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## SEARCH FOR UNDERGROUND OPENINGS FOR IN SITU TEST FACILITIES IN CRYSTALLINE ROCK

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October 1979  
Revised January 1980

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through a contract with the Office of Nuclear Waste Isolation, Battelle Memorial  
Institute and the Nuclear Regulatory Commission.



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## ABSTRACT

This report covers a project to identify existing underground openings which may be utilized as facilities for geomechanical, geochemical and hydrogeologic tests pertinent to the isolation of radioactive wastes in crystalline rock. With a few exceptions, crystalline rocks in this study were limited to plutonic rocks and medium to high-grade metamorphic rocks. A review of the literature was conducted, based primarily on MAS, the Minerals Availability System of the U.S. Bureau of Mines and to a lesser extent on CRIB, the Computerized Resources Information Bank of the U.S. Geological Survey, and GEOREF. Nearly 1700 underground mines, possibly occurring in crystalline rock, were initially identified. Application of criteria, which included:

- Crystalline rock
- Depths below 600 feet
- Workings of adequate size to provide for a Stripa-sized facility
- Workings open within the past 10 years and not flooded or caved
- Workings below the water table
- Good rock support

resulted in the identification of 60 potential sites. Within this number, 26 mines ("class 1") and 4 civil works were identified as having potential in that they fulfilled the criteria; these are summarized in detail. Thirty mines ("class 2") may have similar potential if information on one or more criteria is obtained; information on these mines is tabulated.

Most of the mines identified are near the contact between a pluton and older sedimentary, volcanic and metamorphic rocks. However, some mines and the civil works are well within plutonic or metamorphic rock masses. Civil works, notably underground galleries associated with pumped storage hydroelectric facilities, are generally located in tectonically stable regions, in relatively homogeneous crystalline rock bodies.

A program is recommended which would identify one or more sites where a concordance exists between geologic setting, company amenability, accessibility and facilities to conduct in situ tests in crystalline rock.

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## A C K N O W L E D G M E N T S

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SEARCH FOR UNDERGROUND OPENINGS  
FOR IN SITU TEST FACILITIES IN CRYSTALLINE ROCKS

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INTRODUCTION

The objective of this project was to identify existing underground openings suitable for performing geomechanical, geochemical, and hydrogeologic tests pertinent to the storage of radioactive waste in crystalline rock. Crystalline rock, for the purpose of this study, has been defined to include intrusive igneous rocks and medium- to high-grade metamorphic rocks. The underground openings would be located at sufficient depth and would be of sufficient volume to conduct large-scale in-situ experiments. This project, covering active or recently inactive mines and civil works, was conducted simultaneously with a study (Cohen, 1979) to identify criteria for in-situ test facilities and to formulate a provisional program of experiments.

Concurrently, the Dames and Moore Company conducted a preliminary assessment of crystalline rock bodies in the U. S. which may accommodate a waste-isolation facility.

Based on a search of open literature, 26 "class 1" sites were identified as having, possibly, the greatest potential for underground test facilities. Thirty sites were categorized as "class 2" because data in the open literature were not sufficient to verify one or more established criteria. Potentially suitable underground openings in crystalline rocks, primarily exploration adits, shafts, and drifts, which are not documented in the open literature were not included in this project report.



This report summarizes a systematic search and analysis of the available literature on underground openings in crystalline rocks. Because of its preliminary nature the study was restricted to the open literature. Neither mining companies, state geologists and bureaus of mines, nor utility and transportation authorities were contacted.

There was generally not sufficient information in the open literature on the hydrologic settings of most of the underground workings. This is partially because it is difficult to define a water table in crystalline rocks; also, total water production and its component introduced by mining operations are data normally in company files. It is safe to state, however, that mines encompassing a broad depth range, for example the Homestake, with levels accessible from depths of 1100 to over 8000 ft., would intersect a variety of hydrogeologic conditions.

The report consists of four sections, a bibliography, index, and two appendices as described below:

Section I - Identification and Selection Process - principal data bases, criteria, and the selection process.

Section II - Summaries of Information - locations and tabulations of mines and civil works.

Section III - Conclusions and Recommendations - Summary of findings and an outline of studies designed to refine the list of potential sites.

Section IV - Descriptions of "class 1" mines and civil works.

Bibliography - a general bibliography of all literature searched, including the individual bibliographies for "class 1" sites.

Index - lists place and mine names referred to in the text and bibliography.

Appendix 1 - Sources of Information - description of data bases used.

Appendix 2 - Table giving the number of mines by state which were derived from various sources, and list of mines in crystalline rock which were considered.



## I. IDENTIFICATION AND SELECTION PROCESS

The process of identification and selection of potential underground sites is diagrammed in Figure 1. It depended on the availability of information in the literature and personal knowledge of the authors. To identify candidate sites, a variety of information sources were used to collect data on the existing underground mines and civil works. Information was extracted from two mine data bases: The Minerals Availability System (MAS) of the U.S. Bureau of Mines and the U.S. Geological Survey's Computerized Resources Information Bank (CRIB). Additional sources utilized were GEOREF (the Geological Reference file prepared by the American Geological Institute), mining directories, various geological and mining engineering reports and tunneling and excavation reports. Data on the civil works were obtained from the open literature and consultants. Descriptions of the data bases and examples of printouts are given in Appendix 1. Also listed in the first appendix are the kinds of information obtainable from these sources of information.

Based on underground mine information, a list of 5900 mines was extracted from the 130,000 mines on record in MAS, and an additional 120 sites were identified from other data bases. Thirty-four civil works sites were added from discussions with consultants. After initial review the compiled list of surface and underground mines in crystalline and non-crystalline rock totaled approximately 6100. Application of the criteria described below resulted in identification of 60 underground sites in crystalline rock.

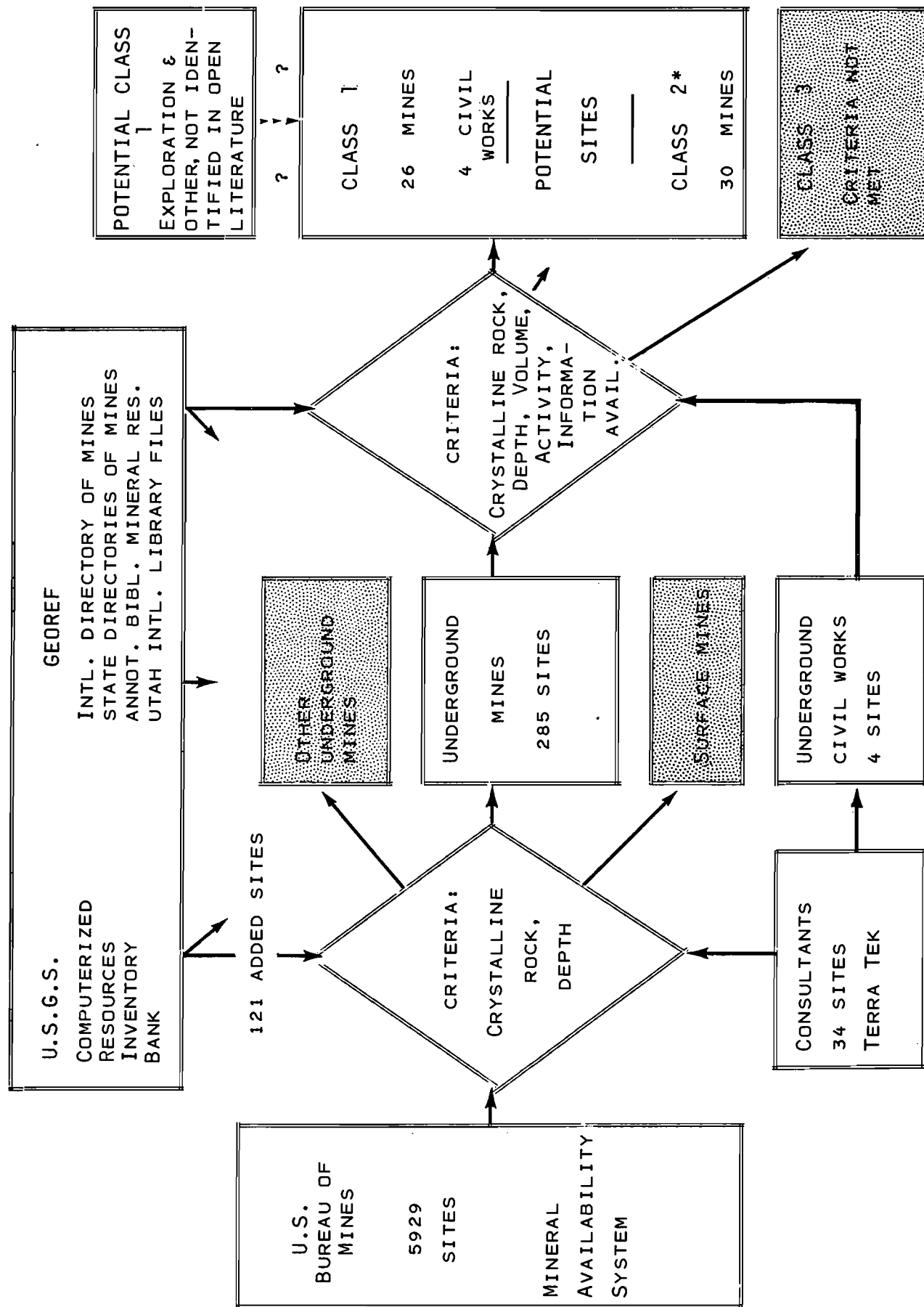


FIGURE 1. IDENTIFICATION AND SELECTION PROCESS FOR POTENTIAL UNDERGROUND SITES.

\*ALL CRITERIA MET, SOME INFORMATION NOT VALIDATED IN OPEN LITERATURE.

Along with information on mines in crystalline rocks, similar data were obtained from MAS on over 3000 mines in non-crystalline rocks. This data base is available for a preliminary characterization of underground workings in argillaceous, carbonate and volcanic rocks.

#### Criteria

The base list of underground sites was reduced by categorizing the openings on how well they fit the criteria defined below. The criteria were designed to include a broad spectrum of underground openings, within which conditions might approximate those of a waste repository in crystalline rock.

- 1) The underground workings or a sufficient portion must be located in crystalline rock (intrusive igneous or medium- to high-grade metamorphic rock). Exceptions are mines located in low- to medium-grade metamorphic rocks of Precambrian age in Idaho, Michigan, Minnesota, and eastern Wyoming. These mines are considered acceptable because of: (a) their location in tectonically-stable, mid-continent regions as in the case of the Michigan, Minnesota, and eastern Wyoming sites; and (b) because a number of them have been the sites of in situ geomechanical testing, resulting in a large amount of information characterizing the sites, especially the Coeur d'Alene mines of Idaho.
- 2) The site must be underground, at a depth greater than 600 ft.
- 3) An acceptable underground working should be of sufficient size to provide for an in situ testing facility, similar in size to the Strip experimental facility in Sweden.

- 4) The workings should not have been closed for over 10 years, caved, sealed or flooded as reported in the literature and annual reports of mining activity.
- 5) It is desirable that the workings be located below the water table, though sites which have workings both above and below the water table may provide access for tests comparing rock and hydrologic properties of the saturated and unsaturated zones.
- 6) The workings should encompass rock with physical and mechanical properties adequate to provide good support in new excavations and long-term access for the experimental program.

In the final review of underground sites, a site was designated as "class 1" if all of the criteria were met and verified in the open literature. A site was assigned "class 2" status if the criteria were believed to be met but it was not possible to verify one or more of the parameters in the literature. Characteristics of the underground sites are summarized in Tables 1 and 2 in the following section.

## II. SUMMARIES OF INFORMATION ON MINED OPENINGS

### IN CRYSTALLINE ROCK

The selection process detailed in the previous section identified 26 mines and 4 civil works in crystalline and high- or medium-grade metamorphic rocks as "class 1" sites for in situ testing facilities. These are listed in Table 1.

A second group of mines which appear to be suitable potential sites, but lack data on one or more established selection criteria, are listed as "class 2" sites. Table 2 summarizes information available on "class 2" sites, and indicates which key criteria for each mine could not be verified.

Several mined openings are summarized under the heading "Civil Works." These include the Helms, Dworshak Dam, and Bad Creek Pumped Storage Projects.

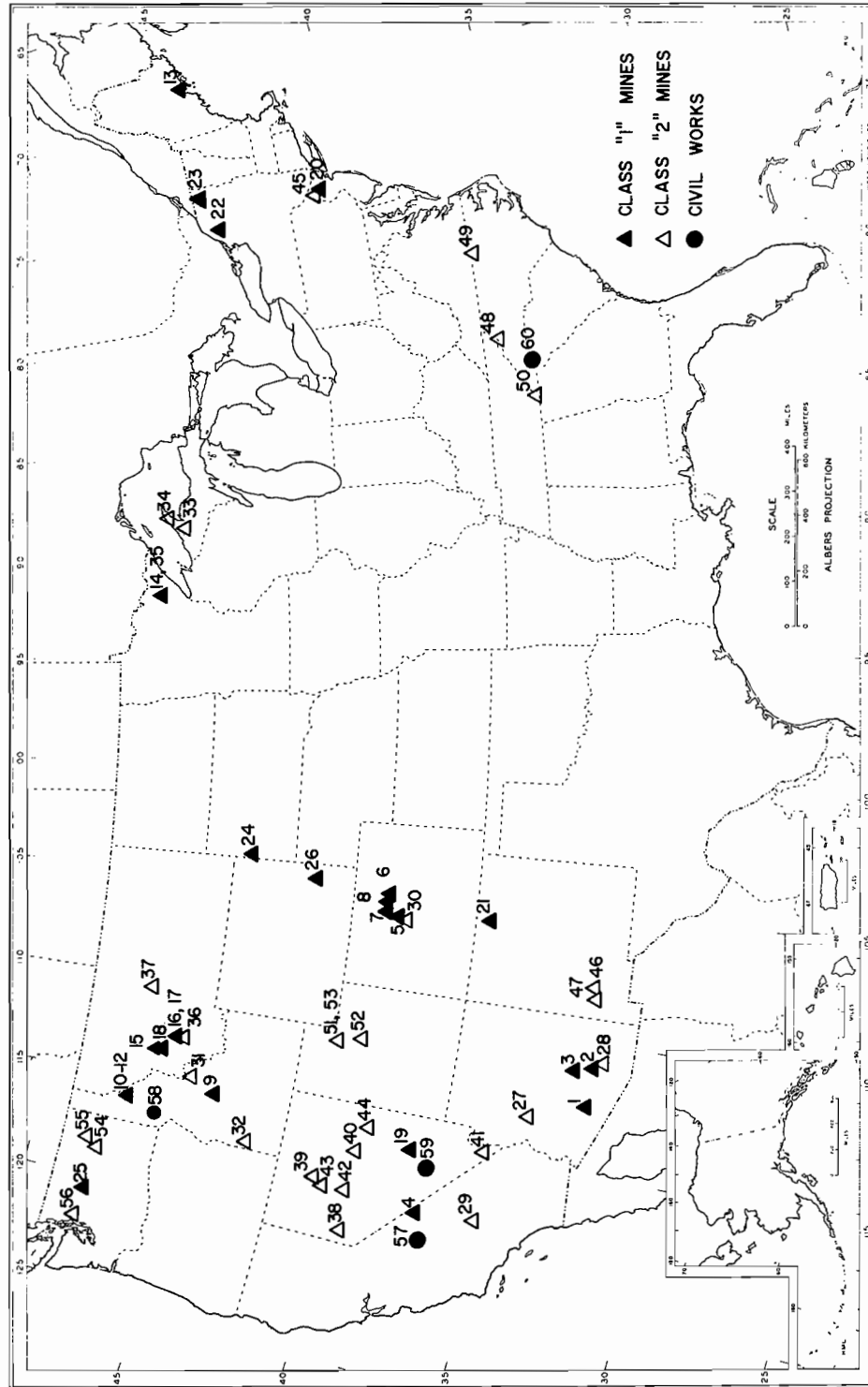
All of the "class 1" and "class 2" sites and the civil works are located on a map of the United States (Figure 1).

A summary description of each "class 1" site is included, alphabetically by state, in the following portion of the report. Each summary includes data on location and accessibility, geologic setting, description of mine or civil workings, and references.



FIGURE 1. Location of Underground workings on map of the United States.

Class "1" Mines	New Mexico	42. Summit King Mine
Arizona	21. Questa Molybdenum Mine	43. Sutton No. 2 Mine
1. Lakeshore Mine	New York	44. Taylor Mine
2. Miami East Mine	22. Balmat-Edwards District Mines	New Jersey
3. San Manuel/Kalamazoo Mine	23. Lyon Mountain District	45. Sterling Mine
California	South Dakota	New Mexico
4. Pine Creek Mine	24. Homestake Mine	46. Continental Underground
Colorado	Washington	47. Groundhog Mine
5. Climax Mine	25. Holden Mine	North Carolina
6. Schwartzwalder Mine	Wyoming	48. Cranberry Magnetite
7. Urad/Henderson Mine	26. Sunrise Mine	49. Tungsten Queen Mine
8. Colorado School of Mines, Experimental Mine	Class "2" Mines	Tennessee
Idaho	Arizona	50. Ducktown District
9. Lost Packer Mine	27. Bagdad Mine	Utah
Coeur D'Alene District	28. Oracle Ridge	51. Ontario Mine
10. Dayrock Mine	California	52. Mayflower Mine
11. Star-Morning Mine	29. Atolia District	53. Park City Mine
12. Coeur Mine	Colorado	Washington
Maine	30. Black Cloud Mine	54. Midnite Mine
13. Black Hawk (Second Pond)-Blue Hill Mine	Idaho	55. Sherwood Mine
Minnesota	31. Kentuck Mine	56. Sunrise Breccia Deposit
14. Minnamax Project, Ely Prospect	32. Silver City Region	Civil Works
Montana	Michigan	California
15. Black Pine Mine	33. Indiana Mine	57. Helms Underground Powerhouse
Butte Mining District and Butte Underground Mines	34. Iroquois Mine	Pumped Storage Project
16. Leonard Mine	Minnesota	Idaho
17. Steward Mine	35. Ely Prospect	58. Dworshak Dam Site
18. Granite-Bimetallic Mine	Montana	Nevada
Nevada	36. Butte Highlands Mine	59. Nevada Test Site-Climax
19. Tem Piute District	37. Dacotah Mine	Stock
New Jersey	Nevada	South Carolina
20. Mount Hope and Scrub Oaks Mines	38. Gooseberry Mine	60. Bad Creek Pumped Storage Project
	39. Mill City Mine	
	40. Ruby Hill Mine	
	41. Searchlight District	



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Table 1 "Class 1" Mines

NUMBER	STATE	COUNTY	U.S. GEOL. SURVEY 1:250,000 QUAD.	COMMODITY MINED	ROCK TYPE	DEPTH (FT)	STATUS
<u>ARIZONA</u>							
1	Lakeshore Mine	Pinal	Tucson	Cu, Fe, Au, Ag	Quartz Monzonite	2000	Active
2	Miami East	Gila	Mesa	Cu, Au, Ag, Mo	Schist, Granite	3450	Active
3	San Manuel/Kalamazoo	Pinal	Tucson	Cu, Mo, Ag, Au	Quartz Monzonite	660-2460	Active (1977)
<u>CALIFORNIA</u>							
4	Pine Creek Mine	Inyo	Goldfield	W, Mo, Cu	Quartz Monzonite	Over 1000	Active
<u>COLORADO</u>							
5	Climax Mine	Lake	Leadville	Mo, W, Sn, S	Quartz Monzonite	600	Active
6	Schwartzwalder Mine	Jefferson	Denver	U	Gneiss, Schist	2400	Active (1978)
7	Urad Mine/ Henderson Mine	Grand & Clear Creek	Denver	Mo	Precambrian Granite, Tertiary Porphyry	500-1000	Active
8	Colorado School of Mines Experimental Mine	Clear Creek	Denver	--	Granite - Biotite Gneiss, Pegmatite, Biotite Gneiss	Max. 600	Active
<u>IDAHO</u>							
9	Lost Packer Mine	Custer	Challis	Au, Cu, Ag	Mica Schist, Granodiorite	1000	Active (1978)
Coeur d'Alene District							
10	Dayrock Mine	Shoshone	Wallace	Pb, Zn, Ag, Cu, Au	Quartzite, Quartz Monzonite	~4000	Inactive, but accessible
11	Star-Morning Mine	Shoshone	Wallace	Pb, Zn, Ag, Au	Quartzite, Argillite	8300	Active
12	Coeur Mine	Shoshone	Wallace	Ag, Cu, Pb, Zn, Au	Quartzite, Slate, Argillites, Calcareous Quartzite	4000	Active (1975)
<u>MAINE</u>							
13	Black Hawk (Second Pond) Blue Hill Mine	Hancock Co.	Bangor	Zn, Cu, Pb, Fe, Ag	Schist, Amphibolites, Metaquartzite	1310	Inactive 1977, on standby

U.S. GEOL.  
SURVEY  
1:250,000  
QUAD.

NUMBER	STATE	COUNTY	COMMODITY MINED	ROCK TYPE	DEPTH (FT)	STATUS
<u>MINNESOTA</u>						
14	Minnamox Project	St. Louis	Ni, Cu, Co, Ti, Pt Group, Au, Ag	Troctolitic Intrusive (Gabbro)	1610	Active
<u>MONTANA</u>						
15	Black Pine Mine	Granite	Ag, Au, W, Cu, Sb, Pb, Zn	Quartzite, Granodiorite	2300	Active
	Butte District Under- ground Mines	Silver Bow	Cu	Quartz Monzonite	to 4600	Inactive (1977)
16	Leonard Mine					
17	Steward Mine					
18	Granite-Bimetallic	Granite	Ag, Au, Pb, Zn, Si	Granodiorite	2625	Inactive ?
<u>NEVADA</u>						
19	Tem Piute	Lincoln	W, Ag, Pb, Zn, F, Bi, Mo	Dolomite, Limestone, Shale, Sandstone, Granite Stock	900	Inactive (1979)
<u>NEW JERSEY</u>						
20	Mt. Hope and Scrub Oaks Mines	Morris	Fe	Gneiss	2500	Inactive (1978)
<u>NEW MEXICO</u>						
21	Questa Molybdenum Mine	Taos	Mo	Granite	1200 (Open pit with underground development)	Active (1977)
<u>NEW YORK</u>						
22	Balmat-Edwards District Mines	St. Lawrence Co.	Zn, Pb, Cd, Fe	Marble, Dolomite, Evaporite, Gneiss, Schist	2100-3100	Active (1978)
23	Lyon Mountain District	Clinton	Fe	Gneiss	81 mine - 2000	Chateaugay Mine - Inactive (1967) 81 Mine - Inactive (1949??)
<u>SOUTH DAKOTA</u>						
24	Homestake Mine	Lawrence	Au, Ag	Schist	8000	Active
<u>WASHINGTON</u>						
25	Holden Mine	Chelan	Cu	Granite, Granodiorite	to 5000	Inactive
<u>WYOMING</u>						
26	Sunrise Mine	Platte	Fe	Schist	Probably adequate	Active (1977)

Table 1a CIVIL WORKS

<u>NUMBER</u>	<u>STATE/NAME</u>	<u>COUNTY</u>	<u>U.S. GEOL. SURVEY 1:250,000 QUAD.</u>	<u>ROCK TYPE</u>	<u>DEPTH (FT)</u>	<u>STATUS (10/79)</u>
	<u>CALIFORNIA</u>					
57	Helms Pumped - Storage Project	Fresno	Mariposa	Granodiorite	~1000	Under construction
	<u>IDAHO</u>					
58	Dworshak Dam Site	Clearwater	Pullman	Granodiorite gneiss	to 700	Access questionable
	<u>NEVADA</u>					
59	Nevada Test Site - Climax Stock	Nye	Death Valley & Las Vegas	Granodiorite	1400	Under construction
	<u>SOUTH CAROLINA</u>					
60	Bad Creek Pumped- Storage Project	Oconee	Greenville	Granite-gneiss	~900	Operating(?)

Table 2 - "Class 2" Mines

No.	Mine Name	Location		U.S. Geol. Survey Quad	Ownership	Commodity Mined	Rock Type	Depth (ft)
		State	County					
27	Bagdad Mine	Arizona	Yavapai	Prescott	Cyprus Mining Corp.	Cu, Mo, Ag	Schist, Precambrian Granite	197(+?)
28	Oracle Ridge	Arizona	Pima	Tucson	Continental Copper Union Copper	Cu, Ag, Au	Quartz Diorite, Marble	
29	Atolia District	California	San Bernar- dino	Trona	Atolia Mining Co.	W, Au, Sb, Hg, Ag	Quartz Monzonite/ Diabase Dike	1050
30	Black Cloud Mine	Colorado	Lake	Leadville	American Smelting & Refining Newmont Mining Co.	Pb, Zn, Ag, Au, Cu	Intrusives, Dolomite, Limestone, Shale	1200
31	Kentuck Mine	Idaho	Lemhi	Elk City		Au, Zn, Pb	Gneissic Granite	800
32	Silver City Region	Idaho	Owyhee	Jordan Valley		Ag, Au, Pb, Cu, Zn	Granite, Diorite, Basalt, Rhyolite	2500
33	Indiana Mine	Michigan	Ontonagon	Iron River	State of Michigan	Cu	Felsic Igneous Intrusive Unspecified Extrusive	1380
34	Iroquois Mine	Michigan	Keweenaw	Hancock	Universal Oil Products	Cu, Ag	Unspecific Extrusive	1050 (to min.)
35	Ely Prospect	Minnesota	Lake	Two Harbors	International Nickel	Cu, Ni	Troctolitic Gabbro	1000
36	Butte Highlands	Montana	Silver Bow	Butte	Butte Highlands Mining Co.	Au	Granite (?), Dolomites, Shales, Quartzite	1000
37	Dacotah Mine	Montana	Cascade	Great Falls	Monarch Co.	Ag, Pb, Zn, Au, Cu	Gneiss, Diorite	700
38	Gooseberry Mine	Nevada	Storey	Reno	Westcoast Oil and Gas Corp.	Au, Ag	Dacite, Intrusive Plug	985
39	Mill City	Nevada	Pershing	Lovelock	Tungsten Properties	W, Mo, Sb	Granodiorite Pegmatite, Limestone, Hornfels	Probably at least 1000
40	Ruby Hill Mine	Nevada	Eureka	Millett	Richmond-Eureka Mining Co.	Ag, Pb, Zn	Dolomite, Quartz diorite	2460
41	Searchlight District	Nevada	Clark	Kingman		Au, Ag, Cu, W, V, Fe	Andesite, Gneiss, Quartz Monzonite	900
42	Summit King Mine	Nevada	Churchill	Reno			Granodiorite, Quartz Monzonite, Volcanics	500 or 1500
43	Sutton No. 2 Mine	Nevada	Pershing	Lovelock	Centennial Development Co.	W	Granite	
44	Taylor Mine	Nevada	White Pine	Ely		W, Cu	Limestone, Quartz Monzonite	
45	Sterling Mine	New Jersey	Sussex	Scranton	New Jersey Zinc Co.	Zn, Fe, Mn	Marble, Gneiss	1000

Table 2 - "Class 2" Mines

No.	Mine Name	State	Mine Status	Mining Method	Number of Openings	Type of Equipment	Mine in "Class 2" Because:
27	Bagdad Mine	Arizona	Active 1975	Cut and Fill Block Caving	2 shafts Tunnels	Tracks & Truck, Rubber tire LHD Units	Sufficient depth? Adequate workings in crystalline rock?
28	Oracle Ridge	Arizona	Active, Opened 1974	Open stoping, Room & pillar	2 adits Ventilation Shaft		Depth unknown. Sufficient workings in quartz diorite?
29	Atolia District	California	Inactive 1973, 1976				How recently inactive?
30	Black Cloud Mine	Colorado	Active 1973	Cut and fill	3 Shafts		Sufficient workings in intrusive?
31	Kentuck Mine	Idaho	Inactive 1976		Mine volume small, on 5 levels		How recently inactive? Adequate size?
32	Silver City Region	Idaho	Inactive				Activity? Adequate workings in crystalline rocks?
33	Indiana Mine	Michigan	Developing				Closed or developing? Conflicting information needs to be resolved.
34	Iroquois Mine	Michigan	Closed		Note: 3.2 million tons mined over life of mine		Closed when?
35	Ely Prospect	Minnesota	Prospect		One Shaft		State of development?
36	Butte Highlands	Montana	Inactive		5 Shafts, 3 adits on 8 levels		Workings in crystalline rock?
37	Dacotah Mine	Montana	Inactive 1977		Note: Small volume 4 adit levels		Working in crystalline rocks? Adequate size?
38	Gooseberry Mine	Nevada	Active 1978	Drifts at several levels			Workings in intrusive? Rock stability?
39	Mill City	Nevada	Active 1974				Workings in crystalline rock?
40	Ruby Hill Mine	Nevada	On standby Inactive (1976)		Note: water inflow a major problem, plugged 1962		Workings in quartz diorite?
41	Searchlight District	Nevada	Inactive				How recently inactive? Workings in crystalline rock?
42	Summit King Mine	Nevada	Inactive (1978)				Adequate depth? Workings in crystalline rock?
43	Sutton No. 2 Mine	Nevada					Depth unknown; status?
44	Taylor Mine	Nevada	Active		Note: Small production		Depth unknown; workings in quartz monzonite?
45	Sterling Mine	New Jersey	Active 1976	Hydraulic cut and fill	2 openings		Workings in gneiss? Filled mine?



Table 2 - "Class 2" Mines (continued)

No.	Mine Name	Location		U.S. Geol. Survey Quad	Ownership	Commodity Mined	Rock Type	Depth (ft)
		State	County					
46	Continental Underground	New Mexico	Grant	Silver City	UV Industries	Cu, Zn, Au, Ag, Fe	Limestone, Marble Monzonite, Hornfels	600+
47	Groundhog Mine	New Mexico	Grant	Silver City	Asarco	Zn, Pb, Cu, Ag	Sandstone, Quartzite, Shale, Granodiorite	
48	Cranberry Magnetite	North Carolina	Avery	Winston- Salem	Greenback Industries	Fe	Granite, Gneiss	
49	Tungsten Queen Mine	North Carolina	Vance	Greens- boro	Rancher's Exploration & Development Co.	W, F	Granodiorite, Schist, Gneiss	1600
50	Ducktown District	Tennessee	Polk	Chattan- ooga	Copper Hill Mine Cities Service Corp.	Cu	Mica Schist, Graywacke, Dolomite, Limestone	1000 - 2400
51	Ontario Mine	Utah	Summit Co.	Salt Lake City	Noranda	Ag, Pb, Zn, Au, Cu, Cd, Sb	Limestone, Quartzite, Sandstone, Granite, Quartz Monzonite	2495
52	Mayflower Mine	Utah	Wasatch	Salt Lake City	United Park City Mines	Pb, Ag, Zn, Au, Cu	Limestone, Quartzite, Diorite Porphyry, Andesite	2400
53	Park City Mine	Utah	Summit	Salt Lake City	Anaconda Company United Park City Mining Co.	Ag, Pb, Au, Cu, Zn	Limestone, Quartzite, Sandstone, Granite, Quartz Monzonite	2000
54	Midnite Mine	Washington	Stevens	Okanogan	Dawn Mining	U	Quartz Monzonite, Schist, Phyllite, Quartzite	150 (+?)
55	Sherwood Mine	Washington	Stevens	Sandpoint	Western Nuclear	U		
56	Sunrise Breccia Deposit	Washington	Snohomish	Yakima	International Brenmac Development Corp.	Cu, Mo, Au, Ag, W	Hornfels, Quartz Diorite	Mineraliza- tion - 1500 ft. thick

Table 2 - "Class 2" Mines (continued)

No.	Mine Name	State	Mine Status	Mining Method	Number of Openings	Type of Equipment	Mine in "Class 2" Because:
46	Continental Underground	New Mexico	Active 1978	Cut and fill Open stoping	3 openings		Workings in monzonite?
47	Groundhog Mine	New Mexico	Active; Reopened 1969	Open stoping, room and pillar, cut and fill, shrink stoping	2 openings	Rail	Depth? Bad ground conditions? Workings in granodiorite?
48	Cranberry Magnetite	North Carolina	Active 1976	Surface and underground			Depth uncertain; extent of activity?
49	Tungsten Queen Mine	North Carolina	Inactive, standby				When inactive? Extent of workings?
50	Ducktown District	Tennessee	Copper Hill mine active				Sufficient extent of workings in crystalline rock?
51	Ontario Mine	Utah	Active 1979	Cut and fill stopes	4 shafts		Workings accessible in crystalline rock?
52	Mayflower Mine	Utah	Inactive 1969	Horizontal cut and fill, some shrinkage stoping	1 shaft, tunnel		Rock stability and water problems; Workings accessible in crystalline rock?
53	Park City Mine	Utah	Closed 1978 Active 1976	Cut and fill	Note: closed because of high water and unstable rock	Rail	Rock stability problems, Workings accessible in crystalline rock?
54	Midnite Mine	Washington	Active 1979	5 ore bodies - open pit 1957			Are there underground workings at sufficient depth; workings in crystalline rock? Mostly open pit?
55	Sherwood Mine	Washington	Active 1979				Depth unknown/ Adequate underground workings? Same rock types as at Midnite Mine?
56	Sunrise Breccia Deposit	Washington	Inactive				Workings accessible in quartz diorite? Depth of workings?



### III. CONCLUSIONS AND RECOMMENDATIONS

#### Summary and Conclusions

Relying primarily on information in the open literature, we have identified 30 "class 1" sites in 14 states which may have potential for underground test facilities. These include, primarily, existing or recently inactive mines, and also civil works such as pumped storage facilities. The search also suggests that another 30 "class 2" sites in 14 states may have similar potential if adequate information on one or more key criteria were available. The criteria include the following considerations:

- Crystalline rock
- Depths below 600 feet
- Workings of adequate size to provide for a Stripa-sized facility
- Workings open within the past 10 years and not flooded or caved
- Workings below the water table
- Good rock support

The locations of the 60 sites are shown on the map of the U.S., Figure 1 in the preceding section. Potential underground workings range in size from a few thousand lineal feet, having employed or employing a few tens of miners, to several hundred miles, employing hundreds of miners. Depths range from near our threshold limit of 600 ft. to over 8000 ft.

"Class 1" mines or civil works in tectonically stable mid-continent or eastern regions of the United States include one in Maine, two in Minnesota, two in New Jersey, two in New York, and one in South Carolina. The remaining "class 1" sites are in the Rocky Mountain region and westward. Of the civil works, pumped-storage facilities incorporating underground

powerhouses and appurtenant galleries may offer the best prospects for in-situ test facilities because, even though they may be operating, access may still be available to test and support galleries.

It is expected that a comparable number of underground openings, primarily exploration adits, shafts, and drifts, not mentioned in the open literature but probably documented in company files, may also exist. These workings may furnish access for test facilities in crystalline rock.

Many of the workings in "class 1" mines are in hydrothermal vein deposits, at or near contacts between plutonic and older sedimentary, volcanic or metamorphic rocks. Test facilities at these sites would therefore be located relatively near the margins of crystalline rock masses. Notable exceptions are the Climax, Urad and Henderson mines in Colorado, mines in the Butte district, Montana, the San Manuel-Kalamazoo in Arizona, and mines in the Duluth Gabbro, Minnesota. All of these ore bodies are located well within plutons.

Mines within medium to high grade metamorphic rock masses include the Homestake, South Dakota, the Schwartzwalder and Colorado School of Mines' experimental mine in the Colorado Front Range, the Mt. Hope - Scrub Oaks, New Jersey, and the Lyon Mountain district, New York.

Structural settings of mining districts are dominated by the aforementioned contact zones, by strong folding and faulting in the case of mines in metamorphic rocks, and by zones of intersecting faults in the mines in plutonic rocks. Because of their stability requirements, underground hydroelectric facilities in crystalline rocks are located in relatively stable tectonic settings, usually away from the contacts with other rock types. Accessible openings associated with hydroelectric facilities may

offer rock property conditions most similar to those of potential waste isolation sites.

#### Recommendations

It is recommended that a program follow which would definitively evaluate the available and accessible underground workings. This program will result in the identification of one or more sites where a concordance exists between rock type and structural setting and depth, company amenability, accessibility, facilities, and hydrogeologic setting.

The recommended program would encompass the following activities:

- 1) The appropriate companies or governmental agencies controlling "class 1 or 2" sites would be contacted to arrange discussions with designated personnel. These discussions would explore the willingness of the companies/agencies to participate in the project and would serve to validate and increase the information developed in the preliminary description of the sites. It is expected that, following the initial company/agency contact, the number of prospective underground workings would be significantly reduced. It is also possible that information on some hitherto unknown potential sites would be obtained, resulting in some additions to the list of prospects.
- 2) During and following the discussions, plans would be made for the initial site visits, which would commence at the earliest convenience of company/agency personnel.
- 3) Concurrently, the results of the companion project (Cohen, 1979) to develop criteria for in-situ test facilities and to formulate a preliminary testing program would be incorporated, providing

criteria for assessment of the prospective sites.

- 4) With these criteria in mind and with the permission of and accompanied by company/agency personnel, the sites would be visited and evaluated.
- 5) The recommended program would culminate in a report covering:
  - (A) the criteria used to evaluate the sites;
  - (B) results of site visits:
    - (1) detailed descriptions of the location and accessibility of the site,
    - (2) detailed descriptions of the geologic settings and underground workings,
    - (3) geotechnical and hydrologic data base.
    - (4) detailed descriptions of facilities which would lend themselves to a test facility;
  - (C) recommendations of which sites, based on their technical merits, would best qualify for in-situ geomechanical, geochemical, and hydrogeologic tests relevant to the underground storage of radioactive wastes in crystalline rock.

#### IV. DESCRIPTIONS OF "class 1" MINES AND CIVIL WORKS

A description of each "class 1" site is included, alphabetically by state, in the following portion of the report. Each summary includes data on location and accessibility, geologic setting, description of mine or civil workings, and references.





## LAKESHORE MINE

(OPERATED BY NORANDA EXPLORATION, INC.,  
A SUBSIDIARY OF NORANDA MINES, LTD.)

## LOCATION

The Lakeshore mine is located at 32°31'N, 111°54'W, within the boundaries of the Papago Indian Reservation, in Pinal County, approximately 28 miles south of Casa Grande, Arizona, and approximately 70 miles northwest of Tucson (as shown in Figure 1). The Lakeshore ore body lies under the southwest pediment of the Slate Mountains. The surface elevation in the area is approximately 1800 feet.

## GEOLOGIC SETTING

Data describing the regional geologic setting were extracted from Board (1977), Hallof (1971), and Harper (1969).

Precambrian Pinal schist is the oldest exposed formation in the area, and it forms the core of the Slate Mountains. The Pinal schist is unconformably overlain by the Late Precambrian Apache Series which is exposed approximately 5 miles north of Lakeshore. The Apache Series consists of the Pioneer shale (425 feet thick), the Dripping Spring quartzite (1085 feet thick), and the Mescal limestone (200 feet thick). Diabase intrusions are common in the units.

The Paleozoic formations in the area of the Slate Mountains are represented by the Troy (or Bolsa) quartzite, the Abrigo, the Martin, the Escabrosa, and the Horquilla formations, which include a variety of sedimentary and metasedimentary rocks (quartzite, mudstone, dolomite, limestone, and siltstone). The aggregate thickness of these formations may exceed 1600 feet in the southeastern part of the Slate Mountains near the Lakeshore property.

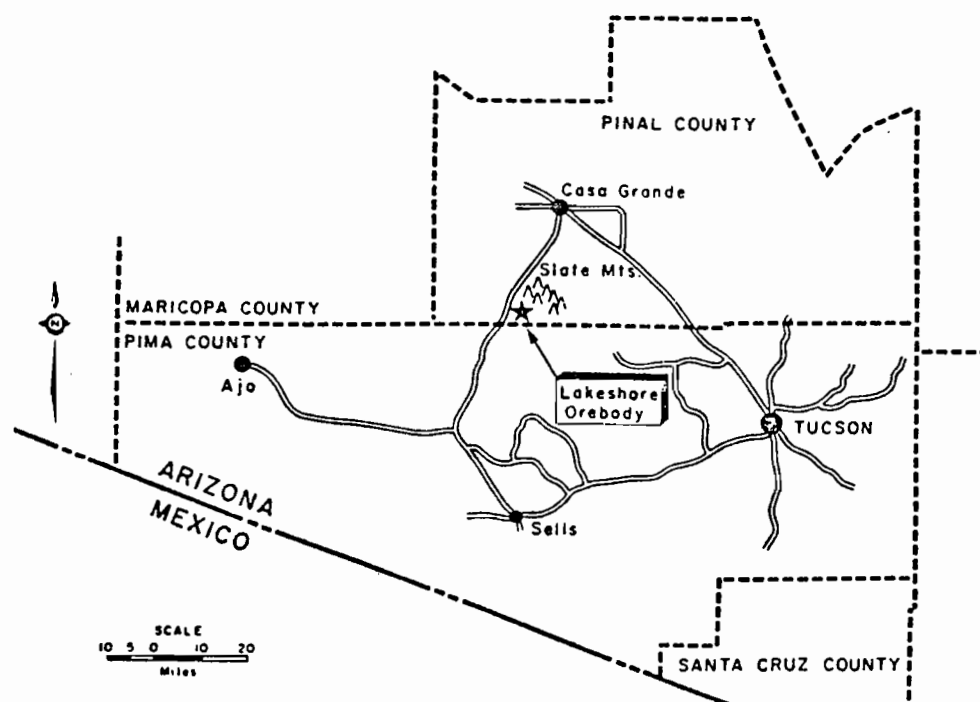


FIGURE 1. Location map of the Lakeshore ore body, Pinal County, Arizona (Hallof and Winniski, 1971).

Recurrent volcanism and continental deposition characterized the Cretaceous and Early Tertiary in southern Arizona. The resulting thick accumulation of clastic and volcanic conglomerates and agglomerates are exposed at several locations in the Lakeshore area. Drilling at Lakeshore has intersected substantial thicknesses of andesite and andesite breccia in the immediate mine area. The andesitic volcanics unconformably overlie the Paleozoic and Upper Precambrian formations, while the andesite is overlain by a thick sequence of Tertiary fanglomerate and young Tertiary volcanics and conglomerate.

#### Mine Area

Information on the geologic setting of Lakeshore mine were extracted from Board (1977), Hallof (1971), Harper (1969), and EMJ (1969).

A stock of quartz diorite and related porphyritic rocks of Tertiary age have intruded the Precambrian, Paleozoic, and Cretaceous formations previously described. The northern and eastern margins of the stock are exposed on the western slope of the Slate Mountains, while the southern and western margins are obscured by alluvium. Complex faulting in a wide zone along the assumed southern and western margins of the stock further complicates the relationship between the quartz diorite and the Late Precambrian and Paleozoic rocks. Fanglomerate overlying the Cretaceous andesite thickens to 1100 feet over the western portion of the deposit.

The geology of the deposit is illustrated in Figures 2 and 3. Figure 3 is a cross-section of the deposit, looking toward the north. The andesite-metasediment sequence is bounded on the east by a steeply dipping normal fault. Quartz diorite is present east of the fault. This fault marks the eastern limit of the major subsurface deposit, as well as the

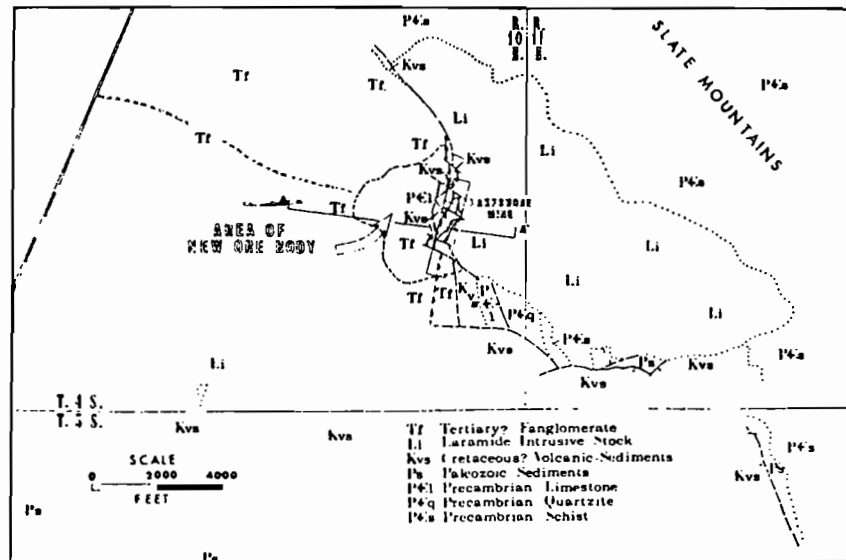


FIGURE 2. Preliminary geology of the Lakeshore mine area has been largely interpreted from drill hole data. Cross section A-A' is seen as Figure 3.

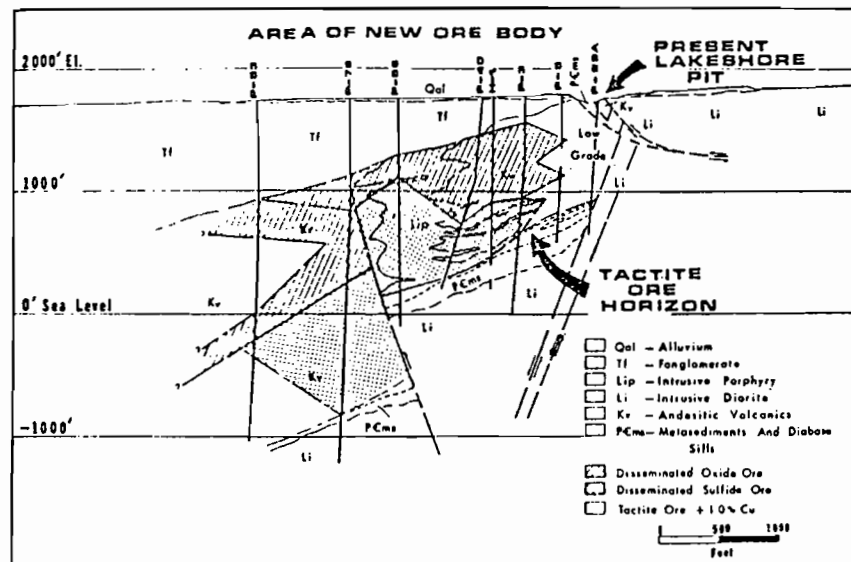


FIGURE 3. Geologic section A-A' of Lakeshore ore deposit.

small open pit ore body. In the central part of the deposit, drill holes indicate that the formations strike northerly and dip westerly at about 25°.

A fine to medium grained porphyry of quartz diorite to quartz monzonite composition intrudes the metasediments and andesite. Its relationship to the quartz diorite stock is not clear. The main mass of porphyry is located in the north central part of the deposit as an irregular body with fingers which extend upward and to the east.

The metasediments in the western part of the area are displaced approximately 700 feet below those in the central part of the deposit by a postoxidation, high angle reverse fault.

The andesites, porphyry, metasediments, diabase, and upper part of the underlying intrusive have been extensively shattered and are moderately to strongly altered. The andesite, porphyry, and metasediment-diabase sequence are the primary host rocks for the mineralization. The upper portion of the underlying intrusive occasionally contains disseminated sulfides.

The ore body has been divided into three distinct zones of mineralization which have been termed: (1) oxide zone, (2) sulfide zone, and (3) tactite zone. The oxide zone occurs in the upper portions of the ore body and consists primarily of leached and oxidized quartz monzonite porphyry and Cretaceous sedimentary and volcanic rocks. The sulfide zone underlies the oxide zone and includes all quartz monzonite porphyry and Cretaceous rocks which have not been oxidized. The thickness of the sulfide zone is variable and ranges from 200-400 feet. The tactite zone occurs in a series of Paleozoic metasediments consisting of tactite, quartzite, diabase, hornfels and dikes of quartz monzonite porphyry. The tactite zone is highly variable in thickness (averaging 63 feet) and underlies

the Cretaceous volcanics and sediments throughout the mine. Figure 4 illustrates the general relationship of ore types in the mine.

#### MINE CHARACTERISTICS

Information concerning the mine was extracted from Board (1977), COBBS Report, EMJ (1978, 1979), and Harper (1969).

The Lakeshore mine was first brought into production as an underground mine by Hecla Mining Company in April 1976. A weak copper market prompted Hecla to close the mine for an indefinite period beginning in September 1977. Maintenance expenses at the closed mine were approximately \$600,000 per month. Noranda Exploration Inc., a U.S. subsidiary of Noranda Mines Ltd. (Canada), has acquired the mine from Hecla/El Paso Natural Gas, and renegotiated leases with the Papago Indians. Noranda plans to begin mining 6000 stpd of ore by September 1979.

#### MINE FACILITIES

When originally opened by Hecla, the mine employed approximately 1600 people, was designed with a daily ore capacity of 16,500 tpd, and mined 1 to 10 million tons of ore per year and 1 to 10 million tons of waste per year, extracting a total volume in excesses of 180,000,000 cubic feet.

Based on its large size ( $\frac{1}{2}$  to 1 billion tons of ore) and layered characteristics, the deposit lends itself to an extraction plan which integrates mechanized underground mining techniques. Hecla's approach to mining the ore body was to develop a block caving operation based on high-grade sulfide ore in the tactite zone underlying the deposit during the early stages of the operation. In contrast, Noranda will reopen the mine

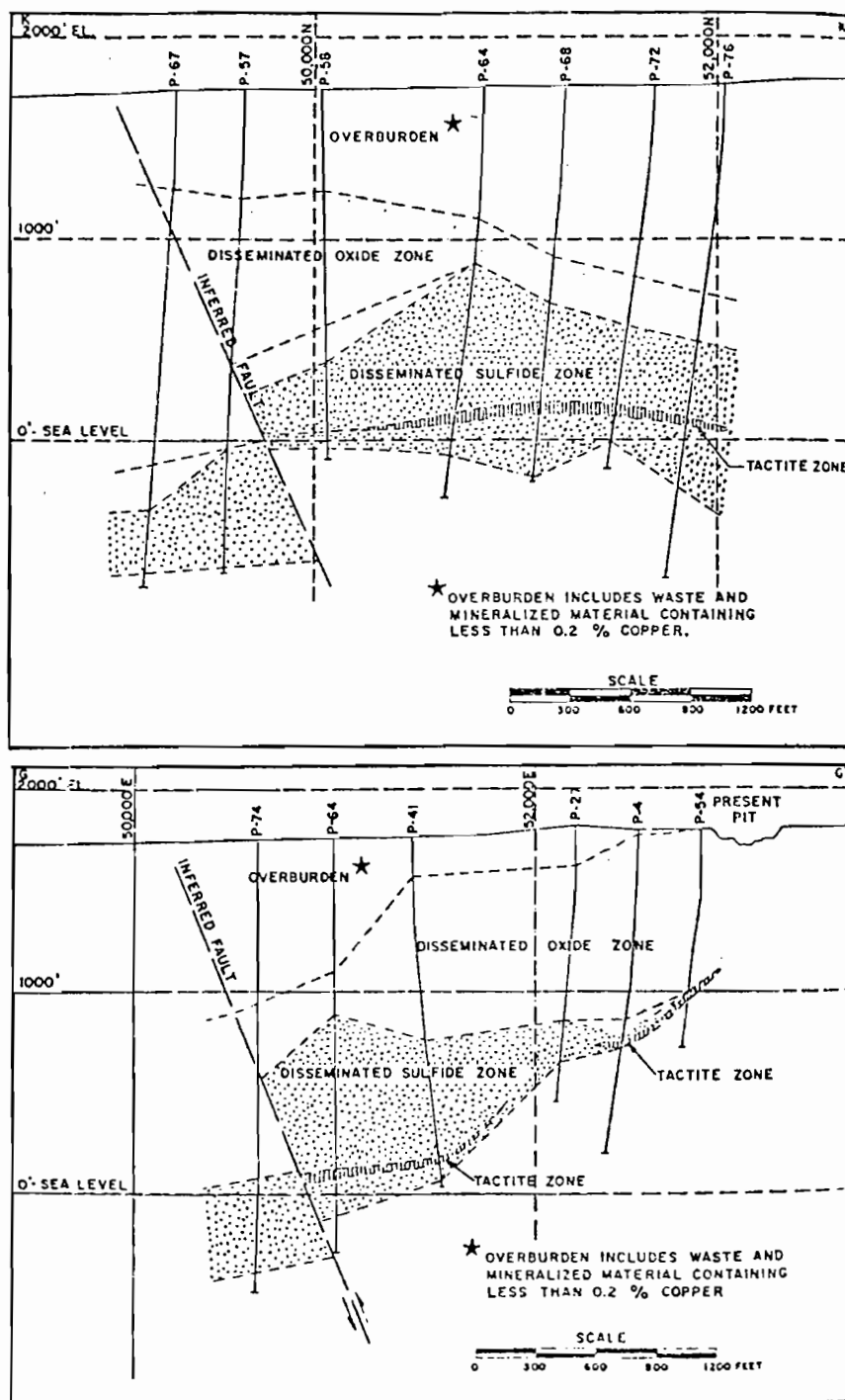


FIGURE 4. North-south and east-west cross-sections of Lakeshore deposit illustrating the three zones of mineralization: oxide, sulfide, and tactite (EMJ, June, 1969).



based on extraction of copper oxide ore, while studying the sulfide ore's grade and quantity. From available data it is not known whether Noranda will be mining copper oxide ore from the open-pit or from underground workings, or from both.

Access to the mine is by a twin decline on a  $15^{\circ}$  slope providing entry to the ore body, and equipped with conveyors, provides the main ore handling facility. The length of the decline to a point beneath the central part of the deposit will be approximately 7500 feet. Information regarding the location and orientation (straight or switch-back) of the decline, and rock types penetrated was not available; the length and slope suggest that favorable rock types are among those encountered. However, published information does not indicate the extent of underground workings in crystalline rock types.

#### Rock Mass Properties

Table 1 lists the basic sulfide mine rock properties. Testing of the intact rock was conducted at the University of Arizona, Tucson, by White (Board, 1977).

TABLE 1

## LAKESHORE MINE ROCK PROPERTIES

<u>Rock Type</u>	<u>Uniaxial Comp. Strength (psi)</u>	<u>Poisson's Ratio</u>	<u>Young's Modulus</u> (x10 <sup>6</sup> psi)	<u>Internal Angle of Friction</u>
Tactite	11,798	0.3	5.42	53
Quartz Monzonite	14,912	0.19	9.00	31
Hornfels	13,542	0.21	14.00	52

Board (1977)

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MIAMI EAST MINE  
(OPERATED BY CITIES SERVICE COMPANY)

#### LOCATION

The Miami East mine is located adjacent to the town of Miami and approximately 6 miles northwest of Globe, Arizona, at 33°24'N, 110°53'W (Figure 1). The elevation at the mine is approximately 3500 feet, with several hundred feet of relief in the area.

#### GEOLOGIC SETTING

##### Regional

The regional geologic setting has been extracted from Olmstead (1966), Peterson (1962, 1954), and Rubly (1938).

The rocks of the Globe-Miami district range in age from Lower Precambrian to Recent. Figure 2 is a geologic map of the region. The Precambrian Pinal schist, diabase of possible Mesozoic age, Willow Springs granodiorite, Schultze granite, dacite, and Gila conglomerate are immediately connected with the Miami East deposit.

The Pinal schist is one of the ore deposit host rocks and is the oldest formation in the area. The Pinal schist makes up the bulk of the Pinal Range, which covers an area of 16 by 12 miles. The disseminated copper deposits of Miami occur in the northeast portion of the range. The schist consists of a sequence of metamorphosed sedimentary rocks, and is irregularly intruded by Precambrian quartz diorite, granite, and the Tertiary Schultze granite. The metamorphic sequence is composed of coarse-grained quartz-muscovite schist, fine-grained quartz-sericite-chlorite schist, and some

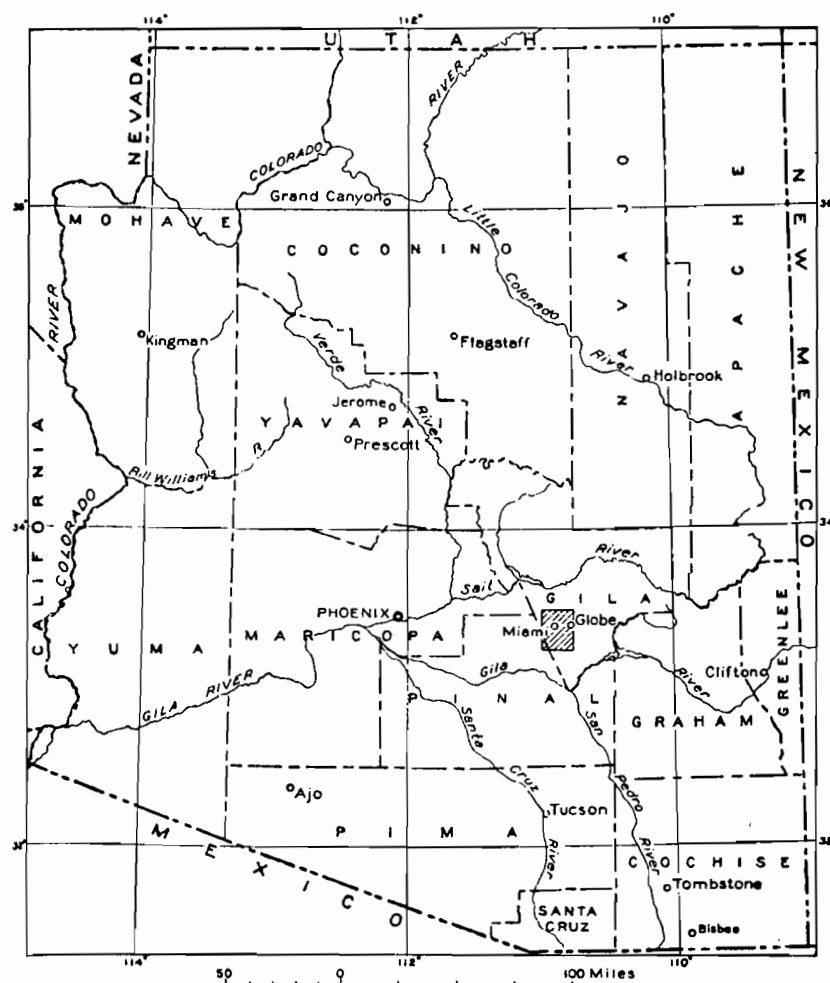


FIGURE 1. Index map of Arizona showing location of Globe quadrangle, (after Peterson, 1951).

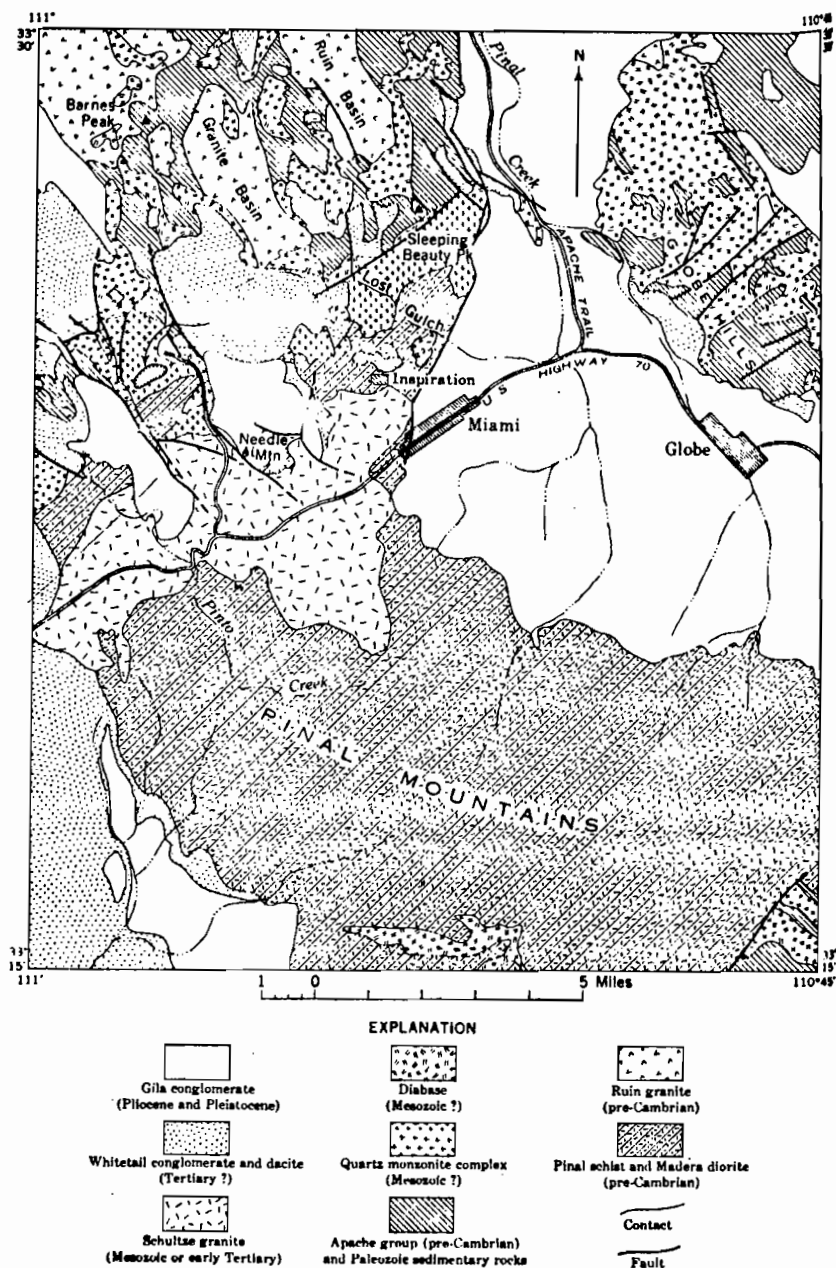


FIGURE 2. Geologic sketch map of Globe quadrangle, Arizona. Data from Ransome with modifications, (after Peterson, 1951).

fine-grained amphibole schist. The general schistosity strikes about N50°E and dips steeply to the southeast. The outlines of the ore deposits and the intrusion of granite porphyry closely parallel the orientation of schistosity.

Tertiary diabase intruded the metamorphic and sedimentary strata as irregular sheets, sills, and dikes.

The Tertiary Willow Springs granodiorite outcrops within several thousand feet of the Miami mine; however, it has no obvious relationship to the ore bodies in the area.

The rock most directly associated with the ore deposits is the Tertiary Schultze granite, which is believed to be contemporaneous with the copper mineralization. Facies of this rock contain part of the ore deposit and often border the ore zones. The Schultze granite stock extends many miles south and west of Miami and constitutes a large portion of the northwest Pinal Mountains. Its composition varies between granodiorite, quartz monzonite, and porphyritic quartz monzonite. From the standpoint of the ore deposit, the most significant constituent of the Schultze granite is a granite porphyry, a separate marginal and younger facies of the Schultze. In some of the ore bodies in the area, half of the ore may be in granite porphyry, while the other half is in Pinal schist. The granite porphyry is a plug which intruded older facies of the Schultze granite and formed sill-like tongues in the schist.

The Tertiary dacite in the area is believed to represent the final stage of igneous activity. The massive dacite shows sheeting, which trends north-south and dips moderately to the west.

Massive thick beds of Plio-Pleistocene Gila conglomerate overlie much of the area. Bedding trends northwest-southeast and dips gently to the southwest.

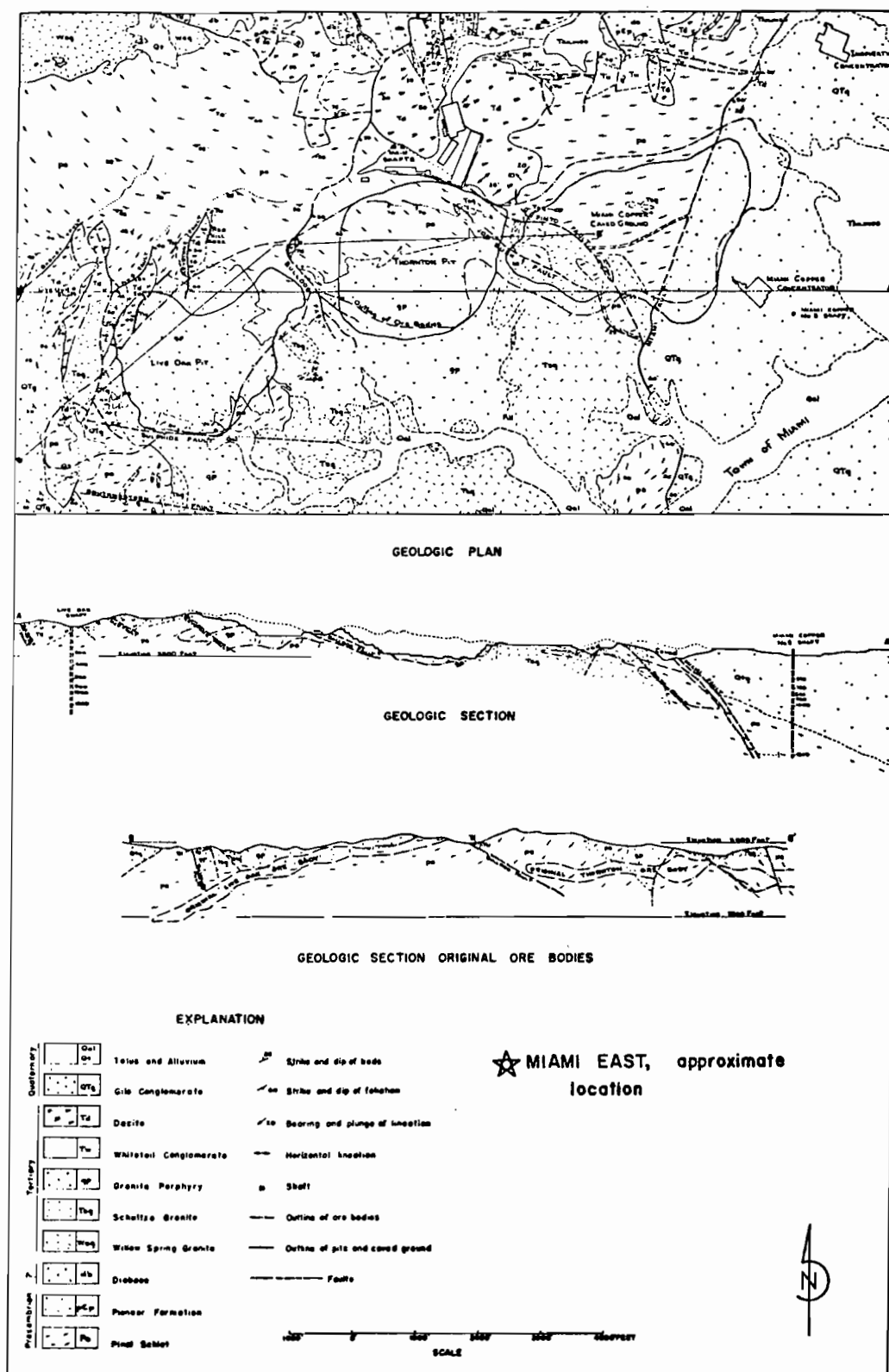


FIGURE 3a. Geologic plan and sections, Inspiration Mine, Gila County, Arizona (after Olmstead, 1966). H.W. Olmstead and D.W. Johnson, "Inspiration Geology," in GEOLOGY OF THE PORPHYRY COPPER DEPOSITS, Spencer Titley and Carol Hicks, Editors, Tucson: University of Arizona Press, copyright 1966.



## MINE AREA

Data concerning the geology of the Miami East mine were not readily available in the literature. The information which was available suggested that rock-type relationships in the Miami East ore body are very similar to those in the Inspiration and Miami mines located several thousand feet to the southwest. Much of the following description of mine area geology is drawn from literature on local mines by Olmstead (1966), Peterson (1962, 1954), Rubly (1938), and Skillings (1975).

The Miami East ore body is located approximately 2500 feet northeast of Shaft No. 5, as shown in Figure 3. The mineralized area is 3000 feet long, has a width of 1400 feet, and a maximum thickness of 400 feet. The deposit has a varying dip to the north and east with a maximum pitch of  $34^{\circ}$ . The ore body is situated nearly 2000 feet east of the original Miami deposit, and its top occurs at a depth of 2500 feet.

