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Geology and Mineralization of the Silver Dyke Mine
Mineral County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology

by

Steven Perry Kilbreath

May 1979
The thesis of Steven Perry Kilbreath is approved:

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May 1979
ABSTRACT

The Silver Dyke Mine is in the eastern Excelsior Mountains about 16 kilometers southwest of Mina, Nevada. The oldest rocks in the area are metasediments of the Permian Mina Formation. Triassic-Jurassic metavolcanic rocks of the Gold Range Formation unconformably overlie the Mina Formation. Both these units are intruded by stocks of diorite, quartz monzonite and granite of Cretaceous age. Andesite flows and rhyolite ashflows overlie all of the above rocks.

The Silver Dyke Mine is an epithermal tungsten deposit in a large, through-going quartz vein. The tungsten mineral present is a yellow fluorescing, high molybdenum scheelite. The scheelite is concentrated in brecciated zones of diorite along the footwall of the vein. The scheelite occurs as veinlets, pods and rims around diorite fragments. The age of the mineralization is 17.3 m.y.,
ACKNOWLEDGEMENTS

Dr. L. T. Larson provided guidance for the project in addition to reviewing the manuscript and helping with mineral determinations. Dr. E. R. Larson provided first hand knowledge of the structure and stratigraphy of the area. Dr. Robert McKee reviewed the manuscript. Peter Kirwin of Continental Oil Company released private data for the study. Larry Garside of the Nevada Bureau of Mines and Geology contributed many stimulating discussions on the local geology. J. Mark Johnson, a fellow graduate student helped with the underground mapping. My father, Marion Kilbreath also gave his time to provide very valuable help with the underground mapping.

Very special thanks go to my wife Phyllis for typing the rough and final drafts of the thesis and for the patience to endure the project.
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INTRODUCTION

Location and Access

The Silver Dyke Mine is in the eastern portion of the Silver Star Mining District, Mineral County, Nevada, in the heart of the eastern Excelsior Mountains (Figure 1). The mine is approximately 10 air miles southwest of Mina, Nevada, and lies within sections 3 and 4, T. 5N., R. 34 E., M.D.B. & M.. The mine is reached from Mina by traveling south on U.S. Highway 95 for seven miles, then turning west on a poorly marked gravel road. This road crosses the western flank of Rhodes Salt Marsh and proceeds up the alluvial fan to the mouth of Silver Dyke Canyon. The road follows the canyon bottom about two miles to the old mill and townsite for the mine. Up to this point, the road can be traveled by a two-wheel drive vehicle. Just past the townsite the road turns into four-wheel drive only for the last 1/4 mile to the portal of the main haulage level. Access to the rest of the mine workings is gained by walking from this point.

The part of the Excelsior Mountains which contains the Silver Dyke Mine has a typical arid vegetation consisting mainly of pinon pine, sagebrush and low grasses.

Purpose

The purpose of this study is three-fold. First, it is to accurately describe the geology of the mine area which includes regional and local stratigraphy and structure, and, to describe some of the underground geology within the mine. Second, to interpret this geology in terms of its relationship to the genesis of the ore deposit. Third, to
Figure 1. General location map to the Silver Dyke area.
determine what, if any, future potential there is for the Silver Dyke Mine.

Methods

Surface geology was mapped at scales of 1:24,000 and 1:6,000. The regional geology was mapped directly on 1:24,000 color aerial photographs and then transferred to a composite base map consisting of portions of the Camp Douglas and Moho Mountain 7-1/2 minute quadrangle maps. The regional map consists of an area of approximately 36 square miles, in which the Silver Dyke Mine is centrally located. The local geology was plotted on 1:6,000 black and white enlargements of the above photographs and then transferred to a 1:6,000 enlargement of a portion of the Camp Douglas quadrangle map. The underground mapping was done on a scale of 1:120 (1"=10') by the Brunton and tape method.

A petrographic study was made of 75 thin sections of rocks collected on the surface and from the underground workings. A total of 12 polished sections were made and analyzed. X-ray diffraction determinations were made on several minerals and staining procedures for alkali feldspar and plagioclase feldspar were used on about 1/2 of the thin section plugs.

Previous Work

The previous work within the Excelsior Mountains is limited to reports on the mining districts and small sections within works of a broad regional nature. The first mention of the Excelsior Mountains is by Spurr (1905) in a brief description of the Paradise Range, Pilot and
Excelsior Mountains. Short comments on the geology are made by Hill (1915) and Vanderburg (1937) in a description of the mining districts within the range. Muller and Ferguson (1936) are the first to describe and name the formations within the area. Muller and Ferguson (1939) and Ferguson and Muller (1949) give more detailed descriptions on the stratigraphy and structure within the Excelsior Mountains. In 1954, a geologic map with text of the Mina quadrangle was printed by the United States Geological Survey. In 1961, Ross put together a compilation report on Mineral County that included all of the above information. Nielsen (1964) named and described a new formation in the Excelsior Mountains. Speed (1977) named two new formations and thoroughly described the stratigraphy of the eastern Excelsior Mountains.

Larry Garside from the Nevada Bureau of Mines and Geology is in the process of publishing a geologic map of the Camp Douglas 7-1/2 minute quadrangle. J. Mark Johnson and Steven Borbas, students at Mackay School of Mines, have recently finished Master's Thesis projects in the Marietta area of the central Excelsior Mountains about 16 kilometers west of the Silver Dyke area.

The "Excelsior Problem"

The first work where any formational names were published was that of Siemon Muller and Henry Ferguson in 1936. They recognized two formations within the study area, the Excelsior and Dunlap formations. In their words, "the Excelsior consists of dominantly effusive and pyroclastic rocks, with subordinate sediment" (Muller and Ferguson, 1936, p. 242). In more detail, they stated that lavas ranging from andesites to rhyolites, andesitic breccias, keratophyres, gabbroic to silicious intru-
sives and marine chert are all present within the Excelsior. The Dunlap was defined as a sandstone-conglomerate sequence. An age of middle Triassic was assigned to the Excelsior on the basis of fossils collected in a limestone lense within a volcanic sequence in the Gillis Range approximately 35 miles NNW of the study area. The Dunlap formation is upper Jurassic in age. From this first description, it can be seen that the Excelsior Formation consists of quite a wide variety of lithologies.

In 1939, Muller and Ferguson published a more detailed description of the stratigraphy of the Hawthorne and Tonopah area. In this work, little change was made in the description of the Excelsior and Dunlap formations. They state that within the Excelsior mountains the sedimentary sequence of the Excelsior was overlain by thick flows of felsite (Muller and Ferguson, 1939, p. 1587). This felsite will later become the Gold Range Formation of Nielson.

In 1949, Ferguson and Muller published U.S.G.S. P.P. 216, Structural Geology of the Hawthorne and Tonopah Quadrangles, Nevada. In this exceptional report, they point out two very pertinent things related to the study area. The first of these is shown on plate 14 of the report. In the cross section through Thunder Mountain, they show chert and felsite of the Excelsior, and breccia and conglomerate of the Dunlap as a conformable sequence. The second point of significance is a statement pertaining to the validity of the age and correlations within the Excelsior. This statement is, "the isolated patches of pre-Tertiary volcanic rocks in the two quadrangles can be correlated with the Gillis Range Excelsior formation only with reservation and as a temporary expedient pending further investigation" (Ferguson and Muller,
1949, p. 5). Ferguson and Muller are admitting that the Excelsior is a problem and to speed up mapping they are putting rocks of various lithologies and ages into it.

The first major breakthrough in solving the Excelsior Problem came in 1964 with the recognition of the Gold Range formation (Nielsen, 1964). In this work, the Excelsior was said to consist of cherts and submarine andesitic tuffs, the former being of tuffaceous nature. The remainder of the Excelsior rocks and the Dunlap were termed Gold Range Formation, and defined as chert pebble conglomerate, sandstones, and subaerial to subaqueous rhyolitic volcanics. In this work, the small amount of Dunlap present on Thunder Mountain was termed Gold Range. This work was never published so the formational changes Nielsen suggested were never formally defined although a few workers have used these names in the literature (Archibald, 1970; Stanley, 1971). This brings us to a point where part of the "Excelsior Problem" has been solved and different rocks of different origins and ages are no longer being called the same formation.

The most recent development in this problem is the abandonment of the usage Excelsior Formation and the formal establishing of Mina, Gold Range and Black Dyke formations (Speed, 1977). The Black Dyke is not within the study area and will not be discussed in this report. The Mina Formation is defined as a series of turbidity deposited graywackes, pelites and chert-clastic units. A minimum age of 256 m.y. is presented for the Mina Formation (Speed, 1977, p. 332). The Gold Range Formation is defined as a lower unit of feldspar-quartz-chert wacke (the quartz keratophyre of Nielsen, 1964) that grades upward into massive tuff,
breccia and sedimentary rocks (the felsite of Ferguson, 1949 and the quartz keratophyre of Nielsen, 1964). Overlying this is a sedimentary sequence of dark gritty or pebbly wacke with a high proportion of volcanic fragments (the Dunlap of Ferguson, 1949; the chert pebble conglomerate of Nielsen, 1964).

The recent work of Bob Speed is truly a beginning in solving the "Excelsior Problem". His work was confined to the Garfield Hills and the eastern Excelsior Mountains, so he did not examine all of the "Excelsior" rocks of Mineral County. Until the time when these detailed examinations are made, I believe we should go along with Speed's suggestions for abandoning usage of Excelsior Formation for the rocks that are newly defined. He suggests that the term "Excelsior Rocks" (not indicating formational standing) be used for the remainder of the previous Excelsior Formation that has not been redefined (Speed, 1977, p. 327).
REGIONAL GEOLOGIC SETTING

The oldest rocks in the area of the eastern Excelsior Mountains are assigned to the Permian Mina Formation (Speed, 1977). Jurassic-Triassic metavolcanic rocks of the Gold Range Formation (Speed, 1977; Nielsen, 1964) unconformably overlie the Mina Formation. Intruding the Paleozoic and Mesozoic rocks are Cretaceous stocks of diorite, quartz monzonite and granite. Rhyolitic ashflow tuffs and andesite flows of Oligocene and Miocene age unconformably overlie all of the above rocks in the study area.

The Eastern Excelsior Mountains is an area of complex faulting and folding. Faulting of two distinctly different ages and styles is present. Thrust faulting of Jurassic (Speed; 1977; Ferguson, 1949) age is present along with Basin and Range related normal and strike-slip faulting. Two separate styles of folding are present in the pre-Cenozoic rocks of the area.

Stratigraphy

The Permian Mina Formation (formerly Excelsior) in this area consists mostly of structurally overturned metasedimentary rocks. Two distinctly different members of the Mina Formation were mapped in the eastern Excelsior mountains during the regional phase of this study. The older of the two is predominantly volcanoclastic graywacke which is about 610 meters thick. The rock is typically dark gray-green, hard, and medium to coarse grained. The unit contains scattered beds of conglomerate that contain clasts of andesite and diorite. Conformably overlying the Graywacke Member is the Chert-Argillite Member of the
Mina Formation (Speed, 1977). This member typically forms blocky to jagged ribs (Figure 2) of chert separated by more easily eroded beds of argillite. The individual chert beds range in thickness from a few centimeters to about 10 meters with similar thicknesses of argillite between them. The Chert-Argillite Member may be as much as 1,525 meters thick.

