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May, 1982
Acknowledgements

Dr. L. C. Hsu reviewed the manuscript and provided valuable assistance in analytical work as well as contributing many ideas during discussions. Director John Schilling of the Nevada Bureau of Mines and Geology is owed a special thanks for providing office space and access to bureau labs during the course of the thesis work. Norm Dirks, Mine Manager at the Nevada Scheelite Mine, is owed thanks for financial support, access to the mine, and to geologic data in the company files. Without his assistance the project would have been impossible. Bill Briner of Noranda is acknowledged for providing assay data on prospects in the area. Jill Kirkam drafted many of the maps and figures.
Abstract

The Nevada Scheelite area is underlain by a Mesozoic sequence of volcanic, volcaniclastic, and carbonate rocks of Jurassic-Triassic age, in part correlative with the Middle Triassic Luning Formation of west-central Nevada.

The tungsten deposit of the Nevada Scheelite Mine is a scheelite-bearing contact metasomatic deposit developed at the contact of Jurassic-Triassic limestone with Cretaceous biotite granodiorite. The tactite display weak calc-silicate zonation from intrusive outward of a garnet-scheelite zone followed by either an epidote, amphibole, or wollastonite zone. Formation of tactite followed an evolutionary trend from an early oxidized assemblage of andraditic garnet, epidote, and Molybdenum-bearing scheelite to a late, in the most part, retrograde assemblage of actinolite and ferroactinolite which formed contemporaneously with sulfidation of the tactite. Scheelite was deposited later than garnet and epidote, prior to sulfides and amphiboles, and is most abundant in the garnet-scheelite zone.

Localization of major ore bodies is controlled by large scale re-entrants, and embayments of marble into granodiorite.
## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures and Plates</td>
<td>vi</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Stratigraphy and Lithology</td>
<td>2</td>
</tr>
<tr>
<td><strong>Mesozoic Sequence</strong></td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td>4</td>
</tr>
<tr>
<td>Description of Units</td>
<td>6</td>
</tr>
<tr>
<td>Unit JTrvc</td>
<td>6</td>
</tr>
<tr>
<td>Unit JTrlls</td>
<td>9</td>
</tr>
<tr>
<td>Unit JTrva</td>
<td>10</td>
</tr>
<tr>
<td>Unit JTrls</td>
<td>13</td>
</tr>
<tr>
<td>Unit JTrm</td>
<td>14</td>
</tr>
<tr>
<td>Units JTrv, JTrv2, JTrv3</td>
<td>14</td>
</tr>
<tr>
<td>Discussion</td>
<td>16</td>
</tr>
<tr>
<td><strong>Mesozoic Intrusive Rocks</strong></td>
<td></td>
</tr>
<tr>
<td>Quartz Diorite</td>
<td>18</td>
</tr>
<tr>
<td>Late Porphyritic Quartz Diorite</td>
<td>18</td>
</tr>
<tr>
<td>Nevada Scheelite Stock</td>
<td>19</td>
</tr>
<tr>
<td>Upper Stock</td>
<td>21</td>
</tr>
<tr>
<td><strong>Tertiary Extrusive Rocks</strong></td>
<td></td>
</tr>
<tr>
<td>Rhyolite Welded Tuff</td>
<td>23</td>
</tr>
<tr>
<td>Olivine Basalt</td>
<td>25</td>
</tr>
<tr>
<td><strong>Tertiary Intrusive Rocks</strong></td>
<td></td>
</tr>
<tr>
<td>Biotite Dacite</td>
<td>25</td>
</tr>
<tr>
<td>Hornblende-Pyroxene Andesite</td>
<td>29</td>
</tr>
<tr>
<td>Flow Banded Rhyolite</td>
<td>30</td>
</tr>
<tr>
<td>Quaternary Alluvium</td>
<td>30</td>
</tr>
<tr>
<td><strong>Structural Geology</strong></td>
<td></td>
</tr>
<tr>
<td>Folding</td>
<td>30</td>
</tr>
<tr>
<td>Faulting</td>
<td>33</td>
</tr>
<tr>
<td>Mesozoic Faults</td>
<td>34</td>
</tr>
<tr>
<td>Tertiary Faults</td>
<td>35</td>
</tr>
<tr>
<td>Mesozoic Faults</td>
<td>37</td>
</tr>
<tr>
<td>Tertiary Faults</td>
<td>37</td>
</tr>
<tr>
<td>Quaternary Faults</td>
<td>37</td>
</tr>
</tbody>
</table>
# List of Figures

<table>
<thead>
<tr>
<th>Page</th>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Figure 1</td>
<td>Location map of study area</td>
</tr>
<tr>
<td>8</td>
<td>Figure 2</td>
<td>Stratigraphic column of JTrvc</td>
</tr>
<tr>
<td>12</td>
<td>Figure 3</td>
<td>Stratigraphic column of Unit JTrva</td>
</tr>
<tr>
<td>20</td>
<td>Figure 4</td>
<td>Modal Qtz:K-spar:Plag triangular diagram for Mesozoic intrusive rocks</td>
</tr>
<tr>
<td>24</td>
<td>Figure 5</td>
<td>Normative Qtz:K-spar:Albite + Anorthite triangular diagram for Mesozoic intrusive rocks</td>
</tr>
<tr>
<td>42</td>
<td>Figure 6</td>
<td>Longitudinal section of Nevada Scheelite Mine</td>
</tr>
<tr>
<td>48</td>
<td>Figure 7</td>
<td>CaO:SiO₂:MgO triangular diagram for carbonate rocks</td>
</tr>
<tr>
<td>56</td>
<td>Figure 8</td>
<td>Photo micrograph of garnet-scheelite tactite</td>
</tr>
<tr>
<td>56</td>
<td>Figure 9</td>
<td>Photo micrograph of garnet-scheelite tactite</td>
</tr>
<tr>
<td>61</td>
<td>Figure 10</td>
<td>Geology of 205 stope, 200 level</td>
</tr>
<tr>
<td>63</td>
<td>Figure 11</td>
<td>Photo micrograph of amphibole tactite</td>
</tr>
<tr>
<td>64</td>
<td>Figure 12</td>
<td>Sketch of scheelite crystal from amphibole tactite</td>
</tr>
<tr>
<td>79</td>
<td>Figure 13</td>
<td>Vertical sections through Nevada Scheelite Mine</td>
</tr>
<tr>
<td>80</td>
<td>Figure 14</td>
<td>Vertical sections through Nevada Scheelite Mine</td>
</tr>
<tr>
<td>83</td>
<td>Figure 15</td>
<td>Superimposed plan view of contact relations: 200 to 500 levels, northeast terminus of mine workings</td>
</tr>
</tbody>
</table>

# List of Plates

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Geologic map of Nevada Scheelite area</td>
</tr>
<tr>
<td>II</td>
<td>Cross sections of Nevada Scheelite area</td>
</tr>
<tr>
<td>A</td>
<td>Plate explanation for plates 2-5 and 2A - 5A</td>
</tr>
<tr>
<td>2</td>
<td>Geology of 200 level between vertical and incline shafts</td>
</tr>
<tr>
<td>3</td>
<td>Geology of 300 level between vertical and incline shafts</td>
</tr>
<tr>
<td>4</td>
<td>Geology of 400 level between vertical and incline shafts</td>
</tr>
<tr>
<td>5</td>
<td>Geology of 500 level between vertical and incline shafts</td>
</tr>
<tr>
<td>2A</td>
<td>Geology of 200 level northeast of the incline shaft</td>
</tr>
<tr>
<td>3A</td>
<td>Geology of 300 level northeast of the incline shaft</td>
</tr>
<tr>
<td>4A</td>
<td>Geology of 400 level northeast of the incline shaft</td>
</tr>
<tr>
<td>5A</td>
<td>Geology of 500 level northeast of the incline shaft</td>
</tr>
</tbody>
</table>
List of Tables

Page
26  Table I  Modal composition of Mesozoic intrusive rocks
26  Table II Normative mineral composition of Mesozoic intrusive rocks
27  Table III Whole rock chemistry for Mesozoic intrusive rocks
32  Table IV Whole rock chemistry and normative mineral composition of biotite dacite
43  Table V Production from Nevada Scheelite Mine
50  Table VI Partial whole rock chemistry of Jurassic-Triassic carbonate rocks
57  Table VII Physical properties and composition of garnets from tactite in Nevada Scheelite Mine
69  Table VIII Paragenesis of minerals in the Nevada Scheelite Mine
INTRODUCTION

Location and Access

The Nevada Scheelite Mine is in the southern extension of the Sand Springs Range, in the eastern portion of the Regent Mining District, Mineral County, Nevada. The mine lies 15 air miles south of Frenchman's Station and is located in sections 1 and 12, T.13N., R.32E. M.D.B.M. The mine is reached by turning south off U.S. Highway 50 onto State Highway 31, three miles west of Frenchman's Station. State Highway 31 is a two-lane paved road in good repair which turns into a well-maintained gravel road one quarter mile from the mine and twenty miles from U.S. 50.

Elevations in the area range from 4500 feet to 7500 feet making the area accessible year round. The region is arid with sparse vegetation consisting of sagebrush, desert shrubs, and low grasses, typical of west central Nevada.

Purpose of Study

The purpose of this study is to describe the geology and the mineralization of the tungsten-bearing tectite at the Nevada Scheelite Mine with special attention being given to the controls on localization of the ore deposit.

Method of Study

Surface geology was mapped at a scale of 1:6000 directly on blowups of the Kasock Mountain 3 SW 7½ minute preliminary quadrangle map. Approximately four square miles were mapped. The underground workings were mapped at a scale of 1:240 (1" = 20') on pre-established level plans by stretching a tape between survey spads.
A Petrographic study was made of 70 thin sections from surface and underground. X-ray diffraction was used extensively to determine mineralogy and for estimating garnet compositions. Whole rock analysis was performed by X-ray fluorescence using a Siemens Kristalloflex IV generator and a universal sequential spectrometer (SRS-1). Assay data were obtained from commercial laboratories.

Previous Work

A brief discussion of the geology of the Nevada Scheelite Mine is given in Geehan and Trengrove (1950). Krauskopf and Stopper (1944) mapped a portion of the surface geology around the mine but their work was unpublished. The general geology of the area is shown on the geologic map of Mineral County (Ross, 1961). Banaszak (1968) mapped the geology of the southern Sand Springs Range, concentrating on stratigraphy within the Mesozoic layered rocks.

Stratigraphy and Lithology

The area under study consists of approximately four square miles surrounding the Nevada Scheelite Mine. Scheelite mineralization occurs at the contact of Jurassic-Triassic limestone with a Cretaceous stock of granodiorite composition and is similar to many contact metasomatic tungsten deposits. The Mesozoic sequence consists of complexly folded carbonate, volcanic, and volcaniclastic rocks intruded by two Cretaceous granodiorite stocks as well as older dioritic dikes.

Tertiary intrusives of andesitic to rhyolitic composition form northeast to east trending dikes, and in one case, a rhyolite dike vented creating a small dome. Overlying a small portion of the Mesozoic rocks are silicic ash flow tuffs and olivine basalt each of Tertiary age.
Mesozoic Sequence

Introduction

A problem exists with the stratigraphic correlation and formational assignment of the older carbonate, volcanic, and volcaniclastic rocks exposed in the vicinity of Nevada Scheelite. These rocks were originally considered part of the Excelsior Formation of Muller and Ferguson (1936, p. 244). They state, "The Excelsior consists dominantly of effusive and pyroclastic rocks with subordinate sediments." They go on in more detail explaining that the lavas range in composition from andesite through quartz latite to rhyolite and are cut by intrusives of gabbroic and diabasic compositions as well as siliceous porphyritic types. These intrusives were considered by them to be in large part contemporaneous with the extrusive rocks. Also mentioned is the presence of lenticular, sparingly fossiliferous limestone beds within the Excelsior. Based on one fossil locality within a limestone bed near Wildhorse Canyon in the Gillis Range the age of the Excelsior Formation was set at Middle Triassic.

In the first published report on the Nevada Scheelite Mine, Geehan and Trengrove (1950, p. 4) reported the sequence of volcanic, volcaniclastic rocks and interbedded limestones probably belong to the Excelsior Formation. Ross (1961) also considered these rocks as part of the Excelsior Formation; however, by this time the Excelsior was being re-evaluated as a viable formational unit. With this in mind Ross (p. 20) discusses the "Excelsior problem". He states that the Excelsior rocks of the Gillis Range and to the west, as well as the area east of Rawhide (Nevada Scheelite) consist predominantly of volcanic flows and tuffs, a lesser amount of fine-grained tuffaceous sedimentary rocks and minor but locally abundant limestone. In contrast to this the Excelsior rocks of
The study area consists of the Excelsior Mountains, the Pilot Mountains, and the Pilot Mountains of Southern Mineral County. The Excelsior Mountains consist of Paleozoic clastic sedimentary rocks with lesser amounts of volcanic and metamorphic rocks. This difference in stratigraphy prompted Ross to suggest the presence of two individual units of limestone within the Excelsior Formation.

Speed (1977) divided the Excelsior Formation into three new formations: The Nevada, the Blackrock, and the Blackrock Range Formations. The Nevada Formation consists dominantly of volcaniclastic rocks, both fine- and coarse-grained with lesser chert, pelitic rocks, and quartz sandstone. The Blackrock Range Formation consists almost entirely of mafic volcanic rocks, while the Blackrock Formation is largely made up of interbedded clastic rocks and carbonate units in the Garfield Hills, Mineral County.

Fortunately, the redefinition and subdivision of the Excelsior as well as rocks of the Luning Formation by Hardyman has been given to the Garfield Hills, the Excelsior Mountains, and the Pilot Mountains of Southern Mineral County.

Work done in the Gillis Canyon Quadrangle approximately thirty miles north of Nevada Scheelite by Hardyman (1976) involved rocks formerly classified as part of the Excelsior as well as rocks of the Luning Formation. Hardyman states that mapping by several people has disclosed the presence of locally abundant volcanic and volcaniclastic rocks within the carbonate sequence historically designated Luning Formation (Now, 1977). Hardyman goes on to say that possibly all of the carbonate, volcanic, and volcaniclastic rocks in the Gillis Canyon Quadrangle may be the Luning equivalent of the Luning Limestones present in Wilburton Canyon in the Gillis Range (Now, 1977). This same limestone may be the Luning equivalent of the Luning Limestones and the Nevada Formation relative with a lenticular limestone exposed by U.S.G.S. geologist.

Figure 1
Location map of Study Area.
the eastern Garfield Hills, the Excelsior Mountains, and the Pilot Mountains consist of fine-grained clastic sedimentary rocks with lesser amounts of volcanic material, limestone being nearly absent. This difference in lithology prompted Ross to suggest the presence of two individual lithic units lumped within the Excelsior Formation.

Speed, (1977) divided the Excelsior into three new formations: The Mina, the Black Dyke, and the Gold Range Formations. The Mina Formation consists dominantly of volcanogenic turbidites both fine- and coarse-grained with lesser chert, pelitic rocks and quartz sandstone. The Black Dyke Formation consists almost entirely of mafic volcanic rocks, while the Gold Range Formation is largely made up of interbedded clastic rocks. The Pamlico Formation of Oldow (1977, p. 223) is also a former member of the Excelsior; it consists of interbedded volcanogenic and carbonate rocks in the Garfield Hills, Mineral County.

Unfortunately, this redefinition and subdividing of rocks formerly termed Excelsior has been limited to the Garfield Hills, the Excelsior Mountains, and the Pilot Mountains of southern Mineral County.

Work done in the Gillis Canyon Quadrangle approximately thirty miles southwest of Nevada Scheelite by Hardyman (1978) involved rocks formerly placed in the Excelsior as well as rocks of the Luning Formation. Hardyman states that mapping by several people has disclosed the presence of locally abundant volcanic and volcanioclastic rocks within the carbonate sequence historically designated Luning Formation (Oldow, 1977). Hardyman goes on to say that possibly all of the carbonate, volcanic, and volcanioclastic rocks in the Gillis Canyon Quadrangle may be the Luning equivalent. One limestone bed present in Wildhorse Canyon in the Gillis Range may be below the Luning limestones (Hardyman, p. 27). This same limestone may be correlative with a lower limestone mapped by U.S.G.S. personnel in the Rawhide-
Nevada Scheelite area. Hardyman (p. 17) raises the possibility that this limestone may be correlative with the upper member of the Middle Triassic Grantsville Formation.