Structures in the mine area are related to the general structure of the Precambrian schist, which trends northeasterly and dips to the southeast. Locally, granitic intrusives have distorted and obliterated the schist structure, but the schistosity prevails as the major lineation that controlled mineralizing solutions. The geology of the local mine area is shown in Figures 3a and 3b.

Faults controlled the intrusion of the granite porphyry with which the ore bodies are associated. The Miami fault (a normal fault) strikes  $N25^{\circ}E$ , dips about  $50^{\circ}E$ , and drops the Gila conglomerate to the east of the exploited ore bodies, between 2000 and 3000 feet. This fault or the ancient break it followed may have had some pre-porphyry movement. East of the mining areas, the ore bodies appear to be terminated by the Miami fault, although there are some indications that the ore did not reach the fault zone or that there is

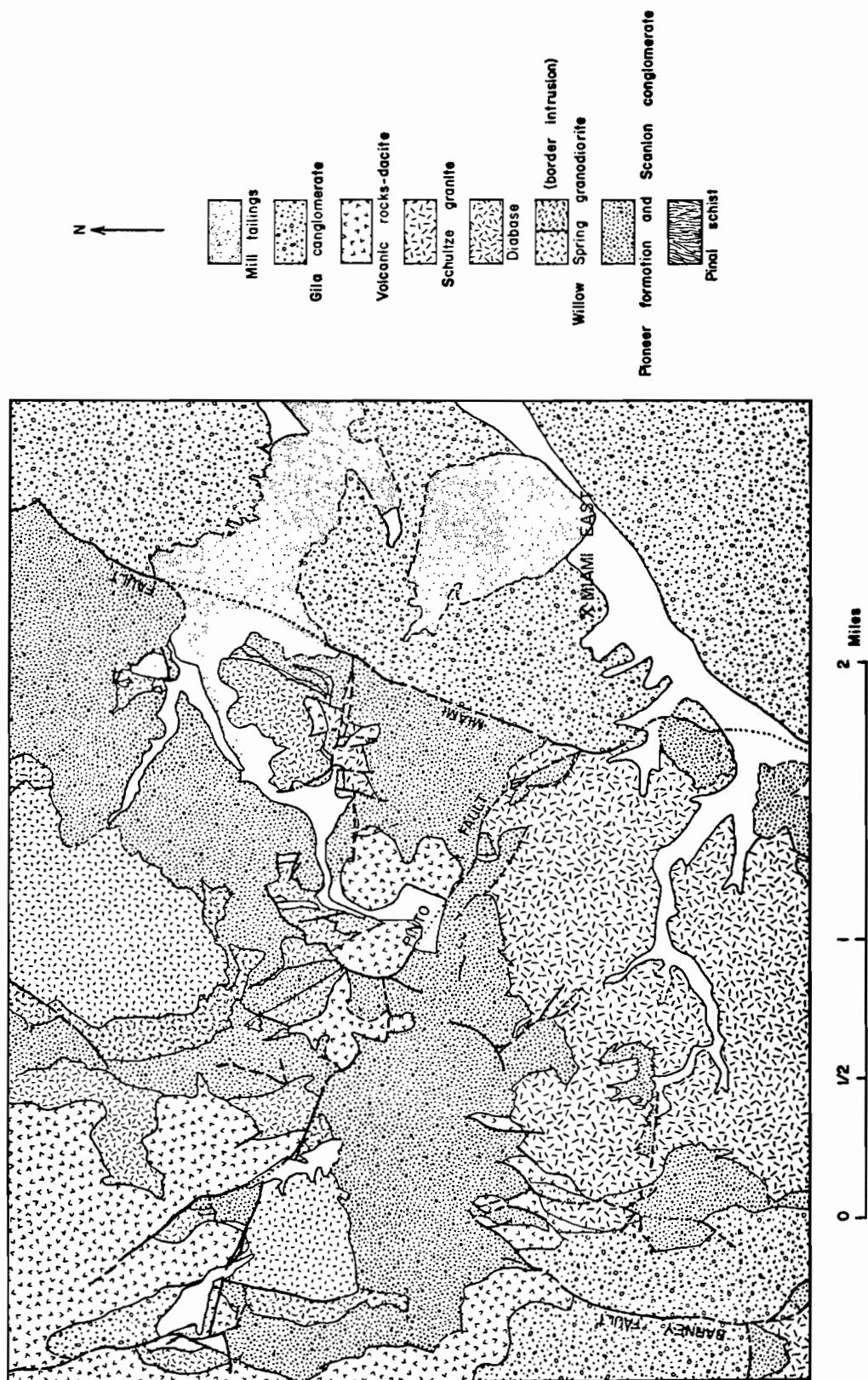


FIGURE 3b. Geologic map of the Miami East area, Gila County, Arizona (Peterson, 1962)

a leached zone near the fault. Some ore in diabase occurs at considerable depth east of the Miami fault, and one drill hole disclosed secondarily-enriched sulfides lying below low-grade primary material near a branch of the Miami fault.

#### MINE FACILITIES

Data related to the Miami East mine facilities were extracted from Carter (1975), Skillings (1975), and Mining Annual Review (1978).

The Miami East mine of Cities Service Company contains an estimated 50 million tons of 1.95% copper ore. Underground mining at the original Miami mine was replaced by in-place leaching in 1959. The deeper Miami East ore body was confirmed by drilling in 1969, and a program of shaft sinking and underground development was commenced. Production was expected to begin in 1976, however, after substantial development work, it was decided to place the mine on standby, which is the current status.

Two shafts were sunk on the Miami East project. The 12 ft-diameter concrete lined No. 11 shaft, which provides downcast ventilation and serves as an escapeway bottomed at a depth below 3300 feet. The 14 ft-diameter concrete-lined No. 12 shaft, an exhaust and ventilation facility, was excavated to a final depth of 2900 feet. At the end of 1973, the existing No. 5 production shaft was deepened from 1150 feet to 3500 feet, with stations developed at the 2900 and 3200 foot levels. The development drifts on the 2900 and 3200 foot levels of No. 5 shaft have been extended approximately 2500 feet to the ore body.

The Miami East ore body is mined by the modified horizontal cut and fill method; block caving was deemed undesirable due to a potential subsidence problem at the site. Production was planned to reach 5000 tpd.

A typical stope will measure 8x11 feet in cross-section, advancing a 100 foot slot. Stopes will be developed on 16 foot centers. Highly mechanized mining equipment will be used for ore recovery. Eimco 911 and 912 LHD's\* will load and transport ore to the mine's main rail haulage network. Ore haulage to the No. 5 shaft will initially utilize battery-powered locomotives. As full productive capacity is neared, these will be replaced by diesel-powered units.

The main haulage levels measure 11x13 feet in cross-section. Ground support will utilize a dry process shotcrete method, with additional rock bolting over shotcrete when necessary.

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\* LHD = Load, haul, dump.

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## SAN MANUEL/KALAMAZOO MINE

(OPERATED BY MAGMA COPPER COMPANY,  
A SUBSIDIARY OF NEWMONT CORPORATION)

## LOCATION AND ACCESSIBILITY

The San Manuel mine is located just south of Tiger, Arizona in the Old Hat mining district of Pinal County, at 32°41'N, 110°42'W (Figure 1). The San Manuel deposit is located in sections 34 and 35, T.8S., R.16E. of the Gila and Salt River meridians. The Kalamazoo deposit is located in sections 3, 4, 9, 10, T.9S., R.16E. The San Manuel/Kalamazoo mine area is approximately 35 miles (46 miles by road) northeast of Tucson. The elevation in the mine area is approximately 3,200 feet, with several hundred feet of relief in the general area. The nearest railroad is at Winkelman on the Gila River, 20 miles north of San Manuel and Tiger. Electric power and natural gas are available.

## GEOLOGIC SETTING

Data describing the regional geological setting has been extracted from Creasey (1965), Lowell (1968), Kendorski (1976), Ridges (1972), Schwartz (1953), and Thomas (1966). Figure 2 illustrates a simplified regional geologic setting. There is a rather limited variety of rocks exposed either on the surface or underground. The San Manuel/Kalamazoo mine is located in an extensive area of Precambrian quartz monzonite, known as the Oracle granite, which itself is part of a much larger granite mass on the north slope of the Santa Catalina Mountains.

The Oracle granite is considered to be the result of metasomatization of earlier rocks, possibly the Pinal schist. A northeasterly grain in the Oracle is evidenced by the alignment of xenoliths in the rock mass

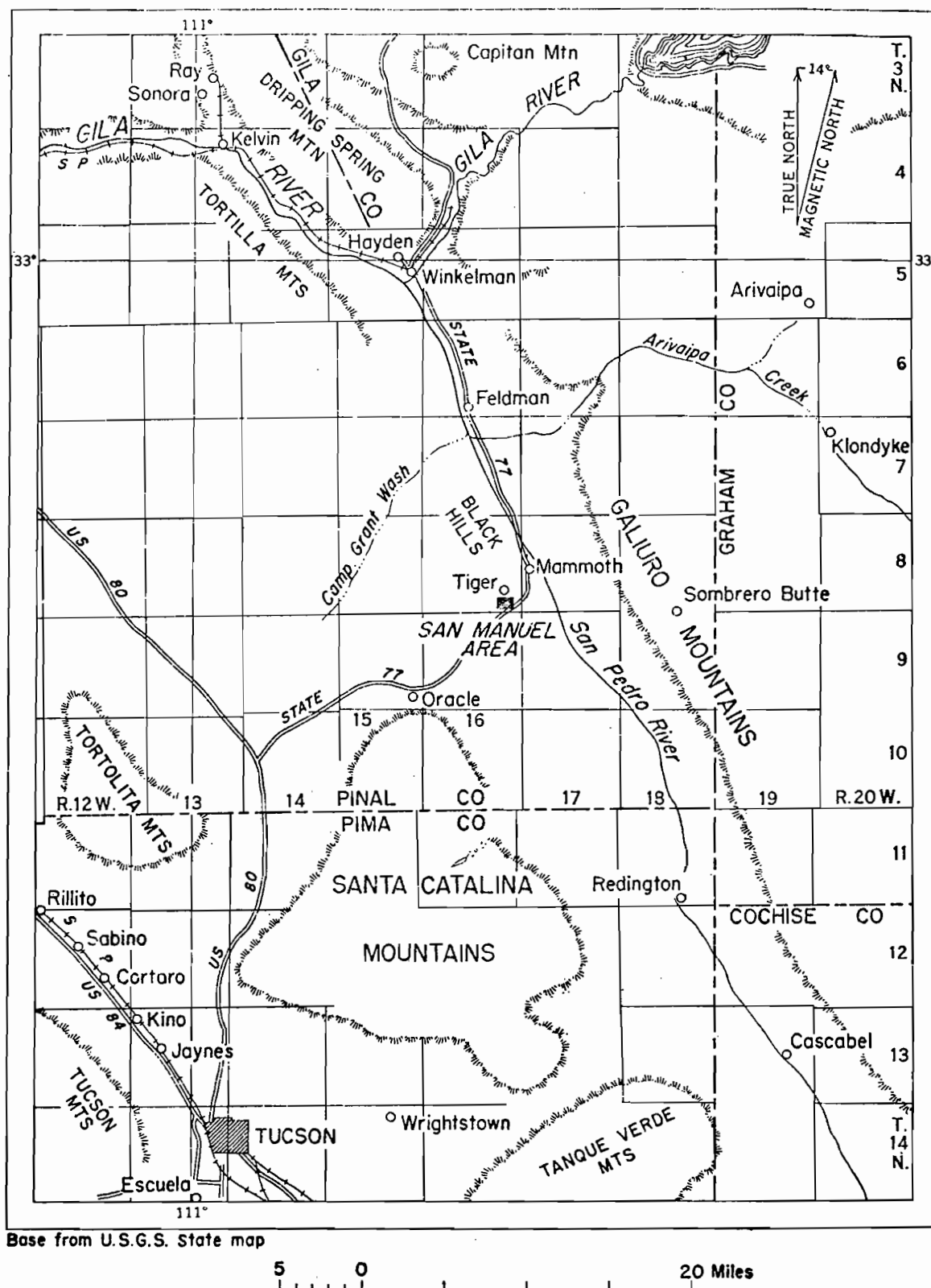


FIGURE 1. Sketch map showing principal towns and topographic features in the area surrounding the San Manuel district, Arizona (Schwartz, 1953).

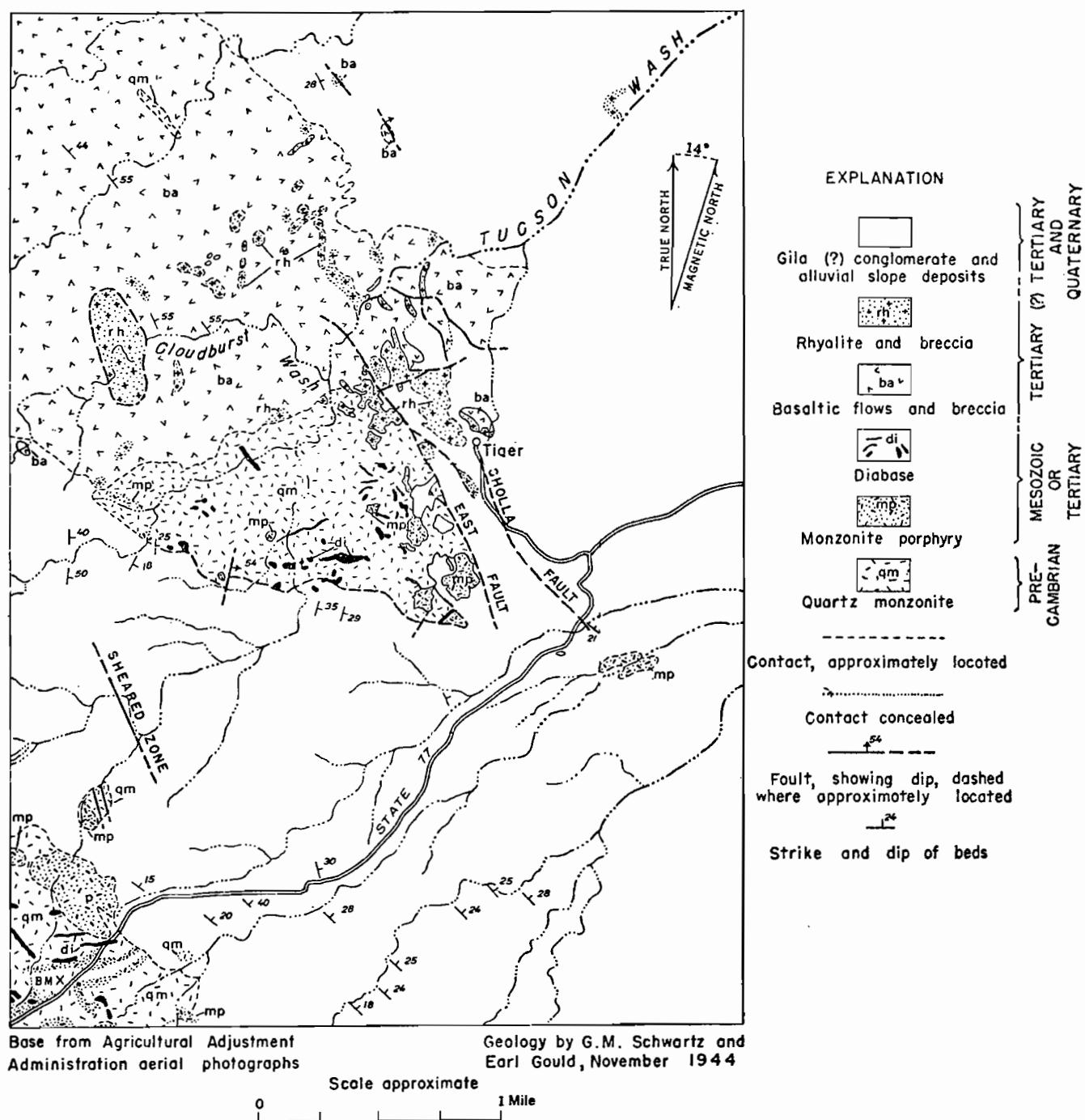


FIGURE 2. Geologic map of area around San Manuel and Tiger, Arizona (Schwartz, 1953).



and the foliation of feldspars and mafics. The rock varies in composition from granodiorite to granite, and is deeply weathered.

The Oracle granite was intruded by monzonite porphyry or perhaps locally metasomatized during Laramide time. A complex relationship exists between the quartz monzonite and the monzonite porphyry. Recent investigations suggest that the monzonite porphyry comprises a dike and igneous mass swarm.

The sequence of episodes which followed the formation of the monzonite porphyry consisted of: (1) intrusion of diabase dikes and irregular masses, which although altered and mineralized, appear to have acted as partial barriers to the movement of ore solutions; (2) a porphyry-type copper-molybdenum ore mineralization, associated with considerable alteration and centered on the monzonite intrusion; (3) post-ore Tertiary rhyolite, intruded in two main sheets; and (4) the deposition of the Gila conglomerate, late Tertiary and Quaternary, which, with the exception of recent alluvium, is the youngest rock in the area, and is normally unconformable to all the older rocks.

Figure 2 shows the geology of the region as described.

#### Mine Area

The locations of the San Manuel/Kalamazoo ore bodies are shown in Figure 3. Data for this section were extracted from Lowell (1968, 1970), Kendorski (1976), Ridges (1972), and Thomas (1966).

Alluvial deposits lie unconformably on the Gila conglomerate. The Gila conglomerate is the most widely distributed surface rock type, and reaches thicknesses in excess of 1200 feet over the mine area. The extensively tilted and deformed conglomerate has a prevailing northwest strike,



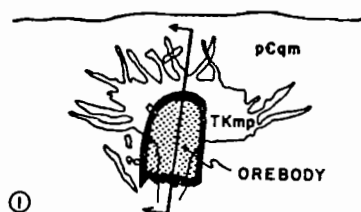
with a dip of  $25^{\circ}$  to  $45^{\circ}$ NE. The quartz monzonite and monzonite porphyry are interrelated in such a complex manner that their detailed structural relationships are difficult to determine.

The conglomerate and underlying rocks are cut by many faults, only a small number of which have been accurately mapped. Of the recognized faults, the San Manuel fault, a normal fault, dipping  $25^{\circ}$  to  $30^{\circ}$ SW and bordering the southwest side of the exposed mineralized area, is the most significant. The San Manuel fault divided the original ore complex (which had previously experienced a tilt of approximately  $70^{\circ}$  to the northeast) into two segments: the San Manuel segment, and the Kalamazoo segment which is faulted some 8000 feet down dip in the low angle normal fault. Figure 4 illustrates schematically the possible origin of the San Manuel/Kalamazoo ore bodies.

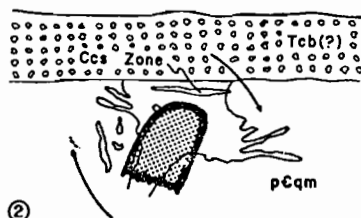
The original pre-faulting ore complex, based on a minimum 0.5% copper content, had the general shape of a flattened cylinder with an axial length in excess of 7700 feet and a diameter between 2500-5000 feet. Mineralization and alteration form approximately coaxial cylindrical zones.

Hydrothermal alteration is characteristic of most rocks in the mine area, with the exception of the Gila conglomerate and younger rocks. Based on the characteristic mineral assemblages, four types of alteration are recognized. A detailed discussion of porphyry alteration has been presented by Lowell (1970).

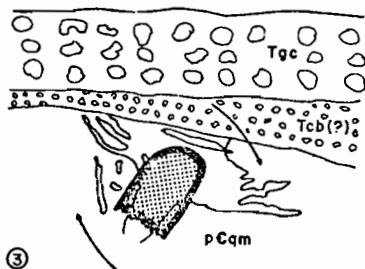
Figures 5, 6, & 7, geologic maps of the 1,475 haulage level and its respective cross-sections (NW-SE and SW-NE) in the San Manuel mine are characteristic of the general rock distribution/relationships found in the San Manuel/Kalamazoo mines. The vast majority of underground workings are either in quartz monzonite or monzonite porphyry.



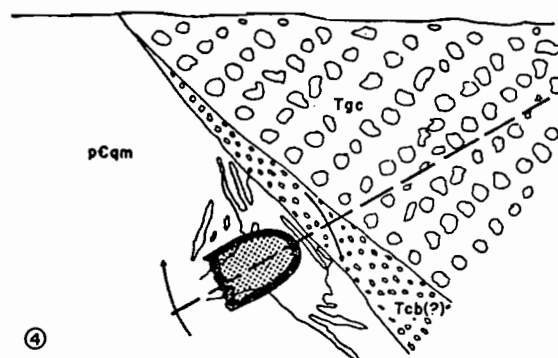
1. Precambrian quartz monzonite (pCqm) was intruded by a Laramide age monzonite porphyry (TKmp) dike swarm. A hollow cylindrical or pipe-shaped orebody with dimensions of approximately  $8,000 \times 3,500$  feet was formed. It was probably nearly vertical and centered on the monzonite dike swarm. (Section line shows position of Figure 7.)



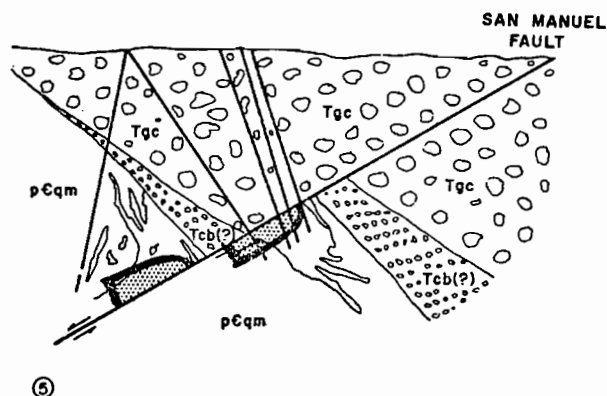
2. Tilting of the orebody was followed by erosion, then deposition of conglomerate and interbedded volcanics (Tcb?). A thin chalcocite blanket (Cc) was formed at the water table.



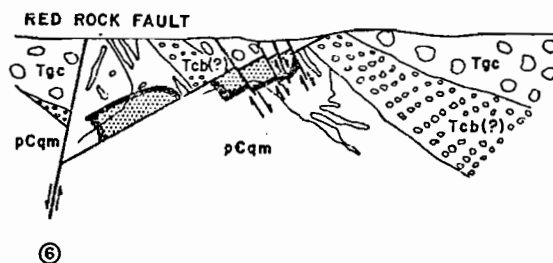
3. Continued tilting was followed by erosion of conglomerate and quartz monzonite and deposition of middle Tertiary Gila Conglomerate (Tgc).



4. Orebody is now at a flat angle due to continued tilting. An erosion surface is cut on the tilted quartz monzonite and Gila Conglomerate. Incipient San Manuel fault is formed.



5. Upper portion of orebody is displaced approximately 8,000 feet down the dip of the San Manuel fault. Some imbricate displacement may have occurred in the Kalamazoo segment.



6. High-angle normal fault displacements produced small offsets in the San Manuel orebody and a large displacement on the Red Rock fault west of the Kalamazoo orebody. Erosion exposed intrusive rocks and a corner of the San Manuel orebody and produced oxidation and limited chalcocite enrichment in the upper portion of the San Manuel orebody.

FIGURE 4. Schematic drawings showing possible origin of Kalamazoo ore body (Lowell, 1968).

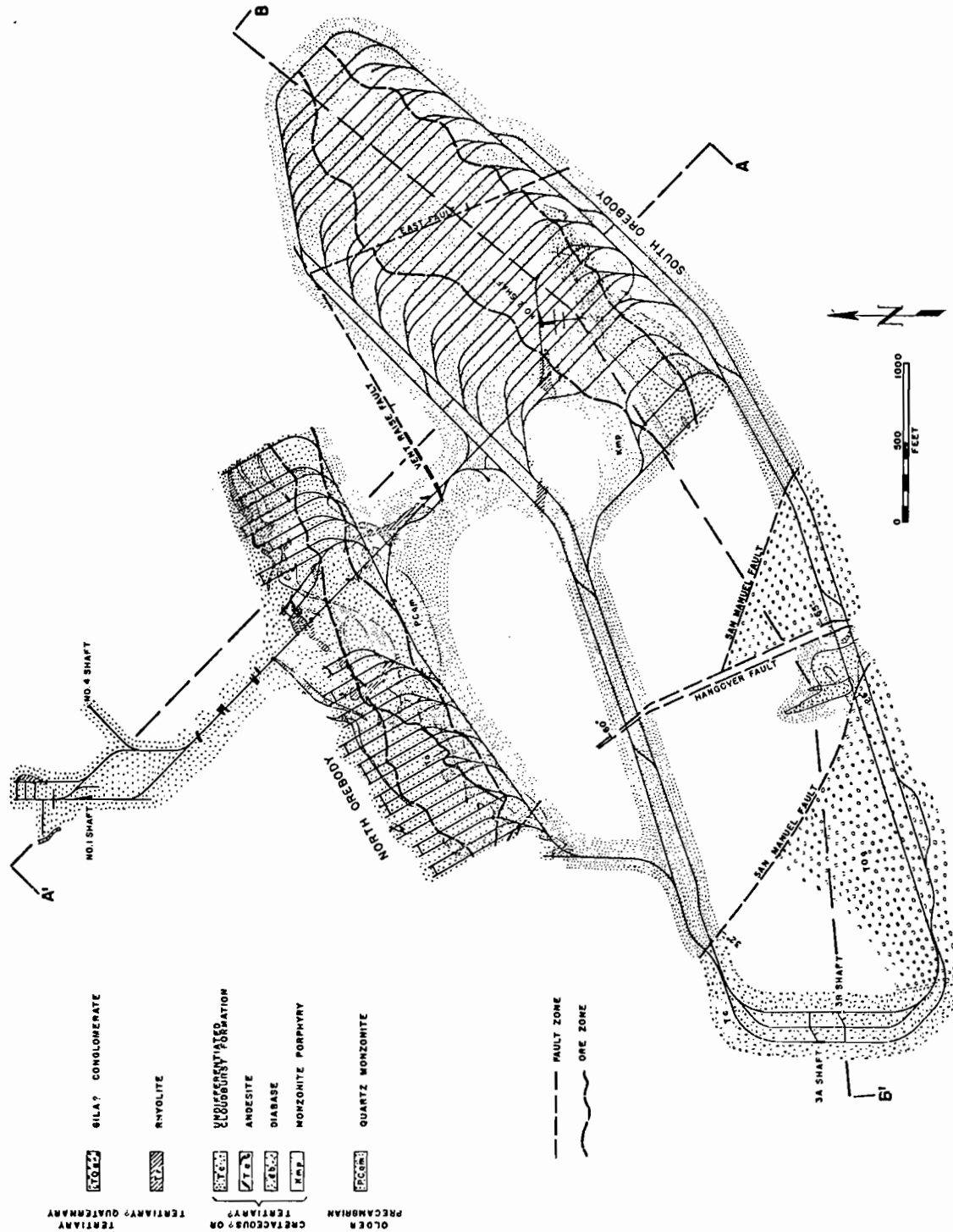


FIGURE 5. Geology of 1,475 haulage Level (Thomas, 1966). By permission, L.A. Thomas, "Geology of the San Manuel Ore Body," in GEOLOGY OF THE PORPHYRY COPPER DEPOSITS, Spencer Titley and Carol Hicks, Editors, Tucson: University of Arizona Press, copyright 1966.

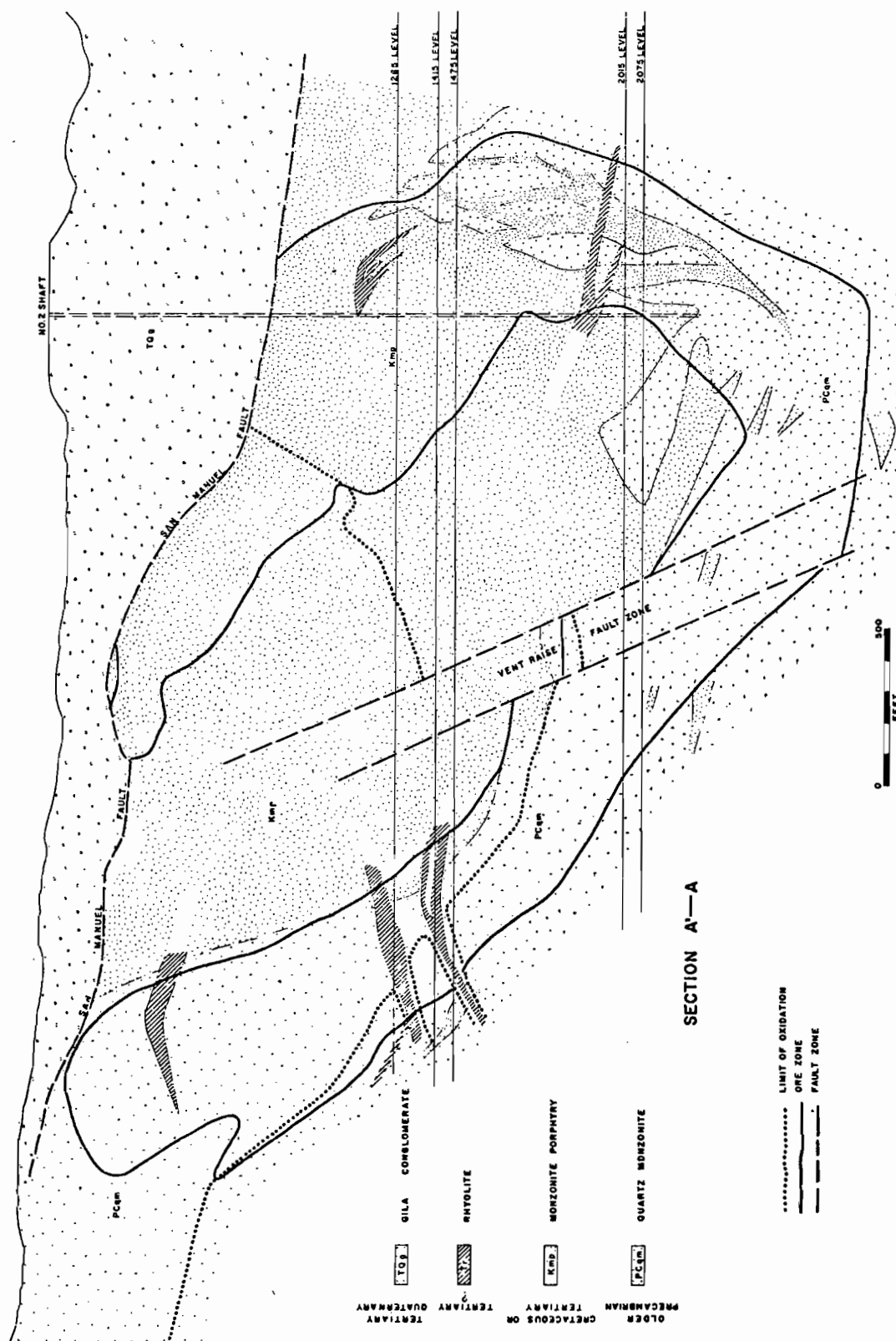


FIGURE 6. Idealized cross section looking northeast (Thomas, 1966). By permission, L.A. Thomas, "Geology of the San Manuel Ore Body," in GEOLOGY OF THE PORPHYRY COPPER DEPOSITS, Spencer Titley and Carol Hicks, Editors, Tucson: University of Arizona Press, copyright 1966.

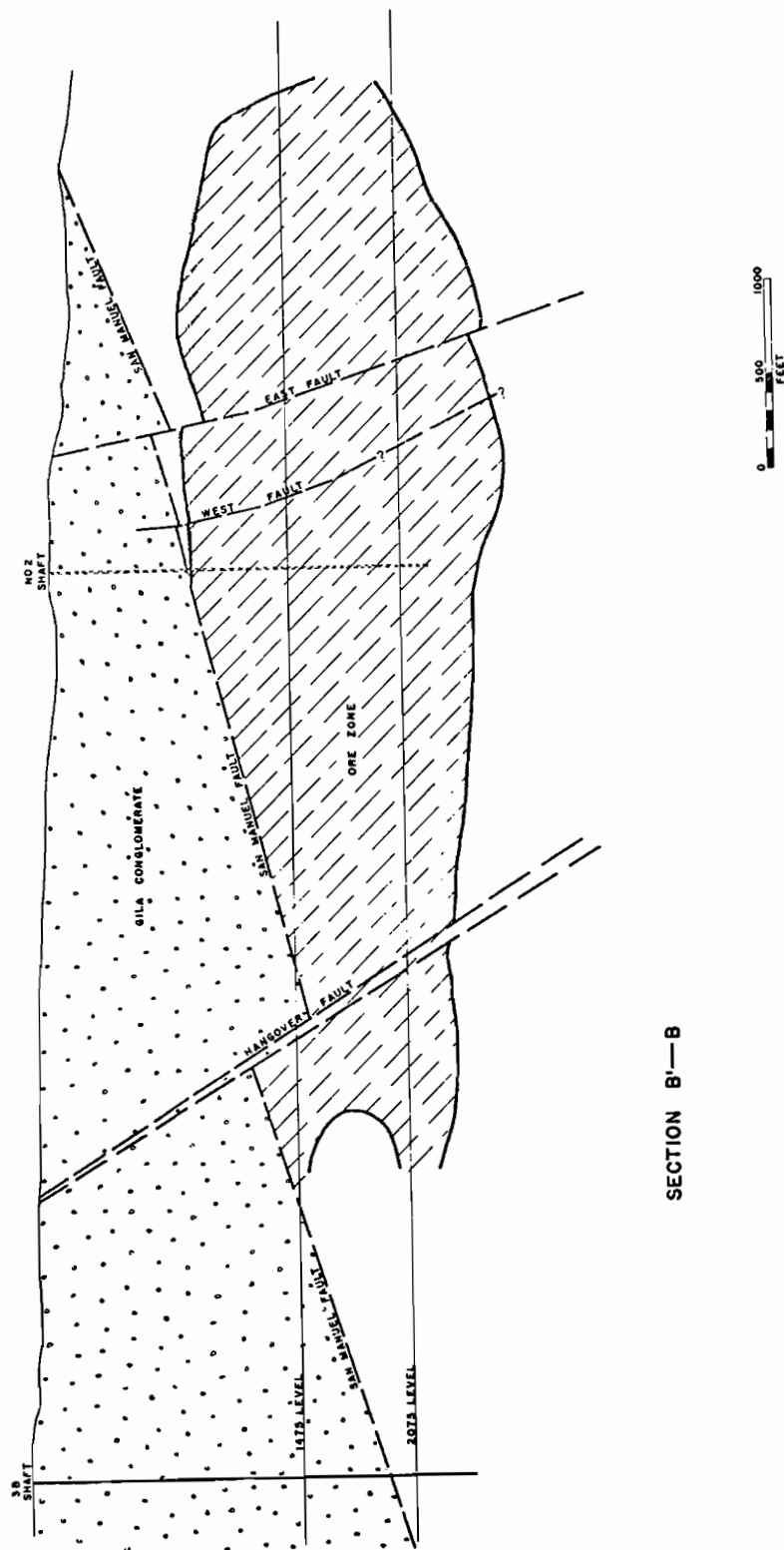


FIGURE 7. Idealized longitudinal section looking northwest (Thomas, 1966).  
 By permission, L. A. Thomas, "Geology of the San Manuel Ore Body,"  
 in GEOLOGY OF THE PORPHYRY COPPER DEPOSITS, Spencer Titley and Carol  
 Hicks, Editors, Tucson: University of Arizona Press, copyright 1966.

### Mine Facilities

The data for this section were extracted from Hynd (1976), Jackson (1978), and Magma Copper Company. Magma Copper Company, a wholly owned subsidiary of Newmont Mining Corporation, opened the San Manuel mine in 1956. Over 300 million tons of ore have been hoisted since the mine opened. Production currently runs at approximately 52,000 tpd. Remaining ore reserves at San Manuel are estimated to be in excess of 600 million tons. The present mining method is block caving.

Mining at San Manuel moved progressively down from the 1,475 level to the 1,775, 2,075, and 2,375 levels. Development work is underway on the 2,675 level, which is scheduled for production in mid-1979.

All production at the mine has come from the San Manuel ore body; however, long-range development work is being done in the Kalamazoo ore body on the 2,950, 3,440, 3,530 (pump station), and 3,740 levels. Since the start of production, 224 miles of horizontal workings, 152 miles of vertical workings, and 115 acres of undercut area have been driven or excavated.

### Mine

The data for this section were extracted from Hynd (1976), Jackson (1978), and Magma Copper Company. At its current rate of production, San Manuel must complete 30,000-40,000 feet of development drifting annually. Drifts outside the cave area are supported by square timber sets; H-beam caps with square timber posts; or by steel arc sets. Normal spacing of sets is 5 feet, but may vary with ground conditions.

There are about 20 drill jumbos in the San Manuel mine, including a spare for each level. There are 73 drifters in the mine, of which 50 are typically in use at one time and 23 are spares.



Ore stored in raises is transported to ore hoisting shafts by a trolley-operated railroad system. There are four hoisting shafts: 3A & 3B (equipped with 6000 hp hoists) and 3C & 3D (equipped with 7000 hp hoists). Additional transportation facilities at the mine include shafts: No. 1 (used for concrete supply, waste rock, and ventilation); No. 2 (sunk for exploration and quick development within the ore body proper, has been abandoned); No. 4 (used for ventilation and transportation of men and supplies), and No. 5 (service and development hoisting). The shafts range in depth from 2310 to 4123 feet.

Ventilation is supplied to the San Manuel mine at a rate of 1.2 million cfm of air. The ventilation department is designing a refrigeration system for the future, with a goal of maintaining a temperature of 80°F.

A total of 6600 gpm of water is pumped from the San Manuel mine, mainly from the deep shafts. Increased flow is expected at the lower levels especially in the Kalamazoo ore body. During early shaft development through the lower Kalamazoo horizon, water inflows reached 2300 gpm at a temperature of 120°F.

#### Rock Mass Properties

The data for this section were extracted from an article by Kendorski (1976). The fracture patterns mapped in the underground workings can be generalized as four sets: EW and NS, both vertical; N80°E to EW, vertical; and horizontal. Oriented compression and Brazilian tension tests on the quartz monzonite showed that the mappable fracture pattern is reflected in planar weaknesses in the rock. Tables 1 & 2 summarize the tests.

TABLE 1. *Summary of Quartz Monzonite Brazilian Test Data*

	Direction 1			Direction 2		Direction 3			Overall Results
Anisotropy planes	030, 105, 165			045, 150		060, 105, 165			–
Identification	A	B	C	D	E	F	G	H	–
Decrease in strength from $\bar{x}$ , percent	15, 23, 6			43, 37		14, 23, 23			23
Density, $\bar{x}$ , g/cm <sup>3</sup>	2.65			2.65		2.77			
Tensile strength, psi									
$\bar{x}$	1474			1263		1405			1389
S	328			224		335			252
Tests in direction breaking along pre-existing planes, percent	63.9			44.4		41.7			50.0
Tests in directions that are highly altered with ragged failure, percent	16.7			16.7		27.8			20.4
Tests in direction with a clean break	19.4			38.9		30.6			29.6
$\bar{x}$ is the mean									
S is the standard deviation									

TABLE 2. *Quartz Monzonite Compression Test Summary*

	Direction			Overall Results
	1	2	3	
Length (in.), $\bar{x}$	4.53	4.39	4.49	4.47
Density (g/cm <sup>3</sup> ), $\bar{x}$	2.65	2.62	2.74	2.67
Uniaxial compressive strength (psi)				
$\bar{x}$	11129	14700	15300	13500
S	3514	2050	4600	3900
Modulus of elasticity (psi $\times 10^6$ )				
$\bar{x}$	6.9	7.0	8.4	7.4
S	3.1	1.7	2.4	2.4
Poisson's ratio				
$\bar{x}$	0.26	0.13	0.20	0.20
S	0.14	0.07	0.12	0.12
Tests in direction failing along weakness planes, percent	71	60	67	67

 $\bar{x}$  is the mean

S is the standard deviation

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PINE CREEK MINE  
(OPERATED BY UNION CARBIDE CORPORATION)

#### LOCATION AND ACCESSIBILITY

The Pine Creek mine is located at 37°22'N, 118°43'W, in the Bishop District on the eastern escarpment of the Sierra Nevada west of the town of Bishop, California. Figure 1 illustrates the location of Bishop, approximately midway between Reno, Nevada and Los Angeles, California. Outcrop relief exceeds 6000 feet; from an elevation of about 7400 feet on the floor of Pine Creek Canyon to a high point of 13,652 feet on the summit of Mt. Tom. Despite the high elevation, the mine is accessible year round by paved road from Bishop.

#### GEOLOGIC SETTING

##### Regional

Data for this section were extracted from Gray (1968), and Bateman (1965).

The Pine Creek pendant, which contains the Pine Creek mine, is a lens of metamorphic rock nearly 7 miles long and as much as one mile wide. As shown in Figure 2, the pendant extends from the northeast face of the Basin Mountains northward across Horton Creek, Mt. Tom, and Pine Creek, to the south end of Wheeler Crest.

Figure 2 and Table 1 summarize the age relationships of the various formations in the area. The pre-Tertiary rocks consist of a series of meta-sedimentary and metavolcanic rock remnants enclosed by plutonic rocks of various compositions ranging from hornblende gabbro to alaskite. The

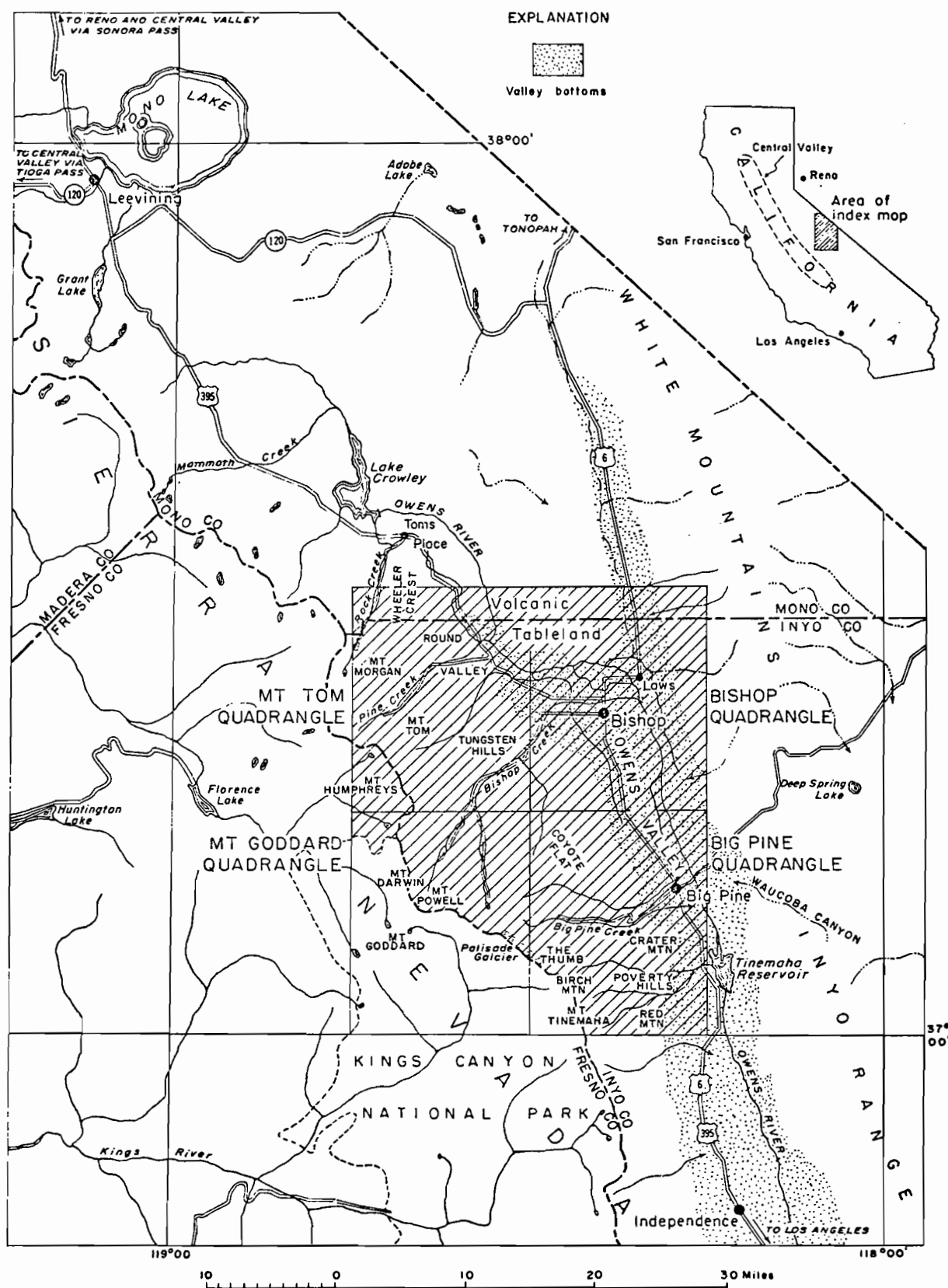


FIGURE 1. Location map of the Bishop, California area, from Bateman (1965).

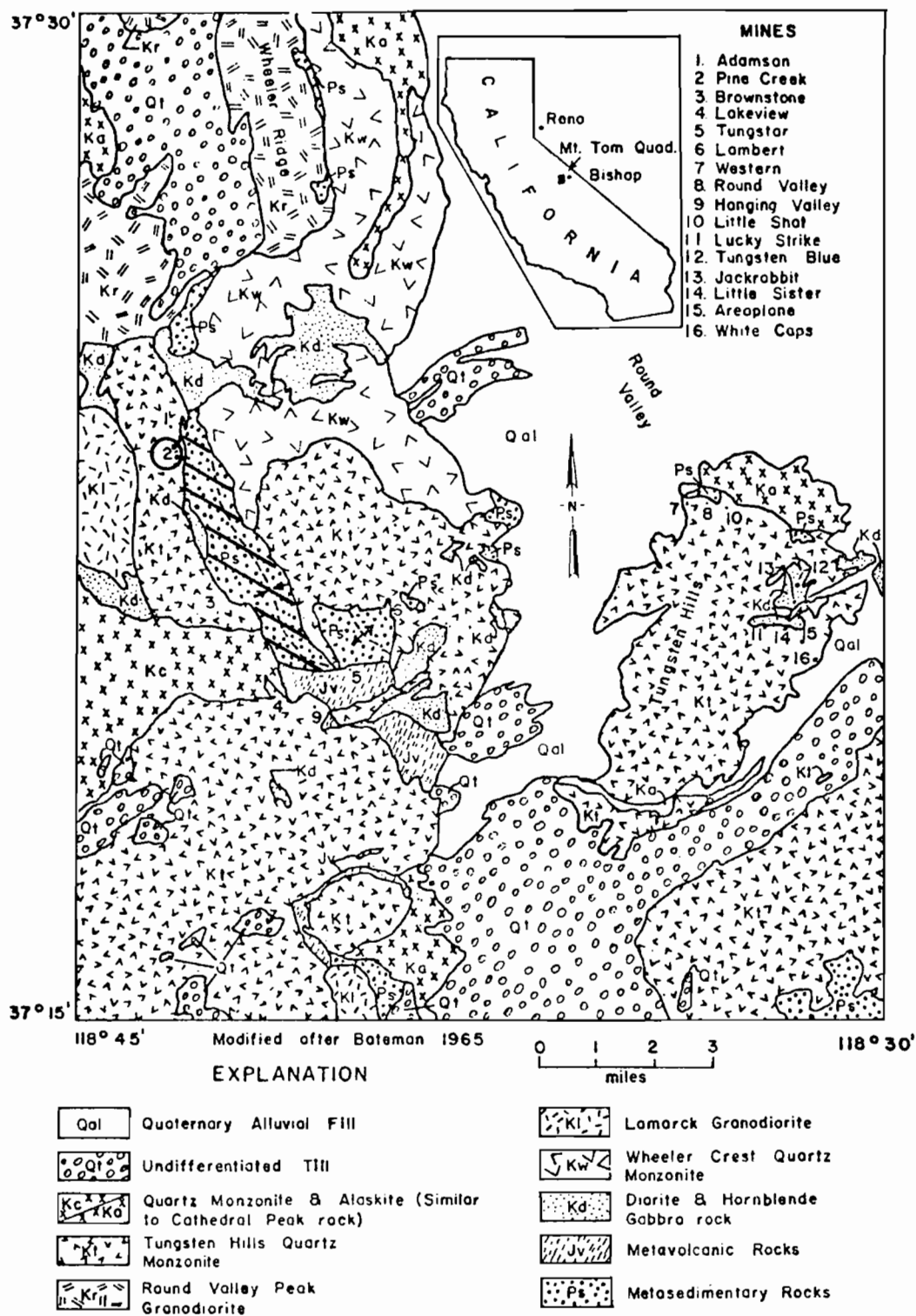


FIGURE 2. Geology of the Mount Tom Quadrangle, from Gray (1968).



TABLE 1.  
Geologic Column

Age m. y. (2)	Geologic Age	Rocks
	Quaternary	Alluvial fill Glacial deposits Volcanic deposits Older Glacial deposits Basalts
		UNCONFORMITY
		Fine grained quartz monzonite
81-87		Rocks similar to the Cathedral Peak Granite
74-76		Tungsten Hills Quartz Monzonite
	Cretaceous	Granodiorite of Deep Canyon
74-84		Lamarck Granodiorite
84-87		Round Valley Peak Granodiorite
69-99		Wheeler Crest Quartz Monzonite
		Diorite, quartz diorite, and hornblende gabbro
		PINE CREEK PENDANT
	Triassic	Mafic meta-volcanic rocks
	& Jurassic	Felsic meta-volcanic rocks
		Micaceous quartzite
	Pennsylvanian (?)	Marble
	& Permian (?)	Pelitic hornfels, micaceous quartzite, and vitreous quartzite.

(from Gray, 1968)

metasedimentary rocks (micaceous quartzite, pelitic hornfels, metachert, marble, calc-hornfels, etc.) consist of low- to intermediate-grade metamorphic equivalents of fine-grained sediments deposited during the Paleozoic era in a miogeosynclinal environment. The metavolcanics are Mesozoic in age, and were deposited in a eugeosynclinal environment, and consist of both felsic and mafic types. Strong folding followed the deposition of sediments and volcanics. During or after this time, magma intruded the folded formations.

The metasedimentary rocks are distributed in a northwest-southeast pattern east of the metavolcanics. The metavolcanics are believed to be stratigraphically higher than the metasediments based on their occurrence along the east limb of a major Paleozoic syncline. Strontium isotope ratios in the granitic rocks suggest that the magma was generated by melting sediments mixed with volcanics.

The intrusive rocks in the region are considered to be of Mesozoic age. The oldest intrusives are hornblende gabbros and quartz diorites. These were followed successively by intrusions of the Wheeler Crest Quartz Monzonite, the Lamarck Granodiorite, the Round Valley Granodiorite, the Tungsten Hills Quartz Monzonite, and alaskite dikes. The Tungsten Hills Quartz Monzonite is a light gray, medium-grained rock, porphyritic with phenocrysts of potassic feldspar. The rock is usually homogeneous, and little foliation is evident. The Wheeler Crest Quartz Monzonite is porphyritic with euhedral phenocrysts in a medium-grained groundmass. The Lamarck Granodiorite consists of quartz, orthoclase, and plagioclase, and ranges in composition from granodiorite to quartz monzonite. Planar foliation is well developed near the margins of the Lamarck, and is weaker toward the center. The Round Valley Peak Granodiorite has a composition similar to the Lamarck Granodiorite, but has a finer texture.

The contacts between intrusives are usually sharp and well-defined. Metasedimentary and metavolcanic rocks show little change as the granitic

contact is approached. The tactites which contain the Pine Creek ore bodies are a product of material exchange along thin boundaries between marble and granitic melts.

#### MINE AREA

Data for this section were extracted from Gray (1968) and Bateman (1956, 1965).

Figure 3 illustrates the surface geology of the mine and vicinity. The Pine Creek ore bodies outcrop along the east wall of a cirque at the head of Morgan Creek, a southward flowing tributary of Pine Creek. The deposits lie along a 3000 foot segment of the contact between quartz monzonite and the marble that flanks the west side of the north part of the Pine Creek pendant. The Pine Creek mine is comprised of six deposits as shown in the cutaway diagram in Figure 4. From north to south they are: the Loop ore body, the North ore body, the Pinnacle ore body, the Main ore body, the South ore body, and the Bend ore body. Typically, the larger deposits have average dimensions on the order of 75 feet in width, 500 feet in length, and 2000 feet in vertical extent.

The lithology and structure of the northern two-thirds of the Pine Creek pendant, of which the Pine Creek mine is part, are relatively simple. The mine area is near the north end of the pendant and on the west side of the marble, along a span where the outcrops of marble are narrowest. The width of the marble varies from 200 feet at the north end of the property to 1000 feet at the south end. Tactite is present along most of the 3000 foot extent of contact in the mine area; however, the thicker masses of tactite which contain the ore bodies compose about 1000 feet of the contact. Along the remaining 2000 feet of contact the tactite is either too thin or too low grade

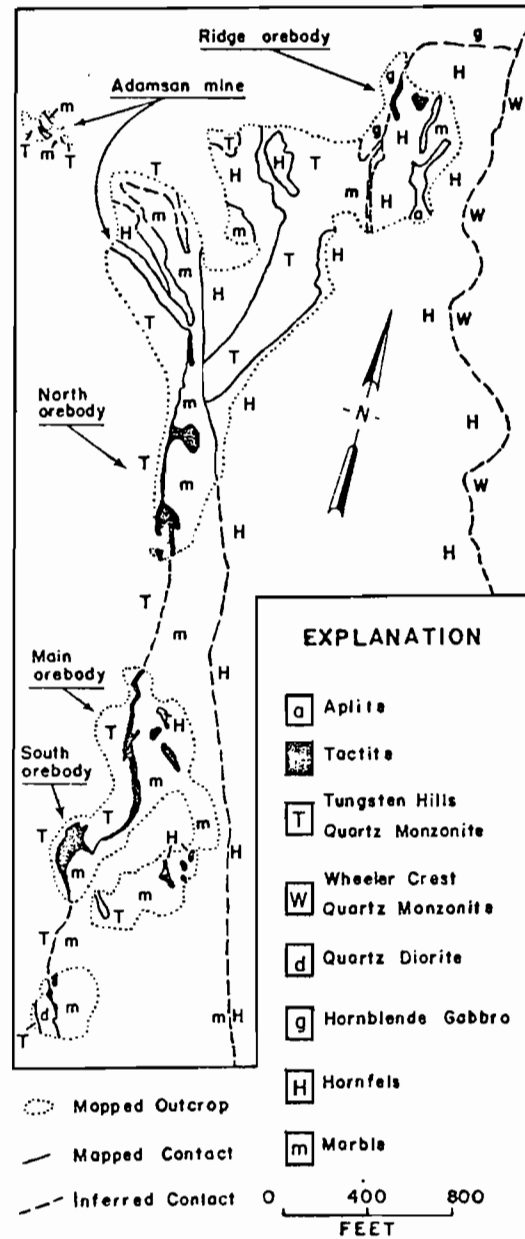


FIGURE 3. Surface Geology of Pine Creek Mine and Vicinity, from Gray (1968).

to be exploited. Of the six ore bodies that make up the Pine Creek mine, only the Pinnacle ore body is totally enclosed in marble, while the others are in the margins of the marble adjacent to the Tungsten Hill Quartz Monzonite. The trace of the intrusive contact with the marble is quite distinct and generally very steep or vertical.

The primary ore control is the contact between the marble and Tungsten Hills Quartz Monzonite, where ore traps formed in irregularities in the granitic contact. The geometry of ore body extensions in the marble is frequently influenced by the original bedding.

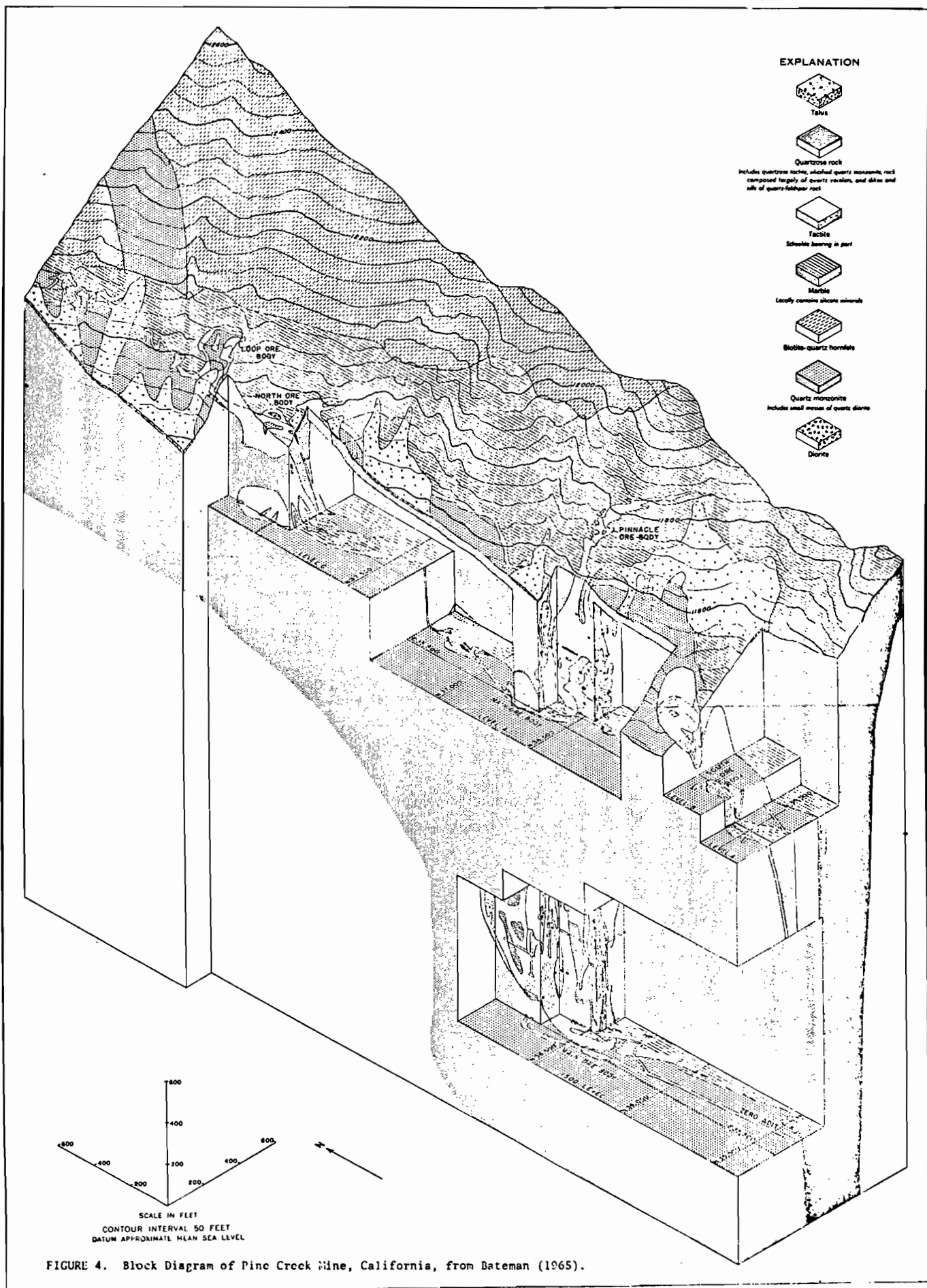
Pre-ore faulting has not been an important element in the mineralization of the tactites. Underground post-mineral fractures are commonly parallel with a regional system of near-vertical joints developed in the quartz monzonite. The displacement on the majority of fractures is less than one foot, with occasional displacement of as much as 40 feet.

#### MINE FACILITIES

Data for this section were extracted from Bateman (1956, 1965) and Gray (1967).

The Pine Creek mine was discovered in 1916, and has been operated by Union Carbide Corporation since 1935. As of 1973, the mine had a production capacity of approximately 325,000 tons of ore per year containing about 6 million pounds of recoverable tungsten.

The mine is entered through adits and is developed by means of raises, levels, and sublevels. Figure 4 illustrates the mine workings and rock types as they existed in 1965. The main adits are level C, level A, the Zero adit, and the Easy-going adit, at elevations of 11,215; 10,940; 9430; and 8100 feet, respectively. Levels A and C intersect the Main, South, and North ore bodies,



the zero adit intersects only the Main ore body, and the Easy-going adit is located about 1300 feet below the bottom of the present ore body.

The mine consists of two parts: (1) the part above level A ("old mine"), and (2) the deeper part between level A and the Zero adit. The "old mine" has been considered to be worked-out; however, higher tungsten prices may cause the reopening of the portion of the mine above level A.

The available literature does not indicate which of the ore bodies are currently being mined, however, it is very probable that at least 3 of the ore bodies are dormant. As indicated on Figure 4 and based on the available cross-sections from Bateman (1965), there are substantial workings in the quartz monzonite.

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## CLIMAX MINE

(OPERATED BY CLIMAX MOLYBDENUM COMPANY,

A SUBSIDIARY OF AMERICAN METAL CLIMAX, INC.)

## LOCATION AND ACCESSIBILITY

The Climax deposit is situated just above Fremont Pass on the west slope of the Ten Mile Range, about 12 miles northeast of Leadville and about 65 miles WSW of Denver, Colorado, at 39°22'N, 106°10'W (Figure 1). The elevation of the mine area is approximately 11,500 feet with 3500 feet of local relief. Excellent all-weather roads connect Climax with Leadville and Denver.

## GEOLOGIC SETTING

Data for this section were extracted from AMAX (1974+), Vanderwilt (1955), and Wallace (1968).

As shown in Figure 2, Precambrian crystalline rocks constitute most of the Ten Mile Range for several miles to the north, east, and south of Climax.

The Precambrian biotite-quartz-feldspar schist and gneisses of the Idaho Springs Formation are the oldest rocks in the region. Locally these rocks have been metasomatized to granite, and reinjected along with scattered mafic dikes. Later in the Precambrian, the Silver Plume Granite intruded the Idaho Springs Formation, in three closely related pulses.

During the Paleozoic Era approximately 5000 feet of sediments (limestone, sandstone, and conglomerate) were deposited. These sediments were metamorphosed to quartzites and dolomites.



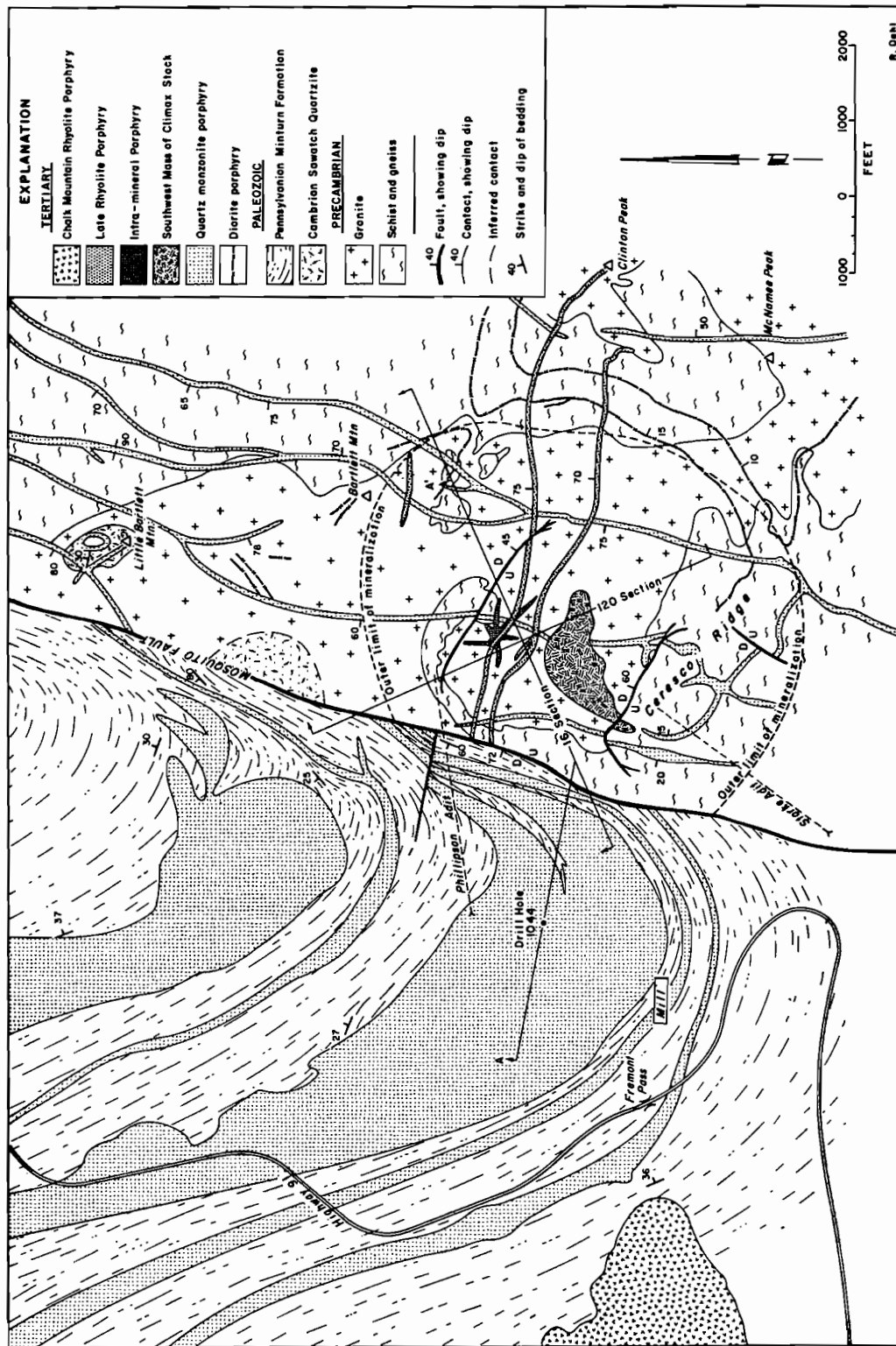


FIGURE 2. Generalized bedrock geology of the Climax area (Wallace, 1968).

Mesozoic sedimentary rocks are exposed to the north and east of Climax. There are no Mesozoic sediments, or their equivalents, preserved in the mine area.

Tertiary dikes and stocks intruded the Precambrian crystalline rocks, and Tertiary sills and dikes cut the Paleozoic sediments. The intrusive bodies range in composition from quartz monzonite to diorite. Porphyry dikes are a common feature of the crystalline rocks north of Leadville. The porphyry dikes represent the last phase of igneous activity in the region.

#### MINE AREA

Data for this section were extracted from AMAX (1974), Vanderwilt (1955), and Wallace (1968).

During the Tertiary Period three granitic stocks intruded the Climax area. The stocks were similar in composition and in close proximity, but were not contemporaneous. Each stock created a molybdenum/tungsten ore body, and was characterized by intense alteration.

The Southwest Mass of the Climax Porphyry was the first stock in the series. The intrusion caused fracturing in the adjacent country rock, which provided channels for ore-forming hydrothermal fluids. The Ceresco molybdenum ore body was formed in the shape of an inverted bowl, approximately 3,500 ft. in diameter above the Southwest Mass, as shown in Figure 3a. Silicification occurred beneath the ore body, replacing the existing rocks with nearly pure quartz.

