This porphyry has undergone both deuteric and hydrothermal alteration. The latter is shown by the iron metasomatism, by the liberal amount of sericite present, and possibly by calcite and epidote replacement of ferromagnesian minerals. Hydrothermal alteration is most apparent in the proximity of crosscutting dikes.

(4) A light-gray porphyry is prominent west and southwest of the Claflin Ranch buildings. Phenocrysts constitute 60 percent of the rock, and a devitrified groundmass constitutes the remainder.
Recognizable minerals are as follows: quartz, 1 percent; plagioclase (An?), 45 percent; altered hornblende and biotite, 2 percent; pennine chlorite, 5 percent; calcite, 4 percent; opaques (including magnetite, ilmenite, and leucocene), 10 percent; and minor sphene, epidote, apatite, and zircon.

The plagioclase occurs as randomly oriented euhedral to subhedral phenocrysts occasionally as long as 6 mm but usually much smaller. Hornblende and biotite have altered to chlorite plus white opaque and have been replaced by calcite and epidote. What apparently were gas cavities are seen throughout the rock. Sometimes equidimensional, sometimes irregularly shaped, these cavities are generally lined with calcite or quartz and filled with pennine chlorite. A few are filled entirely by calcite or chlorite.

Some local hydrothermal activity is indicated by coarse sericite and occasionally thick clay in the feldspar and by the introduction of quartz, calcite, and chlorite.

(5) A purple porphyry with white plagioclase phenocrysts and a few quartz phenocrysts fills a portion of a small basin half a mile southwest of the Claflin Ranch buildings. The bright-purple color of this rock makes the area of outcrop conspicuous from a distance. The groundmass, 40 percent of the rock, is devitrified and recrystallized feldspathic material, while the rest of the rock is composed of quartz, 5 percent; feldspar, 38 percent; iron-replaced ferromagnesian minerals
(biotite and hornblende), 8 percent; calcite, 5 percent; and oxidizing magnetite, 4 percent.

The quartz occurs as embayed subangular to rounded phenocrysts up to 4 mm in diameter and as rounded and corroded grains a fraction of a millimeter in diameter. The feldspar phenocrysts are probably plagioclase. They are euhedral to subhedral, up to 5 mm in length, and strongly altered to clay and sericite. Biotite and hornblende have been completely replaced by iron oxide. Calcite is found as patches throughout the rock in feldspar phenocrysts and in the matrix. Hydrothermal alteration is evinced by quartz mobilization in the form of one veinlet, by the iron replacement of ferromagnesian minerals, and by the extreme argillization of feldspars.

(6) A gray porphyry north of Mesquiti well is found as two elongate bodies which locally display vertical flow structure. The porphyry consists of embayed quartz phenocrysts, 2 percent; euhedral to anhedral altered feldspar phenocrysts, 50 percent; and altered biotite and/or hornblende phenocrysts, 3 percent set in a matrix of brown glass. Minor epidote replaces feldspar, and 4 percent of euhedral and oxidizing magnetite is scattered throughout the rock. Apatite, chlorite, and leucocene are present in small quantities.

Parallel alinement of feldspar phenocrysts, veinlets of a hydrous iron silicate and quartz, and linear zones of coarsened matrix account for the flow structure. Within these latter zones the matrix
has been devitrified and recrystallized, apparently by rising gases and/or solutions.

Monzonite Porphyry Dikes—Supplement

Four types of monzonite porphyry dikes related to the ore zone monzonite are described below. A fifth type—monzonite porphyry No. 1 of table 1—was previously discussed.

(2) Just north and northeast of Oxide pit a second dike type, transitional to the one described previously in the section on "Monzonite Porphyry Dikes," is found in great numbers. This grayish monzonite porphyry has up to 50 percent of phenocrysts, with a few embayed quartz phenocrysts and the occasional presence of a good-sized orthoclase phenocryst of note. Epidote occurs as small radiating crystals, and sphene is a common minor accessory altering to calcite and leucocene. The groundmass is fine grained allotriomorphic granular with much argillized potash feldspar present. The alteration is generally too strong to be deuteric alone. Heavy argillation is common, and small amounts of quartz have been mobilized and concentrated in the matrix.

(3) A third monzonite porphyry, transitional to each of the first two types described, is found always in close proximity to the zone of alteration. It is lighter gray in color with white plagioclase phenocrysts, a few small quartz phenocrysts, and large 6-sided biotite books conspicuous in hand specimen. Petrographically, the plagioclase
(An₃₀) phenocrysts are euhedral to subhedral, strongly kaolinized, and up to 4 mm in diameter. Biotite books as thick as 6 mm are altered to pennine chlorite and opaque and replaced by calcite and epidote. No hornblende was found, but 1 to 2 percent of sphene is commonly present. The groundmass is quartzofeldspathic, fine grained, allotriomorphic granular—so fine grained that the rock is probably more correctly a quartz latite porphyry. This porphyry, where found, is usually pyritized.

(4) A distinctly different type of monzonite porphyry dike is found on, and to the northeast of, Mount Mammoth. These dikes are later than the monzonite porphyry dikes so far described, but they are often found alongside other of the dikes related to the monzonite. In hand specimen this moderately resistant rock is gray to reddish gray in color and contains no more than 20 percent of phenocrysts; especially visible are occasional small quartz phenocrysts, occasional small biotite flakes, and diagnostic euhedral to subhedral pinkish feldspars up to .3 inch in size. Under the microscope, the feldspar phenocrysts are seen to be a twinned plagioclase (An₃₀), moderately argillized and calcitized, and lightly sericitized. Quartz phenocrysts are embayed and as much as 2.5 mm in diameter. Biotite and hornblende are completely altered to chlorite. Minor amounts of ilmenitic magnetite, leucocene, apatite, and zircon are usually present. The groundmass, sometimes very cloudy due to alteration, is fine grained hypidiomorphic granular
(5) A final dike type consists of a single dike that trends north-east from Paleozoic limestone onto Mount Mammoth where it is lost in cover, to be picked up again a mile north of Oxide pit. In this latter area it splits one of the late monzonite porphyry dikes described above and intrudes it. This dike is characterized by well-formed orthoclase crystals—including numerous Carlsbad twins—up to 2 inches in length. Weathering has progressed to the point where these orthoclase crystals can usually be plucked, intact, from the rock. Petrographically, this dike, a quartz monzonite porphyry, is seen to contain 20 percent of quartz (subrounded and embayed, up to 7 mm in diameter), 10 percent of orthoclase crystals, 20 percent of plagioclase (An₂₈₋₃₁, euhedral to subhedral, moderately argillized and lightly sericitized, up to 4 mm in size), 2 percent of chloritized biotite, 3 percent of calcite, 2 percent of ilmenitic magnetite and leucocene, minor apatite and zircon, and 40 percent of feldspathic microcrystalline matrix. The fine-grained matrix of the rock discounts an in situ pegmatitic growth of the orthoclase crystals. These crystals were evidently formed elsewhere and carried to their present positions during the emplacement of the dikes.
CHAPTER XI
REFERENCES CITED


Richard 1963, Structure and mineralization at Silver Bell, Arizona (revision): unpublished manuscript.


MINERALIZATION IN THE EASTERN PORTION OF THE SILVER BELL MOUNTAINS, PIMA COUNTY, ARIZONA
GEOLOGIC SECTIONS OF THE EASTERN PORTION OF THE SILVER BELL MOUNTAINS, PIMA COUNTY, ARIZONA

Vertical exaggeration for all sections-1:1.67. Dike thicknesses are also exaggerated.

Note: see plate 1 for explanation and location of geologic sections. Geology by B. Watson, 1962-63.