Ekren and Byers (1978) have mapped the Luning SE, SW, NE, and NW preliminary 7½ minute quadrangles. The northern boundary of the Luning NW Quad lies one mile south of the Nevada Scheelite Mine. Rocks mapped by Ekren and Byers in the Luning NW Quad southeast of Nevada Scheelite have been designated Luning Formation by these workers. This sequence of carbonate, volcaniclastic, and volcanic rocks is similar to that mapped by the author just ½ miles northeast at Nevada Scheelite. If the sequence mapped in the Luning NW Quad is truly Luning Formation, then it would indicate that the carbonate, volcaniclastic, and volcanic rocks present at Nevada Scheelite are at least in part the Luning or the Luning equivalent.

Excelsior as a viable formational unit has been abandoned (Speed, 1977a). These rocks formerly placed within the Excelsior have since been assigned to new formations over much of the outcrop area of the former Excelsior Formation. The Mesozoic layered rocks of the Nevada Scheelite area have not been correlated with any of these new units although, according to Ekren and Byers (1978), they are more likely correlative with the Upper Triassic Luning Formation. As uncertainty still exists regarding the formational standing of these rocks they are not shown as belonging to the Luning Formation, rather they have been mapped as lower volcaniclastic rocks (JTrvc), lower limestone (JTrlls), volcaniclastic, rocks tuff and lava (JTrva), grey limestone, (JTrls) and marble (JTrm). Three more units are shown also. They are termed JTrv₁, JTrv₂, and JTrv₃. The stratigraphic position of these three units is unclear due to obscure contact relations and, in some cases, faulted contacts.

Description of Units
Unit JTrvc

Unit JTrvc crops out in an east-west trending zone approximately 1000 feet north of the incline shaft (see Plate I). The unit consists of pale green spotted phyllite, crystal-rich intermediate tuff and volcanic conglomerate with intercalated fine volcanic siltstone (Fig. 2). In the western portion of the exposures of JTrvc much of the rock is hydrothermally altered to a whitish, iron-stained rock composed of quartz and sericite. To the east near the Yankee Girl adit where the stratigraphic column of Figure 2 was obtained, the rocks are not hydrothermally altered.

Volcanic conglomerate and crystal-rich tuff, the two most abundant rock types, are dark greenish grey to black on outcrop, with well-shaped relict plagioclase phenocrysts. In the volcanic conglomerate clasts are sub-angular andesitic volcanic rocks with 10-15% relict plagioclase phenocrysts. The matrix is fine siliceous material composed of granoblastic intergrowth of quartz + feldspar + biotite + epidote recrystallized from ash. Rarely, 2-3 cm cherty layers are present, sometimes separated by fine siliceous, plagioclase rich lamella 1-2 cm thick. Compositionally, both rock types are andesitic to dacitic, with 5-20% relict plagioclase crystals in a recrystallized granoblastic matrix of quartz + plagioclase + lesser orthoclase (rarely microcline) with 15-20% fine green biotite and 5-10% epidote. Where An content is determinable on relict plagioclase it is in the andesine field.

Clots of biotite give the appearance of replacing original pyroxene. The phyllitic rocks and siltstone are lighter grey, foliated and, in the case of the phyllite, spotted with biotite porphyroblasts. All rocks are affected by low grade regional metamorphism plus later higher grade contact metamorphism.

On its western boundary unit JTrvc is in apparent fault contact with the nearly identical rocks of unit JTry. To the north it is in conformable contact with the grey limestone of unit JTrlls. This contact is considered conformable based on the following observations:
<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jlls</td>
<td>Massive grey recrystallized limestone</td>
</tr>
<tr>
<td>Jlvc</td>
<td>Grey massive volcanic siltstone</td>
</tr>
<tr>
<td></td>
<td>Light grey spotted phyllite</td>
</tr>
<tr>
<td></td>
<td>Dense grey andesitic volcanic conglomerate</td>
</tr>
<tr>
<td></td>
<td>Light grey spotted phyllite</td>
</tr>
<tr>
<td></td>
<td>Dense grey andesite crystal rich tuff</td>
</tr>
<tr>
<td></td>
<td>Intrusive Contact</td>
</tr>
<tr>
<td></td>
<td>Biotite granodiorite of Nevada Scheelite stock</td>
</tr>
</tbody>
</table>

Figure 2  
Scale 1"=10'  
Stratigraphic Section of Unit Jlvc
The contact north of the Yankee Girl is gradational over several feet and no structural disruption is present, foliation of similar trend is present in both units and attitudes of the two units are similar. To the south JTrvc is in intrusive contact with the Nevada Scheelite Stock. Contact metamorphism of unit JTrvc is within the upper albite-epidote hornfels facies as indicated by the metamorphic assemblage of quartz-plagioclase-biotite-epidote.

Unit JTrlls

Unit JTrlls crops out for 4800 feet in an east-west trending belt 1200 feet north of the Incline Shaft and at the incline shaft. The unit is 380 feet thick. It consists of grey recrystallized limestone cut by coarse white calcite veinlets .5 - 1.5 cm thick. Clots of white calcite are present throughout and give the appearance of pseudo fossils. The limestone crops out in a riblike pattern parallel to bedding planes. The limestone is relatively homogenous with bedding defined by slight color variations. In hand specimen JTrlls is composed of grey, fine-grained calcite with 1-2% white, fibrous tremolite porphyroblasts. In thin section 2-3% detrital quartz and feldspar grains occur.

To the north, in contact with the upper stock (Plate I) grey recrystallized limestone crops out for 1800 feet. The limestone forms two beds separated by volcaniclastic sediments. These beds dip from vertical to steeply south. This northern limestone is tentatively correlated with unit JTrlls. If so, a facies change is present as indicated by the wedge of volcaniclastic sediments within the limestone.

Both the north and south contacts of the northern exposure of the
JTrlls are conformable; to the west at the Vikings Daughter adit the limestone terminates against the Cottontail fault (see Plate I). At the eastern boundary of the map area the JTrlls is presumably concealed by quaternary alluvium and Tertiary volcanic rocks on the east side of State Highway 31.

Unit JTrva

Unit JTrva is the most extensive one mapped within the area. It is exposed in an east-west trending belt 1500 feet north of the incline shaft. The internal stratigraphy of this unit is unclear, partially due to alteration which seems to be common feature of this unit. Within the map area this unit is composed almost entirely of white schistose quartz-sericite rock with 4-6% hornblende phenocrysts replaced by iron oxides. On outcrop the rock is foliated and moderately stained by limonite. Second in abundance are andesite flows. On outcrop this rock is green-grey to black, massive but strongly fractured. In hand specimen the rock is grey on a fresh surface speckled with chalky white or greenish white seriate plagioclase phenocrysts up to eight mm in length and composing 10-30% of the rock. The matrix is grey, very fine siliceous material with biotite the only resolvable mineral.

True thickness of the JTrva is uncertain but a value of 650-700 feet is reasonable. A partial stratigraphic section measured beneath unit JTrlls at the northeast corner of the map area is shown in Figure 3. This section is combined with the observed sequence overlying JTrlls to give a composite stratigraphic section.

On the east side of State Highway 31 rocks of the JTrva unit
previously described as white schistose quartz-sericite rocks are much less altered. The rock is medium grey, strongly iron-stained, and bleached white adjacent to fractures. In thin section the rock is composed of 20-25% polycrystalline quartz clots .2 - .4 mm in size and 10-15% relict, lath shaped plagioclase crystals .1 - .5 mm in length. The latter crystals are partially to completely replaced by sericite and are generally broken; some retain albite twinning and are compositionally in the calcic oligoclase range. In addition, .5 - 1% clots of iron oxide are present after hornblende, plus 10-15% disseminated pyrite. The remainder of the rock is quartz + sericite and/or alkali feldspar + albite which forms a webbing through the rock. Three further samples of this rock type were examined, two from the central exposure area and one from the west border beneath unit JTrls. The latter is composed of ovoid polycrystalline quartz clots in a quartz-sericite webbing, former plagioclase crystals occur as "ghosts" replaced by fine sericite. The specimens from the central area are schistose rocks composed of ovoid polycrystalline quartz clots in a quartz-sericite webbing; no trace of feldspar exists. This rock is rhyolitic in composition and volcanic in origin and is a rhyolite tuff. At some less altered outcrops within this unit a hint of lamellar bedding defined by variation in crystal content is present. A prophrytic andesite flow near the top of JTrva contains 35-40% seriate relict plagioclase phenocrysts partially to completely replaced by epidote + sericite + albite. Clots of green biotite + chlorite + lesser epidote make up 20-25% of the rock and are interpreted as replaced mafic phenocrysts possibly pyroxene. The matrix consists of albite + epidote + lesser actinolite. This andesite is greater than eighty feet thick at the northeast corner of the map.
## Description

**Unit J'Alis**
- Massive grey recrystallized limestone

**Unit J'Rtlva**
- Black slate with silt interbeds, siltstone at base
- Green grey porphyritic andesite
- White pyritiferous rhyolite tuff, locally may display lamellar bedding. Throughout majority of outcrop area is foliated, bleached white, and consists dominantly of quartz and sericite.
- Foliated grey recrystallized limestone

### Figure 3
Scale 1"=50'

Partial Stratigraphic Section of Unit J'Rtlva

Upper portion of section from northeast corner of map area (see Plate I)
Lower portion from center of map area.
area and is not everywhere present.

Overlying the above andesite is 26 feet of black slate with one cm silty interbeds, this slate is the uppermost member of the JTrva unit and is overlain by the grey limestone of unit JTrls. The contacts of JTrva with both the underlying grey limestone of JTrlls and the overlying limestone of JTrls are interpreted as conformable.

Unit JTrls

Unit JTrls outcrops approximately 2400 feet north of the Incline Shaft. The unit does not form a continuous exposure except in the northeast corner of the map area. JTrls is composed of 110 feet of buff to brown and grey limestone. The lower 18 feet of JTrls is buff colored limestone with three inch shale partings occurring towards the base. The remainder of the limestone is grey to dark grey, weakly fissile and generally massively bedded, with calcite veinlets and iron oxide pseudofossils near the center of the unit. Figure 7 shows a partial chemical analysis of dark grey limestone from the upper portion of unit JTrls.

The limestone of unit JTrls is in conformable contact with both the underlying slate member of unit JTrva and the overlying marble of unit JTrm. At the northwestern most exposure of JTrls a three foot quartzite bed is present in the basal section of the limestone. The quartzite is not found at the other exposures of unit JTrls. Yet at two localities within unit JTrm a nearly identical bed is found in light grey to buff limestone which is overlain by marble and whose base is not exposed. The relationships are unclear but if the quartzite bed is the same in all localities then JTrls is exposed in these areas.

Scattered, isolated outcrops of grey limestone which may belong to
unit JTrvl is found in the northern portion of unit JTrva. These limestone bodies are fractured, in some cases brecciated and may be tectonically emplaced.

**Unit JTrm**

Unit JTrm outcrops at the vertical shaft and extends westward forming a large exposure area; it also is exposed in the northeast overlying limestone of JTrvl. Unit JTrm consists of massively bedded, chalky buff, coarsely recrystallized marble. True thickness of the marble is uncertain, sections are evidently repeated by normal faulting in the area north of the mine but the lack of distinctive marker beds makes correlation nearly impossible.

**Units JTrv₁, JTrv₂, JTrv₃**

At three separate localities pyroclastic rocks, volcaniclastic sediments, and lavas are exposed in contact with the marble of unit JTrm. The contact relations, thicknesses, and stratigraphic position of these units are unclear. For this reason each area is designated a separate unit and described individually. The rocks of these units are generally grey to dark grey porphyritic flows and/or crystal rich tuffs. Bedding is extremely rare in these rocks and where it exists it usually consists of thin, lensoid, laminated beds of greywacke and less commonly chert.

Unit JTrv₁ is exposed 400 feet northwest of the vertical shaft and extends in an arcuate belt to the western border of the map area. It consists almost entirely of weakly metamorphosed dense, grey, massive porphyritic andesite flows and pyroclastic rocks with rare lensoid grey
wacke beds. The porphyritic rocks are composed of 15-20%, .5 - 1.5 mm plagioclase phenocrysts in a fine recrystallized granoblastic matrix of quartz, plagioclase, and biotite. The biotite occurs disseminated in the matrix and in clots with epidote possibly replacing pyroxene. In the vicinity of the West adit (see Plate I) and to the west are white, heavily iron-stained rocks consisting of quartz + sericite + rare plagioclase phenocrysts. These rhyolitic tuffs are nearly identical to those previously described under unit JTrva and in fact could belong to that unit.

The contact relations of JTrv₁ with the other units is obscure. On the southwest it is in fault contact with unit JTrm and to the northeast it is in fault contact with units JTrvc and JTrlls.

Unit JTrv₂ is exposed on the west border of the map area. It consists of weakly metamorphosed grey porphyritic andesite or dacite and volcanic conglomerate. Except for the absence of rhyolitic tuff it is very similar lithologically to unit JTrv₁. The lavas contain 10-20%, .5 - .4 mm plagioclase phenocrysts in a recrystallized granoblastic matrix of plagioclase + quartz + lesser orthoclase. Metamorphic biotite and epidote are present in the matrix as well as forming replacements of mafic phenocrysts which in this case are more likely hornblende. Volcanic conglomerate is present at the west border in the locale of the shaft and adit shown on Plate I. Clasts are six inches to one foot in long dimension, sub-round to sub-angular and are porphyritic dacite similar to the lavas. One inch chert beds are locally present contorted about the clasts.

Although bedding altitude was obtained at only one site unit JTrv₂ appears to be a volcanic facies interbedded with the marble of JTrm. The
south contact of JTrv$_2$ with marble is conformable based on a contact gradational over ten feet from marble to siltstone to lavas.

The rocks of unit JTrv$_3$ again are similar to JTrv$_1$ and JTrv$_2$. They are composed of weakly metamorphosed dark grey massive porphyritic andesite lavas. A laminated, lensoid grey wacke bed is present on the northwest side of the unit and bedding altitudes were obtained along this member. Light grey spotted phyllite approximately 15-20 feet thick is present on the contact between limestone and andesite. This bed is mapped within the carbonate unit but is indicative of the change in depositional environment between carbonate sedimentation and volcanic activity.

Unit JTrv$_3$ is a volcanic facies present within the carbonate rocks and was deposited conformably with these carbonates. Both phylite and limestone display strong foliation in the area of Hook Creek. The discontinuation of the massive andesite of JTrv$_3$ to the west could be interpreted as a facies change yet the foliation, presence of phyllite on both borders of JTrv$_3$, and the outcrop pattern point to a structural solution.

Discussion

In summary, the succession of Mesozoic layered rocks as mapped is: JTrvc, JTrlls, JTrva, JTrls, JTrm, and JTrv$_1$ JTrv$_2$, JTrv$_3$. This sequence is interpreted as oldest to youngest with the exception of the last three which are shown coeval with unit JTrm. This interpretation is not necessarily the correct one as few localities exist within the field area where an irrefutable indicator of stratigraphic direction can be found. Yet evidence is present which indicates overturning of beds has taken place
Recumbent minor folds occur in unit JTrm and unit JTrlls is locally overturned in the vicinity of the incline shaft.

The Jurassic-Triassic rocks form a sequence revealing nearly continuous deposition in a shallow marine environment. Precipitation of carbonate took place during periods of quiescence which were periodically interrupted by volcanism and deposition of volcaniclastic and volcanic rocks. Presence of volcanic conglomerates indicates local shoaling occurred, and some of the lavas could have been deposited sub-aerially. The preponderance of extrusives and volcaniclastic sediments in rocks of this age in west central Nevada has led other workers (Speed, 1977b, 1977c) to postulate the presence of an early Mesozoic volcanic arc located off the then west coast. Banaszak (1969) draws analogies between the rocks of the southern Sand Springs Range and those of Sumatra, Indonesia, and Saipan, Mariannas Islands, both of which are island arc environments. The lithology and stratigraphic succession bears resemblance in both instances and Banaszak concludes the Early Mesozoic sequence in the southern Sand Springs Range is genetically related to an Early Triassic island arc.