The area east of the Southwest Mass was intruded next by the Central Mass of the Climax Porphyry. As in the previous intrusion, fracturing, upward migration of hydrothermal fluids, and silicification were repeated, and the Upper ore body was created. The ore body located above the Central

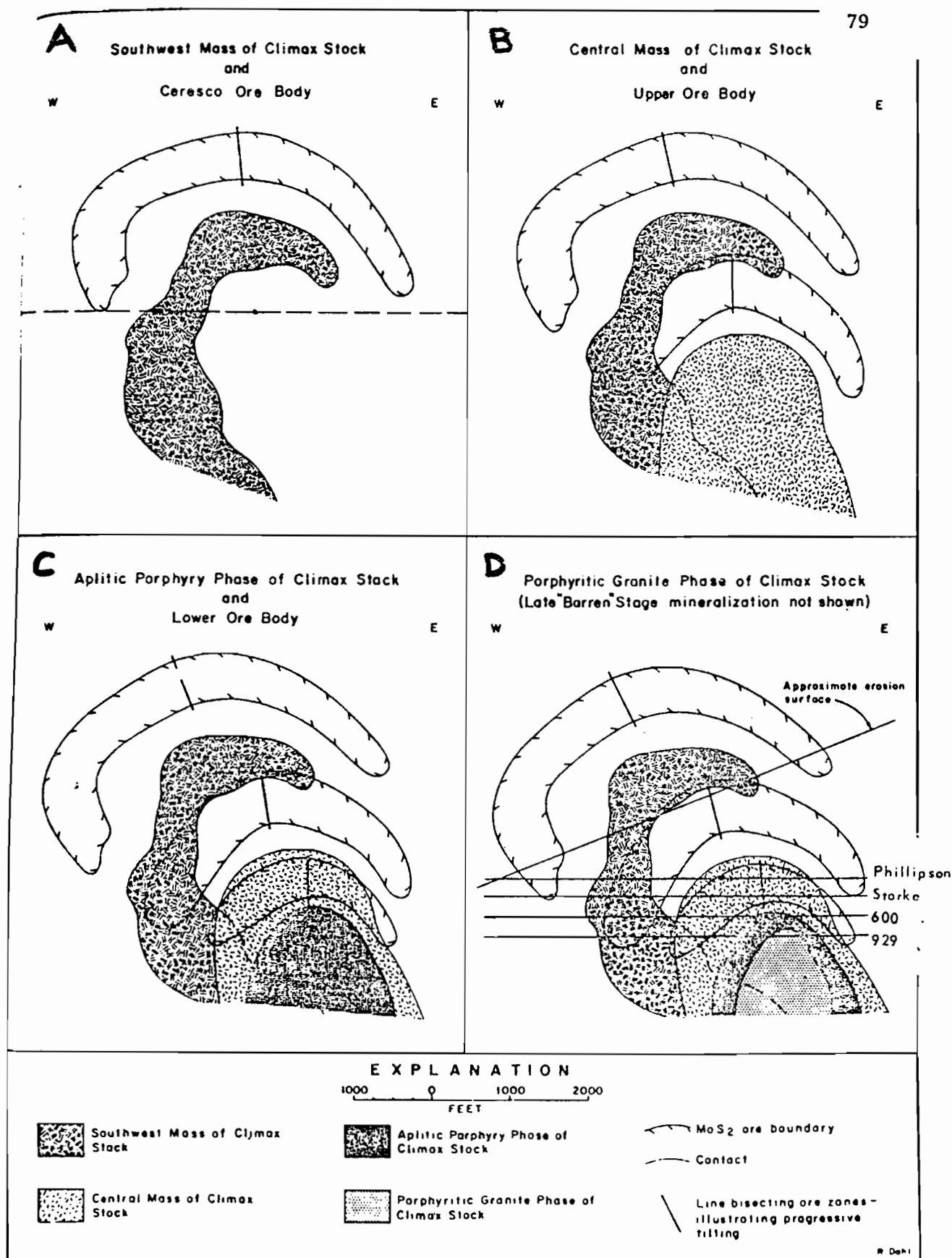


FIGURE 3. Diagrammatic sections showing multiple intrusions and mineralization, and progressive tilting (Amax, 1974+).

Mass as shown in Figure 3b is of similar shape but smaller than the Ceresco ore body.

The Aplitic Phase of the Climax Porphyry was the last ore-related intrusion. It is located slightly east of the Central Mass, and experienced the same series of mineralizing events. The resulting Lower ore body (and Lower ore body high-silica zone), the smallest of the three, is similar in shape to the others, and is located above the Aplitic Phase, as shown in Figure 3c.

A fourth igneous stock, the Porphyritic Granite Stock, was intruded into the Aplitic Phase of the Climax Porphyry, as shown in Figure 3d. This non-ore bearing stock has associated with it several large dikes and numerous small dikes, which cut part of the ore bodies.

The emplacement of igneous stocks was followed by intense faulting and fracturing. Major movements occurred along the Mosquito, South, and East Faults, shown on Figures 2 and 7. The Mosquito Fault is a major structural feature of Central Colorado. Movement along the Mosquito Fault had a profound effect on the Climax mine. Approximately 9000 feet of vertical displacement (west block down with respect to east block) has been recorded. The upward displaced east block, which contains the ore bodies, was subject to erosion and glaciation, which resulted in the destruction of most of the Ceresco ore body and the top of the Upper ore body. The approximate erosion surface is shown in Figure 3d and 4.

#### MINE FACILITIES

Data for this section were extracted from AMAX (1974+) and Vanderwilt (1955).

American Metal Climax, Inc., the owner/operator of the Climax mine, was formed by a merger of Climax Molybdenum Company and American Metal Company, Ltd., in 1957. Prior to 1957, Climax Molybdenum Company operated the mine for

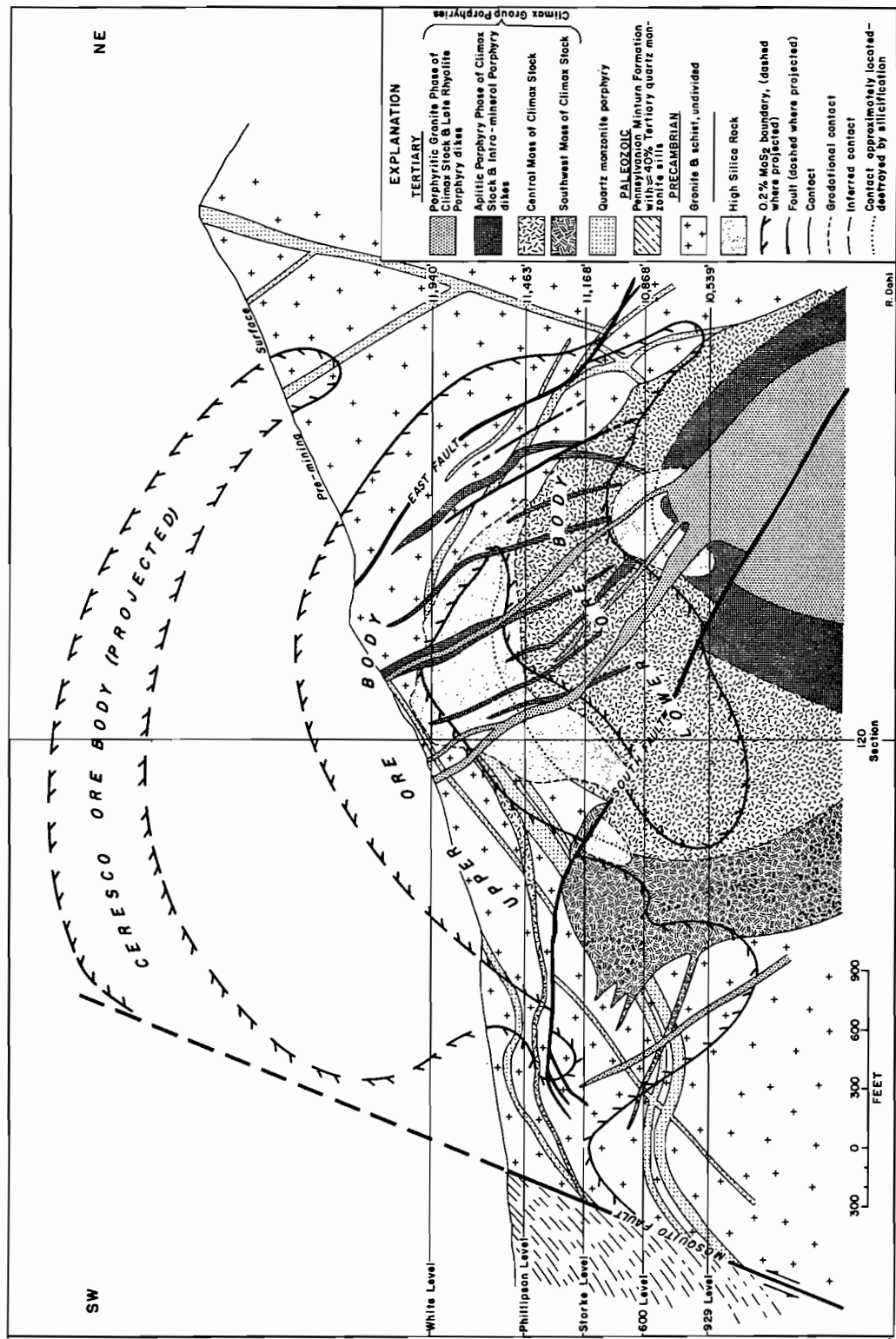


FIGURE 4. Cross section, showing generalized geology and ore zones (Wallace, 1968).



about 40 years. The mine/plant employs approximately 2500 workers. The mine operates three shifts per day, seven days per week, averaging 354 working days per year. The present rate of production is between 37,000 and 48,000 tons per day, depending on market demands and plant efficiencies. As of 1972, the ore reserves at Climax were estimated to be in excess of 450 million tons, of which 64% will be recovered by block caving.

Mining began at Climax in the Upper and White levels which were abandoned in the 1930's when production shifted to the Phillipson level. In the early 1950's a major new production level, the Storke Level, was opened. The Storke Level now produces more than half the current daily production. Development of the Ceresco and lower levels was begun in the 1960's. In 1972 production started from the new 600 level. In 1973 the first open-pit production began. The Phillipson and Ceresco levels were abandoned in 1974. The current production and abandoned levels are illustrated in a cut away view of the mines in Figure 5, and individual production levels are shown in Figure 6.

A substantial amount of the mine workings must traverse igneous intrusive and metamorphic rocks, as shown in Figure 7, a geological plan view of the abandoned Phillipson Level.

The block caving mining method at the Climax mine is very efficient. The current operations are serviced by three shafts: No. 4 shaft, service and hoisting, 19 ft. diameter, 754 ft. deep, the shaft is enclosed underground and services the 600 and lower levels from the Storke level; No. 5 shaft, service, 23 ft. diameter, 670 ft. deep; and No. 7 Shaft, ventilation, 29 ft. diameter, 370 ft. deep, services Storke and lower levels. Adits service the Phillipson and Storke levels, as shown in Figures 2, 6, and 7.

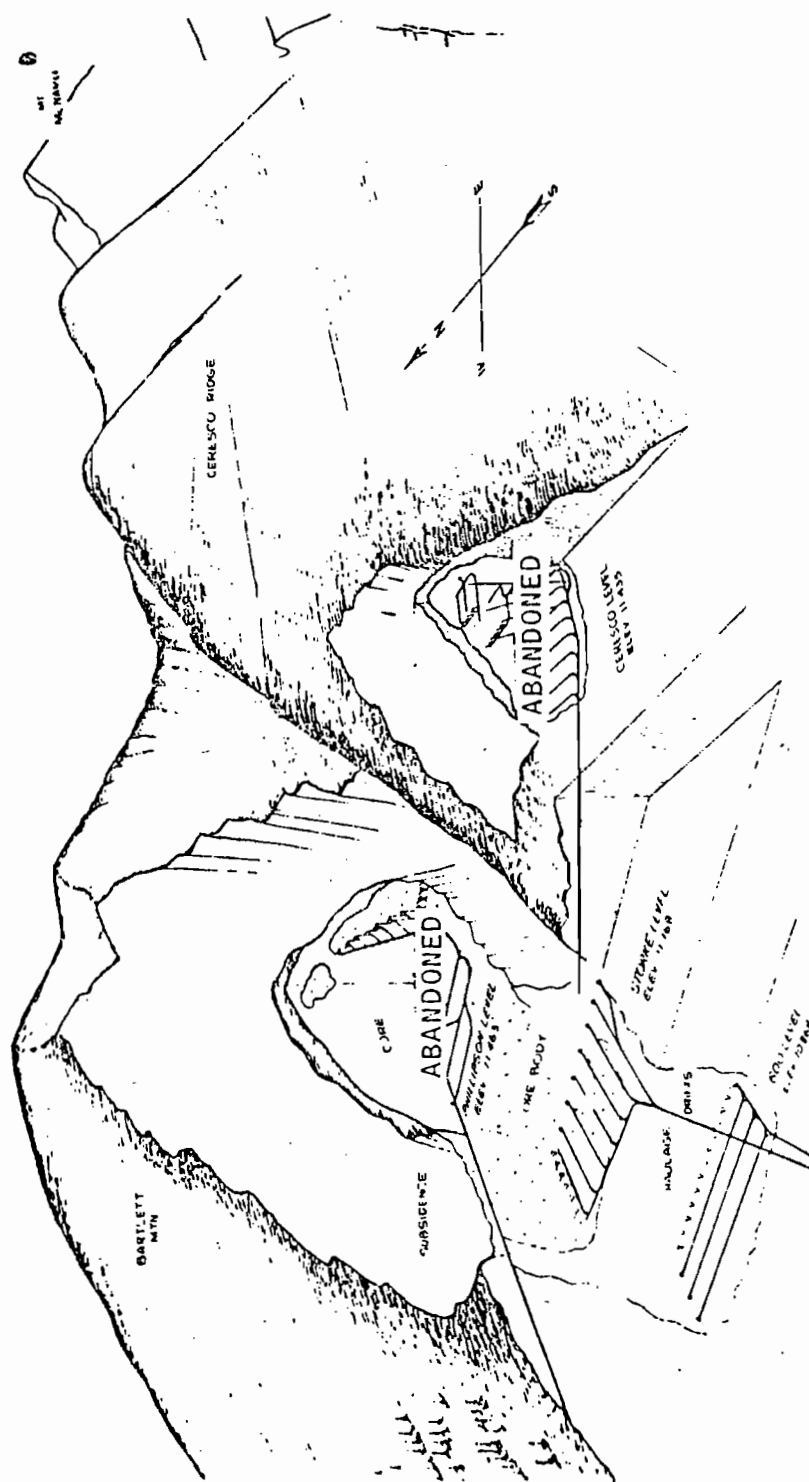
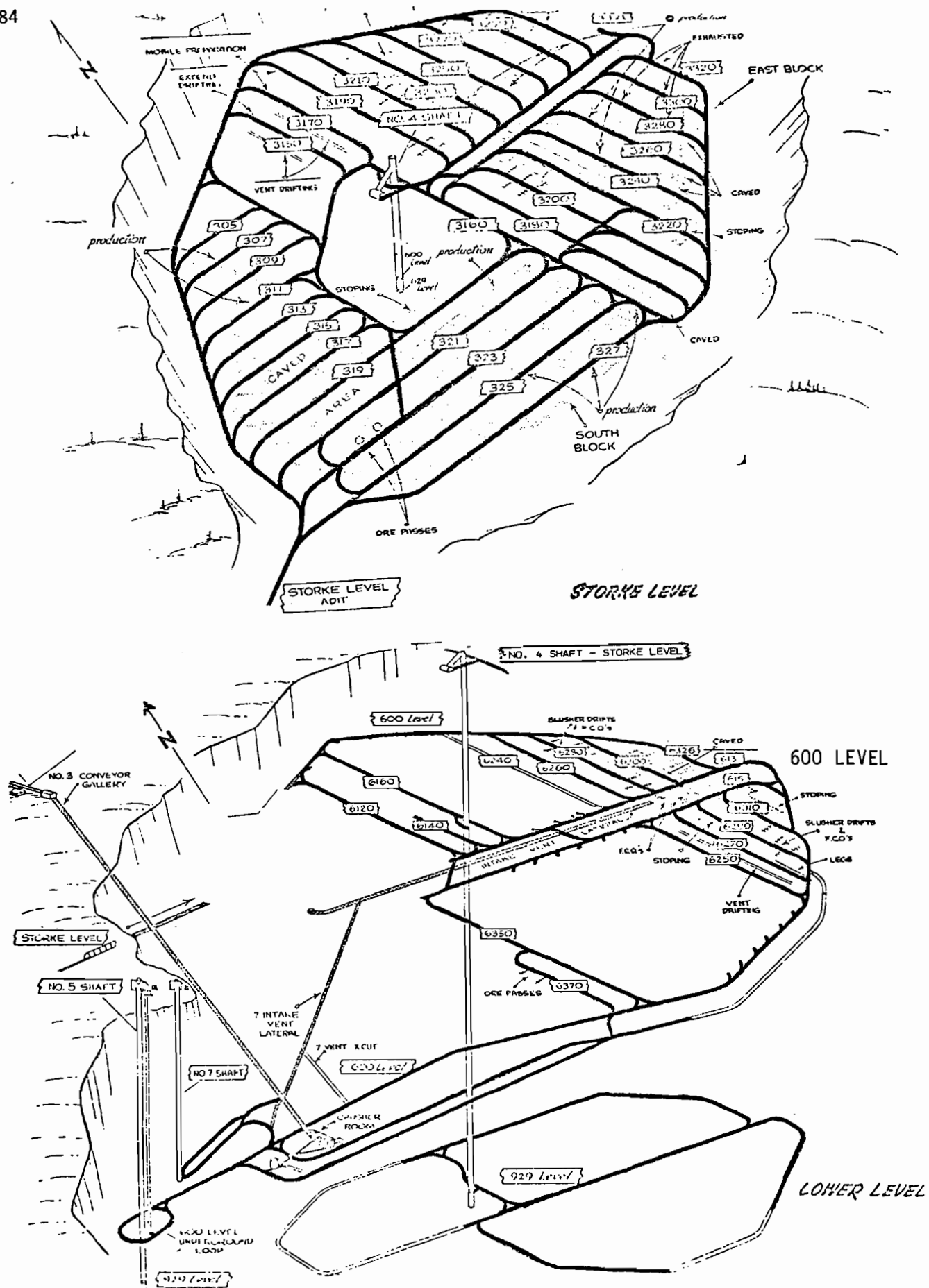


FIGURE 5. Cut-away diagram of Climax mine (Amax, 1974+).



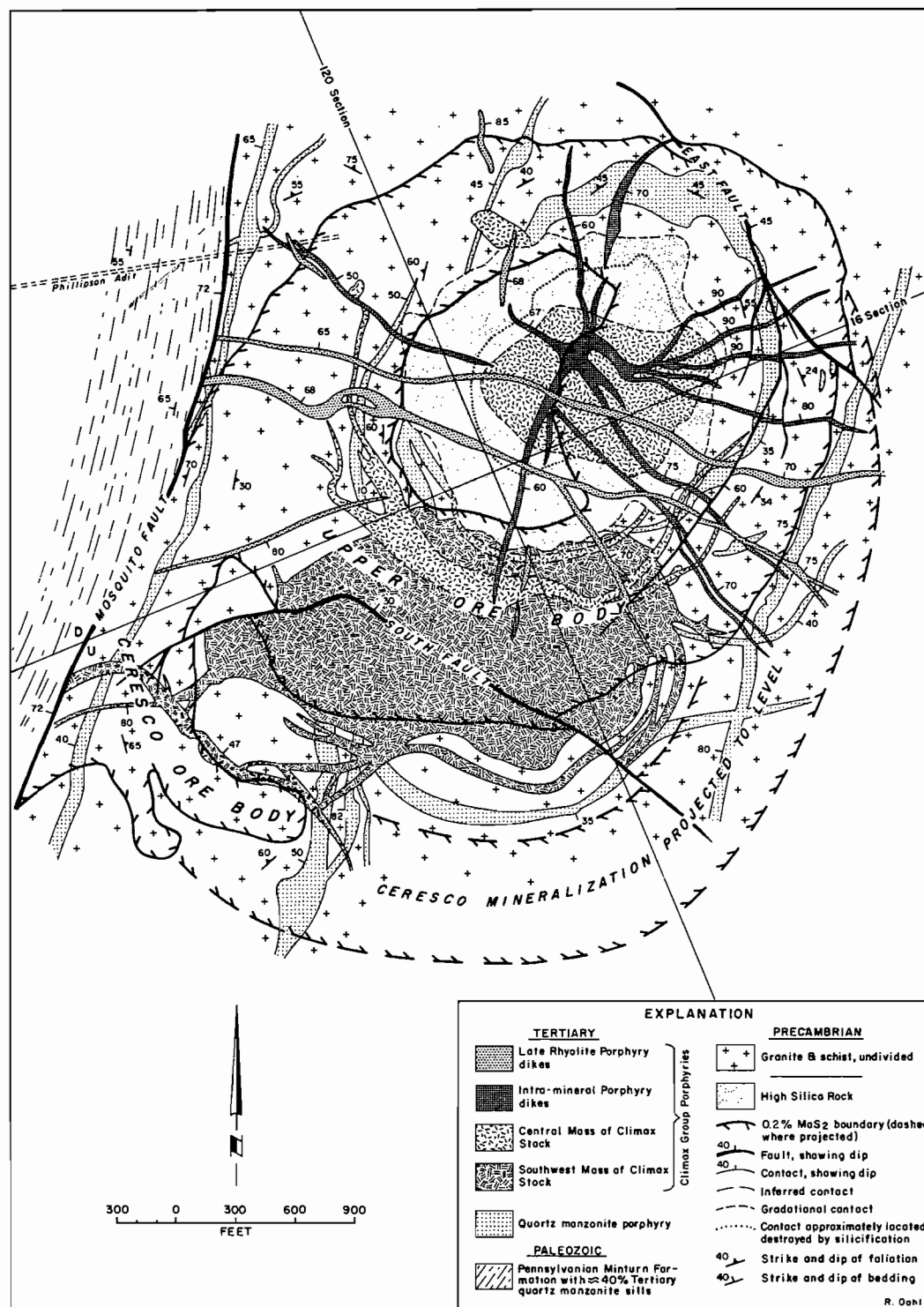


FIGURE 7. Phillipson Level, showing generalized geology and ore zones (Wallace, 1968).

Support is provided by 12" x 12" timber, or 5 ft. long roof bolts and shotcrete, or concrete legs with rock bolts. Haulage is by rail to the underground crushing plant, then by conveyor to the surface. Ventilation is supplied at a rate of 1.3 million cfm. All mine water is collected in flumes and pumped from the sump across the Continental Divide to be reclaimed in the closed circuit mill water supply. Water flow averages 400 gpm with 5000 gpm peaks during spring runoff.

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SCHWARTZWALDER MINE  
(OPERATED BY COTTER CORPORATION)

#### LOCATION

The Schwartzwaldler mine (also known as the Ralston Creek mine) is located at 39°50'N, 105°15'W in the Front Range on the southwest side of Ralston Creek in the northeastern part of the Ralston Buttes district, about 8 miles northwest of Golden, Colorado (Figure 1).

#### GEOLOGIC SETTING

##### Regional

Data for this section were extracted from Sims (1964) and Sheridan (1967).

As shown in Figure 2, metamorphic and igneous rocks of Precambrian age form most of the bedrock of the Ralston Buttes district. In the northeastern part of the district, the Precambrian rocks are overlain unconformably by sedimentary rocks of Paleozoic and Mesozoic age. An interlayered succession of mica schist, gneiss, amphibolite, and quartzite comprises the Precambrian metamorphic rocks. The rocks in this succession are of sedimentary origin, and were intruded in the western and northern parts of the district by Precambrian plutons, comprised of granodiorite-quartz monzonite, quartz monzonite, and hornblende diorite and associated hornblendite.

The predominant trend of layering, foliation, and the axial plane of major folds in the Precambrian metamorphic rocks is east to northeast. This trend is a product of major deformation accompanied by intrusion of the principal



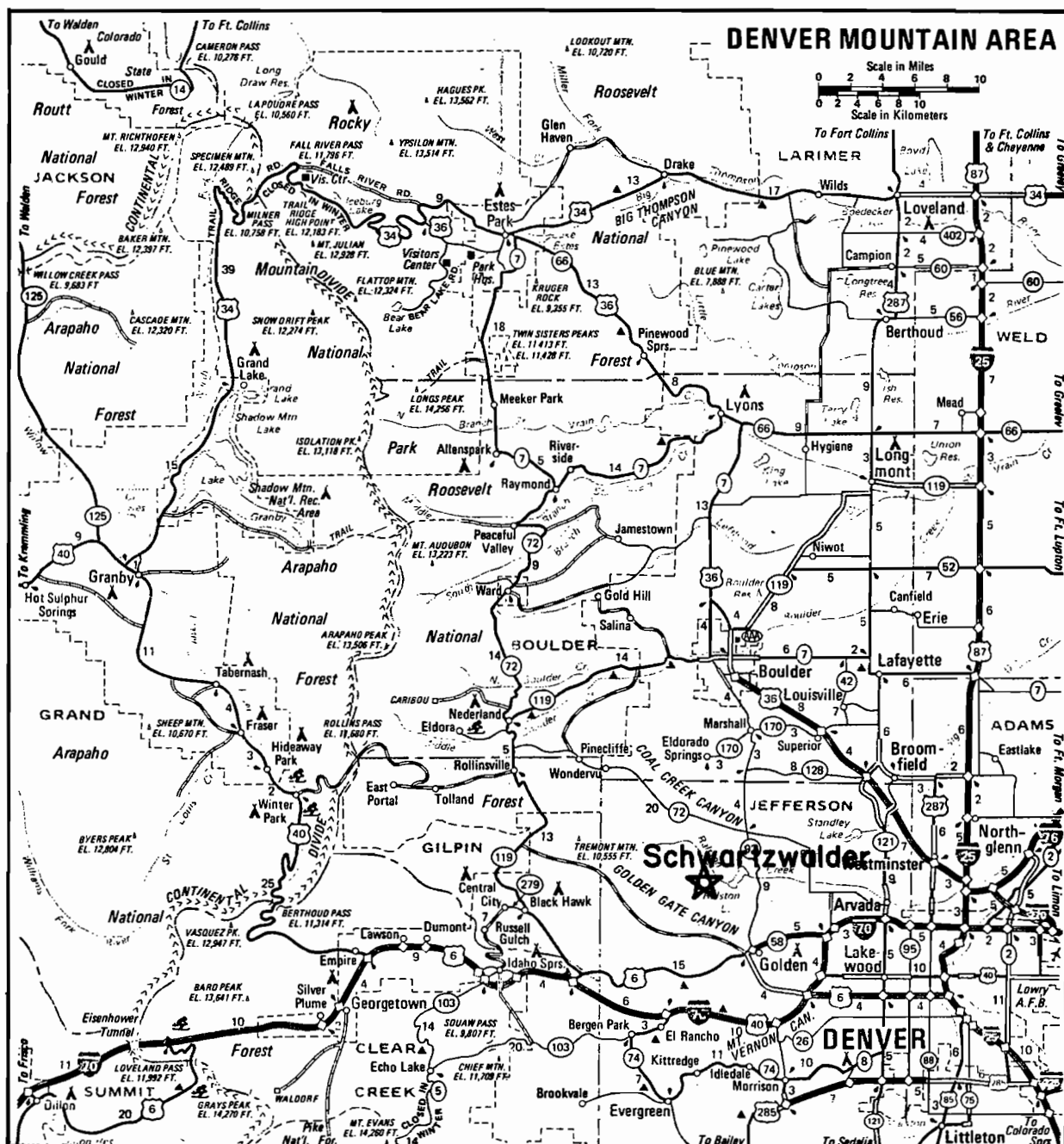
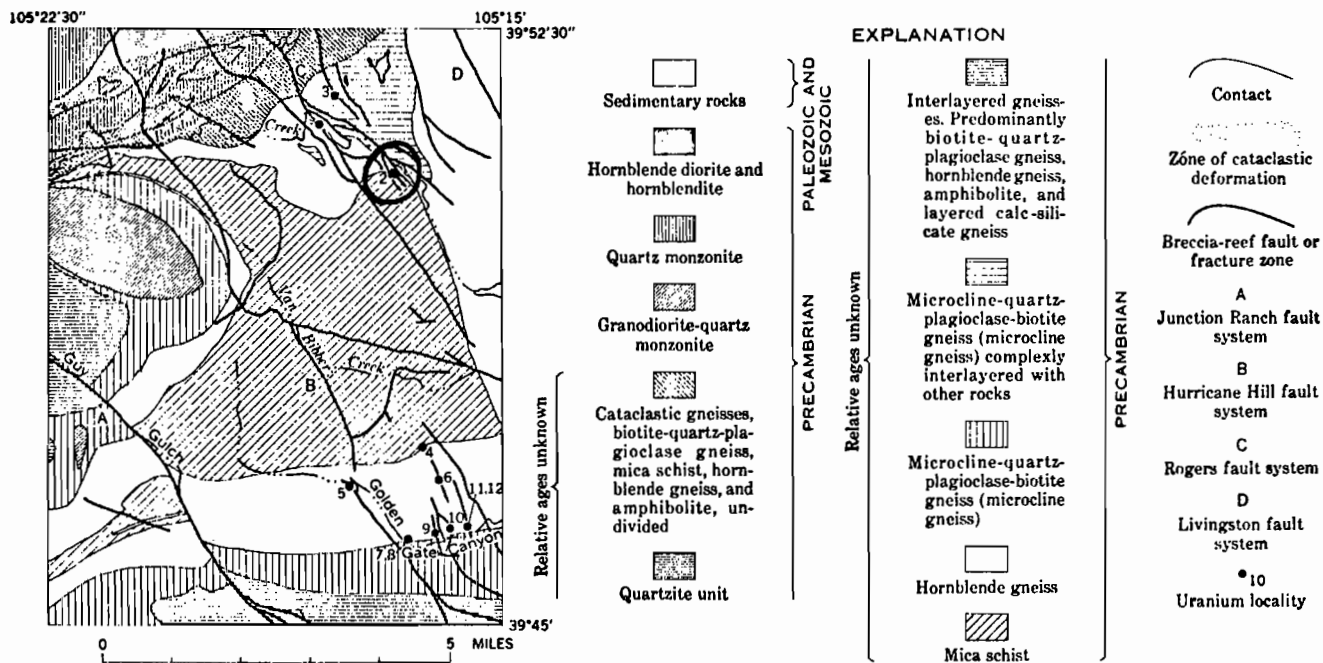


FIGURE 1. Map of Colorado - Denver Mountain area. Basic map reproduced by permission of the American Automobile Association, copyright owner.



Simplified geologic map of the Ralston Buttes district, Jefferson County, showing the principal uranium deposits. Geology by D. M. Sheridan, C. H. Maxwell, A. L. Albee, and Richard Van Horn, 1953-1958. List of mines and prospects: 1. Mena mine; 2. Schwartzwalder mine; 3. North Star mine; 4. Aubrey Ladwig lease; 5. Ascension mine; 6. Fork prospect; 7. Buckman adit; 8. Ohman mine; 9. Ladwig no. 1; 10. Union Pacific prospect; 11. Ladwig no. 3; 12. Ladwig no. 2. Names of fault systems taken from their northwestward extensions (Lovering and Goddard, 1950, pl. 2).

FIGURE 2.

igneous rocks. Four prominent northwestward trending fault systems cross the district, consisting of breccia reefs, related faults, and intensely fractured areas. It is believed that these faults were active during Precambrian time and again during the Laramide revolution.

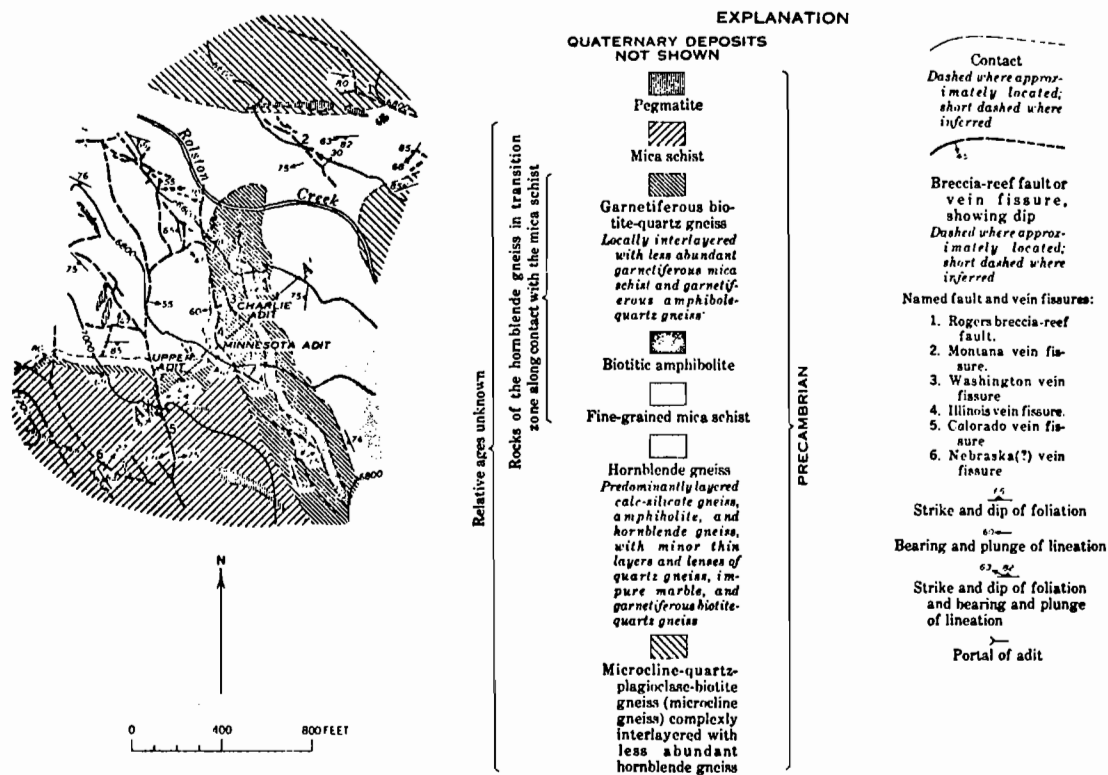
### Mine

Data concerning the mine geology were extracted from Sims (1964), Sheridan (1967), and EMJ (1978).

The Schwartzwalder mine is in the transition zone along the contact between the mica schist unit and the undivided hornblende gneiss unit, as shown in Figures 3 and 4. Bedrock in the mine area is represented by three principal rock units: (1) mica schist in the southern part of the area, (2) hornblende gneiss in the central part, and (3) microcline gneiss inter-layered with less abundant hornblende gneiss in the northern part. The hornblende gneiss is separated from the mica schist by a transition zone 50-300 feet wide. The mine workings are primarily in this transition zone.

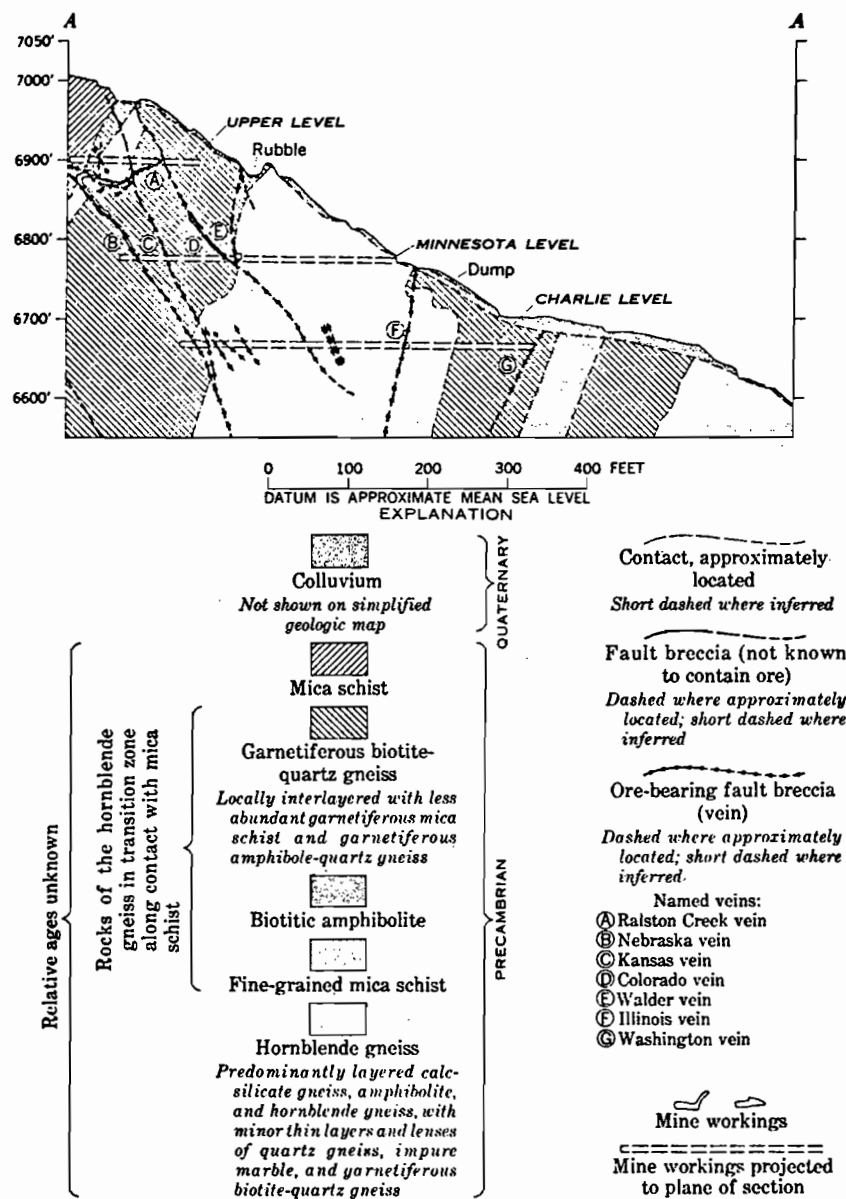
The rocks in the vicinity of the mine are folded into a fairly large syncline and an adjacent anticline, the axes of which plunge steeply to the southwest. In places the syncline is tight, nearly isoclinal, and in part overturned, while elsewhere it is more open. The predominant plunge and bearing of lineations in the area are respectively  $60^{\circ}$ - $70^{\circ}$ S and  $65^{\circ}$ - $70^{\circ}$ W, approximately parallel to the major fold axes.

Numerous faults and fracture zones of the Rogers fault system lie within the area, primarily between two major bounding faults. The bounding fault north of Ralston Creek (a reverse fault) strikes northwest, dips steeply to the northeast, and has resulted in the displacement of the northeast



Simplified geologic map of the Schwartzwalder mine area, Ralston Butte district, Jefferson County. Section A-A' shown in figure 22. Geology and topography by D. M. Sheridan, 1956. Base surveyed by planetable methods by D. M. Sheridan, W. E. Willging, and O. H. Maxwell, 1955-1956.

FIGURE 3.



-Geologic section of the Schwartzwalder mine, Ralston Buttes district, Jefferson County. Line of section shown on figure 21. Geology by D. M. Sheridan, 1956.

FIGURE 4.

block upward and to the southeast, with a lateral displacement of about 2200 feet. The other bounding fault trends northwest and lies approximately half a mile southwest of the mine. The block between the bounding faults is approximately 3500 feet wide, trends about N50°W, and is cut by a group of intricately branching and splitting faults. The history of movements along the various faults is complex, and at least three episodes of fracturing are recognized; however, the net displacement along the subsidiary faults appears to be minimal. Some of the subsidiary faults are occupied by the mineralized veins which make up the Schwartzwalder ore body.

The pitchblende mineralized veins of the Schwartzwalder mine are typically dark-colored fault breccias and adjoining fractured wallrocks which are coated, filled, and veined by ore minerals. The veins range in thickness from a fraction of an inch to as much as 8 feet, however, in places where they converge, stopes up to 35 feet wide have been mined. The locally mineralized, steeply dipping Illinois fault hosts the Schwartzwalder ores. In the mine, the fault can be seen as a breccia structure with mineralization on the second level, as an unmineralized shear zone on the ninth level, and as a mineralized coarsely crustified open fault with post-pitchblende calcite on the 11th level. The ore strike length is usually short in comparison with the mineralized dip length. The source of mineralizing fluids is unknown.

#### MINE FACILITIES

Data for this section were extracted from EMJ (1978).

Cotter Corporation acquired the Schwartzwalder mine in 1965, when the operation was producing about 70 tons of ore per day. Production has since expanded to 600 tpd, the maximum possible based on installed hoisting capacity.

As shown in Figure 5, three internal shafts provide access to the Schwartzwalder stopes: the No. 1 shaft, which is used only as an escape route; the No. 2, with two 60-inch compartments covering a vertical distance of 1300 feet; and the No. 3, with two 72-inch compartments covering a distance of 1000 feet. Twenty levels at 100 foot vertical intervals extend from the surface down to an elevation of about 4430 feet. Development is currently being done on the 16th level.

Shrink stope methods, with jacklegs and stopers for drilling, are used to extract steeper veins. Slushers, trackless loaders discharging into Young Buggies, and 1-cu-yd-capacity front-end loaders expedite transfer of ore and muck to ore passes.

After mining terminates in a vein, stopes are sealed off to prevent the escape of radon gas and to streamline the mine ventilation. About 250,000 cfm of air is downcast through the shafts by 75-hp fans. The air exhausts through an 8-ft diameter, 2500 ft-deep ventilation raise completed in 1977.

Along with possibly providing access for rock mechanics and hydrological testing of high-grade metamorphic rock, the Schwartzwalder mine may also offer sites for the study of natural uranium occurrences as analogs to the behavior of radioelements in a crystalline-rock waste-repository environment.

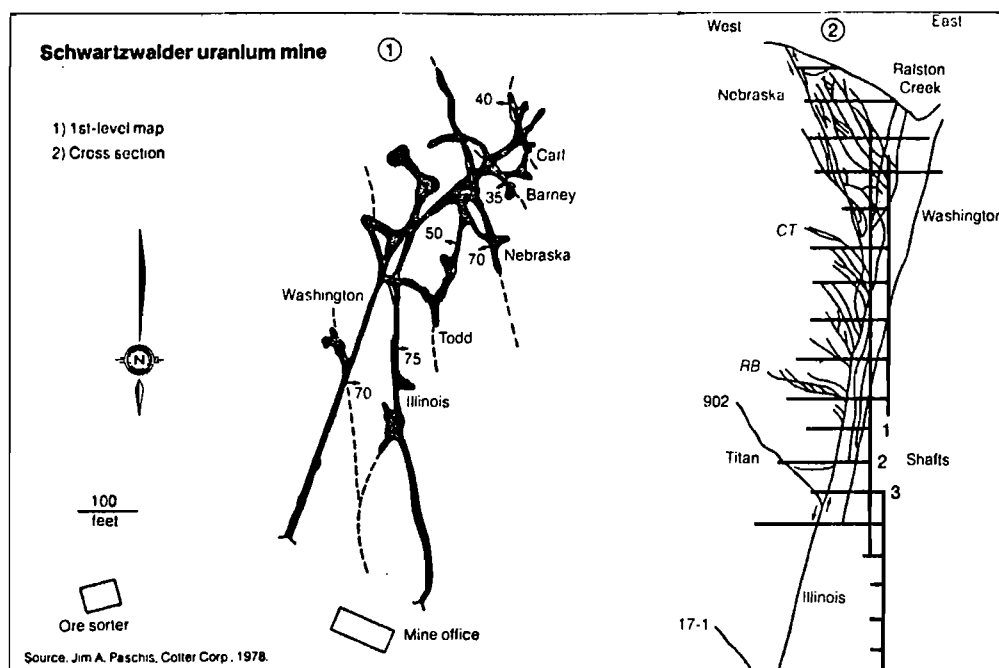


FIGURE 5. Recent Cross-Section of Schwartzwalder Mine, with level map.



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## URAD MINE

## HENDERSON MINE

(OPERATED BY CLIMAX MOLYBDENUM COMPANY,  
A SUBSIDIARY OF AMERICAN METAL CLIMAX, INC.)

## LOCATION

The Urad and Henderson molybdenum mines are located at Red Mountain, about 8 miles west of the community of Empire, in the Front Range of Colorado at 39°46'N, 105°50'W. As shown in Figure 1, the mines are about 50 miles west of Denver. The smaller Urad ore body crops out at the surface, while the Henderson ore body is located about 3700 feet beneath the 12,315 foot peak of Red Mountain. The Henderson mine is about 2000 feet below the Urad mine.

## GEOLOGIC SETTING

Regional

Data on the geology of the region and the ore bodies was extracted from Hoppe (1976) and Ranta (1976).

The regional geologic setting of the Urad and Henderson ore bodies can be discussed jointly because of their proximity to one another within the Red Mountain igneous complex.

The Red Mountain igneous complex was intruded into the Precambrian Silver Plume granite near the convergence of two major fault zones. The Berthoud-Loveland and Vasquez fault zones are believed to have been key structural elements in the emplacement of the Red Mountain complex. The Berthoud-Loveland fault zone has a NE trend and lies southeast of Red

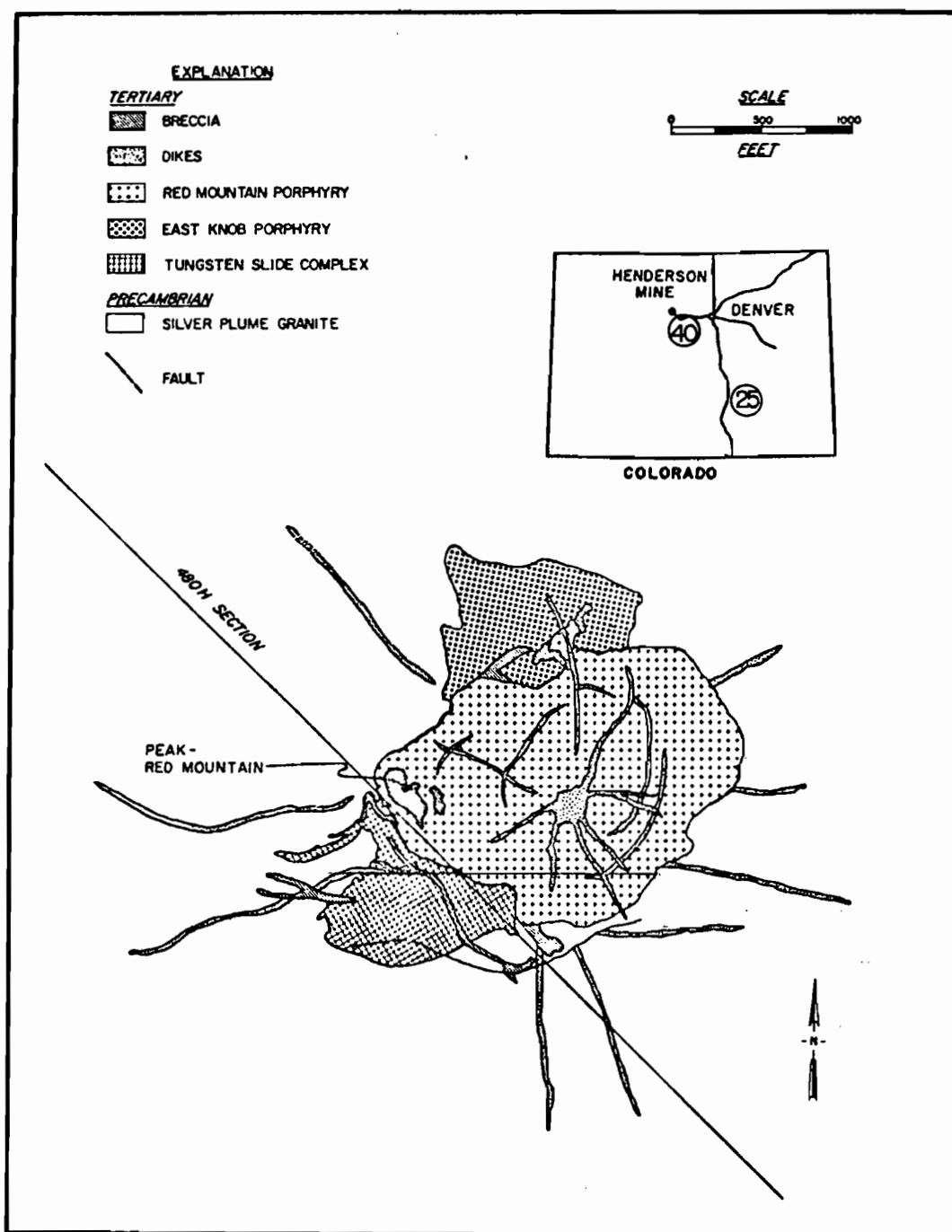


FIGURE 1. Generalized surface geologic map of Red Mountain showing location of section 480H (after Ranta, 1976).

Mountain, while the Vasquez fault has a NNE trend and lies northwest of Red Mountain.

The intrusive complex is exposed at the surface over an outcrop area of 1200 by 2500 feet, at 7500 foot elevation, the diameter of the complex is approximately 5100 feet. Subvolcanic rhyolite porphyries, near the surface, change downward to mineralogically similar, fine-grained granite porphyries and to a fine- to medium-grained equigranular granite. These intrusions were emplaced in late Oligocene to early Miocene time. Five major intrusive episodes, each with two or more phases, formed the Red Mountain intrusive complex.

#### Geology of the Near-Surface Urad Mine

The geology of the Urad mine was extracted from Hoppe (1976) and Ranta (1976).

The ore body originally contained approximately 13 million tons of plus 0.3% MoS<sub>2</sub>. The maximum dimensions of the ore body are 400 feet wide, 1200 feet long, and 1000 feet high.

The Tungsten Slide complex, the East Knob Porphyry, and the Red Mountain Porphyry are the three principal Tertiary intrusions exposed at the surface. The relationship of these intrusions is shown in plan view in Figure 1 and in cross-section in Figure 2. Radial and concentric dike and explosion breccia patterns suggest that the intrusions were of a shallow, subvolcanic nature. The ore at Urad is contained in a system of fractures that transects the Precambrian Silver Plume granite and the Tungsten Slide Complex.

The Tungsten Slide Complex consists of a breccia, in close association with the Crowded Quartz Porphyry and the Square Quartz Porphyry. The

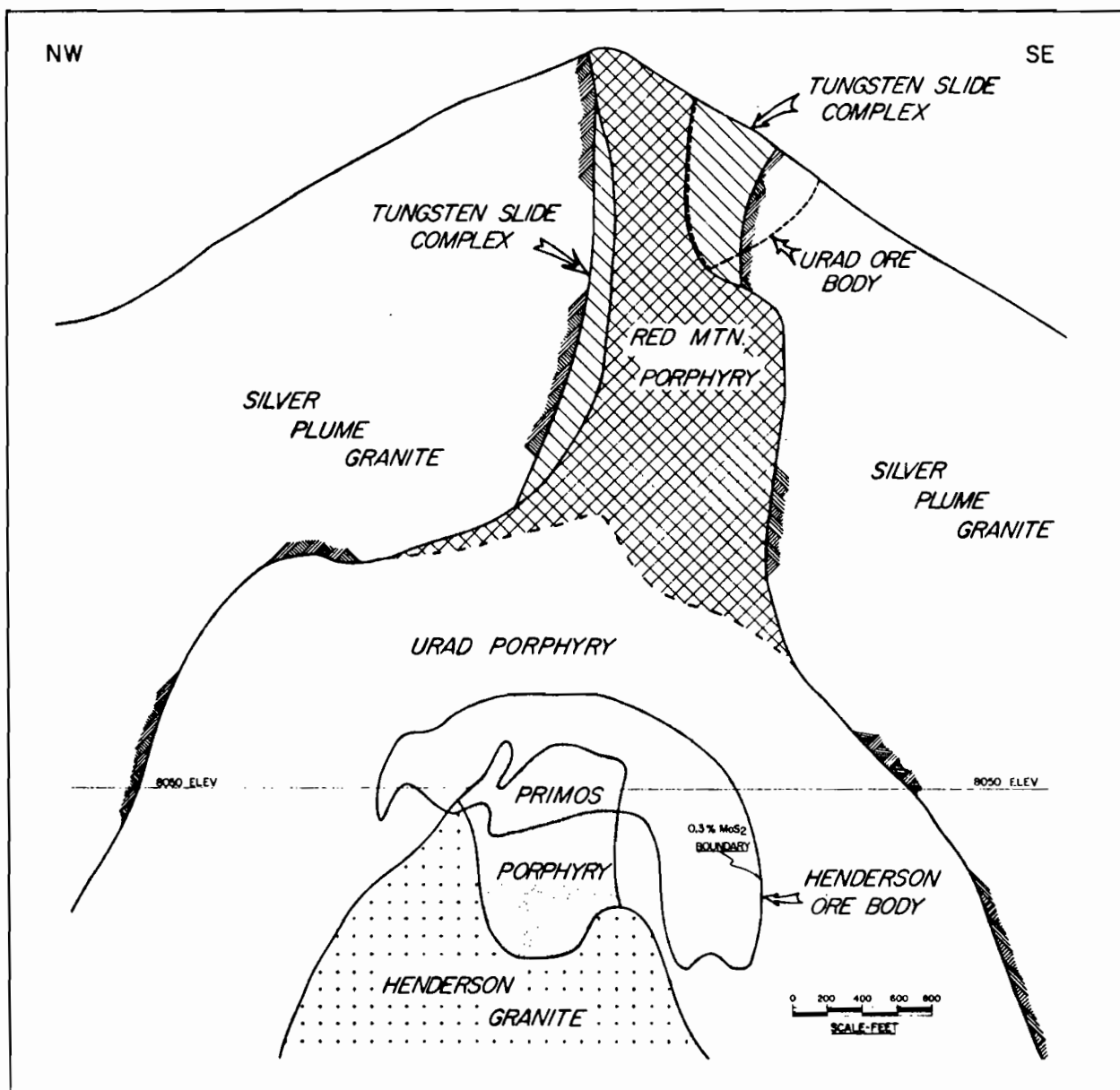


FIGURE 2. Generalized geologic Section 480 H, (after Ranta, 1976).

Crowded Quartz Porphyry lies directly beneath the breccia, while the rhyolitic Square Quartz Porphyry occupies a lower, core position within the Tungsten Slide Complex.

The northeastern part of the Red Mountain intrusive complex consists of Tertiary East Knob Porphyry. The rhyolitic East Knob Porphyry is strongly altered and pyritized, and locally contains presently-uneconomic mineralization.

The Red Mountain Porphyry cuts both the Tungsten Slide Complex and the East Knob Porphyry, and may have removed part of the Urad ore body. This rhyolitic porphyry plug forms the core of the Red Mountain intrusive complex, and may have fed a volcanic vent.

#### Geology of the Deeper-Seated Henderson Mine

Geology of the Henderson Mine was extracted from Hoppe (1976) and Ranta (1976).

The Henderson molybdenum ore body contains in excess of 300 million tons of ore, averaging 0.49%  $\text{MoS}_2$ . The deposit has the shape of an inverted cup, slightly elongate to the northeast. Ore body dimensions are approximately 3000 by 2200 feet with an average thickness of approximately 600 feet.

There is a transitional contact zone between the Red Mountain Porphyry plug and underlying Urad Porphyry, some 2500 feet beneath the surface. Also shown in Figure 2 are the Primos Porphyry and Henderson granite, which make up the core of the Urad porphyry. Primos Porphyry solidified beneath the solid crystalline hood of the Urad Porphyry intrusion, while the late Henderson granite occupies a similar position beneath the combined Urad-Primos hood. All of these deep-seated intrusions are granites.

The Urad Porphyry forms the largest volume of any igneous rock in the complex, and is the host for the bulk of the Henderson molybdenum ore body and associated alteration halos.

#### MINE FACILITIES - Urad Mine

##### General

Climax Molybdenum Company purchased the Urad mine during the mid-1960's. Mining at the Urad has been intermittent since 1920. Beginning in 1967, Climax Molybdenum Corp. produced 6.5 million lbs. per year of molybdenum at a daily ore mining rate of 5000 tons. From 1967 to 1974, the now-depleted Urad ore body produced 13.7 million tons of ore, averaging 0.49 percent  $\text{MoS}_2$ .

##### Mine

Data for this section were extracted from Kendrick (1970).

The literature regarding the Urad mine does not give any information concerning the present condition or type of facilities available.

The Urad ore body was made up of two distinct rock types - a Tertiary fine-grained rhyolite porphyry and a Precambrian coarse-grained granite. On the basis of these rock types, the block (inductive) caving mining plan had two major production levels. The first caving, an area of approximately 300 by 450 feet, was totally within the rhyolite porphyry. Access appears to be by adit rather than shaft. The second caving, about 300 by 300 feet, was entirely within the granite.

## MINE FACILITIES - Henderson mine

### General

Climax Molybdenum Company's Henderson mine began production in July 1976. Ore production began at approximately 3000 tpd and is expected to reach 30,000 tpd by 1980. The mine employs about 1300 workers. The ore body lies 3700 to 5400 feet beneath the crest of Red Mountain, on the eastern edge of the Continental Divide. The mine plant - headframes, shops, warehouse, offices, and auxiliary facilities are situated at the foot of Red Mountain, in the Clear Creek Valley, some 1700 feet above the top of the ore body. The mine plant is located alongside U.S. Route 40, 50 miles west of Denver.

### Mine

Data for this section were extracted from EMJ (January & June, 1976, September 1975).

The Henderson mine project is a significant engineering achievement based on the facts that its haulage tunnel is the third longest railroad tunnel in the world, and its production shaft, at 28 feet in diameter and 3100 feet deep, is the largest in North America.

A mechanized panel-caving mining method is being used at Henderson. In panel caving, the ore body is divided into a series of panels that are defined by production drifts; each panel is 80 feet wide and of varying length. There are no pillars left between the panels, which are caved in sequence, progressing in two directions simultaneously. The first production level, the 8100, is 2350 feet below the collar of the access shaft. The second production level, the 7700, to be opened in later years, is 200 feet above the permanent main railroad haulage level.



The Henderson mine is serviced by 4 shafts: No. 1 with a depth of 2440 feet; No. 2, 3100 feet and offset 2500 feet from the ore body; No. 3, 2290 feet; and No. 4, 1585 feet, located several miles away, which affords exhaust ventilation for the railroad haulage tunnel.

The No. 1 and No. 3 shafts, which are 23 feet in diameter, are exhaust and intake ventilation airways. The No. 2 shaft has three-compartments and is equipped with a 24 x 9 foot man-material cage with a capacity for 100 men or a 20-ton load, a double-deck man cage with 114 man capacity, and a chippy cage for a four-man shaft inspection team.

Figure 3 is a three dimensional view of the Henderson mine workings. Total lateral development exclusive of the railroad haulage tunnel exceeds 114,000 feet, including 13,000 feet of ramps.

Henderson's main haulage way for transferring ore from the 24 loading pockets cut above the 7500 level is a 52,000 foot long railroad tunnel. Ore is transported in 30-car trains from the 7500 level at 3% grade to the western portal at elevation 8950 feet and then another 4 miles to the crusher at the mill site. The tunnel has dimensions of approximately 16 x 15 feet, and is driven through granite on the eastern, underground end, then through Precambrian schists and gneisses. The metamorphosed rocks, which made up the bulk of the western drive, caused some serious problems in tunneling through sections of wet, highly fractured, and squeezing ground.

It appears that there are substantial workings in Precambrian granitic and metamorphic rock, as well as in Tertiary granitic rock, which may furnish access for in-situ geomechanical and hydrologic testing.

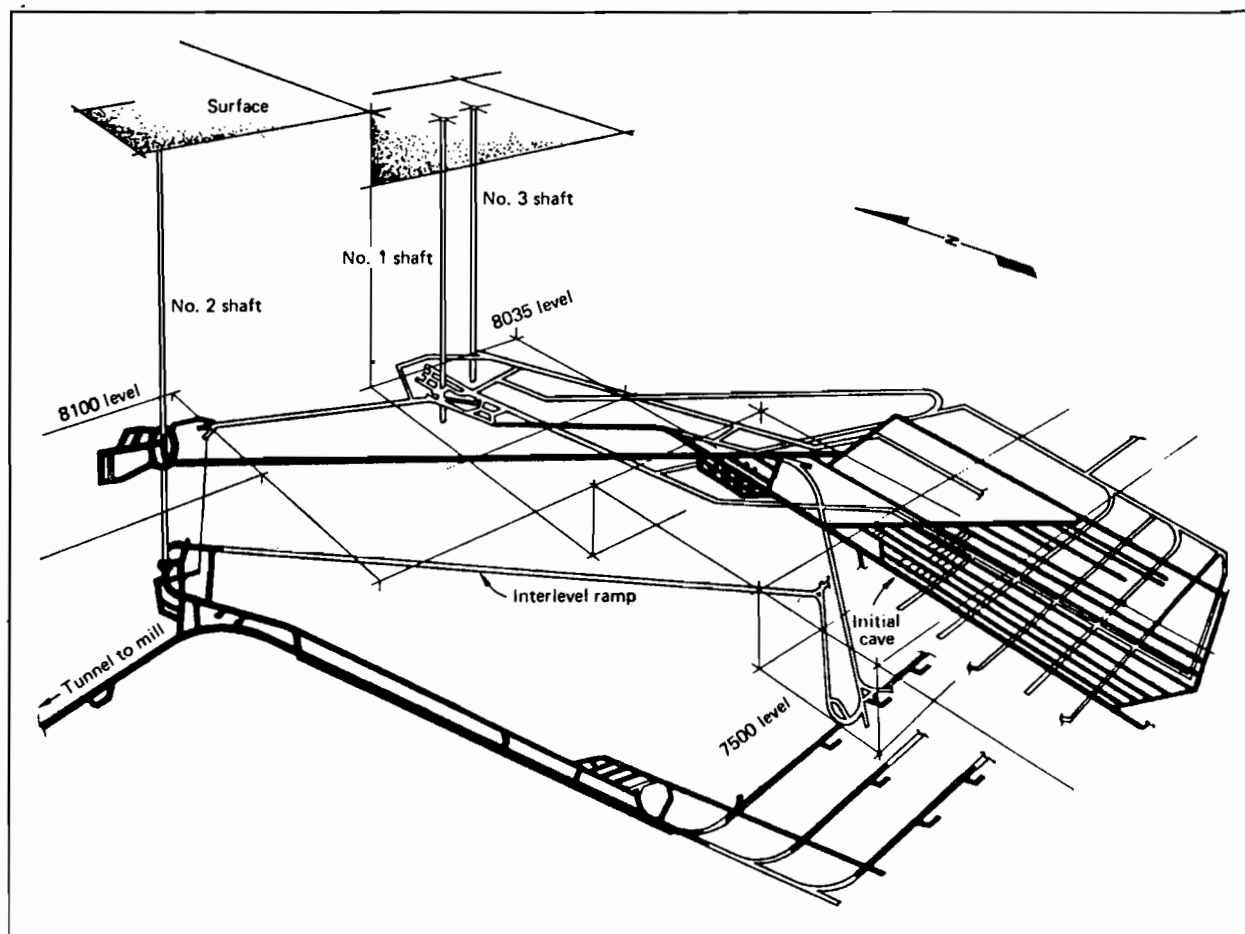


FIGURE 3. The complexity and number of development openings needed for mining the Henderson are enormous. Total lateral development, excluding the haulage tunnel, will exceed 114,000 feet before production begins, including 13,000 feet of ramps, (after Hoppe, 1976).

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## COLORADO SCHOOL OF MINES, EXPERIMENTAL MINE

## LOCATION AND ACCESSIBILITY

The experimental mine of the Colorado School of Mines is located in the Front Range, immediately northeast of the town of Idaho Springs, Clear Creek County, at latitude  $39^{\circ}44'N$ , longitude  $105^{\circ}31'W$ . The location is shown on Figure 1. Year-round access is provided by a road through Idaho Springs, approximately 1/4 mile from Interstate 70.

## GEOLOGIC SETTING

The regional geologic setting has been described by Lovering and Goddard (1950), and the more localized setting by Moench (1964). Figure 2 illustrates the simplified geologic setting of the Idaho Springs area. The mine is located in the Precambrian Idaho Springs Formation, considered to be the oldest rock unit exposed in the Front Range (Lovering and Goddard, 1950). The Front Range in this area is generally composed of gneissic rocks which were intruded at least three times in the Precambrian by igneous rocks. Three principal rock types occur in the Idaho Springs area. They are, in order of importance: granite-biotite gneiss, pegmatite, and biotite gneiss. The granite-biotite gneiss is composed of interlayered granite gneiss and biotite gneiss. The pegmatite is primarily composed of quartz and feldspar, with some mica. The dark gray, fine-grained biotite gneiss is a minor rock type in the area.

Studies of the central portion of the Front Range have shown that the gneissic rocks were deformed at least twice (Moench, 1964). The first deformation was apparently plastic at high temperature and pressure, and was accompanied by regional metamorphism and the emplacement of the intrusive

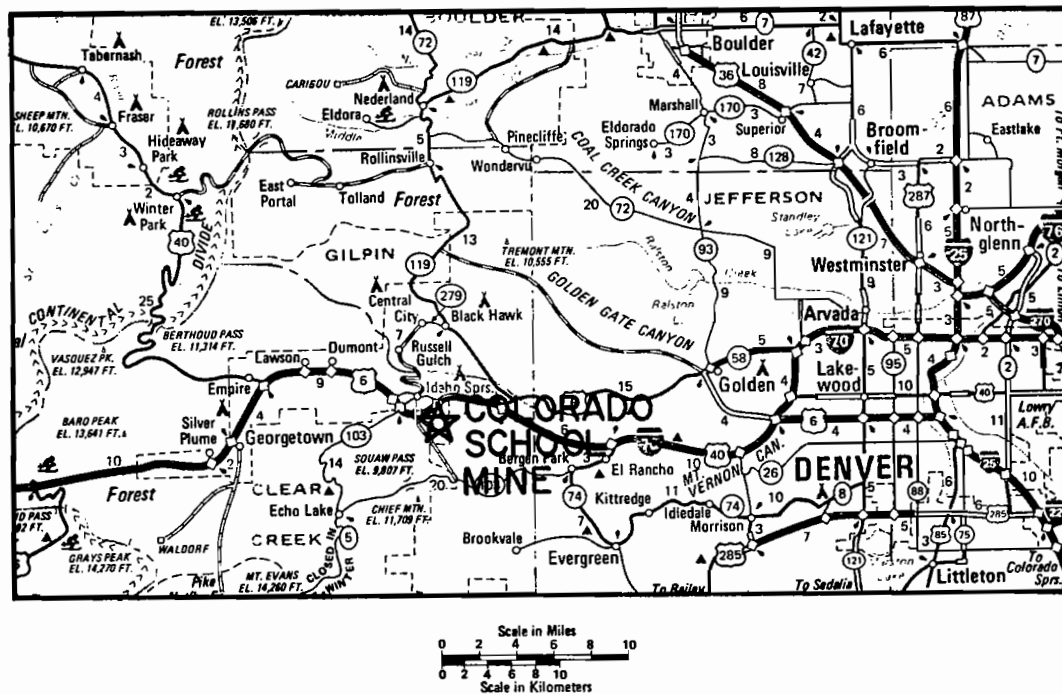


FIGURE 1. Location map - Colorado School of Mines, Experimental Mine, Idaho Springs, Clear Creek County, Colorado. Basic map reproduced by permission of the American Automobile Association, copyright owner.

