Geology of the Little Boulder Creek molybdenum deposit Custer County Idaho

Patrick Charles Cavanaugh

*The University of Montana*

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THE GEOLOGY OF THE LITTLE BOULDER CREEK
MOLYBDENUM DEPOSIT, CUSTER COUNTY, IDAHO

by

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B.S., Boise State University, 1975

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1979

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The Little Boulder Creek stockwork molybdenum deposit is located in the glaciated headwaters of Little Boulder Creek on the south-eastern edge of the White Cloud stock of central Idaho. The 83.6 m.y. old stock intrudes and uplifts Wood River Formation (?) calc-quartzites into an elongate dome. Contact metamorphism of the sediments grades from pyroxene facies (diopside) to meta-quartzite and wollastonite/tremolite bearing calc-silicates. A major N15°E trending fault zone borders the eastern edge of the stock and downdrops a porphyritic quartz monzonite segment and adjacent zone of tactite.

The 300m wide tactite zone is densely criss-crossed by pegmatites, aplites, and quartz veinlets. The highest grade molybdenite mineralization is confined to the quartz (+ orthoclase) veinlets in the tactite. Most molybdenite is found as fine flakes in middle and early Stage veinlets which are generally conformable with bedding (strike N15°E and dip steeply west).

Pyrite and scheelite are found throughout the ore zone and scheelite overlaps into an external halo. Hydrothermal alteration consists of silicification, and localized argillic alteration and sericitization.
ACKNOWLEDGMENTS

My thanks to the American Smelting and Refining Company for their financial and logistical support during the field work on this project. In particular, John Balla of the Northwestern Exploration Office provided base maps, references, and stimulating discussion on the deposit. Wayne Reich helped with sample transport, assisted in the examination of drill core, and drafted Plate 1.

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF PLATES</td>
<td>xi</td>
</tr>
</tbody>
</table>

## CHAPTER

1. **INTRODUCTION**
   - Location and Access: 1
   - History and Previous Work: 1
   - Present Study and Methods: 4

2. **REGIONAL GEOLOGY**
   - Ore Deposits: 14

3. **LOCAL GEOLOGY**
   - Topography and Exposure: 16

4. **ROCK UNITS**
   - Wood River Formation (?): 19
   - Pyritic Hornfels (Pwh): 20
   - Wood River Formation Undifferentiated (Pwu): 22
   - Ferrugenous Breccia (Pwf): 25
   - Banded Tactite (Pwb): 27
TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz-rich Tactite (Pwq)</td>
<td>29</td>
</tr>
<tr>
<td>Diopside-rich Tactite (Pwd)</td>
<td>29</td>
</tr>
<tr>
<td>Interpretations</td>
<td>32</td>
</tr>
<tr>
<td>White Cloud Stock</td>
<td>32</td>
</tr>
<tr>
<td>Main Stock</td>
<td>32</td>
</tr>
<tr>
<td>Porphryitic Core</td>
<td>34</td>
</tr>
<tr>
<td>Foliated Margin</td>
<td>35</td>
</tr>
<tr>
<td>Weathering of Main Stock</td>
<td>35</td>
</tr>
<tr>
<td>Eastern Apophysis</td>
<td>35</td>
</tr>
<tr>
<td>Interpretations</td>
<td>37</td>
</tr>
<tr>
<td>Late State Differentiates (Kd)</td>
<td>38</td>
</tr>
<tr>
<td>Pegmatites</td>
<td>41</td>
</tr>
<tr>
<td>Aplites</td>
<td>41</td>
</tr>
<tr>
<td>Granites</td>
<td>42</td>
</tr>
<tr>
<td>Interpretations</td>
<td>42</td>
</tr>
<tr>
<td>Quartz Veins and Veinlets</td>
<td>42</td>
</tr>
<tr>
<td>Challis Volcanics</td>
<td>46</td>
</tr>
<tr>
<td>V. STRUCTURE</td>
<td>48</td>
</tr>
<tr>
<td>Faults</td>
<td>48</td>
</tr>
<tr>
<td>Orientation of Quartz Veinlets and Late Stage Dikes</td>
<td>50</td>
</tr>
<tr>
<td>Late Fracturing and Jointing</td>
<td>65</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI. METAMORPHISM AND ALTERATION</td>
<td>68</td>
</tr>
<tr>
<td>Contact Metamorphism</td>
<td>68</td>
</tr>
<tr>
<td>Hydrothermal Alteration</td>
<td>70</td>
</tr>
<tr>
<td>Hydrothermal Alteration of the Main Stock and Eastern Segment</td>
<td>70</td>
</tr>
<tr>
<td>Hydrothermal Alteration of the Metasediments</td>
<td>72</td>
</tr>
<tr>
<td>Interpretations</td>
<td>73</td>
</tr>
<tr>
<td>VII. MINERALIZATION</td>
<td>74</td>
</tr>
<tr>
<td>Molybdenite</td>
<td>74</td>
</tr>
<tr>
<td>Interpretations</td>
<td>79</td>
</tr>
<tr>
<td>Scheelite</td>
<td>84</td>
</tr>
<tr>
<td>Other Metallic Minerals</td>
<td>86</td>
</tr>
<tr>
<td>VIII. DISCUSSION</td>
<td>87</td>
</tr>
<tr>
<td>IX. GENETIC INTERPRETATIONS</td>
<td>93</td>
</tr>
<tr>
<td>REFERENCES CITED</td>
<td>98</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Location Map of Little Boulder Creek Molybdenum Deposit</td>
<td>2</td>
</tr>
<tr>
<td>2. Generalized Geologic Map of the White Cloud Region in Central Idaho</td>
<td>7,8</td>
</tr>
<tr>
<td>3. Boulder Talus North of the North Zone</td>
<td>18</td>
</tr>
<tr>
<td>4. Oblique View of Little Boulder Creek Deposit</td>
<td>21</td>
</tr>
<tr>
<td>5. White Cloud Stock and Adjacent Metasediments</td>
<td>21</td>
</tr>
<tr>
<td>6. Pyritic Hornfels</td>
<td>24</td>
</tr>
<tr>
<td>7. Photomicrograph of Wood River Formation Undifferentiated (Pwu)</td>
<td>26</td>
</tr>
<tr>
<td>8. Ferruginous Breccia (Pwf)</td>
<td>28</td>
</tr>
<tr>
<td>9. Banded Tactite (Pwb)</td>
<td>28</td>
</tr>
<tr>
<td>10. Wood River Formation Metasediments in the North Zone</td>
<td>30</td>
</tr>
<tr>
<td>11. Diopside-rich Tactite (Pwd)</td>
<td>30</td>
</tr>
<tr>
<td>12. Photomicrograph of Diopside-rich Tactite in Contact Zone</td>
<td>31</td>
</tr>
<tr>
<td>13. Photomicrograph of Quartz Monzonite in White Cloud Stock</td>
<td>31</td>
</tr>
<tr>
<td>14. Quartz Monzonite of Eastern Apophysis</td>
<td>36</td>
</tr>
<tr>
<td>15. Photomicrograph of Quartz Monzonite of Eastern Apophysis</td>
<td>36</td>
</tr>
<tr>
<td>16. Pegmatite Dikes in Eastern Stock Apophysis</td>
<td>39</td>
</tr>
<tr>
<td>17. Aplite Plug Intruding Wood River Sediments in The South Zone</td>
<td>39</td>
</tr>
<tr>
<td>Figure</td>
<td>Illustration Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>18</td>
<td>Aplitic and Pegmatite Sills and Dikes Along Contact Margin of White Cloud Stock</td>
</tr>
<tr>
<td>19</td>
<td>Quartz Veins and Veinlets Exposed on Weathered Surface of Metasediments in North Zone</td>
</tr>
<tr>
<td>20</td>
<td>Quartz Veinlets in Diopsidic Tactite from Contact Zone, in North Zone</td>
</tr>
<tr>
<td>21</td>
<td>Contour Diagram of Poles to Early Stage Veinlets, Dikes, and Sills</td>
</tr>
<tr>
<td>22</td>
<td>Contour Diagrams of Poles to Middle Stage Veinlets, Dikes, and Sills</td>
</tr>
<tr>
<td>23</td>
<td>Contour Diagrams of Poles to Late Stage Veinlets, Dikes, and Sills</td>
</tr>
<tr>
<td>24</td>
<td>Contour Diagrams of Poles to Veinlets and Dikes in Eastern Extension Quartz Monzonite</td>
</tr>
<tr>
<td>25</td>
<td>Contour Diagrams of Poles to Joints and Fractures in Metasediments of the North Zone</td>
</tr>
<tr>
<td>26</td>
<td>Contour Diagrams of Poles to Joints and Fractures in Eastern Extension Quartz Monzonite</td>
</tr>
<tr>
<td>27</td>
<td>Outcrop Geologic Map of Little Boulder Creek Deposit - North Zone</td>
</tr>
<tr>
<td>27a</td>
<td>Diagramatic Strikes of Early Stage Veinlets, Dikes, and Sills</td>
</tr>
<tr>
<td>27b</td>
<td>Diagramatic Strikes of Middle Stage Veinlets, Dikes, and Sills</td>
</tr>
<tr>
<td>27c</td>
<td>Diagramatic Strikes of Late Stage Veinlets, Dikes, and Sills</td>
</tr>
<tr>
<td>27d</td>
<td>Alteration and Mineralization</td>
</tr>
<tr>
<td>27e</td>
<td>Diagramatic Strikes of Open Fractures and Joints</td>
</tr>
</tbody>
</table>
LIST OF ILLUSTRATIONS (Continued)

Figure                      Page

28. Geologic Cross Section of a Portion of A-A'      59,60
28a. Alteration and Mineralization                  pocket
29. Outcrop Geologic Map of Little Boulder Creek    Deposit - South Zone  61,62
29a. Alteration and Mineralization                  pocket
30. Cross Section Showing Exposure Bias of North-south Striking, West Dipping, Veinlets, Dikes, and Sills in North Zone  63
31. Aplite and Pegmatite Sills and Dikes, and Quartz Veinlets in North Zone Metasediments     67
32. Aplite and Pegmatite Sills, Dikes and Quartz Veinlets in North Zone Metasediments     67
33. Photomicrograph of Banded Tactite (Pwb)         71
34. Photomicrograph of Intensely Sericitized Quartz Monzonite from North Zone  71
35. Aplite Sample Containing Quartz and Disseminated Molybdenite  75
36. Photomicrograph of Mineralized Diopside Rich Tactite  78
37. Photomicrograph of Mineralized Diopside Rich Tactite  78
38. Scheelite Bearing Diopside Rich Tactite          85
39. West-East Cross Section Showing Evolution of the Little Boulder Creek Deposit  94
40. West-East Cross Section Showing Doming of Milligen and Wood River Sediments  94
41. Cross Section Showing Fracturing and Fluid Loss from the White Cloud Stock  95
### LIST OF ILLUSTRATIONS (Continued)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>Cross Section Showing Alteration Zones and Separation of White Cloud Stock Apophysis</td>
<td>95</td>
</tr>
<tr>
<td>43</td>
<td>Cross Section Showing Displacement of Eastern Stock Extension</td>
<td>96</td>
</tr>
<tr>
<td>44</td>
<td>Cross Section Showing Continued Fault Movement, Exposure of Stock, and Eruption of Volcanics</td>
<td>96</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table                                      Page
1. Chemical Analysis of Rocks in Little    23
   Boulder Creek Deposit
2. Sequence of Veining and Mineralization  44
   in the North Zone
3. Comparison of Molybdenum Deposits in    81
   Central Idaho

LIST OF PLATES

Plate                                      Page
1. Outcrop Geologic Map of the Little      pocket
   Boulder Creek Molybdenum Deposit
2. Geologic Cross Sections of the Little   pocket
   Boulder Creek Molybdenum Deposit
CHAPTER I
INTRODUCTION

Location and Access

The Little Boulder Creek deposit is located along the south-eastern margin of the White Cloud Peaks in central Idaho within the boundary of the Sawtooth National Recreation Area (see Fig. 1). The deposit is 56 km (35 miles) by air southwest of Challis, Idaho, and 45 km (28 miles) northwest of Sun Valley, Idaho in T. 8 N., R. 16 E., and T. 9 N., R. 16 E. From Challis the deposit is best reached by traveling 30 km (19 miles) southwest on U.S. 93, then 42 km (26 miles) south on the East Fork of the Salmon River road, and finally 13 km (8 miles) up the well maintained Little Boulder Creek foot trail.

The molybdenum deposit is claimed by the American Smelting and Refining Company (ASARCO), which maintains a permanent camp on the property.