From the foregoing descriptions of the Mesozoic layered rocks and the introductory pages, it is clear much remains to be learned about the stratigraphy, age, and regional significance of the Mesozoic rocks of the southern Sand Springs Range. A portion of the units present at Nevada Scheelite certainly belong to the Triassic Luning Formation or are equivalent (Ekren and Byers, 1978). The depositional environment discussed briefly above and in greater detail by Banaszak (1969) is accurate as well as the relation of rocks of this age and lithology to plate tectonics. Yet a detailed stratigraphic study of the Mesozoic rocks of northeast Mineral County is a task still to be accomplished.
Mesozoic Intrusive Rocks

Four types of Mesozoic intrusive rocks occur in the study area. The oldest is medium to fine grained, locally porphyritic diorite which occurs as dikes cutting the Mesozoic carbonate, volcaniclastic, and volcanic rocks. These dikes generally have a northwest trend, an easterly dip, and are present throughout the exposure of the Jurassic-Triassic rocks. Granodiorite of the Nevada Scheelite stock intrudes the Jurassic-Triassic sequence forming an irregular stock with outlying dikes. The contact metasomatic scheelite deposits of the Nevada Scheelite Mine is genetically related to this granodiorite. Exposed on the northern border of the map area is a second granodiorite stock termed the upper stock.

Quartz Diorite (di)

Northwest trending diorite dikes are well exposed cutting the Jurassic-Triassic rocks both on surface and within the underground workings of the Nevada Scheelite Mine. The dikes are generally from 10-100 feet thick, dense green grey to dark grey and locally porphyritic. Table I shows a modal analysis of two diorite specimens (4-3-1, 7-2-2). Texturally diorite is hypidiomorphic-granular. Though altered by metamorphism, original An content of plagioclase is sometimes determinable and ranges from An$_{30}$-An$_{45}$ placing it in the andesine field. Normal oscillatory zoning with a normal trend is identifiable in some plagioclase crystals. Biotite is the only mafic mineral and is a product of metamorphic recrystallization. It occurs as scattered poorly formed crystals and as polycrystalline clots replacing pyroxene. Epidote varies from 2-10% of the specimens observed in thin section. It occurs
as moderately well formed single crystals, on fracture surfaces, with biotite clots, and replacing plagioclase. Orthoclase is present as small poorly formed crystals interstitial to plagioclase. Sphene, apatite, and magnetite are accessory minerals. In Figure 4 modal qtz:k-spar:plagioclase is plotted on the upper half of the double triangle of Streckeisen (1976). The two specimens examined fall in the quartz monzodiorite field. Diorite shows mineralogic and textural evidence of metamorphic recrystallization. Plagioclase is altered to albite + epidote while original pyroxene is replaced by biotite + epidote. Twinning and zoning in the majority of plagioclase crystals is also destroyed. The recrystallization is interpreted as due to contact metamorphism created by intrusion of the Cretaceous plutonic rocks; metamorphism is of the albite-epidote hornfels facies.

Late Porphyritic Quartz Diorite (pdi)

The contact relations of porphyritic diorite dikes, exposed in the underground workings of the Nevada Scheelite Mine, to granodiorite and tactite lead to the conclusion that there are two stages of diorite intrusion. The earlier dikes show more clearly the effects of low grade metamorphism as mentioned before. These dikes are found cutting the Mesozoic layered rocks at a distance from the younger granitic intrusions. Porphyritic quartz diorite in the underground workings is similar to the earlier dikes with the exception that it is always porphyritic. Table I gives modal compositions of three specimens of late porphyritic quartz diorite. Table I displays CIPW normative mineral composition for a sample from the 200 level of the mine (sample 2-13), and Table III contains the whole rock chemistry for the same sample. The porphyritic
Figure 4

Modal Compositions of Mesozoic Intrusive Rocks

- Diorite
- Late porphyritic diorite
- Granodiorite of Nevada Scheelite stock

Field divisions after Streckienson 1974.
quartz diorite is fine grained, dark grey, with seriate textured plagioclase phenocrysts of andesine composition. On a modal plot of qtz:K-spar:plagioclase (Figure 5) porphyritic quartz diorite falls in the quartz monzodiorite field with quartz diorite but displaced to the upper left corner. However, a larger number of samples should be examined before it can be stated that a mineralogic or chemical difference is present between the two diorites, also orthoclase may have been overcounted as twinning is rarely present in ground mass plagioclase of either diorites.

Granodiorite and porphyritic diorite dikes are not seen clearly cross cutting one another yet are commonly found lying side by side. On the surface no diorite is observed cutting granodiorite. Porphyritic diorite appears to cut tactite at some sites (see Plates 2 and 3) yet is not seen cutting granodiorite. The actual relationship is that tactite formation took place in carbonate rocks around porphyritic diorite, in fact the contact zone of porphyritic diorite with limestone may have been a zone of higher permeability thus a favorable channel way for tactite forming solutions. This relation of porphyritic diorite to tactite is discussed further in the section on economic geology.

The late porphyritic diorite is interpreted as an early phase of the granodiorite emplaced at what at that time was a higher structural level. This diorite dike system was later intruded by the rising granodioritic magma, in some cases granodiorite dikes following the same pathways.

Nevada Scheelite Stock (Kgd)

In Nevada Shceelite stock is an irregular shaped intrusive body covering roughly one square mile. It is composed of relatively homogenous biotite granodiorite and intruded in a single episode. Schilling
(1965) gives ages for the Nevada Scheelite stock of 87.5±1.0 m.y. and 83.6±3.5 m.y. based on two biotite samples dated by the Potassium-Argon method. Table I shows modal composition of several specimens while Table II contains CIPW normative mineral composition for two granodiorite specimens (Gd-1, 5-13). Granodiorite in outcrop is light grey. Sparse 2-10 inch aplite dikes cut the intrusive as well as quartz-K-feldspar veins and quartz-pyrite veins. The biotite granodiorite is medium grained with a hypidiomorphic granular texture. Plagioclase is well-formed, displays both albite and Carlsbad twinning with occasional pericline twins. Single crystals have oscillatory zoning with a normal trend, centers are An_{37} to An_{45} while rims are An_{18} to An_{22}. Plagioclase also has a range in crystal size giving it a seriate texture though not porphyritic. K-feldspar occurs as both perthitic orthoclase and microcline in poorly formed crystals interstitial to plagioclase. Perthitic microcline also occurs as anhedral poikilitic phenocrysts forming 2-3% of the rock. Well-formed biotite with ragged terminations containing zircon inclusions is the major mafic mineral. Hornblende is a minor constituent of the rock; where observed it appears to have crystallized early as euhedral crystals. These crystals are slightly broken and ragged owing to mechanical fracturing during movement of the magma and/or deuteric alteration. Apatite and epidote are accessory minerals. Figure 5 contains a modal plot of quartz:K-feldspar:plagioclase. In both cases the rock is split between the granodiorite and quartz monzodiorite fields. I believe biotite granodiorite is the preferable classification for the stock. Table III contains whole rock chemistry for two specimens of the stock (Gd-1, 5-13).

Aplite dikes present within the stock are fine-grained with a typical
aplitic texture. Mineralogically they are composed of K-feldspar-
quartz-plagioclase-biotite and muscovite. Table I shows modal mineral
composition of aplite while Table II contains CIPW normative mineral
composition from a specimen taken near the center of the stock. In
Figure 5 aplite falls in the granite field, while comparison of whole
rock chemistry in Table II shows aplite notably higher in SiO₂ and K₂O
than biotite granodiorite and low in CaO and MgO. The aplite dikes are
thin (several inches) and do not have great lateral extent. Aplite
dikes formed through the accumulation of later interstitial melt and
may have been channeled into dilational fractures in the almost fully
crystallized stock. As such, the aplite would have an indigenous source
and fit the model developed by Hibbard (1980).

Quartz-K-feldspar and quartz-pyrite veins are common cutting the
stock. Quartz-K-feldspar veins appear to be earlier than quartz-pyrite
veins, with both developing sericite envelopes several inches thick on
each side of the vein. Both vein sets are younger than aplite. These
veins are discussed further in the section on economic geology.

Upper Stock (Kgdu)

The upper stock is exposed in an east-west trending zone at the
northern border of the map area. The rock is a light grey white biotite
granodiorite porphry. In hand specimen the rock consists of 30-35%
plagioclase phenocrysts, 2-3% K-feldspar phenocrysts, 1% quartz pheno-
crysts, and 4-5% biotite phenocrysts set in a fine-grained siliceous
appearing matrix. In thin section the rock is composed of .5 - 1.2mm
plagioclase crystals. This plagioclase is well-formed with strong normal
oscillatory zoning. Crystal cores are oligoclase An₂⁷ to An₃₂ while rims
Figure 5

Plot of CIPW Normative  
Qtz:K-spar:Albite+Anorthite

+ upper stock
O Nevada Scheelite stock
O late porphyritic diorite
△ opalite dike in Nevada Scheelite stock
□ pegmatite from upper stock
▼ biotite dacite

Field divisions after Streckiensen, 1976
are An\textsubscript{14} to An\textsubscript{17}. Poorly formed plagioclase occurs as .1 - .2mm crystals in the matrix. K-feldspar is present as rare well-formed perthitic orthoclase phenocrysts up to 2 mm, as .5 - 1 mm moderately well-formed non-perthitic microcline, and as poorly formed .1 - .2 mm matrix microcline. Quartz occurs as .2 - .4 - .8 mm poorly formed, undulatory crystals and as .1 - .3 mm crystals in the matrix. Well-formed biotite is present as .5 - 1.4 mm phenocrysts and does not occur in the matrix. Epidote, sphene, and apatite are accessory minerals.

Numerous aplite-pegmatite dikes and quartz veins cut the upper stock and surrounding rocks. Table II contains CIPW normative minerals for the upper stock and a granitic pegmatite dike. The accompanying chemical analyses are given in Table III. The upper stock is a one stage porphyry. That is most of the plagioclase, orthoclase, biotite and some quartz crystallized early. The melt plus crystals was then intruded to a higher level where quartz, microcline, and some plagioclase crystallized as a fine-grained aplitic textured matrix.

**Tertiary Extrusive Rocks**

Crystal-rich welded tuff and olivine basalt make up the Tertiary extrusive rocks mapped in the project area. A thorough study of the ash flows was not made as they do not bear on tactite formation. Ash flow tuffs are mapped as Tertiary volcanics (Tv) and olivine basalt as (Tb).

**Rhyolite Welded Tuff (Tv)**

Unit Tv is composed of two cooling units of nearly identical
Table I

Modal Compositions of Mesozoic Intrusive Rocks

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### Whole Rock Analysis of Mesozoic Intrusive Rocks

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**Rb** 88 109 202
**Sr** 616 608 110
**Rb/Sr** .14 .18 1.83

**All Fe reported as Fe₂O₃**

All oxides are in weight %

**Rb and Sr reported in ppm**
Sample Descriptions for Tables I - III

12/24/5 Aplite dike from center of Nevada Scheelite Stock

4-3-1 Diorite dike at Hook Creek

7-2-2 Diorite dike cutting unit JTm

3-6 Late Porphyritic diorite dike from 300 level, Nevada Scheelite Mine

5-6 Late Porphyritic diorite dike from 500 level Nevada Scheelite Mine

2-13 Late Porphyritic diorite dike from 200 level Nevada Scheelite Mine

Gd-1 Nevada Scheelite Stock

5-13 Biotite granodiorite dike just outside main body of Nevada Scheelite Stock

Gr-1 Biotite granodiorite porphyry, Upper Stock

Peg-1 Granitic pegmatite dike outside Upper Stock

Ns-1 Biotite granodiorite of Nevada Scheelite Stock

2-26-2 Biotite granodiorite of Nevada Scheelite Stock located ten feet from contact with tactite
rhyolite ash flow tuff. The ash flows rest unconformably on a nearly planar erosional surface formed over the Mesozoic rocks. Locally beneath the tuff a paleosol can be seen. A 10-40 foot black, welded, locally devitrified vitrophyre is the basal member of the ash flow sequence. The vitrophyre contains 30-40% flattened, elongate pumice fragments and 10-15% lithics. Above the vitrophyre is 80-100 feet of pinkish buff-colored, moderately welded, devitrified crystal tuff. The rock is composed of 8-10% quartz phenocrysts, 5-8% sanidine, 2-3% plagioclase and 0.5 - 1% biotite. Rare pumice and lithic fragments are also present. This welded tuff grades upward into 30 feet of light grey non-welded tuff which in turn grades into a second cooling unit seemingly identical to the lower welded tuff.

On the state geologic map (Stewart, 1979) these ash flows are placed in the 34-17 m.y. category which includes ash flows over a widespread area in western and central Nevada.

Olivine Basalt (Tb)

Olivine basalt outcrops atop a low hill northeast of the Yankee Girl Shaft. The rock is dense, dark grey with 2-3% olivine phenocrysts, often altered to iddingsite, set in an aphanitic ground mass. In thin section olivine basalt consists of: 4-5% subhedral .3 mm - .6 mm olivine phenocrysts partially to completely altered to iddingsite 5-6% .2 - .4 mm subhedral, zoned augite phenocrysts. Plagioclase makes up 68-70% of the rock occurring as well-formed laths with normal zoning. Average plagioclase composition ranges from An^ to An^%. Very fine-grained pyroxene (possibly pigeonite) forms 15-18% of the rock occurring interstitial to plagioclase. 1-2% magnetite is also present.
Olivine basalt occurs as an isolated outcrop overlying the ash flows of unit Tv. Absolute age is uncertain but it is certainly Upper Miocene or younger.

Tertiary Intrusive Rocks

Three tertiary intrusives are exposed in the study area. Early biotite dacite dikes cut the Jurassic-Triassic layered rocks but are not evident cutting younger rocks. Although these dikes are here considered Tertiary, they, in fact, could be a late phase of the Cretaceous intrusive event. Hornblende-pyroxene andesite occurs as an east-west trending dike paralleling a large biotite granodiorite dike in the west central portion of the map area. Flow banded rhyolite forms a small dome and feeder dike on the west border of the study area. This dome is related to the Late Miocene series of rhyolite dikes, domes and flows of the Rawhide volcanic center (Ekren and Byers, 1978).

Biotite Dacite (Td)

Biotite dacite forms 2-20 foot thick, light tan weathering dikes which trend north to northeast and dip shallowly to the east. Biotite dacite cuts the Jurassic-Triassic layered rocks and also crosscuts diorite. The dikes, when less than four feet thick, are aphanitic with the exception of biotite phenocrysts up to 1.0 cm and 1-2% plagioclase phenocrysts. Thicker dikes show a 2-4 foot aphanitic chill zone at their margins and are generally fine-grained towards the dike center. Flow banding and weak lineation of biotite is sometimes observable just inside the chill zone. The coarser-grained core of a dike is composed
of: 35-40% poorly-formed plagioclase with serrate boundaries. Crystals have weak normal zoning, poor polysynthetic twinning, and range in composition from An_{15} to An_{25}, placing the plagioclase within the oligoclase field. 24-28% orthoclase and lesser microcline form anhedral crystals with quartz intergrown around the margins yielding a granophyric texture. Quartz composes 24-28% occurring as granophyric intergrowths with K-feldspar and as .1 mm poorly-formed crystals. Well-formed biotite phenocrysts make up 2-3% of the rock, and are unusually large, up to 1.0 cm in length. Primary muscovite is also present as .1 -.2 mm crystals constituting less than .5%. Very fine hematite is the only opaque mineral.