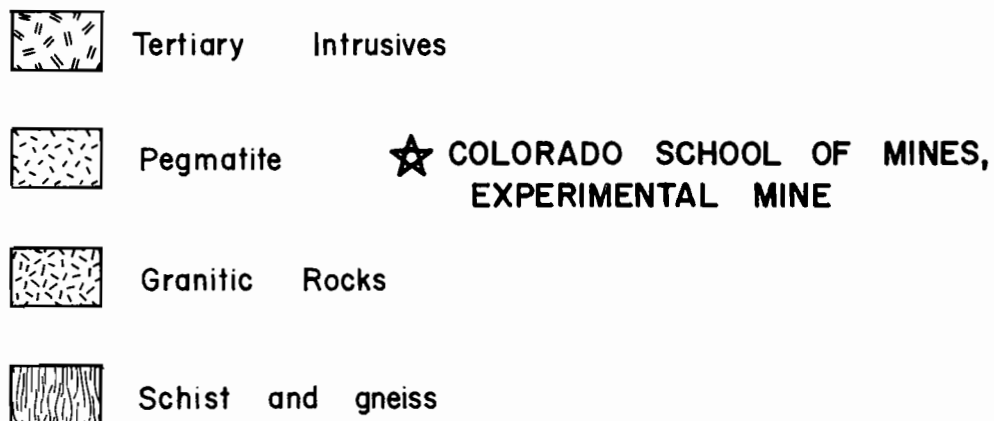
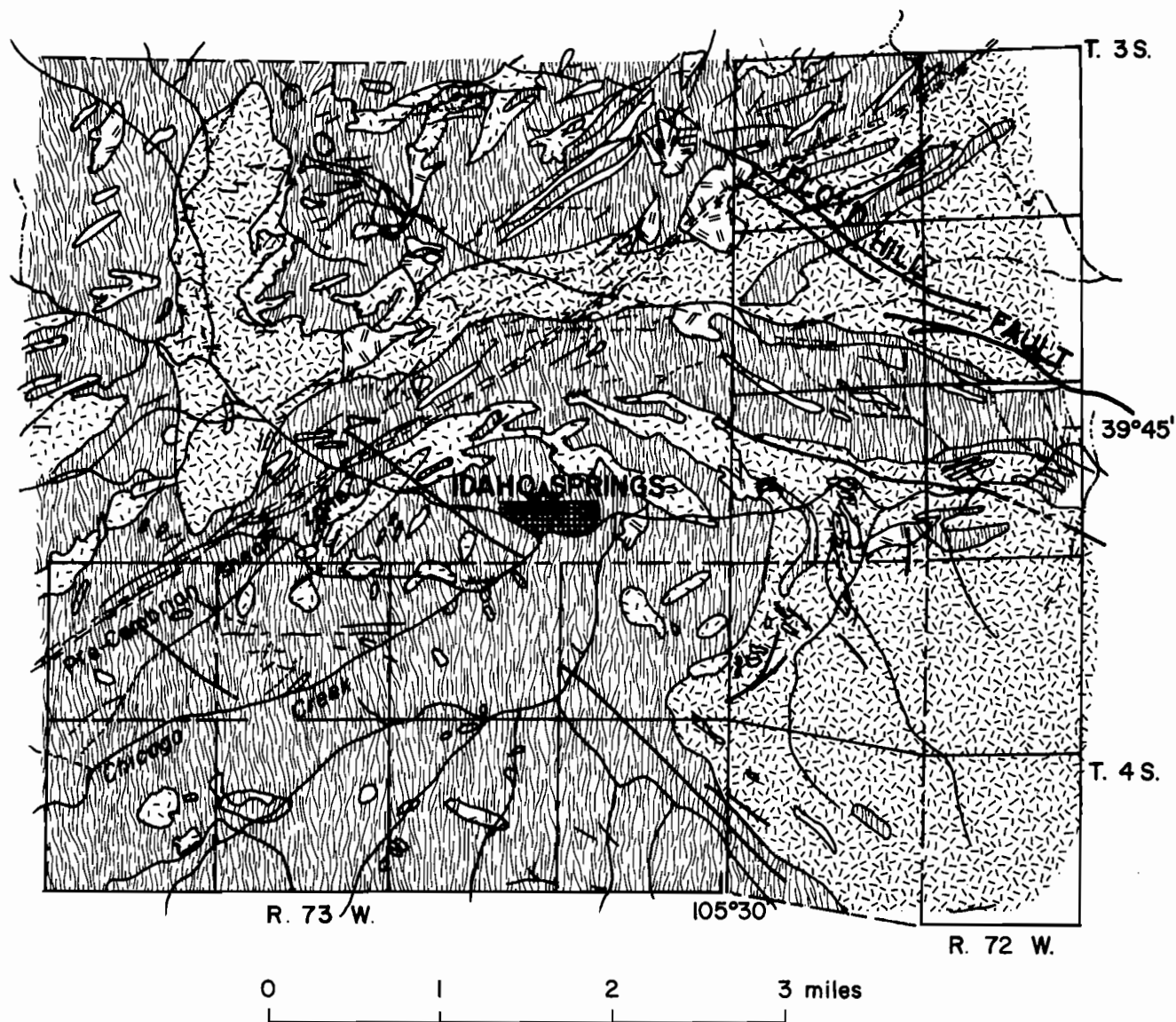


FIGURE 2. Geologic Map of Idaho Springs Area  
(Compiled from Lovering and Goddard, 1950).

bodies. The second deformation was cataclastic at low temperature and pressure and was restricted to the vicinity of the Idaho Springs - Ralston shear zone, located nearby to the south of the mine area. The first period of deformation produced large north-northeast trending folds, and the second produced intense cataclastic and numerous small east-northeast trending folds. The area exhibits extensive jointing, with rehealing of the older joints during periods of deformation.

A plan of the mine workings is shown on figure 3, and a simplified geologic plan and section illustrates lithology and structural features of an experimental area on Figure 4.

#### MINE CHARACTERISTICS

Rock-property data, size, facilities, and characteristics of the experimental mine are summarized:

##### Rock Properties:

	Unconfined	18.2 $\pm$ 3.6 ksi (uniaxial)
Strength:	500 psi	21.2 (triaxial)
	1000 psi	27.8 (triaxial)

Modulus ( $E_y$ )      8.36  $\pm$  .91x10<sup>6</sup> psi

Rock Mass Modulus:    4.0-4.7x10<sup>6</sup> psi

Density:    2.63 gm/cm<sup>3</sup>

Poissons Ration:    .15  $\pm$  .04

In Situ stress:     $\sigma_v$  = 456 psi

$\sigma_H$  = 575 psi

$\sigma_{xy}$  = 43 psi (shear)

##### Hydrologic Conditions:    probably above water table

Size:    (1x7x3600 = 176,400) + (9x20x60) = 12,960 = 189,360 cu ft.  
(7000m<sup>3</sup>) Fig. 1.

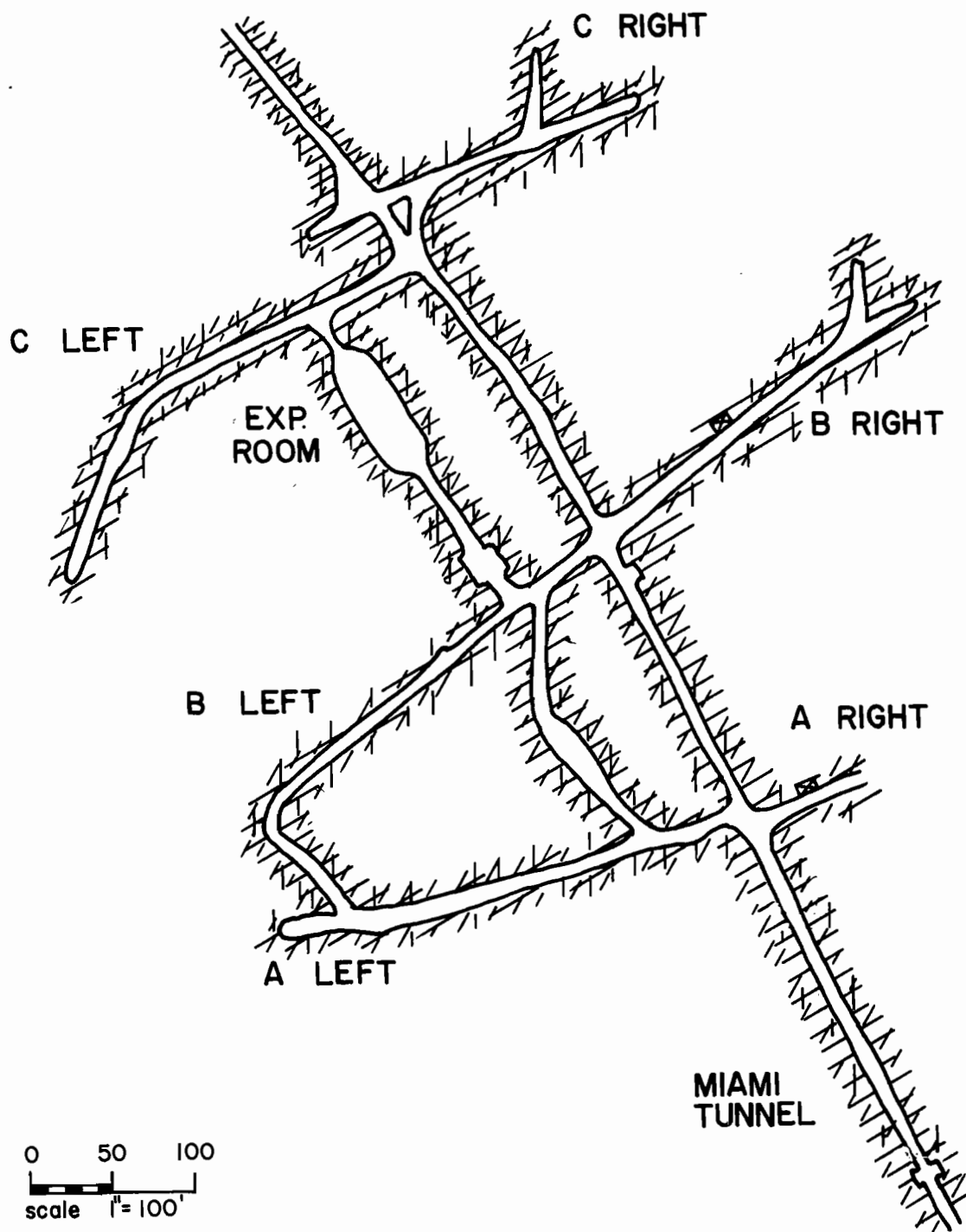


FIGURE 3. Map showing location of experimental room, Colorado School of Mines, Experimental Mine, Idaho Springs, Colorado.



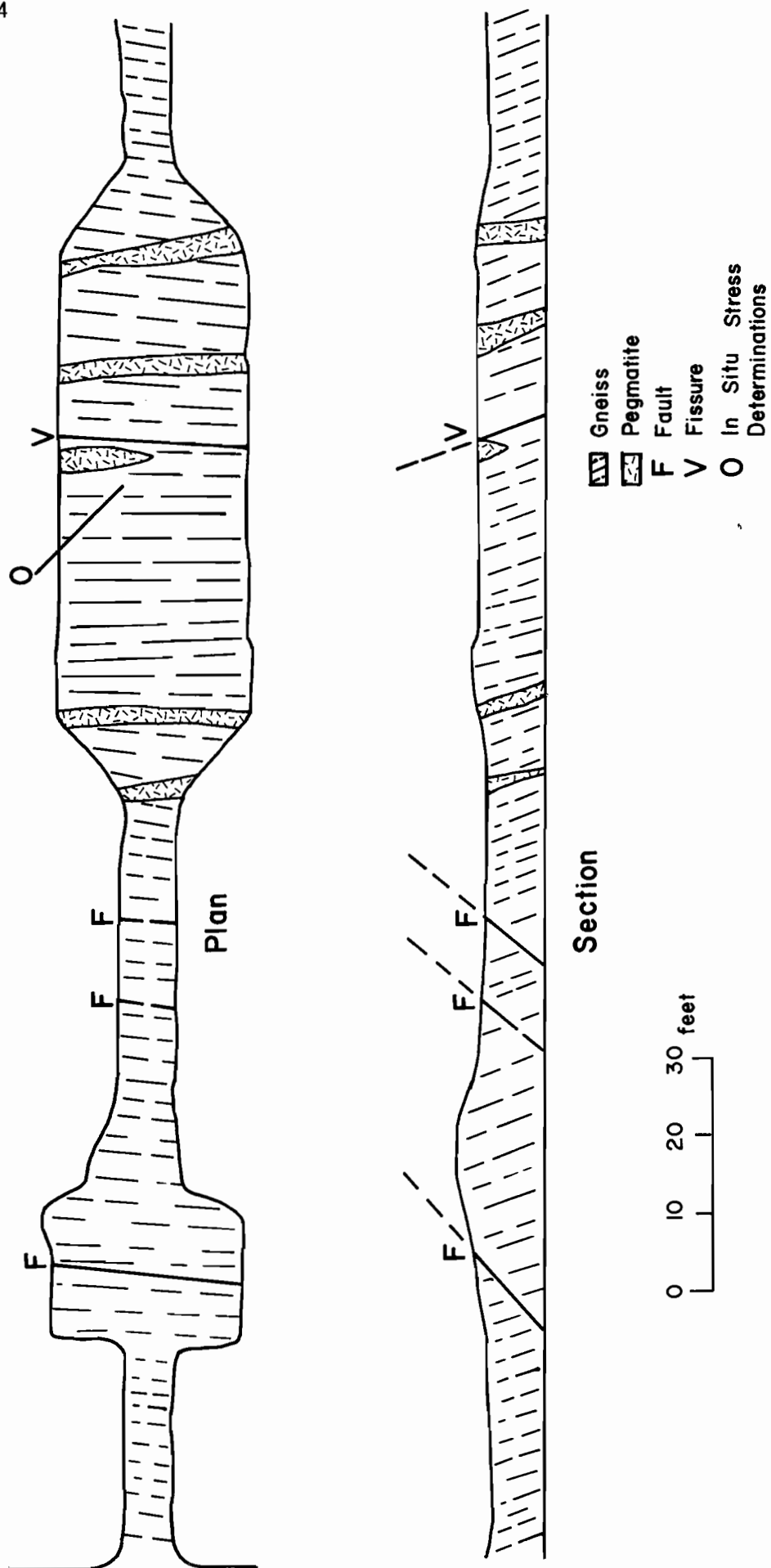


FIGURE 4. Geology of the experimental room area.

Facilities:

Mechanical: Compressors  
 Electrical: Sufficient to conduct a large test program  
 Transportation: 1/4 miles on macadam/dirt road off I 70

Characteristics:

Depth: 350 - 600'  
 Mechanical stability: very good, some rock bolted areas  
 Rock type: Granite gneiss and biotite gneiss w/ pegmatite  
 (Figure 2)  
 Tectonics: Precambrian front range (Idaho Springs Fm), several  
 episodes of deformation  
 Jointing and Fracturing: 3 sets

Set	Strike	Dip	Spacing (ft)	Length(ft)	Block Vol (cu ft)
A	N44W	53S	1.49	0.67	0.55
B	N31E	55S	0.53	1.24	0.55
C	N73E	71N	0.70	1.29	0.55

The mine is presently used by students and faculty members of the Colorado School of Mines for training and research projects. As part of their mining engineering education, essentially all of the underground excavation and maintenance is done by students.

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THE LOST PACKER MINE  
(Ivers Mining Company)

LOCATION

The Lost Packer mine, a small gold, copper, and silver operation, is located in central Custer County 28 miles north of Stanley, Idaho, at  $44^{\circ}37'N$ ,  $114^{\circ}53'W$  (Figure 1). Part of the Loon Creek District located in the Salmon Mountains, the mine lies at an elevation of 8600 ft.

The mine can be reached only by three dirt roads, either from Route 93 or Route 21. Because of the altitude and the fact that Route 21 is closed in winter access may be difficult.

REGIONAL GEOLOGY

The geology of the area has been described by Ross and Forrester, 1958, and Umpleby, 1911, and is illustrated in Figure 2.

The oldest rocks in the district are Precambrian mica schist and quartzites which correlate with the Belt Series. (The Thompson Peak formation is the rock unit in the immediate mine area.) They outcrop irregularly over an area of about two square miles in the central part of the district. These rocks are truncated in most directions by late Cretaceous granodiorite and quartz-diorite outliers of the Idaho Batholith, but they are overlain to the north by quartz latite of Tertiary age (probably part of the Challis volcanic series). Few bedding planes are visible in these Precambrian rocks. Paleozoic rocks overlie the Precambrian rocks in the south central part of the district. The two age groups are usually separated by a structural unconformity, but it was not observed in the area of the Lost Packer mine. The Paleozoic rocks are fine-grained quartzites

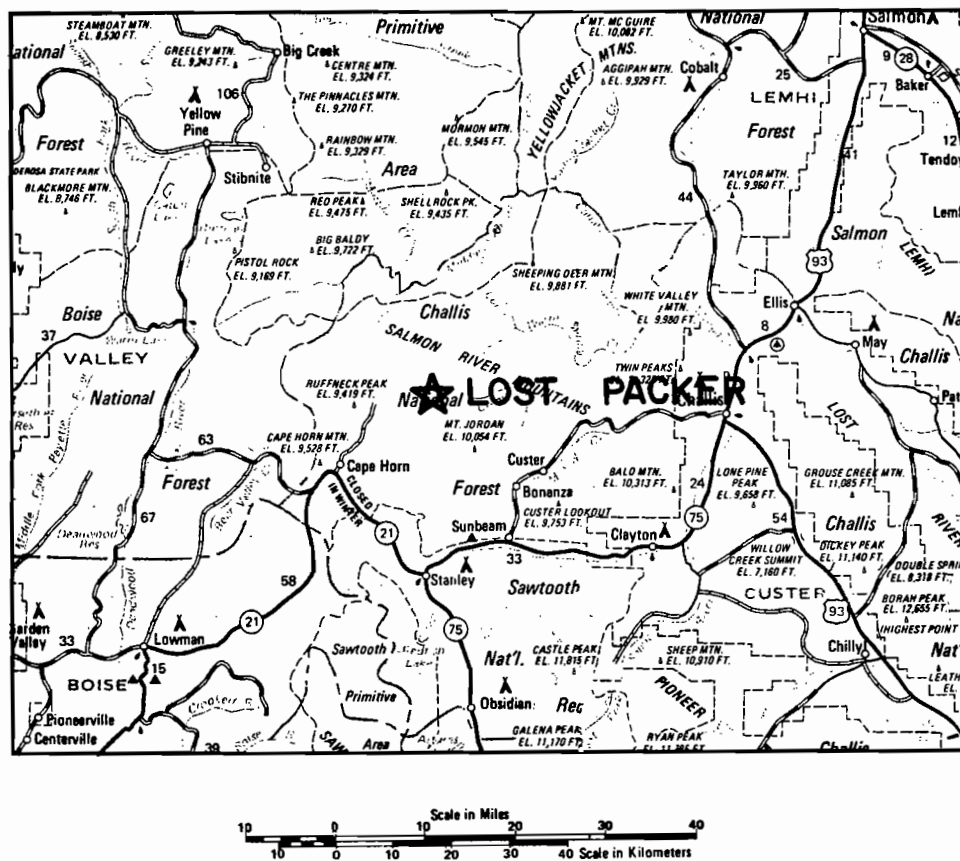


FIGURE 1. Location map showing the Lost Packer Mine, Custer County, Idaho. Basic map reproduced by permission of the American Automobile Association, copyright owner.

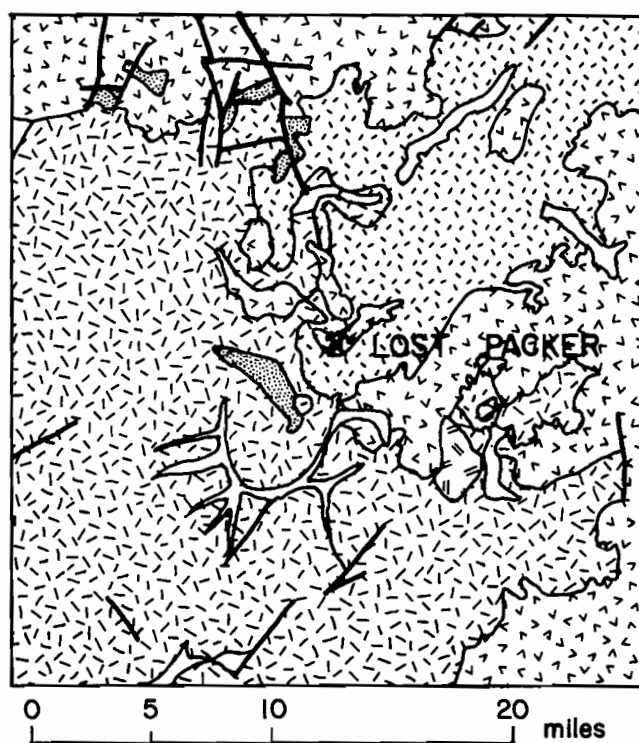


FIGURE 2. Geologic map of the Loon Creek mining district, showing the location of the Lost Packer Mine.

and blue dolomitic limestones which were considered by Ross and Forrester, (1958), to be, respectively, of Cambrian and Ordovician age. Some younger Paleozoic beds appear in other parts of Custer County. The late Cretaceous Idaho Batholith, composed of granodiorite, quartz diorite, and quartz monzonite, extends into the Loon Creek District from the west. Outliers from it appear to the east of the Precambrian metasediments and undoubtedly underlie the whole district. The granitic intrusions in the Lost Packer mine are related to the batholith. Dikes and veins of granite porphyry and diorite porphyry, probable of Eocene age, also cut the area and the mine. Bond (1978) indicates that the porphyries are capped by mixed Eocene, silicic and basaltic volcanic flows and reworked debris, surrounded by large granitic plutons and dike swarms, also Eocene age. The Idaho Batholith borders the Eocene intrusives to the west. Precambrian metasediments, low-grade mica schist and quartzite, crop out 4 miles southwest of the mine (Umpleby, 1911) (Figure 2). Based on the recent Idaho Geologic map (Bond, 1978), it appears that the metamorphic rocks may be mid- to high-grade. Gneissic rocks are found at the borders of the massive batholith intrusion (Ross and Forrester, 1958).

The direction of fracturing in the district is generally northeast to southwest (Bond, 1978). A strong schistosity in the Precambrian metasediments strikes west of north and dips southwest (Umpleby, 1911).

#### MINE GEOLOGY

The ore deposits of the Lost Packer mine occur in a fissure vein which is located in two host rocks: (1) a Precambrian mica schist, and (2) a Cretaceous quartz monzonite granodiorite-granite dike system. The vein is offset and the ore often crushed by granite porphyry and diorite porphyry dikes. The dikes strike roughly parallel to the fissure vein but

dip to the west less steeply than does the vein (Figure 3). The vein strikes N-S and dips 75°W. It varies in width from a few inches to 5 feet. The walls of the vein are well defined, and the vein is filled with gouge, sheeted schists, and/or lenses and stringers of ore. Ore minerals consist of coarse-textured milky-bluish white quartz with chalcopyrite; together with small amounts of pyrrhotite, pyrite, and siderite. The chalcopyrite is the main ore mineral and occurs as bunches, small patches, irregular grains, and interstitial fillings in a gangue of coarse quartz.

The gold is found mainly in the chalcopyrite and quartz. The age of mineralization is late Cretaceous to early Eocene (Umpleby, 1911; CRIB, 1974).

#### FACILITIES

The Lost Packer mine, owned by Ivers Mining Company (801 Tribune Building, Salt Lake City, Utah) and operated by Ivers/Finland, is inactive and consists of six claims and two fractions. There are ten tunnels with a total length of 10,000 feet reaching to a level of 1000 feet below the highest outcrop (Umpleby, 1911; CRIB, 1974). No report was found on when the mine became inactive. There is no information on the state of water in the mine.

The mine is reported as being explored in 1977 and to have three employees (Idaho Dept. of Labor and Industrial Services, 1977).

A memorandum from U.S. Department of the Interior, Bureau of Mines, released in 1979 reports that some form of activity occurred at the mine in 1978.



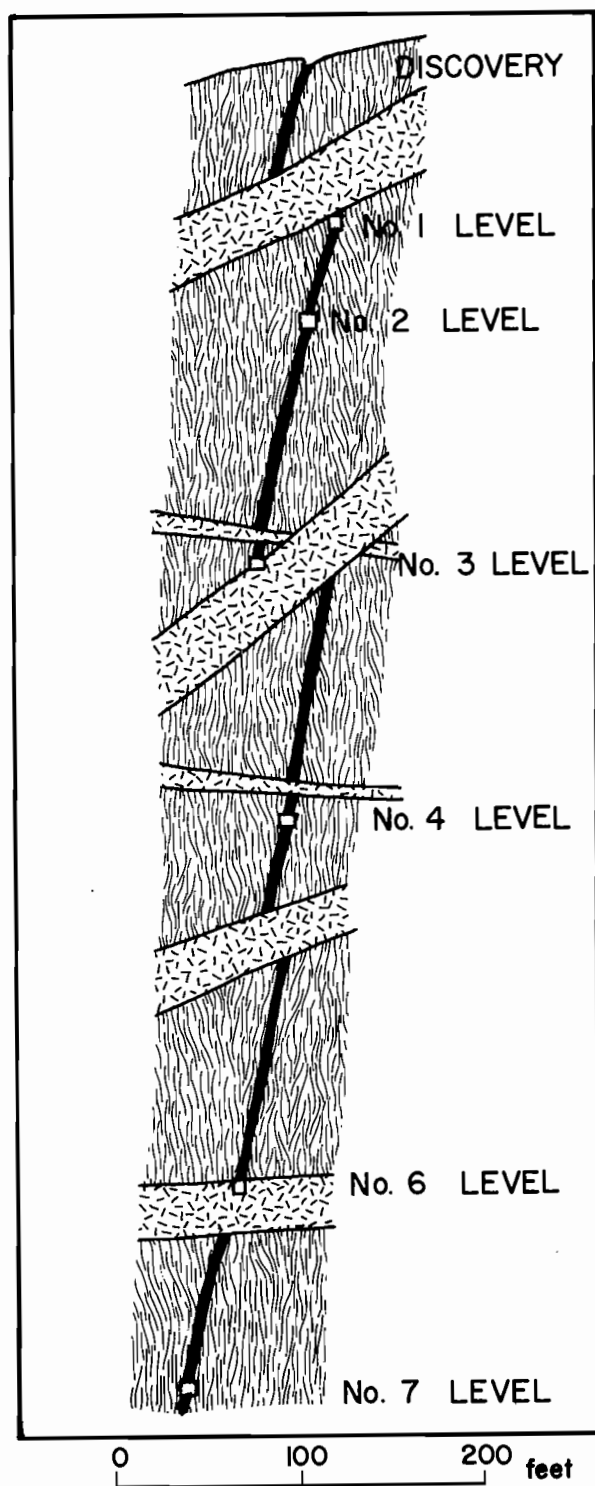


FIGURE 3. Transverse section through Lost Packer vein, Loon Creek district, Idaho, looking north. Illustrates offsets in the vein caused by the intrusion of dikes. (Umpleby, 1913)

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## THE COEUR D'ALENE DISTRICT, IDAHO

## LOCATION

The Coeur d'Alene District contains some of the United States' deepest mines with a value of recorded base metal and silver production exceeding \$2 billion. The district is located in the panhandle of Idaho at 47°30'N, 116°W, between the cities of Wallace and Kellogg, 75 miles east of Spokane, Washington (Figure 1). Though the mines are in metamorphosed argillaceous rock, they are sufficiently deep and extensive, and have been characterized by rock mechanics research, to warrant their consideration in the context of this report.

## GEOLOGIC SETTING

The distribution of mines, major faults and intrusive rocks is shown on Figure 2 (from Sorensen, 1947). The rocks of the Coeur d'Alene district comprise several units of the Precambrian Belt Series; their lithology and stratigraphy have been described by Hobbs and others (1965). The Belt Series is composed predominantly of fine-grained, slightly metamorphosed quartzite and argillaceous quartzite. Small monzonitic intrusions and several varieties of dikes cut across the quartzite and vary in age from Cretaceous to late Tertiary. The Cretaceous monzonite Gem stocks and the other intrusive rocks make up only a small part of the bedrock. However, they are important because of their temporal and geographical relationship to the ore deposits.

The district is at the intersection of a north trending major anticlinal uplift and the west-northwest trending Lewis and Clark line. The Gem stocks crop out near the intersection and are aligned along the axis of the arch. The Osburn fault which strikes roughly east-west, is the dominant structural feature and bisects the district. The Osburn, a right-

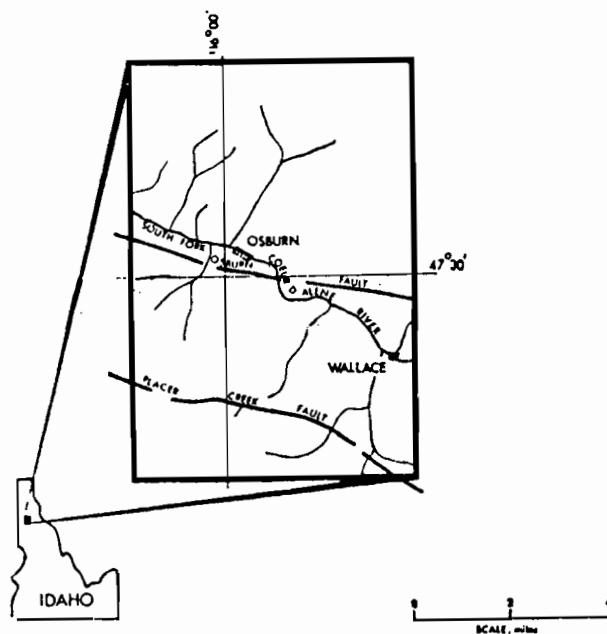


FIGURE 1a. Location map of Coeur d'Alene area (from Chan, 1972).

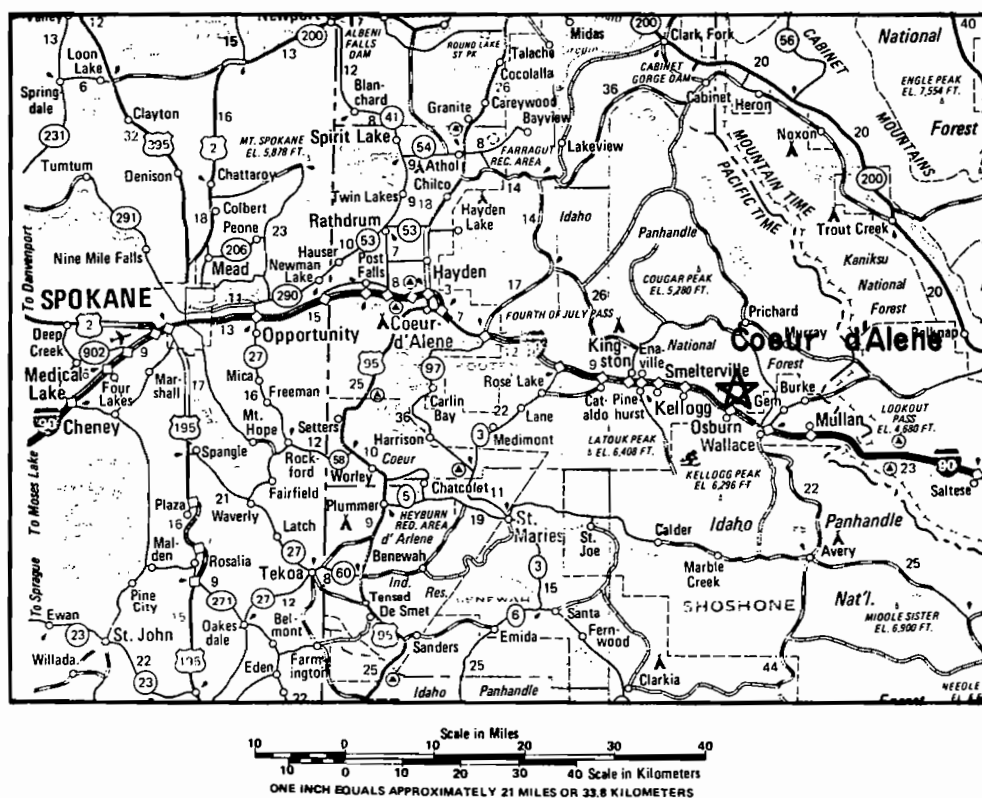


FIGURE 1b. Location of Coeur d'Alene District in Shoshone County, Idaho. Basic map reproduced by permission of the American Automobile Association, copyright owner.

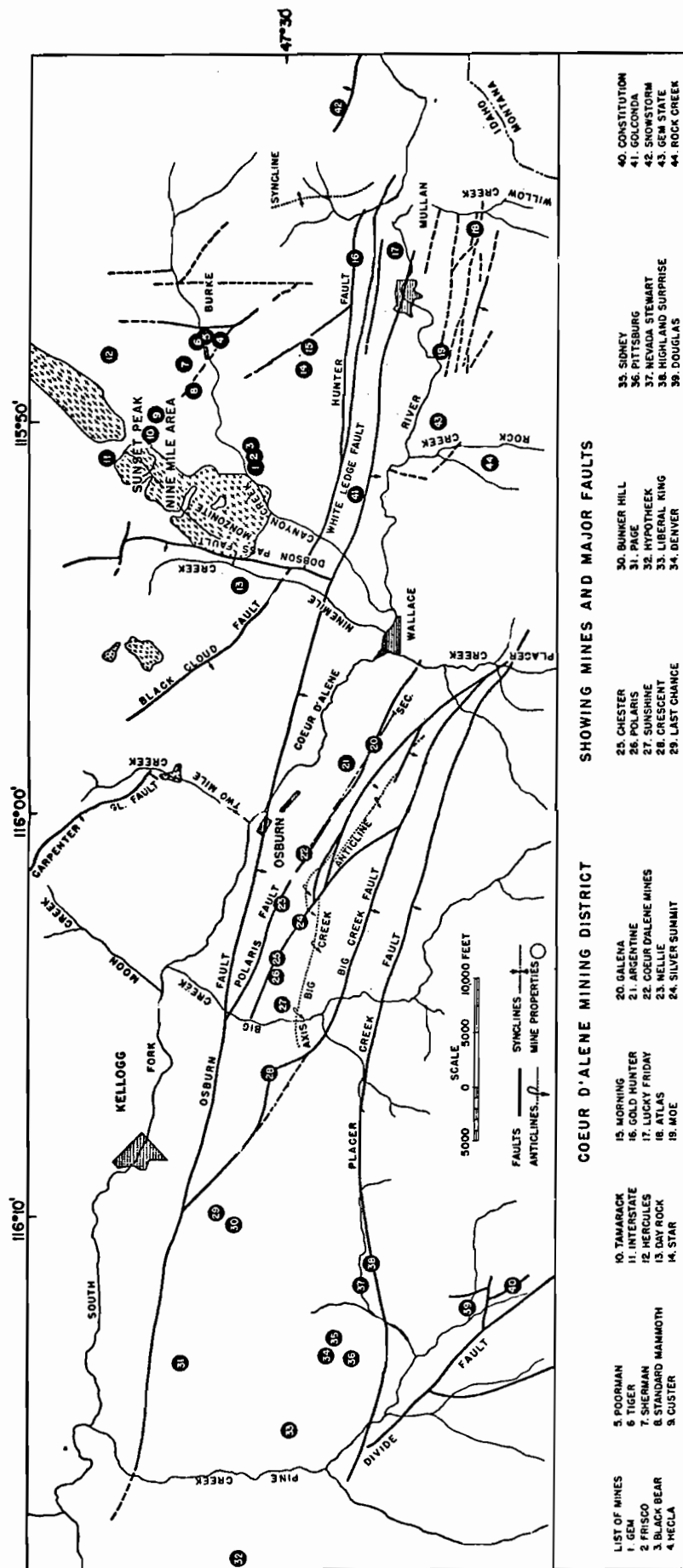


FIGURE 2. Coeur d'Alene mining district showing mines and major faults. (Sorenson, 1947).

lateral strike-slip fault, offsets the major folds and other faults, and separates the northern segment of the ore-bearing area from the segment to the south. The ore occurs in veins mostly in west-northwest striking fracture zones. The veins lie within a group of near-parallel separate mineral belts. Those mines north of the Osburn fault include Hecla, Hercules, Standard-Mammoth, Tamarack, Dayrock, Frisco, and Star-Morning. The group on the south side of the Osburn fault includes the Galena, Coeur, Sunshine, Crescent, Bunker Hill, and Page mines.

In general, the mine workings are in quartzite and argillaceous rocks. However, some mine workings (such as the Tamarack, Interstate, Gem, Frisco, and Dayrock mines) may extend into the Gem stocks and associated intrusives. The district includes the deepest mine in the western hemisphere, the Star mine, with workings extending to 8300 feet below the surface.

In the following sections, the lithology and structure of the district are described, followed by descriptions of three mines characteristic of the district.

### Lithology

The lithology and stratigraphy of the Precambrian Belt Series have been described by Hobbs and others (1965 and 1968) and Sorenson (1947). The stratigraphic section is outlined in Table 1 and illustrated on Figure 3. The Belt Series is predominantly argillite and quartzite. Regional metamorphism is evident in the recrystallization of quartz grains and the formation of micaceous minerals, chiefly sericite. Metamorphism of sandy and muddy beds to quartzite and argillite is common, with the quartzite grading to argillite. Sedimentary structures, such as mud cracks and ripple marks, abundant throughout the sequence. These features reflect a shallow water depositional environment for much of the series and a near balance between deposition and subsidence during much of Belt time. Nowhere is the base of the Belt Series known to be exposed inside the district and

TABLE I. GENERALIZED STRATIGRAPHIC SECTION, COEUR D'ALENE DISTRICT, IDAHO.  
(Adapted from Hobbs and others, 1965, p. 14)

AGE	FORMATION		LITHOLOGY	THICKNESS (feet)	ORE- BEARING
Quaternary	Alluvial deposits		Unconsolidated sands, gravels, channel deposits and glacial and glaciofluvial deposits.	0-150	No
Cretaceous (?) or Tertiary	Lamprophyre dikes		Biotite, hornblende, and pyroxene rich dikes.	0-10+	
	Dikes undifferentiated		Includes diabase, diorite, and monzonite dikes.	0-10+	
Cretaceous	Monzonite		Includes monzonite, syenite, and diorite intrusive crystalline rocks.	0-4000	
Precambrian	Striped Peak Formation		Interbedded quartzite and argillite with some arenaceous dolomitic beds. Purplish gray and pink to greenish gray. Ripple marks, mud cracks common. Top eroded.	1500+	No
	Wallace Formation	Upper part	Mostly medium- to greenish-gray finely laminated argillite. Some arenaceous dolomite and impure quartzite, and minor gray dolomite and limestone in the middle part.	4500-6500	Yes, but limited
		Lower part	Light-gray more or less dolomitic quartzite interbedded with greenish-gray argillite. Ripple marks, mud cracks abundant.		
	St. Regis Formation	Upper part	Light greenish-yellow to light green-gray argillite; thinly laminated. Some carbonate-bearing beds.	1400-2000	Yes
		Lower part	Gradational from thick-bedded pure quartzite at base to interbedded argillite and impure quartzite at top. Red-purple color characteristic; some green-gray argillite. Some carbonate-bearing beds. Ripple marks, mud cracks, and mud-chip breccia common.		
	Revett Quartzite		Thick-bedded vitreous light yellowish-gray to nearly white pure quartzite. Grades into nearly pure and impure quartzite at bottom and top. Cross-stratification common.	1200-3400	Yes
	Burke Formation		Light greenish-gray impure quartzite. Some pale red and light yellowish-gray pure to nearly pure quartzite. Ripple marks, swash marks, and pseudo-conglomerate.	2200-3000	Yes
	Prichard Formation	Upper part	Interbedded medium-gray argillite and quartzose argillite and light-gray impure to pure quartzite. Some mud cracks and ripple marks.	12,000+	Yes
		Lower part	Thin- to thickbedded, medium gray argillite and quartzite argillite; laminated in part. Pyrite abundant. Some discontinuous quartzite zones. Base buried.		





the thickest partial section, between 40,000 and 50,000 ft. (Campbell, 1960), occurs just east of the Coeur d'Alene district and trends north-northwest. The Belt Series is divided into six units. They are, from oldest to youngest: the Prichard and Burke Formations, the Revett Quartzite, and the St. Regis, Wallace, and Striped Peak Formations.

The Prichard Formation consists of dark gray to black argillite and argillaceous quartzite. A maximum thickness of 12,000 ft. is exposed; the thickness of the unexposed basal part is unknown. The upper section of the Prichard, up to 2000 ft., consists of a transitional zone of alternating argillite and quartzite.

The overlying Burke Formation is composed of 2200 to 3000 feet of greenish-gray sericitic quartzite interspersed with some fairly pure quartzite. Some argillaceous quartzite also occurs in the Burke Formation. The contact between the Burke Formation and the overlying Revett Quartzite is indefinite, and a transition zone extends 500 feet or more.

The Revett Quartzite consists of massive, thick-bedded, gray to white quartzite. Vitreous quartzite beds make the Revett the most distinctive formation in the area. Within the district, the formation thickens from about 1500 ft. in the east to about 3400 ft. in the west.

The next overlying unit is the St. Regis Formation which grades from interbedded quartzite and argillite to a dominantly thin-bedded argillite which is typically purplish-red to red in color. The upper section of the St. Regis Formation is characterized by a chert-like, finely laminated argillite. The thickness varies from 1000 - 1400 ft. in some areas.

The Wallace Formation is 4500 - 6000 ft. in thickness and consists of gray to white calcareous quartzite and gray to black calcareous argillite, dolomite, and limestone.

The uppermost formation, the Striped Peak, consists of purplish, pink, and green quartzite and argillite. Only the basal 1500 ft. of the Striped Peak lies in the district and its exposure is limited to small areas.

The Cretaceous monzonite stocks are made up of two main bodies and several smaller ones, and are associated with the Idaho batholith. The bulk of the rock is monzonite but the composition ranges from syenite to diorite. The main bodies are known as the Gem stocks and are located north of Wallace and east of the Dayrock mine (Figure 2). The contacts on the east side of the stocks are generally steep or even overhanging, whereas the west boundaries dip somewhat less steeply to the west.

Diabase and lamprophyre dikes which transect the district apparently represent two separate episodes of intrusion, and are of questionable Cretaceous and Tertiary age. The dikes commonly are located along the prominent west-northwest faults and many have been sheared subsequent to their intrusion. The diabase dikes are most numerous and most continuous south of the Osburn fault. A large dike along the Osburn fault is exposed in several mine workings and is probably fairly continuous. Another dike appears to be continuous from the Sunshine mine eastward to the Coeur d'Alene mine, a distance of about 3 miles, and it may extend farther. The lamprophyre dikes are abundantly exposed in mine workings. They are dark-colored, fine grained rocks characterized by biotite or hornblende phenocrysts. They are most numerous north of the Osburn fault. The lamprophyre dikes are devoid of ore minerals, and some dikes clearly crosscut the monzonite stocks and the veins. Presumably the lamprophyre dikes represent one of the latest igneous episodes in the area. Other dikes include some silicic and intermediate rock types that are in part direct off-shoots from the monzonite stocks and also some dikes of undetermined composition.

### Rock Properties

Rock properties and in-situ deformation behavior of the Revett Quartzite and St. Regis Formation (argillaceous quartzite) have been measured by Chan and others (1972). In general, the quartzites were found to deform nearly linearly, starting at an applied stress of 5000 to 6000 psi and continuing to the ultimate strength of the rock. However, when rocks contain high percentages of carbonate, sulfide disseminations, and microfractures, or are highly argillaceous, the deformation becomes non-linear. Details of these tests and deformation behavior of rock masses in the Galena, Lucky Friday, Silver Summit, and Star mines were reported in Chan and others (1972), in the Bunker Hill mine by Conway (1972), and in the Crescent mine by Skinner (1972).

### Regional Metamorphism

All Belt sedimentary rocks are weakly to moderately metamorphosed. The chlorite and biotite in the Prichard and Burke Formations, far removed from the stocks, indicate the extent of regional metamorphism and show that it was low-medium grade (Hobbs and others, 1965). Though the Belt Series rocks are predominantly quartzite and argillite, in some parts of the district, metamorphism has resulted in phyllite and schist.

Contact metamorphism has occurred around the stocks. The most widespread effect is an aureole of recrystallization, extending a few feet into the sedimentary units.

### Structure

The regional structure of the Coeur d'Alene mining district is illustrated on the geologic map in Figure 2. The district is located at the intersection of the Lewis and Clark Line with a broad anticlinal arch that extends in a northerly direction from the Idaho batholith to Kimberly,

British Columbia, Canada (Hobbs and Fryklund, 1968). The Lewis and Clark Line is a prominent zone of faulting, shearing, and complex folding that trends in an east-southeast direction. The Osburn fault is the major structure of the Lewis and Clark Line in the district. The rocks of the district are intensely deformed, and Hobbs and others (1965) describe the area as a "structural knot". The rocks are tilted, sheared, and faulted, and most dip at angles of  $45^{\circ}$  or greater. Nearly vertical dips are common and many beds are overturned.

Faults are the dominant structural feature of the Coeur d'Alene district and control the location of the ore deposits. The faults have been grouped into four categories by Hobbs and others (1965):

- (1) low-angle reverse faults
- (2) early steep-dipping reverse and normal faults
- (3) strike-slip and related normal faults
- (4) late normal faults.

The Osburn fault, the major structural feature in the district, has a right-lateral displacement of 16 miles. The Osburn divides the district into two parts that differ markedly in structural characteristics (Wallace and others, 1961). North of the Osburn fault, the rocks are moderately deformed and the axes of the folds trend in a northerly direction. South of the Osburn fault, the fold axes trend westerly and the folds are tightly compressed so that beds dip vertically and in some cases are overturned.

Between the Osburn fault and the Placer Creek fault, which roughly parallels the Osburn 3 - 4 miles to the south, are numerous other faults that trend northwest. They form the connecting links between the two faults. Most dip steeply to the southwest and are reverse, normal, or strike-slip. The Crescent, Silver Summit, Consolidated Silver, and Coeur d'Alene mines

are located along these faults. Two sets of faults predominate north of Osburn fault. One set trends west-northwest and is subparallel to the Osburn fault. The Lucky Friday mine is located within this set. The second set trends north and includes the location of the Dayrock mine. (Figure 2).

Fault gouge and zones of sheared, crumpled, or highly fractured rocks are associated with all the faults. Hobbs and others (1965), report that in quartzite:

"The strain along a fault is characterized by a relatively narrow zone of gouge bordered by a zone of breccia which grades outward into small shears and joints. In comparison, along a fault of similar displacement in argillite, the strain produces a relatively wider zone of gouge surrounded by contorted and crumpled rock."

An example of zones of fault gouge and brecciation along the Osburn fault is illustrated in the Morning mine (Figure 4). Bedding-plane slippage and puckering are additional types of faulting or shearing that are common in the district.

Hobbs and others (1965) recognized differences in the structure and lithology on opposite sides of the Osburn fault and use this information to substantiate the 16 miles of right lateral strike-slip displacement along the fault. On the other hand, Full (1955) believed that the geology is too complex to explain the displacement on the Osburn fault as strike-slip. However, geologic evidence substantiates the observations that the pattern of faulting formed after the major period of folding. Displacement along strike-slip faults has offset fold-axes, and displacement on dip-slip faults has cut folds.

Mineralization is probably directly related to the structural history of the region and extends from Precambrian to Tertiary time. The veins of

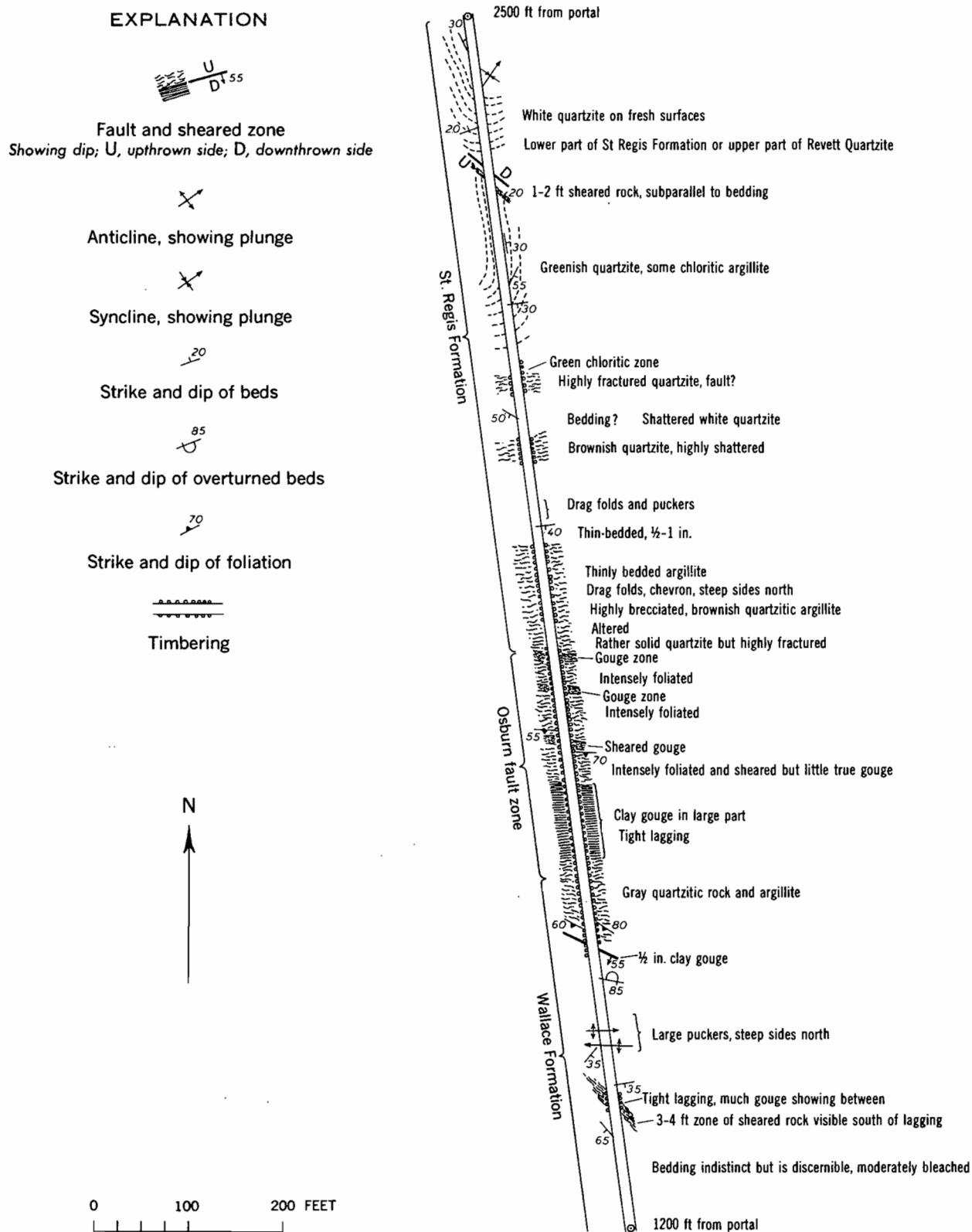


FIGURE 4. Zones of fault gouge and brecciation along Osborn fault as seen in the main cross cut of the Star-Morning mine (Hobbs and others, 1965).

the major period of ore formation were probably localized along a system of throughgoing fractures that were opened after the intrusion of the monzonite stocks. Thus, the major mineralization is Cretaceous or younger. Much of the structural pattern was present prior to the formation of the principal ore deposits; however, a major amount of strike-slip movement took place after ore emplacement. Regardless of the differences in fault pattern and orientation in the district, all the major ore bearing zones have approximately the same orientation, N65°W. The orientation of the zones of ore bodies is about 10° to 15° more northerly than the general trend of the Osburn fault.

#### ORE DEPOSITS OF THE COEUR D'ALENE DISTRICT

The Coeur d'Alene district ore deposits have been described by several authors, including Sorenson (1947), Campbell and others (1961), Hobbs and Fryklund (1968), and Carter and Li (1976). The definitive study is the paper by Fryklund (1964). The major ore deposits are steeply dipping tabular replacement veins containing lead, zinc and silver. The veins range in thickness from less than an inch to a yard, and locally may be several times this thickness. Individual ore shoots are known to range in length from several feet to more than 3000 feet and some may exceed this length when fully developed. The important producing veins are nearly straight, parallel to subparallel, and trend about N65°W.

There were six periods of mineralization, each distinguished by the minerals it emplaced (Fryklund, 1964). Precambrian mineralization is represented by arsenopyrite-pyrite veins cut by uranium-bearing veins. Hydrothermal alteration also occurred in the Precambrian. Late in the Cretaceous, after emplacement of the Gem stocks and monzonite, the main period of mineralization occurred. The metal-producing veins of galena, sphalerite, and tetrahedrite were intruded, and the surrounding country



rock was recrystallized. The final phases of mineralization occurred in the Tertiary period. The first was a period of base metal mineralization. A second phase is represented by stibnite and scheelite-stibnite veins; these veins are older than the Tertiary diabase dikes. A third phase includes arsenopyrite and gold veins; these veins are younger than the diabase dikes.

The mineral belts are structural features. In some places the mineral belts parallel the trends of the fold axes; in others they cut across the axes at high angles. The monzonite stocks interrupt the mineral belts but do not disturb the main trends of the belts that are aligned across them. Within the mineral belts the distribution of veins, shears, and fractures differs from place to place and apparently is affected by the physical properties of the country rock and other factors.

The length of the mineral belts ranges from 1-14 miles. The ore shoots are scattered in the mineral belts in a random pattern. The size of individual shoots covers a broad range. An example of a large ore shoot is the main ore body in the Star and Morning mines. This ore body measures 3000 ft. long and 7500 ft. from its exposure at the surface to the lowest level mined. The maximum vertical extent is not known; its width is up to 60 ft.

The mineralization is clustered in two groups on opposite sides of the Osburn fault, localized along well-defined parallel or subparallel belts. As summarized by Hobbs and Fryklund (1968), the ore belts north of the Osburn fault are zoned concentrically around the Gem stocks; the major ore minerals are galena and sphalerite. The deposits south of the Osburn fault show no evidence of concentric zoning, the gangue minerals show no orderly pattern, and the major ore minerals are sphalerite, galena, and tetrahedrite.

Among the 175 mines of the Coeur d'Alene district, which include 32 active mines (Idaho Dept. of Labor and Industrial Services, 1978), there

are many deep underground workings in metamorphic rock. Two mines north of the Osburn fault, the Dayrock and Star-Morning, and the Coeur mine south of the fault will be described because of their characteristics and potential accessibility. Other mines in the district with potential because of rock type, depth of workings, and possible accessibility are the Lucky Friday, north of the Osburn fault; and the Consolidated Silver, Silver Summit, Crescent, Galena, and Sunshine south of the fault.

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DAYROCK MINE  
(DAY MINES, INC.)

LOCATION

The Dayrock Mine lies 3 miles north of Wallace, Idaho, along Ninemile Creek Canyon, at a surface elevation of 3200 ft. Its location is shown on Figure 2 of the preceding section. The lead-silver-zinc mine is located at township 48N, range 4E, section South 10, 11, 14, and 15. It was reported active in 1978 with seven employees (Idaho Dept. of Labor and Industrial Services, 1978). Currently, the mine is inactive and is being kept open for potential exploration.

GEOLOGIC SETTING

The geologic setting of the Dayrock mine was described by Hobbs and others (1965), Farmin (1961), Fryklund (1964), and Carter and Li (1976). A generalized geologic cross section, Figure 1, shows the rock type, geologic structure, and ore bodies to a depth of 1250 feet. The host rocks are the Precambrian Belt Series argillites and quartzites. The upper three-quarters of the mine is located in St. Regis argillites and the lower quarter is in underlying Revett Quartzite. Shearing and alteration have weakened the rock and there are abundant clay minerals and sericite in the argillite.

One of the Gem stocks lies approximately 250 ft. east of the mine; however, its proximity is the result of movement on the nearby Dobson Pass fault. A few dikes cut across the mine for lengths up to 100 ft. They are altered and softened, requiring timbering in the mine.

The ore is mainly galena, pyrite, sphalerite, and tetrahedrite with subordinate amounts of gangue minerals. The ore occurs in lenses, stringers and disseminations.

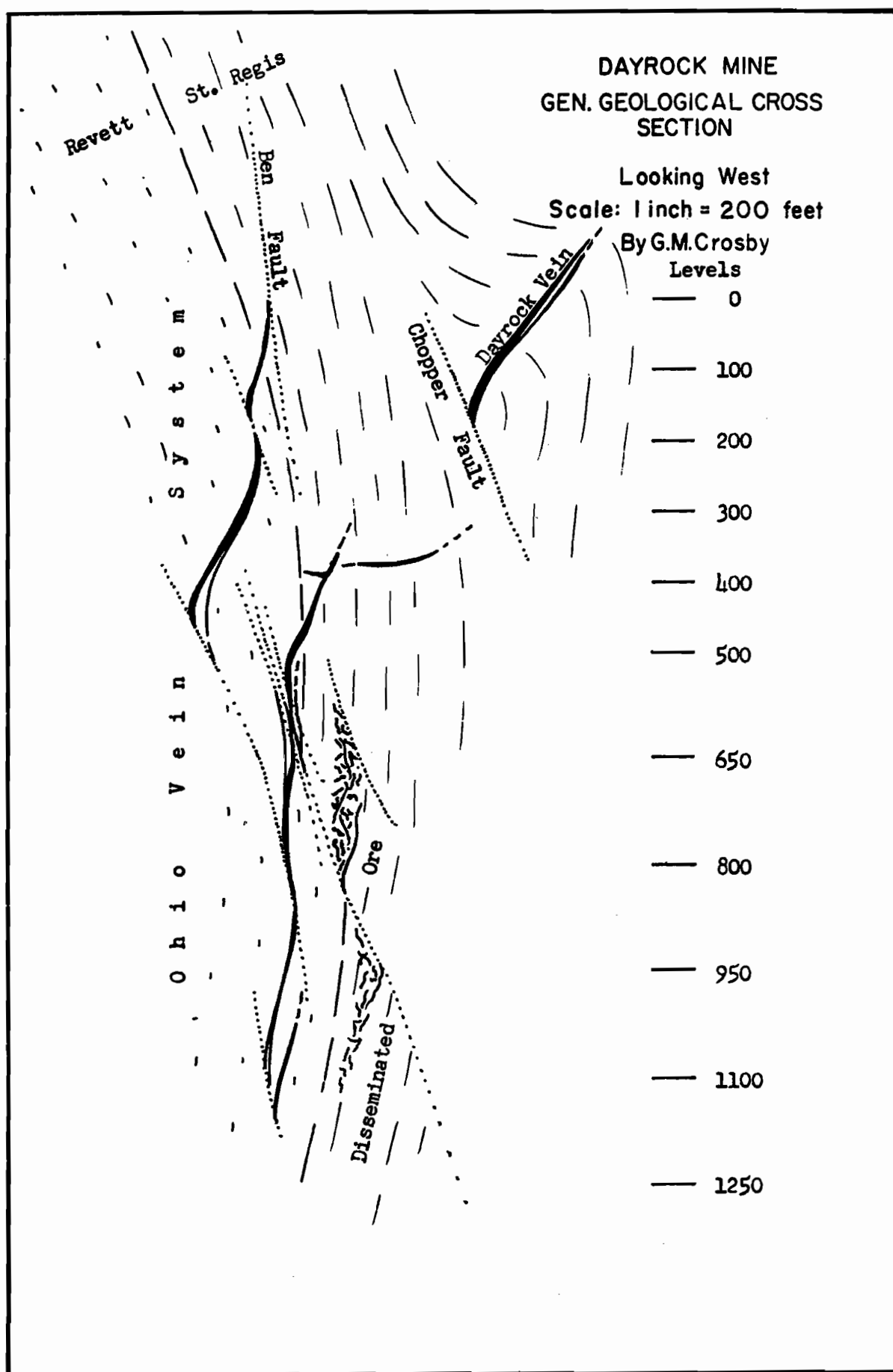


FIGURE 1. Generalized geologic cross section of the Dayrock mine, Coeur d'Alene mining district, Idaho (Farmin, 1961).

## STRUCTURAL SETTING

The Belt rocks in the Dayrock mine strike northwesterly and dip northeasterly  $45^{\circ}$ - $80^{\circ}$ . The mine area is bounded by the Dobson Pass fault on the east and the Blackcloud and Osburn faults on the south. The veins occupy fractures or shears in the host rocks and may be traced for up to hundreds of feet. Numerous stringers, pods, and disseminated bodies of ore minerals are scattered between the veins.

Faulting in the Dayrock mine is complex (Hobbs and others, 1965). Normal faults cut the veins and displace them by as much as hundreds of feet, progressively lower to the west. Another set of faults with reverse movement up to 90 ft. parallels the veins, complicating the geology and mine development. The rocks and, to a lesser extent, the veins are drag-folded, especially near faults.

## MINE CHARACTERISTICS

Notes on the Dayrock mine workings and mining method are based on few sources and a paucity of information. The workings are in quartzite and argillite and may extend into intrusive rock. They include a 300 ft. adit, a vertical shaft, and tunnels at the 1400 ft. and 3000 ft. levels, and possibly others. A total of 900,000 tons of ore were extracted between 1923 and 1962 with a 3.6 million oz. silver content (Idaho Bureau of Mines and Geology, 1963). The mine workings are fairly wet and are timbered in the faulted and sheared areas (Acres, 1975). The lead, silver, and zinc is vein mined by cut and fill (Cobbs, 1976). Some areas are backfilled with quartz sand. Haulage is accomplished by rail.

The Dayrock mine was reported mined out in mid-1974 (Carter, 1976); however, new exploratory drilling was completed in 1975 in an area west of the mineralized zones. Results were inconclusive and additional drilling or shaft sinking may have been undertaken.



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STAR-MORNING MINE  
(BUNKER HILL-HECLA MINING COMPANIES)

LOCATION

The Star-Morning Unit represents the intersection of the Star mine workings on the west and Morning workings to the east. It is situated six miles northeast of Wallace, Idaho, and north of the Osburn fault. The mine's location is shown on Figure 2 of the preceding section. The Star-Morning ore shoot lies in rocks of the Precambrian Belt Series in township 48N, range 5E, section 21 and 22. The mine is reported active and continuing normal operations with very good results during the first quarter of 1979 (Wallace Miner, Apr. 19, 1979). There were 360 employees at the Star mine and 2 at the Morning in 1978 (Idaho Dept. of Labor and Industrial Service, 1978). The Star and Morning mines are operated as a single unit, and are accessible by interconnecting tunnels at depth.

GEOLOGIC SETTING

The geologic setting of the Star-Morning mine has been described by Hobbs and others (1965), Fryklund (1964), and Sorenson (1947). It is assumed that the geology of the Star-Morning Unit is similar to, and closely associated with, the Star and Morning mines; however, literature does not give sufficient detail to validate this assumption. The Star mine is located entirely in Precambrian Revett Quartzite, while the top of the Morning mine is in the St. Regis Formation (argillite and quartzite), but because the contact between the Revett Quartzite and St. Regis Formation dips steeply eastward, most of the mine levels are in both formations. Beds in the Star and Morning mines generally strike slightly west of north, dip

steeply, and are cut by the veins at high angles. A monzonite dike is exposed in the upper level of the Star-Morning mine. Fine grained dikes with phenocrysts transect the mine. The largest dikes extend 5500 ft. from the top of the mine with a maximum width of 70 ft. The dikes are associated with haloes of alteration that may extend 50 ft. or more into the country rock on each side. The alteration includes chlorite and chloritized quartzite.

#### STRUCTURAL SETTING

The Star fault cuts the Star mine veins and is subparallel to them. The fault also offsets the monzonite dike. There is about 270 ft. of displacement on the Star-Morning ore shoot with the north side moving east on the Star 2300 level. More recent faults have developed thick gouge seams in the vein and along the hanging wall and footwall.

#### MINERALIZATION

The Star-Morning ore shoot is the largest in the Coeur d'Alene district. The vein in the Morning mine was stoped for about 6725 ft., with the last 1000 ft. below sea level, where the vein still contains ore. The ore shoot has not been mined to the same depth in the Star mine. Within the ore shoot, the vein is divided by large inclusions of country rock. The average vein width is about 10 ft.

The main ore body of the Star mine is in a nearly vertical shear zone striking N79°W and has a maximum length of 4000 ft. and an average stoping width of 10 ft. The competence of the ore vein is less than the wall rock. Physical properties of the quartzites collected from the lower levels of the mine show an average compressive strength of 26,000 psi (Chan and

others, 1972), an average modulus of elasticity of  $8.5 \times 10^6$  psi, and an average tensile strength of 1500 psi (Waddell, 1966). Additional rock properties and in-situ measurements have been completed by Patricio and Beus (1976).

#### MINE CHARACTERISTICS

The Star-Morning Unit is mined by the horizontal cut and fill method. There are five shafts and extensive tunnelling at depths from 800 to 1400 feet below the surface. Actual ore tonnage is 282,000 short tons with a daily ore capacity of 1100 tpd and 852,000 tons proved reserves (E/MJ, 1977). The mine is a leading producer of silver, zinc, and lead, with a cumulative ore tonnage of 20 million tons (1894-1962) and 49 million ounces of silver (Idaho Bur. of Min. Geol., 1963).

The workings extend to a depth of 6720 ft. with a length of approximately 3900 ft. and width of 49 ft. (CRIB, 1976). The Star and Morning mines, tunnelled through the mountain and joined workings in the late 1970's; currently an exploratory tunnel is being driven to the Lucky Friday mine across the Hunter fault with five miles of tunnelling in barren rock. Recent exploration may have extended workings into plutonic rock.

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THE COEUR MINE  
AMERICAN SMELTING AND REFINING COMPANY  
(COEUR D'ALENE MINES CO.)

#### LOCATION

The newest silver mine in Idaho, the Coeur mine began operation June 1976 and currently ranks fifth in terms of production among underground silver mines in the United States (Wallace Miner, Apr. 26, 1979). It is located along the Polaris fault, south of the Osburn fault, and 3.5 miles west of the city of Wallace. Its location is shown on Figure 2 of the preceding section. The mine came into production after 11 years of exploration and development costing \$20 million (Carter, 1976). The deposits lie in quartzites and slates, in the footwall of the Polaris fault. The mine has extensive workings to a depth of 4428 ft. and the 3400 foot level connects the Coeur to the Galena mine, 7500 ft. to the southeast.

#### GEOLOGIC SETTING

The geologic setting of the Coeur mine was described by Carter and Li (1972), Hobbs and others (1965), and Fryklund (1964). The Coeur ore-bearing veins lie in quartzites, argillite, and slate in the Precambrian St. Regis-Revett transition zone. The transition zone extends from near the surface to the 3700 foot level. The veins strike from the northeast to northwest, dip steeply to the south, average over 5 ft. in width, and have an average strike length of 750 ft.

The ore-bearing veins also occur along the footwall of the Polaris fault which is well exposed in several of the workings. A zone of gouge a few inches wide and several yards of sheared rock are commonly associated

with the fault. On the adit level, the zone of gouge and sheared rock along the fault is more than 10 ft. wide. Very little specific geologic information on the new mine is available in the literature.

#### MINERALIZATION

Most of the mineralization is contained in two veins. One vein has a strike length of 600 ft. and extends vertically for about 1000 ft. The second vein has a strike length of 800 ft. and a vertical extent of more than 1600 ft. These two veins having an average thickness of 5 ft. are the initial mining targets.

#### MINE CHARACTERISTICS

Conventional horizontal cut and fill methods are used to mine the ore. Drifts are being driven on the veins to further develop ore blocks by raising. From the horizontal stope cuts, ore is slushed to chutes that feed the main haulage rail system. Stopes are filled with mill tailings.

The mine workings include two shafts. The main shaft extends to a depth of 4430 ft. with the last 1134 ft. below sea level. Other mine development work includes a 2300 ft. ventilation raise and development raises. A drift has been driven from the Coeur 3400 foot level to the Galena mine 3700 foot level to serve as a secondary exit.

Production in 1977 was 118,600 short tons with daily capacity of 450 tpd (Eng. Min. J. Directory, 1977). The net production in 1978 was 152,000 tons extracted (Wallace Miner, July 5, 1979).

Recent development work has added more than 150,000 short tons of new ore to reserves (E/MJ, March 1979). Plans reported in March 1979 call for

extending working levels of the Coeur mine (E/MJ, March 1979).

Mining equipment includes a rail haulage transport system, and a double-drum hoist in the main hoisting area.



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THE BLACK HAWK (SECOND POND) - BLUE HILL MINE  
(Kerr American, Inc.)

LOCATION

The ore deposits are located at 44°22'N and 68°41' W in Hancock County, Maine, south of Blue Hill village which lies 14 miles west of Ellsworth and 30 air miles from Bangor (Figures 1 and 2).

REGIONAL GEOLOGY

The Hancock County area lies in the Southern Volcanic Belt (Doyle 1966). This belt is composed mostly of granite with smaller amounts of diorite and diabase. The granite of Devonian age (?) intrudes highly altered schists and amphibolites—the Ellsworth formation of Precambrian to Ordovician age (?), the oldest formation in the area and the next in abundance. The formation strikes approximately north-south (Chin-Yuan Li, 1942) (Young, 1968).

In the immediate mine area, the country rock, the Ellsworth formation, strikes approximately north-south and is almost surrounded by the intrusive granite on the east and the south. An intrusive diorite-diabase body bounds it on the west. (Figure 3)

Metamorphism and Structure

Metamorphism of the rocks is of medium to high grade. Folding and faulting is minor. This deformation is considered to be of Devonian age (MAS, 1979). The major structural features of the area strike NE-SW, parallel to the regional structural pattern of Maine. When viewed as a whole, the granite intrusions also occupy a NE-SW belt. In the mine region, the strike of the schistosity is predominantly WNW-ESE and the dip is 50°SW. However, local variation of these features can be large (Ching-Yuan Li, (1942).