History and Previous Work

Prospecting began in the region before the turn of the century. Considerable activity occurred in the Germania and Washington basins, a few miles southwest of Little Boulder Creek. Gold and silver production valued at about $500,000 came from veins and a silicified thrust breccia in this area before 1890 (Tschanz and others, 1974).
Figure 1. Location Map of Little Boulder Creek Molybdenum Deposit (Modified after U.S.G.S. 7 1/2 Minute Topographic Map - Boulder Chain Lakes, Idaho)
Claims were located in 1922 by Jess Baker on several of the base and precious metal bearing, brecciated quartz-chalcedony veins near Baker Lake the site of the Little Boulder Creek molybdenum deposit. Baker held the claims (at times jointly) until 1967. He explored the veins and later the adjacent molybdenite bearing veinlets with several prospect pits and short adits.

Clyde Ross pioneered geologic work in the area with his 1937 report, "The Geology and Ore Deposits of the Bayhorse Region, Custer County, Idaho". He described the known mineral deposits (including the Baker prospect) and mapped the regional geology on a 1:63,500 scale.

The Molybdenum Syndicate sampled the deposit in 1939, and apparently concluded that the grade was submarginal for mining. Shaffer and Gunnell of the U.S. Bureau of Mines examined and sampled the northern part of the deposit in 1942 as part of the War Minerals and Defense Minerals Exploration Administration reports (Tschanz and others, 1974). A discussion of molybdenum deposits of the U.S. by Kirkemo and others, (1965) outlines the geology of the Little Boulder deposit, and presents the assay results of previous sampling by the U.S. Bureau of Mines and the Geological Survey. They concluded that "the deposit contains an appreciable reserve averaging about 0.15 percent molybdenite".

ASARCO optioned the claims in 1967 and began an exploration program in 1968. Before their exploration was curtailed, ASARCO workers delineated a large molybdenite body of marginal grade. Included in
ASARCO company data are a regional geologic map at 1:24000 scale; a local outcrop geologic map at 1:2400 scale (used as a base for Plate 1); detailed topographic mapping; induced polarization and resistivity surveys; drill core logs; soil geochemistry maps for molybdenum, copper, lead, and zinc; metallurgical reports; geologic reports; and miscellaneous weather, survey, and ecologic data for the deposit.

Savage (1970) evaluated the mineral potential of the Salmon River drainage and briefly mentioned the Little Boulder Creek deposit. Bennett (1973) studied the petrology and trace element distribution of the White Cloud stock, compared it to the adjacent Idaho batholith, and concluded that the White Cloud stock is a forcefully intruded late-stage differentiate of the Idaho batholith. Tschanz and others (1974) constructed a 1:63,500 scale geologic map of the eastern half of the Sawtooth National Recreation Area (NSRA), and published considerable information on the Little Boulder Creek (Baker Lake) deposit and many other nearby mines and prospects. The regional geology, and the results of an extensive rock and stream sediment sampling program are discussed in their report.

Present Study and Methods

The purpose of this study was to investigate, describe, and interpret the various geologic parameters and origin of the Little Boulder Creek deposit. A description of the nature of mineralization,
alteration, rock types, structure, and the interrelationships of these is included.

During the summer of 1976 the deposit was mapped in detail at a scale of 1:1200 (reduced to 1:2400 in Plate 1). The ASARCO outcrop geologic map with detailed topography by Barton, Stoddard, Milhollin, and Higgins served as the base map. Surveyed claim corners and drill hole sites were used to maintain ground control during mapping. The orientation of veinlets, fractures, and late-stage dikes and sills was recorded as mapping progressed. An extensive sampling program accompanied mapping, and the area was lamped at night with a short wave ultraviolet light to examine for fluorescent minerals. Selected segments of drill core from the deposit were examined and logged.

Laboratory work included petrographic examination of 23 representative thin sections and several polished sections, sodium cobaltinitrite staining of 25 rock slabs for potassium feldspar identification, and use of a Norelco powder camera X-ray diffraction unit for identification of unknown minerals.
Recent work by several geologists has only begun to unravel the structural complexities and stratigraphy of the region. Some of the Paleozoic formations are not well defined. Stratigraphic correlation among many units is difficult. The recent mapping of many thrust faults, and the more accurate age interpretation for igneous plutons have helped to clarify the regional geologic picture. A generalized geologic map of the region (modified from Tschanz and others, 1974) is presented in Figure 2.

The nature of the Precambrian basement within the region is not known. However, a few scattered occurrences of a possible Precambrian schist are reported. Biotite schists of possible Precambrian age are found in the Pioneer Mountains to the southeast (Dover, 1969), in the Casto quadrangle to the north (Ross, 1934), on Elk Mountain to the northwest (Tschanz and others, 1974), and on Thompson Peak to the west (Reid, 1963). In addition, schist xenoliths are found in the northern part of the White Cloud stock (Tschanz and others, 1974), indicating the possibility of a regional schistose basement.

The Paleozoic rocks form a central band through the region as indicated in Figure 2. The sediments have been compressed into a series of generally north-south trending folds, probably as a
Explanation

- Alluvium
- Eocene Challis Volcanics
- Eocene Intrusives
- Intrusives (Age Unknown)
- Late Cretaceous Intrusives
- Paleozoic Sediments
- Alluvium k'-'l Dikes
- Strike and Dip
- Magnetic Lineaments
- Major Molybdenum Deposits
- > 14 ppm Mo in Rock Samples
- > 99 ppm W in Rock Samples

Major Base and Precious Metal Deposits

1. Livingston Mine - $2,300,000; complex lead-silver-zinc ores; in vein and along nearby parallel granite porphyry dike
2. Hoodoo Mine - 870,000 tons inferred reserves; average grade is 11% zinc, .47% lead, and .35 oz. silver per ton; replacement deposit below regional unconformity
3. Silver Rule Mine - $600,000; lead, silver, zinc, and copper ore; in veins.
4. Golden Glow Mine - $1,200,000; silver, lead, and gold ore; in veins.
5. Germania Creek District - $500,000; silver, lead, zinc, copper antimony, and gold from veins and a mineralized thrust breccia.
6. Fourth of July Creek District - 490,000 tons est. reserves; average 5% lead, 2% zinc, and .26 to 4.4 oz silver per ton.
7. Galena District - 27,000 tons of 4 oz. silver per ton, 5% lead; 180,000 tons of .4 oz. silver per ton, and 1% lead.
8. Giant Spar Mine - 200,000 tons of 20-30% CaF$_2$ resources in veins.

Figure 2. Generalized Geologic Map of the White Cloud Region in Central Idaho (Modified after Tschanz and others, 1974).
result of the isostatic rise of the Idaho batholith to the west. Near smaller stocks the sediments have been uplifted into concentric envelopes, and have locally undergone contact metamorphism.

The oldest mapped formation within the immediate region is the Milligen Formation, which is found (Ross, 1937) in scattered outcrops in the Slate Creek area and beyond the western edge of the White Cloud stock. The Milligen is variously described as a black, carbonaceous argillite with some quartzite and calcareous beds plus some graphitic coal (Ross, 1937), and as a dark, carbonaceous, phyllitic argillite with minor chert (Dover, 1967). The Milligen Formation may contain rocks as old as Late Devonian, but is primarily Mississippian in age (Tschanz and others, 1974). Tschanz and others have restricted the name Milligen to the type lithology in the Wood River region to the south, and have mapped the rest of Ross's Milligen as either Wood River Formation, or as Devonian and Mississippian undivided rocks. The only observed effects of contact metamorphism of the Milligen are recrystallization of the limy beds, and minor bleaching in some locations (Tschanz and others, 1974).

The Wood River Formation outcrops widely throughout the region, and is the principal formation included in the Paleozoic sedimentary rock group of Figure 2. The Wood River Formation consists of Permian and Pennsylvanian calcareous sandstones and quartzites (Dover, 1967). Hall and others, (1974) divided the Wood River Formation into seven units. The lowermost unit, unit 1, is a light gray, siliceous, chert
or quartzite pebble conglomerate with intercalated quartzite and minor brown micrite. Unit 2 is a medium-bedded, white and gray, fossiliferous limestone. Unit 3 is a thinly-bedded, pink and gray, shaly limestone. Unit 4 is a fine grained, gray, calcareous sandstone. Unit 5 is a thickly bedded, fine-grained quartzite and limy quartzite that is generally highly shattered. Unit 6 is a gray and light brown, fine-grained calcareous sandstone with interbeds of sandy limestone and quartzite. Unit 7 is a dark gray chert and sandy limestone commonly interbedded in thin bands. Rocks of the Wood River Formation are contact metamorphosed into two distinct calc-silicate assemblages: 1) diopsidic and garnetiferous tactite, and 2) fine grained, white, wollastonite/tremolite bearing, recrystallized limestone.

Cretaceous and possible Cretaceous intrusive rocks of the region include those of the Idaho batholith, and the White Cloud, Horton Peak, and Thompson Creek stocks (Figure 2). The porphyritic quartz monzonite, granodiorite, and quartz diorite rocks of the eastern part of the Atlanta lobe of the Idaho batholith were emplaced during several stages about 94 to 80 m.y. ago (Tschanz and others, 1974). Although the batholith is usually mapped as a single unit, it is a composite pluton composed of smaller compositionally different phases. The eastern edge of the batholith is locally composed of quartz diorite; aplite and pegmatite dikes become more numerous toward the west (Bennett, 1973).

The Late Cretaceous (Seeland, written communication, 1977), composite White Cloud stock has a central core of porphyritic biotite
quartz monzonite and a margin of slightly foliated, biotite quartz monzonite and biotite granodiorite. Aplite, pegmatite, and granite dikes and quartz veinlets are extremely common along the margins of the stock and extend into the neighboring metasediments.

The Horton Peak stock has the same lithology as the White Cloud core and may be connected with the White Cloud stock at depth. This connection is indicated by a magnetic ridge and a few sporadic quartz monzonite outcrops between the two (Tschanz and others, 1974).

The 86 m.y. old (Bennett, 1973) Thompson Creek stock, a porphyritic quartz monzonite, may be an apophysis of the adjacent Idaho batholith. Much of this stock is hydrothermally altered and broken by fault movement.

Tertiary intrusive rocks of the region include those of the Sawtooth batholith, the Boulder Mountains and Ibex Canyon stocks, and numerous smaller stocks, dikes, and sills (Figure 2). The 44 m.y. old (Armstrong, 1974) Sawtooth batholith is a coarse grained, pink granite that intrudes the Idaho batholith. The potassium feldspar-rich, leucocratic rock with mirolitic cavities is typical of the Eocene intrusives throughout the region.

The Eocene Boulder Mountains stock (Tschanz and others, 1974), intrudes Challis volcanics, Paleozoic rocks, and a dacite porphyry. The stock consists of a medium to coarse-grained pink granite and a fine-grained, nearly granophyric granite (Tschanz and others, 1974).

The Eocene (?) Ibex Canyon stock, which may intrude the Challis
volcanics, consists of a light gray to pink quartz monzonite porphyry (Tschanz and others, 1974) or granite porphyry (Umpleby and others, 1930). It contains plagioclase, quartz, and biotite phenocrysts in a granophyric groundmass of quartz and K-feldspar (Tschanz and others, 1974).

Gray and green dikes, stocks, and sills of variable intermediate calc-alkaline composition (termed dacite porphyry by Tschanz and others, 1974) outcrop in the Boulder Mountains and adjacent area. Granite and rhyolite porphyry stocks and dikes of post-Eocene age are very abundant in the Ibex Canyon area to the southeast. Numerous undifferentiated dikes and sills of intermediate and felsic calc-alkaline composition outcrop throughout the region, striking notably in a northeasterly direction. These are believed to be contemporaneous with the Eocene Challis volcanics and are part of a regional dike bearing zone known as the Idaho porphyry belt (Olson, 1968; Hyndman and others, 1977).

The Eocene Challis volcanics cover much of the region, especially the eastern side. Although the Challis volcanics are generalized as a single unit in Figure 2, they are actually a complex series of interfingering flows, ignimbrites, tuffs, and breccias of intermediate composition. They were extruded over a highly dissected topographic high from numerous volcanic centers. The Challis volcanics have been dated (whole rock K-Ar) as $49.2 \pm 1.8$ m.y. to $43.8 \pm 1.0$ m.y. (Armstrong, 1974).
Very little detailed data exists on the regional structure. However, some tentative generalizations can be made. The aeromagnetic lineaments in Figure 2 (from Tschanz and others, 1974) have been interpreted as long, deep-seated faults which may extend into the basement. Repetitions of units, linear contacts, fault scarps, aligned drainage patterns, and mylonite and breccia zones provide field evidence in support of the existence of high-angle faults along these lineaments. Other high-angle faults with various trends may be related to Cretaceous and Eocene igneous activity.