Table IV displays CIPW normative mineral composition and whole rock chemistry for a sample of fine-grained biotite dacite from a dike center. On Figure 5 the position of this specimen is shown on a normative quartz: K-feldspar:plagioclase triangular diagram. The supposition that biotite dacite is an Early Tertiary intrusive not genetically related to the Cretaceous igneous event is upheld by the following observations. Intense quenching of the magma at dike borders indicates the country rock was much cooler at the time of emplacement than during crystallization of the coarser-grained Cretaceous plutonic rocks. Biotite dacite was likely intruded at a much higher structural level than the earlier granitic rocks. The chemical data on these rocks, though limited to a few specimens and thus not statistically valid, can at least be used for speculation. Biotite dacite, though higher in SiO_{2} and Na_{2}O than either Cretaceous stock, still plots in the same field on Figure 5. Secondly, the Rb/Sr value of .18 for biotite dacite and .14 to .18 for the Nevada Scheelite stock and upper stock are not strikingly different. With this in mind one
### Table IV

**Normative Mineral Composition of Biotite Dacite**

<table>
<thead>
<tr>
<th>CIPW Normative Minerals</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>2</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>20</td>
</tr>
<tr>
<td>Albite</td>
<td>50</td>
</tr>
<tr>
<td>Anorthite</td>
<td>9</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>2</td>
</tr>
<tr>
<td>Magnetite</td>
<td>2</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>.5</td>
</tr>
<tr>
<td>Apotite</td>
<td>9</td>
</tr>
</tbody>
</table>

**Whole Rock Chemistry for Biotite Dacite**

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>73.16</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>16.87</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>3.60</td>
</tr>
<tr>
<td>MgO</td>
<td>0.08</td>
</tr>
<tr>
<td>CaO</td>
<td>1.92</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>5.97</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>3.36</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.19</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.04</td>
</tr>
<tr>
<td>Total Oxides</td>
<td>104.99</td>
</tr>
</tbody>
</table>

Rb 84
Sr 452
Rb/Sr 0.18

All oxides are in weight %

All Fe is reported as FeO.

Rb and Sr reported in ppm.
may speculate that biotite dacite did not form by differentiation of these earlier magmas. Lastly, aphanitic rhyolite to dacite dikes fitting the description of biotite dacite have been observed in the Sand Springs Range cutting Cretaceous granitic rocks and aplite-pegmatite dikes (Jerome, et al., 1964, p. 28).

Hornblende-Pyroxene Andesite (Ta)

Hornblende-pyroxene andesite is found as a solitary 70 foot thick dike trending N80W and dipping steeply. The rock is dark grey, fine-grained with 1-2% hornblende phenocrysts. In thin section andesite has an intergranular texture plus sub-parallel flow alignment of plagioclase. The plagioclase occurs as well-formed \(0.1\) mm lath shaped crystals and composes 75-80% of the rock. Plagioclase is well-twinned on the albite and Carlsbad laws, with weak normal zoning, and ranges in composition from An\(60\) to An\(70\). Augite plus pigeonite make up 18-20% of the rock. Augite forms \(0.1\) mm crystals plus smaller crystals, with pigeonite filling interstices between plagioclase laths. \(0.5-1\) mm hornblende phenocrysts form 1-2% of the rock and are frequently altered to calcite plus iron oxides. 2-3% magnetite is disseminated through the rock in fine cubes.

Age of hornblende-pyroxene andesite is uncertain as the sole dike observed crosscuts only the earlier Mesozoic rocks. Andesite is in contact with a large biotite granodiorite dike but does not crosscut it, yet as no contact metamorphic effects are present in the andesite, it is certainly much younger than granodiorite. Andesitic intrusives are associated with the Miocene Rawhide volcanism (Ekren and Byers, 1978) and hornblende-pyroxene andesite is interpreted as Miocene in age.
Flow Banded Rhyolite (Tr)

Pinkish-white flow banded rhyolite forms a small dome and feeder dike at the west central border of the map area. In hand specimen the rock is white on a fresh surface, devitrified, distinctly flow banded, with 4-5% plagioclase phenocrysts, 1% quartz, and less than 1% biotite. A thin section of the rock contains 6% well-formed, .4 - 1.2 mm plagioclase phenocrysts often in glomeroporphyritic clusters. The plagioclase is oligoclase, ranging in composition from An$_{22}$ to An$_{25}$. Subhedral, partially resorbed quartz phenocrysts form 1-1.5% of the rock, while biotite is less than .5%. The matrix is a very fine devitrified, splotchy intergrowth of cristobalite and/or tridymite, alkali, feldspar and biotite, rare spherulites are also present. Some flow bands in the rhyolite are frothy textured and contain vapor phase silica plus alkali feldspar.

This feeder dike and dome are on the eastern periphery of an extensive volcanic complex termed the Rawhide volcanic center by Ekren and Byers (1978). The age of the complex is Late Miocene and it is believed to have erupted over a short time span. Potassium-Argon dates on intrusive rhyolite from Rawhide yield ages of $14.6 \pm 0.4$ m.y. and $15.5 \pm 0$ m.y. (Silberman, et al., 1975, p. 14). These dates, however, may not give an accurate age for these rocks as the samples were taken from mineralized areas.

Quaternary Alluvium (Qal)

Recent stream deposits have been mapped where they are of sufficient extent to obscure outcrop details of the older rocks. Alluvium has been mapped through the canyon along which the entrance road to the mine runs
and up a tributary canyon. The deposits are young, unconsolidated, poorly-sorted sand, gravel, and cobble-size material.

STRUCTURAL GEOLOGY

Folding

Two phases of folding are identifiable in the southern Sand Springs Range. The earlier is related to orogeny occurring after deposition of the Jurassic-Triassic sequence. This deformation produced isoclinal, sometimes overturned folds around an easterly trending axis, plus axial plane cleavage. Later diastrophism of probable Late Jurassic age produced gentle open folds with fold axis trending southwesterly. This later phase of folding was not identified by the author in the project area but is described by Banaszak (1969) and Wilden and Speed (1974).

Within the project area it is difficult to clearly define folds although their presence is certain. The Jurassic-Triassic units generally strike roughly east-west and dip to the north or south. The outcrop of these rocks is then presumably controlled by folds with easterly trending axis, and at a few sites macroscopic folds of this nature are observable, as well as rare minor folds.

At the western exposure of unit JTrls a synclinal axis trends N60W, with the limbs dipping inward at approximately 60 degrees. The fold plunges shallowly to the northwest. This fold presumably continues eastward beneath the Tertiary volcanics, though it loses definition in that area. In this vicinity unit JTrls strikes north-northwest and dips 25-40 degrees east. That this area is near or at a fold trough is indicated by the intensity of axial plane foliation within the underlying rocks of unit UTrva. Foliation in the uppermost slate member of
unit JTrva intersects bedding at nearly 90 degrees and intersection of bedding and foliation define a lineation trending. Where bedding can be discerned in unit JTrva outward of this area it dips steeply inward. If this area is indeed a synclinal fold trough it is now plunging east. This can be explained by either unidentified faulting or upward doming created by an underlying granitic intrusion.

At the southwest corner of the map area unit JTrv 3 forms a complex outcrop pattern which resembles a tight steeply plunging inclined fold (Dennis, 1972, p. 145). Strongly developed foliation is present in phyllite and carbonate rocks between the fold limbs. This structure is interpreted as a fold, if so, overturning of bedding has occurred. The stratigraphy of rocks affected by this fold is unclear. The carbonate rocks in the center of the fold are continuous with unit JTrm and are shown as such although the relation is uncertain.

Limestone in contact with the Nevada Scheelite stock at the incline shaft has been mapped on the basis of lithology as unit JTrlls. The limestone dips steeply south through its western and southern outcrops but north along the northern exposures. The limestone is interpreted as the partially engulfed southern limb of an anticlinal fold, with bedding altitudes disrupted on a broad scale by emplacement of the stock.

Minor folds present in the southwest portion of unit JTrm, are isoclinal, and occasionally recumbent. Fold axis trend N65E to N75E and plunge steeply. The axial planes of these folds are roughly co-planar with that of the fold described in unit JTrv 3 and with those observed by Ekren and Byers (1978), further to the southwest.

The above-described folding took place during regional Middle Jurassic diastrophism (Speed, 1977; Hardyman, 1978; Ferguson and Muller,
In the Nevada Scheelite area this event produced isoclinal, sometimes overturned folds with attendant axial plane cleavage. Fold axis generally are N65E to N80E but deviations are present.

A second phase of folding of Late Jurassic or Early Cretaceous age has been recognized in the southern Sand Springs Range although it was not observed by the author in the field area. Wilden and Speed (1974, p. 43) describe this deformation as broad folding with westerly axial traces. Based on stereographic plots of lineations and poles to foliation planes Banaszak (1969, p. 22) postulated a second phase of broad folding about a southwesterly axis.

Faulting

Northwest trending normal faults of pre-Late Cretaceous age offset Jurassic-Triassic rocks. These faults locally controlled emplacement of diorite dikes and form contacts between carbonate and volcanic units. Northeast trending normal faults related to Basin and Range tectonics cut all rock types with the exception of Quaternary alluvium.

Mesozoic Faults

Northwest trending probable normal faults offset carbonate, volcanic, and volcaniclastic rocks. These faults do not extend into the Tertiary volcanic rocks and are not seen cutting the Late Cretaceous plutonic rocks, although this relation may occur. If these faults do not cut the Cretaceous stocks their age is constrained as pre-83 m.y. and post Late Jurassic. Intrusion of diorite dikes was locally controlled by northwest running zones of weakness which coincide with the trend of the northwest striking faults.
The Radio and Cottontail faults which form a portion of the west and east borders of unit JTrv, are of uncertain nature. Presence of the Radio fault is deduced on the basis of divergent bedding altitudes between units JTrm and JTrv, while the Cottontail fault terminates unit JTrlls. These two faults may have formed in part contemporaneously with deformation of the Jurassic-Triassic sequence owing to differing competencies of the two lithic units.

Tertiary Faults

Normal faults trending N30E to N45E offset the Mesozoic rocks and in one instance the Tertiary ash flows of unit Tv. These faults are of minor displacement with apparent east side down movement. One exception is the fault mapped on the north side of unit Tv. This fault shows apparent left lateral offset of unit JTrlls as well as dip slip movement to the southeast. The presence of strike slip movement on this fault is based solely on the offset of unit JTrlls. These northeast trending faults are interpreted as Basin and Range faults and are Tertiary in age.

GEOLOGIC HISTORY

During Middle Triassic to Early Jurassic time deposition of carbonate, volcanioclastic, and volcanic rocks took place in a shallow, sometimes shoaling marine environment. Deposition of this sequence is related to an Early Triassic volcanic arc terrane (Speed, 1977b). In Middle Jurassic time intense compressional deformation folded and faulted this sequence producing isoclinal folds and axial plane cleavage. Later gently folding about a southwesterly axis further deformed the
Mesozoic layered rock. Uplift and recession of the ocean during this time ended deposition in the marine environment.

Intrusion of diorite dikes later than the early folding but pre-Late Cretaceous took place along northwest trending zones of weakness. Later porphyritic diorite dikes were emplaced as an early phase of the Cretaceous granitic rocks. This dike system was followed closely by intrusion of the Late Cretaceous Nevada Scheelite and upper stocks. These stocks are related to the widespread magmatic event which emplaced the Sierran plutonic rocks of California and western Nevada. Intrusion of granodiorite caused local doming of the pre-Cretaceous rocks and with intrusion came concomitant thermal metamorphism. Carbonate rocks were converted to marble while volcanioclastic and volcanic rocks were converted to hornfels generally of the albite-epidote facies. At this time the calcium silicate tactite and scheelite mineralization of the Nevada Scheelite Mine was developed.

During Early Tertiary time uplift and erosion produced a surface of low relief. Voluminous silicic ash flow tuffs were extruded throughout much of western Nevada in Late Oligocene through Miocene time covering a portion of the Nevada Scheelite area. Emplacement of biotite dacite dikes along north-northeast trending zones probably predated the ash flows but a larger area should be mapped for this to be certain. Late Miocene time was characterized by formation of the Rawhide volcanic center west of Nevada Scheelite. Hornblende-pyroxene andesite was intruded early in this event and was later cut by flow banded rhyolite which vented creating a small dome on the eastern periphery of the Rawhide volcanic center.

Basin and Range faulting commenced during Middle Tertiary time altering dramatically the topography of the area. Quaternary deposits
were (and are being) produced by erosion of the landscape creating collu-
vium on slopes and filling stream valleys with alluvium.

ECONOMIC GEOLOGY

Introduction

The economic geology portion of this paper deals exclusively with the scheelite-bearing tactite and related features found in the Nevada Schee-
lite Mine. The mine workings and history and production are presented in
the next two sub-sections followed by description and discussion of the
ore deposit and other pertinent features. During the course of the geo-
logic investigation of the deposit not all areas were mapped. For instance,
the 100 level is mined out and inactive at this time; this level was not
mapped. Likewise, some old drifts and stopes on other levels are now
inaccessible. The geology for these areas was obtained from old maps in
the company files. Also, the investigation is limited to the workings of
the Nevada Scheelite Mine; the Moonlight and Caldwell shafts were examined
but not mapped. The workings of each of these shafts are minor, and the
mineralization found in them is nearly identical to that found in the
Nevada Scheelite Mine.

The tungsten-bearing tactite of the Nevada Scheelite Mine is similar
to most contact metasomatic deposits of this type. It is genetically
related to a barren biotite granodiorite stock which is in contact with
Jurassic-Triassic carbonate rocks. The tactite has moderate calc-
silicate zonation and strong structural control on localization of ore
bodies.
Mine Workings

The Nevada Scheelite Mine is an underground mine developed on five levels and one sub-level. The levels are served by two shafts. A three-compartment vertical shaft is located on the carbonate-intrusive contact and is sunk to below the 400 level. 1100 feet northeast is the incline shaft, access to which is by a short adit. The incline shaft serves the 200 through 500 levels. Workings on the 100 level extend southwest and northeast from the vertical shaft but do not reach the incline shaft. The 500 level is developed extensively northeast of the incline shaft with only a short distance working to the southwest. Fifty feet below the northeast end of the 500 level is a 100 foot sub-level termed the 550 sub-level. Figure 6 is a somewhat schematic longitudinal section of the mine layout.

Mining is by square set stoping. Ore and waste from the 400 and 500 levels is hoisted through the incline shaft and trammed across to the vertical shaft where it joins rock removed from the 300 and 200 levels. All rock leaves the mine by means of the vertical shaft; ore is stock-piled or fed directly into the mill, and waste is removed to the mine dump. The mill is located adjacent to the vertical shaft and consists of both gravity and flotation circuits, recovery is generally in the range of 75-82%.