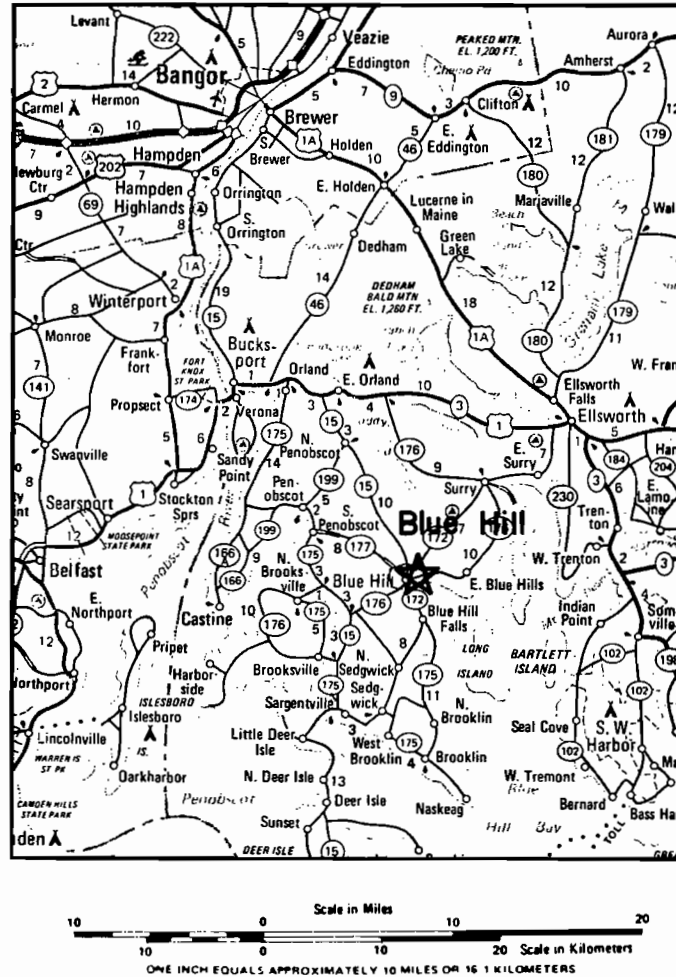


FIGURE 1. Location map of Blue Hill Mine, Hancock County, Maine. Basic map reproduced by permission of the American Automobile Association, copyright owner.

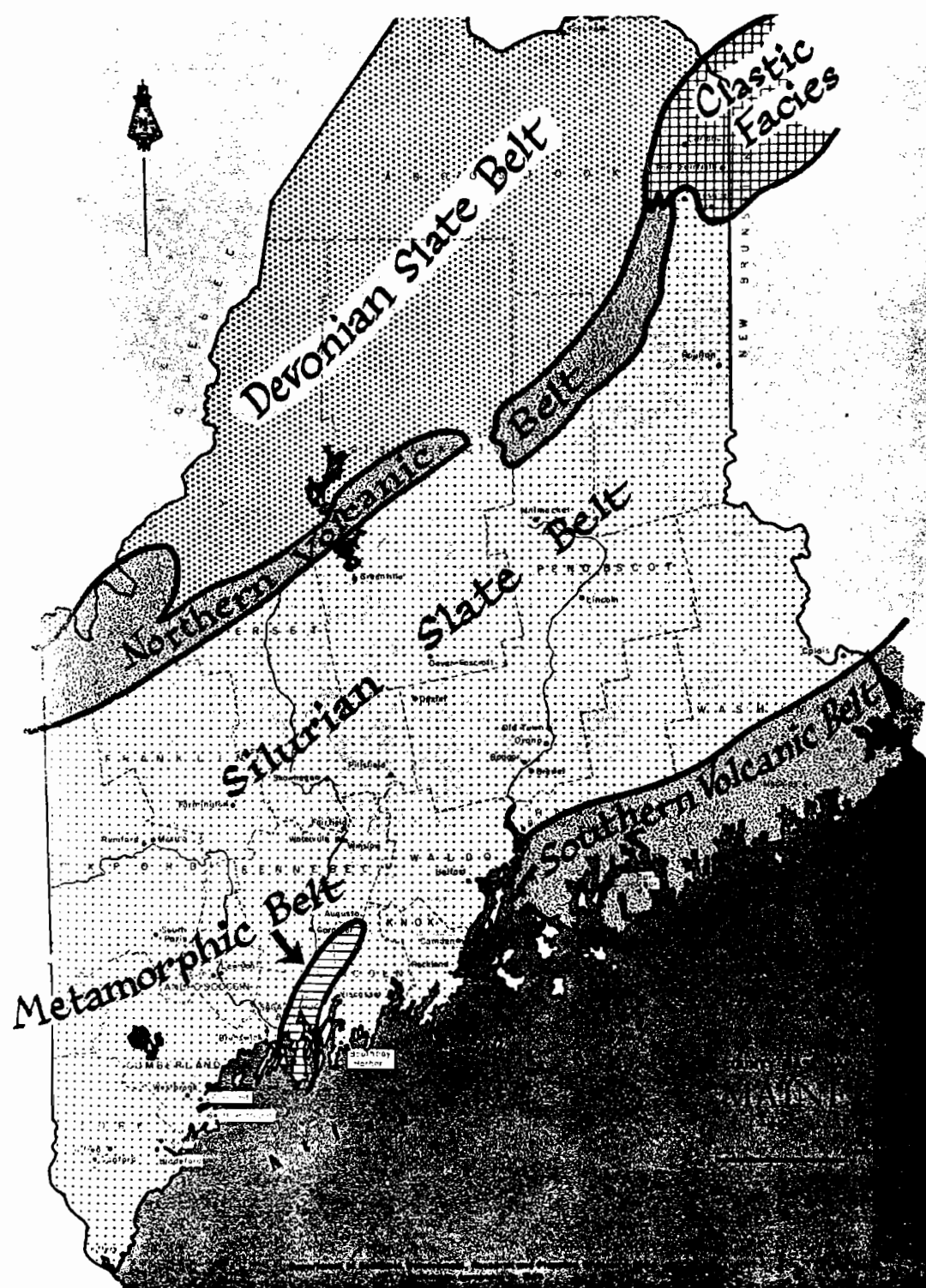


FIGURE 2. Basic geologic environments, State of Maine (Young, 1968).

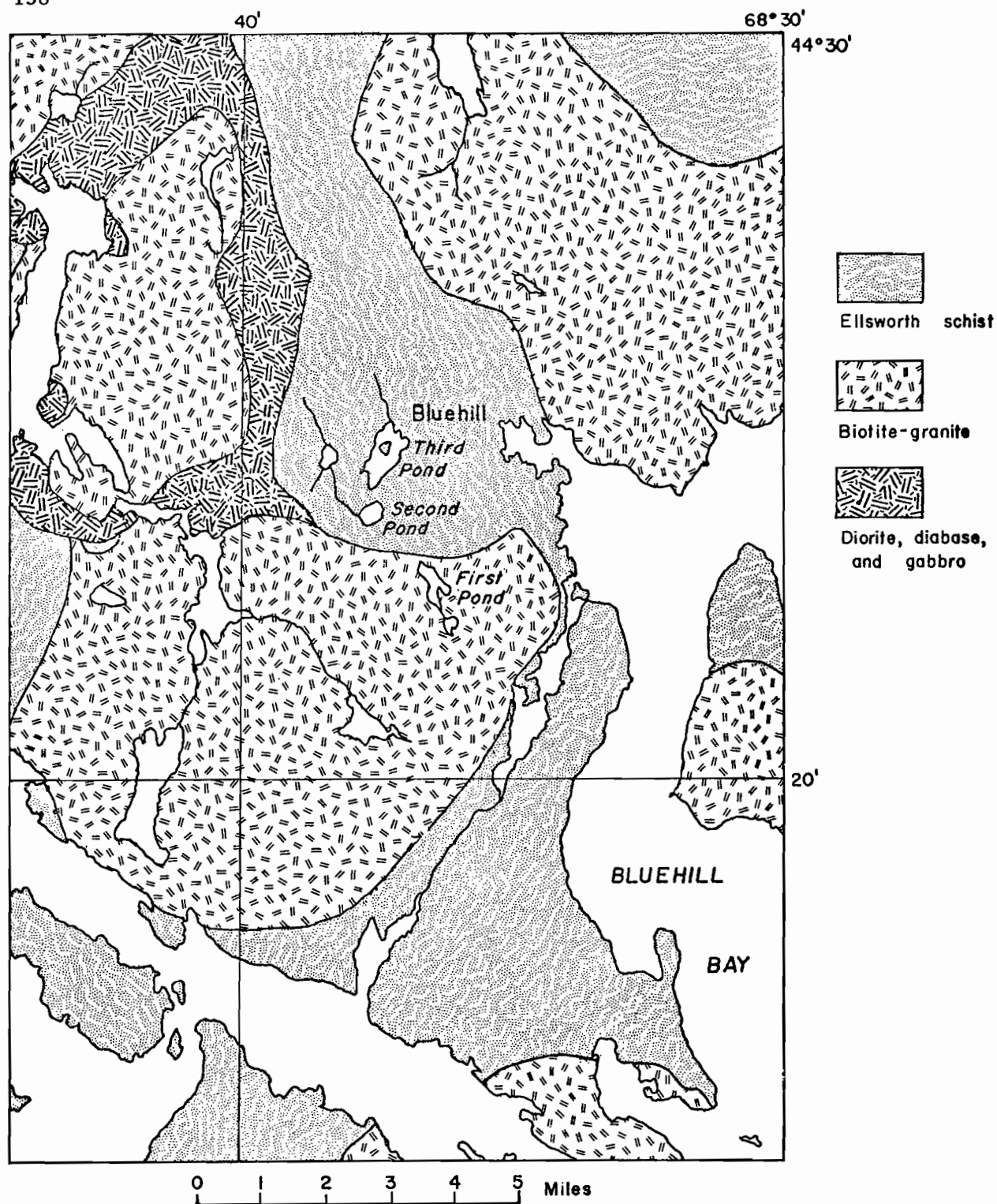


FIGURE 3. Simplified geologic map of the Blue Hill area (after Smith, 1907).

### Mine Geology

The Second Pond deposit occurs as a series of shallow dipping ( $26^{\circ}$ ) parallel ore zones wrapped around the nose of a gently folded southerly plunging anticline (CRIB, 1978). The ore bands are in highly altered schists and amphibolites of the Ellsworth formation and near granite intrusions and are thought to be genetically related to these intrusions (Young, 1968) (Ching-Yuan Li, 1942). The ore minerals are chalcopyrite, sphalerite, galena, and pyrrhotite.

### Hydrology

In Maine, some tracts of land considered suitable for mineral rights staking are controlled by the state. These are usually called "public lots." Natural water bodies greater than ten acres are in this category (Young, 1968). Second Pond is one of the latter. This suggests that the mineralization is beneath a water body and is, evidently, the reason for the inclined shaft on this property. Water removal is therefore a problem in the mine because of the high water table. At present the Second Pond Mine is completely water filled. In fact, when the mine was put on standby, the water followed the departing miners (private communication).

### FACILITIES

The mining property is owned and operated jointly by Kerr American Inc. (subsidiary of Kerr Addison) and Black Hawk Mining Ltd. (subsidiary of Denison Mines Ltd.), (3900 S. Tower, Royal Bank Plaza, Toronto, Ontario, Canada) which are Canadian companies. The ore reserves as of December 31, 1976, were estimated to be 140,200 tons. In 1973, ore reserves were estimated to be 670,000 tons (CRIB, 1977). In 1970, the

shaft depth was 698 feet with levels at 280, 380, 400, 580, and 680 feet.

A trackless mining method was used.

Engineering and Mining Journal (1965) stated that the company was sinking an inclined shaft to 1300 feet. Young (1968) reported that a three compartment 1300 foot shaft was sunk and several thousand feet of development completed on the 380, 480, and 580 levels. CRIB (1977) stated that in 1968, the shaft depth was 400 meters with levels of 116, 146, and 177 meters.

Operations were halted in 1977 and the mine placed on standby because of low copper and zinc prices. In 1977, the total amount of mined ore was 144,964 tons (483 tons/day) (Canadian Mines Handbook, 1978-79) (The Mineral Industry of Maine, Minerals Yearbook 1971). The Kerr Addison 1977 Annual Report indicates that mine openings were closed with concrete bulkheads at that time. Their 1978 report states that mining and milling operations were being conducted on a care and maintenance basis only.

The mine is now inactive and filled with water.

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## MINNAMAX PROJECT

(OPERATED BY AMERICAN METAL CLIMAX INCORPORATED)

## LOCATION

The Minnamax project site is located approximately 5 miles SSE of Babbitt, and about 60 miles north of Duluth, Minnesota (Figure 1) at 47°37'N and 91°52'W. The elevation of the area is about 1600 feet.

## GEOLOGIC SETTING

Regional

Data for this section were extracted from Bonnichsen (1972), Minnesota Department of Natural Resources (1977), and Phinney (1972). The Duluth Complex of northeastern Minnesota includes about 2500 square miles of Upper Precambrian anorthositic, troctolitic, gabbroic, and granitic intrusive rocks. The complex has an arcuate pattern extending from Duluth northeastward into the northeasternmost tip of Minnesota, a distance of 150 miles. The complex was intruded along an unconformity between the overlying volcanics (North Shore Volcanic Group - mainly rhyolite) and underlying older rocks of Early and Middle Precambrian ages (Virginia Formation sediments, Biwabik Iron Formation, and Giant Range batholith). Radiometric dating indicates an age of approximately 1120± 15 million years for the Duluth Complex intrusives.

The region in which the Minnamax project is located is referred to as Babbitt-Hoyt Lakes, and is approximately midway along the northwestern edge of the Duluth Complex, as shown in Figure 2. The geology of the Babbitt-Hoyt Lakes region as well as the location of the Minnamax project is shown in Figure 3.

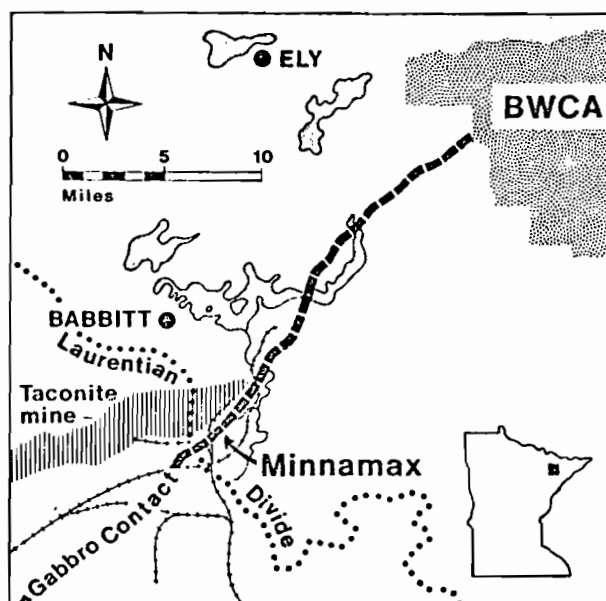


FIGURE 1. Location map of Minnamax Project, St. Louis County, Minnesota (E/MJ, 1976).

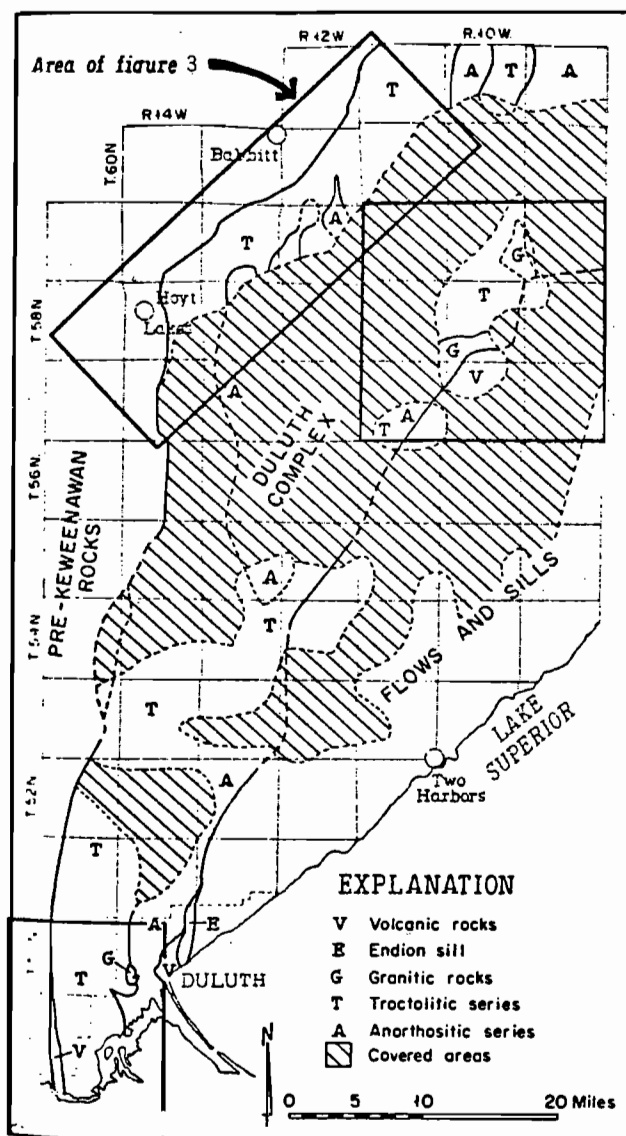


FIGURE 2. Geologic map of southern part of Duluth Complex (Bonnichsen, 1972).

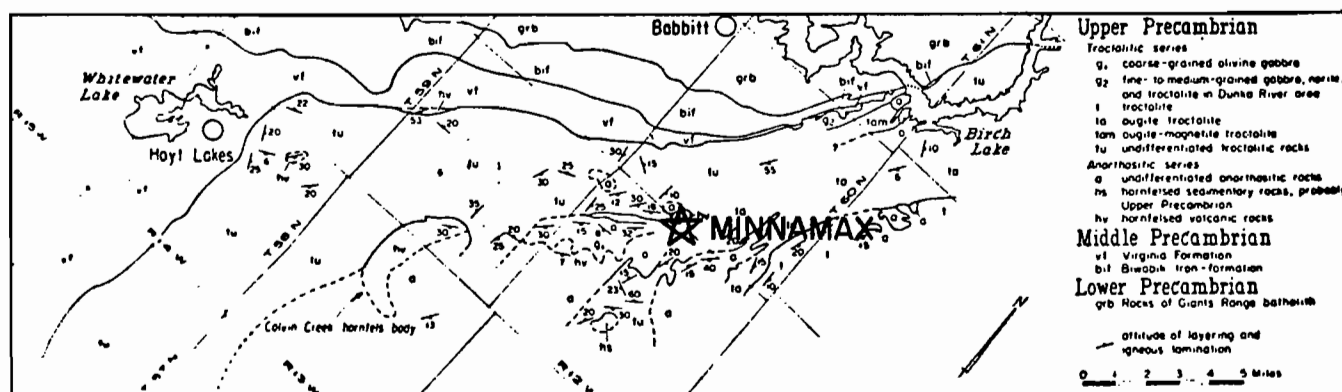


FIGURE 3. Geologic map of Babbitt-Hoyt Lakes region (Bonnichsen, 1972).

Two major rock groups in the complex are recognized, a troctolitic series and an anorthosite series. The troctolitic series consists of troctolite (primarily calcic plagioclase and olivine), and augite troctolite, while the anorthositic series consists primarily of gabbroic anorthosite and troctolitic anorthosite. The troctolitic series occurs adjacent to the western margin of the complex. The anorthositic series generally is located east and south-east of the troctolitic series. Numerous inclusions of fine-grained, generally granular hornfelses, ranging in size from a few inches to thousands of feet, are present in the southern half of the complex, and are especially abundant within the troctolitic series adjacent to the western margin. Hornfelses derived from mafic volcanic rocks probably are most abundant.

#### MINE GEOLOGY

The data for this section were extracted from Phinney (1972), and CRIB.

Exposures are poor in the area of the Minnamax project, and the relationships among the various units are not well understood. The host basal troctolitic gabbro of the Duluth Complex varies in grain size, mineral proportions, structural attitude, and texture. The exploration shaft and accessory tunnels are apparently in the Duluth Complex intrusive. The data available suggests that the main rock types in the mine workings are medium-grained troctolite grading locally into olivine gabbro; the texture in places may be pegmatitic. The copper/nickel mineralization is in the form of a sulfide segregation in the troctolitic intrusive.

The shape of the deposit is tabular, with dimensions of approximately 6000 meters in length, 115 meters in width, and 100 meters in thickness. The ore body strikes N45°E and has a dip of 17°SE. The depth to the top of the ore body is about 430 meters.

## MINE FACILITIES

The data for this section were extracted from CRIB, EMJ (1976), and USGS (1979).

The Minnamax ore body was discovered by Bear Creek Mining Company in 1957, and was later acquired by Amax Exploration, Inc. Amax has carried on a substantial amount of exploration since acquiring the property. A 14 foot diameter shaft has been sunk to a depth of 1710 feet, as illustrated in Figure 4. Approximately 6000 meters of drifting has been done from the shaft.

A decision to develop the prospect will not be made before 1980, and startup will require an additional 3 to 4 years.

Amax is permitting the U.S. Geological Survey and the University of Minnesota to use part of its Minnamax underground workings to conduct a comprehensive series of stress measurements.

## ELY PROSPECT

The Ely prospect of International Nickel Company is located approximately 15 miles east of Ely, Minnesota, less than 20 miles north of the Minnamax project. The geology of the Ely prospect is likely similar to Minnamax, since both are part of the troctolitic gabbro of the Duluth Complex. The underground workings at the Ely prospect consist of a shaft approximately 1,000 ft. deep, a 400 ft. long, 8 ft. wide drift, and a 40 ft. wide, 180 ft. deep stope. A limited description of the site, along with a more complete discussion of hydraulic fracturing field tests, were given by Von Schonfeldt (1970). In this report the Ely prospect is categorized in group 2 because sufficient data are presently not available.

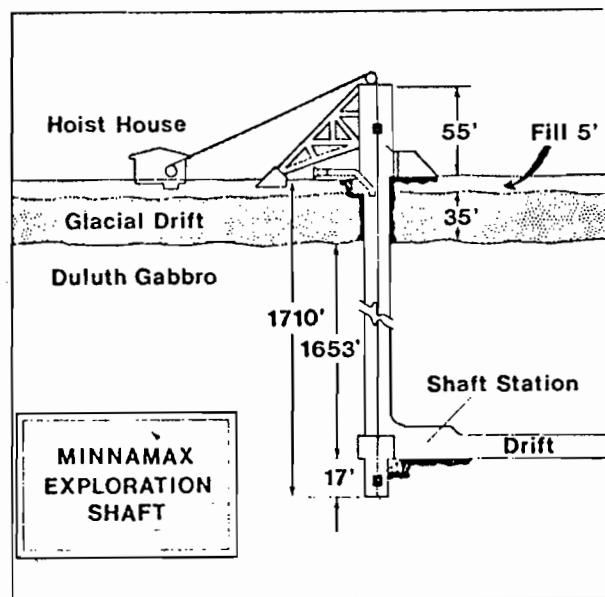


FIGURE 4. Minnamax exploration shaft (E/MJ, 1976).

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BLACK PINE MINE  
(CONSOLIDATED COPPER CO.)

LOCATION AND ACCESSIBILITY

Black Pine Mine is an active small silver mine in the Philipsburg District, Granite County, Montana. Since 1882, it has been mined intermittently with an estimated cumulative production (1885-1964) of 2.6 million ounces of silver and 3000 ounces of gold (Krohn and Weist, 1977). Formerly called the Combination mine, it is located west of Henderson mountain at 46°27'N, 113°22'W at an elevation of 6500 ft. It is accessible by gravel road, 12 mi. northwest of the town of Philipsburg (Figure 1).

The Black Pine Mine is included among the "class 1" mines in this study, as representing an active mining district, and also for comparison with mines of the Coeur d'Alene District, Idaho. The Coeur d'Alene mines are located in quartzitic rock types similar to those of the Philipsburg district, but the structural settings of the two districts are distinctly different. The new development drifts at Black Pine may extend into the nearby intrusive rocks.

GEOLOGIC SETTING

The geology of the Black Pine mine area was briefly outlined by White (1976) and described in detail by Wallace and others (1978), Prinz (1967) and Emmons and Calkins (1913). It is an area of folded and faulted Precambrian sedimentary rocks that have been intruded by Cretaceous batholiths (Figure 2). The sedimentary rocks consist mainly of limestone, dolomite, shale, quartzite, and phosphatic quartzite which,

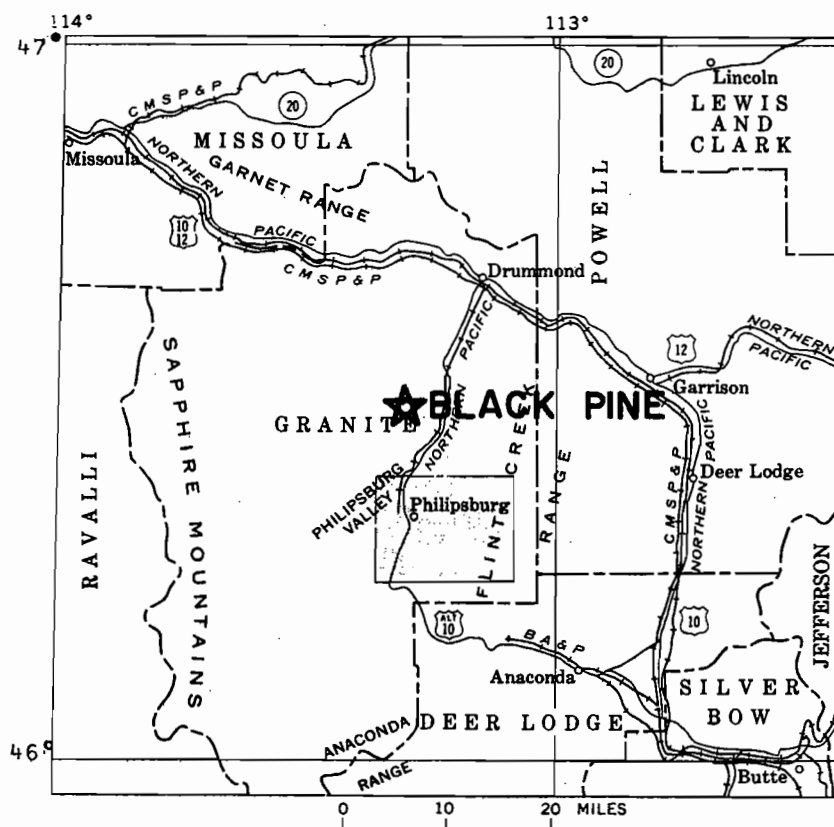
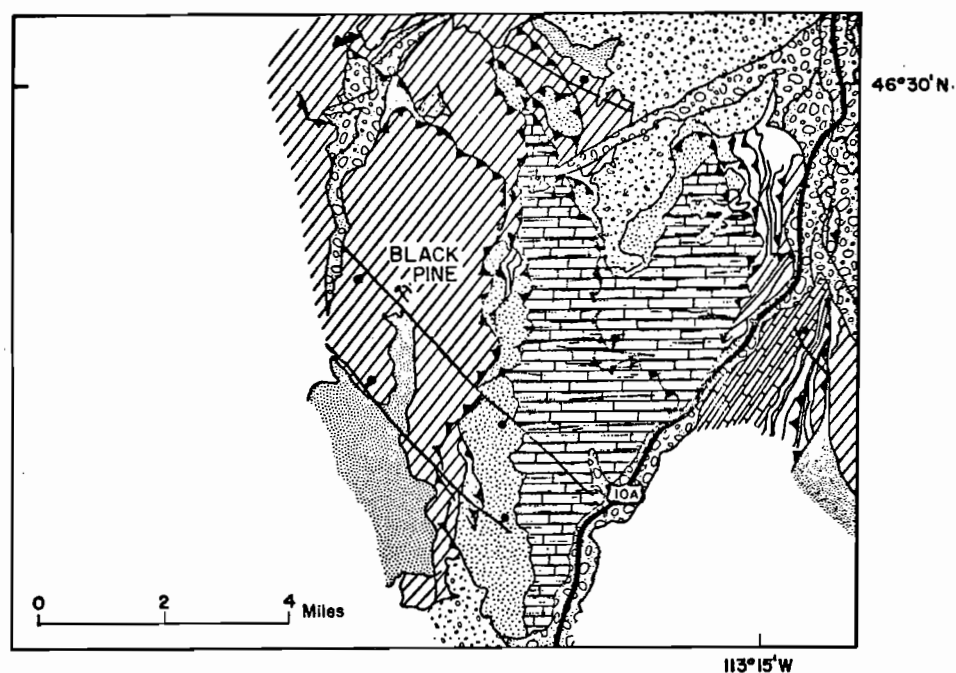


FIGURE 1. Location map of Black Pine mine, Granite County, Montana (Prinz, 1967).















-  Quaternary alluvial deposits and glacial debris
-  Tertiary alluvial, lacustrine and volcanic deposits
-  Cretaceous granitic stocks and dikes
-  Mississippian Madison limestone
-  Precambrian Mt. Shields Formation
-  Unit 1-argillite, fine sandstone interbedded with quartzite
-  Unit 2-quartzite with coarse pebbly zone bottom and top
-  Unit 3-interbedded argillite and fine sandstone
-  Precambrian Snowslip Formation - argillite and siltstone interbedded with sandstone
-  Precambrian Helena Formation - argillaceous limestone and limy siltstone
-  Thrust fault, triangles on upper plate
-  Normal fault, balls on down-thrown side

FIGURE 2. Geologic map of the area around the Black Pine Mine, Granite County, Montana. (Wallace, 1978)

near the contacts with batholithic rocks, have been metamorphosed to marble, tactite, and hornfels. The stratigraphic sequence in the Philipsburg district is outlined in Table 1.

The oldest unit in the district is the Spokane Formation, equivalent to the Missoula Group of the Precambrian Belt Series (Ross, 1963). The Spokane Formation consists of a series of thin-bedded red to brown siltstone, massive gray to reddish brown quartzite and thin-bedded sandstone and shale, with an aggregate thickness of 5000 ft. (Ross, 1963). The Spokane Formation is the only rock unit at the mine, and the ore, so far as is known, is confined to the quartzite members. The quartzite is slightly metamorphosed. Some secondary quartz has been added by circulating waters, and white mica or sericite has been developed from the clay between the grains of sand. Otherwise, the quartzite has not been greatly metamorphosed. Other units of the Belt Series that crop out in the area, but are not exposed in the mine, are Newland limestone and shale, Ravalli quartzite, and shale and Neihart quartzite and argillite. The rocks strike approximately N30°W and dip from 10-20°SW.

Intrusive igneous rock has not been reported in the mine, but more recent exploratory drifts may have intersected intrusives. The nearest known intrusive is a granodiorite porphyry dike about 1 mile north of the mine. The Philipsburg batholith, a large granodiorite pluton, lies several miles south of the mine. The batholith is elliptical in plan and underlies an area of 45 square miles. Mineralization of the mine may be associated with the intrusion of the batholith, which is described in more detail in the section covering the Granite-Bimetallic mine.

#### STRUCTURE

The structural setting of the Black Pine mine is simple compared to the highly contorted and faulted conditions in the Coeur d'Alene mines.

Rock Unit	Thickness	Description
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## CRETACEOUS

Philipsburg Batholith		Coarse grained granodiorite, even textured to porphyritic, associated stocks and dikes. Radiometric age 78-68 million years before present (Tilling et al, 1968).
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## PRECAMBRIAN

Belt Series	Spokane Formation	1525 m. (5,000 ft.)	Massive gray to reddish-brown quartzites, thin-bedded red to brown siltstone and thin-bedded sandstone and shale; mud cracks and ripple marks present.
	Newland Formation	1200 m. (4,000 ft.)	Calcareous shales and impure limestones characterized by buff tints on weathered surfaces.
	Ravalli Formation	600 m. (2,000 ft.)	Gray quartzitic sandstone with much dark shale in upper part.
	Neihart Quartzite	300 m. (1,000 ft.)	Pure thick-bedded light colored quartzite.

TABLE 1. Generalized geologic column for the Black Pine Mine area, Philipsburg mining district, Granite County, Montana (adapted from Ross, 1963; and Emmons and Calkins, 1913).

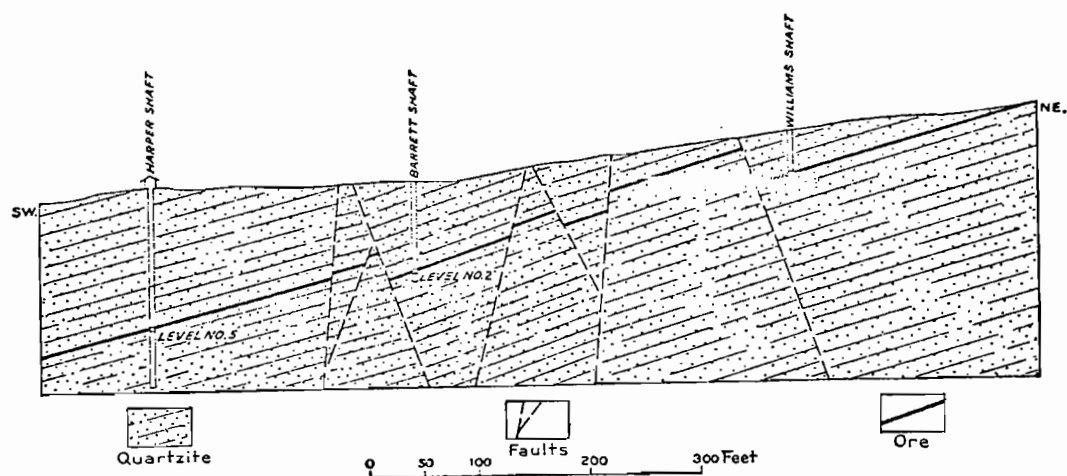
At Black Pine, the rock units are gently dipping and the ore-bearing veins lie along the bedding planes. Several normal faults traverse the area, while no thrust or strike-slip faults occur. The normal faults strike northwesterly, paralleling the strike of the quartzite with displacements up to 33 ft. However, some faults cut the quartzite strata at right angles to its strike.

The principal structural features originated during the Laramide orogeny after broad folding of the Precambrian sediments. The Spokane quartzites were thrust eastward over younger Paleozoic rocks and folding continued. Intrusion of the Philipsburg batholith south of the mine area followed the folding and faulting. The period of ore deposition then occurred along fissure veins. Normal faulting along bedding postdates mineralization and was the last event of the orogeny.

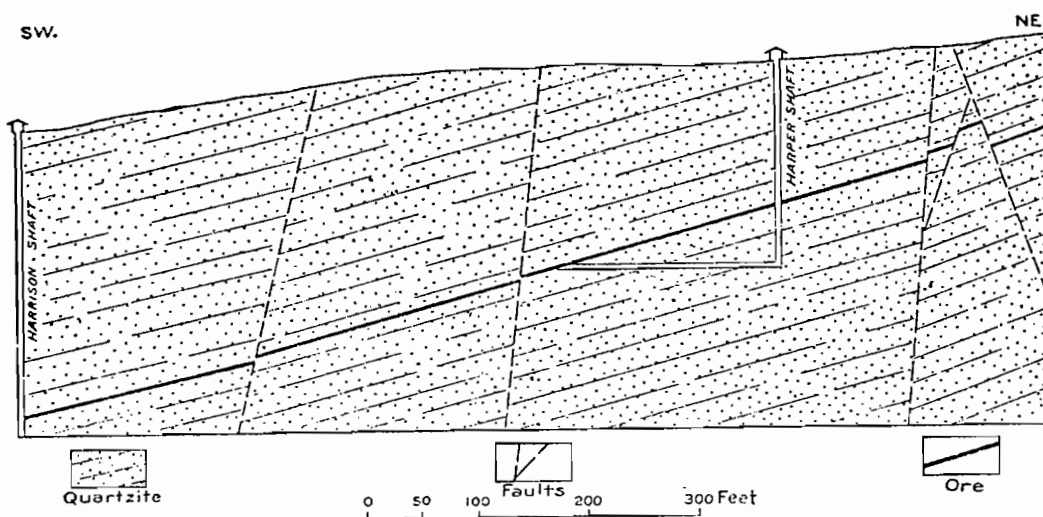
#### MINERALIZATION

The Black Pine ores occur in bedding fissures of the Spokane Formation. The silver-bearing replacement veins are silica rich, and as a group range from a few inches to twenty feet in thickness. The average thickness is probably 3-5 ft. The veins are banded, and breccia zones parallel the layering and the walls in many places in the veins. The walls of the veins are generally sharp and commonly marked by fault gouge.

The Combination vein, the principal vein, is in quartzite and nearly everywhere conforms to the bedding of the country rock (Figure 3). Generally, it is a simple fissure filling deposited in an open space along a single bedding plane; locally it is divided by large slabs of the country rock. The vein dips  $10^{\circ}$ - $30^{\circ}$ SW and extends more than 3500 ft. along the strike and an equal distance down dip. The hanging wall and footwall of the Combination vein are barren and unaltered.



Cross section of the Combination lode, a bedding-plane fissure vein in quartzite. It is cut by normal faults across the bedding.



Cross section of Combination lode through Harper shaft to Harrison shaft.

FIGURE 3. Geologic cross section of the Combination Vein, Black Pine Mine in relation to the Spokane Formation quartzite. Displacements are shown along several faults, and early mine workings (from Emmons and Calkins, 1913).



The structure of the ore-bearing veins is comparatively simple (Figure 3). The veins follow the bedding planes of the quartzite, except in areas of post-ore faulting. On level 5, near the Harper Shaft, the main vein strikes N30°W and dips 15°SW, typical of the strike and dip of the vein at most places in the mine.

In addition to the Combination vein, three other mineralized veins are recognized: the Upper, the Tim Smith, and the Onyx. Only the Combination vein was mined extensively in the past and is now being worked. The Tim Smith vein is located 150 ft. above the Combination vein, and contains ore-grade material. Not much is known about the Onyx vein, located 400 ft. below the Combination vein, as it is largely unexplored. Nothing was reported about the Upper vein in the literature.

#### MINE CHARACTERISTICS

The mine was originally developed through eight vertical shafts and three tunnels (Emmons and Calkins, 1913). Four shafts and mine workings along the Combination vein are illustrated in Figure 3. The ore body is a large blanket deposit. Levels were excavated at about 100 ft. intervals down the dip of the vein and have a difference in elevation of about 20 ft. A long incline was driven on the main vein from a station near the bottom of the Harper Shaft to the Harrison Shaft. In 1913, the workings comprised in all about 12,000 ft. of intersecting drifts, inclines, and crosscuts.

In 1970, Inspiration Consolidated Copper Co. acquired the Black Pine mine (White, 1976). The exploration program included drifting in the ore and diamond drilling from the surface. The present development plan prior to stoping is reprinted from White (1976), in Figure 4. Four shafts that were sunk in the early operations are presently being used. The Harper is used today as an exhaust shaft in the ventilation system. A second shaft,

the Lewis, will be added to the ventilation system when the main haulage reaches a length of 2200 ft.

The ore body is extracted in 100 x 100 ft. ore blocks. Three panels are driven in each direction across the ore blocks with 6 x 6 ft. pillars left between panels to support the back. The stope headings are 6 ft. high by 15 ft. wide.

Rock bolting provides roof support, with landing mat strips between bolts. The ground is competent, and a number of stopes from early mining operations remain open.

The mine is essentially dry and does not require pumping for dewatering (White, 1976). However, Emmons and Calkins (1913), reported that mine workings below level 14 were flooded and above this level were accessible and in good condition after a long period of idleness (about 1897 to 1913).

Equipment includes Gardner Denver 83 jacklegs for drilling, Eimco 911 LHDS for mucking, Caterpillar 950 for loading ore, and Eimco 980T-10 for haulage. Air is circulated by two 40-hp Joy Axivane fans with a 80,000 cfm capacity. Several surface facilities are also present.

## Development drifting at Black Pine mine

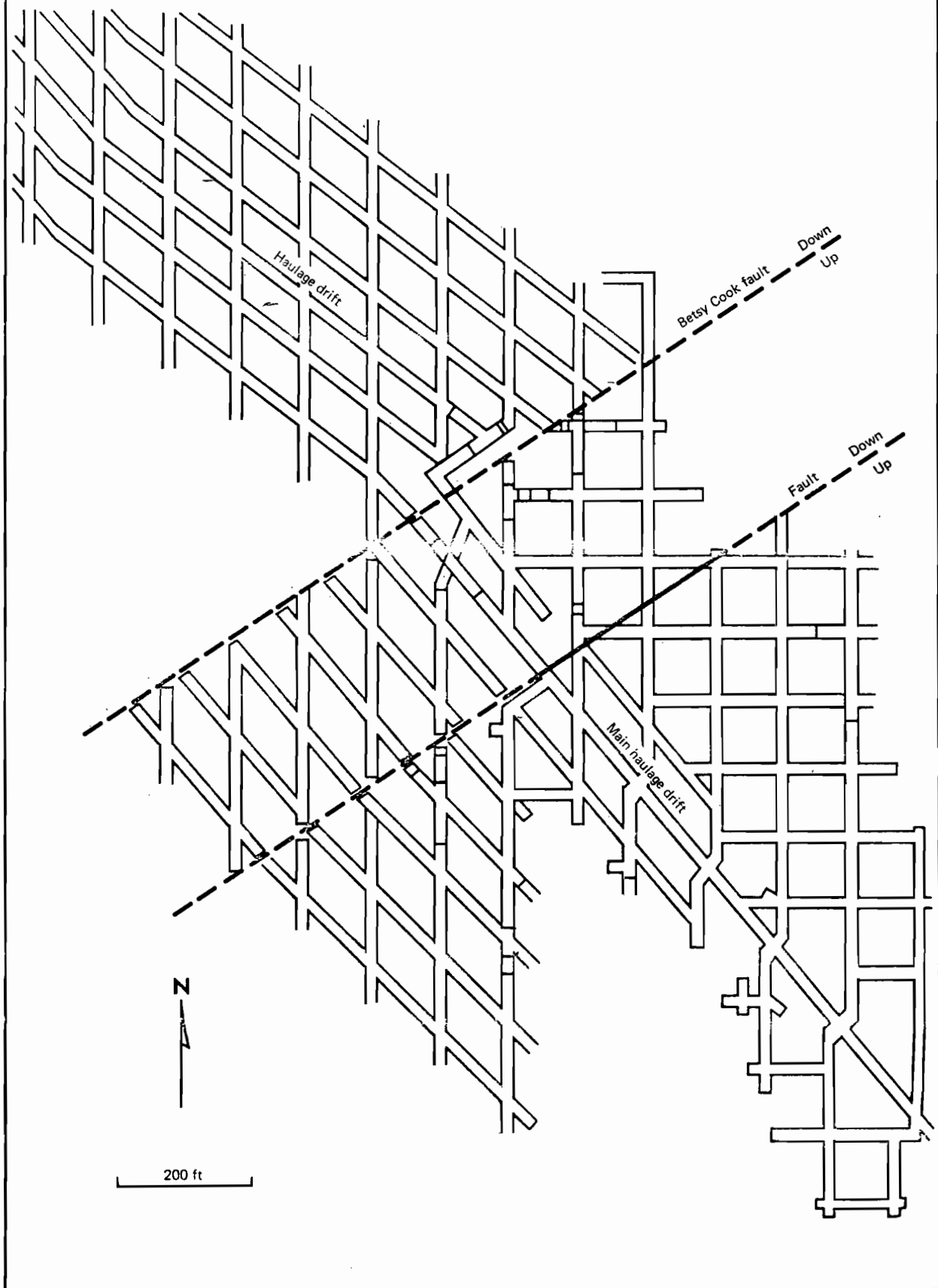


FIGURE 4. Recent development drifts at Black Pine mine. The main haulage drift is along Combination Vein (Figure 3) (from White, 1976).

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BUTTE MINING DISTRICT AND BUTTE UNDERGROUND MINES  
(THE ANACONDA COMPANY)

LOCATION AND ACCESSIBILITY

The Butte district is composed of underground and surface mining operations in Silver Bow County, Montana at 46°1'N, 112°33'W, (Figure 1). The mining district is located east of the city of Butte (population ~23,000), surrounded by the Tobacco Root Mountains at an elevation of 5700 ft. The area is accessible by air, rail and highway year round.

GEOLOGY

The geology of the Butte district is described in detail by several authors; notably by Sales (1914) and more recently by Meyer and others (1968). In this review the general lithology, structure, and mineralization of the district are described, followed by brief descriptions of two accessible underground mines, the Leonard and Steward mines.

LITHOLOGY

The Butte district is underlain by the Boulder batholith which intruded into a central tectonic block bounded by faults and the Lewis and Clark lineament. The generalized geologic setting is illustrated in Figure 2 and a generalized lithologic column, vein-type and alteration sequence in Figure 3. The Boulder batholith is a composite of epizonal plutons that range in composition from gabbro to granite. The batholith and related intrusives were emplaced during a ten million year interval from 78-68 million years. Knopf (1957) and Klepper (1962) show that emplacement occurred in phases, beginning with intrusion of mafic bodies near the north and south portions of the present-day batholith, followed by massive granodiorite emplacements, and finally the Butte quartz monzonite. The Butte District is located in the

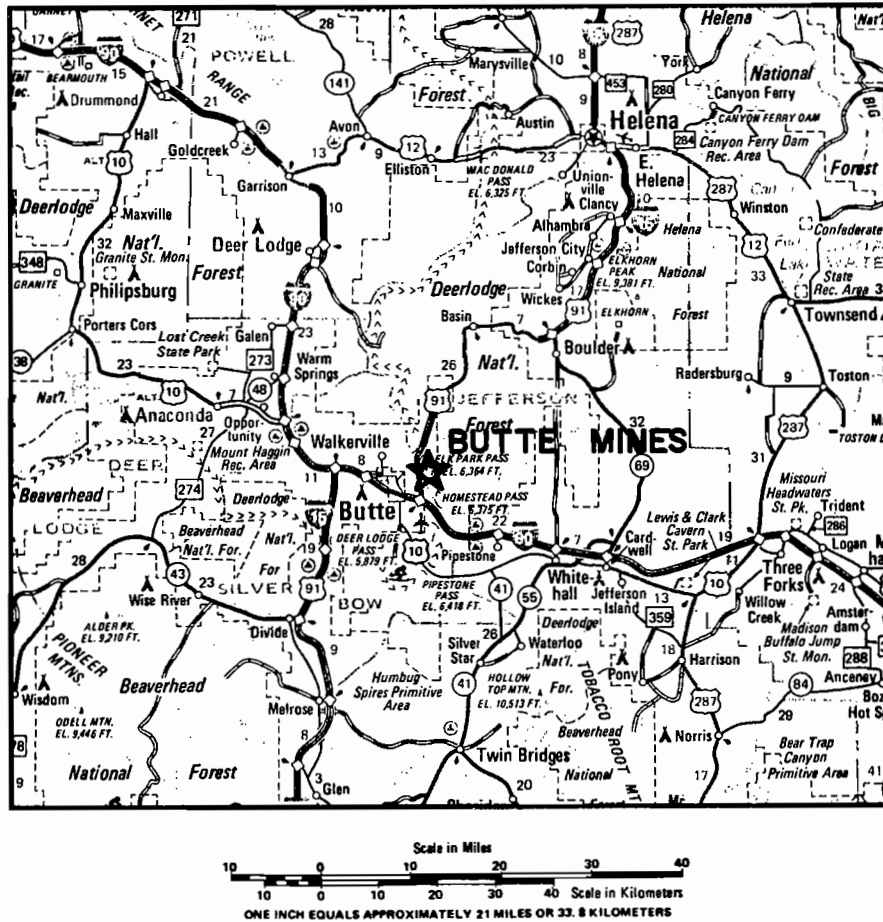


FIGURE 1. Location map of Butte underground mines, Silver Bow County, Montana. Basic map reproduced by permission of the American Automobile Association, copyright owner.

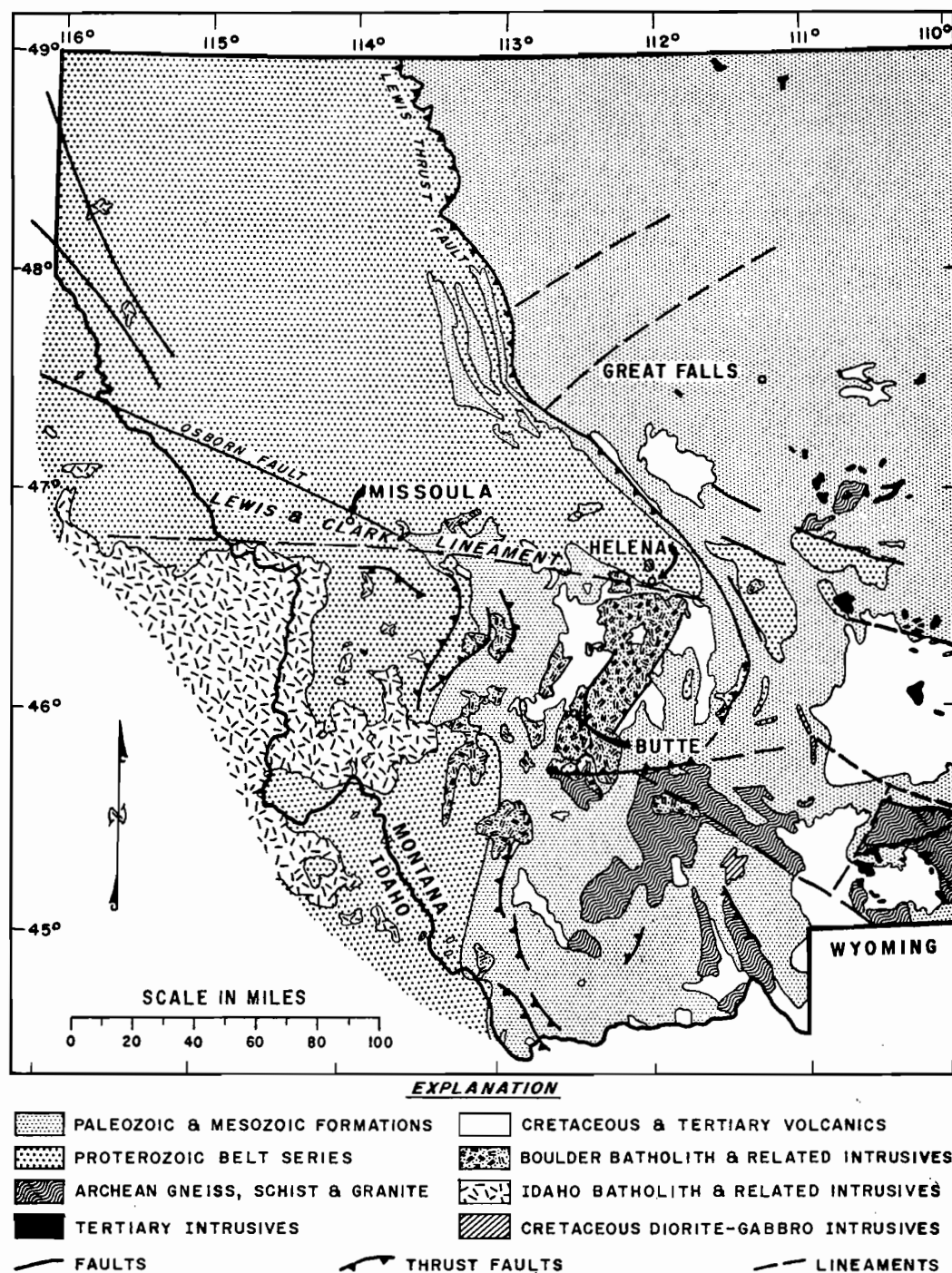


FIGURE 2. Generalized geologic map of the Butte mining district and Boulder batholith relative to major tectonic elements in southwestern Montana (from Meyer and others, 1968).



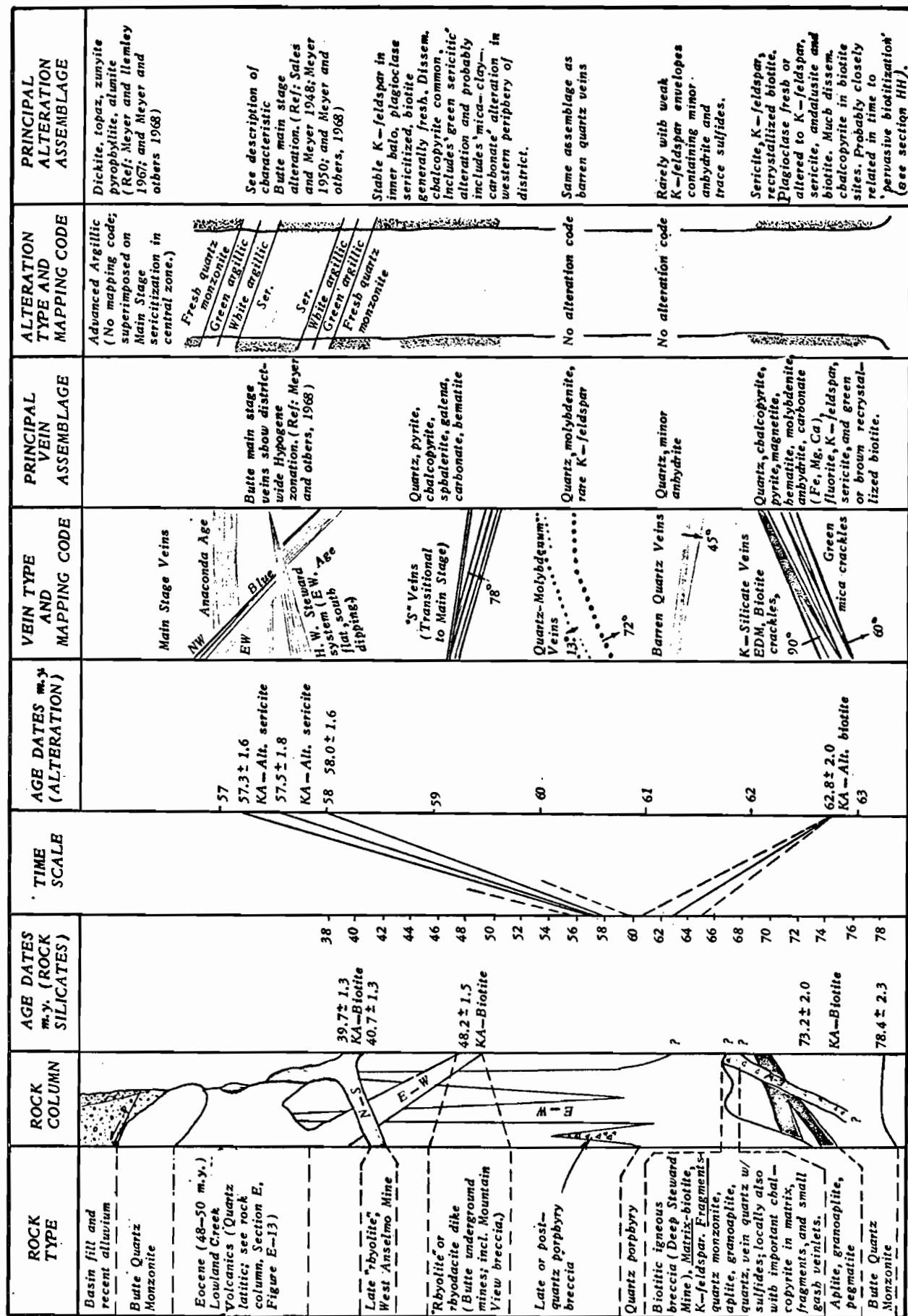


FIGURE 3. Generalized rock column for the Butte Mining District, Montana, showing intrusive-vein-alteration sequence and available age dates of rock-alteration assemblages, (from Miller, 1973).

Butte quartz monzonite which forms the main mass of the batholith. Large dikes and smaller irregular bodies of younger quartz monzonite cut older rocks. Late magmatic alaskite and aplite dikes cut all rock types and vary in size, shape, and texture.

The Butte mines worked fissure veins in the Butte quartz monzonite. The Butte quartz monzonite is medium to rather coarsely textured, homogeneous in composition, and contains about 65 percent  $\text{SiO}_2$  and equal parts of quartz and orthoclase. Plagioclase is abundant and the mafic minerals present are hornblende and biotite. Isolated dikes and irregular masses of aplite and pegmatite, composed predominantly of quartz and K-feldspar, are scattered throughout the quartz monzonite. The aplites and pegmatites are usually closely associated and, in some places, grade into the quartz monzonite. Most of the aplites are tabular and fill cracks in the quartz monzonite.

Quartz porphyry dikes and plugs are associated with the quartz monzonite and were present in the district at the time of mineralization. They are irregular porphyritic dikes with prominent quartz phenocrysts, and cut the quartz monzonite. The dikes range from 10 to 50 ft. in width, are roughly parallel in trend, and have nearly vertical dips. They have been observed as deep as the 4200 foot level, still in dike-like form. The contacts of the quartz porphyry are sinuous with only moderate fragmentation of the quartz monzonite.

Another set of intrusives locally called the "rhyolite dikes" followed the ore emplacement. They are rhyolitic or quartz latitic in composition and contain quartz phenocrysts and euhedral phenocrysts of albite and K-feldspar in a predominantly aphanitic groundmass. The rhyolite dikes have offset and brecciated ore veins and locally metamorphosed the vein minerals. These dikes were intruded in two stages. The earlier stage strikes roughly east-west and dips nearly vertically. It is essentially a single dike which

crosses the entire district. It follows pre-existing planes of weakness, such as the Anaconda fissures, and the Stewart and Middle faults. The second set of dikes, trending north-south, cuts the east-west dike, with "chilled" margins at the contact with that dike. Most of the north-south dikes extend to the surface and are a few hundred feet wide near the surface. They are less altered than the east-west dike. Radiometric dates using  $^{40}\text{K}/^{40}\text{Ar}$  indicate that the east-west dike is about 48 million years old and the north-south dikes are about 40 million years old (Woakes, 1949).

#### STRUCTURE

The Butte district is located in a central tectonic block of an active mountain-building region. To the north, a thick sequence of Precambrian Belt Series sediments is faulted and folded along axes parallel to the regional northwesterly Rocky Mountain trend and displaced northeastward as the Lewis thrust plate. The district is bounded on the south by a stable block of gneiss, schist, and granite which has resisted deformation since the Precambrian. The central block is also bounded on the north by the Lewis and Clark lineament and on the south by an east-west lineament. This central mass has been an area of recurrent subsidence and deformation, and has migrated eastward relative to the adjacent blocks. It is postulated by Meyer and others (1968) that the eastern movement was retarded by the stable block to the south, inducing clockwise rotation. This rotational movement explains the northwesterly structural trend in the northern block, the northeasterly trend in the central block, and the northwesterly trend again in the southern block. It appears that the structural trend of the district was established before the main stage of mineralization, and the reverse "S" curvature of structural trends influenced orientation of the Boulder batholith itself.

Structural development continued during and after mineralization (Prof-fett, 1973). Post-ore structures include intrusions, strike faulting along earlier veins, and movement along several systems of faults with accompanying

brecciation. These events are not described in more detail here as they have little effect on the underground mine workings.

In addition to the lineaments and thrust faulting in the district, there are several other fault systems. The Blue fault strikes north-westerly and offsets the Anaconda veins in a left lateral motion. The Steward fault system is the earliest of a series of northeast-striking normal faults which offset the Anaconda fissures. The Rarus fault consists of a zone of 50 ft. or more of bifurcating individual fault gouges. The Middle fault system strikes slightly north of east and steeply dips to the south; the movement is apparently normal. The chief member of the Continental fault system is a north striking normal fault, located at the eastern edge of the district. Topographic evidence indicates displacement of 1500 ft. and there are strong indications that movement since mineralization may be several times that much.

The extreme complexity of the fault patterns in the Butte district indicates that the structural epochs were not sharply defined or separated by periods of stability. There was much refaulting throughout and following mineralization.

#### MINERALIZATION

The main stage of mineralization occurred between phases of intrusion, uplifting and faulting. In general, mineralization in the large veins occurred as roughly concentric zones of zinc and manganese around a central zone of copper. Slightly offset from these zones and earlier structurally, is a zone of quartz-molybdenite veinlets occurring at the 2800 foot level and widening downward.

Butte is one of the world's outstanding examples of metal and mineral zoning. Three zones were outlined by Sales (1914). These zones are:

- (1) A central zone occupying an area of altered granite in which the ores are characteristically free of sphalerite and manganese minerals,
- (2) An intermediate zone in which the ore is predominantly copper, but is seldom free from sphalerite, and
- (3) A peripheral zone in which copper has not been found in commercial quantities.

The approximate positions of these zones are illustrated in Figure 4. The line between the Central and Intermediate zones is called the "Copper Front" and delineates the area within which ores of copper may be found in major structures. The "Copper Front" includes some islands of copper ore lying outside of the zone of continuous copper mineralization. Most of these islands are connected along veins to the main copper zone at deeper levels. The association of wall-rock alteration and ore at Butte was the subject of a classic paper by Sales and Meyer (1948).

Nearly all the production from Butte has come from large veins and from zones of closely spaced fractures called "horsetail ore bodies." A plan view of three major veins is illustrated in Figure 5.

Sales (1914) reported that the east-west striking veins were the first of the large veins in the district to open and receive mineralization. He named these the Anaconda system; a cross section view of one of the Anaconda veins is shown in Figure 6. Five principal veins of the Anaconda system have been mined extensively along with 12 to 15 smaller veins and numerous splits and bifurcations. The average width of the Anaconda veins is between 20 and 30 ft., and locally the veins may extend to 100 ft. in width. These maximum widths generally occur in the zone of changing strike.

In the eastern part of the district the "horsetail zones" occur. These ore bodies are hundreds of yards long and up to 200 ft. in width, and have been mined over vertical distances as great as 2000 ft. The zones strike about N70°E, perpendicular to the small individual mineralized fractures.

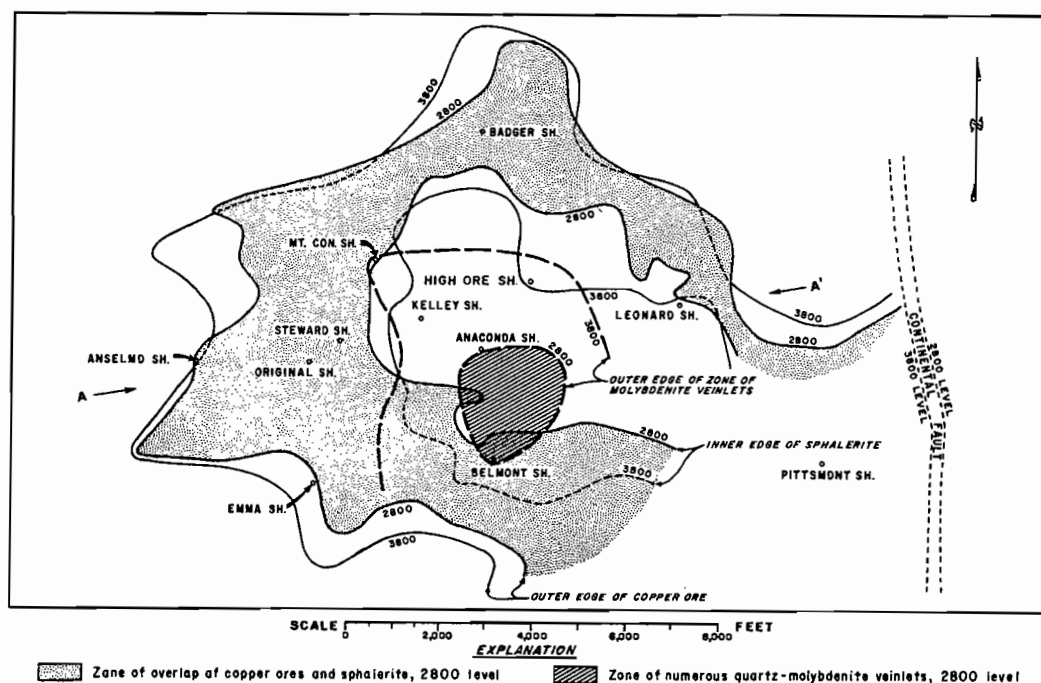


FIGURE 4. Composite Plan at 2800 and 3800 Levels showing zones of mineralization within which there is no sphalerite mineralization, the zone beyond which there is no copper ore, and the outer edge of the zone of quartz-molybdenite veinlets, all in relation to the principal shafts of the district (Meyer and others, 1968).

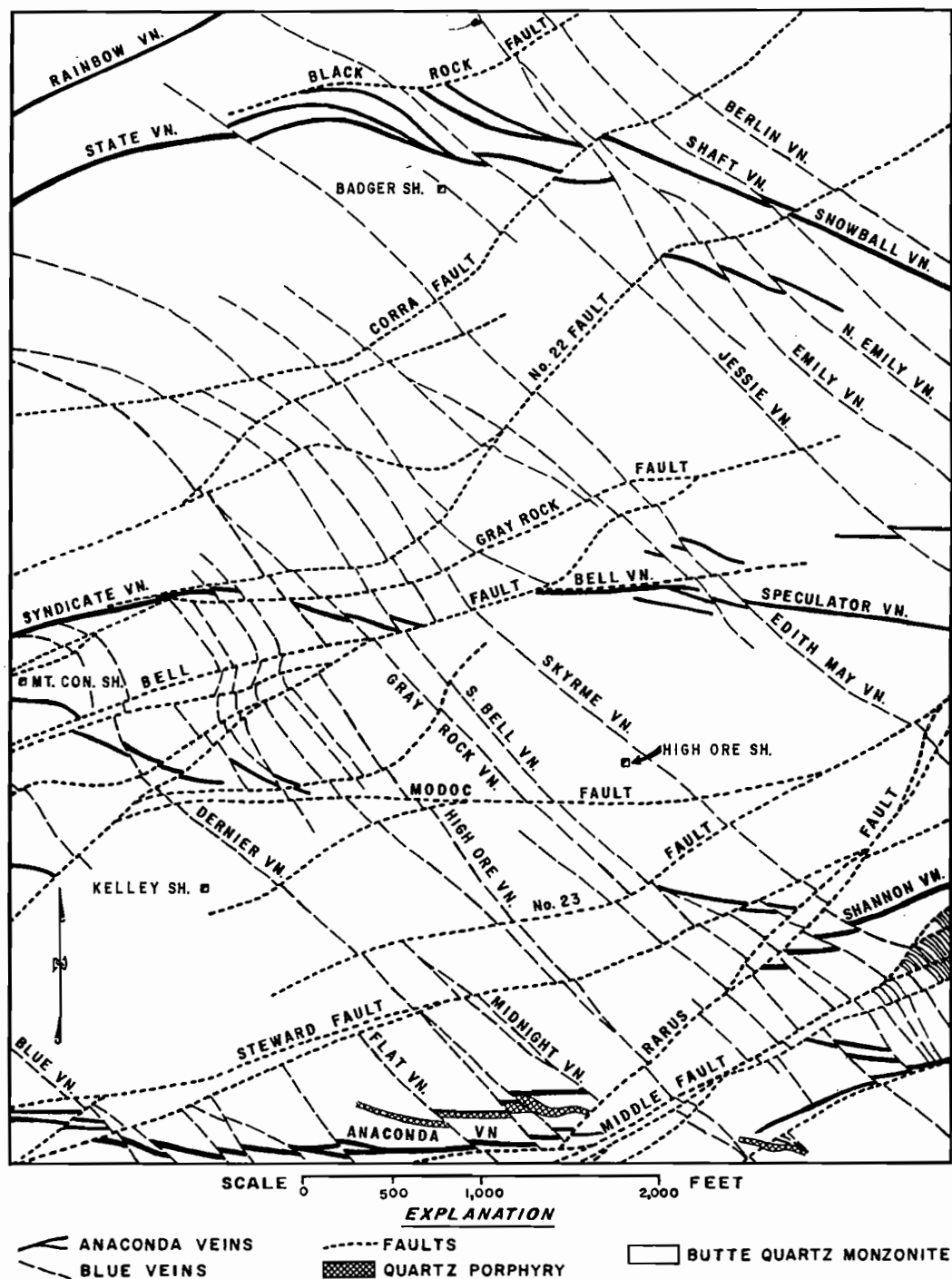


FIGURE 5. Plan view of the State, Syndicate, and Anaconda vein systems near the center of the district at the 1800 level, high ore. The Bell-Speculator eastward extensions of the Syndicate vein system die out below this level, and the two zones which contain no Anaconda-age veins merge and expand with increasing depth (Meyer and others, 1968).





Each small fracture or fracture zone contains a miniature ore shoot bordered on either side by gangue.