A large number of small, high angle faults in the region appear to be Tertiary in age and often have a northeasterly strike. These younger faults may result from tension produced by early Tertiary arching. A northeast arching trend was suggested by Ross (1934) for the Casto Quadrangle to the north, by Anderson (1947) for the Stanley area to the west, and by Olson (1968) for much of central Idaho.

In the southern part of the region, in the Boulder and Pioneer Mountains, several imbricate thrust faults involving Paleozoic sediments have been mapped (Dover, 1967; Tschanz and others, 1974). A large north-south trending thrust fault was mapped by Kern in the sediments north of the White Cloud Stock. More thrust faults will probably be discovered along the band of Paleozoic sediments. The direction of overthrusting is often west to east with the upper plate on the west or southwest. Movement may have been generated by the
isostatic rise of the Idaho batholith to the west, and gravity sliding of sediment sheets to the east. The orientation of thrust faults and folds was complicated by Tertiary igneous activity.

Ore Deposits

The total metal production from the region shown in Figure 2 has been about $5 million. The potential value of newly discovered molybdenum and zinc deposits is several hundred times greater. Ore deposits within the region include: 1) high temperature molybdenum and tungsten deposits within quartz veinlet systems in plutons or adjacent metamorphic halos, or sometimes disseminated in metamorphic halos; 2) low and medium temperature lead, zinc, silver and other metal bearing veins in Paleozoic sediments near igneous plutons, and within the plutons; 3) zinc, lead, and silver bearing hydrothermal replacement deposits in sedimentary rocks; and 4) placer deposits of gold and heavy "black sand" metals. There are no reported syngenetic metal deposits within the region, despite their occurrence in nearby regions.

The higher temperature (greater than 300°C) molybdenum deposits show promise of being the most valuable deposits in the region. The Little Boulder Creek and the Thompson Creek deposits each have molybdenite reserves of more than 100 million tons. Other deposits (including the Walton prospect and deposits in the Sawtooth Range) may also have large reserves (Figure 2). Molybdenite deposits are related to both Cretaceous and Eocene plutons within the region.
Tungsten is usually associated with the molybdenite deposits. Scheelite is found in trace quantities at Little Boulder Creek, and in greater quantities in veins at the Red Robin and Washington Basin prospects just a few miles southwest (Figure 2). Scheelite is also found in economic quantities with molybdenite on Peach Creek, and disseminated in a tactite at the Ura deposit (Figure 2). The locations of anomalous values of molybdenum and tungsten as indicated by U.S. Geologic Survey sampling (Tschanz and others, 1974) are shown in Figure 2.

The zinc, lead, and silver replacement type deposits are found in the Slate and Mill Creek drainages to the north of the White Cloud stock. The replaced sediments are argillites of the Milligen Formation below the unconformity at the base of the Wood River Formation.

Gold placers occur in the Stanley Basin and along the Salmon River and its tributaries. Small black sand placers containing niobium, tantalum, uranium, thorium, titanium, ilmenite, sphene, magnetite, zircon, and garnet are found in streams draining the Idaho batholith and similar rocks.
CHAPTER III
LOCAL GEOLOGY

Topography and Exposure

The molybdenum deposit is located near the headwaters of Little Boulder Creek at an elevation of from 8500 ft. to 9400 ft. A detailed topographic base with 10 foot contour intervals is given in Plate 1. Much of the topographic relief is a result of Pleistocene and Recent alpine glaciation. The higher peaks to the west have been sculpted into majestic tarns and aretes. Daily rock falls are evidence that much of the quartz monzonite is resting at its maximum angle of repose. Glaciers carved the Boulder Chain Lakes basin to the north of the deposit, and the hanging Slickenside Creek drainage to the west (Figure 1). A large glacier also traveled down the eastern side of Castle Peak and carved the upper part of the Little Boulder Creek drainage. Striations and glacial polishing are found in the rocks along the cliffs between Castle Lake and Baker Lake. Slickenside Creek takes its name from the prominent glacial striae which remain in the quartz monzonite along the sides of this U-shaped valley. Most of the local lakes were carved by glaciers during several advances and retreats. Baker Lake is the exception; it was probably formed as a result of damming by Challis volcanic flows and glacial till. Glacial till was deposited along valley bottoms and margins,
and is conspicuous south of Baker Lake, where it forms a hummocky surface with poor drainage.

Subalpine vegetation gives moderate cover to the area below about 9500 feet. Northern slopes in the Baker Lake area are more highly vegetated and afford fewer outcrops. In general the areas underlain by Challis volcanics have thick soils and dense vegetative cover. The area north of the deposit is covered by a large boulder talus pile (Figure 3). Outcrops are therefore limited to about 35 percent of the mapped area (Plate 1).

The molybdenite deposit is divided into two zones: 1) the area northeast of Baker Lake, including the main ore body, is called the North Zone, and 2) the area southeast of Baker Lake, including the southern ore extension, is called the South Zone (ASARCO, 1970; Tschanz and others, 1974). The locations of both zones are shown in Figure 1.
Figure 3. Boulder Talus North of North Zone
View looking south toward Castle Peak.
CHAPTER IV
ROCK UNITS

Wood River Formation (?)

The metamorphosed Paleozoic tectites, calc-silicates, quartzites, and marbles which outcrop in a narrow band along the eastern margin of the White Cloud stock are probably part of the Wood River Formation (Plate 1). Ross (1937) mapped these rocks as Wood River Formation, but Tschanz and others (1974) mapped the same rocks as "Paleozoic rocks undivided". All of the Paleozoic sediments in the map area have been contact metamorphosed to some degree, making stratigraphic correlation difficult. Tschanz and others (1974) did observe dark gray "argillites" in the arete immediately south of the South Zone (Figure 1), which "may" belong to the uppermost unit in the Wood River Formation. The underlying tectites, calc-silicates, and quartzites are probably part of the Wood River Formation also. The Paleozoic sediments in the mapped area (Plate 1) may be metamorphosed equivalents of unit 5 of the Wood River Formation as mapped by Hall and others (1974).

No fossil evidence in support of a particular age has been found, however, some highly deformed fusulinids (?) were observed in the calc-silicates (Pwu) along cliff walls east of Castle Lake.
The Wood River Formation (?) sediments outcrop in a discontinuous band along the margin of the White Cloud stock, with moderate frequency northeast of Baker Lake (in the North Zone), and sparsely south of Baker Lake (in the South Zone) (Figure 3). Fine, erosion-etched lamellae mark bedding planes in the metasediments. The beds adjacent to the White Cloud stock strike parallel with the contact, about N 15° to 20° E, and dip steeply to the east (Figure 4). The beds in the North Zone strike N 20° E to N 10° W, dip steeply west, and tend to wrap around the adjacent igneous mass. The beds in the South Zone strike generally N 15°E to N 35°E, and dip moderately to steeply east. The total exposed thickness of metasediments is nearly 300 m (about 1000 feet) in the North Zone (Plate 2).

Subdivisions of the Wood River Formation (?), based on mappable changes in mineralogy, texture, and metamorphic grade are shown in Plates 1 and 2. These subdivisions are:

**Pyritic hornfels (Pwh)** The pyritic hornfels unit is a black, metamorphosed, calcareous shale which outcrops in a narrow band along the fault scarp (Plate 1). Sharp interfinger ing contacts with the white calc-quartzites occur on both sides of the 3 to 4 meter wide unit. The hornfels is composed of fine, black, argillaceous and carbonaceous material with less than 10 percent carbonate (Figure 6). A few angular honey-brown quartzite or chert fragments are enclosed in the rock. Fine pyrite coats fractures and encrusts the quartzite fragments in the "strain shadows".
Figure 4. Oblique View of Little Boulder Creek Deposit

View looking northeast of North Zone (NZ) and South Zone (SZ). Representative rock types are: Wood River Formation (Pw), White Cloud Stock (Kqm), and Challis Volcanics (Tcv).

Figure 5. White Cloud Stock and Adjacent Metasediments

View looking west of Baker Lake. Cliff is scarp along Little Boulder Creek Fault.
This unit closely resembles rocks of the Milligen Formation, which also commonly contain very fine-grained disseminated pyrite, and fine to medium-grained pyrite coating fractures. The pyrite is probably authigenic because it is confined to the hornfels unit. The mineralogy and grain size of the hornfels indicates probable deposition in a reducing environment adequate for the deposition of pyrite. During subsequent metamorphism the pyrite was remobilized and deposited in fractures and around breccia fragments.

Wood River Formation undifferentiated (Pwu) This unit includes calc-silicates, calc-quartzites, quartzites, and marbles with generally a white to gray color in hand sample. The distinctive light color of these rocks is attributed to metasomatic "bleaching", the formation of new light colored minerals during metamorphism.

Rocks along the cliffs adjacent to the main stock (Plate 1 and Figure 5) are primarily wollastonite and tremolite bearing calc-silicates, although quartzites are intercalated north of Baker Lake. The calc-silicate beds are very thin (1 cm) to medium (.5 m), and there is a strong tendency for parting along foliation planes. Both foliation and bedding parallel the contact, and breakage along partings has resulted in extensive talus piles at the bottom of the steep dip slopes, and fault scarps. Microscopic examination of the calc-silicates reveals quartz and diopside porphyroblasts enclosed in a foliated matrix of very fine wollastonite, tremolite, quartz, diopside, calcite, and sphene. The wollastonite and tremolite laths wrap around the porphyroblasts (Figure 7).
Table 1. Chemical Analysis of Rocks in Little Boulder Creek Region
*Semiquantitative Analysis; all units ppm unless otherwise noted. (after Tschanz and others, 1974; Bennett, 1973)

<table>
<thead>
<tr>
<th>Element</th>
<th>White Cloud Stock</th>
<th>Idaho Bath.</th>
<th>Qtz Monzonite of Eastern Apophysics with Qtz Vein-lets (1 sample)</th>
<th>Quartz-Chalcedony Breccia Veins (3 samples)</th>
<th>Diopside-Rich Tactite of North Zone (3 samples)</th>
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<td>---</td>
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<td>---</td>
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Figure 6. Pyritic Hornfels

Extremely fine grained black hornfels with fragments of quartzite (light color). Fractures are lined with pyrite (Py). Sample is 20 cm in length.
Quartzites and calc-quartzites are found intercalated with the calc-silicates along the cliffs west of Baker Lake, north of the North Zone, and in the South Zone. The massive quartzites are white, gray, and light brown. The rocks contain a trace of pyrite and minor iron-oxide staining. The quartzites and calc-quartzites are composed of very fine-grained, recrystallized quartz (60-95%), calcite (0-20%), diopside (0-10%), hornblende (0-10%), chlorite (0-5%), and trace amounts of pyrite, tremolite, garnet, epidote, and sphene. Clastic textures have been destroyed by recrystallization. Fine bedding lamellae consisting of quartz-rich layers and calcite-rich layers were noted. The quartzites in the South Zone have particularly conspicuous alternating brown and white lamellae.

The marbles are found on the southeastern margin of the South Zone. The white marbles consist of coarsely crystalline calcite (90-99%), and minor iron oxides and clays coating grains and lining fractures. Large brown chert fragments are found in a marble breccia along cross section C - C' (Plate 2).

**Ferruginous breccia (Pwf)** The ferruginous breccia consists of brecciated quartzite fragments in a dark red-brown silica cement. The rock fragments and the matrix are highly corroded and stained by hematite and limonite (Figure 8). The angular to subangular fragments vary in size from 1 to 5 cm.

The ferruginous breccia forms a linear outcrop band in a north-south direction just east of Castle Lake. All of the outcrops are
Figure 7. Photomicrograph of Wood River Formation (?)
Undifferentiated

Porphyroblastic calc-silicate rock from Pwu unit west of Baker Lake. Porphyroblasts of diopside (A), and quartz (B), surrounded by foliated tremolite, wollastonite, calcite, and quartz matrix (C).
confined to a single stream gully. The adjacent sediments on both sides of the breccia are fine-grained, white and brown, banded quartzites (Pwu). Many of the quartzites on the western edge of the breccia zone have been crushed into a white mylonite. Slickensides are also found on the margins of the breccia zone.

The absence of sedimentary structures, the linear outcrop pattern, and the adjacent mylonite zone suggest that the ferruginous breccia was produced by fault movement. Circulating fluids in the brecciated zone deposited iron oxides derived from the breakdown of pyrite. The fluids also corroded the breccia fragments. Erosion of the less resistant breccia zone created a linear drainage channel.