History and Production

Outcropping scheelite-bearing tactite was discovered in the Nevada Scheelite canyon in 1934 by W. H. Leonard, and the original claims on the property filed in 1935. In 1937, the Nevada Scheelite Corporation
was organized and purchased the property, initiating underground development. The Nevada Scheelite Corporation held and worked the property until 1951 when it was sold to Kennametal Corporation. From 1951 to 1957, Kennametal fully exploited the deposit and boasts the largest production of any operator. In 1957 production from the mine was discontinued, presumably in response to government deregulation of imported price controls. However, milling and metallurgical work continued at the site. Union Carbide explored the property under a prospecting agreement with Kennametal from 1967 to 1968, and although some ore was discovered they dropped the project after one year. The mine then lay dormant until 1973 when Rawhide Mining Company leased the property, operated it until 1974 and then sold it to 1975. At that time Rawhide Mining ended all operations and fallhoula Corporation immediately obtained a lease from Kennametal, subsequently operating the mine for one year before ending their investment. In the fall of 1979 the mine was purchased by the present owners, National Resources Development of Vancouver, British Columbia. National Resources has renovated the mill and equipment and is currently in the midst of a recent drill program. The following table is taken from the Nevada Scheelite Mine:

<table>
<thead>
<tr>
<th>Year</th>
<th>Owner</th>
<th>Operator</th>
<th>Units of O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1937-61</td>
<td>Rev. Sch.Corp</td>
<td>Rev. Sch.Corp.</td>
<td>107,000</td>
</tr>
<tr>
<td>1961-67</td>
<td>Kennametal</td>
<td>Kennametal</td>
<td>153,000</td>
</tr>
<tr>
<td>1971-75</td>
<td>Kennametal</td>
<td>Rawhide Mining</td>
<td>30,000</td>
</tr>
<tr>
<td>1978-79</td>
<td>Kennametal</td>
<td>Fallhoul Corporation</td>
<td>10,000</td>
</tr>
<tr>
<td>1979-</td>
<td>Nat. Resources</td>
<td>Nat. Resources</td>
<td></td>
</tr>
</tbody>
</table>

*In short tons
**One unit is 6000 lbs
was organized and purchased the property, initiating underground development. The Nevada Scheelite Corporation held and worked the property until 1951 when it was sold to Kennametal Corporation. From 1951 to 1957, Kennametal fully exploited the deposit and boasts the largest production of any operator. In 1957 production from the mine was discontinued, presumably in response to government deregulation of tungsten price controls. However, milling and metallurgical work continued at the site. Union Carbide explored the property under a prospecting agreement with Kennametal from 1967 to 1968, and although some ore was discovered, they dropped the project after one year. The mine then lay dormant until 1971 when Rawhide Mining Company leased the property, operating both mine and mill up to 1975. At that time Rawhide Mining ended its operation and Fallondale Corporation immediately obtained a lease from Kennametal, subsequently operating the mine for one year before making their departure. In the fall of 1979 the mine was purchased by the present owners, National Resources Development of Vancouver, British Columbia. National Resources has renovated the mill and reopened the mine, as well as embarking on a recent drill program. Table V summarizes production from the Nevada Scheelite Mine.

Table V

Production from the Nevada Scheelite Mine

<table>
<thead>
<tr>
<th>Year</th>
<th>Owner</th>
<th>Operator</th>
<th>Ore</th>
<th>Units of WO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>1937-51</td>
<td>Nev. Sch. Corp.</td>
<td>Nev. Sch. Corp.</td>
<td>---</td>
<td>107,000</td>
</tr>
<tr>
<td>1951-57</td>
<td>Kennametal</td>
<td>Kennametal</td>
<td>179,000</td>
<td>173,000</td>
</tr>
<tr>
<td>1971-75</td>
<td>Kennametal</td>
<td>Rawhide Mining</td>
<td>30,000</td>
<td>21,000</td>
</tr>
<tr>
<td>1975-76</td>
<td>Kennametal</td>
<td>Fallondale Corp.</td>
<td>2,000</td>
<td>--</td>
</tr>
<tr>
<td>1979-</td>
<td>Nat. Resources</td>
<td>Nat. Resources</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

*In short tons
**One unit WO₃ equals 20 lbs.
Emplacement of the Nevada Scheelite Stock

Texture, mineralogy, and grain size of the Nevada Scheelite stock indicate the rock was emplaced in a single episode and is not a multiple intrusion. Similarly, there is no evidence of a chill zone at the margins of the stock suggesting a high thermal gradient did not exist between country rock and intrusive. The lack of a porphyritic texture and absence of flow structures or mineral lineations point to crystallization near or at the present level of exposure. Depth of emplacement is speculative but Hyndman (1972, p. 141) lists comparative criteria for depth of crystallization of granitic plutons. General characteristics indicate emplacement at 6-10 km, lithostatic pressure at these depths would range from 1.5 to 2.6 Kilobars.

Late stage activity in the stock produced aplite dikes, quartz-K-feldspar veins and quartz-sulfide veins. Quartz-K-feldspar veins are typical of most granitic stocks and are common in mineralized intrusives (Scherba, 1964). Quartz-K-feldspar veins are older than quartz-sulfide veins and have only weakly developed sericitic envelopes. The former veins formed during the early post-magmatic stage of Hibbard (1980, p. 413). The later quartz-sulfide veins cut quartz-K-feldspar veins and have well-developed sericitic envelopes. The sulfide bearing veins are common within the stock, though not abundant, and the sulfide content is not above a few percent. Sericitic envelopes around these veins are rarely greater than a foot in width. These vein selvages are the only alteration present in the intrusive; the mass of the granodiorite being notably barren of alteration or evidence of mineralization. Sulfides
present in the veins located inside the stock are limited to pyrite and rare chalcopyrite. However, quartz-sulfide veins within granodiorite but adjacent to tactite commonly contain molybdenite and blue fluorescing scheelite in addition to pyrite and rare chalcopyrite. The quartz-sulfide veins are a later event in respect to garnet tactite formation and scheelite mineralization.

Quartz-sulfide veins are particularly abundant in a zone (hashed pattern on Plate I) inside granodiorite and roughly paralleling the carbonate/intrusive contact. This zone is adjacent to the Moonlight Shaft and is also exposed below the Caldwell Shaft. The two exposures may be the ends of an arcuate belt connecting them and concealed by alluvium in the mine canyon. The veins themselves are from several inches to two feet thick, and their number often yields overlapping sericitic envelopes. The location of this zone suggests an elongate belt of shearing and/or stress release which allowed localization of silica rich fluids and their channeling into the ore deposit producing late quartz flooding and introduction of sulfur. Presence of this zone during early tactite formation would have played a dominant role in the migration of tactite forming solutions into the contact region. If this were so, the solution ways remained open and were utilized by later fluids from which quartz plus sulfides precipitated.

Intrusion of the stock initiated widespread contact metamorphism overprinted on low grade (greenschist facies) regional metamorphism. The country rock is partially to completely recrystallized while locally at carbonate/granodiorite contacts metasomatism has produced coarse-grained calc-silicate tactite and scheelite mineralization.
Contact Metamorphism

Metamorphic effects are observable in the pre-Cretaceous rocks throughout the project area. At localities distant from exposed plutonic rocks metamorphism cannot clearly be attributed to a regional or contact metamorphic origin. Yet even the most distal portions of the map area lie within the outer limits of the contact aureole. Carbonate rocks are recrystallized to varying degrees and the metamorphic facies grade from hornblende hornfels facies to albite-epidote hornfels facies (Turner, 1968) moving away from the contact.

Carbonate Rocks

Both grey limestone and marble are recrystallized to a greater or lesser extent in all exposures of the carbonate section. Unit JTrm southwest of the vertical shaft is buff to white and consists of medium to coarse-grained, nearly pure calcite. Closer to exposed contacts with granodiorite the marble is moderately coarser-grained. Development of light-colored marble is due to driving off of carbonaceous matter during recrystallization. Yet grey recrystallized limestone is present in greater proximity to granodiorite, and contains abundant graphite in some cases. Evidently there exists an original difference in content of carbonaceous material between grey limestone and marble.

The grey recrystallized limestone of unit JTrlls (incline limestone) contains most of the scheelite ore bodies previously mined and presently being developed in the mine. Table VI contains partial whole rock chemistry for two specimens taken intermediate between the upper
and lower contacts of the incline limestone with granodiorite (12-8-1, 12-8-la). A thin section from the same site contains: .2 mm - .5 mm calcite showing preferred orientation, .1 - .2 mm muscovite aligned parallel to elongated calcite crystals, and abundant 10-20 micron graphite crystals commonly occurring at calcite-calcite grain boundaries. No dolomite was observed in thin section nor did X-ray diffraction disclose its presence. As can be seen from Figure 7, a plot of normalized CaO: SiO₂: MgO, wt. percent dolomite might be an expected mineral. Yet MgO being present in such small quantity it likely occurs in calcite. As the contact with the intrusive is approached graphite and muscovite become rare and very fine equant, colorless diopside appears.

Samples 3-2 and 3-1 from Figure 7 will not be discussed here as they are adjacent to tactite and probably do not reflect the original chemistry of the limestone. However, specimens 12-8-1 and 12-8-la (Table VI) were carefully chosen, and are sufficiently removed from the intrusive contact to give an indication of the original character of the rock. The chemistry of the incline limestone makes abundantly clear the metasomatic introduction of silica, iron, and alumina to produce calc-silicate tactite.

Tremolite as white fibrous porphyroblasts is commonly observable in hand specimen. However, the mineral is not present in the northeast exposure of unit JTrls but does appear in that unit west of the Tertiary ash flows. Sample 10-8-1 (Table VI) is from unit JTrls and, as can be seen on Figure 7, it plots near the calcite-tremolite tie line; again, dolomite is not present as indicated by X-ray diffraction. The association of calcite-tremolite which is common outward of granodiorite is typical of the albite-epidote hornfels facies for carbonate rocks of this composition.
Figure 7
Normalized CaO:SiO₂:MgO
Dashed lines indicate mineral assemblages in the Albite-Epidote Hornfels Facies

Table VI Partial Whole Rock Chemistry for Carbonates

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-8-1</td>
<td>Incline Is, grey crystalline limestone</td>
</tr>
<tr>
<td>3-2</td>
<td>Near vertical shaft, outside tactite ore body, White sugary marble</td>
</tr>
<tr>
<td>10-8-1</td>
<td>Grey crystalline limestone of unit Jk11s</td>
</tr>
<tr>
<td>3-1</td>
<td>White coarse calcite marble several inches outside garnet tactite. Garnet adjacent is brown and similar to brown garnet identified as hydrogrossular.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CaO</th>
<th>SiO₂</th>
<th>MgO</th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>%C O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-8-1</td>
<td>50.82</td>
<td>1.43</td>
<td>3.63</td>
<td>.06</td>
<td>.09</td>
<td>39.93</td>
</tr>
<tr>
<td>3-2</td>
<td>41.92</td>
<td>12.79</td>
<td>5.19</td>
<td>.10</td>
<td>nd</td>
<td>32.94</td>
</tr>
<tr>
<td>10-8-1</td>
<td>46.88</td>
<td>4.21</td>
<td>4.01</td>
<td>.10</td>
<td>nd</td>
<td>36.83</td>
</tr>
<tr>
<td>3-1</td>
<td>49.37</td>
<td>1.17</td>
<td>.36</td>
<td>na</td>
<td>nd</td>
<td>38.80</td>
</tr>
<tr>
<td>12-8-1A*</td>
<td>49.63</td>
<td>1.39</td>
<td>na</td>
<td>nd</td>
<td>nd</td>
<td>39.00</td>
</tr>
</tbody>
</table>

na = not analyzed
nd = below detection limit
* Incline limestone — grey crystalline limestone 60° NNE of Incline shaft
* calculated
Mafic Hornfels

Mafic hornfels consist dominantly of andesitic volcaniclastic sediments and andesitic flows. Also included are diorite dikes removed from granodiorite exposures as they are chemically similar and their mineralogy will aid in a discussion of metamorphic facies. As previously mentioned under the section on Mesozoic stratigraphy, the pre-Cretaceous noncarbonate rocks are metamorphosed to mineral assemblages stable in the albite-epidote hornfels facies or the greenschist facies of regional metamorphism. Only specimens 60 + 20 feet from the granodiorite contact contain higher temperature assemblages.

Mafic hornfels of the albite-epidote facies carry the assemblage albite, biotite-epidote; relict textures are commonly well preserved. Diorite present at Hook Creek, dacitic lava near the Sunnyside Mine, and andesite of unit JTrva all contain albite + epidote and biotite with X = green, Y=Z dark green. Actinolite is not a common constituent though present. Within the underground workings, mafic hornfels form lensoid beds several feet to 40 feet thick (see Plates 2-4, 2e, 5a). On the 200 level (Plate 2) a large mass of grey, fine-grained hornfels near the incline shaft contains the assemblage: biotite (X=red brown, Y=Z dark red brown) + plagioclase (An_{25}) + microcline + quartz + muscovite. The texture is granoblastic, "ghost" relict phenocrysts of plagioclase are also present. The original rock is igneous of andesitic or dacitic composition. It is not truly mafic as the mineral assemblage indicates yet the abundance of plagioclase over microcline distinguishes it from quartzo-feldspathic hornfels. On the 300 level a hornfels unit (Plate 3) just outside tactite and approximately 40 feet from granodiorite
carries the assemblage: hornblende (green) + plagioclase (An29) + biotite (X=green, Y=Z dark green) with lesser quartz and microcline. The texture is granoblastic, though hornblende occurs as well-formed crystals. A specimen of unit JT vc from the north contact of incline limestone with granodiorite contains: green hornblende + plagioclase (An26), + biotite (X=green, Y=Z dark green) + quartz + epidote. The texture is porphyroblastic. Epidote may not be an equilibrium member of the assemblage as it occurs both in the rock and as a veinlet cutting the thin section.

The above-described mafic hornfels suggest a widespread thermal aureole. Alteration to the albite-epidote hornfels facies is pervasive, while within 60 ± 20 feet of granodiorite mineral assemblages diagnostic of the hornblende hornfels facies (Turner, 1968, p. 190) make their appearance.

Quartzo-Feldspathic Hornfels

Quartzo-feldspathic hornfels are only dealt with where they are found in the underground workings. These hornfels are termed quartzo-feldspathic due to the abundance of K-feldspar and quartz, low plagioclase content, absence of hornblende, and lesser biotite content. In the remainder of this paper they will be abbreviated QF hornfels. QF hornfels are dense, grey, fine-grained, locally-banded rocks displaying no relict igneous textures. On the 400 level (Plate 4), a ten-foot QF hornfels bed is observable in a crosscut drift. The rock is layered in one inch bands which are interpreted as original compositional variation in bedding. The rock has a granoblastic texture with well developed polygonalization and mineralogically it consists dominantly of .02 mm - .05 mm quartz and
orthoclase with lesser plagioclase. Fine 10-30 micron biotite with X= pale red brown, Y=Z, red brown is disseminated through the slide. 2-3% pyrite is also present and is a ubiquitous constituent of all QF hornfels. Accessory minerals are epidote and idocrase, idocrase commonly occurring in microveinlets. Originally this rock may have been a silicic, tuffaceous siltstone.

West of the vertical shaft on the 300 level (Plate 3) and west of the incline shaft on the 500 level (Plate 5), are large masses of dense, fine-grained nearly black pyritiferous QF hornfels. These two hornfels are identical mineralogically and texturally and may belong to the same bed. These hornfels have abundant quartz-garnet veinlets with selvages of very light pink thulite, plus actinolite and calcite veinlets. In general, actinolite veinlets cut quartz-garnet veinlets but the reverse also occurs. Calcite veinlets are later and cut both of the earlier structures. The hornfels consists of interlocking granoblastic .1 - .2 mm quartz and microcline with lesser plagioclase. Biotite with X= pale red brown, Y=Z, red brown is disseminated through the rock, as well as 2-3% pyrite. 10-20 micron thulite, showing anomalous "berlin blue" interference colors forms quartz-garnet vein envelopes. Larger epidote crystals occur sporadically as well, often partially replaced by pyrite.

The QF hornfels just described is in contact with granodiorite and is cut by granodiorite dikes also. The hornfels contains the equilibrium mineral assemblage quartz + microcline + plagioclase + biotite which is indicative of the hornblende hornfels facies (Turner, 1968, p. 193, and Hyndman, 1972, p. 381).
Formation of the tungsten-bearing tactite of the Nevada Scheelite Mine proceeded in a series of overlapping stages. Each stage is characterized by a distinct mineral assemblage and can be in part correlated to a mineralogically defined zone within the tactite. These zones, from intrusive outward are: (1) granodiorite at the contact, (2) garnet-scheelite zone, (3) epidote zone, (4) amphibole zone, (5) wollastonite zone, and (6) the peripheral zone. All zones do not exist at one site and local reversals of zonation do occur. Late hypogene clay alteration and shearing have affected all zones and locally has intensely altered granodiorite in contact with tactite. In the following sections each zone is described in terms of mineralogy, structure, and distribution. This is followed by a paragenetic discussion of tactite development as a whole.

Granodiorite Zone

The contact between garnet-scheelite tactite and granodiorite is almost invariably a zone of intense argillization and shearing. This zone varies in thickness from several inches to ten feet. Where at its thickest the zone is made up of a number of clay-filled shears paralleling the tactite/intrusive contact but existing only in granodiorite. Within this area the original texture of granodiorite is partially to completely destroyed. Where alteration is most intense only biotite and quartz remain as the original constituents of the rock. Where alteration is absent to weak the original texture and
mineralogy is intact. Plagioclase and K-feldspar are moderately dusted with sericite and kaolinite and fine veinlets of green clay cut the rock.