#### MINE DESCRIPTIONS

The Anaconda Company phased out all underground mining operations at Butte in November 1975 (Thomas, 1977). It was once the largest copper producing district in the United States, including both surface and underground workings, and has produced 16.2 billion pounds of copper, 4.8 billion pounds of zinc, and great quantities of manganese, lead, silver, gold, and other metals (Meyer and others, 1968). After almost a century of deep vein mining, more than 42 miles of vertical shafts have been sunk and thousands of miles of other underground passageways were excavated. Although the underground mines are not operating, a few deep workings are being maintained to facilitate reopening should mining become economically feasible (Thomas, 1977).

##### Leonard Mine

The Leonard mine was exploited for copper almost continuously from 1886 to 1967 and reopened in January, 1972. Three levels were active; the 3500, 3600, and 3800; with plans to reopen the 3400 and 3900 foot levels (Society Economic Geologists, 1973). The host rocks in the mine are Butte quartz monzonite, quartz porphyry, and aplite. The structural setting and mineralization of the area consist of N70°E trending, steeply-dipping horsetail ore bodies and east-west and northwest trending main stage veins. Post-mineral rhyolite dikes cut across the mine between the Leonard and East Colusa shafts. Left lateral movement is evident in the mine on some fault systems. Mine workings were active on veins west of the Middle fault, on horsetail ore bodies and selective veins between the Middle fault and No. 20 fault. Figures 7 and 8 illustrate the workings at the 3600 and 3800 foot levels, respectively.

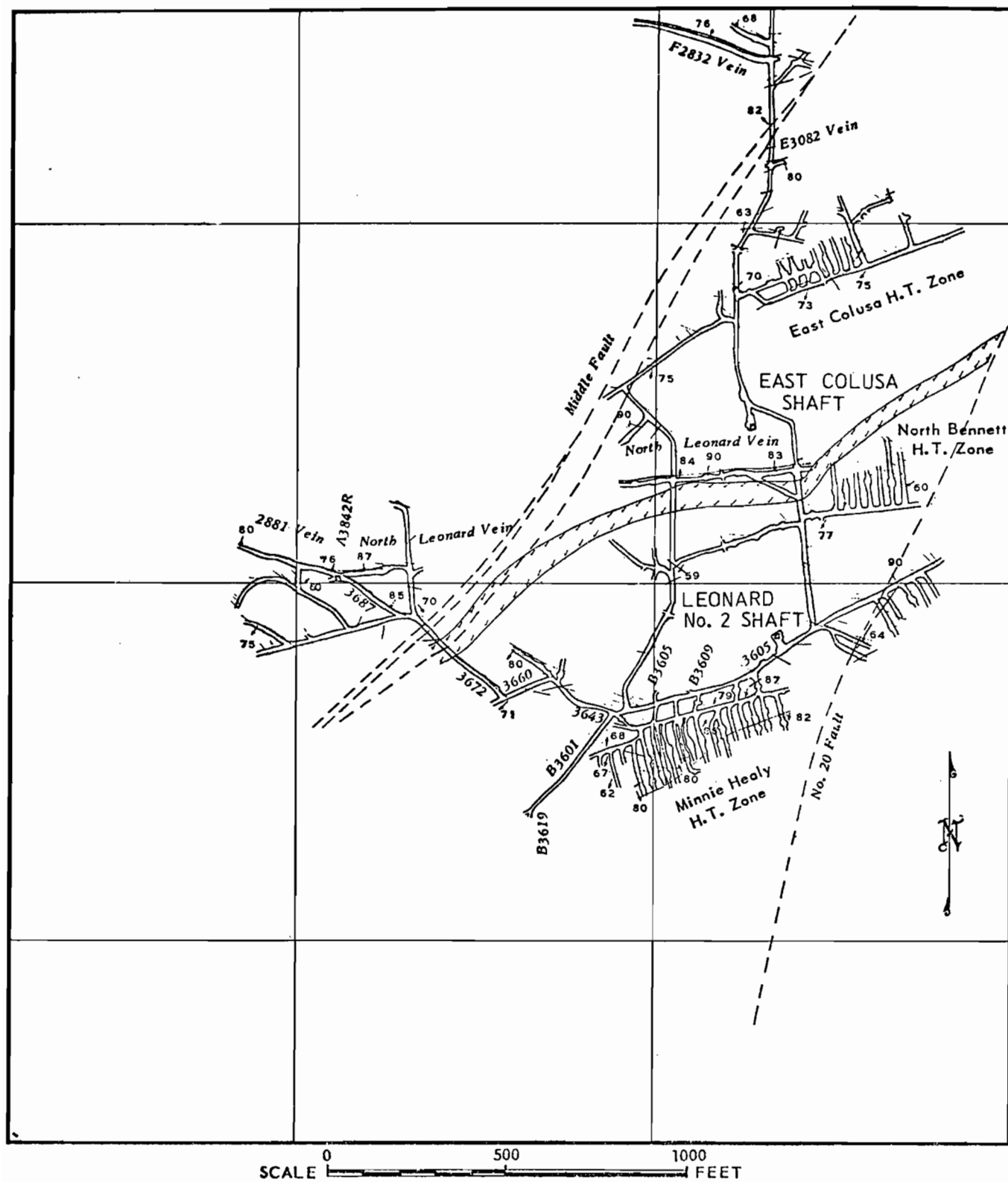


FIGURE 7. Map of the Leonard mine at the 3600 level, Silver Bow County, Montana. (Miller, 1973).

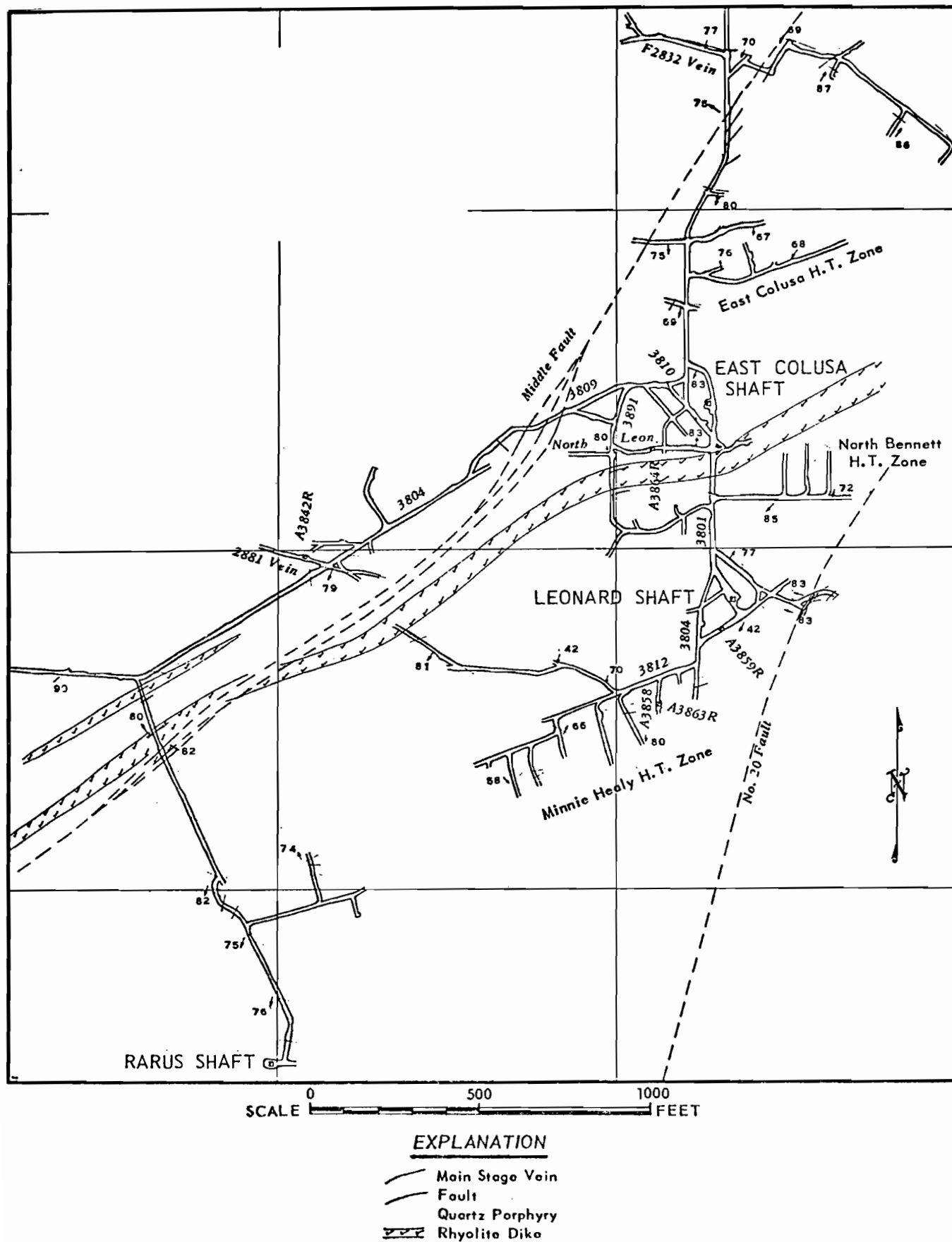


FIGURE 8. Map of the Leonard mine at the 4800 level, Silver Bow County, Montana. (Miller, 1973).

### Steward Mine

The Steward mine is one of the oldest underground workings, with copper mining beginning in 1879. It had nine levels active in 1973 and was being mined at a rate of 800 to 900 tpd. The active levels were the 3400, 3800, 3900, 4000, 4100, 4200, 4400, 4500, and 4600 foot levels.

The host rocks in the Steward mine are the same as at the Leonard mine. The Steward mine illustrates the entire range of pre-Main Stage vein and alteration events. The post-mineral Rarus fault cuts northeasterly through the mine and dips northwesterly. The fault has two main strands, each offsetting Main Stage veins right-laterally. The Middle fault and smaller parallel faults strike northeasterly and dip steeply to the south in the mine. These structures cut and offset Main Stage veins 20 to 40 ft. left laterally.

In 1973, three systems of Main Stage ore-bearing veins were reported being mined at the deeper levels of Stewart. Five veins were being exploited, and development headings on the 3900 and 4000 foot levels were being extended to the southeast. Further, trackless mining equipment was assisting development on the 4500 foot level. Figures 9 and 10 indicate mining activities on the 4200 and 4400 levels, respectively.



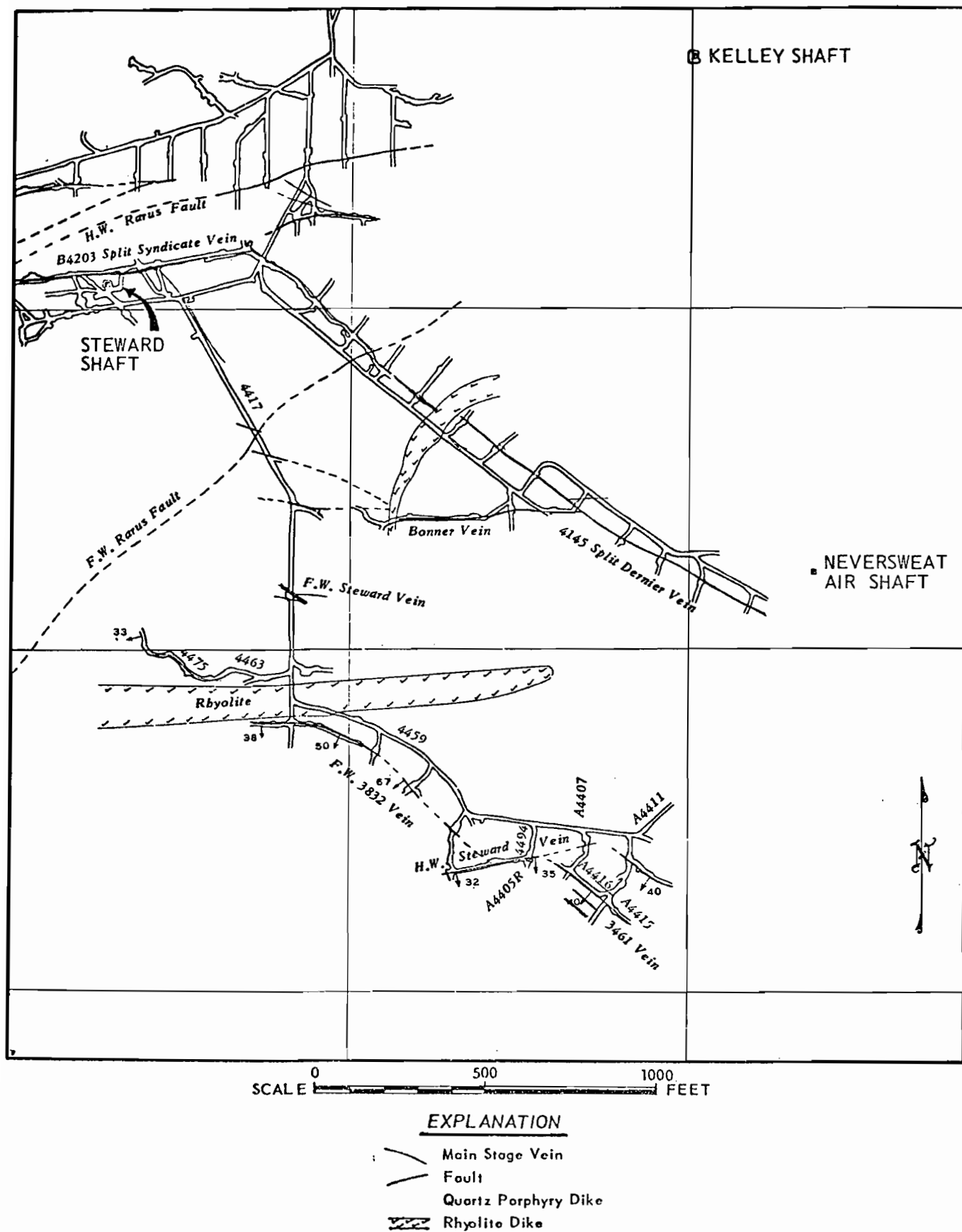


FIGURE 10. Map of the Steward mine at the 4400 level, Silver Bow County, Montana. (Miller, 1973).

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## GRANITE - BIMETALLIC MINE

(PETER FRANK and WILLIAM ANTONIOLI, owners)

## LOCATION

The Granite-Bimetallic Mine is located 2.5 miles southeast of the town of Philipsburg, in Granite County, Montana, at 46°19'N, 113°15'W, (Figure 1). The mine is on the western slope of the Granite Mountain Range at an elevation of 6780 ft. One of the principal producers of silver in the Philipsburg district, the mine was identified as being active in 1976, with ore reserves estimated at one million tons (U.S. Geol. Survey, 1976), and was inactive in 1978 (Lawson, 1979).

## GEOLOGY

The geology of the district is described by Prinz (1967), Ridge (1972), and Emmons and Calkins (1913). The Granite-Bimetallic mine is in an area of folded and faulted Precambrian and Paleozoic sedimentary rocks that were intruded by the Philipsburg batholith, stocks and dikes of Cretaceous age (Tilling and others, 1968), (Figure 2). The sedimentary rocks consist primarily of quartzite, shale and limestone, which have been metamorphosed near their contact with the batholith. The stratigraphic sequence is listed in Table 1. The oldest rocks, the Missoula Group quartzite of the Belt Series, are exposed in the core of a north-trending anticline. Above a slight unconformity is the middle Cambrian Flathead quartzite, which is overlain by the mid-Cambrian Silver Hill formation. The upper Cambrian consists of the carbonate rocks of the Hasmark and Red Lion formations. Several miogeosynclinal sedimentary units lie unconformably above the Red Lion limestone; however, they do not crop out in the mine area.



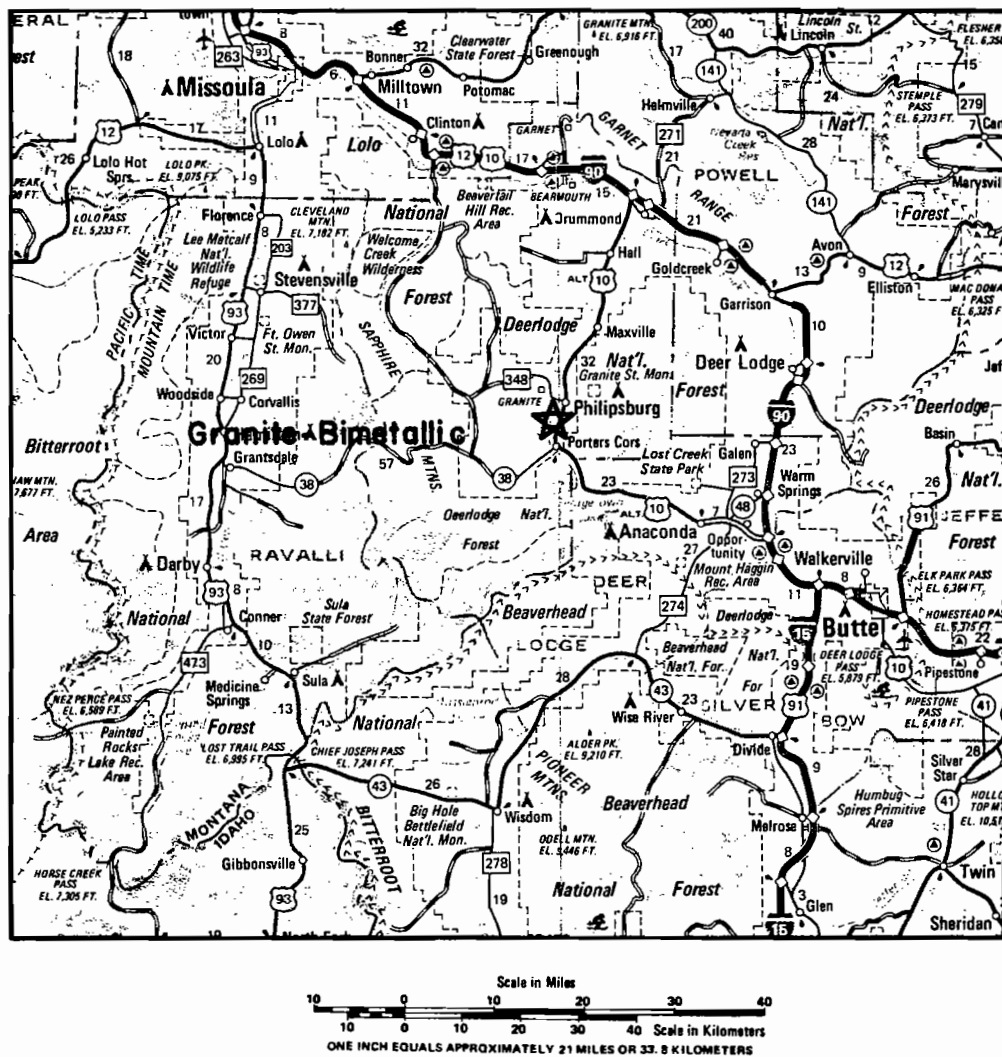


FIGURE 1. Location map - Granite-Bimetallic Mine, in Granite County, Montana. Basic map reproduced by permission of the American Automobile Association, copyright owner.

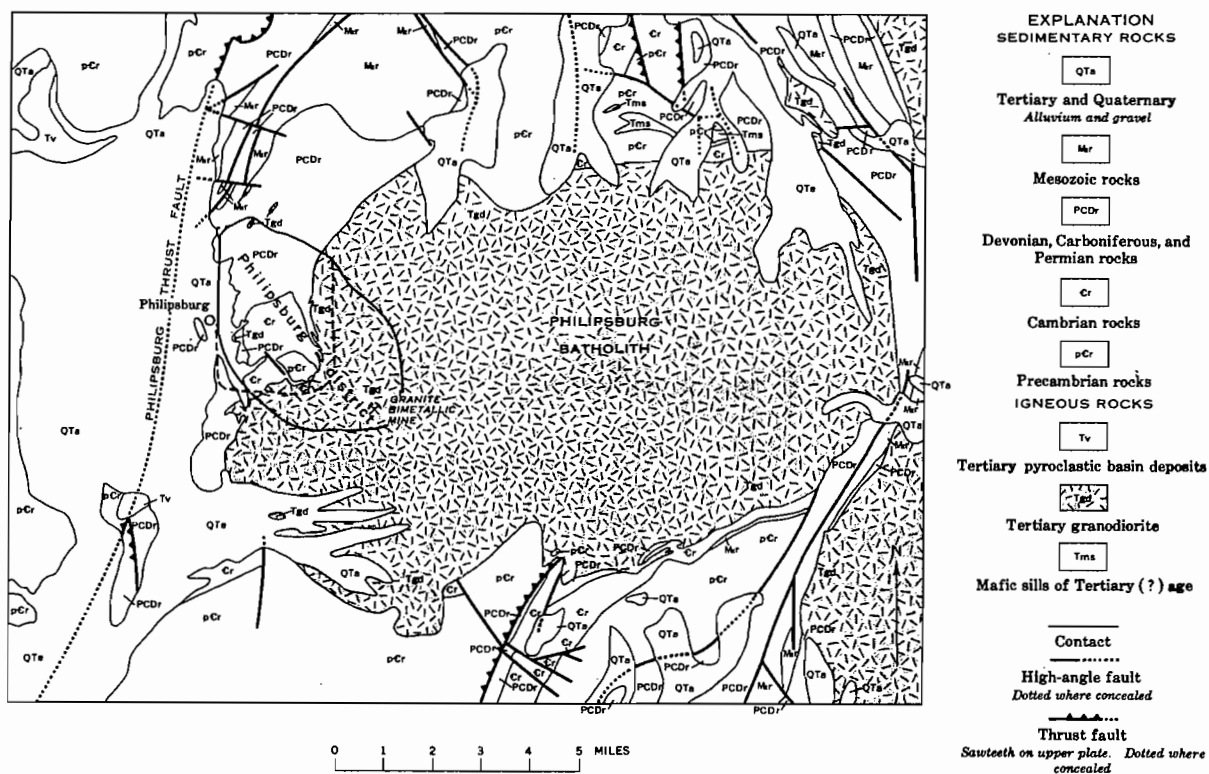


FIGURE 2. Generalized geology of the Philipsburg batholith and surrounding area showing location of the Philipsburg district (solid outline). The Granite-Bimetallic mine is located in the southeast area of the district (from Prinz, 1967).

TABLE 1.—*Stratigraphic succession in the Philipsburg district*

Age		Formation	Thickness (feet)	Character
Permian		Undifferentiated	180	Yellowish-brown to gray sandstone and quartzite, red to brown shale, and phosphate rock.
Carboniferous	Pennsylvanian	Quadrant Quartzite	300-325	Massive white to brown quartzite.
	Mississippian	Madison Limestone	1,000-1,500	Fine-grained dark-gray limestone with some chert.
Devonian		Jefferson Limestone	1,000-1,300	Fine-grained gray, blue-gray, or brown calcitic and dolomitic limestone; metamorphosed to medium-grained white to gray marble near batholith.
		Maywood Formation	210-490	Fine-grained greenish- or brownish-gray and purple dolomitic limestone, siltstone, and sandy limestone. Gray shale at base. Some silicates and hornfels formed during metamorphism.
		Unconformity		
Cambrian	Upper	Red Lion Formation	225-350	Thin-bedded light- to dark-gray limestone with thin shaly and siliceous layers. Partly metamorphosed to marble, hornfels, and tectite. Uppermost 2-8 ft is nearly pure marble (Headlight bed).
		Hasmark Formation	300-1,300 (average 900)	Medium- to coarse-grained white to buff thick-bedded dolomitic marble with a few thin beds of shale.
		Unconformity		
	Middle	Silver Hill Formation	260-320	Limestone with irregular beds of siliceous shale. Lower third predominantly shale. Metamorphosed to marble, tectite, and hornfels. Locally called garnet rock.
		Flathead Quartzite	135	White to gray quartzite with some interbedded dark-gray shaly quartzite.
Precambrian (Belt Series)		Missoula Group (undifferentiated)		Gray to greenish-gray impure quartzite with some shaly beds; similar to Flathead Quartzite.

(from Prinz, 1967).

The Precambrian and Paleozoic sedimentary rocks were intruded by the Philipsburg batholith, which is predominantly medium-grained granodiorite. The Philipsburg is one of the larger satellite plutons of the Boulder batholith (see the description of the Butte underground mines), and is associated with numerous stocks and dikes of similar composition. Although the bulk of the Philipsburg batholith is granodiorite there are older, more mafic masses along the margins. The batholith is elliptical in plan and extends over an area of 45 sq. mi.. Most of the granodiorite is unweathered; however, it is intensely altered near the veins.

#### STRUCTURE

The structural setting of the region includes a broad north-northeast trending, north-plunging anticline truncated by the Philipsburg batholith. The anticline and the batholith are cut by a number of fault systems. In general, they fall into three groups: 1) pre-intrusive faults trending northwest and dipping steeply northeast, 2) post-intrusive faults striking easterly and dipping steeply south, and 3) post-intrusive faults striking northwest and dipping 45-60° southwest. The faults are normal and displacements are rarely greater than 5-30 ft. Dikes and sills of granodiorite cut the sedimentary rocks near the batholith.

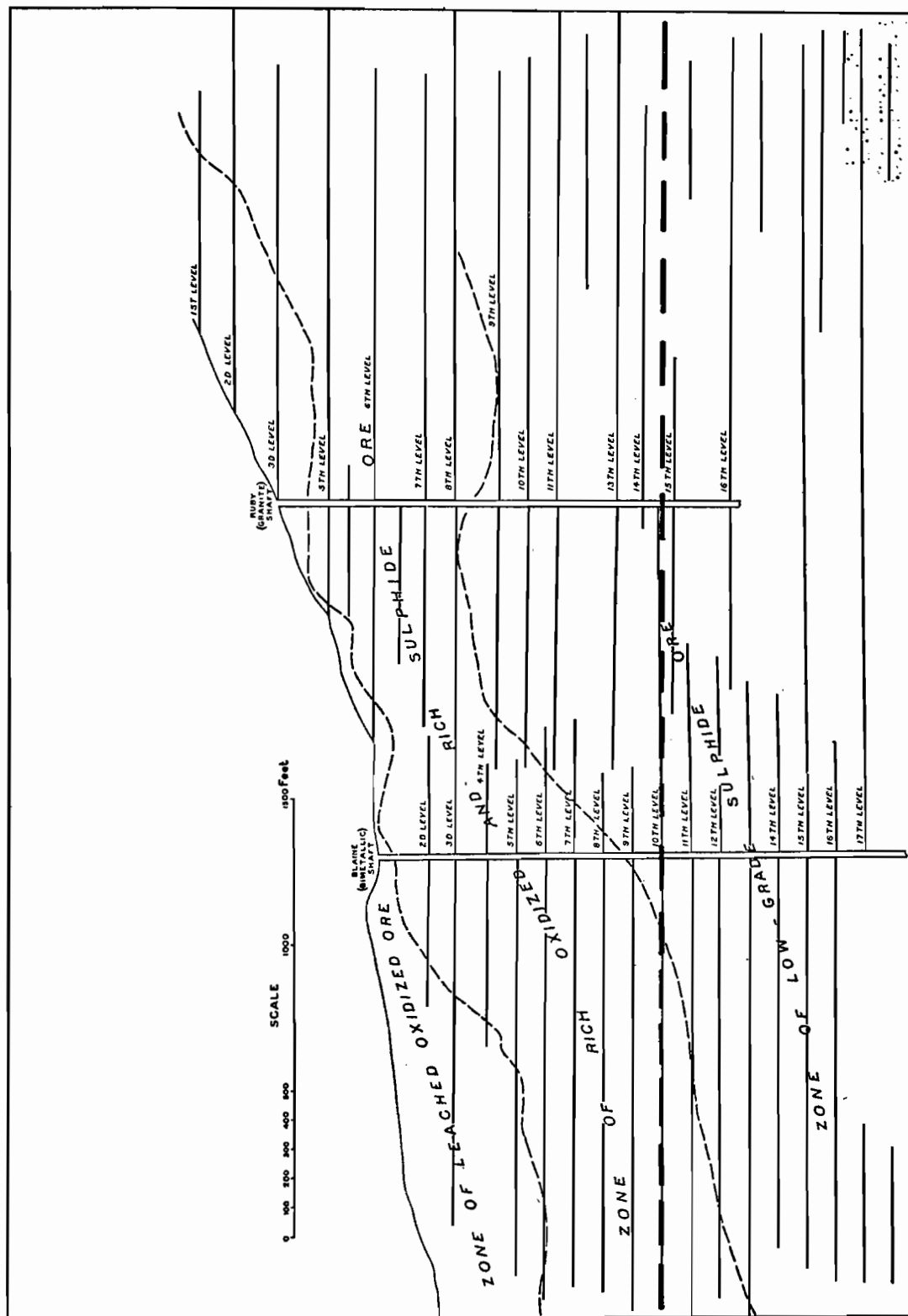
#### MINERALIZATION

The steeply-dipping veins of the mine are located in the western portion of the Philipsburg batholith. The deposits of the Philipsburg district are divided by Prinz (1967) into four groups: (1) steeply dipping quartz veins, (2) quartz veins along bedding planes, (3) manganese-rich replacement deposits, and (4) contact metasomatic magnetite deposits. Quartz veins (1)

predominate in the Granite - Bimetallic mine. They have been mined primarily for silver, zinc and lead and cut both the batholith and the surrounding sedimentary rocks. The ore occurs as fissure-filling and as replacement deposits. In the mine, the veins strike west or northwest and dip steeply to vertical. Zoning is common. The principal ore body is a tabular mass and measures from 3-10 ft. in thickness and is about 4,600 ft. long (U.S. Geol. Survey, 1976). The deepest part of the mine is in the eastern portion where the ore extends downward more than 2600 ft. The Granite vein (Figure 3) is the largest and richest; it strikes about N78°E and dips generally about 75°S. Its average width varies from 4-8 ft., and in some places it widens to a maximum of 26 ft.

#### MINE CHARACTERISTICS and FACILITIES

The Granite Mountain and Bimetallic mines were worked separately until 1898; since then they have been worked together as both are located on the same ore body. During early operation the mine was worked from five drift tunnels, two deep shafts and a long adit which drains the Granite Mountain mine between the 14 and 15 levels and the Bimetallic mine at level 10. The Granite shaft is about 1550 ft. and the Bimetallic shaft is about 1800 ft. (Emmons and Calkins, 1913). The largest vein, the Granite vein, has been stoped for 4500 ft. along the strike and to depths of 2,600 ft. The aggregate length of workings reported in 1976 is 20 mi. (U.S. Geological Survey, 1976). The mine is drained by an 8,850 ft. tunnel from Douglas Creek Canyon, crossing the Bimetallic shaft at a depth of 1000 ft. and the Granite shaft at 1,450 ft. Below this level, the mine was pumped (Emmons and Calkins, 1913).



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TEM PIUTE DISTRICT  
(OPERATED BY UNION CARBIDE CORPORATION)

#### LOCATION

The Tem Piute mining district is located approximately 85 road miles west of Caliente and 100 miles east of Tonopah, Nevada, in the Timpahute Range at  $37^{\circ}38'N$ ,  $115^{\circ}38'W$ . (Figure 1). The major tungsten deposits are located at the north end of Coyote Peak. Elevation in the mine area is approximately 6,400 feet with several hundred feet of local relief.

#### GEOLOGICAL SETTING

##### Regional

The data for this section were extracted from Tschanz (1970).

As shown in Figure 2, the geologic map of the Tem Piute district, the Timpahute Range is primarily composed of Paleozoic sediments dipping steeply to the east. Permian rocks are present on the east side of the district. Mississippian rocks at the north end of the district have been intruded by two Tertiary granite stocks, each less than one mile in diameter. The dip of the bedding steepens northward along the west side of the stocks until the rocks are overturned; this is assumed to be the result of pre-granite thrust faulting. The Devonian and older rocks in the main part of the district are thrust over the Chinaman shale and younger rocks. In the southern foothills, the Devonian rocks make up the upper thrust plate, while north of Tempiute, they make up the lower plate. On the west side of the range, Middle Pennsylvanian rocks are in contact with Ordovician rocks, due either



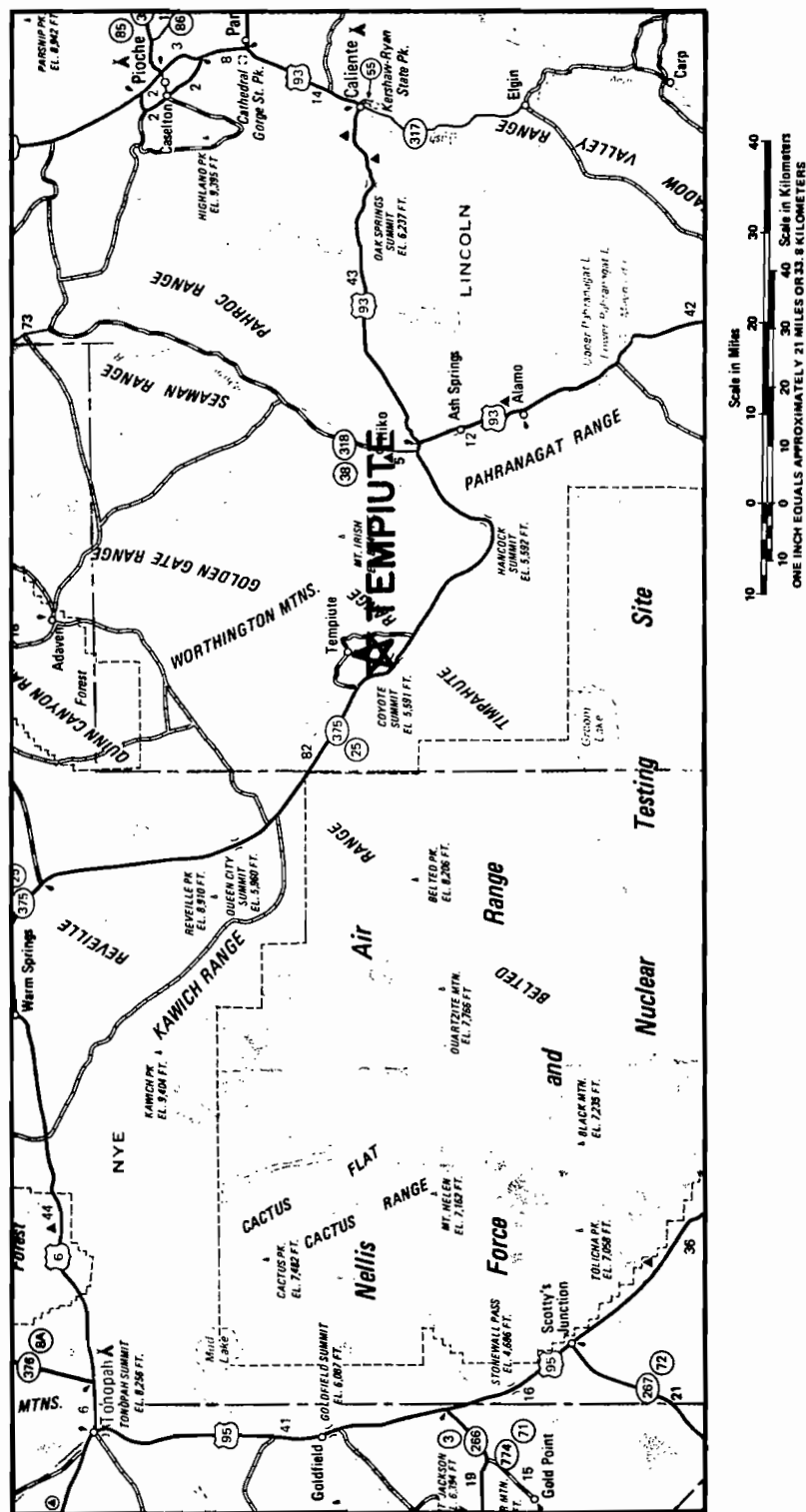


FIGURE 1. Location map of Tempiute operations, Lincoln County, Nevada. Basic map reproduced by permission of the American Automobile Association, copyright owner.

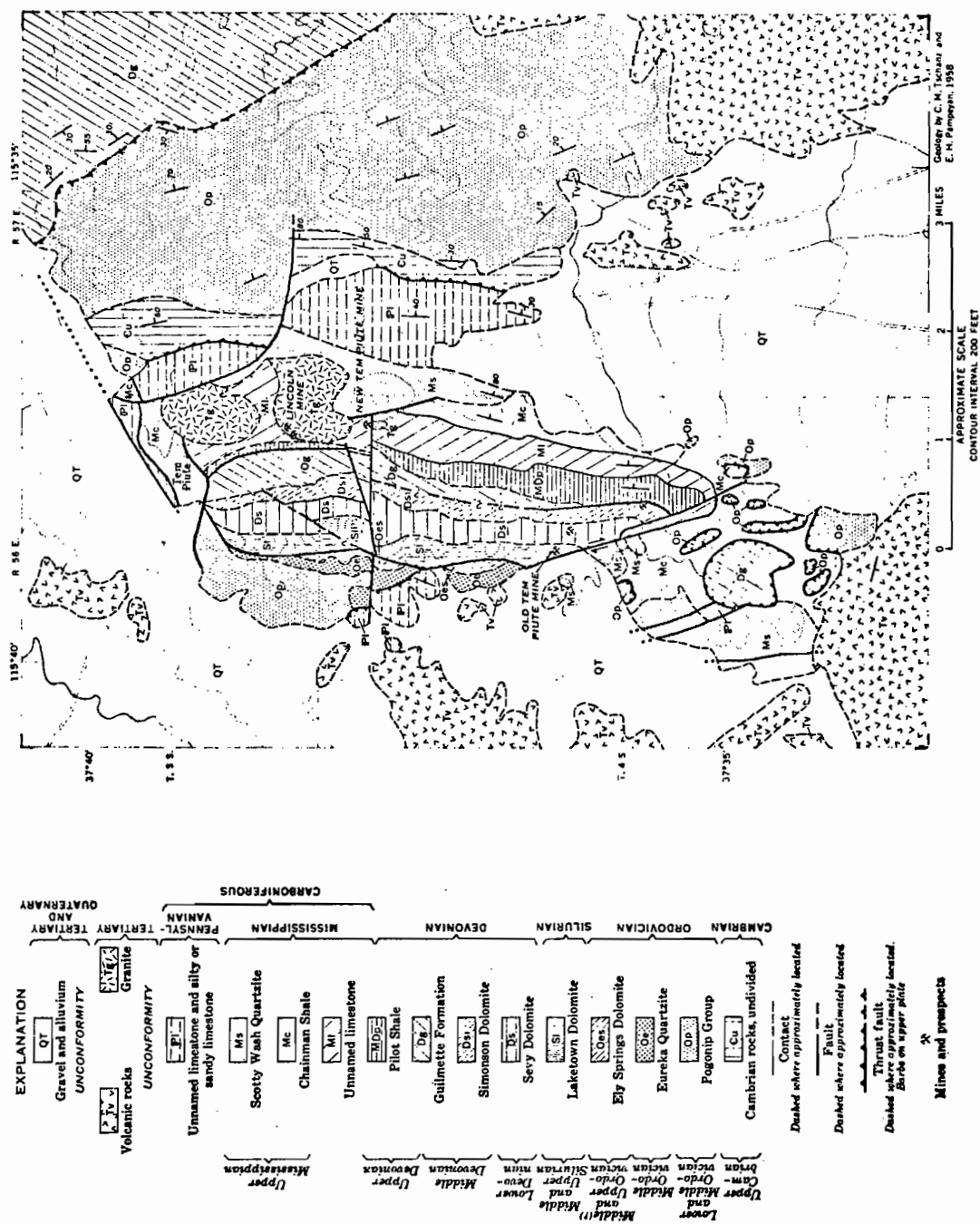


FIGURE 2. Geologic map of the Tem Piute district. (Tschanz, 1970).

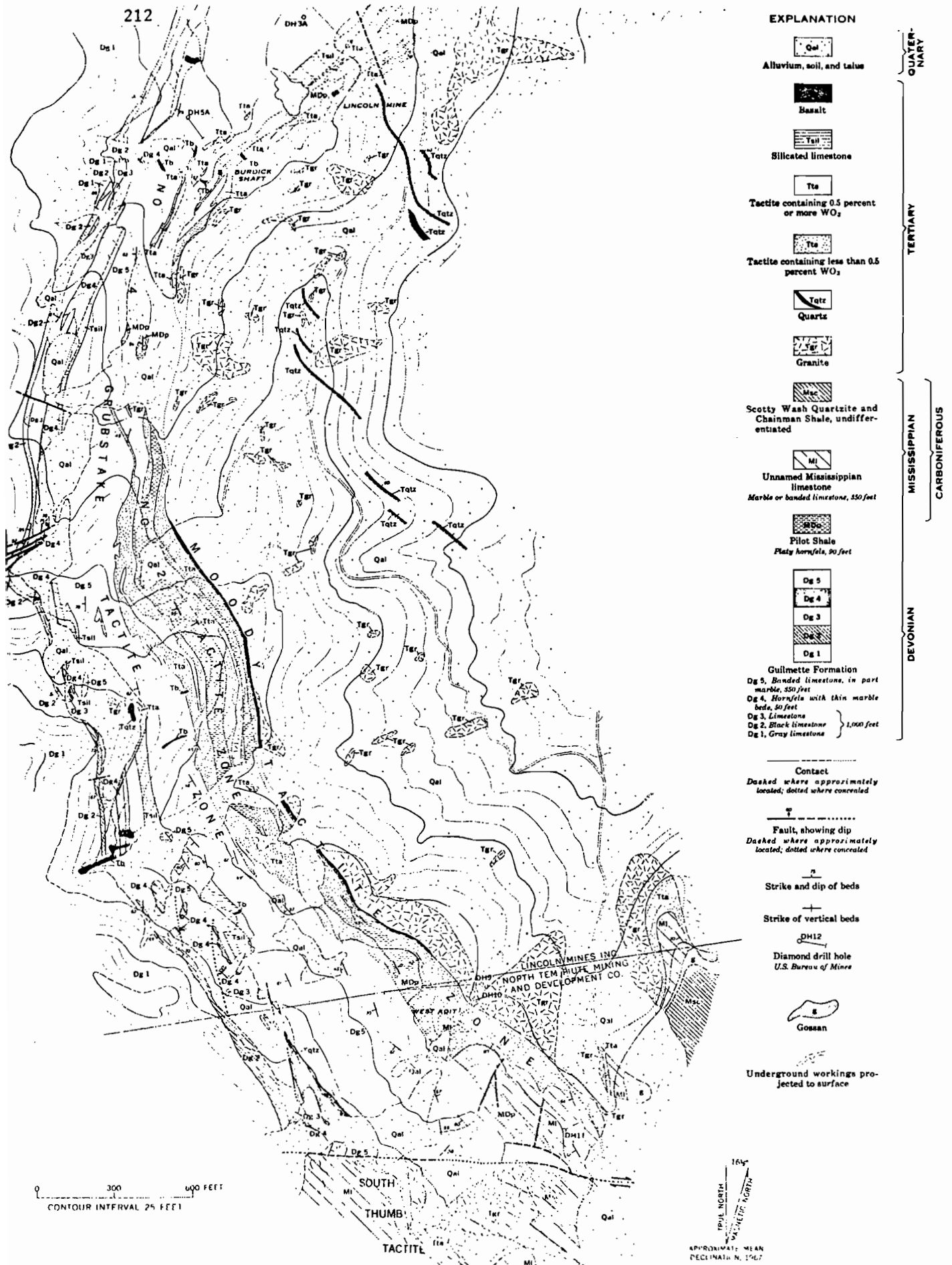


FIGURE 3. Geologic map of Tempiute (Lincoln) mine property (Tschanz, 1970).

to thrusting or right lateral faulting.

#### MINE AREA

Data for this section were extracted from Tschanz (1970).

The tungsten deposits are found in or near thick bodies of tactite, at or near the contact between the Paleozoic rocks and the granite. As shown in Figure 3, there are three elongated bands of tactite parallel to the bedding of the Devonian and Mississippian limestones along the west side of the south granite stock. The south stock is conspicuously more altered and less resistant to weathering than the north stock. The granite and tactite are partially concordant with the limestone. The limestone is irregularly bleached and recrystallized as far as 700 feet from the granite contact; the tactite is irregularly developed as far away as 450 feet; and silicated limestone is found even farther from the contact. A contorted septum of Mississippian limestone 600 to 800 feet thick, which has been altered to tactite, separates the two stocks. The bedding in this septum is nearly vertical, and it strikes nearly east-west, perpendicular to the regional strike.

Two principal tactite zones are shown in Figure 3. The No. 1, or Moody, zone is located along the west contact of the southern stock. The Moody zone extends for about 6,200 feet along the contact and is 15 to 110 feet thick, averaging about 40 feet thick in the Lincoln mine. The zone consists of bands of various forms of tactites. The second principal tactite zone is less continuous, less productive and does not extend to depth. The tactite is relatively uniform in grade through a vertical range of 1,300 feet.

## MINE FACILITIES

Data for this section were extracted from EMJ (1974, 1977), Cobbs (1976), and Tschanz (1970).

Tungsten mineralization was discovered in the district in 1916, but was not exploited until the mid-1950's. The mining lasted only a few years until 1957. Union Carbide became involved in the district in 1968, and made the decision to reopen the mine in 1974. A 1,000 ton per day tungsten mining operation was begun in June 1977. Approximately 2 million pounds of tungsten are produced annually.

The original Lincoln mine was developed by more than 20,000 feet of underground workings on six levels, the 100, 200, 300, 500, 700 and 900 levels, with adits on the 100, 300, and 700 levels and an inclined shaft from the surface to the 900 level. Mining was by shrinkage stopes. The workings required little support.

Data on the current mining operation are sparse. It is assumed that the Lincoln mine has been reopened and developed further. The new mine is a combination of tracked and trackless mining. The volume of the mine is at least 90 million cubic feet.

The distribution and amount of underground mine workings in the intrusive rocks are not known. However, the similarity between the Tem Piute district and the Pine Creek mine suggest that there probably are some workings in the intrusive.

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## MOUNT HOPE AND SCRUB OAKS MINES

NEW JERSEY  
(Halecrest Co., Inc.)

## LOCATION AND ACCESSIBILITY

The Mount Hope and Scrub Oaks mines are located in Morris County, New Jersey, in the Dover District, one of the oldest mining regions in the United States. The district, in the New Jersey highlands, is 18 miles long and 4-5 miles wide, and is within 30 miles of New York City. The Mount Hope mine is at Mount Hope, 3 miles north of Dover; the Scrub Oaks mine is 2 miles west of Dover. The approximate location is  $40^{\circ}54'N$  and  $74^{\circ}35'W$  (Figure 1).

The region has a good network of primary and secondary roads and all areas are readily accessible. (U.S. 46 and State 10 cross the district east to west and U.S. 202 and 206 extend north to south. The town of Dover is on both the Delaware, Lackwanna, and Western Railroad and the Central Railroad.)

## GEOLOGIC SETTING

Regional Lithology

The geological setting of the Dover district was described by Sims (1958).

The district is part of the New England physiographic province. Topography is controlled by the effects of stream erosion on bedrock structure and lithology and consists of northeastward trending ridges separated by valleys 200 to 300 feet deep. Altitudes are 500 to 1100 feet. The Wisconsin glacial terminal moraine crosses the central part of the district.

The bedrock consists of Precambrian metasedimentary rocks, migmatites, and intrusive igneous rocks which are cut by small Triassic diabase dikes. In the northwestern portion of the district the Precambrian rocks are disconformably



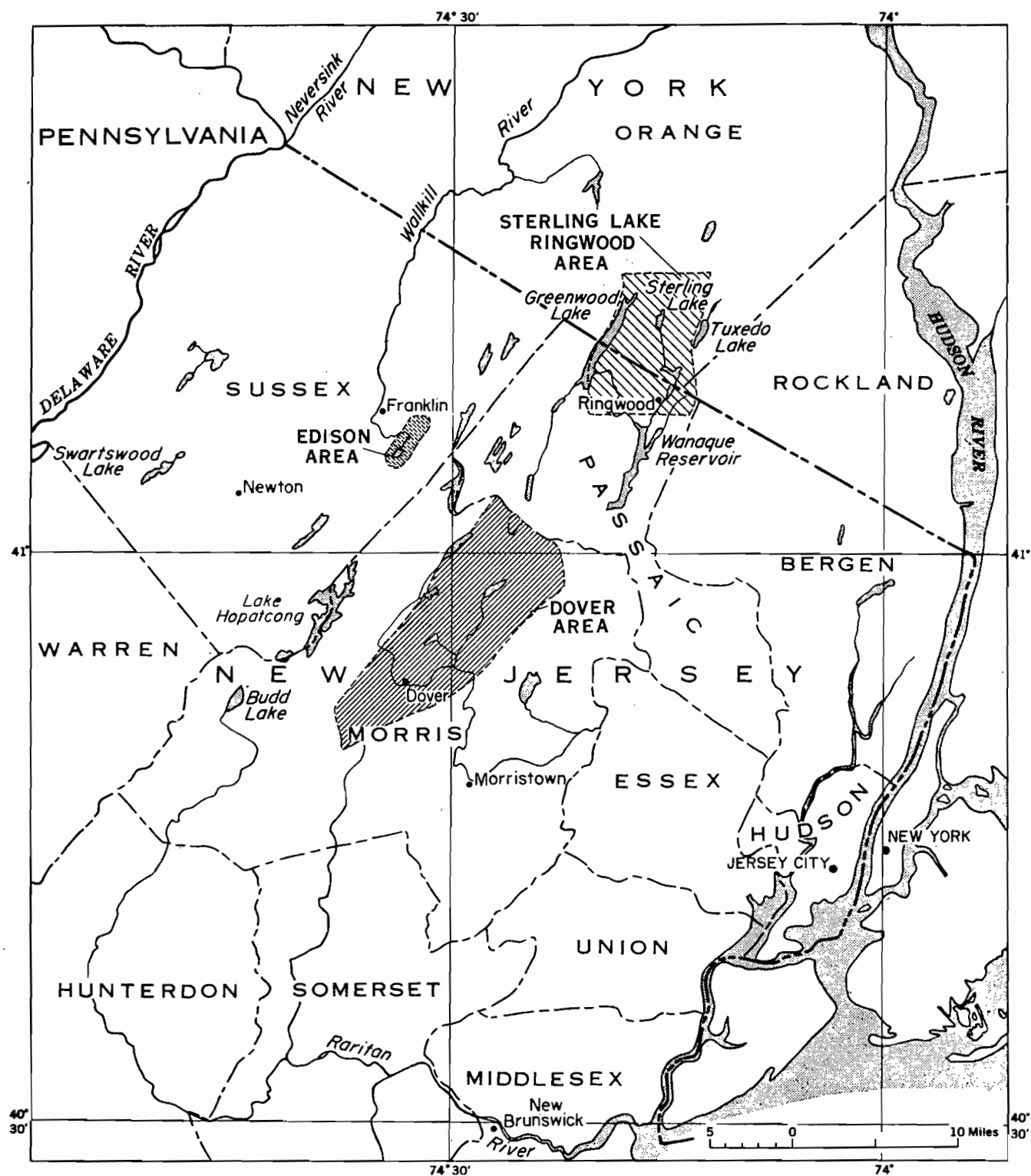


FIGURE 1. Index map showing the location of the Dover District (Sims, 1958).

overlain by steeply dipping early Paleozoic sedimentary rocks. Quaternary surficial deposits cover the bedrock in a discontinuous and usually thin layer (Figure 2).

The oldest Precambrian metasedimentary rocks are widely distributed and make up about 25 percent of the bedrock. They are high-grade metamorphics: marble, pyroxene gneiss, skarn, amphibolite, biotite-quartz-feldspar gneiss, oligoclase quartz-biotite gneiss, and related types. These rocks have been isoclinally folded and intruded by igneous sheets and phacoliths. The thickness and age sequence of the metasedimentary rocks is poorly understood because of their complex structure and the abundance of younger igneous rocks.

The inferred age order (oldest to youngest) of the Precambrian intrusive rocks is quartz diorite, albite oligoclase granite (alaskite), albite quartz pegmatite, and hornblende granite plus related facies. A NW-SE traverse across the Dover District, normal to the regional strike through the Mount Hope mine area, intersects the following rock types: hornblende granite, quartz diorite and related facies, oligoclase quartz-biotite gneiss, albite oligoclase granite, hornblende granite, biotite quartz-feldspar gneiss, alaskite, hornblende granite, alaskite, oligoclase quartz-biotite gneiss, alaskite, hornblende granite (Simms, 1958). As can be noted from the presence of gneisses in the district, the metamorphism is high grade.

## REGIONAL STRUCTURE

### Faulting

Northeast trending faults bound the Precambrian rocks and separate them from Paleozoic and Mesozoic strata. The faults are considered to be Triassic or younger. The Green Pond fault which separates Precambrian rocks from Paleozoic rocks is the one large fault in the district. The smaller faults of

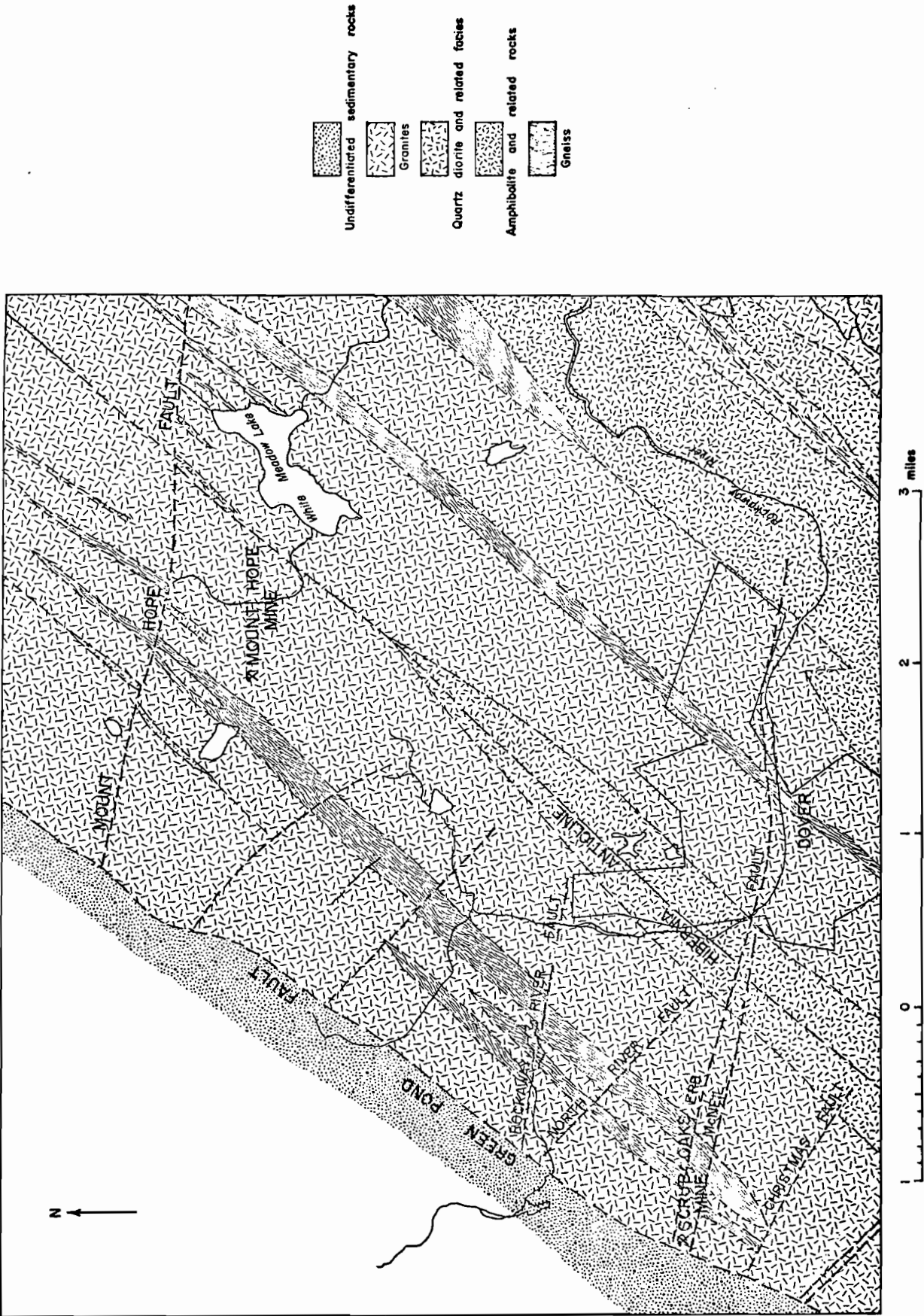


FIGURE 2. Geologic map showing the location of the Mount Hope and Scrub Oaks Mines in the Dover mining district, Morris County, New Jersey. (Sims, 1958)

the district, most exposed only in the mines, cause serious mining problems. With reference to regional trends, smaller faults can be classified as transverse, longitudinal, and oblique. Transverse faults are high angle gravity types striking northwest and dipping steeply southwest. The Mount Hope fault, striking N78°W and dipping 80°SW, is in the mine area and is a transverse fault. Longitudinal and oblique faults are reverse faults striking northeastward and dipping moderately to steeply northwestward.

#### Folding and Foliation

In the Dover District, the Precambrian rocks trend northeast and dip steeply southeast with considerable local variation. This pattern is produced by northeastward-trending isoclinal and open folds and conformable granite sheets on the fold limbs. The folds, ranging in width from a few feet to over a mile, plunge to the northeast. This structural pattern was developed in Proterozoic time with little subsequent deformation. The direction of principal tectonic stress was to the northwest. Metasedimentary rocks formed parallel layers or belts on fold limbs, foliation is parallel to the original bedding. Igneous rocks were intruded later into the deformed country rock, accompanied by development of skarns in pre-intrusive carbonate rocks. Dominant granitic foliation developed before the final crystallization of the magma, and in some places secondary foliation is superposed on the original foliation. All rock types show very uniform lineation which is usually parallel to the fold axes and plunges 17° N 52°E on the average.

#### MOUNT HOPE MINE GEOLOGIC SETTING

The Dover district contains 91 mines, 58 of which have produced iron ore. Iron ore has been mined intermittently since the early 18th century.

Many of the mines are abandoned now. There are seven ore belts in the district. The Wharton ore belt contains most of the large mines, including the Mount Hope and Scrub Oaks. This belt is 10 miles long and 900-3000 feet wide. It extends from near Ironia to about 1 mile northeast of Mount Hope Village.

The 300 year-old Mount Hope mine has workings in nine ore bodies. It is said to be the oldest operating mine in the United States with production back to 1710. It may have been worked as early as 1665. Surface and underground mining were employed.

The bedrock at the Mount Hope mine consists of metasedimentary rock, mixed metamorphic rocks, and granites. The most abundant metasedimentary rock, oligoclase-quartz-biotite gneiss, is exposed at the surface as well as throughout most of the mine. Alaskite (albite-oligoclase granite) is the most widespread rock type. The mine rocks are deformed into isoclinal folds trending and plunging northeast. The most prominent fold is the overturned Mount Hope syncline, illustrated in Figure 3. Oligoclase-quartz-biotite gneiss comprises the limbs of the syncline and ore deposits occupy both limbs. The axial trace trends N45°E and the axis plunges 12°-20°NE. The principal fault associated with the mine is the transverse Mount Hope fault. Longitudinal faults are common and cause serious mining problems, though they are not continuous for long distances.

The Mount Hope iron ore deposits are of Precambrian age and occur in various metasedimentary and igneous rocks. Massive magnetite ore (containing 35-60% iron) is found in most deposits. The ore occurs in belts or ranges forming steeply dipping vein-type bodies essentially conforming to the gneissic wall rock structure with strike and dip parallel to the foliation and plunge parallel to the lineation. The important ore bodies are mostly lath shaped.

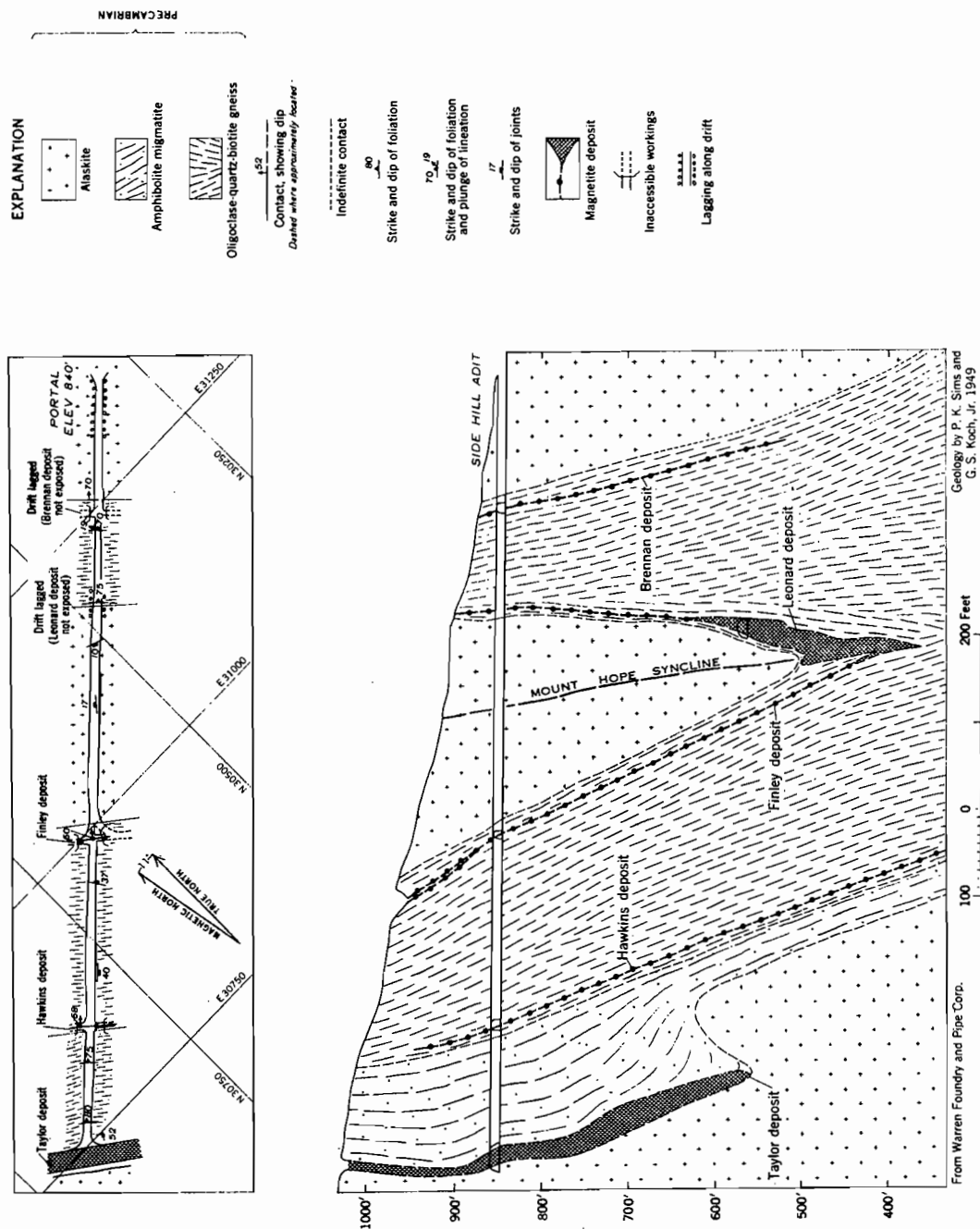


FIGURE 3. Geologic map and section of Side Hill adit, Mount Hope mine (Sims, 1958).

Principal iron ore bodies occur as metasomatic replacement in (1) oligoclase-quartz-biotite gneiss, (2) hornblende skarn, (3) pyroxene skarn, (4) albite-oligoclase-granite (alaskite), and (5) reconstituted amphibolite and microantiperthite granite.

Low grade iron ores occur in amphibolite, interlayered biotite-hornblende-pyroxene-feldspar gneiss and granite pegmatite. The ore minerals in order of abundance are: magnetite, hematite, martite, ilmenite, pyrite, pyrrhotite, and chalcopyrite.

The Mount Hope magnetite deposits occur as replacement bodies in gneiss and hornblende skarn. Figure 4 illustrates some of the mine workings.

#### MOUNT HOPE MINE HYDROLOGY

Water inflow into the Mount Hope mine is approximately 350 gpm from surface runoff and seepage from local lakes. There is no information as to whether this included water introduced by mining operations (personal communication). The Acres report (1975) indicates that the inflow into the Mount Hope mine is 400 gpm above the 1700 foot level. Sims (1958) states that the Mount Hope fault in the mine workings is a shattered brecciated zone. This zone may produce water at a rate of several hundred gallons/minute when the fault is intersected, but when the fault is tapped at lower levels, the flow diminishes abruptly.

#### MOUNT HOPE MINE FACILITIES

The Mount Hope mine was owned, as of 1978, by Halecrest Company, Inc. (Talmadge Road, Edison, New Jersey). It is located in a rural hilly area on a three square mile site. The mine had a number of different owners, and was inactive from 1959-1977 (SRI - World Minerals Accessibility Report, 1976).

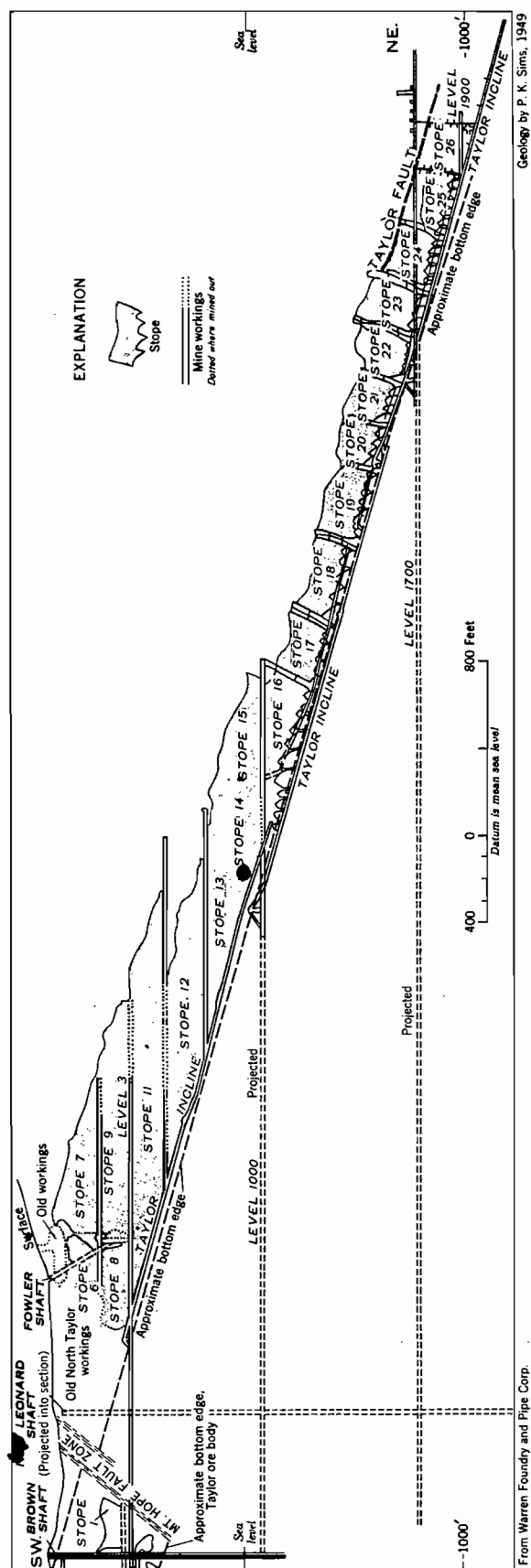


FIGURE 4. Vertical longitudinal projection of Taylor ore body, Mount Hope mine (Sims, 1958).



The Mount Hope mine was considered by the Jersey Central Power and Light Co. as a potential site for a pumped-storage hydroelectric facility. As described by Richert (1974), a surface reservoir would be connected with underground powerhouses and reservoirs which would be excavated from the mine workings. The mine was reopened in October 1977 and closed in February 1978 because of a need for more capital. It is not known if it has reopened again (Engineering and Mining Journal, 1978).

#### MOUNT HOPE MINE WORKINGS

The vertical three-compartment shaft is 2800 feet deep with levels at 1000, 1700, 2100, and 2500 feet. The 1000 foot level has road workings, the 1700 foot level extends one mile south and one mile north of the shaft, the 2100 foot level is one mile long, and the 2500 foot level extends 3000 feet to the northeast and southwest. Drifts and haulage ways are generally 9 x 11 feet with various larger stoped-out areas (Acres, 1975). Several types of mining methods have been employed, in order of time: (1) open pit, (2) underground open stopes (stull timbered) (3) shrinkage stoping, and (4) sublevel stoping. The mine has been kept pumped out (Acres, 1975).