**Banded tactite (Pwb)** The massive banded tactite unit is characterized by forest green diopside-rich bands transecting a white, quartz-rich tactite (Figure 9). The green bands are of two types: fracture-controlled and bedding-controlled. Both types of banding are quite narrow (less than 2 cm), and have margins which grade abruptly (within .1 to 1 cm). The green bands derive their color from the dark minerals: diopside, chlorite, and hornblende plus minor epidote, andradite garnet, geothite, and sphene. These dark minerals compose 20-60 percent of the bands, and 5-20 percent of the matrix. The remaining portion of the dark bands and the majority of the white matrix is composed of quartz, orthoclase, calcite, tremolite, and plagioclase. The banded tactite is very brittle (like a metaquartzite which it resembles), and grades into the next subunit, quartz-rich tactite.
Figure 8. Ferrigenous Breccia (Pwf) Sample is 13 cm in length

Figure 9. Banded Tactite (Pwb) Dark green diopside-rich metasomatism on fracture margins. Matrix is quartz-rich tactite. Sample is 10 cm wide.
Quartz-rich tactite (Pwq) The quartz-rich tactite is a pale green, very fine grained calc-silicate which occurs in a transition zone between the banded tactite and diopside-rich tactite (Plate 1). It is composed of quartz (40-70%), diopside (10-60%) orthoclase (0-10%), hornblende (0-5%), calcite (0-5%), and trace sphene, garnet, chlorite, epidote, molybdenite, and scheelite. The uniformly fine anhedral and subhedral grains have an interlocking texture indicative of recrystallization. The exposed surfaces of this unit, due to weathering of the ferromagnesian minerals, are stained reddish-purple. The quartz-rich tactite is massive and also brittle like a metaquartzite.

Diopside-rich tactite (Pwd) The diopside-rich tactite is a fine to medium-grained calc-silicate characterized by a high diopside content and dark color (Figures 10 and 11). Rocks of this subunit are found in the contact zone of cross cutting sills, dikes, and veinlets. The diopside-rich tactites develop in close proximity to the stock and related dikes and sills. Compositional and textural differences between the metasediments and intrusives are erased by diffusion across the contacts. The compositional range of the diopside-rich tactites is diopside (40-100%), quartz (0-50%), orthoclase (0-40%), plagioclase (0-10%), hornblende (0-15%), pyrite (0-5%), sphene (0-5%), garnet (0-50%), epidote (0-5%), chlorite (0-10%), and trace calcite, biotite, tremolite, actinolite, molybdenite, scheelite, and apatite (Figure 12).
Figure 10. Wood River Formation(?) Metasediments in North Zone

View looking northeast along strike of beds. Change in metamorphic facies is gradational over short interval (a few meters) around contact line. Arrow indicates dip of bedding.

Figure 11. Diopside-rich Tactite (Pwd)

Rock is cut by numerous pyrite and molybdenite (Mo) bearing quartz veinlets. A large, late vein is zoned with orthoclase (Or) margins and a quartz (Qtz) center. Sample is 17 cm in length.
Megacrysts of plagioclase and orthoclase are enclosed in a fine grained matrix of quartz, diopside, and orthoclase. Plagioclase megacrysts (A) are broken, altered, and show oscillatory zoning. Magnified X 10.

Medium grained, hypidiomorphic granular texture. Minerals are quartz (A), orthoclase (B), biotite (C), and myrmekite (D). Magnified X 10, Crossed Nichols.
Garnet rich zones tend to occur toward the outer margin of the diopside-rich tactite; more feldspar rich zones tend to occur closer to the contact. Pervasive silicification and fine quartz veining are found commonly throughout the subunit.

**Interpretations** On the whole, the Wood River sediments appear to have been quite uniform in composition and texture prior to metamorphism. Variations due to metamorphic grade are the primary differences in the subdivisions. The sediments were originally fine-grained, calcareous quartzites, orthoquartzites, and sandy limestones. The sediments were physically and chemically well-sorted with few argillaceous or lithic contaminants. The strike of the beds is rather consistent, and changes in dip are probably due to slight differences in the angle of steeply dipping contacts (with which the bedding is conformable), and do not represent a tight synclinal fold. The sediments were apparently uplifted into steeply dipping, conformable envelopes by intrusion of the White Cloud stock. The subsequent fracturing and metamorphism of the sediments will be discussed later.

**White Cloud Stock**

**Main Stock.** The White Cloud stock was considered to be, on the basis of the surrounding steep magnetic gradients, Eocene in age (Tschanz and others, 1974). Seeland (written communication, 1977) obtained a K-Ar date on the biotite in the stock of $83.6 \pm 2.8$ m.y.
This date corresponds with K-Ar dates of 79.4 ± 1.6 m.y. to 94.5 ± 1.9 m.y. for the Idaho batholith to the west (Bennett, 1973), and a date of 85.9 ± 3.0 m.y. for the compositionally and texturally similar Thompson Creek stock to the north (Hall, W. E., written communication, 1977). A few kilometers north of Little Boulder Creek, Marvin and others (1973) dated vein molybdenite mineralization in the metasediments on the eastern White Cloud stock margin at 86-87 m.y. In contrast, Armstrong (1978) obtained a whole rock, K-Ar date on the mineralized metasediments of the North Zone of 61.5 m.y. The White Cloud stock is probably Late Cretaceous in age, and associated differentiate intrusions, veining, and hydrothermal alteration may have continued into the Paleocene.

The White Cloud stock is roughly 78 square kilometers (30 square miles) in total area. The stock has generally concordant (but locally discordant) contacts with the Wood River (?) metasediments along the eastern margin. The contact between the stock and adjacent metasediments is very steep as indicated in outcrop and in drill holes (Plate 2). The eastern contact is also marked by a 30 meters wide zone of cross cutting sills, dikes, and metasediments.

The White Cloud stock is a composite pluton consisting of a porphyritic quartz monzonite core surrounded by a narrow (approx. 30 m wide) foliated quartz monzonite and granodiorite margin. The distinction between the core and margin, gradational over 100 m, is based on a decrease in megacrysts and an increase in biotite content and foliation.
Porphyritic Core. The slightly to moderately porphyritic quartz monzonite contains pink and white potassium feldspar megacrysts from 2 to 10 cm in length in a speckled white to light gray matrix. The rock contains potassium feldspar (30-45%), plagioclase feldspar (25-50%), quartz (20-40%), biotite (less than 5%), and trace amounts of sphene, pyrite, zircon, apatite, molybdenite, and scheelite. The euhedral and subhedral orthoclase megacrysts are commonly perthitic, and contain numerous fine anhedral poikiloblasts of quartz, plagioclase, biotite, and euhedral pyrite. The megacrysts often have narrow white albite rims and irregular embayed margins. The potassium feldspar in the matrix is dominantly subhedral to anhedral perthitic orthoclase, but minor microcline is also present. Myrmekite inclusions of quartz are common in the orthoclase (Figure 13). Most of the orthoclase grains are fractured.

All of the plagioclase is within the oligoclase (An$_{20-30}$) field. Most of the oligoclase forms coarse to fine (1-10 mm) subhedral to euhedral prisms which show some fine oscillatory zoning. Most of the plagioclase grains show a uniform composition from centers to margins, but a few grains are rimmed by albite. Fine poikiloblastic inclusions in the plagioclase include quartz, orthoclase, biotite, and pyrite. Some plagioclase grains are cut by parallel microfractures. The small euhedral quartz grains frequently show undulose extinction and are also frequently cut by tiny fractures. The pleochroic brown biotite
flakes are somewhat smaller than the feldspars, but larger than the quartz grains. These flakes are anhedral with ragged edges.

**Foliated Margin.** The composition of the marginal quartz monzonite is similar to the porphyritic quartz monzonite core except there is an increase in plagioclase (35-60%), biotite (5-10%) and a decrease in quartz and orthoclase. The characteristic biotite foliation parallels the contact margin of the stock. The foliated marginal rocks otherwise show the same textures and alteration as observed in the porphyritic quartz monzonite core.

**Weathering of main stock.** The porphyritic quartz monzonite west of Baker Lake appears quite fresh in hand specimen probably as a result of recent glacial exposure. In thin section, however, biotite is incipiently altered to narrow chlorite rims, and plagioclase and orthoclase grains are very slightly altered to clays and fine white mica (sericite?) along the microfractures. The poikiloblasts of pyrite are almost completely oxidized to limonite and geothite.

**Eastern segment.** The quartz monzonite which outcrops northeast of Baker Lake is compositionally and texturally very similar to the main White Cloud stock, and is probably a fault displaced segment of the stock (Figure 14). Common petrologic characteristics between the main White Cloud stock and this eastern extension include: twinned pink and white orthoclase megacrysts in a medium grained matrix, poikilitic inclusions, myrmekitic textures, and oscillatory zoning.
Figure 14. Quartz Monzonite of Eastern Stock Segment.

Note porphyritic texture of the rock and the large orthoclase phenocrysts (C). The quartz monzonite is transected by several aplitic and pegmatite (B) dikes and later iron oxide lined fractures (A).

Figure 15. Photomicrograph of Quartz Monzonite of Eastern Segment.

Note ragged white albite rims (A) on orthoclase, oscillatory zoning in plagioclase (B), and slight chloritization of biotite (C). Mag. X 10; Crossed Nichols.
The eastern extension rocks are, however, more extensively altered and show more indication of strain and fracture than the rocks of the main stock (Figure 15). The eastern extension rocks are heavily stained by iron oxides released during weathering, and both the oligoclase and orthoclase show strongly corroded rims and microfractures. Alteration products include clays and minor fine white mica. The quartz and feldspar grains in these rocks are more severely broken and undulose extinction is more prominent.

Interpretations The White Cloud stock may be a late stage differentiate of the larger Idaho batholith 8 km to the west as suggested by Bennett (1973). The stock appears to be slightly younger and compositionally more felsic than the batholith. Samples from the stock are uniformly low in mafic minerals and early fractionated trace elements (Table 1). Bennett also found the trace element chemistry of the White Cloud stock comparable to that of aplites and pegmatites in the neighboring batholith.

Evidence indicates the White Cloud stock solidified at a depth greater than 5 km (3 miles). The stock has many characteristics (Buddington, 1959) of shallow mesozone formation including: 1) Contacts with the metasediments are primarily concordant. 2) Contacts are locally gradational. 3) There are no related volcanic rocks in the area. 4) Well-developed contact metamorphic aureoles are present. 5) Steep planar foliation occurs in a 100 feet wide zone parallel with the stock margins. 6) Miarolitic cavities are absent. 7) Pegmatite and aplite dikes are abundant. 8) There are two feldspars present in
the rock (subsolvus). However, the steep magnetic gradient, abundance of veinlets, porphyritic character of the stock, and presence of wollastonite in the contact halo, suggest that the pluton was intruded to a high crustal level.

The eastern stock extension may be a fault displaced segment of the main stock, or it may be a later differentiate intrusion. The Paleocene age for the North Zone contact metamorphism (Armstrong, 1978) may be due to the thermal metamorphism by the eastern segment, or the age may be due to partial resetting by late hydrothermal emanations or the Challis volcanic event. The bent and broken grains indicate stress which would be expected in the solid upper and outer margins of a rising stock.

Late Stage Differentiates (Kd)

The White Cloud stock is laced with aplite, pegmatite, and granite dikes. These crosscut the stock in numerous directions. Based on cross-cutting relationships, three dike and sill generations are present (Table 2). The dikes are more numerous toward the margins of the stock, and become extremely numerous in the adjacent metasediments. Aplite and pegmatite sills are very abundant in the contact zone west of Baker Lake (Figure 18). Only the larger sills are diagrammatically represented in Plates 1 and 2. The sills tend to become narrower with depth, but the pinching out (Plate 2) is diagramatic. Both dikes and sills of pegmatite and aplite are common in the North Zone (Figures 14
Figure 16. Pegmatite Dikes in Eastern Stock Segment.
View looking west at two sets of parallel pegmatite dikes. Both sets were apparently joint controlled. Set "A" is earlier, and cut by set "B".

Figure 17. Aplite Plug (Kd) Intruding Wood River Sediments (Pwd) in the South Zone. Closely spaced joints in aplite plug are nearly horizontal.
Figure 18. Aplite and Pegmatite Sills and Dikes Along Contact Margin of White Cloud Stock.

View looking northeast along strike of beds. Numerous aplite and pegmatite sills (A) are concordant with bedding in the contact zone. A few dikes (B) cut across the sills and bedding.

Figure 19. Quartz Veins, Veinlets, and Aplite Dikes and Sills Exposed on Weathered Surface of Metasediments in North Zone.