The total thickness of the Mina Formation in the eastern Excelsior Mountains is about 2,135 meters. The top and bottom of the formation are not exposed so this is minimum thickness. The Permian age for the Mina Formation is attained by radiometric and paleontological dating. Speed (1977) dated hornblende samples from the Graywacke Member and obtained a minimum age of 256 m.y. for the time of deposition. The reasoning behind dating detrital hornblendes is deposition and the volcanism supplying the hornblendes are considered by Speed to be fairly contemporaneous. Also giving evidence for a Permian age were fossils collected near the Moho Mine (Plate 1). The fossil collection contains fragmental fusulinids, crinoid stems, bryozoa and organic debris. The fusulinids were identified as Schwagerina sp., which is an early Permian form (Speed, 1977, p. 332).

The Jurassic-Triassic Gold Range Formation (Speed, 1977; Nielsen, 1964) of the eastern Excelsior Mountains consists of terrigenous and sedimentary volcanogenic layered rocks. Three members of this formation were mapped in the study area. The lower and upper members are volcanoclastic-sedimentary rocks and the middle member is comprised entirely of sub-aerial volcanic rocks. The lower member of the Gold Range Formation is a sequence of silts, wackes, conglomerates, and breccias. The low-
Figure 2. Typical outcropping of the Chert-Argillite Member of the Mina Formation. Note the blocky rib-like outcrops of the chert with the interbeds of argillite being more easily eroded.
est exposed portion of this member is a sequence of dark gray-green to black hornfels with interbeds of dark gray, chert-volcanic pebble conglomerate. Overlying the hornfels is a sequence of feldspathic-lithic wackes with minor lenses of coarse volcanic breccia. The wacke is typically gray to dark green and consists of medium to coarse sand sized grains of plagioclase, pyroxene, amphibole, rock fragments, and minor quartz. Scattered breccia beds are made up of angular fragments of feldspar-quartz-biotite porphyry. The middle member of the Gold Range Formation is comprised entirely of subaerial rhyolitic ashflow tuffs. They are typically gray to brown with phenocrysts of quartz and feldspar. Compaction foliation, flow banding, and shard textures are locally recognizable within these rocks. Scattered through the section are breccia zones of plagioclase-alkali feldspar-quartz-biotite porphyry. The top of this member is marked by a distinct zone of flow banding and flow brecciation. Conformably overlying the tuffs are volcanoclastic-sedimentary sequences of wackes and interbedded conglomerates. The conglomerate beds range from a few centimeters up to 30 meters in thickness and are separated by equivalent thicknesses of wacke. Near the base of this unit the clasts in the conglomerate are predominantly volcanics, derived from the underlying tuffs. As you go up section, the volcanic clasts give way to an increasing number of chert and argillite clasts. Locally, the conglomerate beds may be comprised entirely of chert-argillite or volcanic clasts.

The age of the Gold Range Formation is somewhat speculative and uncertain. An age of Triassic to Early Jurassic has been assigned by Speed (1977) and Nielsen (1964). Total thickness of the Gold Range
Formation is approximately 2,450 meters. The lower member is 1,500 meters thick, the middle member is 580 meters thick and the upper member is 370 meters in thickness.

Intrusive Rocks

Intruding all of the pre-Cenozoic bedded rocks are stocks ranging in composition from diorite to granite. The easternmost and oldest of the intrusives are two stocks of diorite that are 101 ± 4 m.y. in age (Garside, 1978). These are typically medium grained, equigranular, dark gray, hornblende-biotite-hypersthenoe diorite. These two bodies are thought to be separate outcrops of the same intrusive. The next oldest stock is a 92.8 ± 2.8 m.y. old (Garside, 1978) quartz monzonite. It is typically buff in color, equigranular to porphyritic, with phenocrysts of biotite, quartz, plagioclase and alkali feldspar. The most recent of the intrusive rocks are dikes and plug-like masses of granite porphyry. These porphyries are 89.5 ± 2.7 m.y. in age (Garside, 1978). The porphyries consist of phenocrysts of quartz with lesser amounts of alkali and plagioclase feldspar with a minor amount of biotite in a very fine grained matrix of quartz and alkali feldspar.

Extrusive Rocks

A wide variety of Tertiary volcanic rocks cap the pre-Tertiary rocks in the study area (Plate 1). Two units were mapped, a sequence of ash-flows and a series of undifferentiated andesite flows. The tuffs are very distinct white, crystal rich, ash-flow units that mark the base of the Tertiary section. As many as five different tuffs may be present in this unit that range from 21.9 ± 1.4 to 27.2 ± 1.5 m.
y. in age (Marvin & others, 1977). Overlying the basal tuff is a series of dark gray, porphyritic, hornblende andesite flows. The age of these flows ranges from 15.7 ± .5 to 17.4 ± .5 m.y. (Marvin & others, 1977; Garside, 1978).

**Structure of the Eastern Excelsior Mountains**

The eastern Excelsior Mountains are in the western margin of the Basin and Range Structural Province. There are three periods of structural deformation present within the eastern Excelsior Mountains. These are early Jurassic, Cretaceous and late Tertiary (Ferguson and Müller, 1949). The first of these, early Jurassic, consists of thrust faulting and two separate styles of folding. The second period of deformation is related to the intrusive emplacement of Cretaceous age. Superimposed on the older structure is Basin and Range high angle normal faulting and large displacement strike-slip faulting of Miocene to present in age (Silberman, 1976).

The early Jurassic deformation is manifested in two ways: first, in thrusting of the Mina Formation over the Gold Range Formation with accompanying folding of the Mina Formation; and, second, folding of the Gold Range Formation. In the area of Silver Dyke Canyon (Plate 1), a large section of the Chert-Argillite Member of the Mina Formation is thrust upon the younger Gold Range (Figure 4) Formation. The rocks of the Mina Formation are all structurally overturned and tightly folded in the upper plate of the thrust. A series of tight antiforms and synforms were developed during the period of thrusting. The axial trend of this type of folding should be at right angles to the direction of thrust emplacement. The axial trend developed is N 10°-20° W and in-
icates a direction of thrust emplacement from roughly due east or west of the Excelsior Mountains. The large antiform just east of Silver Dyke Canyon exemplifies the style of folding present. This is an antiformal syncline with the west limb overturned to the point where the bedding is upright (Figures 3 and 4). Gentle and open folding occurring in the Gold Range Formation is also related to this Jurassic period of deformation. This type of folding is exemplified by the gentle syncline in the Thunder Mountain area with an axial trend of N 10° E.

The age of the above described deformation is clearly early Jurassic or younger as evidenced by the fact that the upper beds of the Gold Range Formation in the Pilot Mountains contain a fauna indicative of early Jurassic age (i.e. Weyla sp., Speed, 1977). Since the Mina Formation is thrust on the Gold Range and the Gold Range is folded, the deformation has to be post Gold Range, at least early Jurassic.

Another period of pre-Cenozoic deformation in the eastern Excelsior Mountains is shown by the doming of the Gold Range Formation due to intrusion of the diorite stock. Rocks of the Gold Range Formation are clearly pushed up and away from the contacts of the diorite. The diorite has been K/Ar dated at 98 m.y. so this deformation has to be of that age. It is possible that the gentle folding of the Gold Range described above may be related to intrusive doming also.

The last period of structural deformation is the development of Basin Range normal faults and accompanying large displacement strike-slip faults. This deformation is Cenozoic in age and probably began in the Miocene and is still going on today (Silberman, 1976).

The Basin Range topography has long been recognized as a series of
Figure 3. Map view and cross section of the folding present in the upper plate of the Silver Dyke Thrust. This map is located at the mouth of Silver Dyke Canyon just south of the boundary of Plate 3.
Figure 4. The Silver Dyke Thrust, rocks of the Permian Mina Formation are thrust over the Triassic-Jurassic Gold Range Formation. The direction of the photograph is looking due east over Silver Dyke Canyon to the Pilot Mountains on the horizon.
mountain ranges that are horsts and grabens with gently tilted fault blocks bounded by steeply dipping normal faults. In the central and northern part of the Great Basin these ranges generally trend north to northeast (Sales, 1965). The western margin of the Basin and Range is marked by a noticeably nonlinear, contorted and low set of ranges. A large number of these ranges trend in a northwesterly direction as a result of a series of northwest trending right lateral strike-slip faults of the San Andreas type. This zone was first recognized as an area of major right lateral slip by Gianella and Callaghan (1934) and was named "Walker Lane". Nielsen (1965) has 16.1 kilometers of right lateral displacement on the Soda Springs Valley Fault and 3.2 kilometers on the Battle's Well Fault (Figure 5). Stewart and others (1968) have documented 16-19 kilometers of right lateral offset on the Stewart Valley Fault, and Hardyman (1975) has found 48 kilometers total displacement on four faults in the north end of the Gillis Range. This brief summary shows that there has been a very significant amount of movement on the "Walker Lane".

The "Walker Lane" for practical purposes can be defined as a zone of right lateral offset that is 50-80 kilometers wide which extends from the Monte Cristo Range on the south through the Gillis Range and probably extending to Pyramid Lake on the north. In Mineral County there is 30-50 kilometers of right lateral offset on a series of at least four parallel faults. Associated with the "Walker Lane" is a conjugate left lateral fault of unknown displacement along the southern end of the Excelsior Mountains (Shawe, 1965). For a detailed discussion on the origin of the "Walker Lane" and San Andreas type features as they
Figure 5. General relationships of the Walker Lane and the Eastern Excelsior Mountains (after Nielsen, 1965; Shawe, 1965; Stewart, 1975; and Ekren, 1976).
relate to the development of the Basin and Range Structure, see the work of Sales (1965), Atwater (1970) and Wright (1976). Figure 5 summarizes the general relationships of the Walker Lane in and near the study area.

Shawe (1965) discusses a left lateral fault in the area of the Excelsior Mountains that is a secondary feature off the "Walker Lane". He termed this the Walker Lane-Excelsior conjugate strike-slip system. There is strong evidence that the range front fault on the south side of the Excelsior Mountains has left lateral displacement in the Marietta area (Borbas, 1977; Don Hudson, personal communication, 1978). This fault trends about S 70° W and passes through the epi-center of the 1934 Excelsior Mountain Earthquake.