#### MOUNT HOPE MINE EQUIPMENT

A lift and general utilities are available. The equipment is moth-balled but sound (Acres, 1975, and personal communication).

At the time of closing 150 men were employed (E/MJ, 1978).

Six thousand tons per day of ore were produced when the mine was in operation. The available ore reserves proven are  $5 \times 10^6$  tons, probable  $15 \times 10^6$  tons, and possible  $30 \times 10^6$  tons. There is sufficient ore for twenty years operation (E/MJ Directory, 1977-1978).

#### SCRUB OAKS MINE GEOLOGIC SETTING

The Scrub Oaks mine, located 2 miles west of Dover, operated intermittently from 1856-1950. The bedrock in the area is covered with up to 40 feet of unconsolidated debris. The principal rocks exposed in the mine are alaskite, the host rock for the ore, and microantiperthite granite. The average strike of foliation in the mine is N33°, dip is 50°SE. The lineation plunges about 28°N, 52°E. It is thought that the mine is situated on an isoclinal fold limb. Two transverse faults offset the ore body into three segments. Figure 5 shows the faults and workings in the mine.

#### SCRUB OAKS MINE FACILITIES

The Scrub Oaks mine was owned by the Alan Wood Steel Company of Conshohocken, Pennsylvania in 1975 (Acres, 1975). It has been shut down and capped since May, 1966 and is probably flooded. A fault was encountered in the shaft and blasting also created many fractures in the surrounding rock. The mine workings (Figure 5) consist of a four-compartment inclined shaft 3000 feet long on a 55° dip, and six working levels 250 feet apart vertically. The shaft is in country rock and 100 feet into the ore footwall and is connected to the main haulage levels in the ore body footwall by cross cuts. Mining was done by shrinkage stoping without timbering or filling (Sims, 1958). The Acres report (1975), however, refers to mining by the longwall sublevel mining method. The total crude ore mined between 1918 and 1950 was reported to be  $10.5 \times 10^6$  long tons; in 1950,  $6.3 \times 10^5$  tons were mined.

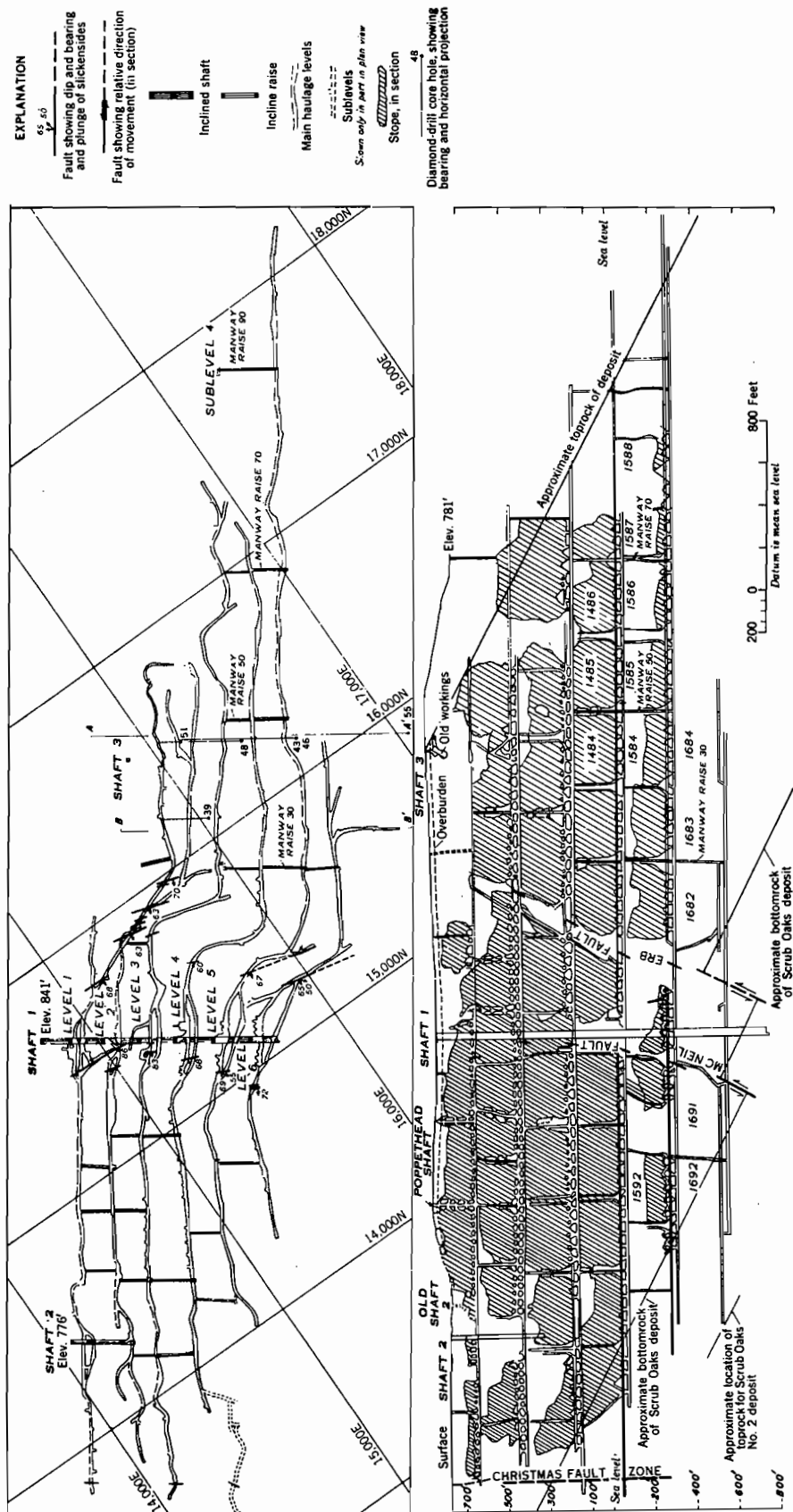


FIGURE 5. Map and longitudinal projection of main workings at Scrub Oaks mine (Sims, 1958).

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QUESTA MOLYBDENUM MINE  
(MOLYBDENUM CORPORATION (MOLYCORP))

LOCATION AND ACCESSIBILITY

The Questa Molybdenum Mine is located at  $36^{\circ}42'N$ ,  $105^{\circ}30'W$ , on the western slope of the Taos Range in the Sangre de Cristo Mountains of northern New Mexico (Figure 1). The underground mine is adjacent to a large open pit operation, 6 miles east of the town of Questa in Taos County. The altitude of the uppermost workings of the mine is nearly 8900 feet above sea level. Both underground mine and open pit are owned and operated by Molybdenum Corporation (Molycorp Inc.).

The mine portals range in altitude from 8000 to 9000 feet. The mill, haulage adit, and dump are located along Red River Canyon, 5-6 miles east of Questa. The adits of the older workings are along Sulphur Gulch, an intermittent tributary of the Red River.

State Highway 38, a graded gravel road (in 1956), passes the mine and camp and connects the mine to Questa and Red River.

GEOLOGIC SETTING

The geologic setting is illustrated in Figure 2 and has been described in detail by Carpenter (1968), McKinley (1957), and Schilling (1960 and 1956). A generalized stratigraphic section is shown in Figure 3. The Taos Range is made up of Precambrian metamorphic and granitic rocks overlain by Tertiary volcanics and late Paleozoic sediments. Tertiary granitic rocks, including the ore bearing units, intrude the older rock and in turn are capped with Quaternary gravels and alluvium. The ore body occurs in the Tertiary Sulphur Gulch soda granite stock. Most of the veins are in contact, or close to the contact with the granite and the veins roughly parallel the contact. The ore zone is over 1500 ft. long.

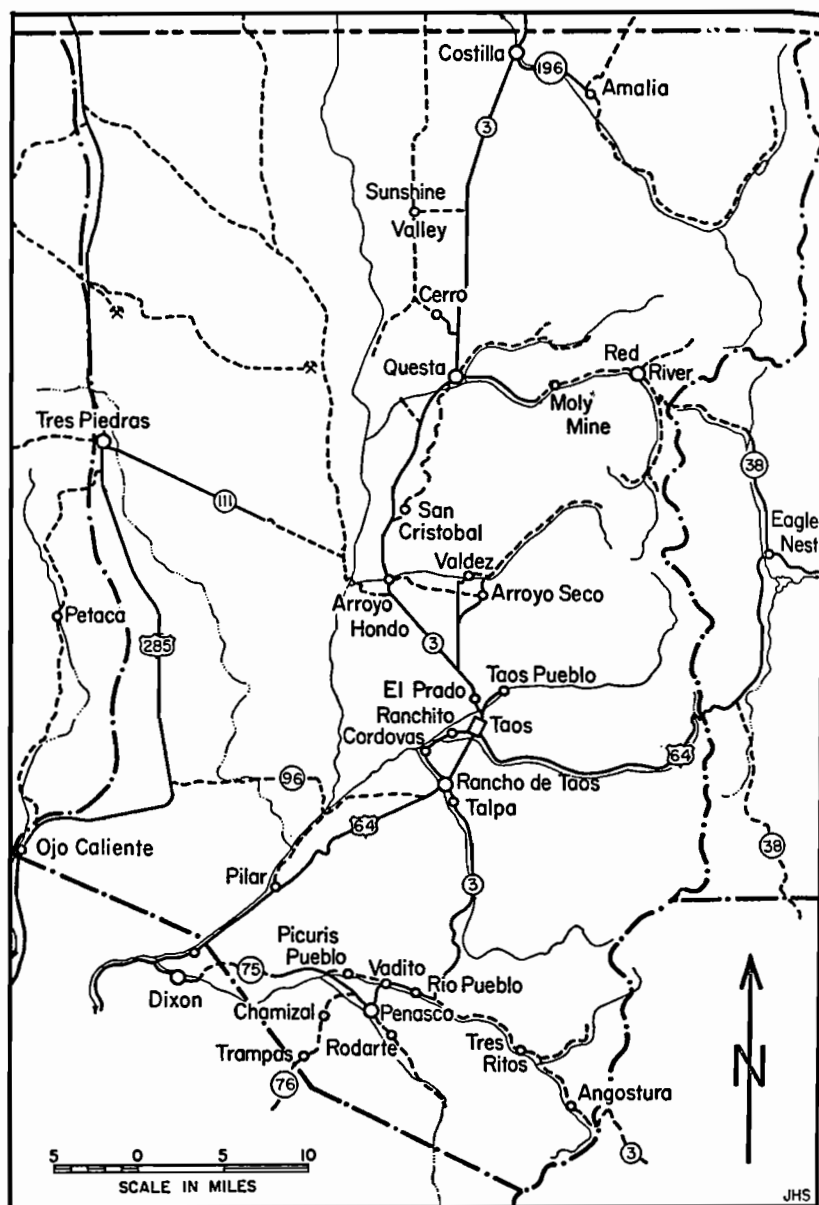


FIGURE 1. Map of Taos County, New Mexico, showing location of Questa Molybdenum mine (from Schilling 1960).

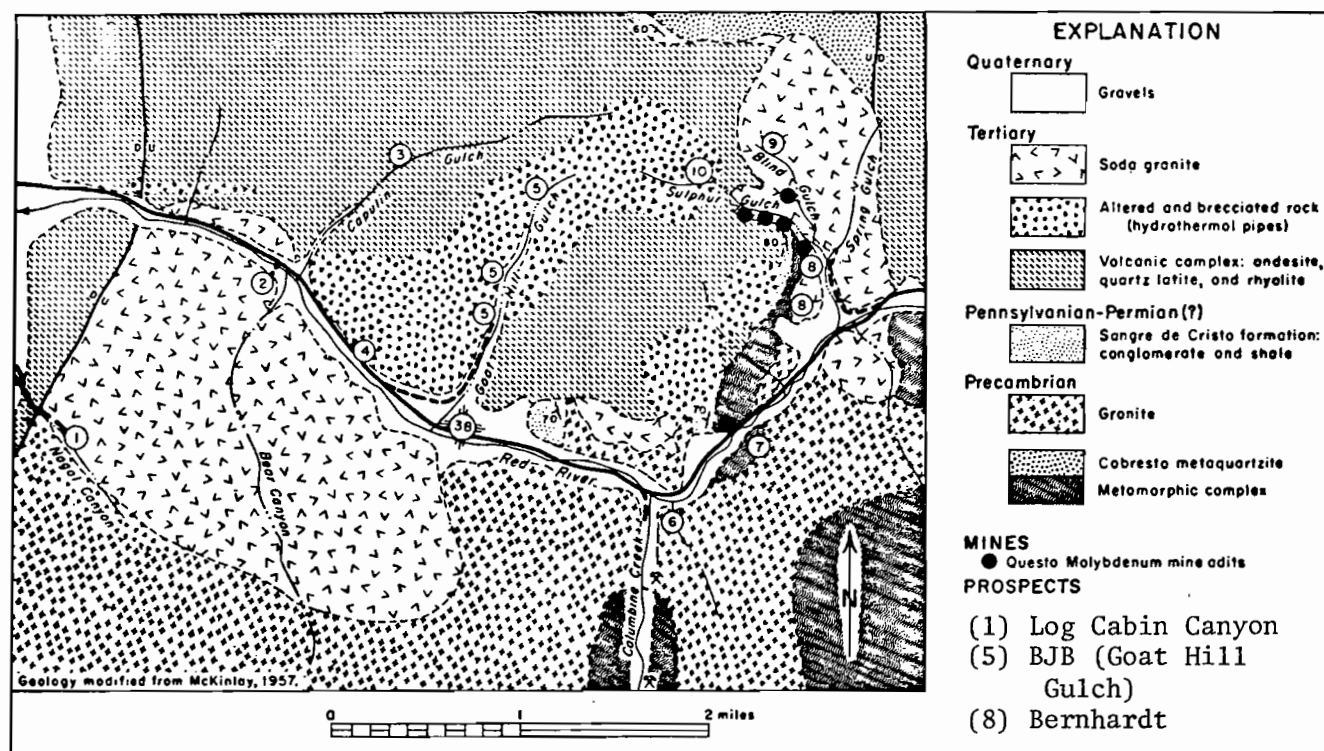
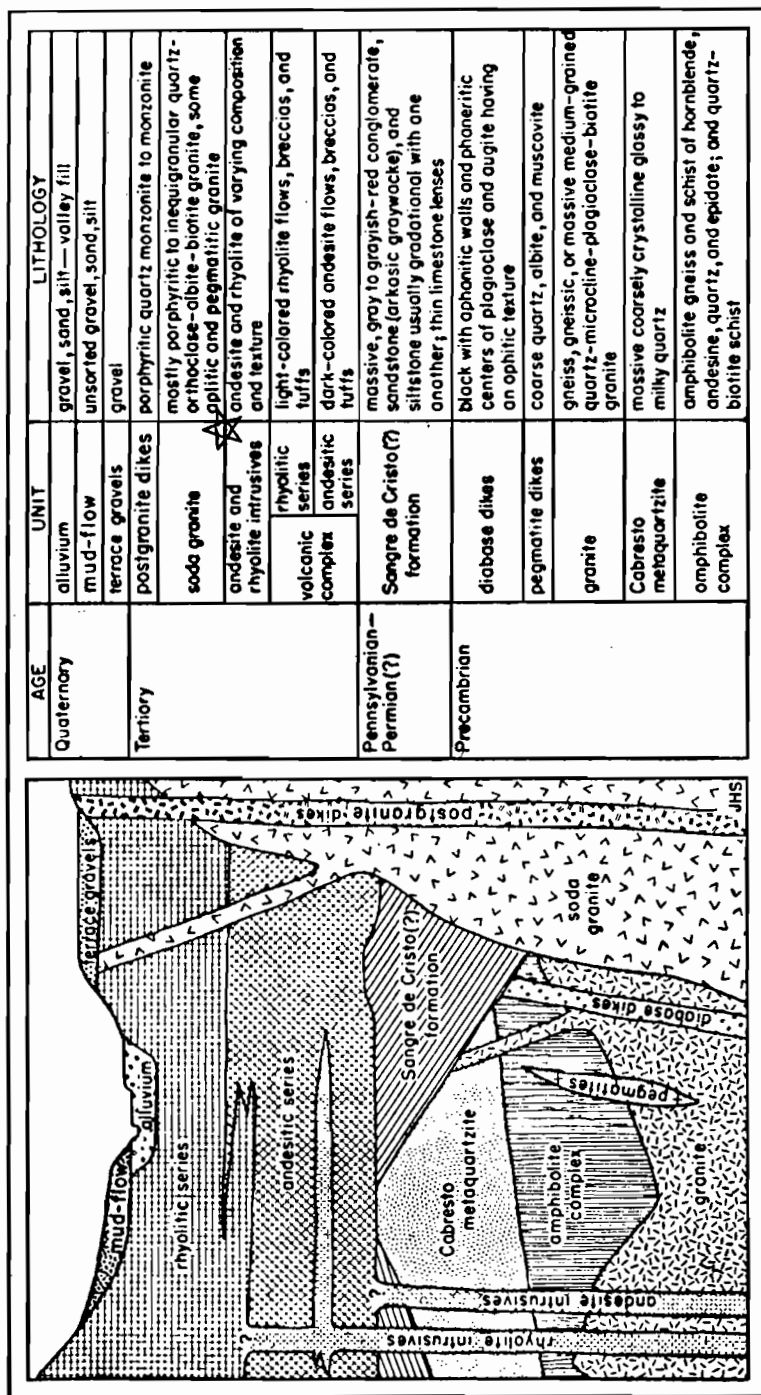


FIGURE 2. Generalized geology of Questa Molybdenum mine area (from Schilling 1960).





★ Molybdenite ore veins

FIGURE 3. Generalized rock section of the Questa Molybdenum mine area (from Schilling, 1956).

## LITHOLOGY

The Precambrian metamorphic rocks include amphibolites, schists, and quartzites. The amphibolite complex covers large areas both east and west of the mine. A detailed geologic map and cross section, parallel to the main haulage adit (Moly tunnel) is illustrated in Figure 4. For orientation a cutaway diagram of the mine (as of 1956) is shown in Figure 5. The quartz biotite schist of the amphibolite complex crops out in the main haulage adit (Moly tunnel). These rocks are found also in the long crosscuts extending south from the main drive of Z tunnel level. The rocks range from massive to foliated, and can be separated into four varieties: (1) massive, coarse-grained; (2) massive, medium-grained; (3) gneissic; and (4) coarse-grained schist.

The Precambrian granite covers large areas in the vicinity of the mine and is exposed along the main haulage adit. It has been divided by Schilling (1956) into three varieties: (1) granite gneiss; (2) gneissic granite; and (3) massive granite. The granite intrudes the amphibolite complex and meta-quartzite. It is overlain unconformably by Pennsylvanian-Permian (?) sediments and a late Tertiary volcanic complex.

Pegmatites in dike-like bodies intrude the amphibolite complex, meta-quartzite, and, less commonly, the Precambrian granite. Several diabase dikes crop out in the vicinity of the mine. The largest dike strikes generally N60°E, with a vertical dip and an average width of 25 ft.

A thick, complex sequence of Tertiary volcanic rocks crops out at all levels in the mine. The volcanics, including andesite, quartz latite, and rhyolite flows, breccias and tuffs, are almost completely altered in some areas.

Late intrusives, ranging from monzonite to granite in composition and plutonic to transitional in texture, crosscut the volcanic sequence. As an illustration, the soda granite occurs in several areas near the mine (based on observation at the surface and 7800 ft. level (Carpenter, 1968). One

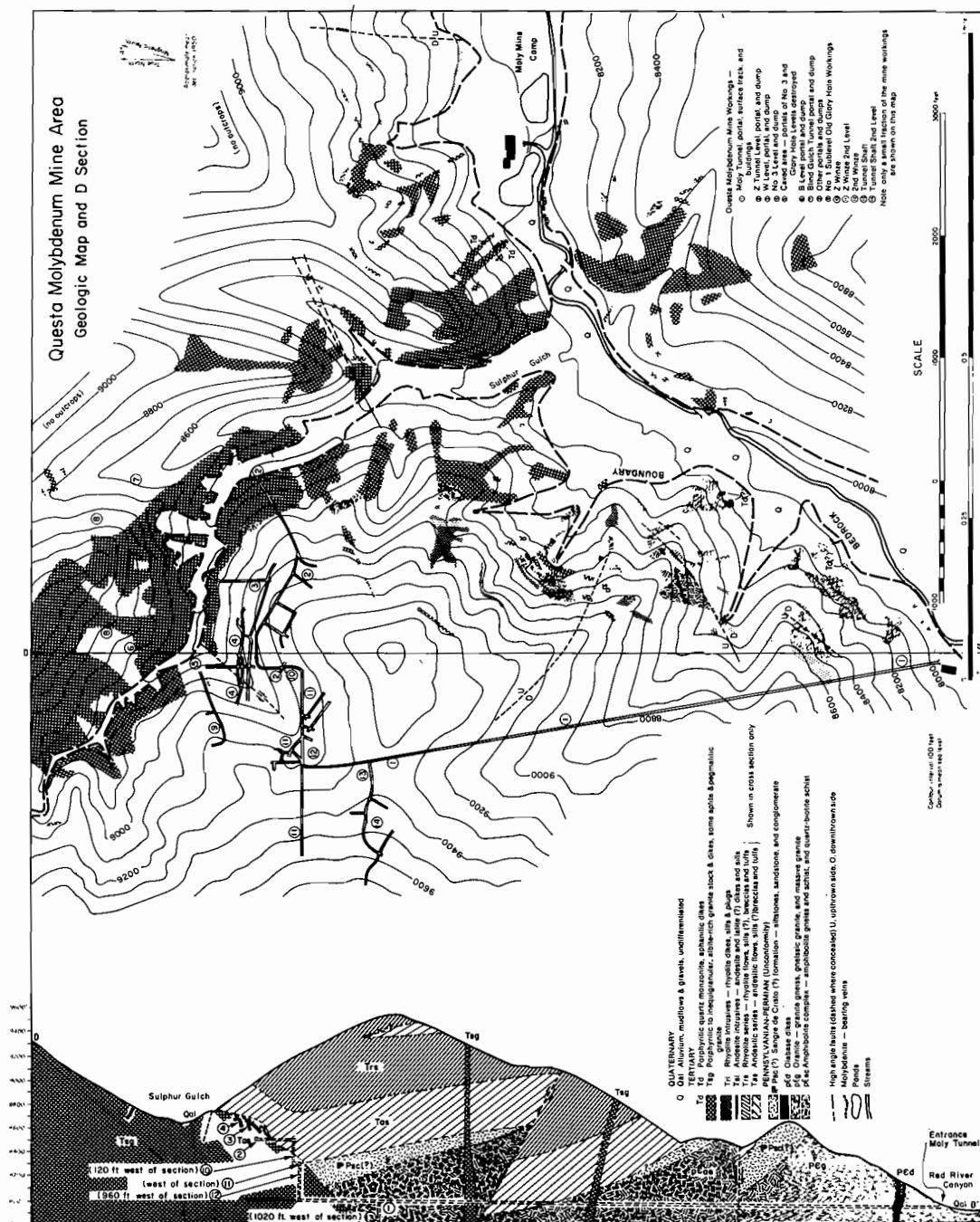


FIGURE 4. Questa Molybdenum Mine area, geologic map and D section.

BLOCK DIAGRAM  
of the  
QUESTA MOLYBDENUM MINE  
TAOS COUNTY, NEW MEXICO

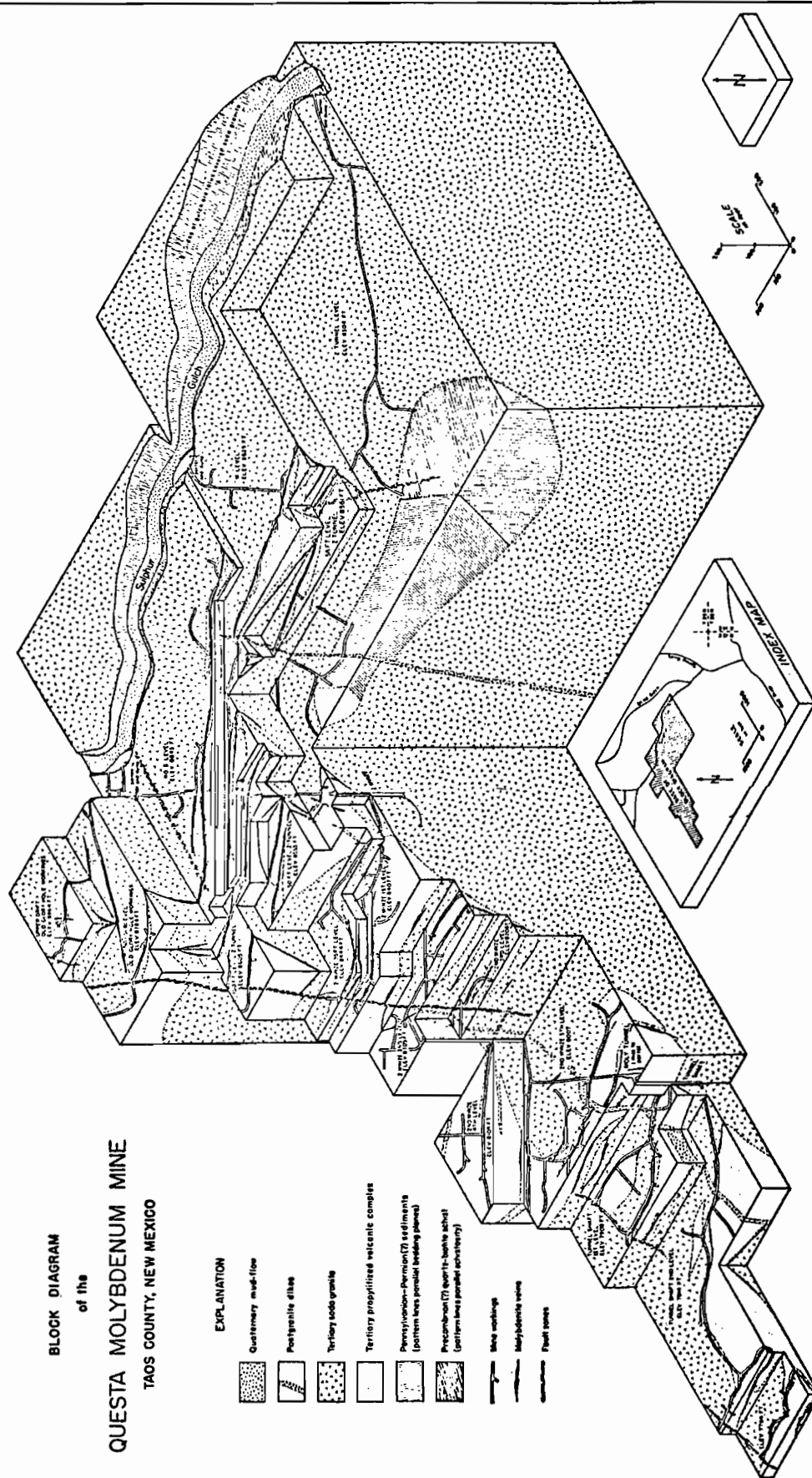


FIGURE 5. Block diagram of the Questa Molybdenum mine, Taos County, New Mexico (Schilling, 1960).

north-trending occurrence, the Sulphur Gulch Stock, covers an elliptical area 0.7 x 15 miles. The top of the stock is domed with gentle dips; its sides dip more steeply. The soda granite is inequigranular to porphyritic at the margins of the stock. Coarser inequigranular granite makes up the core of the stocks. The pegmatitic and aplitic phases of soda granite, in contrast, are in sharp contact with each other. However, these phases make up less than 1% of the soda granite, by volume, and are not significant in the mine workings.

The region is capped with Quaternary gravels and alluvium. Mud flows have occurred in the Quaternary gravels and talus along many of the canyons and are of special interest because of the damage they have caused to mine facilities.

#### MINERALIZATION

The underground mine workings at Questa are in a group of molybdenite-bearing veins. The ore occurs in the Sulphur Gulch soda granite at or near the contact. Most veins parallel the contact and range from less than 1 inch to over 7 feet in thickness, and are largely quartz and molybdenite. The veins were deposited as fissure fillings, probably during the late Tertiary and on the basis of their mineralogy are classified as mesothermal.

#### STRUCTURAL SETTING

The structure of the Taos Range of the Sangre de Cristo Mountains is extremely complex. The mine is located in an east-west down-faulted zone several miles wide, in which structural features combine to form a pattern quite different from the rest of the range. This zone apparently has served to localize the soda granite intrusives.

The Taos Range has been uplifted and tilted eastward along a fault zone paralleling the western edge of the range. The high angle Frontal fault crosses east of the mine and has a total estimated displacement of 6000 ft. (Schilling, 1956). Several high angle faults were noted underground. They cut the soda granite and older rock and show horizontal displacements of a few to tens of feet. Along the soda granite contact several post-soda granite dikes are intruded along these faults. Thrust faulting, though common to the Taos Range, was not observed in the vicinity of the mine.

The Sulphur Gulch soda granite is extensively fractured. The fracturing is roughly parallel to the contact and is called sheeting. It is concentrated in the outer 50 feet of the granite and commonly cuts across irregularities. Some of the sheeting fractures curve toward the contact, reversing in dip as they approach the contact. This sheeting apparently was formed by the upward force of the intruding soda granite.

In the mine area, fracturing and faulting are irregular, except for the regional east-west striking, vertically dipping fractures common to the Taos Range.

Evidence of alteration at depth is found in the Moly tunnel. Here disseminated pyrite occurs in Precambrian granite. Porphyritic alteration of the rocks (indicated in Figure 4) surrounds the soda granite stocks and decreases rapidly away from the granite.

#### HYDROLOGY

The mine is located at 8000-9000 ft. elevation in the Taos Range. The water table is probably within a few tens of meters of the surface and the mine workings would then be tens to hundreds of feet below the water table and well within the saturated zone. Water from the levels above the

haulage adit drains by gravity, while water from the workings below the haulage adit drains into a sump at the bottom of the tunnel shaft and is pumped out.

#### MINE CHARACTERISTICS

The mine has more than 35 miles of workings with a vertical extent of 1200 feet and is divided into three areas. They are Sulphur Gulch north workings, Sulphur Gulch south workings, and Tunnel Shaft workings. The Sulphur Gulch south workings are mined through adits. The Tunnel Shaft workings are mined through a vertical winze and the Moly tunnel. The main haulage adit (location shown in Figure 5, the geologic cross-section roughly parallels adit) cuts across the Precambrian granite and amphibolite complex, Tertiary volcanic rocks and the soda granite. The maximum depth of workings is 1600 feet. The depth and extent of workings as reported in 1956 are shown in Figure 5.

The mine is developed in an irregular pattern following the irregularity of the vein system. Adits, drifts, crosscuts, raises, and winzes occur at intervals of 15-100 feet vertically. Machine mucking is used in all easily accessible drifts. The rock, when granite, is moderately hard and usually stands well without timbering; the altered volcanics are broken and require timbering. Surface tracks extend from the adits to the mine ore bins and dump.

#### MINE ACTIVITY

The Questa mine has been in almost continuous operation since 1920, when the Molybdenum Corporation acquired the property. Total production data are classified but production was estimated to exceed \$10 million in

1968 (Kottlowski, 1969). The production in 1965 was estimated at 20 million lb. (Schilling, 1965).

The Molybdenum Corporation received from the Defense Minerals Exploration Administration an exploration contract for \$255,250 in 1957, and the Molybdenum Corporation was required to spend an equal amount (New Mexico Bureau of Mines and Mineral Resources, 1977). An intensive exploration program was carried out in 1957, including a geochemical survey, extension of the lowest level in the mine, and core drilling both from the surface and underground. Again in 1975-76, extensive exploration was undertaken. Molybdenum Corporation joined in partnership with Kennecott and \$5.7 million was spent for exploration of the Goat Hill, Log Cabin, and Southwest Zone ore bodies. Exploration included 130,000 feet of drilling (World Mining, June 1977). The Goat Hill reserves are estimated at 140 million tons, however, the known workings are located in altered volcanics, and two of the three adits had caved prior to 1960 (Schilling, 1960). The Log Cabin reserves are estimated at 50 million tons. The Log Cabin workings prior to 1960 (location shown in Figure 2) include an adit driven 750 feet into a mountain with the last 500 feet in the soda granite (Schilling, 1960). Details of the 1975-76 exploration were not available from the literature for either location. No reserve estimates were given for the southwest zone, nor was the location identifiable from the literature. Since recent exploration has been undertaken in these areas, and the Log Cabin workings are located in crystalline rock, this site may be a potential candidate.

In the summer of 1977, mud and rock slides closed the Molybdenum mine (open pit?) for the rest of the year (Wall Street Journal, Friday, December 2, 1977), costing the corporation about one half year's production (1976 production at 11.5 million lb.).



In May 1979 Molybdenum Corporation initiated a \$200 million project Skillings Mining Review, May 5, 1979) to develop a large underground mine to begin operation in 1983 at a rate of 18,000 tons/day. At approximately the same time, 1983, the open pit operations would close. Preproduction construction for the new underground workings include shaft sinking, outfitting, and underground development. A work force of 800 will sink a 24 ft. diameter service shaft along with a 14 ft. diameter ventilation shaft (Engineering and Mining Journal, February 1979). The project is estimated to produce 18-20 million pounds per year of molybdenum for at least 20 years. Block caving methods will be used to mine the ore. An electric rail haulage system will tram ore to a decline and a conveyor will transport it to the surface. No other mine activity or equipment information was available from the literature.

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July 25, 1977, p. 12.
- World Mining, June 1977.



BALMAT-EDWARDS DISTRICT MINES  
(St. Joseph Zinc Co.)

LOCATION

The Balmat-Edwards district is located in the northwestern portion of the Adirondack Mountains in Lawrence County, upper New York State. General coordinates are  $44^{\circ}15'N$ ,  $75^{\circ}15'W$ . Within the district are several zinc mines of interest: the Balmat #1,2,3, and 4; the Edwards; and the Hyatt mines. These are located about 10 miles ESE of Gouverneur, New York (Figure 1). The district extends for 10 miles from Sylvia Lake and Balmat NE to Edwards.

GEOLOGIC SETTING

The district lies in the northeast striking belt of Grenville lowlands mostly underlain by highly deformed Precambrian metasedimentary rock. It is bounded on the northwest by undisturbed Paleozoic sedimentary rock and on the southeast by igneous gneisses of the Adirondack massif. The general trend of exposed formations, topography, and structure, roughly NE-SW, is the same as that of the Grenville lowlands (Figure 2) (Lea, 1968).

The Precambrian rocks in the region range from older quartzite, quartz-biotite gneiss, and dolomitic marble to intrusive syenites and granitic gneisses of the Adirondack massif, to younger Precambrian granite gneisses. The ore bodies occur as replacements in the various types of dolomitic marble as lenses, pods, and tabular bodies. They are of Precambrian age. The ore minerals are sphalerite, pyrite, and galena, with minor amounts of pyrrhotite and chalcopyrite.

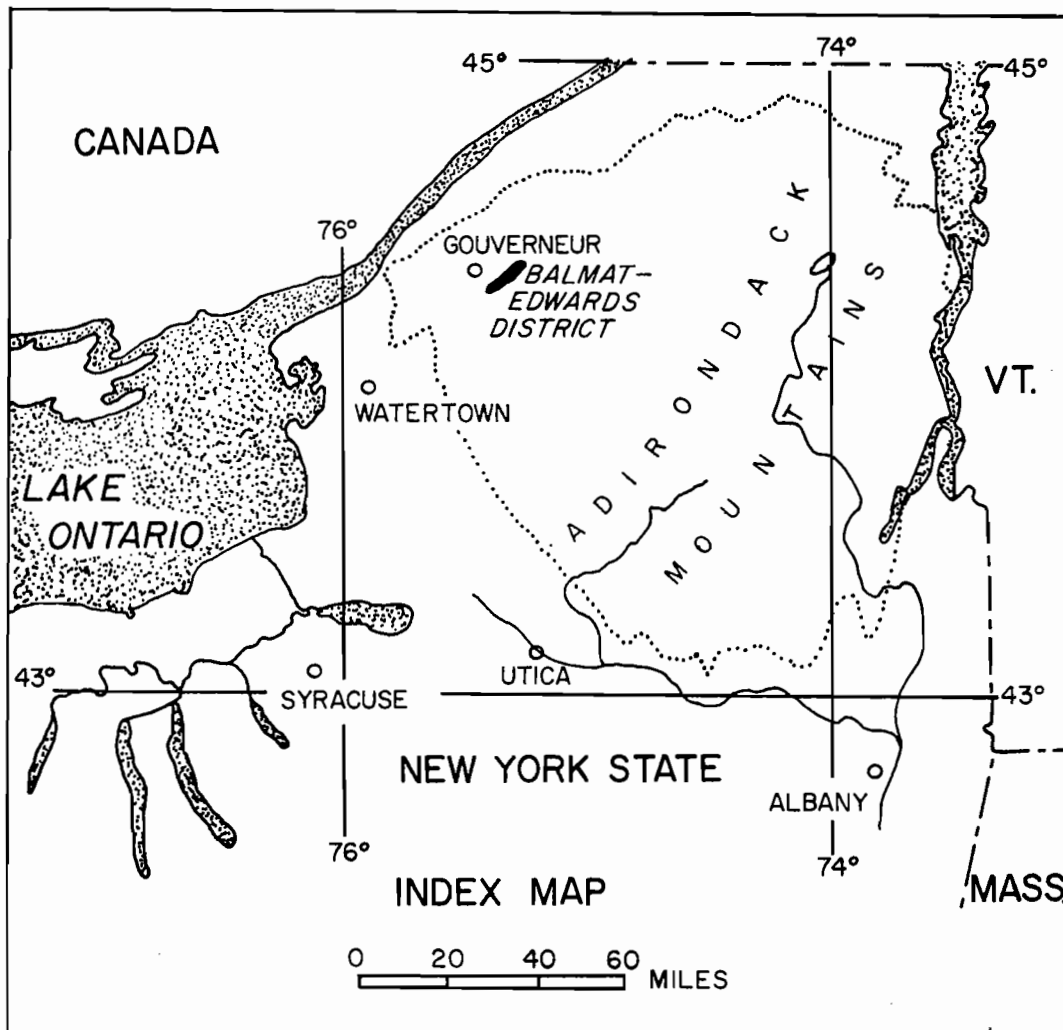


FIGURE 1. Index Map, showing location of the Balmat-Edwards District, New York. (Lea, 1968)

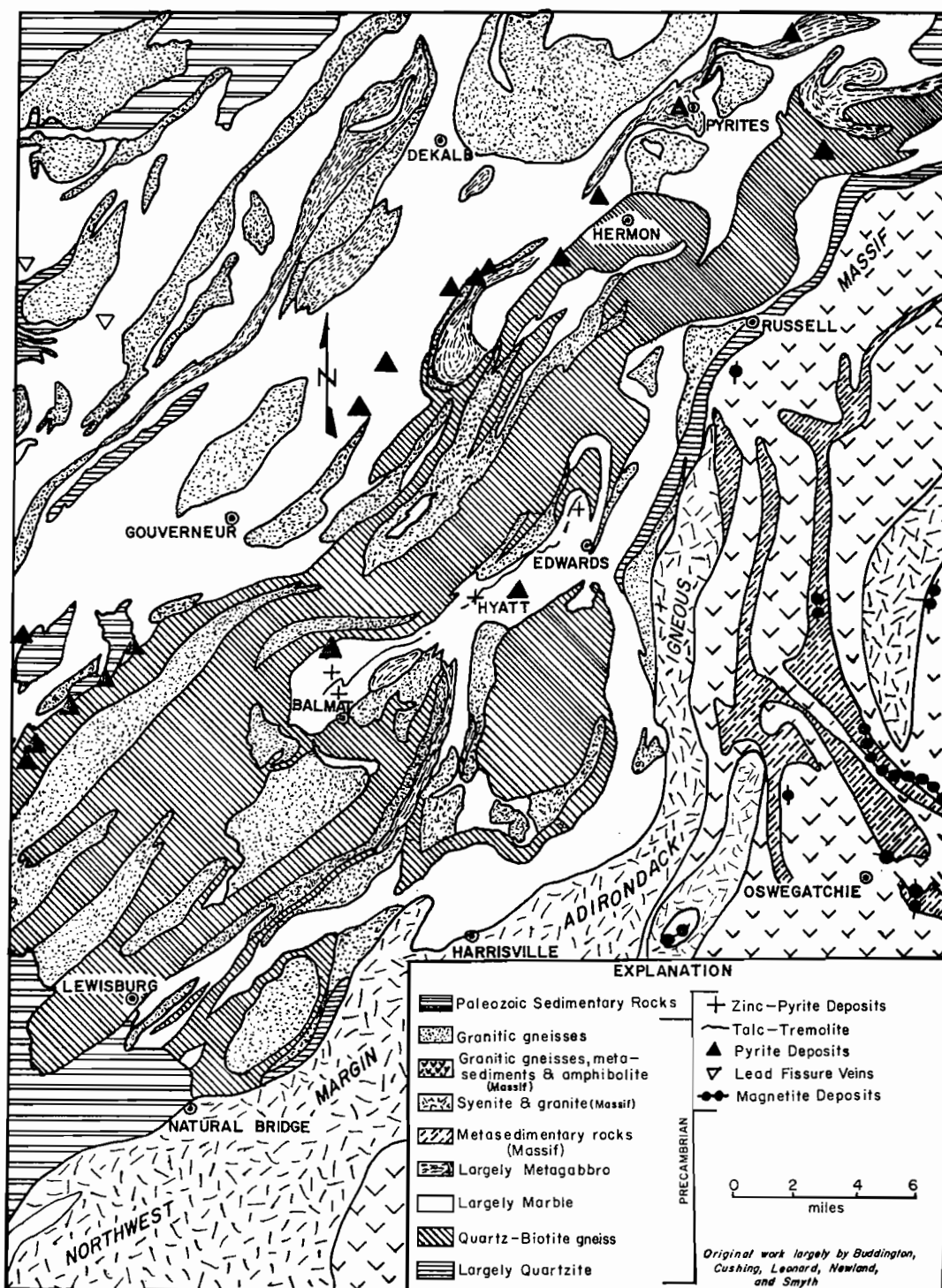


FIGURE 2. Generalized Geologic Map of the Balmat-Edwards District within the Northwestern Adirondacks, showing the distribution of major rock types and mineral deposits. (Lea, 1968)

### Structure

The structure of the northwestern Adirondacks has been divided by Buddington (1962) into three major structural units. They are: (1) a unit of mostly granitic gneiss and minor metasedimentary rocks in the extreme northwest; (2) the Grenville lowland unit, a broad belt 25-30 miles wide composed of 70% metasedimentary rocks with minor granitic intrusions, in the southeast; and (3) the main igneous complex southeast of the lowlands.

The Grenville unit is considered by Engel and Engel (1958) to be anticlinorial. In the Balmat-Edwards area, the southeastern flank of the dominant anticlinorium is overturned to the northwest. There were two major Precambrian folding deformations in the area: (1) a primary one which produced the regional northeast trend (fold axes) with a northwest dip and (2) a secondary folding which produced crossfolds intersecting the regional trend and plunging north to northwest. The ore bodies are located in the complex folds (in overturned limbs of anticlines or synclines) developed by the interaction of the two deformations, in competent and incompetent beds (Buddington, 1962, Brown, 1956).

### Metamorphism

The relatively high grade of metamorphism is indicated by the gneisses and also by high-temperature features of the mineralization. The mineralization is thought, however, to originally have been premetamorphic, and later remobilized by the metamorphism.

### Hydrology

No general information on the district water table and water regime was found. However, an article in the Engineering and Mining Journal

November 1976 states that all three of the mines in the Balmat area produce 750 gpm and that most mine water originates above the 1300 foot level underground. There is no information as to how much of this inflow is due to mining activity. Lea, (1968) reports that there has been a water problem in the Balmat #3 mine because of the location of an aquifer, the Potsdam sandstone, above it.

#### MINE FACILITIES

The Balmat-Edwards district mines are owned and operated by St. Joseph Zinc Co. (Oliver Plaza, Pittsburg, Pa. 15222) a subsidiary of St. Joseph Mineral Corp. (250 Park Avenue, New York, 10017, 212/953-5000). Four mines were actively in operation as of 1976 (E/MJ 1976); they were the Edwards mine (Figures 3-5) (depth almost a mile down dip at an average 40° plunge), Balmat #2 (at least 2300 feet), Balmat #3 (883 feet), and Balmat #4 (Figure 6) (2500 feet). Balmat #2 and 3 mines are connected to Balmat #4 and their ore along with that of #4 is hoisted through the #4 shaft. The main Balmat ore bodies may be seen in Figure 6 in projection. The Edwards mine was inoperative from June 1978 to at least the first quarter of 1979 because of a strike (St. Joseph Minerals Corp. 1978 Annual Report and St. Joseph release 1979). CRIB (1977) reports that the Edwards mine would be exhausted by 1980.

In 1977,  $1.1945 \times 10^6$  tons (3982 tons/day) were mined (St. Joseph Minerals Corp. Annual Report 1977). As of 1971, the proven ore reserves were  $5.4 \times 10^6$  tons. Therefore at the 1977 tonnage removal rate, the present reserves will be depleted in about 3 years. It should be noted, however, that the ore bodies are erratically located because of regional complex folding and faulting.



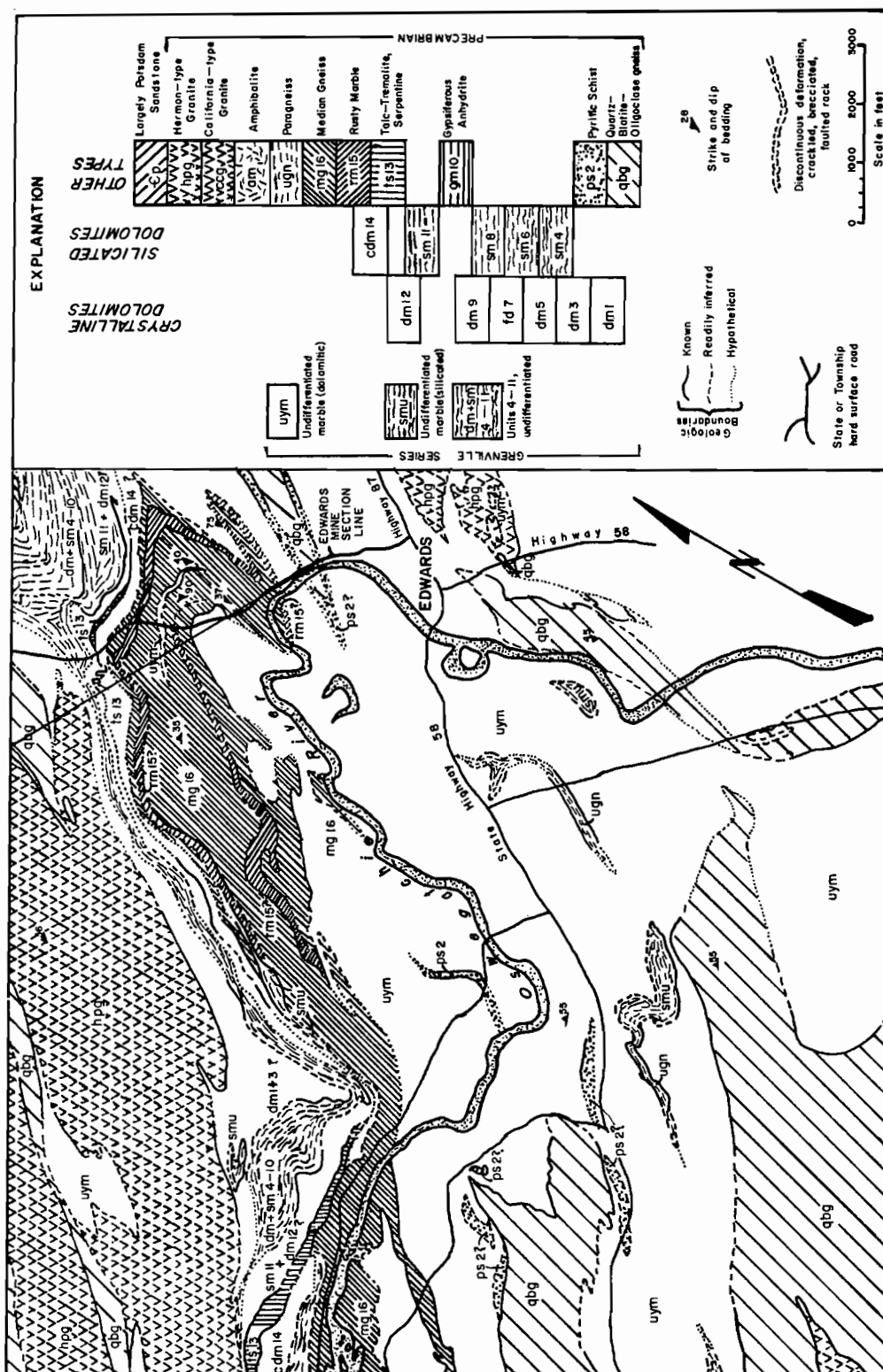


FIGURE 3. Geologic Map of the Balmat-Edwards District: Edwards Area. (Lea, 1968).



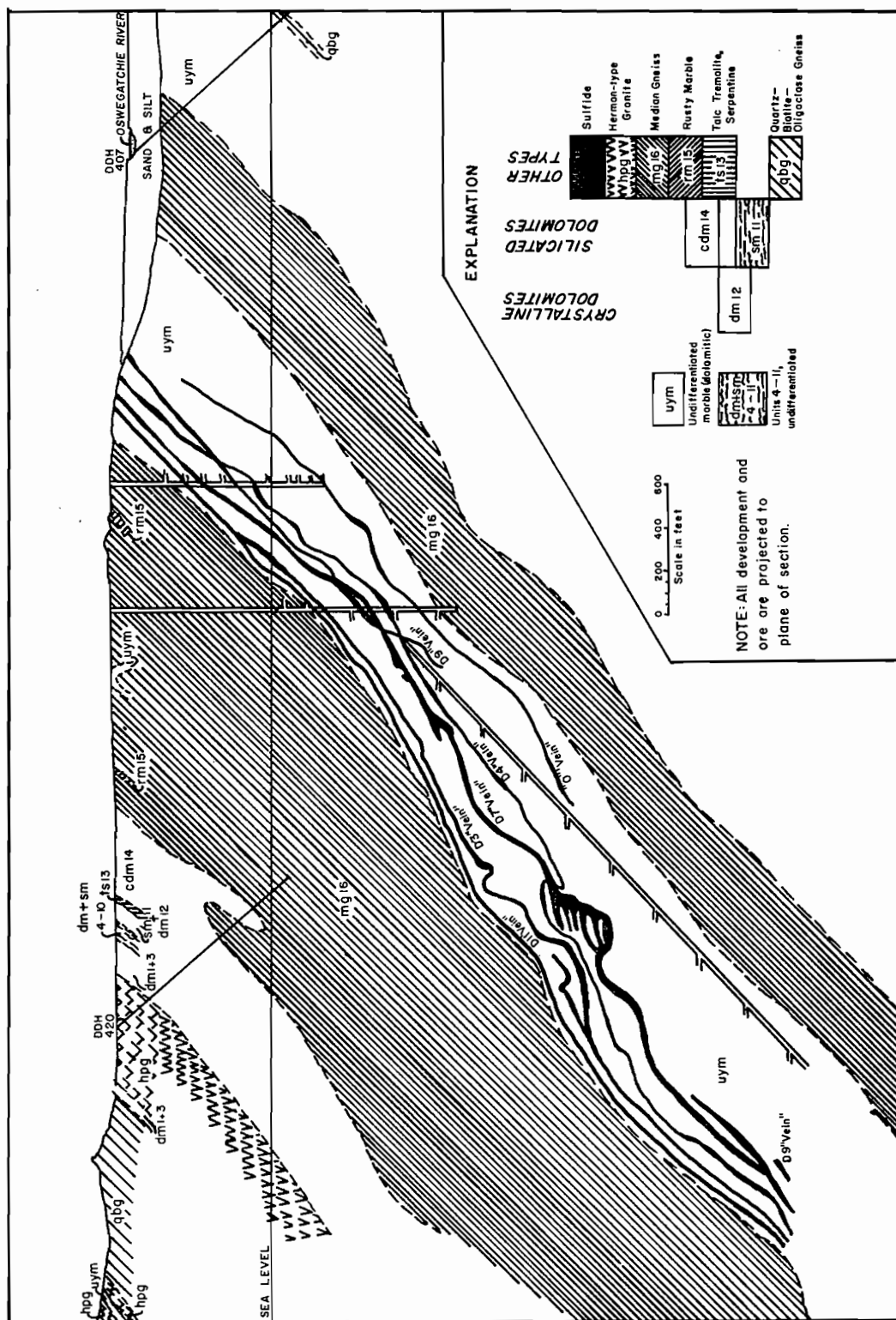


FIGURE 5. Edwards Mine: Northwest-Southeast Section. (Lea, 1968).

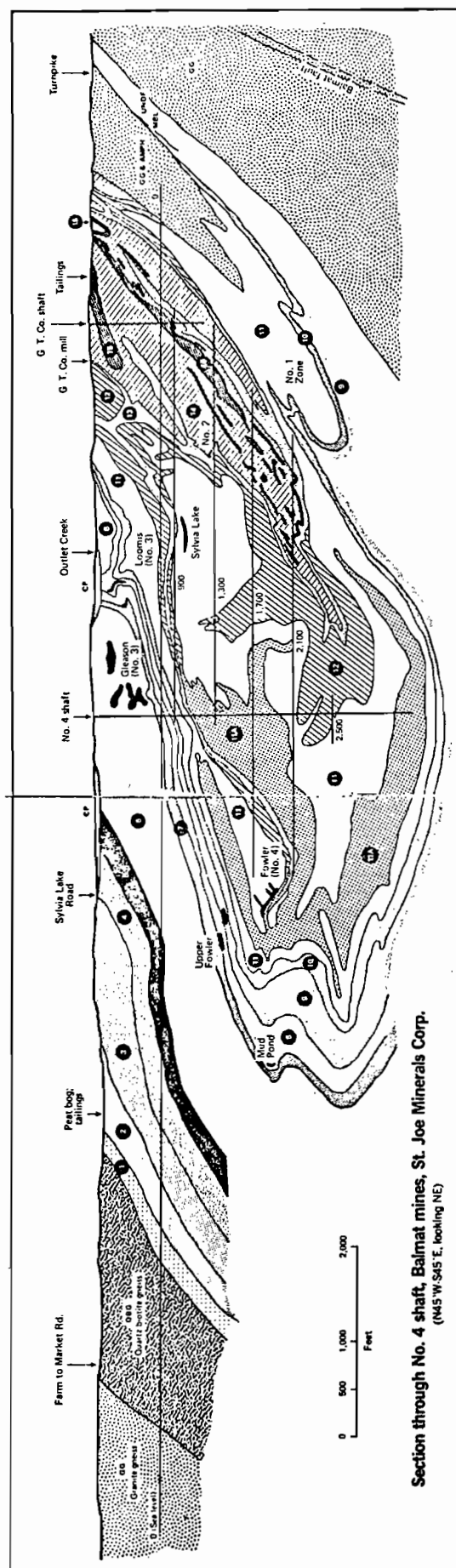


FIGURE 6. Generalized geologic section through the No. 4 shaft includes projections of the main Balmat ore bodies and haulage levels onto the plane of the section. The Grenville series, in which the Balmat ores occur, is characterized by an alternation of almost pure dolomites and strongly silicified units, as follows (oldest to youngest): 1) dolomitic marble; 2) pyritic schists; 3) dolomitic marble; 4) dolomite, quartz, dolomitic marble; 5) dolomite, quartz, dolomitic marble; 6) siliceous dolomite, quartz, dolomitic marble; 7) gray feldic dolomite; 8) dolomite, quartz, dolomitic marble; 9) dolomitic marble; 10) anhydrite, gypsum, talcose dolomite; 11) dolomite, calcitic and dolomitic marble, quartz, and 11a) locally anhydrite; 12) dolomitic marble, locally anhydrite; 13) tremolite schist, anhydrite; 14a) serpentized dolomitic and calcitic marbles, dolomite; 14b) calcitic marble, quartz augen; 14c) quartz-dolomite rock, minor UNDF-- serpentized dolomitic marble, minor quartz-dolomite rock, calcitic marble, tremolite-anhydrite. (Eng. Min. J., v. 177 (11), p. 92-99, 1976)

It is expected that more ore may be located in the future. Probable reserves may be  $8.4 \times 10^6$  tons as of 1976 (E/MJ 1976). Engineering and Mining Journal (1976) reports that St. Joseph can be expected to be mining the Balmat District until the end of this century.

#### MINE OPERATIONS

Slusher stopes to large room and pillar stoping are used because of the complexity of the ore body. Drifts which are arched may be in either the footwall, hanging wall, or in ore, because of ore location variability. Roof bolts are usually the only support necessary. They are 5/8 inch diameter and 4-6 feet long with 6x6 inch plates on a 4x4 foot pattern. In soft ground resin bolts are used. In fractured areas, chain link fence and/or roof mats with bolts are needed. Trackless hauling is used with battery locomotives, Plymouth 6-8 ton diesel locomotives, and Sien 10 ton trucks. Hoisting equipment for Balmat mines are for #2 - 8.5 ton hoist, #3 - 3 ton hoist, #4 - 11 ton hoist. The latter can handle 287 tph. No. 4 shaft also has a 10 ton service hoist (E/MJ 1976).

The Edwards mine cross-section and plan views (Figures 4 and 5) show that some workings extend into the gneissic rock. While the other mines may also have such drifts into the gneiss, the maps available do not show such workings. The Hyatt mine, while of small production, is operating and may be a prime candidate since, from MAS data (1978), gneiss and schist lie over and under the ore.

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## LYON MOUNTAIN DISTRICT

## LOCATION AND ACCESSIBILITY

The magnetite deposits of the Lyon Mountain district are located in far northeastern New York State, at 44°44'N, 73°55'W, 25 miles slightly north of west from Plattsburg and 145 miles slightly west of north from Albany. Access is by State Highway 374, an all weather road. Two mines, the Chateaugay, located in the village of Lyon Mountain, and the 81 mine, approximately 1 mile NNE of Standish, have been worked in recent years (Figure 1).

## GEOLOGIC SETTING

Lithology

The geologic setting of the Lyon Mountain district was described by Postel (1952).

Four major ore bodies comprise the district: the 81, the Chateaugay, the Parkhurst mines, and the Phillips vein, located in the southwest-northeast trending Lyon Mountain ore belt (Figure 2). Most of the metamorphic and igneous rocks of the district have gneissic structures as a result of the Grenville metamorphic episode. The oldest rocks in the district are sedimentary rocks of the Precambrian Grenville Series but these rocks do not occur in the mineralized area. The oldest felsic igneous rock in the district is the Hawkeye granite gneiss, outcropping 1 to 1.5 miles southeast of the ore belt; its axis is oriented roughly parallel to the ore belt. A younger quartz syenite gneiss crops out 10 miles south of the ore belt. The youngest rock in the district is the Lyon Mountain granite gneiss which contains the ore belt. Pegmatites are common in the district and are found in all mines. Dikes of varying composition also transect the area and are all younger than



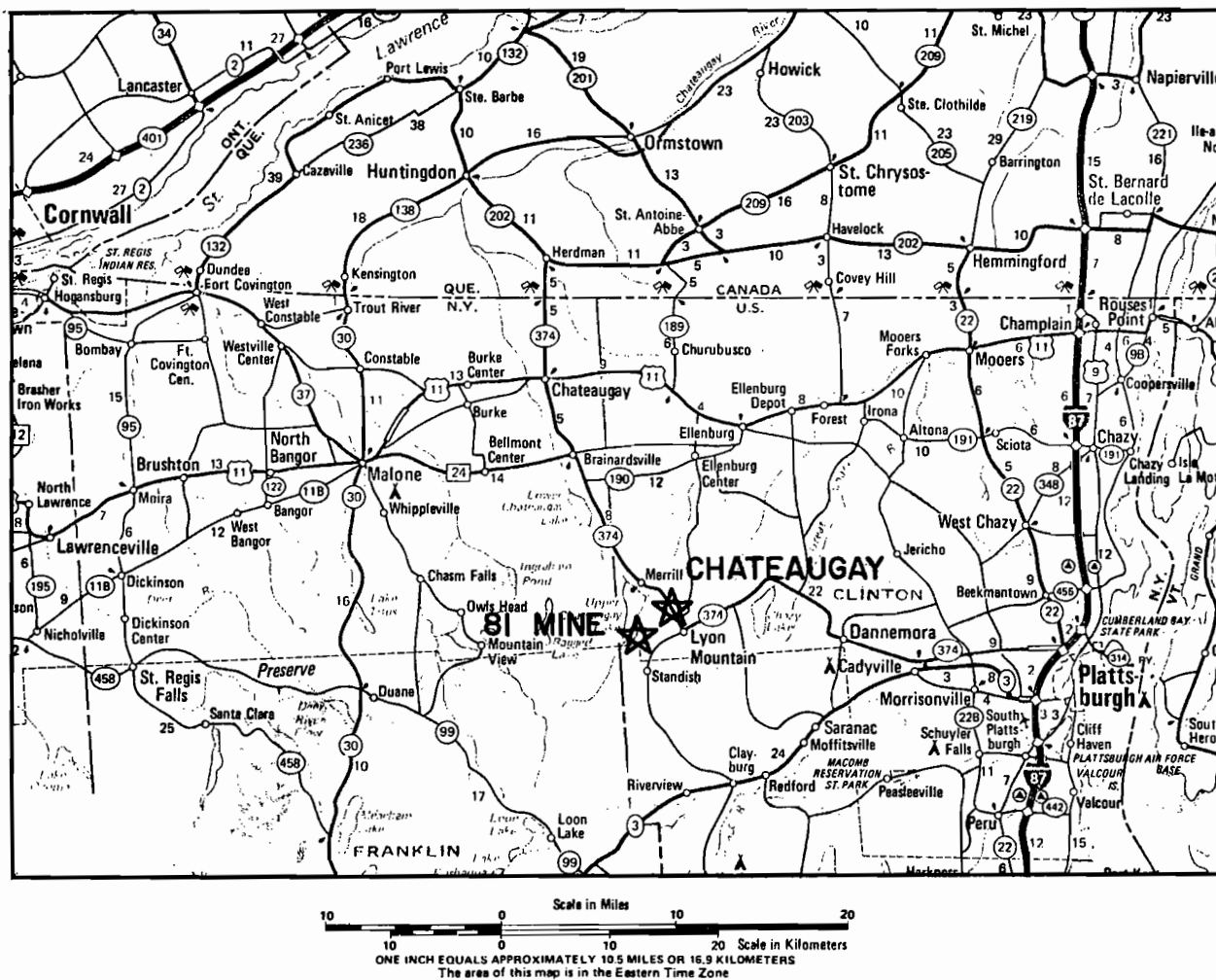


FIGURE 1. Map showing locations of the Chateaugay and 81 Mines, Clinton County, New York. Basic map reproduced by permission of the American Automobile Association, copyright owner.

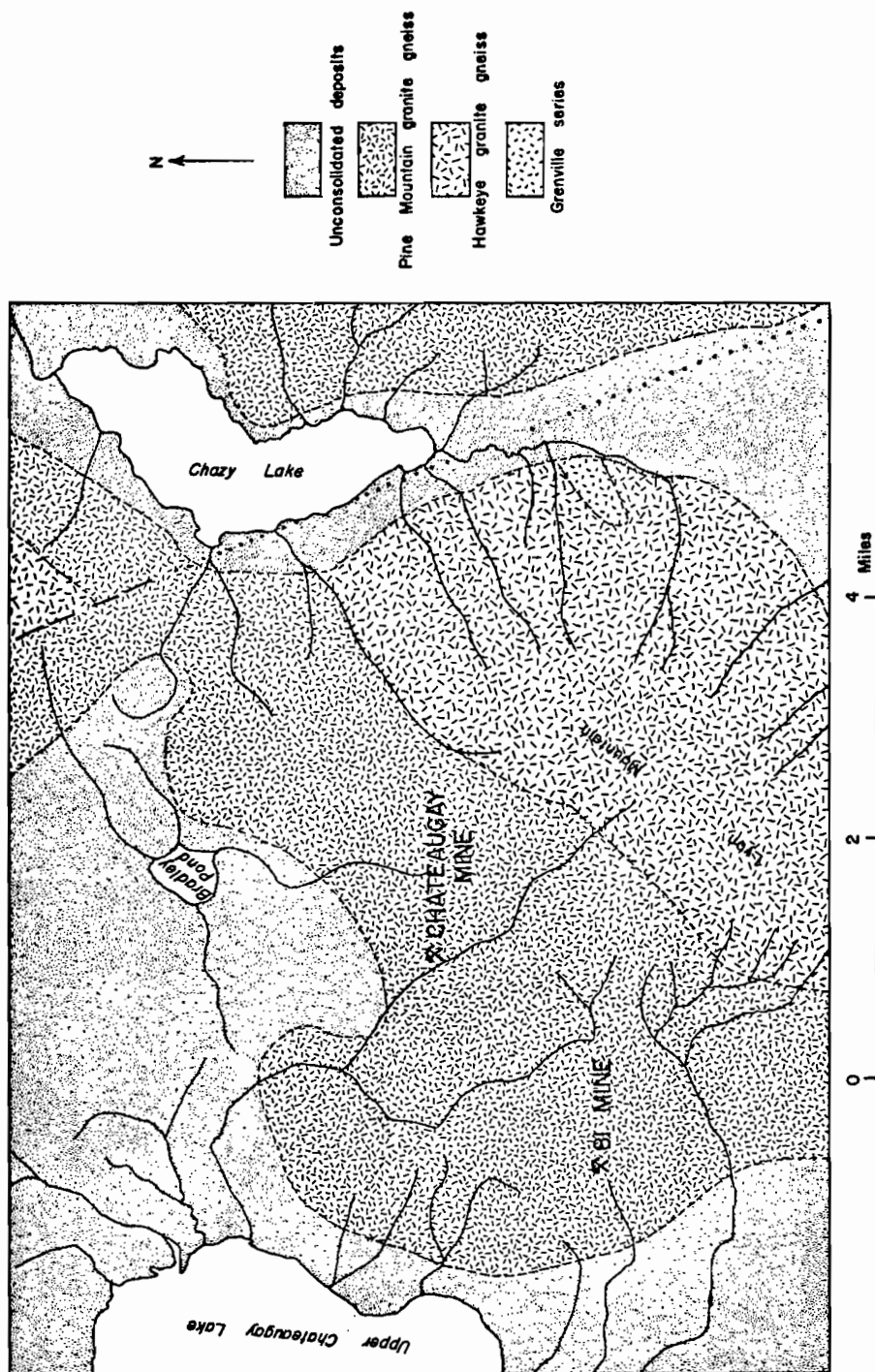


FIGURE 2. Geologic map of the Lyon Mountain area, Clinton County, New York, showing the location of the Chateaugay and 81 Mines. (Postel, 1952)

the Lyon Mountain granite gneiss. Numerical rock ages do not appear in the literature on the ore belt area or its surroundings. Metamorphism and intrusive relationships suggest that the ore bodies developed at the time of Grenville orogeny, about 1 million years ago (Ridge, 1972, Postel, 1952). The presence of schist and gneiss indicates that metamorphism was medium to high grade. The principal ore mineral is magnetite. The ore deposits probably were formed by hydrothermal solutions derived from the granitic magmas (Ridge, 1972).

The Precambrian rocks are encompassed in isoclinal, overturned, and open folds. Generally, the folds plunge to the north or northeast but a few also plunge to the south. Some synclines in the Lyon Mountain granite gneiss are economically important because many of the district ore bodies are located in their limbs. For example, the 81 mine ore body occurs in the 81 syncline north of the town of Standish, and the ore in the Chateaugay mine in the village of Lyon Mountain occupies two synclines, the east and west, which are separated by an anticline.

Both large and small faults transect Clinton County. Small normal and reverse faults with a few inches of displacement are noted in the ore district. The evidence for the large faults, all normal, is based on the presence of brecciation, discordant strike of gneisses, and topographic features. An example is the Chazy Lake Fault which strikes NNW, east of Lyon Mountain. In the Chateaugay mine two sets of faults are found. One set strikes east while the other strikes northeast, both having vertical dips.