View looking west showing numerous quartz veinlets, and dikes and sills exposed by weathering. Note the general northeasterly strike of the veinlets and sills, concordant with bedding.
and 16). The dikes and sills are contemporaneous with quartz veining as shown in Table 2. Pegmatite and aplite dikes in the contact zones grade compositionally and texturally into diopside-rich tectite. A large fractured aplitic plug intrudes the metasediments in the southernmost part of the South Zone (Figure 17).

**Pegmatites** Most of the dikes and sills have a pegmatitic texture. The pegmatites are composed of orthoclase, quartz, microcline, oligoclase-albite, and minor biotite or muscovite. Grain size varies (often within the same dike) from 0.5 to 3 cm. Many of the pegmatite dikes have extremely sharp contacts but the larger dike boundaries are frequently gradational with the metasediments. Some dikes have dilated and offset earlier dikes and veinlets. There is a compositional gradation between late stage dikes and quartz veinlets. Late stage dikes and sills contain variable amounts of quartz and most quartz veinlets contain some feldspar. In addition many dikes are compositionally zoned with early formed minerals such as orthoclase, plagioclase, and biotite on dike margins, and later formed minerals such as quartz and orthoclase in dike centers (Figure 11).

**Aplites** Aplite dikes and sills are less common than pegmatites. Some of the aplites are nearly equally dimensional and resemble plugs. Most aplites are composed of both quartz and orthoclase or microcline in approximately equal amounts. The aplites vary in color depending on the color of potassium feldspar. Contacts adjacent to the aplites are
either sharp, or gradational for several centimeters into the meta-
sediments.

Granites Granite dikes appear to be nearly compositionally identical
to the pegmatites and aplites. The granites are medium-grained and
contain quartz (30-60%), orthoclase (25-40%), microcline (15-40%),
biotite (0-5%), plagioclase (5-30%), and trace amounts of pyrite, iron
oxides, garnet, sphene, diopside, calcite, and hornblende.

Interpretations The late stage dikes and sills are joint and fracture
filling crystallization products of residual magmatic fluids. Generally
volatile-rich fluids crystallize to form pegmatites and volatile-poor
fluids crystallize to form aplites. The loss of volatiles would be a
continuous and complex process during dike formation and fracturing.

Quartz Veins and Veinlets

A stockwork system of quartz veins and veinlets is poorly developed
in the stock and very well developed in the adjacent metasediments,
particularly in the North Zone. The quartz veins and veinlets transect
each other to form a closely spaced network of intersecting planes
(Figures 19, 29, and 30). The quartz veins are of two main types:
1) veins and veinlets contemporaneous with the late stage dikes and
sills (Figure 20), and 2) quartz-chalcedony breccia veins (Kqb) which
are distinctly younger than the above veinlets, late stage dikes, and
sills.

The contemporaneous quartz veins and veinlets range in width from
greater than 1 meter to microscopic. The larger milky quartz
veins are later than most veinlets, rare in occurrence, and always unmineralized. The veinlets average about 2 mm in width. Most individual veinlets have sharp contact margins, but a few grade into pervasive silicification. Cross-cutting relationships show at least seven distinct "generations" of veinlets in a single outcrop. Lack of distinguishing compositional or textural qualities for individual generations prohibits assignment of veinlets to a particular generation from outcrop to outcrop. However, veinlets are assigned to "general stages" based on cross-cutting relationships with other veinlets and dikes within a particular outcrop. "Early" veinlets do not cut through any veinlets, and are cut by all other veinlets and most dikes and sills. "Middle" veinlets both cut and are cut by veinlets, dikes, and sills. "Late" veinlets cut all other veinlets, dikes, and sills. Table 2 illustrates the temporal relationship of various elements, including veining, in the North Zone. The quartz veinlets frequently contain orthoclase sphene, pyrite, and minor biotite (plus molybdenite and scheelite). The interlocking, anhedral quartz crystals in the veinlets are of a fine to medium grain size, much larger than the quartz in the enclosing rock (Figures 34, 35, and 36). Early veinlets tend to be dark and glassy and later ones more milky. Offsets of cross-cutting veinlets are common (Figure 20). The orientation of veinlets by stages are discussed later.

The late quartz-chalcedony breccia veins are found in the North Zone stock and metasediments. They vary in width from .5 m to 50 m.
Table 2. Sequence of veining and mineralization in North Zone

<table>
<thead>
<tr>
<th>late jointing and fracturing</th>
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<th>early fracturing</th>
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<tr>
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<td>late quartz veinlets</td>
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<td>veinlets</td>
<td>diking &amp; mineralization</td>
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<tr>
<td></td>
<td>Mo - Py +</td>
<td>tr = trace; minus (-) = light; plus (+) = moderate; ++ = heavy</td>
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<td></td>
<td>middle quartz veinlets</td>
<td>Mo = molybdenite</td>
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<td></td>
<td>Mo ++ Py +</td>
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<tr>
<td></td>
<td>early quartz veinlets</td>
<td>w = scheelite</td>
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<tr>
<td></td>
<td>Mo + Py - W tr</td>
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</table>
Figure 20. Quartz Veinlets in Diopsidic Tactite from Contact Zone in North Zone.

Narrow molybdenite bearing quartz veinlets (A), are slightly displaced along quartz-filled fracture (B). Veinlets A and B are both crossed by younger aplite veinlets (C) which are light in color due to staining by sodium cobaltinitrite. Photo is actual size. Sample width - 7.5 cm.
The brecciated veins consist mostly of milky quartz and minor transparent gray chalcedony. The veins are heavily stained with iron oxides. Pyrite is nearly ubiquitous in the quartz-chalcedony breccia veins. Arsenopyrite and other base and precious metal sulfides are also locally abundant as indicated in Table 1.

Challis Volcanics

The Challis volcanics are poorly exposed within the study area. Bedding in the volcanics was not observed in outcrop in the map area, but was observed to the southeast and northeast. A uniform $N\ 60^\circ W$ strike and $15^\circ NE$ dip are apparent for a large area of volcanics to the east. Volcanics in the map area probably have the same orientation. The protruding tongue of altered volcanics southeast of Baker Lake was encountered in vertical drill holes from the base of the glacial debris and alluvium to a depth of at least 692 feet.

The volcanics are primarily andesites. Some porphyritic units with fine-grained plagioclase phenocrysts were intersected in drill holes. Agglomerates, breccias, and scoria were also common in drill cores. Amygdules of chalcedony and calcite are common in some units. A brilliant deep blue and green celadonite stain is locally present on exposed surfaces of the volcanics. Celadonite is quite common in the Challis volcanics throughout the region. Some celadonite staining and encrustations are also found on fractures in the metasediments in the North Zone.
The Challis volcanics apparently erupted onto a rugged topographic high about 45 million years ago (Axelrod, 1968). The coarse clastic textures of some rocks and the abundance of chalcedony veining may indicate a nearby eruptive source. However, the more common uniform, shallowly dipping beds probably represent flows with a more distant source. The protruding central tongue may represent altered volcanic debris from an ancient slump or slide plus glacial talus. The central tongue may also be a thick, fault-displaced flow sequence.
CHAPTER V

STRUCTURE

Structural features observed in the study area include: 1) two major faults, the Little Boulder Fault and the Uncle Jess Fault (ASARCO, 1970), 2) several minor faults, 3) early formed joint sets and fractures now filled by veinlets, dikes, and sills, and 4) late open joints and fractures.

Faults

The dominant structural feature in the study area is the major N 10°E trending Little Boulder Fault, which parallels the eastern margin of the White Cloud stock. This fault also roughly parallels the trend of the Little Boulder Creek magnetic lineament outlined by Tschanz and others (1974) (Figure 2). The presence of the Little Boulder Fault is indicated by several surface features (Plates 1 and 2): 1) A steep east-facing scarp occurs along the western edge of this major fault zone. 2) There is displacement of the metasediments in the arete on the southern projected trend of the fault. 3) A linear ferrigenous breccia and mylonite zone mark the bifurcating southern extension. 4) Rock types, veining, diking, mineralization, alteration, and easterly decreasing contact metamorphism are repeated on both sides of the fault zone. 5) There is an absence of reverse
gradation (west to east) in metamorphism in the metasediments between the main White Cloud stock and the fault displaced eastern extension.

The presence of this major fault is also demonstrated by three drill holes, which intersect the fault along cross sections A-A', C-C', and near B'B'. A wide zone (greater than 50 m) of intense alteration, brecciation, and mylonitization is intersected in all three holes, but no hole penetrates through the fault zone.

On the basis of drill hole intersections and projected surface trends, the Little Boulder Fault is a steeply dipping normal fault. The dip roughly parallels the bedding dip (approx. 70°E), and the eastern side is downthrown. Total fault displacement is unknown, but a large vertical component is probable.

Along the eastern side of the North Zone the Challis volcanics are in fault contact with the metasediments. This fault is named the Uncle Jess Fault after Jess Baker. Its surface expression includes a fault scarp in the metasediments, a linear stream alignment, and the occurrence of a breccia zone (Kqb) on the edge of the metasediments. The Uncle Jess Fault was penetrated in two drill holes south of A-A'. The fault is actually a 30 m wide zone of intense brecciation, mylonitization, and chlorite and clay alteration. The Uncle Jess Fault also appears to be steeply east dipping, with the Challis volcanics downthrown. The total displacement is not known. The southern trend of the fault, based on an aerial photo lineament and limited drill hole information, is tentatively projected to a juncture with the Little Boulder Fault (Plate 1).
Two other faults parallel the Uncle Jess Fault. The contact between the Challis volcanics and the metasediments in the South Zone is marked by considerable brecciation of the metasediments (solid fault lines in Plate 1). The northern extension of this fault was interpreted from aerial photo linears. The other fault with a north-east trend crosses the eastern stock extension. This fault is marked in aerial photos as a linear patch of deep green vegetation.

Orientation of Quartz Veinlets and Late Stage Dikes

Veinlets, dikes, and sills occupy joint sets and fractures which formed prior to (and during) the release of magmatic and hydrothermal fluids from the White Cloud stock.

The most prominent steeply dipping dikes in the main stock have a general strike of N 60°E to N 80°E. Time limitations prevented detailed study of the orientation of other veinlets and dikes in the main stock. Aplite and pegmatite sills and quartz veinlets in the metasediments adjacent to the main stock are almost exclusively conformable with bedding (Figure 18). A paucity of outcrops prohibited study of veinlet and dike orientation in the South Zone.

Contour diagrams of poles to 1117 early, middle, and late stage veinlets, dikes, and sills in the metasediments of the North Zone are presented in Figures 21, 22, and 23. Aplite and pegmatite dike and sill orientations are combined with veinlet orientations because
Figure 21. Contour Diagram of Poles to Early Stage Veinlets, Dikes, and Sills. Total orientation measurements shown below each diagram. • = MoS$_2$ bearing veins.

Contour intervals: Area A 1%, 2%, 4%, 8%, Area B 1%, 2%, 4%, 8%, 16%, 32%] of 1%
Area C 1%, 2%, 4%, 8%
Figure 22. Contour Diagrams of Poles to Middle Stage Veinlets, Dikes, and Sills. Total orientation measurements shown below each diagram. ● = MoS₂ bearing veins.

Contour intervals: Area A 2%, 4%, 8% of 1%
Area B 4%
Area C 4%, 8%
Figure 23. Contour Diagrams of Poles to Late Stage Veinlets, Dikes, and Sills. Total orientation measurements shown below each diagram. ● = MoS-bearing veinlets.

Contour intervals: Area A 2%, 4%, 8%  
Area B 2%, 4%  
Area C 4%, 8%  

(Contour interval denoted as 1%)
Figure 24. Contour Diagrams of Poles to Veinlets, and Dikes in Eastern Extension Quartz Monzonite. Total orientation measurements shown below each diagram.

Contour intervals:  
Area A $1\%, 2\%, 4\%, 8\%$  
Area B $1\%, 2\%, 4\%, 8\%, 16\%$  
Area C $8\%, 16\%$  

of 1%
Figure 25. Contour Diagrams of Poles to Joints and Fractures in Metasediments of North Zone. Total orientation measurements shown below each diagram.

Contour intervals: Area A 1%, 2%, 4%, 8%, 16% of 1%
Area B 1%, 2%, 4%, 8%, 16% of 1%
Area C 1%, 2%, 4%, 8%
Figure 26. Contour Diagrams of Poles to Joints and Fractures in Eastern Extension Quartz Monzonite. Total orientation measurements shown below each diagram.