The clay mineral of this alteration is a green-grey smectite group mineral. X-ray diffraction patterns of this clay, using the 100 peak of beryl as a standard, display the first order 001 reflection at 14.75 Å - 15.00 Å. On addition of ethylene glycol the basal spacing expands to 17.00 Å - 17.20 Å. Other peak positions are also compatible with smectite (Thorez, 1975, p. 201).

On the 500 level (Plate 5) granodiorite on the contact is strongly silicified in a zone 2-4 feet wide. Quartz forms large anhedral crystals which make up the majority of the rock. Plagioclase and orthoclase are also present though rare. Present in varying amounts from sample to sample are epidote, scheelite, apatite, actinolite, calcite, sphene and secondary green biotite. The epidote occurs as .4 -.8 mm, well-formed crystals, and is older than quartz. This epidote is of metasomatic origin as is the scheelite. This rock is interpreted as a silicified endoskarn as feldspars are not seen in the exoskarns. The intersection of a porphyritic diorite dike with granodiorite may have produced a locus of fracturing allowing endoskarn formation at this limited locality. Inward of the endoskarn biotite granodiorite contains elongate clots of pyrrhotite and pyrite, a feature not observed elsewhere.

Garnet-Scheelite Tactite Zone

Garnet-scheelite tactite is the most abundant alteration type present in the mine. It is composed dominantly of garnet with lesser amounts of pyroxene, quartz, epidote, actinolite, calcite, apatite, pyrite, magnetite,
molybdenite, chalcopyrite, and scheelite. Garnet-scheelite tactite, except at one limited locality, is always the closest calc-silicate zone to granodiorite. Banding of garnet tactite is sometimes observable and inspection with the ultraviolet lamp reveals scheelite similarly oriented. This banding parallels the tactite/intrusive contact. Though bedding in marble is rarely discernable it generally parallels the contact through the northeast workings (Plates 2a-5a), but at the northeast terminus of the mine workings the contact cuts across bedding. The marble outside tactite is normally homogenous, showing no trace of bedding or compositional variation. These considerations suggest the banding of garnet-scheelite tactite is more likely related to a migrating "solutional front" than to original bedding control. The garnet-scheelite zone varies in thickness from several inches to over forty feet in the Million Dollar stope (Plate 3) and is the most important ore type in the mine. On the marble side of garnet-scheelite tactite one of three situations may occur. Either garnet-scheelite ends abruptly in a sharp contact against marble with a thin intervening wollastonite zone, or grades over several inches into epidote tactite, or grades over several inches to a foot into amphibole tactite. These are the only relations occurring outside the garnet zone. Nowhere does the epidote, wollastonite, or a well-developed amphibole zone occur in a sequential arrangement outside garnet tactite. The most common sequence is garnet-scheelite to wollastonite to marble. Amphibole tactite is a later stage of skarn growth than garnet-scheelite. Where developed it crosscuts, partially replaces and locally forms a zone up to ten feet thick outside the remnant of the garnet-scheelite zone. Formation of a strong amphibole zone destroys the wollastonite zone and could conceivably replace a prior epidote zone although this is not believed to
be the case.

The garnet zone is the earliest stage of metasomatic tactite formation and replaces marble. Garnet is deep red brown through the majority of the tactite and brown to light brown at marble contacts and where only an extremely thin calc-silicate zone exists adjacent to granodiorite. In hand specimen and in thin section garnet is anisotropic, concentrically-zoned, and displays sector twinning (Figure 9). Garnet-scheelite tactite is strongly brecciated and a single intact garnet crystal is rarely found. Quartz and calcite selectively replace zones within garnet crystals, and less commonly, scheelite is observed in this relationship (Figure 8).

Six garnet specimens were chosen from varying positions within garnet tactite for compositional determination. The procedure used was measurement of the three physical parameters: specific gravity, refractive index, and unit cell edge. The approximate compositions were then calculated using the diagrams of Winchell (1958). As previously noted, red-brown garnet is zoned, anisotropic, and contains inclusions as well. Thus compositions arrived at in this manner are not very accurate but are correct in a relative sense. Table VIII contains the values determined for the three parameters, the compositions calculated from the data, and a brief sample description. Red brown garnets through the majority of the garnet-scheelite zone (specimens 3-1, 2-10, 2-11) are composed dominantly of sub-equal amounts of andradite and grossularite with much lesser amounts of pyrope, spessartine, and almandine. Red-brown garnets adjacent to the granodiorite contact show refractive indices in the range 1.82 - 1.87, and the composition determined on one specimen (2-14) of this garnet is And$_{89}$Gro$_3$Pyr$_7$Alm$_1$ suggesting increasing ferric
Figure 8
Scheelite replacing zoned garnet
Sch - scheelite
Gt - garnet
Qtz - quartz
Cl - calcite

Figure 9
Zoned sector twinned garnet
Field of view consists of a single crystal
Table VII
Garnet Physical Properties

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Specific Gravity</th>
<th>Refractive Index</th>
<th>Unitcell Edge (In Angstroms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>3.734</td>
<td>1.808</td>
<td>11.88</td>
</tr>
<tr>
<td>2-10</td>
<td>3.675</td>
<td>1.814</td>
<td>11.91</td>
</tr>
<tr>
<td>2-11</td>
<td>3/855</td>
<td>1.816</td>
<td>11.88</td>
</tr>
<tr>
<td>2-14</td>
<td>3.835</td>
<td>1.874</td>
<td>12.00</td>
</tr>
<tr>
<td>4-9</td>
<td>3.545</td>
<td>1.745</td>
<td>11.88</td>
</tr>
<tr>
<td>4-X</td>
<td>3.420</td>
<td>1.795</td>
<td>11.94</td>
</tr>
</tbody>
</table>

Garnet Composition and Sample Description

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Garnet Composition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>And$<em>{44}$Gro$</em>{42}$Pyr$_{10}$Sp$_4$</td>
<td>Red-brown garnet near center of garnet-scheelite zone on 300 level</td>
</tr>
<tr>
<td>2-10</td>
<td>And$<em>{49}$Gro$</em>{38}$Pyr$_9$Alm$_4$</td>
<td>Red-brown garnet near center of garnet-scheelite zone on 200 level</td>
</tr>
<tr>
<td>2-11</td>
<td>And$<em>{45}$Gro$</em>{36}$Sp$_{14}$Alm$_5$</td>
<td>Red-brown garnet in central portion of garnet-scheelite zone on 200 level</td>
</tr>
<tr>
<td>2-14</td>
<td>And$_{89}$Gro$_3$P$_7$Alm$_1$</td>
<td>Red-brown garnet adjacent to granodiorite on 200 level</td>
</tr>
<tr>
<td>4-9</td>
<td>Hydrogrossular</td>
<td>From garnet vein along granodiorite contact having a four inch calc-silicate border</td>
</tr>
<tr>
<td>4-X</td>
<td>And$<em>{42}$Gro$</em>{56}$</td>
<td>From pre garnet-scheelite zone garnet vein</td>
</tr>
</tbody>
</table>
iron content towards the intrusive. Specimen 4-9 is a light brown garnet found in a six inch garnet vein which begins at a granodiorite contact nearly barren of calc-silicates. The vein extends four feet into marble pinching out rapidly. The specific gravity of 3.545 is anomalously low and cannot be entirely attributed to inclusions. Furthermore, the intersection of refractive index and unit cell edge falls outside Winchell's diagrams but very near the grossularite end member. The anomaly is explained if the garnet is hydrogrossular. Skinner (1956) lists the physical properties of hydrogrossular as: refractive index 1.734 - 1.675, specific gravity, 3.594 - 3.13, and unit cell edge, 11.85 - 12.16. Although not a perfect fit, the garnet is interpreted as hydrogrossular. Specimen 4-X is a brown garnet from a one foot, flat-lying, brecciated garnet vein just outside garnet tactite and hosted in marble. The vein does not cut the tactite and is apparently older. Intersection of refractive index and unit cell edge again fall off Winchell's diagrams but very near the grossular-andradite tie line. The high refractive index precludes hydrogrossular as a solution and thus suggests the low specific gravity is in error. If specific gravity is dropped as a factor and the garnet corrected onto the grossular-andradite tie line in its composition could range from And$_{42}$Gro$_{58}$ to And$_{44}$Gro$_{56}$. The field relations of the brown grossular garnet show it was deposited in two stages. The earlier was prior to main stage garnet-scheelite zone formation and before iron metasomatism had attained its peak; or where the metasomatic fluids barely penetrated the contact. The evidence for this has been cited in the above discussion. Brown garnet found at the marble side of garnet-scheelite tactite is contemporaneous with red-brown garnet and
reflects the concentration gradient of iron in garnet from high near granodiorite and lowering towards marble.

Pyroxene is a minor constituent of tactite. In the garnet-scheelite zone it rarely exceeds one percent in a given thin section and sometimes is not even present. The pyroxene is pleochroic from brownish-green to green to yellow-green, optically positive, with an optic axis angle of 80-86 degrees. Though no definitive tests were made to determine composition of the pyroxene it is believed to be a member of the diopside-hedenbergite series. The color and pleochroism indicate an iron-rich member and this pyroxene is tentatively considered ferrosalite. In thin section the pyroxene is fragmented, sometimes enclosed in garnet, and partially replaced by quartz, calcite, and actinolite. The pyroxene crystallized contemporaneously with garnet.

Scheelite occurs as .3 mm - 1 cm fragmented, rounded crystals displaying undulatory extinction. It locally can be seen replacing garnet (Figure 8) and broken single crystals still in optical continuity are cut by quartz, calcite, and actinolite. Scheelite in garnet tactite fluoresces pale cream yellow indicating the presence of molybdenum.

Yellow fluorescing scheelite has in the past been falsely called powellite when actually only a few mole percent CaMoO₄ are necessary to yield a yellow fluorescing scheelite (McLaren, 1943). Locally a scheelite crystal will display somewhat mottled fluorescent colors. Cream yellow will be dominant while blue-white color can be observed near the outside of the crystal and forming embayments into the crystal. The blue-white color is characteristic of a purer scheelite and crystals of this nature are more common in areas of intense microbrecciation and high sulfide content with occasional presence of molybdenite.
In hand specimens, brecciation of garnet-scheelite tactite is not always apparent but in thin section moderate to intense microbrecciation is observable. This event took place after deposition of garnet, scheelite, and pyroxene. Contemporaneous with or later than brecciation came introduction of quartz, sulfides, actinolite, and calcite. These minerals occur as replacements, breccia fillings, and microveinlets. Apatite also appears later than brecciation and is commonly associated with quartz; scheelite also is present where apatite is abundant. The amphibole occurring in garnet-scheelite tactite is associated with sulfides, particularly pyrite, and quartz, and also replaces pyroxene. In thin section the amphibole has a fibrous habit and is pale green and pleochroic in plane light. The optic angle is approximately 80 degrees and the sign is negative. The amphibole is an iron-rich intermediate member of the tremolite-actinolite series. The specific composition was not determined but the amphibole is actinolite.

Epidote Zone

The epidote zone is of limited importance. It is found as a discreet zone outside the garnet-scheelite zone at only two localities, both of which are in well exposed surface cuts. The contact between the two zones is sharp as is the outside contact of epidote tactite with marble. This zone is two to four feet thick at its two localities. 0.5 - 1.5 mm, well formed epidote is the dominant constituent. Epidote displays inclined extinction, is pale yellow in plane light, and optically negative with a high 2V. The epidote is finely brecciated with coarse calcite filling in around epidote crystals. Quartz-actinolite-calcite-pyrite veinlets cut the rock and form fill in structures around epidote as well. Cream yellow
Figure 10
Geology of the 205 slope.

Scale 1" = 20'

- Amphibole zone
- Garnet-scheelite zone
- Granodiorite
- Incline limestone

The amphibole zone (the low amphibole zone in 685) consists mainly of amphibole, but unlike the latter, schistose in nature. The amphibole zone is well-developed in the 205 and 206 slopes. In the 206 slope (Figure 10), amphibole replaces garnet-scheelite schist, sometimes surrounding yourself. The amphibole consists mainly of fine-grained muscovite and other interlocking varieties of muscovite and quartz. Wherever in the amphibole, amphibole, and scheelite have essentially non-existing to the rock.
fluorescent scheelite is present also though in lesser amount than in the garnet-scheelite zone.

On the 400 level near the vertical shaft (Plate 4) dark green, massive epidote tactite is in contact with a granodiorite dike. The width of the epidote is uncertain as it is only found in the north rib of the drift. Epidote makes up 95% of the rock and is optically identical to that described above. Unlike other calc-silicate rocks examined this shows no brecciation event. Quartz, calcite, and shreddy green biotite form wormy microveins following epidote crystal boundaries. Scheelite is essentially non-existent in the rock.

Amphibole Zone

The amphibole zone like the epidote zone is developed at only a few localities, but unlike the latter scheelite is an important constituent of amphibole tactite. On the 200 level (Plate 2a) the amphibole zone is well-developed in the 204 and 205 stopes. In the 205 stope (Figure 10), amphibole replaces garnet-scheelite tactite sometimes surrounding unreplaced pods of garnet and goes on extending into marble. The contacts between amphibole tactite and other calc-silicate rocks and marble are gradational. Elsewhere in the mine quartz, actinolite, and pyrite are common later minerals in garnet-scheelite tactite and often form veins and small pods in marble just outside the garnet-scheelite zone. Where veins traverse marble coarse pyrite forms the vein center, surrounded by a thin selvage of ferroactinolite grading outwards through actinolite to colorless tremolite and finally to calcite.

In a thin section of amphibole tactite from the 205 stope amphibole
Figure 11

Amphibole Tactite

Act - actinolite
Py - pyrite
and pyrite (Figure 11) are seen to compose nearly the entire slide. Two optically distinct amphiboles of slightly different ages are present. Intimately associated with pyrite is a strongly colored amphibole displaying a pleochroism with X, yellow green, Y, green, and Z, dark blue-green. This mineral is optically negative, with a high 2V, and extinction angle Z:Y of 12-15 degrees. This mineral could be considered ferrohastingsite except for the high 2V, or hornblende, yet the low extinction angle in conjunction with the other properties is believed diagnostic of ferroactinolite (Deer, Howie, and Zussman, 1978, p. 165). A weakly pleochroic amphibole considered actinolite forms radiating clusters of crystals surrounding ferroactinolite and pyrite, and also occurs in a microvein. Scheelite found in amphibole tactite forms crystals up to 2 mm in diameter. Scheelite is fragmented and fluoresces cream yellow with sometimes blue-white fluorescence at boundaries or where fractures cut the crystal. Figure 12 is a sketch of a scheelite crystal exhibiting this relation. Scheelite in amphibole tactite is older than the surrounding mineral assemblage. Scheelite formed in garnet tactite and remained essentially stable during replacement of garnet tactite by the amphibole tactite forming solutions.

The amphibole zone is a retrograde assemblage, altering and replacing previously formed calc-silicate minerals. The controls on the intensity of its development are structural. Strong fracturing as is

Figure 12
Sketch of scheelite crystal from amphibole zone
present at the northeast end of the 200 level provided effective passages for the retrograde solutions. Formation of amphibole tactite also corresponds to a change in the nature of the ore forming solutions. In particular sulfur enters the contact region in quantity, reacting with iron-bearing calc-silicates to form pyrite and other skarn minerals (Park and McDiarmid, 1975, p. 271). Quartz deposition took place over a wider time span than most other tactite minerals. During formation of actinolite and pyrite quartz was being deposited.