Within the eastern Excelsior Mountains, the most pronounced structural trend is the strong east-west lineation of the range. The range is blocked out by east-west Basin Range normal faults and the majority of the faults within the interior of the range are parallel or sub-parallel to this trend. As best as can be determined, all the faults are normal with the north side down dropped. One interesting set of faults are the Silver Dyke (N 60-70° W) and Camp Douglas (E-W to N 80° W) faults (Plate 1) which form a small graben with the Mesozoic Gold Range Formation and the Tertiary volcanic rocks in the Thunder Mountain area being down dropped.
GEOLOGY OF THE SILVER DYKE AREA

The Silver Dyke Mine is in the eastern Excelsior Mountains about 19 kilometers southeast of Mina, Nevada. This portion of the Excelsior Mountains consists of a series of complexly faulted and folded metamorphic and metavolcanic rocks. The oldest of these is the Permian Mina Formation. Overlying the Mina Formation is the Gold Range Formation of Triassic-Jurassic age. Intruding these two formations are stocks of diorite and granite porphyry of Cretaceous age. Oligocene and Miocene volcanic rocks unconformably overlie all of the above rocks.

Paleozoic-Mina Formation

The Mina Formation is the oldest unit exposed in the study area and consists of approximately 900 meters of chert, argillite, and graywacke. The age of the Mina Formation is Permian (Speed, 1977). This formation has been divided into two members, a chert-argillite member and a graywacke member. The Mina Formation is exposed in the upper plate of a thrust fault and only a small portion of the section is present within the area of Plate 2.

Chert-Argillite Member

The oldest exposed rocks of the Mina Formation are interbedded cherts and argillites. The total exposed thickness in the map area is around 500 meters. This member is exposed in the area of Silver Dyke Canyon (Plate 2, 7000 S x 2000 E) in the upper plate of a thrust fault that is informally termed the Silver Dyke Thrust.

The Chert-Argillite Member is marked by blocky rib-like outcrops of chert beds. The chert is typically dark gray to black, very hard
and dense, heavily fractured, and contains millimeter size laminations. Scattered through the chert are thin (1-10 mm.) interbeds of sandy and silty material. The fractures are usually coated with limonite or jarosite. Chert beds range in thickness from a few centimeters to a few tens of meters. Occasional small pods of limestone are scattered through the chert.

In thin section, the chert is seen to consist of 90-95 percent very fine grained quartz. The individual grains are around .02 millimeters in size and have complex grain boundaries that are sutured and serrated. The dark color of the chert is due to 2-5 percent included organic material. Closely associated with the organic material is a small percentage of clay. Randomly scattered through the chert are coarser grained (.5 mm.), very angular fragments of quartz (Figure 6).

Interbedded with the chert are equivalent amounts and thicknesses of argillite. The argillite is typically gray to pinkish-gray in color, soft and easily eroded, and contains fine bedding laminations. The argillite is always heavily fractured and occasionally is stained with limonite. The argillites are comprised of fine grains of quartz, feldspar, clay/mica, and organic material with accessory amounts of apatite, epidote, and zircon. The argillite ranges from an almost pure quartz sediment to a quartzo-feldspathic rock containing about 20 percent feldspar grains.

Graywacke Member

The youngest member of the Mina Formation in the Silver Dyke area consists of 350 meters of graywacke. This unit is exposed in the core of an antiformal syncline in the upper plate of the Silver Dyke Thrust
Figure 6. Photomicrograph of the chert from the Chert-Argillite Member of the Mina Formation. Note the angular quartz fragments and the opaque clay/organic material in the matrix. Crossed nicols.
(Plate 2, 5000 S x 5000 E).

The Graywacke Member is marked by its color and coarse clastic nature. It is typically gray-green to greenish-brown in color, and medium to coarse grained (1-2 mm.). Within the graywacke, the matrix to clast ratio is roughly 1:3. Locally, the matrix is flecked with bright red flakes of hematite. Scattered through the section are finer grained interbeds of gray-green argillite that are rhythmically interbedded with the graywackes. Also present is one bed of a very coarse conglomerate about 30 meters in thickness. It consists of rounded to angular clasts of andesite and diorite ranging in size from 2-25 centimeters.

In thin section (Figure 7), the graywacke is seen to consist of plagioclase (60-80%), hornblende (20-30%), and magnetite (2-5%) with about 10 percent accessories. These accessories are andesitic rock fragments, zircon, sphene and tremolite. The plagioclase grains are all sericitized making An determinations impossible. The hornblende grains range from fresh to completely replaced by calcite, chlorite and magnetite. The clasts in the conglomerate consist of trachytic augite andesite, trachytic hornblende andesite and a coarse grained hornblende diorite.

Discussion

Problems pertaining to the Mina Formation in the Eastern Excelsior Mountains and the Silver Dyke area that have to be worked out include:
1) The total thickness of the Mina Formation, 2) The detailed intraformational stratigraphy, 3) Is there a regional thrust base for this formation as proposed by Speed (1977) ?, and 4) The origin of the chert.
Figure 7. Photomicrograph of the Graywacke Member of the Mina Formation. Note the angular fragments of quartz (q), feldspar (f) and chloritized amphibole (c) set in a finer grain-ed matrix of the same material. Crossed nicols.
The first three of these problems can be discussed together. Speed (1977) believes that the Mina Formation consists of a series of tectonically interleaved blocks, each containing rocks of the Mina Formation. Marker beds that one could trace from block to block have not been recognized and thus there is no way of determining either thickness or stratigraphy of the section. For example, graywacke is present within the Mina Formation in three places in the eastern Excelsior Mountains. In the Moho Canyon (Plate 1) area, graywacke underlies the Chert-Argillite sequence. In Silver Dyke Canyon, (Plate 2) graywacke overlies the Chert-Argillite sequence. In Douglas Canyon, (just north of Plate 2) graywacke is depositionally and structurally interleaved with the Chert-Argillite sequence as a series of interbedded lenses and structurally bounded blocks. From the complex structural relationships present, it is impossible to tell if these are all the same graywacke unit or if they are separate lenses scattered through the section. Until the detailed structural relationships are worked out, there can be no way of determining total thickness and intra-formational stratigraphy. In this study, I have assigned both thicknesses and stratigraphic positions to the Graywacke and Chert-Argillite Members. These are apparent thicknesses and stratigraphic positions based on local field evidence.

Another question pertains to the origin of the chert. Nielsen (1964) believed that the chert was the product of silicification of waterlain tuffs and that shard textures were preserved. During my work I found nothing to prove or disprove this fact. I have seen angular quartz fragments in the chert; however, these are not enough to assume tuffaceous origin. No diatom or radiolarian remains were seen, like-
wise very little ribbon texture was seen that might indicate a deep
water biogenic origin for the cherts. Speed (1977) feels that the
majority of the chert is due to silicification of fine grained sedi-
mentary rocks, possibly tuffaceous. Again, I have seen nothing to
prove or disprove this. If this is true, it opens up a new question
about where the silica comes from to produce the large amounts of
chert present in the Mina Formation.

In referring to the rocks of the Mina Formation, I have called
them metasedimentary. The metamorphism is of the greenschist facies
and consists of the assemblage chlorite and epidote forming from the
ferromagnesium minerals present. I believe this metamorphic assemblage
is regional in extent and due to the intrusion of several stocks scatter-
ted through this portion of the range.

The Mina Formation was deposited on a subsea fan in a basin prox-
imal to a site of andesitic volcanism. This type of environment can
best be represented by a Permian intraoceanic island arc system (Figure
8).

The graywackes are thought to represent a series of turbidity flows
(Speed, 1977) deposited on the subsea fan. The coarseness of the con-
glomerate beds indicate a depositional site very close to the source of
the sediment and a very high energy regime at the depositional site.
The abundance of andesitic volcanic clasts and the presence of diorite
clasts indicate the sediment source was an andesitic volcano.

The chert and argillite were being deposited in the basin during
the time that graywacke turbidity flows were being flushed into the ba-
sin. The result is the interbedding of the two. Island arc environ-
Figure 8. Proposed depositional environment of the Mina Formation.

- Subaerial andesite flows - sediment source for Mina Fm.
- Mudstones, turbidites, tuffs and chert - depositional site of the Mina Formation.
- Submarine lahars, turbidites and pyroclastic rocks
- Diorite pluton - source rock for the Mina Formation
- Pillow lavas and flows
ments have a high silica content in the water due to the large amount of volcanism nearby. The silica reaches saturation and chert begins to precipitate. At the same time chert is coming out of solution, there is deposition of argillite. This simultaneous deposition of the two results in a mixing of fine grained clasts in the chert. This type of environment for the deposition of the Mina Formation alleviates the necessity for a replacement origin for the cherts.

**Mesozoic - Gold Range Formation**

The Gold Range Formation unconformably overlies the Mina Formation and consists of 1,975 meters of intermediate to silicious volcanoclastic sedimentary and silicious volcanic rocks. Speed (1977) and Nielsen (1964) consider these rocks as Triassic-Jurassic. Six members were mapped during this portion of the study and will be discussed from oldest to youngest in the following section. (See Figure 9 for stratigraphic column).

**Hornfels Member - JT gh**

The lowest member (Figure 9) of the Gold Range Formation exposed in the study area is the Hornfels Member. This member is exposed along the southern margin of the diorite (Plate 2, 7000 S x 4000 W) stock and in the northwest portion of the map area of Plate 2 (1000 N x 7000 W). Total exposed thickness of the Hornfels Member is 395 meters.

The Hornfels Member consists of a series of interbedded siltstones and sedimentary breccias. Overall, the hornfels/breccia ratio is approximately 3:1, but locally, outcrops may consist entirely of one or the other. The hornfels is typically very fine grained, dark greenish-gray
335 meters  
Conglomerate Member - JT gc

60 meters  
Felsite Breccia Member - JT gbf

485 meters  
Felsic Tuff Member - JT gt

0 - 205 meters  
Breccia Member - JT gb

700 meters  
Sandstone - Wacke Member - JT gs

- Breccia bed

- Sandstone lense marking basal contact

395 meters  
Hornfels Member - JT gh

1" = 300 meters

Figure 9. Stratigraphic column of the Gold Range Formation.
to black in color, dense and hard, and breaks with a semi-conchoidal fracture. The hornfels is usually massive and featureless except for scattered clots and stringers of chlorite, epidote, actinolite, and light brown garnet. On weathered surfaces, the clastic nature of these rocks along with primary bedding features may be recognized (Figure 10). In thin section, the hornfels is seen to be a very fine grained (.05-.2 mm.) quartz rich, dirty siltstone. Angular quartz fragments make up 10-20 percent of the rock, angular hornblende fragments account for 5-10 percent, and the remainder of the rock is matrix. The matrix, finer grained that the clasts by about a factor of 10, is very dark colored and appears dirty due to included organic material and fine grained volcanic debris. Scattered through the matrix are clots and stringers of epidote and light brown garnet. Locally, chlorite, actinolite, and minor biotite can be seen replacing patches of the matrix. The hornfels becomes sugary and granular due to recrystallization near the diorite contact.

Interbedded with hornfels are beds and lenses of coarse grained sedimentary breccia. The breccia beds range in thickness from a few tens of centimeters to a few tens of meters. The clasts in the breccia range in size from .5-3 centimeters and consist of euhedral, argillite, and a fine grained intermediate volcanic. Typically, the matrix of the breccia beds is altered to light-brown garnet with lesser amounts of epidote, which suggest a calcareous nature to the original matrix material.