Contour Intervals:

Area A 4%, 8%
Area B 1%, 2%, 4%, 8%, 16% of 1%
Area C 4%, 8%
**Explanation**

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<tr>
<td>Kd</td>
<td>Late stage differentiates of the White Cloud Stock (aplites and pegmatites)</td>
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<td>White Cloud Stock (quartz monzonite)</td>
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<td>Pwq</td>
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<tr>
<td>Pwb</td>
<td>Wood River Fm - Banded tactite</td>
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<tr>
<td>Pwu</td>
<td>Wood River Fm - Undifferentiated calc quartzite, quartzite, and limestone</td>
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<tr>
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<td>Strike and dip of joints</td>
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<td>Veinlet orientation Area boundary (A, B, C)</td>
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**Figure 27a.** Diagramatic Strikes of Early Stage Veinlets, Dikes, and Sills.

**Figure 27b.** Diagramatic Strikes of Middle Stage Veinlets, Dikes, and Sills.

**Figure 27c.** Diagramatic Strikes of Late Stage Veinlets, Dikes, and Sills.

**Figure 27d.** Alteration and Mineralization

**Figure 27e.** Diagramatic Strikes of Open Fractures and Joints

**Figure 27.** Outcrop Geologic Map of Little Boulder Creek Deposit-North Zone (Plate 1 - reduced)
Figure 28. Geologic Cross Section of a Portion of A-A'. See Figure 27 for explanation.

Overlay: (In back pocket)

Figure 28a. Alteration and Mineralization.
Figure 29. Outcrop Geologic Map of Little Boulder Creek Deposit-South Zone (Plate 1 - reduced)

See Figure 27 for explanation

Overlays: (In back pocket)

Figure 29a. Alteration and Mineralization
of their temporal similarities (Table 2). Quartz (+ orthoclase) veinlets are most common in the early and middle stages, and aplites and pegmatites are most common in the late stages.

It should be noted that veinlets, dikes, and sills in the North Zone metasediments which strike nearly North-South and dip moderately west were often better exposed than their counterparts with a moderate dip east. This exposure bias is illustrated in Figure 30.

![Figure 30](image)

**Figure 30.** Cross Section showing exposure bias of north-south striking, west dipping veinlets, dikes, and sills in North Zone.
Both the eastern stock extension and the metasediments are subdivided into three structural areas as shown in Figure 27. Progressive changes in veinlet and dike orientation can thus be compared from north to south (Area A to C).

Most of the 657 early stage quartz veinlets and aplites and pegmatites are conformable with bedding, having an average strike of N 15°E and an average dip of about 75°W (Figure 21). A few veinlets and dikes have a northwest to east-northeast strike, and a moderate to shallow dip. There is little change in the dominant strike and dip of these early veinlets from Area A to Area C (Figures 21 and 27a).

The 228 middle stage veinlets and dikes occupy a bedding joint set in Area A, B, and C. In addition, the middle stage veinlets and dikes occupy a secondary steeply dipping joint set which strikes North-South in Area A; N 30°W in Area B, and N 60°W in Area C.

The 232 late stage veinlets, dikes, and sills are also steeply dipping, and occupy a bedding joint set and a cross joint set. The cross joint set strikes N 45°E in Area A, N 65°E in Area B, and N 75°E in Area C (Figure 23).

Contour diagrams of poles to 258 combined stage quartz veinlets and dikes in the eastern stock segment are presented in Figure 24. Most dikes and quartz veinlets occupy steeply dipping joint sets which strike N 60-80°W, or N 80°E.
Figures 27 a,b,c,d,e and 28a show the orientations of veinlets relative to outcrop pattern, rock type, alteration, and mineralization in the North Zone. A comparison of the overlays shows a close spatial association among veining, alteration, and mineralization because all three were fracture controlled. Figure 29a shows the location of alteration and mineralization in the South Zone. The patterns of veining, mineralization and alteration are more complex in the South Zone, but also appear to be spatially related.

Late Fracturing and Jointing

A large number of open joints and fractures developed in the main stock, the eastern extension, and in the North Zone metasediments after the quartz and potassium-feldspar "healing phase". These late, open joints and fractures have smooth plane surfaces, and are coated with iron oxides.

Within the main stock a conspicuous, nearly vertical set of cross joints is visible on the ground and in aerial photos. These joints are regularly spaced about .5 meters apart and strike N 80°E. A secondary vertical set of less prominent joints with smooth to irregular surfaces strikes subparallel with the contact margin of the stock.

Contour diagrams of the orientations of joints and fractures within the stock apophysis and metasediments in the North Zone are shown in Figures 25 and 26. Most of the joints in the eastern stock segment belong to a set which strikes about N 60°W and dips steeply south. A secondary joint set is parallel with the contact. Other
joints and fractures in the eastern stock segment fall into cross sets which are dominantly steeply dipping. A major joint set in the metasediments strikes northwesterly and dips steeply south or north. There are also numerous bedding joints in the metasediments, striking N 5-20°E and dipping steeply west. The relative strike of late joints and fractures compared to veining, diking, rock type, alteration and mineralization is shown in Figure 27e.
Figure 31. Aplitic and Pegmatite Sills and Dikes (Kd), and Quartz Veinlets in North Zone Metasediments. View looking south; sills and most veinlets are concordant.

Figure 32. Aplitic and Pegmatite Sills and Dikes, and Quartz Veinlets in North Zone Metasediments. View looking west showing dikes, sills (A), and veinlets with a strike subparallel with bedding. Late vertical joints (B) strike N 65°-75°W.
CHAPTER VI

METAMORPHISM AND ALTERATION

In this deposit both contact metamorphism and hydrothermal alteration of the sediments and stock resulted primarily from the establishment of thermal and chemical gradients via fluid movement. Probably the same fluids were also responsible for mineral deposition in veinlets. Diffusion apparently played a spatially limited role in accomplishing hydrothermal alteration or metamorphism.

Contact Metamorphism

All the sediments in the study area were contact metamorphosed to varying degrees. The calc-quartzites were generally impermeable to the magmatic fluids except along fractures. Limited fracturing along bedding planes in the metasediments near the main stock allowed the hot fluids to metamorphically alter the rocks in a zone up to 150 meters wide. Moderate fracturing in the South Zone and intense fracturing in the North Zone permitted much larger volumes of rock to be metamorphosed (Plates 1 and 2). As expected, the effects of contact metamorphism diminish away from the stock. However, because alteration is fracture controlled, the transition to lower metamorphic grades in the sedimentary rocks is not spatially uniform (especially in the North and South Zones).
In the outermost zone (Wood River undifferentiated Pwu), contact metamorphism is limited to minor recrystallization and the formation of less than 10 percent new minerals. Metamorphism increases to pyroxene hornfels grade as the stock is approached. Pyroxene facies minerals are found in a zone extending a few meters away from large dikes, and in a zone extending a few centimeters away from fine veinlets. Fracture control of pyroxene facies metamorphism is exhibited throughout the metasediments, but it is best exhibited in the banded zone (Figure 9). Narrow diopside halos line fractures in the banded zone creating a conspicuous stockwork pattern, which widens at intersections.

The effects of contact metamorphism include: 1) the formation of new metamorphic minerals such as diopside, wollastonite, tremolite, hornblende, epidote, chlorite, orthoclase, microcline, plagioclase, and actinolite, and 2) the recrystallization of minerals such as quartz and calcite.

Many of the metamorphic minerals require only a temperature increase for their formation. Necessary components for the formation of diopside, tremolite, and wollastonite are already available in the sediments. The formation of other metamorphic minerals in the sediments requires elemental input and removal. A comparison of the percent mineral content of metamorphic subunits of the Wood River metasediments reveals a progressive increase in minerals bearing the elements Ti, Fe, Mg, K
and Na as the stock is approached. The above elements were probably derived from circulating hydrothermal or magmatic fluids. There is a decrease in Si, Ca, and CO$_2$ bearing minerals as the grade increases and the stock is approached. Both the Si and Ca were carried away by the hot fluids and precipitated in numerous quartz and calcite veins. Much of the CO$_2$ escaped allowing wollastonite to form.

Hydrothermal Alteration

Only minor amounts of hydrothermal alteration occurs in the main stock, the eastern segment and the adjacent metasediments. The intense hydrothermal alteration found in other stockwork molybdenum deposits is conspicuously absent from this deposit. Hydrothermal alteration is most pronounced in the major fault zones. The locations of hydrothermal alteration zones are shown in Figures 27, 28, and 29.

Hydrothermal Alteration of the Main Stock and Eastern Segment

Hydrothermal alteration in the quartz monzonites of the main stock and eastern segment consists of minor silicification, and local argillic alteration, and sericitization. Minor silicification consists of the quartz veining (previously described), and very minor quartz flooding along the margins of some larger veins. The zone of incipient silicification includes all of the main stock and eastern extension within the map area. There is an apparent increase in quartz vein and veinlet density in the eastern segment. Only incipient
Figure 33. Photomicrograph of Banded Tactite (Pwb). Metamorphic mineral segregation is shown by dark appearing bands (A) containing mostly diopside, and alternating light bands (B) containing mostly quartz. Hornblende laths (C) are elongate in the same direction as the mineral segregation bands. Mag. X 10.

Figure 34. Photomicrograph of Intensely Sericitized Quartz Monzonite from North Zone. Sericite (A) is replacing all feldspars leaving only quartz (B). Mag. X 10. Crossed Nichols.
argillic alteration of the feldspars occurs in most rocks of the main stock and eastern extension. Intense sericitization is confined to narrow zones (a few meters wide) on the margins of quartz-chalcedony breccia veins (Figure 27). Feldspars in these zones are totally altered to sericite (Figure 34). Minor sericite also occurs on fractures with iron oxides throughout the eastern stock extension.

There is intense argillic alteration along the Little Boulder Fault Zone (Figures 27 and 28). Rocks on the margins of this zone are intensely altered to green and white clay minerals along fractures. Many of the rocks in the center of the fault zone are completely altered to white clays, finely crushed quartz, fine white mica (sericite), and chlorite. Many fractures and minor faults in the eastern stock extension are lined with chlorite.

Hydrothermal alteration in the Metasediments

Hydrothermal alteration in the metasediments consists of the introduction and formation of minerals commonly found in typical hydrothermal zones (i.e. Lowell and Guilbert, 1970). However, the initial chemical composition of the metasediments (almost no aluminosilicates) dictates that the process of hydrogen metasomatism probably plays a very limited role in the development of hydrothermal minerals in the study area.

Hydrothermal alteration in the metasediments consists of silicification, incipient biotite alteration, and sericitization.
Silicification includes both quartz veining and pervasive flooding. The quartz flooding is difficult to distinguish from recrystallization of the calc-quartzites. Usually sedimentary textures are more diluted or destroyed by quartz flooding. The flooding is generally limited to the diopside-rich tactite of the North and South Zones (Figures 27 and 29). Quartz veining diminishes away from the stock, but extends into the Wood River undifferentiated (Pwu) subunit. Biotite is disseminated very sparsely in the metasediments throughout the zone of incipient biotite alteration (Figure 27). However, much of what appears to be biotite in hand specimen is pyrolucite and/or dark chlorite. Intense sericitization is found in the metasediments along the margins of the quartz-chalcedony breccia veins (Kqb). Minor amounts of sericite are also found in quartz veinlets and in open fractures throughout the metasediments of the North Zone, and occasionally in the South Zone. Many fractures in both the North Zone and South Zone are thickly coated with chlorite.

Interpretations

With the exception of quartz veining in the apophysis and metasediments, argillic alteration along the major fault zones, and sericitization along the quartz-chalcedony breccia veins, pervasive hydrothermal alteration is absent from this deposit. The limited alteration might be explained by: 1) a low water content for the magmatic and hydrothermal fluids, 2) a high degree of fracture control of fluid movement, or 3) an absence of aluminosilicate minerals in the host metasediments.
Molybdenite

At the Little Boulder Creek Deposit trace amounts of molybdenite are disseminated in the main stock and eastern extension, disseminated in a tactite along both the main stock and eastern extension, contained in large quartz veins, contained in pegmatite dikes, and contained in a quartz veinlet stockwork.

Greater than 95 percent of the molybdenite mineralization at Little Boulder Creek is confined to quartz veinlets. Molybdenite-bearing veinlets occur in the main stock, in the eastern stock apophysis, and in the adjacent metasediments of both. The highest grades of molybdenite mineralization are found in the North and South Zone metasediments, because of the greater molybdenite bearing veinlet density in these areas.