Wollastonite Zone

The wollastonite zone is present as a very thin (1-2 inch) zone between garnet-scheelite tactite and marble. Wollastonite also locally forms one-inch veins in marble outside the garnet-scheelite zone. The veins parallel the tactite/carbonate contact and may be found up to ten feet from the contact. Wollastonite of this nature is found on the 400 level (Plate 4). Wollastonite also occurs at a distance from granodiorite. On the 200 level (Plate 2), a belt of wollastonite veining follows a hornfels/marble contact. Wollastonite veins also crop out in marble northwest of the vertical shaft roughly 80 feet from exposed granodiorite. Wollastonite in the veins forms coarse, white fibrous crystals partially altered to a thin smectite group clay mineral (saponite) and stevensite. The wollastonite found as a border to the garnet-scheelite zone is invariably altered to stevensite plus a white smectite. The original presence of a wollastonite border zone is thus in part interpretative, based strongly on the alteration minerals and the wollastonite veins that occur outside the tactite/marble contact and parallel
Formation of wollastonite at 40-80 feet from the intrusive contact as seen on the 200 level and at the surface exposure demands an explanation. Temperatures at this distance from the contact would be lower than the 650-670 degrees C necessary for wollastonite to form at 1kbar (Winkler, 1979, p. 129). A low PCO₂ and higher temperatures that those expected by radiative conduction would allow the reaction:

\[ \text{CaCO}_3 + \text{SiO}_2 = \text{CaSiO}_3 + \text{CO}_2 \]

to proceed to the right more readily. Field evidence suggests both of these criteria were met. Wollastonite forms vein type structures, its formation is not related to chert nodules or other siliceous impurities in marble. Solutions were therefore traveling through fissures which wollastonite now fills. Transfer of heat by fluid movement is a more efficient mechanism than radiative conduction. Similarly, the presence of a fracture system would facilitate the escape of CO₂ lowering PCO₂ and allowing wollastonite to form at lower temperatures.

Peripheral Zone

The peripheral zone is not a calc-silicate zone but instead a zone of distal effects related to intrusion and tactite formation. Jasperoid, wollastonite, and quartz veins are the three distal effects related to the ore deposit. Wollastonite occurring at a distance from the contact has been discussed in the preceding section and will not be repeated. Orange-brown oxidized jasperoid crops out in unit JTmr and JTtIlIs (see Plate I). The jasperoid forms 2-4 foot lenses in the host carbonates, both following and crosscutting bedding. A fresh specimen is dark grey to black and aphanitic. Vugs are present, though small and not abundant.
A second generation of milky white quartz forms irregular shaped clots within the earlier black very fine-grained quartz. In thin section jasperoid has a reticulate texture (Lovering, 1972, p. 13) made up of abundant elongate quartz crystals in a matrix of smaller, equant, anhedral quartz. The presence of a reticulate texture in jasperoids is evidence of deposition of crystalline quartz as opposed to deposition from a colloidal gel (Lovering, p. 12). Lovering describes the first phase in formation of a jasperoid of this nature as marmorization of limestone followed later by migration of silica solutions along fractures and replacement of calcite. These observations and the paucity of vugs lend credence to the assumption that the jasperoids are related to the Nevada Scheelite Stock and not to a low temperature, shallow, Tertiary hydrothermal event. Jasperoid bodies are ubiquitous in carbonate rocks outside copper skarns developed where mineralized porphyries intrude limestone (James, 1971) but are not usually mentioned in association with tungsten-bearing tactites (Morgan, 1975; Gray, et al., 1968; Buseck, 1967; Sato, 1980).

Quartz veins are not well-developed in country rock outside the ore deposit but several are present. At the Galena Shaft (Plate I), a three foot quartz vein contains abundant galena. In unit JTrlls a brecciated quartz vein associated with jasperoid also carries galena. Galena is not a visible constituent of veins within the intrusive or is it seen in tactite. Assay data, (Appendix I) show Pb in tactite and quartz veins hosted in granodiorite is below 100 ppm. This leads to the speculation that Pb is dispersed outward from the ore deposit precipitating with quartz. An alternative to this is that Pb was
originally present in the carbonate rocks and was remobilized during metamorphism and metasomatism. Two assays of incline limestone contain 20 ppm Pb each, as opposed to graodiorite which contains between 5-10 ppm Pb. The uniformity of the two limestone assays from different positions within the unit is suggestive of an original Pb content. However, at the Sunnyside Mine galena bearing quartz veins are hosted in metavolcanic rocks and have not traversed limestone. From the foregoing discussion it is concluded that Pb in the form of galena is dispersed outside the intrusive and beyond the limits of calc-silicate tactite.

Paragenesis

The paragenesis of minerals found in the Nevada Scheelite Mine is shown in Table VIII. Deposition of certain minerals took place in more than one stage and deposition from the magmatic stage to the later alteration stage spanned a considerable range in temperature. Magnetite, biotite, quartz, and apatite all crystallized in the magmatic stage and later during tactite formation. Quartz was deposited over wide range of conditions. The earliest quartz is in part contemporaneous with scheelite but the majority is later. Quartz replaces garnet and ferrosalite, and cuts epidote and scheelite. A second late stage of quartz occurs as elongate crystals growing normal to crystal boundaries of older, larger, anhedral quartz.

The early stage of tactite formation was characterized by growth of zoned andraditic garnet, ferrosalite, and magnetite. Magnetite is a rarely observed mineral and its certain paragenesis is unclear. Hematite might also have been present as the abundance of iron and
## Table VIII

### Paragenesis of Minerals in the Nevada Scheelite Mine

**Tactite Formation**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Magmatic</th>
<th>Early</th>
<th>Late</th>
<th>Late Alteration</th>
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<tbody>
<tr>
<td>Quartz</td>
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<tr>
<td>Orthoclase</td>
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<td>Microcline</td>
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<td>Biotite</td>
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<td>Magnetite</td>
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<tr>
<td>Hornblende</td>
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<td>Apatite</td>
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<td>Ferrosalite</td>
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<td>Garnet</td>
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<td>Epidote</td>
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<td>Ferroactinolite</td>
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<td>Actinolite</td>
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<td>Wollastonite</td>
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<td>Pyrrhotite</td>
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<td>Chalcopyrite</td>
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<td>Molybdenite</td>
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<tr>
<td>Psilomelane</td>
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oxidizing conditions (see next section) prevailing during early tactite growth would favor its formation. Epidote generally formed slightly later than, but in the most part contemporaneously, with garnet. Epidote crystals sometimes have moderately well-developed crystal faces against garnet.

Apatite and quartz are common associates, scheelite is often present as well. Quartz occurring with apatite is early quartz; apatite is present as euhedral rods inclosed in quartz. Wollastonite formed at the marble side of garnet-scheelite tactite is contemporaneous with the garnet zone.

Scheelite deposition may have occurred in two stages. Scheelite of the first stage crystallized in large part later than garnet, ferrosalite, and epidote. This scheelite is characterized by cream-yellow fluorescence and replaces garnet. Scheelite is also common with apatite and early quartz indicating scheelite deposition continued during crystallization of apatite and early introduction of quartz. Scheelite grains are subhedral, rounded, often fragmented, and range in size from 30 microns to several millimeters. Second stage formation of scheelite is not interpreted as a second influx of complexed tungsten ions from the intrusion. A more likely explanation is partial dissolution of previously formed scheelite and redeposition as \( \text{CaMoO}_4 \) poor, pale blue-white fluorescing scheelite. Scheelite of this nature formed during sulfidation of the tactite creating weak spotty overgrowths of molybdenum poor scheelite on earlier molybdenum bearing scheelite. Quartz-pyrite-molybdenite veins in granodiorite and within ten feet of tactite contain sparse blue-white fluorescing scheelite. This scheelite is believed formed
from reworked scheelite originally present in tactite. The higher sulfur fugacity existing during sulfidation of the tactite favored the partitioning of molybdenum into molybdenite, simultaneously yielding a molybdenum-poor scheelite.

Ferroactinolite, some actinolite, pyrite, pyrrhotite, chalcopyrite, and molybdenite are all roughly contemporaneous. These minerals formed later than garnet, scheelite, epidote, and ferrosalite. They occur as disseminated late minerals replacing garnet, epidote, and pyroxene in the garnet-scheelite zone and locally have entirely replaced the earlier calc-silicates creating a retrograde tactite. Molybdenite, pyrrhotite, and chalcopyrite are more often found nearest the granodiorite contact. Molybdenite especially is more common in quartz very near the contact where it forms rosettes up to two millimeters. Pyrite is widely distributed and is found in essentially every rock type including marble. The paragenesis of the sulfide minerals in relation to one another has not been determined. The sulfides formed during the same broad stage yet close examination of polished sections may reveal a sequential development.

Actinolite crystallized dominantly with the above assemblage but continued growth of actinolite as an alteration of ferroactinolite is present. Actinolite also forms radiating crystals growing normal to pyrite boundaries in amphibole tactite, indicating actinolite is the latest of the amphiboles. Colorless tremolite is found as the outermost alteration envelope around actinolite-pyrite veinlets in marble and is coeval with those minerals.

Biotite is very rarely found in the calc-silicate zones. On the
400 level, fine shreedy green biotite is present in barren epidote tactite. The biotite is younger than epidote and similar in age to quartz. Biotite found in endoskarn on the 500 level is in part original magmatic botite as indicated by color and pleochroism. Later biotite is also present as replacements of epidote. This biotite is finer grained and shows pleochroism from green to pale green. In hornfels biotite veinlets with pyrite selvages occur near the intrusive contact. The biotite is pleochroic with: $X=$ pale red tan, $Y=Z$, dark red brown. This biotite is identical to matrix biotite in the hornfels with the exception it is coarser and deeper in color. Formation of biotite veinlets in hornfels reflects different physico-chemical conditions prevailed between hornfels and adjacent tactite.

Clay minerals, stevensite, malachite, chalcanthite, psilomelane, and halotricite are the latest minerals to form. The latter four are supergene in origin, and with the exception of malachite, are forming on the walls of old stopes. Stevensite occurs as an alteration product of wollastonite (Rose and Burt, 1979, p. 223). It is a white, fine grained clay appearing mineral and is only identifiable by X-ray diffraction. Present with stevensite and in strongly bleached marble along fractures is a white expandable smectite group clay mineral. This clay mineral may be saponite as it has been observed in a similar occurrence (James, 1971, p. 126). However, X-ray diffraction patterns are not considered sufficiently diagnostic for a certain identification to be made. At tactite/granodiorite contacts, and for up to ten feet into the intrusive, the wall rock is intensely altered to a dark green-grey smectite (see p. 53). Clay alteration of granodiorite locally destroys
all prior constituents of the rock except quartz and biotite. The intensity of this alteration, and the nature of fine clay veinlets cutting granodiorite in thin section suggest the clay alteration is hypogene. Clay alteration is the very last phase of hydrothermal activity affecting the ore deposit. The solutions which brought about this alteration were low temperature, very late fluids still being released from the intrusive and/or convecting meteoric waters may have played a role. Post-ore shearing is strongly developed in clay altered granodiorite.

**Tactite Formation and Metasomatism**

The exchange of chemical constituents between wall rock and intrusive is a complex process. To make quantitative estimates of additions and subtractions of elements taking place during the tactite-forming process requires detailed chemical work and resolution of the volume change problem. Therefore, only a qualitative discussion of metasomatic changes will be attempted, based on the observed mineral assemblages.

Table VI displays partial whole rock chemistry for two specimens of incline limestone (12-8-1, 12-8-1a) both samples are low in Fe$_2$O$_3$ and Al$_2$O$_3$. Similarly, specimens 3-1 and 3-2 taken from marble outside tactite are equally low in these two oxides. Minerals found in tactite (e.g. andraditic garnet, ferrosalite, ferroactinolite, pyrite) are iron rich minerals, and strong evidence for metasomatic introduction of iron from the early stage of tactite formation to the latest. Introduction of alumina is not so strongly indicated by the mineral assemblage. However, an ideal mixture of and$_{50}$gr$_{50}$ (excluding Ti$^{4+}$ in andradite)
contains 10.60 wt. percent $\text{Al}_2\text{O}_3$ (Gray et al., 1968, p. 1551). Red-
brown garnet is composed dominantly of similar proportions of andradite
and grossularite end members with lesser pyrope, spessartine, and
almandine. The abundance of garnet and presence of epidote in tactite
point to enrichment in alumina over that found in unaltered carbonate.

Metasomatic introduction of silica is obvious, quartz is a ubiquitous
and abundant constituent of tactite. Similarly the presence of scheelite
is "prima facie" evidence for introduction of tungsten. The manner in
which tungsten is transported in metasomatic fluids is uncertain. A
common assumption is transport as complex halide ions, (Bryzaglin, 1960)
although transport in silicon complexes or as metatungstates is equally
feasible if not more so. In light of this, the common association of
apatite with scheelite may be significant in terms of the transportation
mechanism.

Introduction of sulfur during the later stage of tactite formation
is clearly indicated by the timing of deposition of pyrite, pyrrhotite,
chalcopyrite, and molybdenite. Copper most likely entered the system
with sulfur. The evidence for this is debatable but Rose and Burt
(1979, p. 223) consider sulfidation and base metal introduction as con-
temporaneous in a "typical" skarn system. Molybdenum was present in
the ore fluid from the early stage to the early late stage when sulfur
became enriched in the ore solutions. During growth of the garnet-
scheelite zone the physico-chemical conditions were such that molybdenum
was partitioned into scheelite; as sulfur became available, formation of
molybdenite ensued.

Certain aspects of the mineralogy of the Nevada Scheelite Mine
differ from other tungsten-bearing tactites. Foremost is the extremely low amount of pyroxene found in the tactite. Only in one locale was ferrosalite clearly identified and that site was at the marble side of one of the thickest garnet-scheelite zones found in the mine (300 level, Million Dollar stope). Zharikov (1970) correlated relative iron contents of co-existing garnet and clinopyroxene in tactites and found in tungsten-bearing skarns, hedenbergitic pyroxene co-existed with grossularitic garnet indicating reducing and/or acid conditions. At Nevada Scheelite pyroxene is nearly absent and garnet is andraditic. Iron in andradite and in epidote occurs dominantly in the ferric state, which suggests early oxidizing conditions. Formation of Mo-bearing scheelite is also favored by oxidizing conditions (Hsu and Galli, 1973, p. 689; Sato, 1977). However, it must be noted that low sulfur fugacity could also be responsible for partitioning of molybdenum into scheelite. In general, the early mineral assemblage of andraditic garnet, Mo-bearing scheelite, and epidote point to oxidizing conditions during early tactite formation. Morgan (1975) studied four tungsten-bearing skarns in the Mount Morrison pendant, California. Of these, three contained mineral assemblages dominated by hedenbergitic pyroxene and grossularitic garnet, while the fourth was an andradite dominant assemblage. Morgan (p. 140) believed the latter tactite formed under oxidizing conditions and postulated a structural solution. The four tactites are associated with the same pluton and reconstruction of the original geometry shows the andradite rich skarn was overlain by the intrusive. Morgan suggests that the structural situation created a trap whereby the metasomatic solutions evolving from the pluton were strongly diluted by CO₂-rich fluid in
the manner put forth by Nokelberg (1973) yielding relatively high oxygen fugacity during early tactite formation. The broad scale structural configuration of the Nevada Scheelite Mine is analogous to that described above. Granodiorite almost invariably forms the hanging wall of the ore deposit, in places dipping as shallow as 20 degrees but more commonly between 45 and 60 degrees. The model developed by Morgan (1975) is speculative, and dependent on the experimental studies of Nokelberg (1973) but is certainly a possible explanation for the early oxidized mineral assemblage occurring at Nevada Scheelite.

A change in the physico-chemical conditions through time is indicated by the late sulfidation of the tactite and development of a reduced mineral assemblage, e.g. actinolite, ferroactinolite. A detailed evaluation of the physico-chemical conditions of tactite formation is beyond the scope of this paper; however, a possible explanation for the change in oxidation conditions will be presented. Butler (1923, 1927) suggested iron in contact metasomatic environments may be oxidized according to the reaction:

\[ 3\text{FeO} + \text{CO}_2 = \text{Fe}_3\text{O}_4 + \text{CO} \]

The reaction to the right is favored by higher temperatures occurring near the intrusive contact or during the earlier phase of tactite growth. At lower temperature and/or greater distance from the contact the reverse reaction is more probable. In Nokelberg's (1973) model for oxygen evolution during metasomatism of carbonate rocks, he uses the reaction:

\[ \text{CO} + \frac{1}{2}\text{O}_2 = \text{CO}_2 \]

as a starting point. Although numerous factors play a role here, in
general lower temperatures will allow the reaction to move to the right lowering oxygen fugacity.