Sandstone-Wacke Member - JT gs

The Sandstone-Wacke Member is about 700 meters in thickness and is
Figure 10. Field photograph of the Hornfels Member of the Gold Range Formation showing the interbedded coarse and fine nature of this member.
the most widespread of the six members of the Gold Range Formation present in the Silver Dyke area.

The Sandstone-Wacke Member is a thick sequence of quartz-feldspar-lithic wackes with minor interbedded volcanic breccia and feldspathic quartz sandstone. The wacke is typically gray to gray-green in color and consists of poorly sorted fine to medium sand size (.25 mm.) clasts in a very fine grained matrix (Figure 11). The clasts comprise 20-50 percent of the rock and are sub-rounded to angular in shape. Quartz, plagioclase, and lithic fragments are the main clast constituents with minor amounts of hornblende and magnetite present. The matrix is fine organic (?), volcanic and clayey material. Scattered through the wackes are very thin laminations and lenses of finer grained sand and silt material. These features impart a sense of bedding to a usually massive sequence. Occasionally the lenses contain graded bedding and channel scours.

Along the basal contact of the Sandstone-Wacke Member in the west side of Silver Dyke Canyon (Plate 2, 6700 S x 1000 W), there is a distinct lense of feldspathic-quartz sandstone (Figure 9) about 650 meters along strike and 30 meters in thickness. This sandstone is medium gray, equigranular, medium grained, and consists of predominantly quartz grains with lesser feldspar grains. The ratio of grains to matrix is about 5:1.

Scattered through the section are occasional zones of coarse volcanic breccia (Figure 9). These are usually discontinuous and hard to follow. One 30-meter thick bed of breccia, however, could be followed for 650 meters along strike before disappearing under the Silver Dyke
Figure 11. Photomicrograph of the Sandstone-Wacke Member of the Gold Range Formation. Angular grains of quartz (q) and feldspar (f) are set in a fine grained epidotized (e) matrix. Crossed nicols.
Thrust (Plate 2, 7000 S x 1000 E). The bed consists of angular to rounded clasts of quartz-feldspar-biotite porphyry that range in size from a few centimeters up to 30 centimeters across. The matrix of this bed was a dark gray, laminated, quartz-rich wacke. The grain size of the matrix was that of coarse sand (1-2 mm).

**Breccia Member - JT gb**

Overlying the Sandstone-Wacke Member is a wedge of coarse clastic material that constitutes the Breccia Member (Figure 9). This member is exposed along the ridge crest just south of the diorite stock (Plate 2, 8000 S x 1000 W). The Breccia Member consists of about 205 meters of exposed thickness and lenses out over a distance of about 900-1,200 meters to the north.

The Breccia Member is greenish-gray in color and consists of poorly sorted, angular to rounded fragments of chert and argillite. The fragments range in size from 1-10 centimeters and are set in a sandy matrix. Scattered through the clasts is an occasional andesitic volcanic clast. The clasts show a faint alignment that is parallel to the bedding. The matrix consists of sub-equal amounts of quartz and feldspar grains 2-4 millimeters in size. Scattered through the matrix are clasts of epidote, actinolite and pyrite. Locally, the matrix consists almost entirely of these minerals. Figure 12 shows a typical example of the breccia.

**Felsic Tuff Member - JT gt**

Next in stratigraphic succession is the Felsic Tuff Member of the Gold Range Formation (Figure 9). This member is exposed on the southern
Figure 12. Photomicrograph of the Breccia Member of the Gold Range Formation. The coarse clastic nature of this rock with the abundance of volcanic rock fragments (vrf) and sedimentary rock fragments (srf) set in a matrix of epidote (e), quartz (q), and pyrite (the opaque mineral in the matrix) distinguish this member in the field. Crossed nicols.
flank of Thunder Mountain (Plate 2, 2000 S x 1000 E) where it reaches a maximum thickness of 485 meters. It thins to the west and pinches out over a distance of about 3.2 kilometers near the Tungsten Dyke Mine (Plate 2, 1000 S x 5000 W).

The Felsic Tuff Member is marked in the field by rounded phenocrysts of quartz and subhedral to euhedral phenocrysts of milky-white plagioclase. The tuff is typically dark gray in color, faintly laminated, and very dense and hornfels-like. Banding due to flow and/or compaction wraps around the phenocrysts of quartz and plagioclase. Flow banding, collapsed pumice fragments, and zones of flow breccia are present and can best be seen on weathered surfaces. One of the breccia zones consists of quartz-plagioclase-K feldspar-biotite porphyry in a fine grained tuff matrix. The clasts range in size from 2-50 centimeters.

In thin section, the tuff consists of rounded and embayed quartz phenocrysts (.5-4 mm.) and angular to euhedral albite (Figure 13) phenocrysts of the same size set in a fine grained, quartz rich matrix. The matrix shows devitrification textures locally. In detail, the matrix is seen to consist of a felted mass of quartz and feldspar laths. All of the feldspar present has been converted to a cloudy albite. Occasionally, a euhedral phenocryst of hornblende about 1-2 millimeters in size can be seen.

Also of interest is the presence of scattered blebs of bright green, strongly pleochroic sodic amphibole. This, coupled with the albititized feldspars, indicates a fairly large scale zone of sodium metasomatism. This could be due to two things: 1) hydrothermal alteration from the
Figure 13. Photomicrograph of the Felsic Tuff Member of the Gold Range Formation. A large embayed phenocryst of quartz (q) is shown in a fine grained matrix of quartz and albite. Crossed niclos.
Silver Dyke and Camp Douglas hydrothermal vein systems or, 2) volitization of sea water from the underlying sediments by the heat of the tuff flowing over them; this steam then circulates upward through a porous tuff. Lack of sodium metasomatism in the other rocks of the area tends to favor the latter of these two possibilities.

Felsite Breccia Member - JT gbf

Overlying the tuff is a distinct zone of flow breccia designated as the Felsite Breccia Member (Figure 9). The thickness of this member is about 60 meters. The Felsite Breccia Member is exposed in a belt that wraps around Thunder Mountain about 50 meters below the summit (Plate 2, 1000 S x 00 to 00 x 6000 W).

The Felsite Breccia Member is a very coarse zone of angular flow breccia and flow banding on the top of the Felsic Tuff Member. In the field, this member is marked by angular clasts of the underlying tuff that range in size from 1-20 centimeters set in a fine grained matrix. The matrix is a distinct brownish-gray to purple-gray in color and is spotted with flecks of bright red hematite. The matrix is heavily banded and the banding can be seen to wrap around the breccia fragments. Scattered through the matrix are small phenocrysts (1 mm.) of quartz.

Conglomerate Member - JT gc

The highest stratigraphic member (Figure 9) of the Gold Range Formation in the eastern Excelsior Mountains is the Conglomerate Member. Approximately 350 meters of this member was mapped during this portion of the study. This is less than the true thickness because mapping was stopped along the crest of Thunder Mountain (Plate 2, 1000 S x 2000 W).
and exposures of this member continue down the north side well beyond the border of Plate 2.

The Conglomerate Member is a sequence of interbedded conglomerate and wacke beds. This member is typically dark gray-green to maroon in color and consists of beds ranging in thickness from 2 to 30 meters. The conglomerate beds consist of rounded to angular pebbles (1-4 mm.) of volcanic rocks, chert and argillite. Near the base of this member, volcanic rock fragments from the underlying tuff and tuff breccia predominate. Up section there is a general increase in the number of chert and argillite fragments, although locally, beds are entirely volcanic fragments. The interbeds are a dark gray, fine to medium grained (.5-1 mm.) quartz-feldspar wacke. These wackes consist of 30-50 percent grains in a fine grained, dirty matrix.

The Conglomerate Member of the Gold Range Formation in the Silver Dyke area is also the Upper Member in the regional study (see Stratigraphic column, Plate 1).

Discussion

The age of the Gold Range Formation is speculative. The youngest beds in the Pilot Mountains and Central Excelsior Mountains (Marietta area) contain a fauna indicative of Early Jurassic (Weyla sp.; Speed, 1977; Nielsen, 1964). The oldest beds present somewhat more of a problem as they are unfossiliferous. These lower beds rest unconformibly on the Permian Mina Formation and therefore have to be younger than Middle Permian. In the Marietta area, rocks correlative with the lower members of the Gold Range Formation rest conformably upon andesitic rocks that have been dated at 254 m.y. (J. Mark Johnson, personal com-
communication, 1978; Speed, 1971). All that can be clearly said about the age of the lower beds is that they are post Mina Formation which is Middle Permian.

The Gold Range Formation is regionally metamorphosed to the greenschist facies with local zones of higher grade contact metamorphism. The most dominant metamorphic minerals present are chlorite, epidote, light brown garnet and schorl. The epidote and chlorite form as replacements of ferromagnesium minerals and as clusters in the fine grained matrix of the volcanoclastic sediments. Garnet is seen in combination with epidote as a fairly massive replacement of the matrix of the conglomerate beds in the Hornfels Member. Scattered through the Sandstone-Wacke Member around the margins of the diorite are porphyroblasts of schorl. The schorl is controlled by the original host rock composition in some uncertain way; it could be composition or permeability of the beds. The metamorphism is due to abundant regional intrusive activity giving rise to a regional thermal event. Coupled with this are higher grade zones of contact metamorphism along the margins of the diorite stock.

The Gold Range Formation was deposited in a shallow marine basin on the margin of an upland area. The depositional sequence is schematically shown by figure 14.

1. Deposition of the Hornfels, Sandstone-Wacke and Breccia Members in a shallow marine basin. The Hornfels Member derives its clastic material from the Mina Formation. The rocks of the Mina Formation are uplifted on the regional thrust base or are uplifted during or prior to a period of volcanism. There is development of intermediate volcanic activity on the upland area that gives the clastic material for the Sandstone-Wacke Member. The Breccia Member is deposited in a subaerial/subaqueous environment at the foot of the upland area during depo-
Figure 14. Proposed depositional periods of the Gold Range Formation. Refer to the text on the previous page for a detailed description of the sequence of events.
position of the Hornfels and Sandstone-Wacke Members.

2. Uplift of the basin above sea level and deposition of the Felsic Tuff and Felsite Breccia Members. There is a change in the composition of the volcanism to rhyo-
litic ashflows. These are deposited on a fairly level plane. The underlying rocks are probably still wet and fairly unconsolidated.

3. Subsidence of the basin coupled with erosion on the up-
land area to deposit the Conglomerate Member. Mina Formation has to be exposed and eroded to provide the chert and argillite clasts in the conglomerate. The volcanic clasts are derived from the rhyolitic tuffs.

The basin where the Gold Range Formation was deposited can be either at the edge of the continent or on the margin of an island arc.

Mesozoic - Cretaceous Intrusive Rocks

Stocks of two different compositions are present within the Silver Dyke area. The oldest of these, a diorite, intrudes the layered rocks of the Gold Range Formation. The younger of these is a quartz porphyry which intrudes both the diorite and the Gold Range Formation (Plate 2).