Figures 27, 28, and 29 show the distribution of molybdenite mineralization in the North and South Zones. A line marking a minimum average grade of 0.15 percent Mo roughly outlines the ore zones (modified after Tschanz, 1974; Kirkemo et al., 1965; ASARCO, 1970).
Figure 35. Aplitic Sample Containing Quartz and Disseminated Molybdenite.

Quartz veinlets are often brecciated and displaced indicating nearly contemporaneous deposition of aplite. Molybdenite flakes are found both within the quartz and aplite portions of the rock. Molybdenite flakes are coarse and randomly disseminated. Sample is 8 cm wide.
The dashed line denotes the outer limit of visible molybdenite mineralization. A comparison of overlays (Figures 27 and 28) shows the direct spatial correlation of veining, alteration, and mineralization. The grade of mineralization changes only slightly (both on the surface and in drill holes) in the North Zone, but is more variable in the South Zone. Further from the intrusive contact the grade of mineralization, alteration, and veining decrease sporadically. Drill hole assay results indicate that the grade in the North Zone is quite constant to depths exceeding 240 meters. Drilling indicates that well mineralized rock extends north under the talus cover, but the grade may decline somewhat. Drilling also indicates an extension of the ore zone under the Challis volcanics southwest of Baker Lake. Because of extreme changes in grade and lack of outcrops, the ore zone is more difficult to define in the South Zone. Drilling has delineated two ore bearing zones, one along cross section C-C', and the other south near the aplite plug.

All previous estimates of ore grade rock at Little Boulder Creek are in excess of 100 million tons. Based on an average width of 180 m, an average length of 900 m and an average depth of 300 m, the ore reserves in the North Zone total a minimum of 149 million tons. The ore reserves in the South Zone total a minimum of 18 million tons, based on one drilled ore zone 150 m by 180 m by 180 m, and a second drilled ore zone 120 m by 60 m by 120 m. The value of one ton of .15 percent molybdenum ore would exceed $15 at current prices (approx. $5.50/lb conc.)
The molybdenite-bearing veinlets decrease away from the stock in the same proportion as total veining. There is apparently no particularly favorable horizon for molybdenite deposition in the metasediments. Generally the finer veinlets contain a higher percentage of molybdenite. The orientation of early, middle, and late stage molybdenite-bearing veinlets is shown in Figures 21, 22, and 23. Most molybdenite-bearing veinlets are roughly conformable with bedding (strike N 15°E and dip steeply west), and many others occupy the dominant joint sets with other orientations. The middle stage veinlets contain the most molybdenite. The early stage veinlets contain less molybdenite, and the late stage veinlets often contain no molybdenite. By contrast the middle and late stage veinlets contain moderate amounts of pyrite and early veinlets contain very little pyrite (Table 2).

Most molybdenite-bearing quartz veinlets also contain potassium feldspar, and minor diopside, calcite, and oligoclase. The molybdenite flakes are euhedral to subhedral, and grew in irregular clusters and radiating clots along the margins of the veinlets (Figures 36 and 37). The molybdenite flakes often adhere to diopside or orthoclase grains. Some very coarse (greater than 5 mm) molybdenite flakes were found with iron oxides on the margins of late fractures.

The molybdenite flakes have a very low rhenium content (15 ppm.) (Tschanz and others, 1974). The low rhenium content is characteristic of molybdenum stockwork deposits (Climax - 2-5 ppm; Questa - 12 ppm) rather than copper-molybdenum porphyry deposits (Santa Rita = 800 ppm; Bingham Canyon = 360 ppm) (Clark, 1972).
Figure 36. Photomicrograph of Mineralized Diopside Rich Tactite

Fine grained molybdenite flakes occur along margins of quartz veinlets, usually in contact with diopside grains. Note cluster of molybdenite flakes enclosing quartz. Note single large sphene (Sp) crystal in diopside-rich region. Mag. X 10.

Figure 37. Photomicrograph of Mineralized Diopside Rich Tactite

Medium to coarse-grained molybdenite flakes are found on quartz veinlet (A). Quartz in veinlet is much coarser than quartz and diopside in the matrix (B). ossed Nichols.
Molybdenite flakes and adjacent fracture surfaces in the North Zone metasediments are often coated with fluorescent yellow powellite. No ferrimolybdite was observed in the study area except on the surfaces of molybdenite-bearing, late quartz-chalcedony breccia veins (Kqb). Formation of the ferrimolybdite in the breccia veins may be due to the abundance of pyrite and the locally acid pH of circulating waters.

Interpretations

The molybdenite was deposited in quartz (+ orthoclase) veinlets from hydrothermal fluids. Based on the spatially and temporally associated pyroxene facies metamorphism and the mineral assemblages in the quartz veinlets, the temperature of deposition was probably between 350°C and 450°C (Hyndman, 1968). The extensive fracturing of the sediments created a high veinlet density, and significant molybdenite deposition in the North and South Zones. Extensive fracturing could best take place at low confining pressures (shallow depths), or near a zone of weakness. A large vertical displacement along the Little Boulder Fault would account for the extensive fracturing in the down dropped block (North and South Zones), and the mesozonal features of the main stock in the upthrown block.

The apparent great difference in time between the cooling of the main stock (83 m.y.) and the final thermal event in the metasediments in the North Zone (61 m.y. (?) Armstrong, 1978) suggests that the eastern extension might be a separate pluton that was intruded much later than the White Cloud stock. The possibility of this being a
separate late intrusion is low because of the absence of east to west gradational contact metamorphism in the sediments west of the eastern extension (Plate 1), and because of the repetition of identical rocks, metamorphism, veining, mineralization, and alteration on both sides of the Little Boulder Fault. The apparent time lag between cooling of the main stock and the last thermal event in the metasediments might be explained by: 1) a long time interval during cooling of the stock and introduction of hydrothermal fluids causing veining, alteration, and mineralization, 2) An error in calculation of one or more of the age dates, or 3) Partial resetting of radiometric clocks in the metasediments due to heating by adjacent Eocene volcanism.

A comparison of the characteristics of the Little Boulder Creek Deposit in relation to some other large molybdenite deposits of central Idaho is shown in Table 3. All of these deposits are found in what has been termed the White Cloud-Cannivan Porphyry Molybdenum Belt of Idaho and Montana (Armstrong, 1978). Other mineral belts with different trends also include the above deposits (Badgley, 1959; Landwehr, 1967; Olson, 1968; Green, 1972; and Tschanz and others, 1974). None of the proposed mineral belts has strong evidence for its existence. The proposed belts vary widely in orientation and include almost all exposed rocks in central Idaho. The single common spatial characteristic of molybdenum deposits in Idaho appears to be their close association with granitic plutons.
Table 3. Comparison of Molybdenum Deposits in Central Idaho

<table>
<thead>
<tr>
<th></th>
<th>Little Boulder Creek</th>
<th>Thompson Creek Deposit</th>
<th>Little Falls Prospect</th>
<th>Walton Prospect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity to LBC</td>
<td>------</td>
<td>27 km north</td>
<td>96 km west</td>
<td>35 km SE</td>
</tr>
<tr>
<td>Elevation</td>
<td>2592-2867m</td>
<td>2318-2379m</td>
<td>1022-1281m</td>
<td>2562-2623m</td>
</tr>
<tr>
<td>Host Rocks</td>
<td>tactite adj. to porphyritic quartz monz.</td>
<td>porphyritic quartz monz.</td>
<td>rhyolite dikes and qtz monz.</td>
<td>qtz. monz. and aplite</td>
</tr>
<tr>
<td>Age in m.y.</td>
<td>83.6 stock</td>
<td>85.9 stock</td>
<td>post- Eocene</td>
<td>Eocene</td>
</tr>
<tr>
<td>Structural Controls</td>
<td>In down-dropped block adj. to N 15°E fault</td>
<td>In fault zone with N 60°W trend</td>
<td>In N 35°E dike swarm</td>
<td>In fault zone with N 20-30°W trend</td>
</tr>
<tr>
<td>Alteration</td>
<td>silicified, potassic zones, sericite near fault and late breccia veins.</td>
<td>completely altered to at least propylitic grade. Envelopes throughout include all grades- (prop.-silic.)</td>
<td>silicified, sericite throughout, potassic dikes</td>
<td>silicified, plus ?</td>
</tr>
<tr>
<td>Average Deposit Burial Depth (to top)</td>
<td>0’ - 300’ 0 - 91.5 m</td>
<td>0’ - 500’ 0 - 152.5 m</td>
<td>0’</td>
<td>0’</td>
</tr>
<tr>
<td></td>
<td>Little Boulder Creek</td>
<td>Thompson Creek Deposit</td>
<td>Little Falls Prospect</td>
<td>Walton Prospect</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------</td>
<td>------------------------</td>
<td>----------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Size in m (approx.)</td>
<td>180 X 900 X 300; 150 X 180 X 180; 120 X 60 X 120.</td>
<td>600 X 180 X 240</td>
<td>900 X 300 X?</td>
<td>1 X 12 X?; 3 X 90 X?</td>
</tr>
<tr>
<td>Tonnage (est.)</td>
<td>167 million</td>
<td>100 million +</td>
<td>&quot;significant&quot;</td>
<td>? ? ?</td>
</tr>
<tr>
<td>Grade (est.)</td>
<td>0.15% Mo</td>
<td>0.15% Mo</td>
<td>&quot;sub-economic&quot; 1968</td>
<td>0.60% U 0.20% L</td>
</tr>
<tr>
<td>Occurrence of Moly</td>
<td>In fine qtz, qtz-Kspar veinlets</td>
<td>In coarse qtz veins &amp; veinlets</td>
<td>In fine qtz veinlets</td>
<td>In fine to coarse quartz veins &amp; veinlets</td>
</tr>
<tr>
<td>Molybdenite Description</td>
<td>fine flakes on veinlet margins</td>
<td>coarse flakes in veins &amp; silicified zones</td>
<td>fine flakes in veinlets</td>
<td>? ? ?</td>
</tr>
<tr>
<td>Late barren qtz veins?</td>
<td>present</td>
<td>present</td>
<td>present</td>
<td>present</td>
</tr>
<tr>
<td>Pyrite Association</td>
<td>about .5% in veinlets and dissem. No halo.</td>
<td>In veins, and units within ore zone. Crse crystals.</td>
<td>&quot;intense&quot; in zone 10,000' X 2000'. Distinct halo</td>
<td>? ? ?</td>
</tr>
</tbody>
</table>
Table 3. (Continued)

<table>
<thead>
<tr>
<th>Scheelite Association</th>
<th>Little Boulder Creek</th>
<th>Thompson Creek Deposit</th>
<th>Little Falls Prospect</th>
<th>Walton Prospect</th>
</tr>
</thead>
<tbody>
<tr>
<td>In veins throughout ore zone. Distinct outer halo.</td>
<td>Trace in ore zone veins. Ore grade in veins adj. to deposit</td>
<td>???</td>
<td>In tactites on stock margins</td>
<td></td>
</tr>
<tr>
<td>Magnetic Expression</td>
<td>On side of large magnetic high</td>
<td>In magnetic high</td>
<td>???</td>
<td>In magnetic high</td>
</tr>
<tr>
<td>References</td>
<td>---</td>
<td>---</td>
<td>Olson, 1968</td>
<td>Kirkemo, Anderson, and Creasey, 1965</td>
</tr>
</tbody>
</table>
Scheelite

Scheelite is found in trace quantities disseminated in aplites and pegmatites, and disseminated in the main stock and eastern extension. Scheelite-bearing veinlets are found throughout the North Zone metasediments, but they are most common in a zone on the outer edge of the diopsidic tactite (Figure 27). No scheelite was found in the South Zone.

Scheelite grains are often disseminated in the tactites, and replace andradite garnet, epidote, and diopside (Figure 3). Molybdenite and scheelite are not found within the same veinlet. Scheelite-bearing veinlets are cut by molybdenite-bearing veinlets, but the reverse is not true. All of the scheelite fluoresces blue-white. Most of the scheelite grains are very fine (.1-1 mm), but a few are greater than 1 cm (Figure 38) across.

The scheelite was probably deposited early in the veining process. The scheelite contains very little molybdenum as indicated by the color of fluorescence and assay results. Contemporaneous deposition of molybdenite and low molybdenum-bearing scheelite will occur in a high sulfur - low oxygen fugacity system (Hsu and Galley, 1973).