The oxidation state of iron may also be controlled by the concentration of sulfur in a silicate system (Park and McDiarmid, 1975, p. 272). Sulfur reacting with iron in andradite would produce pyrite and new skarn minerals.

In summary, during retrograde alteration of the skarn reducing conditions were created by dropping temperatures which halted oxygen evolution from CO$_2$-rich aqueous fluids. Sulfur also played a role in controlling the oxidation state of iron but the specific mechanism is not clear.

**Ore Controls**

The dominant control on deposition of ore is, of course, the intrusive/carbonate contact. However, tactite is not present at all sites where granodiorite is in contact with marble, and where present the width may vary dramatically. Structural controls are by far the most important in localizing the larger ore bodies. Bedding, fractures, hornfels, and pre-ore diorite dikes, and the natures of the intrusive/carbonate contact all play a role in controlling the location and thickness of tactite. Chemical controls are of lesser importance as far as being a determining factor in the size of ore bodies. However, chemistry is the deciding element in precipitation of scheelite in tactite.
Physical Controls

The single most important structural trap in the Nevada Scheelite Mine is formed by shallow pitching vertical curves in the granodiorite contact with marble. Figure 13 shows three vertical sections through levels 200 to 500. Section I is approximately 345 feet N45E of the vertical shaft and each successive section is displaced to the northeast (the section lines are located on the level plans). The sections display a strongly developed vertical curve gradually straightening to northeast. The point of maximum curvature defines a lineation trending N35E and pitching 28 degrees to the northeast. Nearly all the major ore bodies between the vertical and incline shafts owe their existence to this structure. These vertical embayments were areas of stronger early fracturing thus increasing permeability for tactite forming solutions. The manner in which granodiorite overhangs marble evidently created an efficient trap for the metasomatic fluids, in a sense damming them and forcing development of thicker calc-silicate sections.

Other traps of this nature are present, although none is so large and continuous. The ore body on the 200 level (Plate 2A), developed by the 204 stope is localized by both a strong vertical curve in the contact and a less well-developed horizontal embayment into the granodiorite. On Figure 14, the vertical curve of the contact is shown on Section IV. In the 204 stope above 200 level the contact is locally as flat as 20 degrees and a raise from the 300 level enters the widening ore body approximately forty feet beneath the 200 level just below the beginning of curvature. This structure is typical of those controlling the thicker ore bodies, on all levels, northeast of the incline shaft.
Figure 13
Vertical Sections I-III
Section lines N45W, sloping SW

- Tectite
- Granodiorite
- JTrlle Incline limestone

10400E/10600N - Coordinate intersection

100 0 100 200 feet
Figure 14
Vertical Sections IV-VI

Section lines N45W, looking SW

- Tectite
- Granodiorite
- Late porphyritic diorite
- Jtils Incline limestone

1000E/1000N - Co-ordinate intersection
with the exception of those at the northeast terminus of the mine workings. These structures are local, generally not showing continuity between levels (although advance of the 300 drift may indicate otherwise) and related to irregularities in the contact, most favorably forming an overhanging granodiorite contact.

At the northeast extremity of the mine workings a large ore body (in part mined out) is present on the 500 level, 550 sub-level, 400 level, and, to a lesser extent, on the 200 level. Inspection of the level plans (Plates 2A-5A) and the surface geologic map (Plate I) reveals the intrusive contact at this site makes a sharp turn from a bearing of N50E - N60E to an approximate trend of N30W. The trough thus developed is also successively displaced to the southwest with depth. This displacement is apparent from the 200 to 400 levels whereupon a reversal of dip occurs and the contact on the 500 level is offset slightly southwest but more strongly to the south. Figure 14 depicts this structure in superimposed plan views of the 200, 400, and 500 levels. The picture is complicated on the 500 level by a shallowly east-dipping pre-ore porphyritic diorite dike; however, tactite in quantity is present in the trough above and below the dike. This structural trap is similar to those described above as below the 400 level granodiorite overhangs the ore deposit. The situation from the 400 to the 200 level is different, and is not seen elsewhere in the mine. This feature is, however, analogous to the important ore controlling structures seen at the Pine Creek Mine, California (Gray et al., 1968).

Selective replacement of favorable beds has not been identified in the Nevada Scheelite Mine (one possible exception is the elongate tactite
body at coordinates 10000N, 10200E, on the 200 level). However, mineralization does extend along bedding but is controlled more by bedding plane cleavage than original composition. The incline limestone shows moderate foliation on outcrop and display preferred orientation of calcite and muscovite in thin section. Foliation parallels bedding in the mine area trending roughly N28E to N45E between the vertical and incline shafts and N50E to N80E northeast of the incline shaft. Near the intrusive contact, and/or adjacent to tactite, it is common to find elongate pods and vein-like calc-silicate bodies surrounded by marble. This bedding plane-controlled mineralization is from several inches to several feet in width and where attempts have been made to exploit thicker bodies they pinch out rather quickly. Post-ore shear zones and faults of minor displacement also utilize bedding plane cleavage.

A set of fractures trending N30W to N40W and dipping 55-80 degrees east locally allowed mineralization to extend outward into marble. The mineralization thus produced is rarely thicker than one foot and thins rapidly away from the intrusive contact. As a secondary ore control these fractures are of lesser importance than the bedding plane fractures.

Hornfels present in contact with granodiorite and thicker than 10-15 feet inhibits formation of tactite. On the 500 level southwest of the incline shaft a large mass of quartz-feldspathic hornfels is in contact with the stock. The hornfels contains quartz-garnet-thulite veinlets, actinolite veinlets, and abundant pyrite but scheelite is absent. Where thin hornfels beds are on the contact as on the 400 level (Plate 4a), 300 level west of the vertical shaft, and in the 204 stope, mineralization is present on the marble side of hornfels. The thin, more competent
hornfels allowed fresh投降 or near-formed phases omitted and
into the adjacent marbles yielded a comparable zone out in contact with
granodiorite was not generally difficult to recognize.

Where hornfels and late-porphyritic diorite dikes intersect a mineral-
ized contact area, finger-like bodies of tactite within extend our from
the contact zone following the margins of hornfels or porphyritic diorite.
The proximity of hornfels and diorite were presumably areas of increased
permeability and thus became favored percolation for tactite-forming solu-
tions The contact of porphyritic diorite dikes with marble is particu-
larly notable for these phenomena. At a distance from mineralization
marbles in contact with porphyritic diorite is coarse, recrystallized
but no calc-silicates are present, which is a hike in chemical affinity to a
tactite and granodiorite. Zones of alteration begin extend out along dior-
ite margins. Ridges can develop on the top-level (Plate 2, figure 11)
showing recrystallized calcite along.

Diorite contacts are better documented. Similarly, the
movements and present distribution would again be a favorable site for
fractions of apatite can be readily done. This secondary permeability
along localized passage or water-bearing fluids outward from the contact region
and subsequent tactite formation.

Chemical control is not the primary factor in this case. It is a

The close association of scheelite with calc-silicate as emanate from
tactite has been noted by many workers, as has the affinity of scheelite
for calcite (Kinzl, 1946). Some laboratory work has been done on
transportation of tungsten and precipitation of scheelite in the stero.
hornfels allowed fracture transport of ore-forming fluids through them and into the adjacent marble yielding a calc-silicate zone not in contact with granodiorite. Where hornfels and late porphyritic diorite dikes intersect a mineralized contact area, finger-like bodies of tactite often extend out from the contact zone following the margins of hornfels or porphyritic diorite. The margins of hornfels and diorite were presumably areas of increased permeability and thus became favored channelways for tactite-forming solutions. The contact of porphyritic diorite dikes with marble is particularly notable for this phenomena. At a distance from mineralization marble in contact with porphyritic diorite is coarsely recrystallized but no calc-silicates are formed. Where a dike is in close proximity to tactite and granodiorite fingers of tactite often extend out along diorite margins. Examples can be seen on the 200 level (Plate 2, coordinates 10300E, 10480N). Coarsely recrystallized calcite along diorite margins was better able to sustain fractures; similarly, the more brittle and competent diorite would also be a favorable site for fractures to form and be maintained. This secondary permeability localized passage of metasomatic fluids outward from the contact region and subsequent tactite formation.

Chemical Controls
The common association of scheelite with calc-silicate minerals in tactite has been noted by many workers, as has the affinity of tungsten for calcium (Kerr, 1946). Some laboratory work has been done on transportation of tungsten and precipitation of scheelite in the skarn
environment (Bryzaglin, 1960; Barabanov, 1971; and Wilson, 1975). A full
development of this aspect of ore deposition will not be attempted here
as it is beyond the scope of this paper. However, in these experimental
studies various tungsten sources were reacted with the common calc-
silicate minerals found in tactites. It is found certain tungsten
sources at a controlled pH will react with pyroxene, calcic plagioclase,
calcite, and sphene to produce scheelite. If a source of calcium is the
sole restraint on formation of scheelite then scheelite should be found
in the carbonate rocks adjacent to tactite. An occurrence of this
nature is not observed; scheelite invariably is deposited within the
calc-silicate zone. The explanation most common in the literature
(Bryzaglin, 1958, 1960, and Barabanov, 1971) is transportation of tungsten
as complex ions in weakly alkaline or alkaline solutions. Precipitation
of scheelite (if calcium is available) is induced by lowering the pH of
the solution; a function carbonate rocks are incapable of. However, the
calc-silicate minerals pyroxene, garnet, and calcic plagioclase are
capable of reducing pH by reaction with the ore fluid. These minerals
are also normally earlier than scheelite mineralization. Another feature
of this reaction is albitization and sericitization of plagioclase (if
present) and amphibolization and/or quartz replacement of pyroxene and
garnet.

Scheelite in the deposit under study occurs in the garnet-scheelite
and amphibole zones previously described. It is paragenetically younger
than garnet, pyroxene, and epidote, and can be seen growing at the
expense of garnet. Actinolite, quartz, and apatite are present with
scheelite, apatite and some quartz crystallized within the span of
scheelite deposition, but the majority of quartz and all actinolite are slightly later than scheelite. The petrographic evidence is broadly compatible with the scenario described above. From the discussion it may be concluded that the chemical controls on scheelite deposition include: (1) a source of calcium and (2) a pH reducing agent; both are provided by the previously existing calc-silicate minerals present in the tactite, in this case dominantly andradite-grossularite garnet.

Exploration Potential

Surface and underground drilling is being pursued at the Nevada Scheelite Mine as of this writing, so some of the proposals here may be after the fact. Substantial ore bodies are not likely to be discovered within the present limits of the mine workings. A large footage of drill core has been compiled by Kennametal Corporation, subsequent lessee operators, and National Resources Development, the present owners of the property. This drilling has been concentrated dominantly within the existing workings and only a few, and mostly local, blank spots remain to be investigated. Therefore, the following proposals deal with areas outside, but within reach of the present workings.

1. The northeast terminus of the incline limestone against granodiorite is a structurally favorable site. Underground drilling should investigate this contact on the 300 level and/or the 300 level drift be advanced to the contact. Beneath the northeast end of the 500 level, on the 550 sub-level and below, drilling by Kennametal and Union Carbide has indicated mineable ore widths. This drilling should be continued. In fact, deep drilling from surface if needed should be done to deter-
mine the depth to which a granodiorite/carbonate contact might be expected. In view of long-term exploitation the nature of this system at depth is an invaluable piece of information.

(2) What drill data exists below the 500 level northeast of the incline shaft indicates favorable lithologies in contact but little tactite. This drill data also hints that the contact is dipping north placing granodiorite on the footwall. It is possible that the incline limestone is bottoming out at this point. It is equally conceivable that the contact will again reverse dip yielding a structurally favorable contact. Either way this should be evaluated.

(3) At the north contact of the incline limestone with granodiorite the intrusive again overhangs limestone. This contact should be checked down to the elevation of the 500 level. If drilling results are favorable drifts could be driven from the present workings to the north contact.

These three proposals are by no means the only possible exploration sites simply the most outstanding. The contact of unit JTrm with granodiorite from the vertical shaft to the Moonlight shaft has not been fully explored. However, marble near the contact dips shallowly and as has been noted, a suggestion exists that the base of unit JTrm is very nearly exposed just west of the extension of granodiorite into unit JTrm. Also surface drilling indicates granodiorite in this area dips shallowly towards the marble. In short, this area is considered less favorable as at depth hornfels is more likely in contact with the stock and/or much of unit JTrm is underlain by shallow dipping granodiorite which is less likely to produce the desirable traps seen elsewhere.
SUMMARY AND CONCLUSIONS

The Nevada Scheelite Stock was emplaced, and crystallized in a passive manner at an estimated depth of 6-10 Km. Intrusion produced a widespread contact metamorphic aureole extending to the limits of the map area. Within this aureole the Jurassic-Triassic sequence of carbonate, volcanic, and volcaniclastic rocks have been converted into mineral assemblages characteristic of the albite-epidote hornfels facies and the hornblende hornfels facies when they were within 60 ± 20 feet of the main intrusive body.

In the vicinity of the Nevada Scheelite Mine where biotite granodiorite intrudes carbonate rocks of unit JTrm and the incline limestone; contact metasomatism produced a coarse-grained scheelite-bearing calc-silicate tactite. The tactite displays an evolutionary trend from an early assemblage dominated by andraditic garnet, lesser epidote, and very minor ferrosalite; while the late, in the most part retrograde, assemblage is characterized by actinolite, ferroactinolite, and sulfides. The early assemblage is high in ferric iron and formed under relatively high oxidizing conditions produced by evolving oxygen from a CO₂-rich fluid. During sulfidation of the tactite and formation of the retrograde assemblage evolution of oxygen halted, possibly in response to lowering temperature, and minerals bearing ferrous iron were deposited.

Tungsten was transported in alkaline or weakly alkaline solutions into the contact region where molybdenum-bearing scheelite was precipitated in response to falling pH brought out by reaction of the ore fluid
with previously formed calc-silicate minerals, dominantly garnet. Mo-bearing scheelite is later than garnet, ferrosalite, and epidote; and contemporaneous with apatite and early quartz. During genesis of the retrograde amphibole tactite some reworking of scheelite took place, subsequent scheelite was deposited as blue-white fluorescing molybdenum-poor scheelite.

The localization of economic ore bodies in the Nevada Scheelite Mine is controlled almost exclusively by the geometry of the contact between the intrusive and the sedimentary works. Vertical curves result in shallow dipping granodiorite overhanging marble. These curves may be of limited extent both vertically and laterally; or, as is the case for the dominant structure within the mine, form a shallowly pitching trough across the face of the intrusive/carbonate contact. Horizontal curves of granodiorite around marble are not as efficient as the vertical curves in localizing ore bodies, but in conjunction with lateral displacement of the contact with depth as at the northeast end of the mine workings, substantial ore thicknesses are developed.
REFERENCES CITED


, 1960, Chemical Character of Tungsten Bearing Solutions in the Skarn Ore-Forming Process. Geochemistry, no. 6, p. 624-629.

Buseck, P.R., 1967, Contact Metasomatism and Ore Deposition: Tem Piute, Nevada. Econ. Geol., v. 62, p. 331-353.

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APPENDIX I
Assay Data

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Sample Description:

6253 Quartz-sulfide vein in granodiorite, strong sericitic envelope
6262 Quartz vein in unit JTrlls near jasperoid
6260 Quartz vein in meta-volcanic rocks at Sunnyside Mine
6254 Granodiorite of Nevada Scheelite Stock
6257 Brown-grey recrystallized incline limestone 10 feet from tactite
6258 Grey recrystallized incline limestone 20 feet from tactite
12-24-5 Aplite hosted in Nevada Scheelite Stock
Gd-1 Biotite granodiorite approximately 15 feet from limestone contact
12-24-3 Biotite granodiorite 600 feet from limestone contact