Diorite

The diorite stock in Silver Dyke Canyon (Plate 2, 5000 S x 1000 W) comprises roughly one-fifth of the rocks exposed in the area. The diorite is typically medium grained (2-4 mm.), equigranular, and dark green to dark gray in color. This rock is strongly magnetic due to the high percentage of magnetite. In thin section (Figure 15) the diorite is seen to consist of about 70 percent plagioclase and 30 percent mafic minerals. The plagioclase ranges in composition from An 30-47 and is 1-4 millimeters in size. The plagioclase is slightly dusted with sericite and certain compositional zones show a more complete replacement by sericite. Mafic minerals present, in order of abundance are
Figure 15. Photomicrograph of the diorite in Silver Dyke Canyon. Phenocrysts of plagioclase (p), hypersthene (h) and biotite (b) are shown with interstitial alkali feldspar (a). Locally the hypersthene shows urlitic alteration (u) to an assemblage of actinolite and chlorite. Crossed nics.
hypersthene, augite, hornblende, biotite and magnetite. Locally, the mafics have urlitic rims of actinolite, chlorite, biotite and magnetite that is probably a deuteritic alteration product. Also present as a late magmatic alteration product are occasional rims of green hornblende on augite. Comprising 1-2 percent of the diorite are small patches of semi-graphic/granophyric intergrowths of quartz and alkali feldspar. These patches occur interstitially to the plagioclase and mafic minerals and consist of very thin, wavy rods of quartz within the alkali feldspar host. Thin bands of myrmekite (quartz-oligoclase intergrowths) occur along the interface of plagioclase phenocrysts with late stage alkali feldspar.

By modal percentages, this rock falls into the diorite class of Streckeisen's (1976) classification system.

Quartz Porphyry

Intruding the diorite along its western margin (Plate 2, 5000 S x 6000 W) is a stock of quartz porphyry. The quartz porphyry is typically brown to pink, extremely fine grained with phenocrysts of quartz, alkali feldspar, plagioclase and minor biotite. There is always limonite staining on the fractures and occasional limonite pseudomorphs after pyrite. Hexagonal book-like patches of sericite with limonite around them are present in small quantities and are believed to represent altered primary biotite. Phenocrysts of quartz and feldspars range in size from 2-7 millimeters and occur individually or as glomeroporphyritic clusters. All phenocrysts range in shape from subhedral to euhedral. About 40 percent of the phenocrysts are large quartz crystals with minor inclusions of alkali feldspar. Perthite constitutes another
40 percent of the phenocrysts. These perthite phenocrysts contain crystallographically oriented patches of exsolved albite. About 20 percent of the phenocrysts are plagioclase 2-4 millimeters long of An 25 composition. These range in shape from subhedral to euhedral and display well developed oscillatory zonation. Pericline and albite twinning is also present. The matrix consists of a fine grained intergrowth of quartz and alkali feldspar grains about .1-.2 millimeters in diameter (Figure 16).

According to Streckeisen's classification (1976) this rock is a granite.

Age

Rocks from these two stocks have been dated by K/Ar methods. The diorite is 101 ± 4 m.y. (CONOCO, unpublished data), and the quartz porphyry is 89.5 ± 2.7 m.y. (Larry Garside, 1978). Field evidence for age relationships includes chilled margins in the quartz porphyry against the diorite and dikes of the quartz porphyry in the diorite (Figure 17). These features can be seen in Silver Dyke Canyon about 400-500 meters west of the main adit of the Silver Dyke Mine.

Cenozoic - Volcanic Rocks

Unconformably overlying all the pre-Tertiary rocks in the area are scattered remnants of a large ashflow tuff sheet and andesite flow rocks. The ashflow tuff marks the base of the Tertiary section in the eastern Excelsior Mountains. The andesites are a series of flows that were laid down over a fairly short period of time on the tuff sheet. Intruding the tuffs— and the andesites are dikes of andesite and dacite.
Figure 16: Photomicrograph of the quartz porphyry showing large, euhedral phenocrysts of quartz (q), alkali feldspar (a) and perthite (p) in a fine grained matrix of quartz and alkali feldspar. Crossed nicols.
Figure 16: Photomicrograph of the quartz porphyry showing large, euhedral phenocrysts of quartz (q), alkali feldspar (a) and perthite (p) in a fine grained matrix of quartz and alkali feldspar. Crossed nicols.
Figure 17. Field relationship of the quartz porphyry and the diorite stock showing the porphyry intruding the diorite.
White Tuff - Twt

The basal member of the Tertiary section is a very distinct white crystal tuff (Plate 2, 7000 S x 5000 W). Typically, this unit is bright white, quartz rich and carries pumice and lithic fragments. The lithic fragments are those of the underlying Gold Range Formation. Locally, flow banding, shard textures, and compaction foliation around the quartz phenocrysts are abundant. In thin section, (Figure 18) the tuff is seen to consist of phenocrysts of quartz (10%) and sanidine (10%), with lesser amounts of shards, lithic fragments and muscovite. The matrix is a fine grained felted mass of quartz and sericite. Occasionally, a completely sericitized phenocryst of plagioclase is seen.

The thickness of the tuff varies from 0-60 meters. This tuff was probably deposited on a fairly flat surface as a uniform sheet. The surface was then eroded prior to and during deposition of the later andesite flows (Proffett, 1976) giving rise to the spotty occurrence and variable thickness of the tuff.

Detailed mapping in the tuff unit indicates there may be as many as five distinct tuffs present in the section. These tuffs are around 27 m.y. in age (Marvin & others, 1977). This age and their stratigraphic position under a series of andesites makes them a possible lateral correlative of the Mickey Pass Tuff of the Yerington District (Proffett, 1976).

Hornblende Andesite - Ta

These andesites are dark gray to gray-green to light olive-green in color depending on the chlorite content. Scattered throughout the andesites are discontinuous zones or lenses of flow breccia. These
Figure 18. Photomicrograph of the White Tuff showing a large embayed phenocryst of quartz (q) in a sericitized matrix. Sericitized shards (s) are abundant throughout the section. Crossed nicols.
breccia bodies consist of large angular clasts of andesite in a fine
grained, sometimes glassy, banded matrix. In thin section, (Figure
19) the andesite is seen to consist of 40-70 percent phenocrysts of
plagioclase and hornblende in 30-60 percent fine grained, sometimes
glassy matrix. The hornblendes are usually aligned in a sub-parallel
fashion due to flow movement. Locally, the hornblendes are altered to
a deep reddish-brown oxyhornblende with well developed rims of magne-
tite. Scattered through the andesite are occasional phenocrysts of
augite and biotite. All of the phenocrysts are set in an extremely
fine grained, sometimes glassy matrix with abundant microlites of
plagioclase.

The age of andesite in the Excelsior Mountains ranged from 17.4
to 15.5 m.y. (Marvin & others, 1977; Larry Garside, 1978). These dates
were obtained by K/Ar method on hornblendes. The age of the andesite
in the Silver Dyke area falls into this range and is probably closer to
the 17.4 m.y. date. The andesites of this area are included in Silber-
man's (1970) Walker Lane Suite of calc-alkaline volcanic rocks related
to subduction along the continental margin during the period of 22-6
m.y. ago. These rocks are thought to be a southern continuation of the
Cascades of Washington, Oregon and northern California.

Other Volcanic Units - Tda, Trd, Ts

Three other volcanic units mapped during this portion of the study
are a glassy andesite dike (Tda), a dacite dike (Trd), and isolated
patches of silicified volcanic (Ts).

The glassy andesite dike and the dacite dike crop out about 300
meters SSW of the Tungsten Dyke Mine (Plate 2, 2000 S x 8000 W) where
Figure 19. Photomicrograph of the hornblende andesite showing large, euhedral phenocrysts of plagioclase (p) and hornblende (h). The matrix consists of abundant microlites of plagioclase and volcanic glass. Crossed nicols.
they intrude the andesite. The older of these two is a small circular plug 60 meters in diameter of a black, glassy, porphyritic andesite (Tda). This andesite consists of phenocrysts (30-40%) of plagioclase and hornblende set in black volcanic glass. The plagioclase is oligoclase to andesine in composition and the hornblendes are green. Due to the similarity with the andesite flows discussed above, this unit is assumed to be andesitic in composition and it is possible that this plug is a feeder dike for some of the flows in the upper portion of the pile of andesite flows. Intruding the andesite plug is a dike of light-brown, quartz bearing dacite (Trd). The dacite forms a dike about 300 meters in length and 40 meters wide that culminates in a triangular plug 70-80 meters across (Plate 7, 2000 S x 7500 W). This dike contains plagioclase (An 25-45), hornblende, quartz, and minor biotite and alkali feldspar. Two very distinctive features are present within this unit; lithic fragments from the Gold Range Formation and vertical flow banding. No correlations between this dike and any flow rocks can be made.

The last volcanic unit present (Ts) is a series of completely silicified volcanic rocks on the eastern margin of Plate 2 (3000 S x 5000 E). These rocks are typically light gray and form featureless, blocky outcrops. Occasionally angular clasts and zones of breccia can be seen along with silica pseudomorphs after hornblende. The silicified volcanics occur in areas of intense brecciation along fault contact with the andesitic volcanics. These rocks are probably some type of andesite flow that has been completely replaced by silica. The source and significance of this type of silicification is unknown.
Quaternary - Qal

Occupying the top of the geologic column are undifferentiated deposits of alluvial material. These deposits are stream gravels and valley fill material.

Structure of the Silver Dyke Area

The Silver Dyke is a continuous fault system for 5.5 kilometers along strike that consists of a series of 1 to 3 parallel faults that strike N 60°-80° W and dip 70°-80° N (Plate 2). These faults occur across a zone ranging from 10 to 180 meters in width with an average of 30-35 meters. On the extreme eastern and western margins of this fault system, one fault is present, represented by a single massive quartz vein. As you move toward the Silver Dyke Mine, this fault branches into two faults, both of which are filled with quartz veining. This branching is best seen in the area of the Tungsten Dyke Mine (Plate 2, 1000 S x 7000 W). In the section from the Tungsten Dyke Mine to the Silver Dyke Mine (1.6 km.) there are three parallel faults, two of which are filled with quartz. These faults pinch and swell along strike. The area of the Tungsten Dyke Mine is a good example where over a strike length of 500 meters, the two faults attain a separation of over 180 meters.

On the northwest, the Silver Dyke Fault crops out on the front of the range where it terminates against Basin and Range frontal fault (Plate 1). To the southeast, the fault dies out through a strike length of about a kilometer in a series of branching "horsetail" faults (Plate 2, 4000 S x 3000 E). The main Silver Dyke Fault ends abruptly after passing through this "horsetail" area. The "horsetail" consists
Figure 20. View of the Silver Dyke Fault along the western flank of Thunder Mountain. The diorite stock (Kd) is present in the footwall of the fault and the Sandstone-Wacke Member (JT gs) makes up the hanging wall. The dump from the main haulage level of the Silver Dyke Mine is present in the lower left corner of the photograph.
of five faults that branch off the main fault and then in turn each of these faults splits into other faults. All of the "horsetail" faults are normal with the south side downdropped except for the northernmost of the faults which has the north side down. This northern fault forms the contact between the Sandstone-Wacke Member and the Felsic Tuff Member of the Gold Range Formation. "Horsetail" faulting appears to be a mechanism for taking up the displacement of the Silver Dyke Fault through a series of offshoots from it, thereby letting it terminate.