The average grade of WO₄ in the diopside-rich tactite of the North Zone was subecononic (drill hole assays ASARCO, 1970). The outer margin of the diopsidic tactite and the banded tactite contain a visibly higher percentage of scheelite, and some byproduct recovery may be feasible.
Figure 38. Scheelite Bearing Diopside Rich Tactite

Sample is from outer margin of Pwd zone, and shows the maximum scheelite content present in rocks of the North Zone. Scheelite (Sh) is outlined in black to facilitate identification. Dark minerals in rock are garnet and diopside, and light minerals are orthoclase, plagioclase, and quartz. Sample is 8 cm long.
Other Metallic Minerals

Base and precious metals, except pyrite, are confined to quartz breccia veins. The large (Kqb) quartz-chalcedony breccia veins in the North Zone contain up to 90 percent (of vein) arsenopyrite and pyrite, and minor amounts of galena, sphalerite, and molybdenite. Textural evidence indicates sphalerite and galena were deposited last. Assay results of the Kqb veins indicate .02-3.5ppm gold, 1.0-9.0ppm silver, and minor Mo, Pb, Zn, Cu, Sb, and Sn (Table 1).

The quartz-breccia veins in the South Zone (near the Kd plug) contain pyrite, chalcopyrite, and minor malachite. Copper bearing minerals are not found elsewhere in the study area.

The quartz-breccia veins cut all veinlets and dikes, and are only cut by late fractures. The associated intense sericitization is the result of H+ metasomatism of the host rocks. Because base and precious metal bearing veins are common around the White Cloud stock, they may not be directly related to molybdenite mineralization.
The Little Boulder Creek deposit has many characteristics which are common to most stockwork molybdenum deposits (Clark, 1972; King, 1970; Kirkemo et al., 1965; Laine, 1974; Wallace et al., 1968): Molybdenite is the only ore mineral present. It is accompanied by pyrite and minor amounts of scheelite. The deposit occurs in a major structural belt, the Little Boulder Creek Fault zone. The deposit host rocks (metasediments) were severely fractured prior to mineral deposition from hydrothermal fluids. Hydrothermal alteration occurred probably contemporaneous with mineral deposition. The genetically associated igneous host (the White Cloud stock) is a differentia (Bennett, 1973) rich in late fractionated elements (such as K, and Be) and poor in early fractionated elements (such as Fe, Mg, Ca and Mn). The Little Boulder Creek deposit is also found in the same area (radius 20 miles) as several other stockwork molybdenum deposits.

Many characteristics of the Little Boulder Creek deposit are unique: The molybdenite bearing veinlets occur mainly within a tactite zone. The tactite resulted from contact metamorphism controlled by fracturing and jointing which decreases away from the White Cloud stock. Intense hydrothermal alteration is confined to fault zones. A large fault zone, the Little Boulder Creek fault zone (zone of late active movement),
passes immediately west of the ore bodies and displaces the ore and host rocks downward. A second large fault zone, the Uncle Jess fault, truncates the eastern edge of the ore bodies. The mineralized zones were partially covered by Challis volcanics. The deposit occurs on the side of the largest magnetic high in the region. (This characteristic is common among other deposits of the region, but it is uncommon among other deposits in the western hemisphere.) The eastern fault displaced stock segment is enriched in Fe, Ca, and Mn and depleted in Cu, Ba, and Sr when compared with the main White Cloud stock. The ore zone tactites are enriched in Cu, Zn, Mo, W, Zr, Mg(?), Ba, Mn, and Sr when compared to the stock and eastern segment (Table 2). (Normally stockwork molybdenum deposits have associated negative anomalies in Al, Ca, Na, Fe, Mg, Ti, Sr, Ba, V, and Cl accompanied by positive anomalies in H₂O, S, Cu, Pb, Zn, K, F, and Zr - Laine, 1974).

The existence of the ancient Little Boulder Creek fault zone probably was the most important factor in ground preparation for molybdenite deposition. The 500 feet wide intensely fractured area developed in the upper portions of this regional fault zone (zone of weakness shown in Figures 42, 43, and 44) served as a strong structural control for veining, alteration, and mineralization. The evidence for the existence of this regional zone prior to mineralization includes: 1) this zone can be traced on aeromagnetic maps for more than 20 miles, which indicates that it is deep-seated, and probably extends into the p6 basement. Such
faults are often very old. 2) Metallic mineral deposits are located in this zone for 6 miles along the eastern margin of the White Cloud stock. 3) Molybdenum mineralization at Little Boulder Creek occurs in elongate zones aligned within the ancient fault zone (zone of weakness).

In the area of the Little Boulder Creek deposit the ancient fault zone was healed with quartz veinlets and aplite/pegmatite dikes and sills. Continued rise of the White Cloud Stock caused a new zone, the current Little Boulder Creek fault zone, to be activated. This new zone is located slightly west of the ancient fault zone (Figure 43) in the deposit area, but appears to be coincident with the ancient zone further to the northeast and southwest.

In the Little Boulder Creek deposit most of the early veinlets occupy bedding joint sets, later veinlets more frequently occupy cross joint sets. The mechanism for the production of bedding joints is unknown, but cross joints probably resulted from: 1) tension produced by the doming of sediments during rise of the stock, 2) shrinkage due to crystallization and fluid loss from the stock, or 3) shattering by hydrothermal fluid pressures.

The occurrence of a mineralogic continuum between quartz veinlets and aplite and pegmatite dikes supports the theory that hydrothermal fluids are a continuation of magmatic processes. The normal sequence of events in a differentiation process would result in early deposition of aplite and pegmatite dikes and later deposition of quartz veinlets.
The more common presence of quartz veinlets in the early and middle stages suggests a late resurgence of magmatic activity in the deposit area.

Based on the general characteristics of stockwork molybdenum deposits (Clark, 1972; King, 1970; Kirkemo et al., 1965; Laine, 1974; Wallace et al., 1968), and the characteristics of the Little Boulder Creek deposit in particular, several local areas might serve as good exploration targets: 1) the eastern margin of the White Could stock, 2) a zone west-northwest and east-southeast of the Thompson Creek deposit, and 3) a large zone along the eastern margin of the Atlanta lobe of the Idaho batholith (Slate Creek Lineament area in Figure 2).

The eastern margin of the White Cloud stock along the ancient Little Boulder Creek fault zone is a good exploration area because there are sporadic molybdenite occurrences in this zone between the Livingston Mine in the north and the Washington Basin in the south. In addition, small tactite bodies are found on the stock margin in this area. Some evidence indicates the possible existence of a large stockwork-type molybdenum deposit at depth in this zone: 1) The ancient Little Boulder Creek fault zone apparently was the primary physical control on fluid migration and molybdenum deposition in the Little Boulder Creek deposit. 2) Such characteristics as confinement of intense hydrothermal alteration to fault zones, lack of pervasive alteration or significant mineralization in the eastern stock segment, and an increase in molybdenite content in late stage differentiates (aplites and pegmatites) suggest that the
Little Boulder Creek deposit may be located on the upper or outer periphery of a large magmatic-hydrothermal system. A molybdenite ore body at depth would be confined to a later phase intrusive which would be intensely and pervasively altered. Such a differentiate would be isostatically lighter and would cause the White Cloud stock block to rise. The most probable location for such a buried molybdenite bearing intrusive phase is directly below or west of the Little Boulder Creek deposit. However, structural preparation may have been more favorable in another location along the ancient Little Boulder Creek fault. It should be noted that there is much greater negative evidence against existence of a buried deposit in the Little Boulder Creek area: 1) There is no apparent increase in mineralization or hydrothermal alteration with depth of the deposit. 2) If the source of mineralization is a down dropped segment of the White Cloud stock, then the quantity and grade of the deposit in the tactite zone decreases with depth. (This is demonstrated by the narrow tactite zone and sparse mineralization along the main stock west of the North Zone.)

The zone along the west-northwest trending fault system, which apparently controls the Thompson Creek deposit, is also a good exploration area. The main Thompson Creek ore body is elongate along this zone. A second, smaller molybdenite body is located near the surface along the fault zone 1 mile west-northwest of the main ore zone. Numerous ore deposits (including tungsten and molybdenum) occur in Paleozoic sediments
and small intrusives wherever this fault zone is not covered by Challis volcanics. Exploration in covered areas might prove fruitful in the area between the Yankee Fork District and Poverty Flats (east of the Clayton Silver Mine). The fault zone is easily identified as a wide lineament on ERTS photos.

A third target for exploration comprises a large zone along the eastern margin of the Atlanta lobe of the Idaho batholith. Along this margin there are numerous felsic Tertiary intrusives which were originally mapped as Idaho batholith (W. E. Hall, written communication, 1977). Considerable molybdenite is related to other Tertiary intrusives in the region (i.e. Walton Prospect) and these scattered intrusives may be favorable targets.
CHAPTER IX
GENETIC INTERPRETATIONS

During Paleozoic time, fine, quartz-rich, and calcareous clastic sediments were deposited in Central Idaho (Pw). During early Mesozoic time the Pacific Plate was subducted near the western continental margin (somewhere near the Idaho-Oregon border - Hyndman and Talbot, 1976). Partial melting of the lower crust was initiated by the temporary increase in the thermal gradient near the subducting plate. Magmas created by the partial melting began to rise through the crust. When these magmas reached lower confining pressures, they slowly cooled and solidified. Sediments to the east were folded and overthrust east due to gravity sliding away from the rising intrusions (Figure 39). A separate magma, perhaps derived from the residual fluids in the partially solid (Idaho batholith) magmas, rose along a zone of weakness east of the main plutonic mass. Rise of this magma caused the overlying sediments to be uplifted in an elongate dome (Figure 40). Continued isostatic rise of the stock and possibly magmatic and hydrothermal fluid pressures caused the sediments near the zone of weakness (the ancient Little Boulder Creek fault zone) to be intensely shattered. Shattering of this zone may have allowed some protuberance of the stock (Figure 41). When internal boiling pressures of the residual liquids in the partially crystalline stock exceeded the external hydrostatic pressures, the residual liquids
Figure 39. West-East Cross Section Showing Evolution of Little Boulder Creek Deposit. Newly generated magma, begins to rise through crust. Milligen Fm. (Mm) sediments and Wood River Fm. (Pw) sediments have been folded and overthrust as a result of the rise of Idaho batholith to the west. Note the LBC fault which extends into the basement.

Figure 40. West-East Cross Section Showing Doming of Milligen (Mm) and Wood River Sediments (Pw) by Rising Magma. Little Boulder Creek (LBC) fault zone partially controls the rising magma.
Figure 41. Cross Section Showing Fracturing and Fluid Loss from the White Cloud Stock. A solid cap (B) forms in the rising stock. Fractures and joints (C) develop in the cap and in the adjacent metasediments particularly near the fault zone (D). Residual fluids escape from the partially liquid core (A) and fill the fractures. Continued fracturing allows escape of more fluids and fluid influx.

Figure 42. Cross Section Showing Alteration Zones and Separation of White Cloud Stock Apophysis. A wide zone of metamorphism and alteration developed in the Fault Zone or Zone of Weakness. Continued rise of the White Cloud Stock activated a major fault plane causing the separation of the segment.
Figure 43. Cross Section Showing Displacement of Eastern Stock Extension. White Cloud stock continues to rise isostatically and there is greater erosion of uplifted blocks than downdropped blocks.

Figure 44. Cross Section Showing Continued Fault Movement, Exposure of Stock, and Eruption of Volcanics. Challis volcanics (Tcv) flowed over the topographic low above downdropped blocks. Glaciation caused excellent exposure of main stock. Note narrow band of metasediments near stock and wide band (of mineralized metasediments) near eastern extension.
escaped through fractures. As the escaping fluids cooled and reacted chemically with the wall rocks, minerals were precipitated along the sides of fractures until the fractures were completely filled. Continued fracturing during this period allowed tremendous volumes of fluids to escape into the solid stock shell and adjacent sediments. The escaping fluids produced a thermal and chemical gradient in the calcareous quartzites near fractures and near the stock itself, causing metasomatic replacement of primary minerals. Later, cooler hydrothermal fluids rich in base metals and sulfur escaped through a few large fractures and formed the quartz-chalcedony breccias. Continued isostatic rise of the stock (and perhaps external forces) caused reactivation of the western edge of Little Boulder Fault Zone (Figure 42). The protruding arm of the stock and adjacent mineralized tectite were separated and downdropped along the Little Boulder Fault. Erosion of the area developed a rugged topographic surface. In the Eocene Epoch the Challis volcanics were erupted on the eastern side and associated dikes were intruded. Continued rise of the stock created several down-dropped blocks and allowed rapid erosion of the western side of the blocks. Finally, glacial erosion of the stock created steep aretes and tarns, and deposited considerable till in the lower areas (Figure 43).
REFERENCES CITED


Clark, K.F., 1972, Stockwork molybdenum deposits in the western Cordillera of North America: Econ. Geol., v. 67, no. 6, p. 731-758, illus.


Figure 27b.
Figure 28a.