A fault system parallel to the Silver Dyke Fault is best developed in the footwall rocks along the southeast end of the Silver Dyke Fault (Plate 2, 6000 S x 1000 E and 6400 S x 3000 E). Two faults of 2 and 1.5 kilometers in length occur at a distance of about 350 to 450 meters to the main fault. One of these faults dips 70°-80° S on the eastern part of the fault; crosses through an inflection point and dips 75° N on the western end of the fault. Several other parallel faults of a couple of hundred meters in length are present along the south side of the Silver Dyke Fault.

Two groups of faults cut the Silver Dyke Fault. One group strikes N-S and the other N 80° W to S 80° W. The N-S group is represented by the large fault near the Tungsten Dyke Mine (Plate 2, 2000 S x 5700 W) and two small faults near the Silver Dyke Mine (Plate 2, 3500 S x 1800 W) on the north side of the Silver Dyke Fault. The two smaller faults have dips of 55° and 65° to the west and east, respectively. The N 80° W to S 80° W fault group have dips that range from 75° S to 75° N. This group is represented by the cross faults located in the area around the Silver Dyke Mine (Plate 2, 4000 S x 2000 W).
MINEARIZATION IN THE SILVER DYKE AREA

Introduction

The Silver Dyke vein system is a very large, through-going, composite set of dike-like quartz veins. This dike-like nature coupled with the fact that the first known prospect on the vein was for silver gives rise to the name Silver Dyke (see Figure 21).

Tungsten was discovered in 1915 by Mr. C.E. Noble of Mina, Nevada. Nearby claims were held by Mr. Edward Wagner also of Mina, Nevada. In 1916, Noble's claims were purchased by Atkins, Kroll and Company of San Francisco who opened and operated several mines in the area. In 1918, these holdings were sold to Beane, Beck and Noonan and later the interests were sold to the senior-partner, Beane. In 1929, the Beane holdings, along with those of Wagner, were leased to the Nevada-Massachusetts Company (Kerr, 1936). The Nevada-Massachusetts Company operated the mine until 1938, when low tungsten prices and litigation problems forced lease relinquishment to the Beane estate. From 1938 to 1951, a series of small lesors worked the property. In 1951, the mine was sold to Mr. Chauncey Florey. Shortly thereafter, Mr. Florey put the mine into a short lived production (Rennie, 1954). There have been a few attempts at opening the mine since 1951 with the latest being in the early 1970's.

Production records for the Silver Dyke Mine have never been published, but county tax records indicate a production in excess of $1.2 million during and in part after World War I (Ross, 1961). The actual tonnage mined was around 800,000 L.T. with an average grade of 1% WO₃ (Kerr, 1936; Rennie, 1954). At 1979 prices ($9/pound) the Silver Dyke
Figure 21. Outcrop of the Silver Dyke Vein System with blocky, erosion resistant, iron stained quartz ribs typical of the vein. The vein is cut off by one of the N 80°W - S 80°W cross faults. The photograph is looking northeast towards the Tungsten Dyke area.
Mine production would amount to $144 million dollars of WO₃.

Within the Silver Dyke area two distinctly different types and ages of mineralization are present, base metal-silver veins and vein tungsten. In the following sections, the oldest of these, the base metal-silver veins will be discussed first, followed by the vein tungsten of the Silver Dyke Mine.

Base Metal-Silver Veins

Fracture controlled base metal-silver mineralization occurs in the diorite stock in Silver Dyke Canyon. The mineralization is in veins ranging in thickness from hairline fractures to 3 centimeters with an average of .75 centimeters. These veins are scattered throughout the diorite stock (Plate 2, 5000 S x 00, 5000 S x 1000 W, 6000 S x 3000 W). As the granite porphyry to the west is approached, there appears to be an increase in the number of veins present (Plate 2, 5500 S x 5500 W, 4500 S x 5000 W). The veins fill fractures that are related to the jointing of the diorite stock and a set of fairly flat lying fractures appear to be most intensely mineralized. On the eastern margin (Plate 2, 5000 S x 00) there are several flat lying veins exposed.

The opaque vein filling minerals are, in decreasing abundance, pyrite, arsenopyrite, chalcopyrite, molybdenite, goethite, miargyrite (Ag₂S. Sb₂S₃), hematite, bornite and scheelite. The opaque minerals are in a gangue of quartz (90%), epidote (5%), and chlorite (5%), with traces of calcite and alkali feldspar. Locally, the silicate gangue may be lacking or make up as much as 95% of the veins. Pyrite and arsenopyrite are almost always euhedral while chalcopyrite, miargyrite and molybdenite are seen as inclusions and fracture fillings in the pyrite and arseno-
pyrite (Figure 22). Pyrite, chalcopyrite and molybdenite occur as disseminations in the diorite around the veins. These disseminated zones are 4-5 centimeters in width and are fairly symmetrical on either side of the veins. Goethite and hematite are scattered randomly throughout the gangue. Also occurring in these veins are a few scattered grains of bright blue fluorescing scheelite. A paragenetic sequence based on textural relationships of the opaque minerals is presented in table 1.

The base metal-silver veins have a well-developed alteration halo. The zone closest to the veins (Figure 23) is predominantly quartz and alkali feldspar with lesser amounts of sericite, chlorite, montmorillonite and kaolinite. The width of this zone ranges from a few tenths of 1 millimeter up to 2 centimeters. The inner zone grades outward into an assemblage of montmorillonite, kaolinite, chlorite and sericite. This zone may contain a small amount of alkali feldspar and sericite. The width of this zone varies but is about 0.5-1 centimeters. This assemblage grades into an outer zone consisting of chlorite, epidote, calcite and lesser amounts of montmorillonite. The width of the outer zone is quite variable and ranges from a few centimeters up to a few tens of centimeters. Using Meyer and Hemley's (1967) classification of wall rock alteration, these veins show zonation from a potassium silicate assemblage to a propylitic assemblage.

The alkali feldspar from the potassium silicate alteration zone has been dated by K/Ar methods by Morton and others (1977) at 75.9 ± 2.3 m.y. The base metal-silver veins are probably related to the granite porphyry intrusive to the west of the Silver Dyke Mine. This is apparent because as you approach the contact there is an increase in the
<table>
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<th>Hypogene</th>
<th>Supergene</th>
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<tr>
<td>Pyrite</td>
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<td>Arsenopyrite</td>
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Table 1. Paragenetic sequence of the opaque minerals in the Base Metal-Silver Veins.
Figure 22. Photomicrograph of the opaque minerals in the Base Metal - Silver veins. Pyrite (p) makes up the bulk of the section with chalcopyrite (c) and miargyrite (m) filling in around the pyrite.
Figure 23. Photomicrograph showing the Potassic alteration zone adjacent to the Base Metal - Silver veins. Alkali feldspar (a) with lessor chlorite (c) and epidote (e) form a narrow zone adjacent to these veins. Crossed nicols.
number of veins present in the diorite (Plate 2, 5500 S x 5500 W).
The granite porphyry has been dated at 89.5 ± 2.7 m.y. on biotite and
73.9 ± 2.2 m.y. on alkali feldspar (Garside and Silberman, 1978). The
two alkali feldspar dates appear concordant and strongly suggest that
the mineralization is related to the granite porphyry. It should be
noted that the variation in the biotite and alkali feldspar dates is a
function of the ability of the two minerals to retain argon. Alkali
feldspar has a more open crystal structure than biotite and cannot re-
tain the argon as well so it gives a lower age date.

Silver Dyke Vein System

The Silver Dyke Vein System is in the Silver Dyke Fault and is
continuous for 5.5 kilometers along strike. The vein system consists
of a single quartz vein on the northwest and southeast ends of the vein
system and in the area of the Tungsten Dyke Mine (Plate 2, 1000 S x
7000 W) the vein divides into two sub-parallel veins. These two veins
are continuous for about 3 kilometers along strike to the southeast
where they converge back into one vein. The widths of the individual
veins vary from about 5 to 50 meters and they are seen to pinch and
swell along strike. In general, the surface trace of the vein system
is marked by bold, iron stained outcrops of massive quartz (Figure 21).

Divisions of the Vein System

In 1936, Kerr recognized five major divisions in the vein system;
the ribbon quartz, replacement quartz, stringer, cemented breccia and
sheared quartz zones. During this study, the author recognizes seven
zones that in part correlate with Kerr's (Figure 24).
Figure 24. Vein divisions present in the Silver Dyke Mine. No scale is intended, but the width of the 7 zones is usually around 75 feet. See the text for a detailed description of the zones.
Each vein division will be discussed in the order that they occur from footwall to hanging wall and are shown on plate 3.

Zone One. The zone encountered along the footwall (Plate 3) is stringer quartz in diorite (Kerr's ribbon quartz). This zone consists of abundant small quartz veinlets that are either parallel or sub-parallel to the main vein. These quartz veinlets range in width from a few millimeters up to a few tens of centimeters with an average width of 2 centimeters. The veinlets are fairly uniform in thickness and appear to have formed by filling of open fractures. Quartz crystals within the veinlets are elongate perpendicular to veinlet walls. Occasional open spaces lined with drusy quartz are present in the center of the veinlets. Adularia, epidote and scheelite occur along contacts of the veinlets with the diorite wall rock. Locally, a few specks of pyrite may be seen in with the scheelite. The overall width of this zone is variable and ranges from less than a meter up to 4-5 meters. Only occasionally within the mine workings examined was this zone mined.

Zone Two. Zone two (Figure 24 and Plate 2) is the ore zone (Kerr's replacement quartz zone). This zone has the largest amount of scheelite. The width of this zone is variable and ranges from slightly less than one meter up to 5 meters with an average width of about 1-1/2 meters. The ore zone is a fault breccia consisting of diorite fragments varying from a few millimeters to 5 or 6 centimeters in width. The fault breccia is cemented by quartz and the diorite fragments are replaced by quartz, adularia, clinozoisite/epidote, limonite, sericite and pyrite. The ore zone contains several periods of quartz veining as evidenced by the presence of barren and mineralized veinlets within the larger vein.
Banding, cockscomb quartz and open space cavities lined with drusy crystals are abundant features of this zone. The fragments tend to be surrounded by bands of elongate quartz crystals with their long axes perpendicular to the fragment side. In general, barren veinlets cut the mineralized ores indicating that the scheelite was introduced early in the vein forming processes. The occurrence of scheelite is random and spotty. Locally there are small areas of solid scheelite while a few inches away the quartz is barren. About two thirds of the ore zone carries at least some scheelite (Kerr, 1936).

Zone Three. Immediately adjacent to the ore zone (Figure 24 and Plate 3) on the hanging wall side is another quartz stringer zone in diorite. The width of this zone varies from 0 to 1 meter. The quartz stringers range in thickness from a few millimeters up to few tens of centimeters. These veinlets contain random and spotty occurrences of scheelite that locally was of high enough grade to constitute ore.

Zone Four. On the hanging wall side (Figure 24 and Plate 3) of the quartz stringer zone lies the boxwork quartz zone. This zone consists of a series of fractures that intersect roughly at right angles with one another and have been filled with vein quartz. The overall width of this zone ranges from 2-12 meters. The individual quartz veins are usually narrow (2-10 cm.) with the blocks of diorite between them ranging in size from a few centimeters up to 3 meters. The quartz veins show banding, cockscomb quartz and abundant open spaces lined with drusy quartz. Scheelite occurs randomly throughout this zone and locally may attain enough grade to make ore. The scheelite tends to form indistinct rims along the vein contacts with diorite. This box-
work zone corresponds to Kerr's (1936) stringer zone.

**Zone Five.** Forming the hanging wall (Figure 24 and Plate 3) of the boxwork zone is the massive quartz zone (Kerr's cemented quartz zone). The massive quartz zone ranges in thickness from 1-6 meters and pinches and swells along strike. A very dense and compact nature, lack of distinct fragments and lack of open space cavities help distinguish this zone from the ore zone. In thin section, the massive quartz is seen to be finely and rhythmically banded. There are indistinct fragments present that are comprised of extremely fine grained, chalcedonic quartz. These are probably part of the hanging wall metavolcanic rocks that have been silicified. Minor scheelite is scattered through this zone and is spatially related to the fragments. An occasional cross-cutting quartz vein can be seen in this zone.

**Zone Six.** Immediately on the hanging wall side (Figure 24 and Plate 3) of the massive quartz zone is a narrow (1-2 m.) zone of friable fault gouge. This gouge corresponds with Kerr's (1936) sheared quartz zone. The gouge is comprised entirely of granulated quartz vein. There are abundant 2-4 millimeter sized quartz balls that are in a matrix of flour-like quartz. These balls were formed by granulation of the massive quartz with the balls representing the more resistant pieces of fault breccia. An occasional streak or smear of scheelite powder can be seen in the gouge. On the surface this gouge zone is well cemented by iron oxide and forms large blocky outcrops (Figure 21).

**Zone Seven.** On the hanging wall side of the gouge (Figure 24 and Plate 3) is a zone of quartz stringers in the metavolcanic rocks of the Sandstone-Wacke Member of the Gold Range Formation. The majority of
the quartz veinlets are small (less than 2 cm.) and are parallel or sub-parallel to the main vein zone. Nowhere in the mine was the scheelite content of this zone great enough for it to comprise ore. The thickness of this zone is unknown due to the fact that it is only exposed in crosscut tunnels that stopped after they encountered it. In a few locations (Plate 3) the fault gouge zone and the quartz stringer zone in the metavolcanics switch places, that is, the gouge zone occurs hangingwall to the quartz stringer in the metavolcanics.

Vein Divisions at the Tungsten Dyke Mine

In the area of the Tungsten Dyke Mine (Plate 2, 1000 S x 7000 W), the sequence of vein divisions is similar and correlates with those seen in the Silver Dyke Mine. From footwall to hanging wall the sequence is quartz stringers in andesite, ore zone, silicified andesite with quartz-adularia veins, massive quartz, and propylitically altered andesite with minor quartz veins. At the Tungsten Dyke Mine the ore zone contains brecciated fragments of ashflow tuff and andesite instead of diorite and a much lower scheelite content. The silicified andesite zone with quartz-adularia veins is much wider than its counterpart (stringer quartz in diorite and boxwork quartz) in the Silver Dyke Mine and ranges in thickness from 0-165 meters. The massive quartz zone at the Tungsten Dyke Mine is indistinguishable from the massive quartz zone at the Silver Dyke except for a higher chalcedony content. The propylitized andesite zone is correlative with the quartz stringer zone in metavolcanics but it is less altered and contains less quartz veining. Overall, the quartz in all the zones in the Tungsten Dyke area is very chalcedony-like in nature.
The Noble Vein

The Noble Vein occurs in the west workings (Plate 3) of the Silver Dyke Mine and is footwall to the main vein system. The Nobel Vein strikes N 30°-40° W, intersects the Silver Dyke Vein at an angle of 20°, is vertical, and varies in thickness from a few centimeters up to a meter. The Noble Vein consists of nicely banded, cockscomb quartz with abundant open spaces lined with euhedral quartz crystals. Locally, euhedral scheelite crystals can be seen growing into these open spaces. One particularly interesting thing is that the Noble Vein carries calcite, and where the calcite is abundant the scheelite is very sparse. The thickness of the vein varies greatly along strike and pinches and swells over short distances. Locally, the scheelite content of the Noble Vein was very high; Kerr (1936) reports of a few places where a three foot thickness of solid scheelite was encountered.

Mineralogy of the Vein System

The mineralogy of the Silver Dyke Vein System is quite simple and can be thought of as three major hypogene constituents, quartz, adularia, and scheelite. Several minor hypogene vein constituents along with several supergene minerals comprise the remainder of the vein minerals.

Quartz. Quartz is the dominant vein constituent and comprises from 90-95 percent of the vein material present. Two varieties of quartz were seen during this study, clear quartz and chalcedonic quartz. The term chalcedonic or chalcedony-like quartz can be defined as optically clear quartz with a fan shaped, fibrous, radiating and concentrically banded nature. This chalcedonic quartz can be seen grading into and as rims on clear quartz. Quite often there is a clear center that
is euhedral and outlined with inclusions that is coated with the chalcedonic quartz. In the main workings of the Silver Dyke Mine, chalcedonic quartz is present as rims on clear crystals and comprises roughly 25 percent of the quartz present. In the area of the Tungsten Dyke Mine (Plate 2, 1000 S x 7000 W), chalcedonic quartz occurs throughout the vein system in great abundance and comprises 50-80 percent of the quartz present. In the Tungsten Dyke area, the vein system is very well banded with bands containing elongate, fan-shaped crystals with the long axis of the crystal perpendicular to the direction of the band (Figure 25). The fan-like nature of these crystals is marked by very pronounced inclusions of an opaque, white reflecting clay mineral that is thought to be kaolinite. Also present in the bands are numerous adularia crystals that are attached to a band with a fairly flat surface and are euhedral away from the direction of the band (Figure 26). In both the Silver Dyke and the Tungsten Dyke areas the scheelite mineralization is associated with the clear quartz.

Several interesting facts about the temperature of formation and nature of the hydrothermal solutions of the Silver Dyke Vein System can be pointed out from the presence of the chalcedonic quartz. White and Corwin (1961) and Oehler (1976) state that chalcedony forms between 100° C. and 300° C. in an environment with a pH from 7-10. They also state that pressure is very important in the formation of chalcedony, that it is a near surface mineral and with increasing pressure it converts to quartz. In terms of temperature of formation of the Silver Dyke solutions, the initial fluids were in excess of 300° C. and as mineral deposition proceeded there was a cooling to below 300° C. This
Figure 25. Photomicrograph of quartz from the Silver Dyke Vein System showing elongate crystals with the long axis of the crystal perpendicular to the fragments (df) in the vein. Crossed nicols.
Figure 26. Photomicrograph of the vein quartz from the Tungsten Dyke area. Adularia (a) forms triangular projections into the delicately banded quartz. Crossed nicols.
is seen by the fact that clear quartz with associated scheelite is rimmed with the chalcedonic quartz. The greater abundance of chalcedonic quartz in the Tungsten Dyke area points to a lower temperature of formation than the Silver Dyke area. This is supported by the fact that the Tungsten Dyke area is about 1000 feet higher in the hydrothermal system and one would expect lower temperatures. The solutions that formed the vein system were alkaline and ranged in pH from 7-10. This is supported by the presence of chalcedonic quartz (Oehler, 1976) and by the presence of adularia (Meyer and Hemley, 1967; Silberman, 1971).

**Adularia.** The second most abundant vein constituent is adularia. Adularia is a relatively pure (Or 90-100) alkali feldspar that is characterized by the "adularia habit" (Smith, 1974) which is dominated by the (110) form and in thin section is characterized by diamond shaped outlines. Adularia forms very rapidly in a hydrothermal environment and typically has a disordered structural state (Silberman, 1971) resulting from a rapid cooling history.

The adularia in the Silver Dyke Vein has two modes of occurrence, in the altered wall rock fragments and freely in the quartz. The adularia in the quartz occurs in close association with scheelite, rock fragments, or in isolated patches. Typically, the rock fragments in the vein are rimmed by adularia or have adularia banding around them a short distance away. Some of this banding is very fine and delicate (.05 mm.) while other parts are fairly massive (up to 1 cm.). Usually when scheelite is present in the quartz, adularia is close by, and in some cases forms rims on the scheelite grains. The adularia that occurs
free in the quartz usually occurs interstitially to larger quartz grains. In well banded vein material adularia will form as triangular projections in which the apex of the triangle points away from the band it is growing out of (Figure 26). A feature that is very typical of epithermal vein systems is adularization of breccia fragments in the vein (Silberman, 1971). This is a massive replacement of the fragments by adularia, quartz, and sericite. This type of replacement fits into the potassium silicate alteration assemblage of Meyer and Hemley's (1967) classification. According to Meyer and Hemley, adularia is formed in a low temperature (about 250° C.) and alkaline environment. Adularization of the diorite, andesite, and ashflow tuff fragments within the Silver Dyke Vein System is a very common feature.

Scheelite. The most important constituent of the Silver Dyke Vein System is the tungsten bearing mineral, scheelite. The scheelite fluoresces a pale yellow instead of the sky blue color that is so typical of most scheelite. The reason for this is that scheelite is one member of a binary solid solution with powellite which fluoresces yellow. This solid solution ranges from CaWO₄, the pure scheelite end member, to CaMoO₄, the pure powellite end member. Small amounts of molybdenum in scheelite alters the typical blue fluorescence to that of pale yellow (Hsu and Galli, 1973). By using x-ray diffraction techniques and plotting the 211/114 reflections of scheelite, the percent CaMoO₄ can be obtained (Hsu and Galli, 1973). The scheelite from the Silver Dyke contains from 2-4 mole percent CaMoO₄. The formation of Mo-bearing scheelite is thought by Hsu to be a function of low sulfur fugacity in the system and the Mo is being converted to powellite instead of
molybdenite. This corresponds very well with the fact that there are only a few traces of pyrite or any other sulfide mineral in the system.

The occurrence of scheelite in the vein system is spatially related to the occurrence of diorite or andesite fragments. Scheelite is seen as rims or coatings on these fragments or as isolated grains in the quartz next to the fragments (Figure 27). When a small vein cuts the diorite, it typically contains a rim of scheelite along the boundary between the quartz and the diorite (Figure 28). The calcium needed to form the scheelite has to be coming directly from the breccia fragments in the vein and the wall rocks that contain the vein. In thin sections of the diorite next to the vein, the An composition of the plagioclase is about 20 while that of the fresh diorite is about 40-45. This decalcification of the plagioclase as you approach the vein is probably a hydrothermal leaching effect that supplies the Ca for the formation of the scheelite.

The Mo content of the scheelite can be explained by a similar mechanism. The diorite host rock contains the base metal-silver veins which contain molybdenite. The Mo from these veins could be leached from the wall rock or the fragments in the same way as that for the Ca. The other explanation is that the hydrothermal solutions contained primary Mo that was later tied up in the scheelite. The former of these seems the most feasible because Hsu (1973) states that hydrothermal scheelite is essentially a pure Ca end member usually containing less that .01 percent CaMoO₄. Keeping this in mind, it seems very reasonable to assume the Mo content of the scheelite was due to leaching of the base metal-silver veins rather than a primary Mo content in the hydrothermal
Figure 27. Photomicrograph of an isolated grain of scheelite (s) in the main ore zone from the Silver Dyke Mine. A large euhedral crystal of quartz (q) is present next to the scheelite. Crossed nicols.
Figure 28. Photomicrograph of a quartz vein in the stringer zone footwall to the main ore zone in the Silver Dyke Mine. Scheelite (s) occurs along the margin of the vein in contact with the altered diorite. The diorite is altered to an assemblage of chlorite (c), epidote (e) and kaolinite/montmorillonite (p). Crossed nicols.
solutions.

Fluid inclusion data from scheelite in the Silver Dyke Mine indicates a formation temperature of 313° C. ± 19° C. (Sigurdson, 1974). Sigurdson also shows a distribution histogram of fluid inclusion homogenization temperatures showing five main temperature peaks — 275° C., 250° C., 225° C., 200° C., and 175° C. These peaks represent quartz deposition that is continued as the hydrothermal system decreases in temperature. These temperatures correlate very well with the ones predicted from the presence of quartz and chalcedony.

Other Vein Constituents. Other primary vein minerals are pyrite, Ag-Au tellurides and calcite. Scattered through the quartz in the ore zone are small amounts of euhedral pyrite. Because of its euhedral occurrence in isolated grains, the paragenetic position of the pyrite is difficult to determine, but it is thought to be associated with the scheelite bearing quartz. Locally, this pyrite is being weathered to goethite. Also associated with the scheelite bearing ore zone are small amounts of Ag-Au tellurides. The author did not find these minerals during this study, but Sigurdson (1974) found hessite (Ag₂Te) and petzite (Ag₃AuTe₂) during his fluid inclusion work. He states the tellurides have formed rims around chalcopyrite and indicate that they have formed simultaneously with, or after the chalcopyrite. The only chalcopyrite the author found was in the base metal-silver veins; it seems likely that the tellurides Sigurdson saw were in reality the miargyrite in these veins. Calcite forms a very minor constituent of a small quartz vein in the west workings and a fairly major constituent of the Noble vein (Plate 3). Locally, the Noble Vein will contain up to 25 percent
calcite. Scheelite and calcite show an antithetic relationship in the Noble vein. This is probably because the available Ca was fixed with carbonate instead of the tungstate.

Wherever open space is present in the Silver Dyke Vein, there are a variety of supergene minerals that coat the interior of these vugs. Iron and manganese oxides form yellow, brown and black films on the quartz crystals in the vugs. Siderite and gypsum form as small euhedral crystals attached to the faces of the quartz crystals in the vugs. Bright white to dirty brown kaolinite are seen to fill entire open spaces in the vein system. All of these minerals are much later than the scheelite mineralization and are formed by the percolation of ground water through the cavities and cracks within the vein system. The paragenetic sequence of the vein mineralogy is shown in Table 2.

Controls of Mineralization

The most important control of mineralization in the Silver Dyke area is host rock composition. The only economic quantities of scheelite occur where the diorite intrusive forms the footwall of the vein system. The diorite is the source of Ca for scheelite (CaWO₄) and when you get abundant diorite fragments in the vein, scheelite mineralization is usually present. The unaltered diorite contains 5 percent CaO (Kerr, 1936) and apparently is the only rock with enough Ca to form scheelite. Metavolcanic rocks of the Gold Range Formation are barren of scheelite when they occupy the footwall position.

The andesite in the Tungsten Dyke area contains small amounts of scheelite mineralization. According to Carmichael (1974) the average CaO content of a continental margin, subduction related andesite ranges
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<th>Mineral</th>
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<td>Epidote/Clinozoisite</td>
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Table 2. Paragenetic sequence of the minerals present in the Silver Dyke Vein.
from 4-9.8 percent. From CaO content alone it is clear that the andesite is an equivalent if not more favorable host rock for scheelite mineralization than the diorite. The question of why there is not more scheelite in the andesite can probably be answered in terms of pressure and temperature. The Tungsten Dyke area is 1000-1500 feet higher in the hydrothermal system than the main mineralized zone in the Silver Dyke Mine. This difference is enough to account for a significantly lower temperature and pressure to inhibit the formation of scheelite.

Within the Silver Dyke Mine there are several areas of significant tungsten mineralization. These are the Beane-Wagner stope in the east workings (Plate 3), the 600 West stope, Goodale stope, and a small unnamed stope in the west workings. All these stopes have diorite in the footwall and represent zones in which the brecciation was very well developed so that the ascending solutions could easily leach Ca from the fragments and the fractured wall rocks. Another area of significant mineralization is the Noble Vein in the west workings (Plate 3). Kerr (1936) reports that certain portions of the Noble Vein were solid scheelite up to three feet thick. This must be due to the fact that both walls of the vein are diorite giving a ready source of CaO required to form the scheelite.

Wall Rock Alteration

The hydrothermal alteration zones developed in and around the Silver Dyke Vein system vary with respect to the host rock composition. Within the Silver Dyke Mine where the wall rock is diorite, there is a very narrow zone of alteration developed. The innermost zone (which includes the vein) consists of the assemblage of quartz and adularia.
The breccia fragments in the vein are altered to predominantly quartz and adularia with lesser amounts of sericite, pyrite, clinozoisite, chlorite, and biotite. There is a narrow zone (less than 1 m.) of quartz-adularia-sericite alteration that forms directly on either side of the ore zone. This alteration zone grades outward into a chlorite-kaolinite/montmorillonite-sericite-pyrite-epidote assemblage, 1-6 meters in width. Within this zone the feldspars are altered to kaolinite/montmorillonite and sericite while chlorite, pyrite, and epidote develop from the ferromagnesium minerals. This assemblage grades outward into weakly propylitized diorite (minor chlorite, epidote, and sericite) which in turn grades outward into fresh diorite over a few meters. The most significant feature of the alteration within the Silver Dyke Mine is the narrowness of the alteration halo. In a well altered zone, fresh rock is encountered within 8-10 meters from the vein.

In the area of the Tungsten Dyke Mine where the wall rocks are predominantly andesite flows there is a similar alteration assemblage developed, but the width of the outer zone varies considerably from that of the Silver Dyke area. The inner zone in and around the vein consists of quartz and adularia with minor sericite. The fragments in the vein are altered to a quartz-adularia-sericite assemblage with lesser amounts of kaolinite/montmorillonite, epidote, and chlorite. This inner zone is quite narrow and grades outward into an assemblage of chlorite-albite-sericite-pyrite with quartz-adularia veinlets. Due to poor outcrop in the area of the vein, it is difficult to estimate the width of this zone, but it does not appear to be wider than a few meters. This zone grades outward into a chlorite-calcite-epidote-iron oxide +
pyrite assemblage. This outer zone is very wide and can be seen as far away from the vein as 400-500 meters. Figure 29 shows the typical altered andesite from the outermost alteration zone by the Tungsten Dyke Mine.

Age and Origin of the Silver Dyke Mineralization

Adularia from the scheelite bearing ore zone in the Silver Dyke Mine gives a K/Ar age date of $17.3 \pm 0.2 \text{ m.y.}$ (Garside, 1978). This corresponds very well with the age of the andesite ($17.4 \text{ m.y.}$) that is cut and mineralized by the vein system. There is a series of epithermal precious metal camps in western Nevada that are related to andesitic volcanism (Silberman, 1976). A few of the better known of these camps are Tonopah, Aurora and the Comstock Lode. Silberman (1976) believes that mineralization in these camps immediately follows a period of andesitic volcanism. The andesitic magma chamber provides the heat source and some of the hydrothermal fluids responsible for alteration and mineralization in these camps. At Silver Dyke, the andesite that caps the range is $17.4 \text{ m.y.}$ in age (Garside, 1978). The similarity of this date with that of the mineralization clearly points to the fact that the mineralization was derived from the same source as the andesitic volcanic rocks.

Exploration Potential in the Silver Dyke Area

The potential of finding another economically viable tungsten deposit in the Silver Dyke Vein is very small. The ore bodies that were mined were small and irregular with very erratic tungsten values. Due to the steeply dipping vein system and the nature of the ore bodies,
Figure 29. Photomicrographs showing the propylitically altered andesite in the Tungsten Dyke area. Large phenocrysts of plagioclase (p) are altered to albite and sericite while the hornblende phenocrysts are altered to epidote (e) and magnetite. The upper photograph is taken with the nicols crossed and the lower with them uncrossed.
the only way to explore for a hidden ore body would be very close spaced angle drilling with a diamond coring drill. This is an extremely expensive type of exploration and the potential to find something large enough to justify the expense is very small. If a company were to drill in the area, several targets can be suggested from the surface and underground geology. The first of these would be a deep extension under the main workings, this hole should intercept the Silver Dyke vein at least 1,200 feet below the surface. The other target that might warrant drilling would be the diorite to the west of the main workings. There are scattered scheelite showings underground in this area and there may be the possibility of a small ore body.
CONCLUSIONS

Several important conclusions related to the geology and mineralization of the Silver Dyke area were reached during this study. These are:

1. Rocks of the Mina Formation are lithologically very different from rocks of the Gold Range Formation, the former being predominantly sedimentary and the latter volcanic.

2. The Gold Range-Mina contact in the Silver Dyke area is a thrust fault with the Mina Formation being allochthonous with respect to the Gold Range Formation.

3. The age of the Gold Range Formation is unclear and needs further work.

4. Detailed intraformational stratigraphy of the Mina Formation is unclear at this time.

5. The most dominant structural trend of the Eastern Excelsior Mountains is east-west.

6. The Silver Dyke Fault dies out in an area of horsetail faulting, this as a mechanism for taking up all the movement along the fault.

7. Two distinct types and ages of mineralization are present in the Silver Dyke area.

8. Molybdenum from the Base Metal-Silver Veins was incorporated in scheelite of the Silver Dyke vein giving it a yellow fluorescence.

9. Diorite is the host rock of the Silver Dyke Mineralization.

10. The hydrothermal solutions that formed the Silver Dyke vein were alkaline and 300°C. in temperature.

11. The Silver Dyke deposit is a typical "Walker Lane" epithermal
deposit that is 17.4 m.y. in age.

12. It is very unlikely that significant tungsten mineralization remains in the Silver Dyke area.
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