Foliation occurs in varying degrees in all Precambrian rocks in Clinton County. In general, the direction of foliation is northeast, especially

in the ore district areas. Lineation usually trends northward or a little east of north with a moderate plunge in the same direction. This trend is usually close to the strike of the foliation plane in which the lineation occurs (Postel, 1952).

#### MINE GEOLOGY - Chateaugay, 81, and Parkhurst Mines

The ore at Chateaugay mine is a replacement of a pyroxene-contaminated microcline-microperthite granite gneiss and plagioclase granite gneiss, and occurs as cigar-like shoots in two synclinal structures which plunge in a northeast direction. The ore bearing limbs strike  $N30^{\circ}E$  and dip  $60-65^{\circ}NW$ . The ore at the 81 mine replaces plagioclase granite gneiss, and occurs on the heel and northwest limb of a syncline; the limb strikes  $N45^{\circ}E$ . There is a small anticlinal fold between the southeast limb at the 81 mine and the Chateaugay mine. The host rock has a strong mineral lineation which plunges  $20^{\circ}NE$ . The ore body at the Parkhurst mine is reported to be walled by schist (Postel, 1952).

#### FACILITIES

Very little information was found on facilities. The total ore output from the Chateaugay mine in the period 1871-1948 was  $15 \times 10^6$  long tons. In 1948, the output was  $1.5 \times 10^6$  long tons. Postel states that the mine geologist for Republic Steel Corporation at Lyon Mountain Village was planning a detailed description of the Chateaugay and 81 mines which would undoubtedly give pertinent information. The mine was still producing in 1956 (Minerals Yearbook, 1956). The mine was permanently closed in 1967 (Minerals Yearbook, 1967).

The 81 mine was opened in 1840 but not mined continuously until 1848. It was shut down in 1902. In the late 1940's, Republic Steel Corp. investigated the deposit again and started production in 1948-1949. Contracts were let to build a six-compartment vertical shaft to 2500 feet underground (Skillings Mining Review, August 28, 1948).

There is no information on the Phillips' vein. It may never have been mined. No further information has been found on the Parkhurst mine other than the fact that it is flooded, and produced  $4 \times 10^4$  tons of ore between 1889 and 1892.

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## HOMESTAKE MINE

LEAD, LAWRENCE COUNTY, SOUTH DAKOTA  
(Homestake Mining Co.)

## LOCATION AND ACCESSIBILITY

The Homestake mine is located at Lead (pronounced "leed"), Lawrence County, in the Black Hills of southwestern South Dakota at 44°15'N and 103°50'W.

Lead is 35 miles northwest of Rapid City, South Dakota from which it is readily reached by Highways 90 and 14 (Figure 1).

The mine, which extends to a depth of 8000 ft., is the largest gold producer in the western hemisphere and has operated almost continuously since 1876. It produces native gold, with silver as a major accessory metal and a small amount of copper (CRIB, 1974; E/MJ, 1976; Slaughter, 1968).

## GEOLOGIC SETTING

The geologic setting of the Lead district is illustrated in Figure 2. The Homestake mine is located in Precambrian schists, formerly mudstones which, along with other rock types, were folded and intruded by igneous rocks and then metamorphosed. The total thickness of the schists at Lead is about 2000 feet. Great compression of the schists resulted in a plastic rock flow and the production of tightly closed isoclinal folds. Refolding and deformation of the isoclinal folds resulted in the present configuration of a complex synclinorium. Most metamorphism took place in the Precambrian time during or following the first folding period. The metamorphosed rocks were severely eroded and covered with Paleozoic and Mesozoic sediments. In early Tertiary time large amounts of igneous rocks intruded this rock sequence. The whole region was then uplifted and eroded so as to produce the present surface (Slaughter, 1978; Nobel and Harder, 1948).





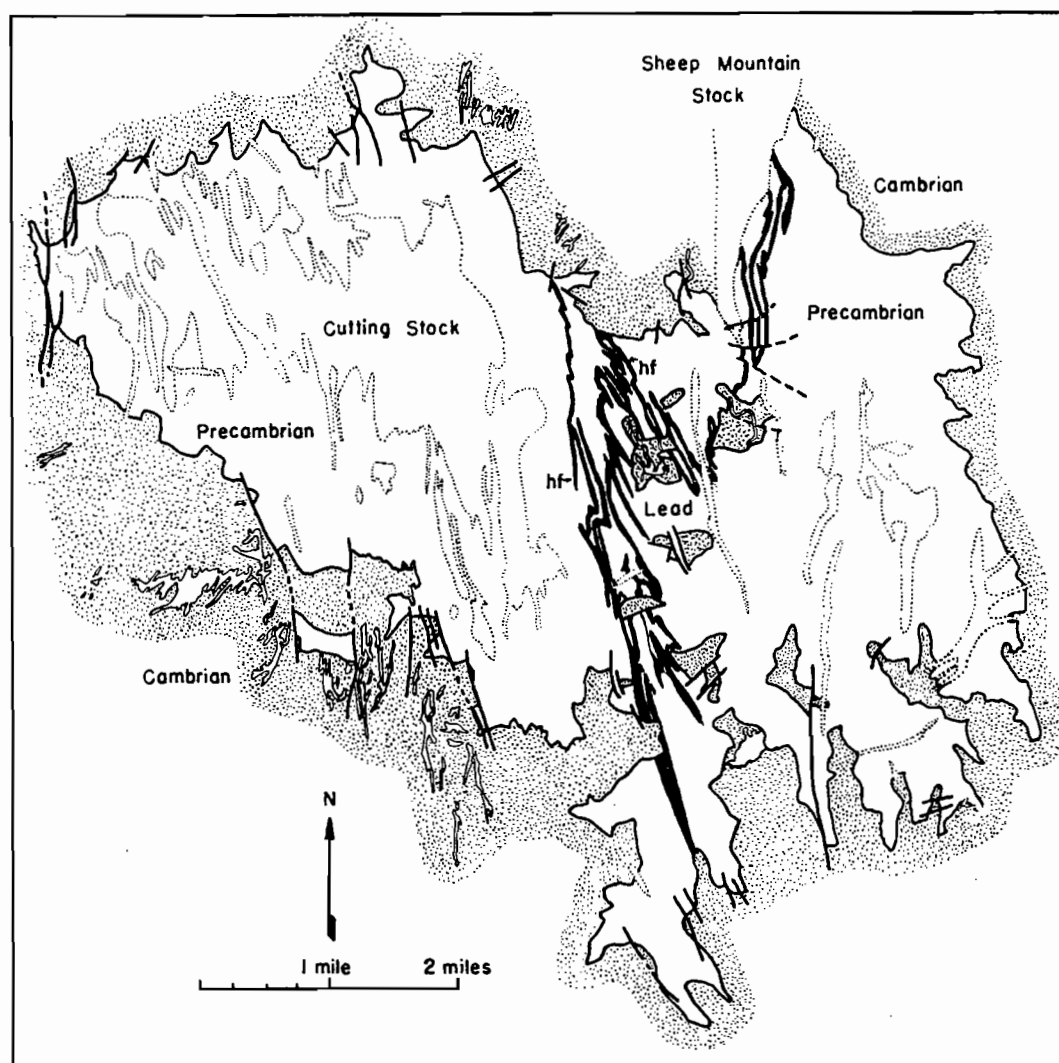


FIGURE 2. Geologic Map of the Lead District. The surrounding Cambrian Deadwood Formation is stippled. Tertiary intrusive rocks are within the dotted outlines. Sills in the Cambrian strata, small dikes, and Tertiary gravel deposits are omitted. The Precambrian Homestake Formation is shown in solid black. The white areas within the stippled areas are mine workings in the Cambrian rocks, both open pit and underground. (Slaughter, 1968).

Noble and Harder (1948) have established the following stratigraphic column for this region:

Tertiary, Quaternary, and Recent gravel deposits (at least 90 ft.)	
----- unconformity -----	
Tertiary intrusive rocks $\sim 60 \times 10^6$ years	
Cambrian Deadwood Formation (300-500 ft.)	
----- unconformity -----	
Precambrian intrusive rocks	} Precambrian Rocks
Precambrian sedimentary rocks -	
Grizzly Formation (3000 ft. or more)	
Flagrock Formation (possibly 5000 ft.)	
----- unconformity -----	
Northwestern Formation (possibly 4000 ft.)	
Ellison Formation (3000-5000 ft.)	
Homestake Formation (200-300 ft.)	
Poorman Formation (possibly more than 2000 ft.)	

A description of the rock units, from oldest to youngest, follows.  
The oldest formation, the Poorman, is mainly a gray phyllite, but  
some parts of it are slaty and schistose. The Homestake Formation is a

sideroplesite-quartz-cummingtonite schist, having a reddish to brownish hue, sometimes green (due to chlorite). Small white quartz veins, and pods and seams of gray to white quartz are common. The Homestake ore bodies occur in this formation. The Ellison Formation is composed of phyllites and schists with large amounts of dark quartzite. The phyllites have a sandy texture. Primary structural features such as bedding, cross-bedding, or other types are not found. The Northwestern Formation is made up of phyllites, schists, and a little slate. Most of this formation is also structureless. The Flagrock Formation is composed of many rock types. The most abundant is a light gray sericitic phyllite or schist. There are also soft sooty black schists or phyllite with pyrite, quartzite, and sideroplesite schist (converted to cummingtonite in some places). A fine grained sericitic gray to dark gray phyllite is the common rock in the Grizzly Formation which also has very few bedding structures.

The Precambrian intrusive rocks are amphibolites, thought to have originally been gabbro. Above the unconformable contact with the Precambrian, the Upper Cambrian Deadwood formation consists of a quartz pebble conglomerate which grades upward into a light brown quartzite, overlain in turn by a brown sandy dolomite with thin partings of green shale. The remainder of the Deadwood formation in the Lead District is thin-bedded green and gray glauconitic shale with some beds of limestone and dolomite and some intraformational limestone conglomerate.

The Tertiary intrusives are of granitic and syenitic composition and are fairly abundant in the Lead district (Figures 2 and 3) (Slaughter, 1968; Nobel and Harder, 1948).

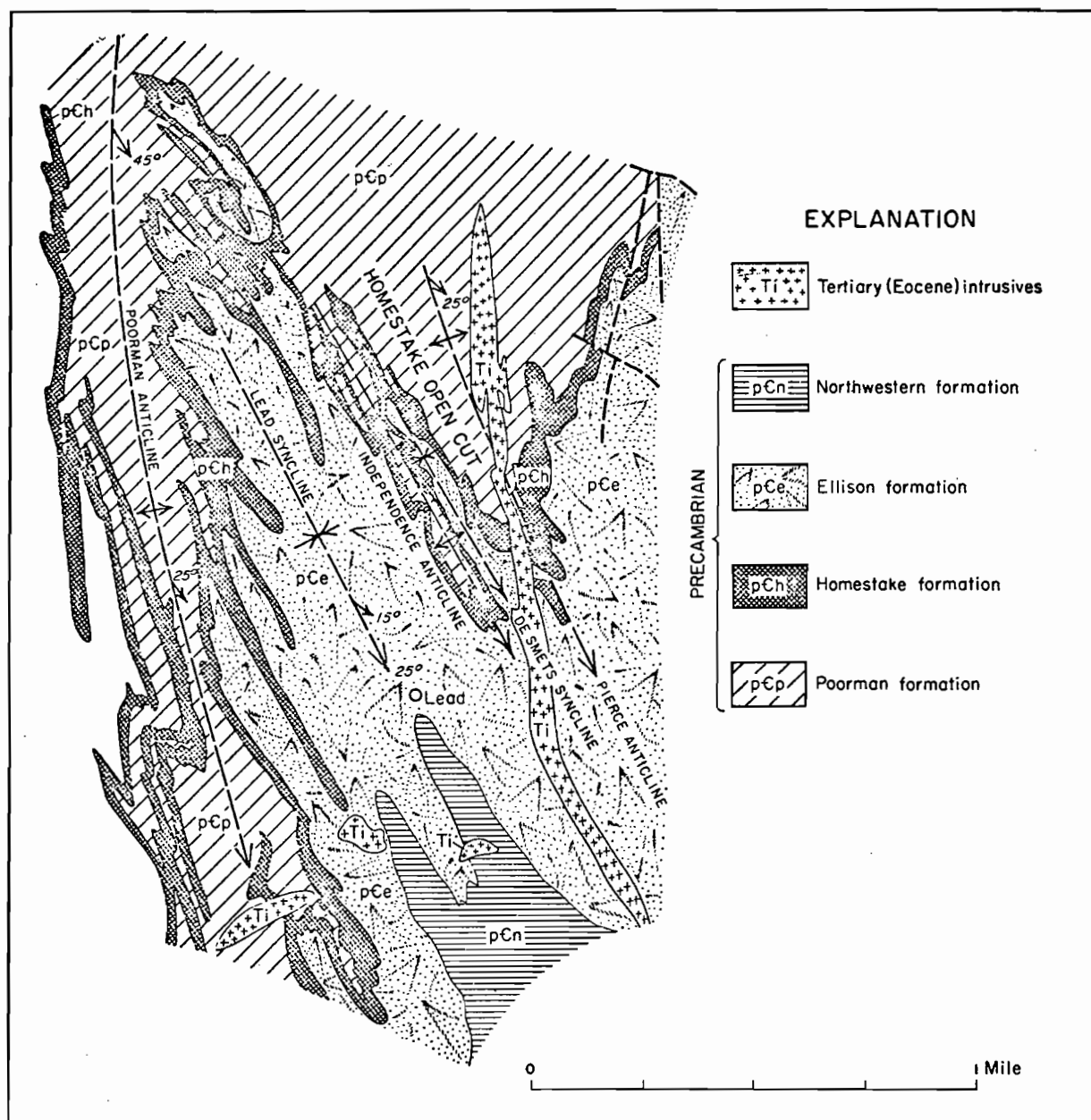


FIGURE 3. Precambrian geology in the vicinity of the Homestake Gold Mine, Black Hills, South Dakota. (Hendrix, 1962, after Noble, 1949).

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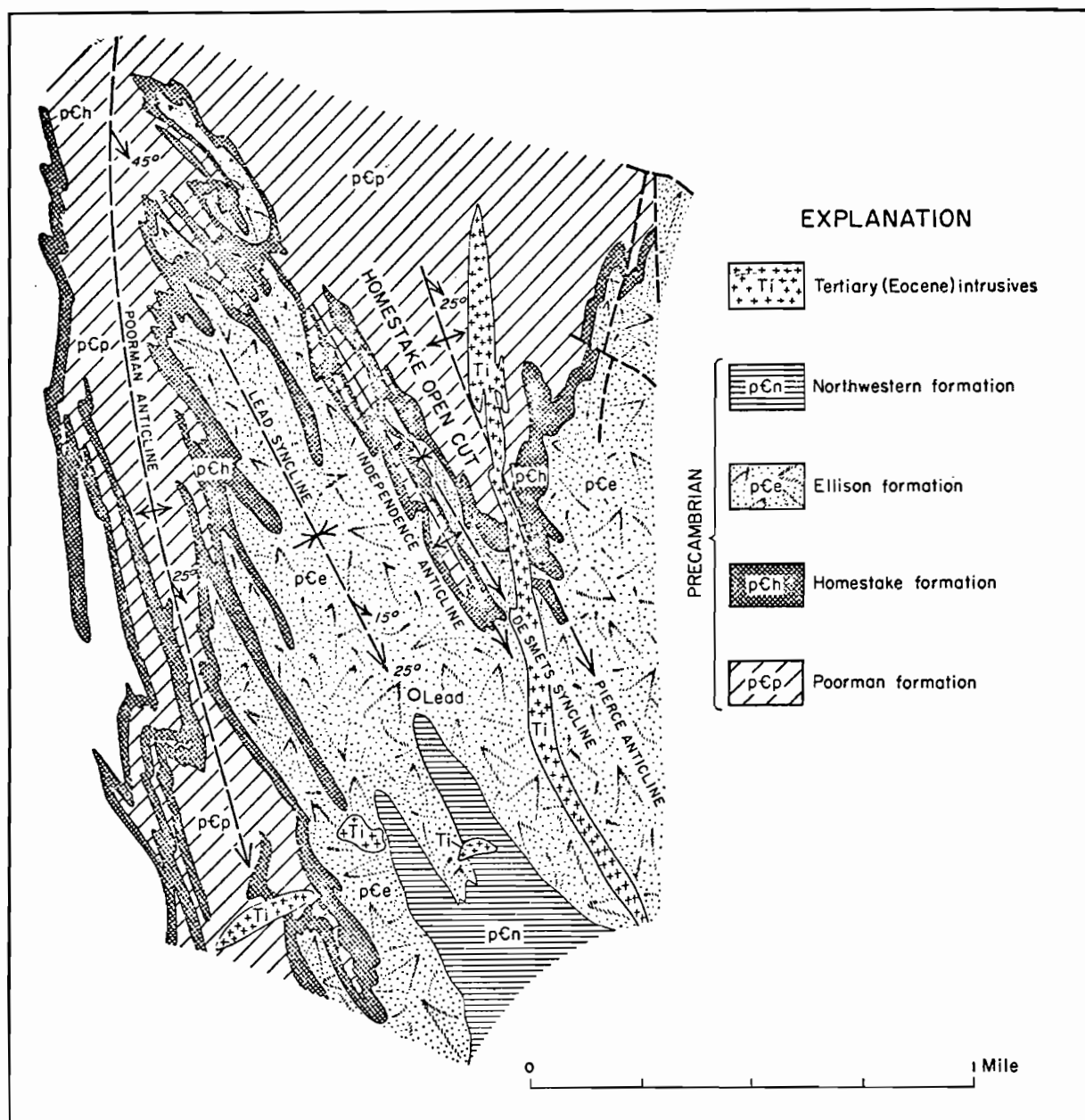


FIGURE 3. Precambrian geology in the vicinity of the Homestake Gold Mine, Black Hills, South Dakota. (Hendrix, 1962, after Noble, 1949).

## METAMORPHISM

The Precambrian rocks in the Lead district have been progressively regionally metamorphosed. The degree of metamorphism increases from southwest to northeast across the district (Figure 4), from a biotite zone representing low to medium grade, to a garnet zone of middle to high grade, to a high-grade staurolite-kyanite zone.

The ore bodies are found only in the biotite and garnet zones. The carbonate, sideroplesite of the Homestake formation, is altered to cummingtonite (amphibole) on the garnet isograd. The cummingtonite isograd determined by Nobel and Harder (1948) is very close to the garnet isograd. There is also some evidence for retrogressive metamorphism, as shown by the alteration of garnet to quartz-sericite and iron oxide, and of biotite to sericite (Noble and Harder, 1948; Slaughter, 1968).

## REGIONAL STRUCTURE

The Lead District is located in one of the roughly east-west oriented domes of the northern Black Hills, whose dimensions are 10 x 12 miles. In the center of the dome is the Cutting stock, a Tertiary granite porphyry, which intruded the Precambrian and Paleozoic rocks. The Deadwood Formation and other Paleozoic rocks have been domed and faulted by the Tertiary porphyry intrusions. Dikes of the porphyry intruded along many of the faults. The Precambrian rocks are not strongly faulted; the other deformations present are most likely due to the Tertiary intrusions (Noble, Harder and Slaughter, 1949; Slaughter, 1968).

The primary Precambrian rock structure in the Lead district (shown in Figure 3) is dominated by the Poorman anticline and the Lead syncline. The axial plane of the Poorman strikes a little west of north, dips east, and



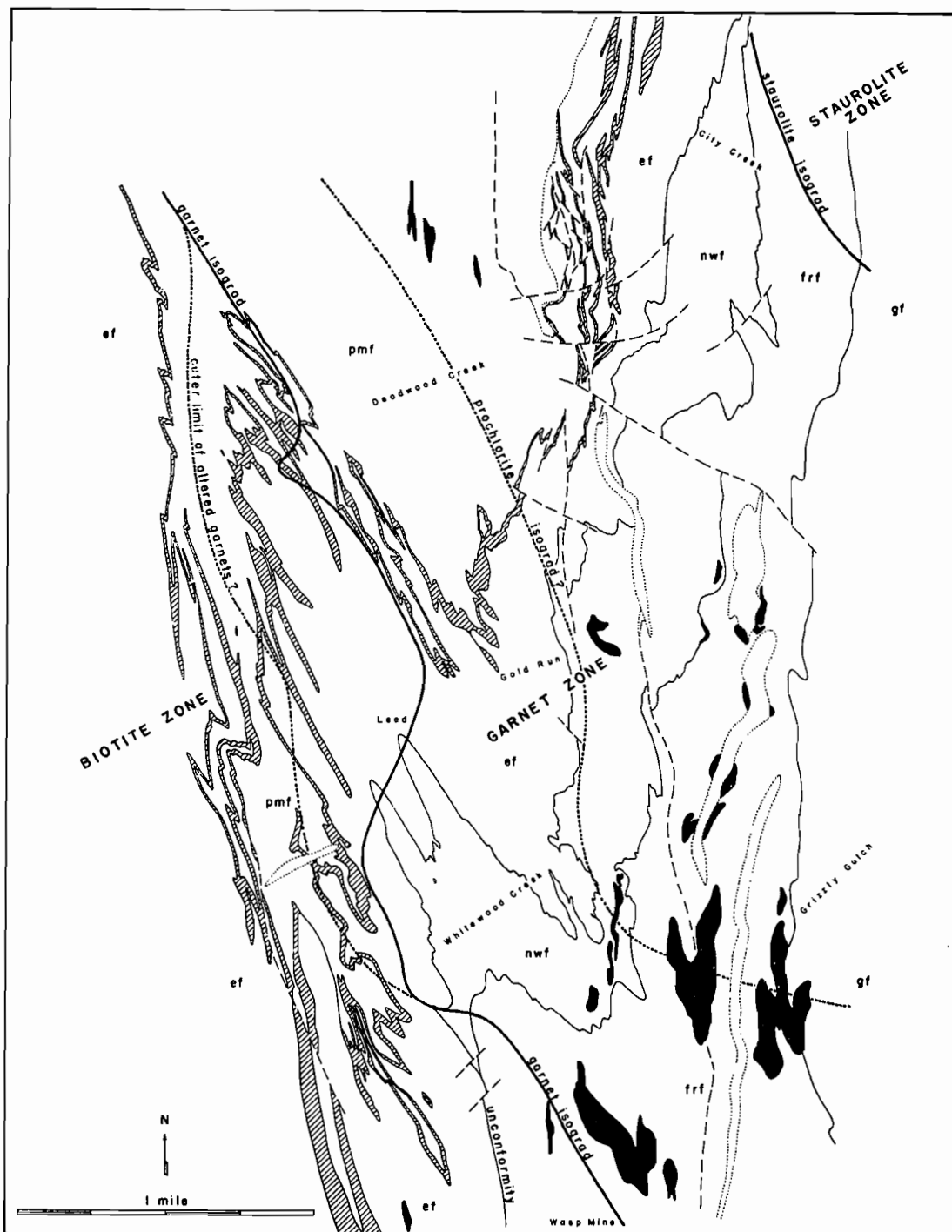


FIGURE 4. Distribution of the pre-Cambrian sedimentary rocks and the metamorphic zones in those rocks in the Lead district. Large amphibolites are in solid black. Faults are shown by dashed lines. Poorman formation, pmf; Ellison formation, ef; Northwestern formation, nwf; Flag Rock formation, frf; Grizzly formation, gf; Homestake formation, cross hatched. (Noble, 1948). (Reprinted with permission of the Geological Society of America.)

plunges 25°SE. The limb between the Poorman anticline and the structure to the east, the Lead syncline, contains many very narrow smaller anticlines and synclines. To the east of the above structures are the tight isoclinal folds of the Independence anticline, the De Smet syncline, the Pierce anticline, and the Caledonia syncline. All axial planes and fold limbs dip about 65°-70°E and the folds plunge southeast. The overall structural relationships of the region are those of minor folds related to the dominant Poorman anticline. Two features are not in accord with this relationship. The first is that axial planes west of the Pierce anticline strike northwest but axial planes east of this anticline strike north or northeast. The second feature is the crossfolding of the isoclinal axial planes (Figure 3). This crossfolding, like the isoclinal folding, was produced by slipping along shear planes. These folding types cannot always be distinguished from each other. The crossfolding may have been caused by the Tertiary intrusion (Figure 3).

#### FAULTING

Major faulting is not common in the area of the Homestake mine, but one fault near the eastern edge of the district has been traced throughout the full length of the area. It strikes a little west of north and dips steeply. Small faults have been mapped at many places in the mine. They also have a strike similar to the fault mentioned above and may dip steeply east or west.

#### CLEAVAGE

In most of the isoclinally folded areas, cleavage and bedding are straight and very parallel. However, four general types of relations between

cleavage, bedding, and shear planes are found: (1) on the limbs of isoclinal folds cleavage and bedding are parallel, (2) in other isoclinal folds a second cleavage set is inclined to the first set and the bedding, (3) isoclinal folds with cleavage and/or shear planes cutting the bedding (the intersection angles may range from a few degrees to  $90^\circ$  on the crest of the folds), and (4) some isoclinal folds have cleavage which intersects the bedding and shear planes, intersecting both of the other structural features (Slaughter, 1968; Noble, Harder and Slaughter, 1949).

#### MINE GEOLOGY

The ore bodies, confined primarily to the Homestake formation, are selective Precambrian and/or Tertiary age replacements of the sideroplesite cumingtonite schist. The ore is localized in certain parts of the Homestake formation by zones of relatively high permeability thought to be caused by cross folding. Nobel and others (1949) recognized six ore-bearing structures ("ledges"); in order of importance, they are: Main Ledge (Pierce anticline), 9 Ledge (Lead syncline), Caledonia, now worked out (Caledonia syncline), 7 Ledge (Lead syncline), 11 Ledge (Lead syncline), and 5 Ledge (De Smet syncline) (Figure 5). More recent reports indicate that eight ledges have been, or are, under production. The synclines and anticlines containing the ore bodies are tight isoclinal folds dipping steeply east and plunging southwest. They probably developed by shear folding with the possibility that earlier transverse compression bending may have also contributed. Small faults have been mapped at many places in the mine. They strike a little west of north and dip steeply east or west. The six irregular pipelike, podlike, and lenselike ore bodies are localized in areas of a second stage of crossfolding, superimposed on the original isoclinal folds. The axial planes of the isoclinal and crossfolds

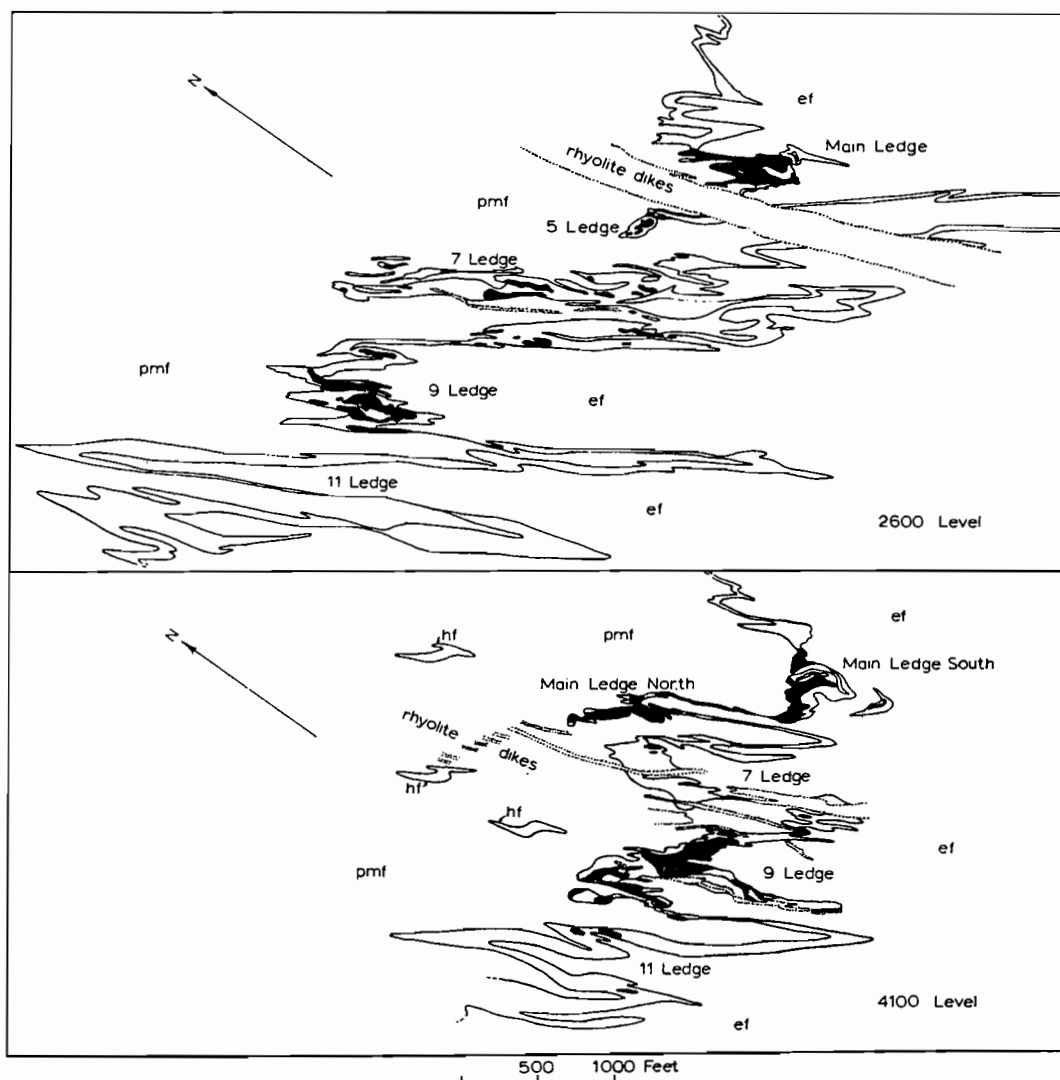


FIGURE 5. Relation of Ore Bodies to Structure. The outline of the Homestake Formation is shown on 2600 and 4100 levels. The changing relationship of the ore-bearing structures to each other brings about a marked shortening of total strike length of the whole group of folds. Ore is solid black, dikes are dotted. Poorman Formation, pmf; Ellison Formation, ef. (Slaughter, 1968)

intersect at angles of 20°-30° and less in some cases. The ore bodies occur at the intersections of shear planes of the second stage folding with either limbs or axial planes of the isoclinal folds. The 5 Ledge ore body in the De Smet syncline (Figures 6 and 7) best shows this ore localization.

#### MINERALIZATION

The ore bodies are hydrothermal replacements of the cummingtonite or sideroplesite schist to mainly chlorite with many veins and masses of quartz with minor amounts of pyrrhotite, pyrite, and arsenopyrite. The gold is found finely disseminated in the quartz. The age of the gold mineralization is still controversial. The usual opinion is that most of the gold mineralization is of Precambrian age with minor amounts introduced in the Tertiary (Slaughter, 1968; Noble, 1950).

#### MINE FACILITIES

The Homestake gold mine (illustrated schematically in Figure 8) is a multilevel mine with a volume of 44,200,000 cubic feet (E/MJ, 1976; Cobbs, 1976). There are two main shafts, the Yates and Ross Shafts, which reach 5000 feet underground. There are four winzes, No. 3, from the 4100 to the 5000 foot level; No. 4, from the 4850 to the 6800 foot level; No. 6, from the 4550 to the 8000 foot level; and the No. 7 winze, from the 6800 to the 8000 foot level. All ore and waste rock is brought to the surface by the shafts and winzes. (About 1000 mine employees are raised and lowered each day.) There are also four ventilation shafts.

Mining operations are conducted on 34 levels from 1700 to 8000 feet. Levels above 1100 feet (mostly worked out) are spaced 100 feet apart. Below this level, they are spaced at 150 foot intervals. There are now over 200

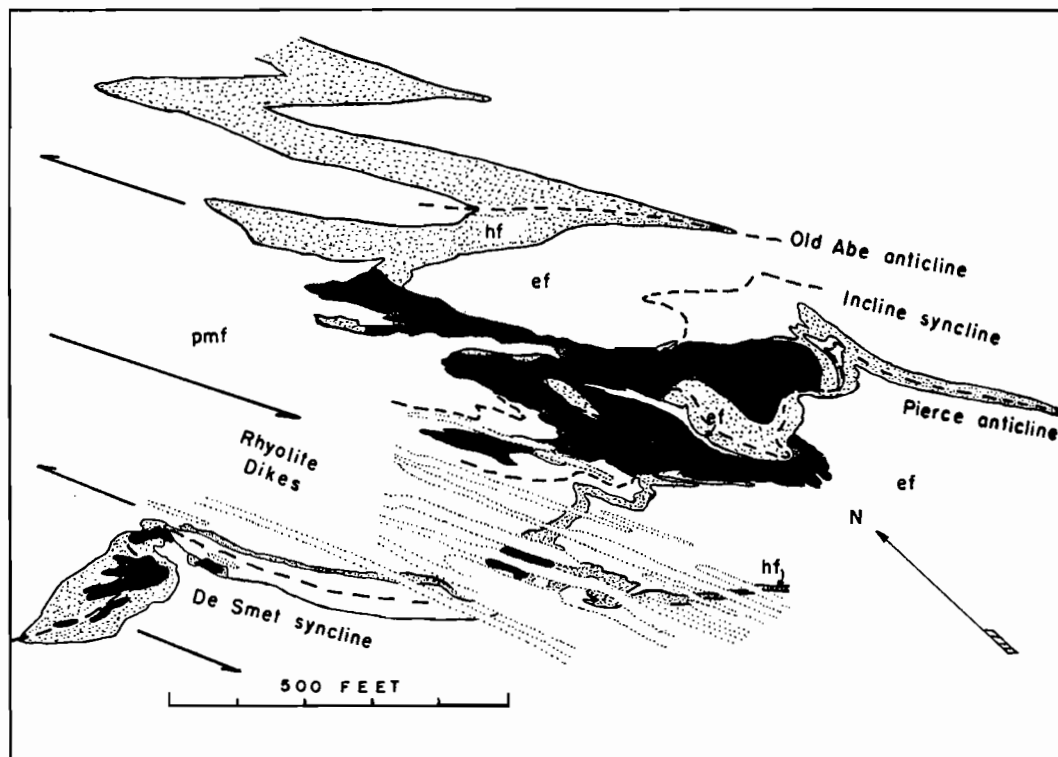


FIGURE 6. Cross-Folded Structures, 2600 Level. Ore-bearing parts of the Homestake Formation are solid black; non-ore-bearing parts are stippled. Poorman Formation pmf; Ellison Formation, ef. Dikes are dotted. Traces of axial planes of the folds are shown by dashed lines. Relative directions of displacements in the cross-folded zones are shown by arrows. (Slaughter, 1968)

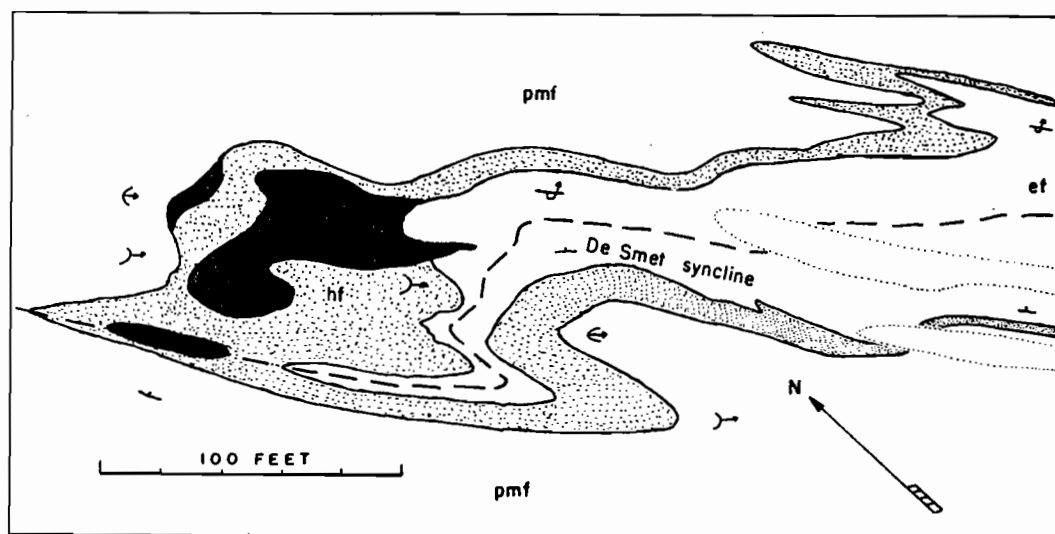


FIGURE 7. Cross-Folded Syncline, 2300 Level. Ore-bearing parts of Homestake Formation are solid black; non-ore-bearing parts are stippled. Poorman Formation, pmf; Ellison Formation, ef. Trace of axial plane of syncline is shown by dashed lines. Tertiary dikes are dotted. (Slaughter, 1968)

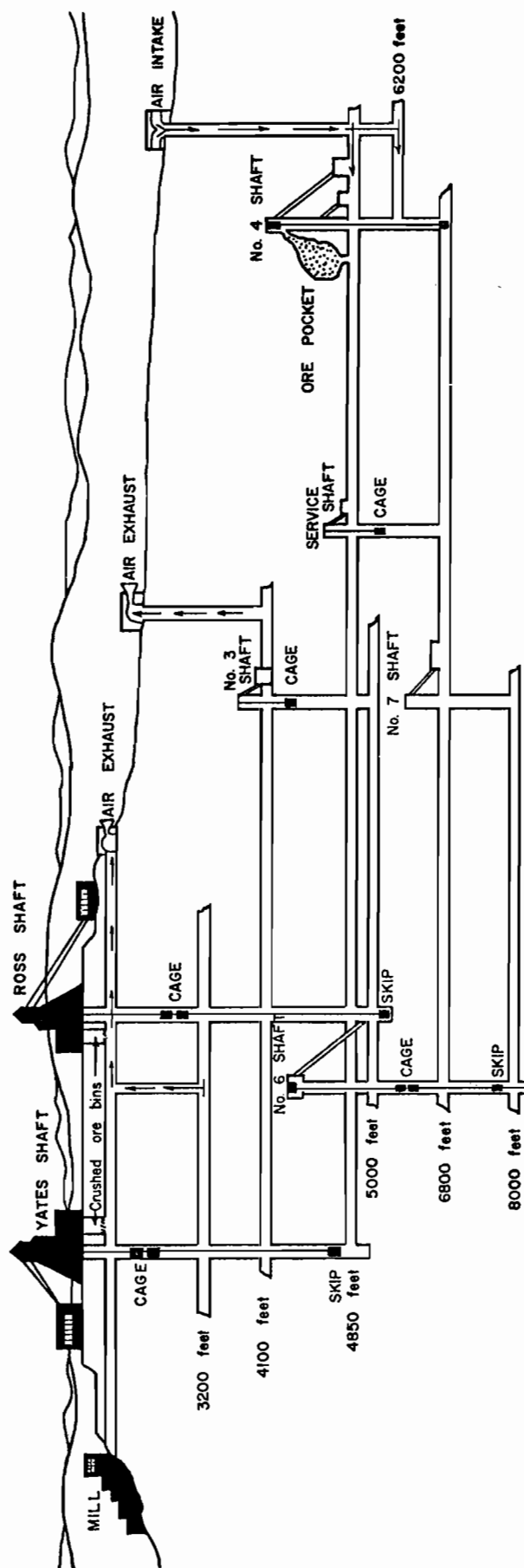


FIGURE 8. Idealized Section of Homestake Mine (Homestake Mining Company, 1976)



miles of workings on all the levels (Figure 8). Drifts and crosscuts are 7' x 7' in the upper mine levels and 7.5' x 7.5' in the lower levels. The mining of the ore bodies is mostly by horizontal cut and fill stoping, since the rock is in most cases very competent (Figure 9). Timbered cut and fill stoping, shrinkage stoping, and blast hole stoping are also used. The mined-out stopes are back filled with 'sand' from mill tailings (Homestake Centennial, 1976; Homestake Annual Report, 1977). Removal of ore is done by the use of air rock drills (Jumbos), blasting, slushers, etc. The ore is then dumped into waiting ore cars. The mine has two rail haulage systems, an 18 inch track gauge for upper levels and a 30 inch track gauge for lower levels. Electric and compressed air locomotives are used to transport the ore to the shaft ore bins. The ore is then loaded into ore skips of 9-10 ton capacity and transported to the surface by high speed hoists. There are presently 250 miles of open drift, more than 125 miles of rail and 100-120 stopes in various stages of development.

In some mine areas, rock stability problems have resulted in the use of patterned rock bolting, e.g. the 19 Ledge area. The system is a 5 x 5 foot pattern of 5 foot rock bolts overlapped by 5 x 5 foot pattern of 8 foot bolts. The reasons for the rock stability problems are: (1) some rock is less metamorphosed, and (2) the ore bodies do not have a straight but an undulating plunge which results in fractures at right angles to the ore plunge. When horizontal openings are cut in ore which plunges 30°-40°, the fractures tend to knit together, but when the plunges reach 85°, the rock is much less stable. Rock stability decreases with depth, requiring more rock bolting, chain link fencing, steel mats, and timbering to support this pressure (Homestake Centennial, 1976; Homestake Mining Annual Report, 1977).

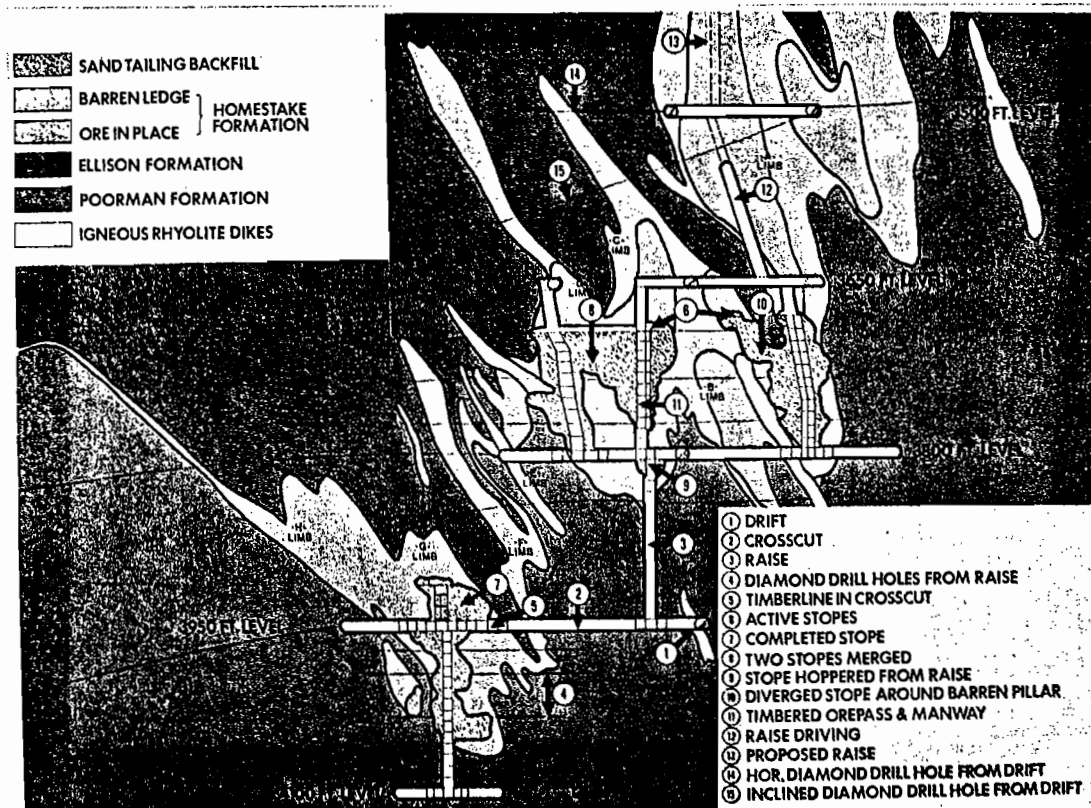


FIGURE 9. Cross section of 9-Ledge structure, showing Open Cut-and-Fill Stopping. (Homestake Mining Company, 1976)

## MINE VENTILATION

Rock surface temperatures at deeper levels reach more than 130°F, accompanied by mine air of high humidity. Ventilation is accomplished by the shafts mentioned above and the use of large ventilation fans, vent tubes, and portable 30 and 60 ton air refrigeration units. As of 1976, 800,000 to 900,000 cubic feet of air was removed per minute. A new water chilling ventilation system (water at 42°-45°F) is now being tested for use at the deeper mine levels.

## EXPLORATION AND DEVELOPMENT

CRIB 1974 reports that in 1973, 22,634 feet of drifting and 8150 feet of raising were completed. E/MJ, May 1976, states that drifting was to be accelerated to 67,000 feet per year, and that in 1975 the following improvements were made at the 5900 and 6800 foot levels: track drifting, 2000 feet; diamond drilling, 6500 feet; conventional raising, 318 feet; and borehole raising, 554 feet.

In 1977, mining continued in the Main, 7, 9, 11, 12, 13, 19, and 21 Ledges between the 1700 and 6800 foot levels. There were 107 active stopes at the year end. New ore was found in the upper levels of 9 Ledge and in the 12, 19, and 21 Ledges between the 5600 and 7100 foot levels. Drifting was completed between No. 6 and No. 7 shafts on the 7100 foot level. The amount of diamond drilling for the year was 72,000 feet. Drifting was being done on the 7400 and 8000 foot levels also, and No. 7 shaft was being extended from the 7100 to the 8000 foot level (Homestake Mine Annual Report, 1977).

#### ORE RECOVERY AND RESERVES

The Homestake mine has been in continuous operation since 1876. From that time to 1976 the total production was  $1.15 \times 10^8$  tons of ore milled. Present production is ~5200-5500 tons per day.

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THE DUCKTOWN DISTRICT  
(Cities Service Co.)

LOCATION

The Ducktown District (Copper Basin) is located in the extreme southeast corner of Tennessee in Polk County in a topographic basin somewhat greater than 100 square miles. Elevations in the basin range from 1500-1800 feet above sea level with the encircling mountains rising to 4200 feet above sea level. The latter are heavily wooded but the cover in the basin has been almost completely removed in a 36 square mile area.

The mines are located a few miles from the towns of Ducktown and Copperhill at 35°N, 84°20'W (Figure 1). The ore deposits outcrop along resistant ridges striking northeastward and occur as massive tabular sulphide bodies, ranging in size from 250,000 tons to  $20 \times 10^6$  tons (Magee 1968).

REGIONAL GEOLOGY

Lithology

The regional geologic map (Figure 2) and the stratigraphic sequence of the Ducktown District (Table I) are taken from Magee (1968). The Athens shale and Knox Group of Ordovician age occur 15 miles northwest of the district. The Great Smoky fault zone separates them from the underlying early Cambrian Chilhowee Group (sandstone, shale, and conglomerate). The Precambrian Sandsuck formation (quartzites, phyllites, impure limestone, limy shale) of the Walden Creek Group unconformably underlies the Chilhowee Group.

The older Great Smokies Group conformably underlies the Walden Creek Group and is composed of interbedded metagraywackes, conglomerates, mica schists, quartzites, chlorite-garnet schists, and chlorite-garnet-staurolite

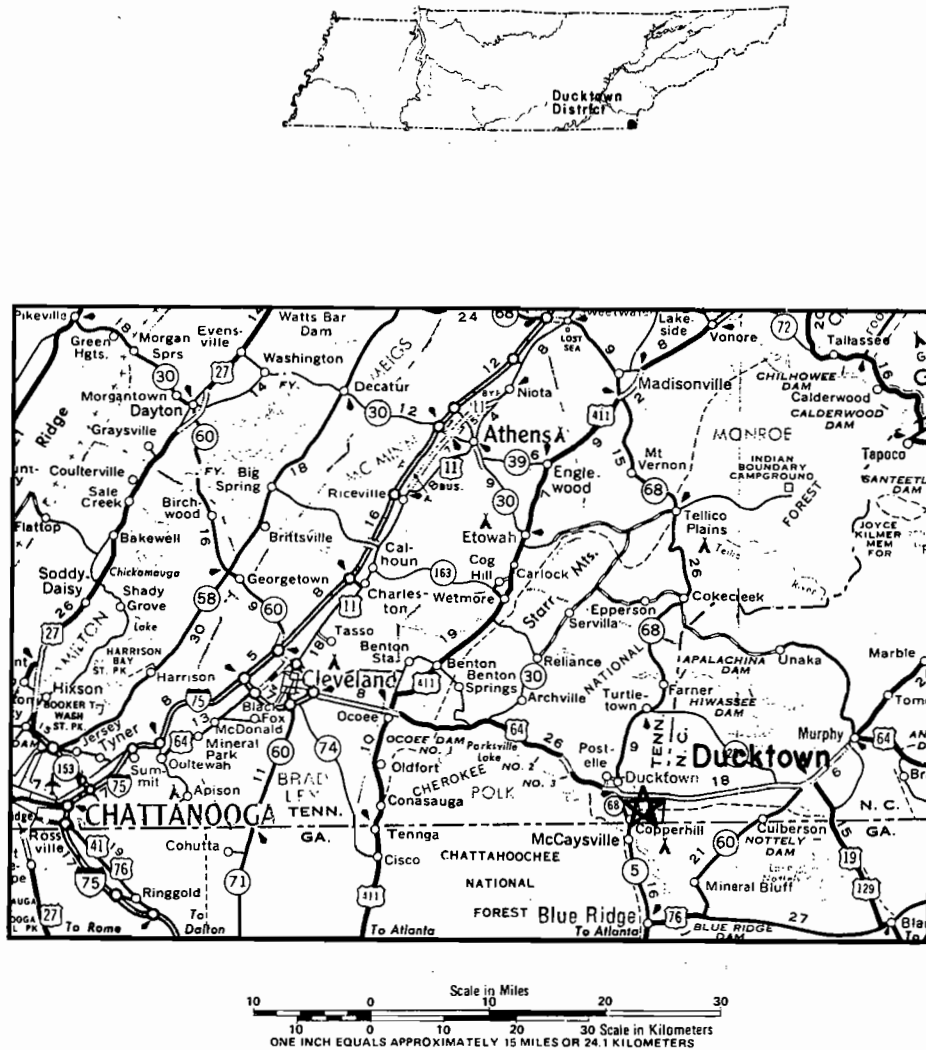


FIGURE 1. Location maps - Ducktown District, Polk County, Tennessee. Lower map, basic map reproduced by permission of the American Automobile Association, copyright owner.

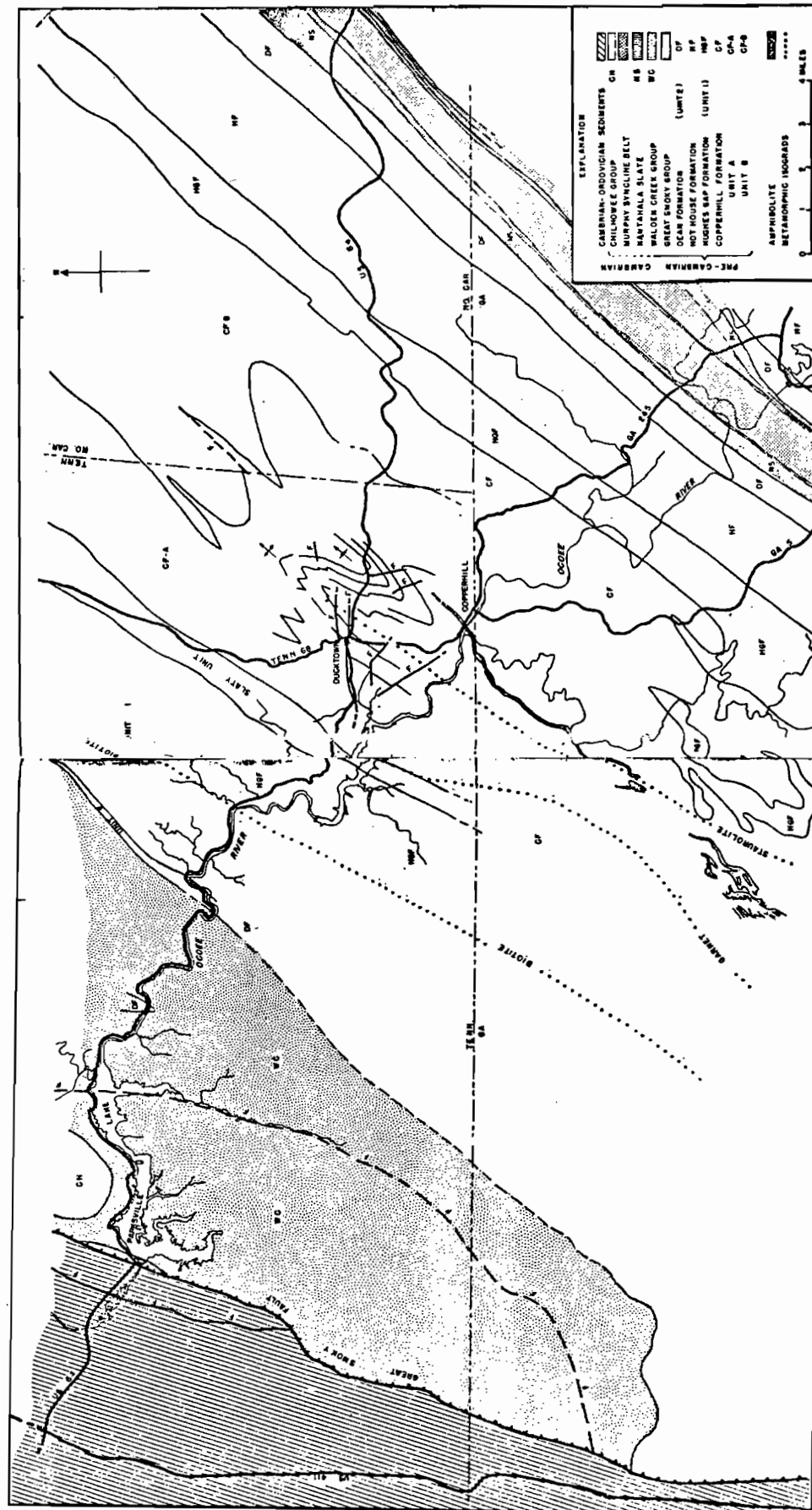


FIGURE 2. Regional Geologic Map of the Ducktown Area, compiled from the Geologic Map of Tennessee, 1966 (25); Tennessee Copper Company map, 1947; Hurst, V.J. (11, 12, 16); Hernon, R.N. (21) (Magee 1968).



Age	Series	Group	Northwest formations	Southeast formations
Ordovician		Chickamauga Knox	Athens Shale Undifferentiated	
Cambrian	}	Chilhowee	Nebo Sandstone Nichols Shale	
				Nottely Quartzite Andrews Schist Murphy Marble Brasstown Tusquitee Quartzite Nantahala Slate
				Murphy Belt
Precambrian	}		Disconformity	Conformable
		Walden Creek	Sandsuck	
		Ocoee	Great Smoky	
			(16) Dean Unit 2 Unit 1	Dean
			Hughes Gap Slaty Unit	Hughes Gap Hot House
			Copperhill Unit B Unit A	Copperhill

Table I. Stratigraphic sequence across the Ducktown Region of the Great Smoky Mountains (Magee 1968).

schists. These formations all lie in the southern portion of the Blue Ridge Province.

The rock types in the district are metamorphosed Precambrian sediments composed of 60 percent graywacke, 30 percent mica schist, and 10 percent metaconglomerate (meta-arkose, quartzite, chlorite-garnet schists, and chlorite-garnet-staurolite schists). Thicknesses of the metagraywackes range from a few feet to greater than 500 feet. Mica schist beds are a few inches to 20 feet thick but sometimes exceed 200 feet.

Metamorphic intensity and structural complexity increase across the Great Smoky Group from west to east.

### Structure

Intense deformation and recrystallization have occurred in the area. There are two major northeast plunging folds - the Burra anticline and the Coleman syncline each of which contain smaller superposed folds. General schistosity and bedding dip from  $45^{\circ}$ - $80^{\circ}$  southwesterly and the general strike is  $N35^{\circ}E$ . Small domes and basins, which may have influenced ore localization, are found in the central anticlinal area. Schists are strongly foliated and crinkled. The angle between schistosity and bedding is  $0-15^{\circ}$  but may be greater in fold noses. The metamorphism ranges from the chlorite to kyanite grades, i.e., between low to high grade metamorphism; retrogressive metamorphism is also evident in the country-rock and ore. There are three major fault systems in the area. They strike N.E., N.W., and E.-W.

### ORE DEPOSIT GEOLOGY

Ore bodies are usually of tabular shape, conforming to the regional strike and dip of the bedding. They plunge southwest in contrast to the

northwest plunge of the major anticlinal bodies. The three regional fault systems are evident in the ore bodies along with fracturing and smaller faults; crossfaulting is evident associated with the smaller ore bodies. Most ore levels and tabular bodies have a sharply-defined footwall, usually of unaltered graywacke. The hanging wall is usually schistose rock, which may be somewhat incompetent (Figures 3 & 4). Two modes of ore emplacement have been proposed: (1) hydrothermal replacement of limestone lenses (Emmons and Laney, 1926), and (2) hydrothermal replacement of favorable zones in lime-bearing schistose layers and shear breccia (Magee 1968). The latter view is presently favored.

#### HYDROLOGY

Nothing definite has been found in the literature with respect to water tables or percolation in the area. However, reports from Acres (1975) and Thomas Lomenick (personal communication) indicate that there is considerable water inflow in the mines since continuous pumping is necessary when operating.

#### MINE FACILITIES

The presently operating workings are owned and operated by Cities Service Company (110 West 7th Street, Tulsa, Oklahoma). The mine and plant at Copperhill, Polk County, Tennessee employ 2,150 men.

Underground mining is by long hole blasting. Present production is 53 tons of copper metal/day (World Mines Register 1979-80). As of 1978, there were five shafts; mining is by open stoping, haulage is by rail (International Directory of Mining and Mineral Processing Operations, 1978). The Minerals Yearbook of Tennessee (1975) states that Cu metal production was

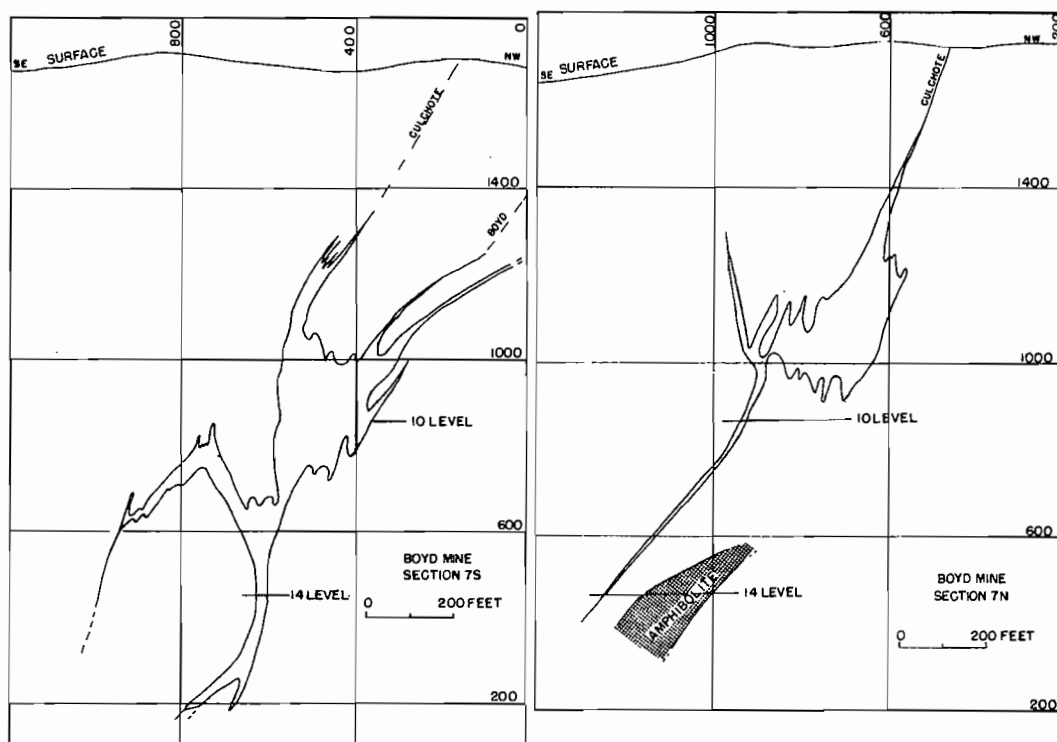
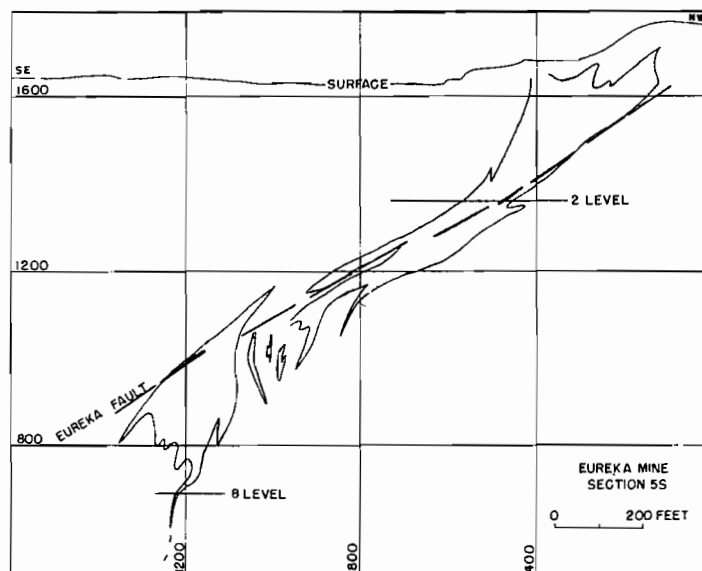


FIGURE 3. Cross sections of the Boyd and Eureka ore deposits. The drag fold pattern of the Boyd ore body is evident (Magee, 1968).

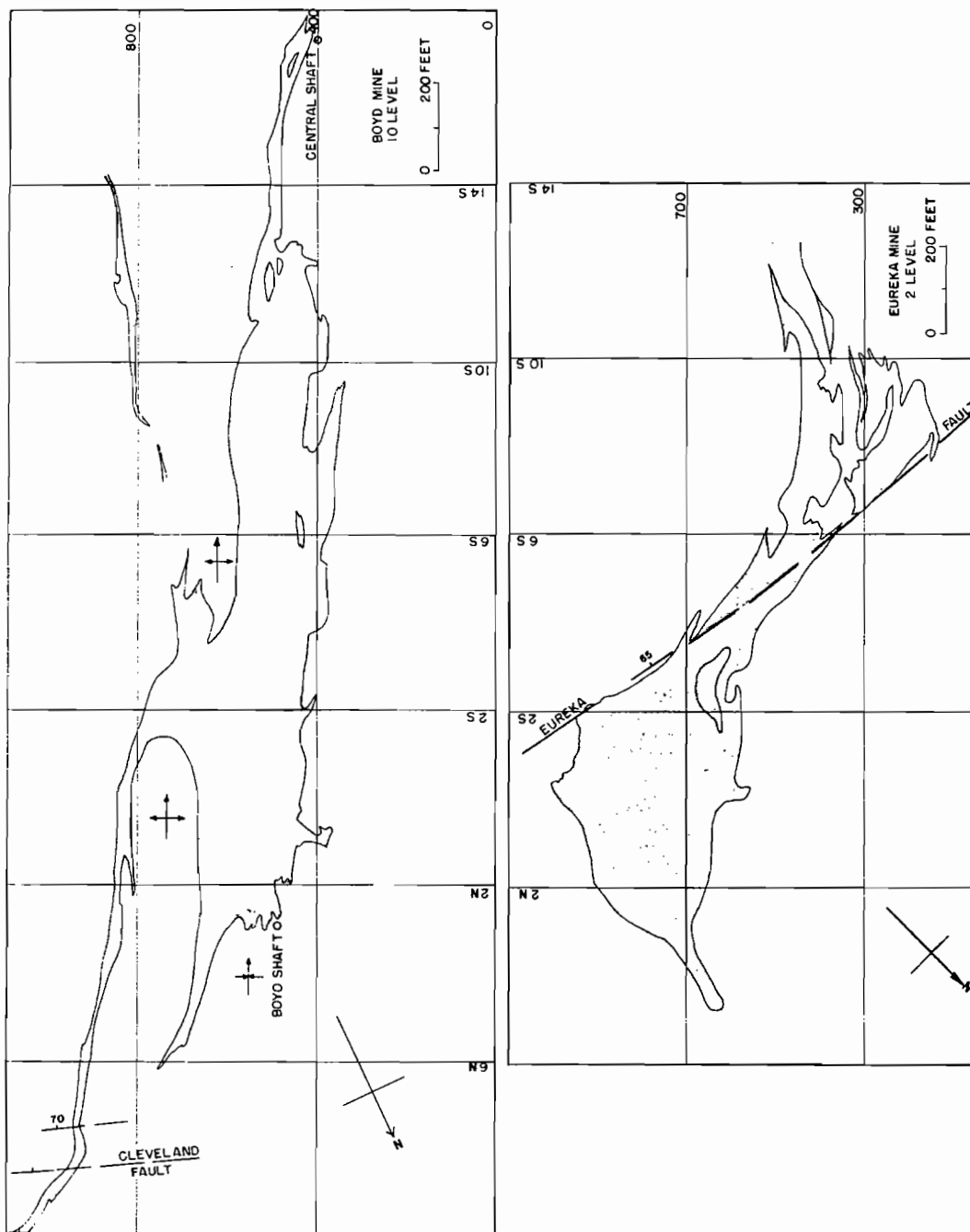


FIGURE 4. Horizontal plan views of the Boyd and Eureka ore deposits (Magee, 1968). (Reprinted with permission of AIME, New York.)

then at a rate of 10,041 lbs./year and that the company's Copperhill operations included four mines (Boyd, Calloway, Cherokee, and Eureka Mines) at depths of 1000-3000 feet underground.

In 1965 five mines were operating with some operations at 2400 feet depths (Lloyd, 1965).

At present, it is not possible to determine from the literature the abundance or extent of underground workings in the schistose rock at Ducktown. For that reason the district is considered to be in "class 2" in this report.

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HOLDEN MINE  
(HOWE SOUND COMPANY)

LOCATION AND ACCESSIBILITY

The Holden mine in Chelan County, Washington, is situated at  $48^{\circ}12'N$ ,  $120^{\circ}45'W$ , on the east slope of the Cascade Mountains on Railroad Creek, which flows eastward into Lake Chelan (Figure 1). The mine was Washington's largest producer of copper, gold, and zinc from 1938-1958. Silver, molybdenum, and other metals have also been mined. The ground facilities are now owned and operated by the Lutheran Church as a camp and retreat center. The mine was owned by Howe Sound Co. and is presently owned by the Lutheran Church.

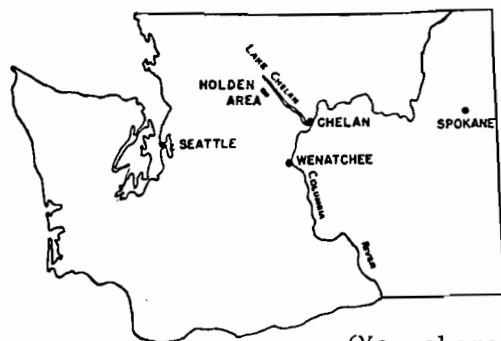
The Holden mine is located at 3435 ft. elevation, in a rugged mountainous region with relief of 6000 ft. or more between valley floors and ridge tops. All of the valleys show evidence of glaciation. The mine is reached by a 40 mile boat or airplane trip from Chelan to Lucerne, a small resort community on the west shore of Lake Chelan, and thence by automobile 11 miles from Lucerne to Holden.

GEOLOGIC SETTING

The geologic description of the region is based principally on work by Youngberg and Wilson (1952), and also on reports by Grant (1969), and Tabor and Crowder (1969). The Holden mine is situated in gneiss, schist, and quartzite of a roof pendant cut by intrusive igneous rocks.

The oldest units whose ages are in the range Precambrian to Early Paleozoic are metasedimentary rocks of the pendant. They were divided by Youngberg and Wilson (1952) into three formations: the Martin Ridge and Buckskin schists, and Fernow gneiss; these are illustrated in Figure 2. The Martin Ridge schist is an argillaceous amphibole schist with alternat-





(Youngberg and Wilson, 1952)

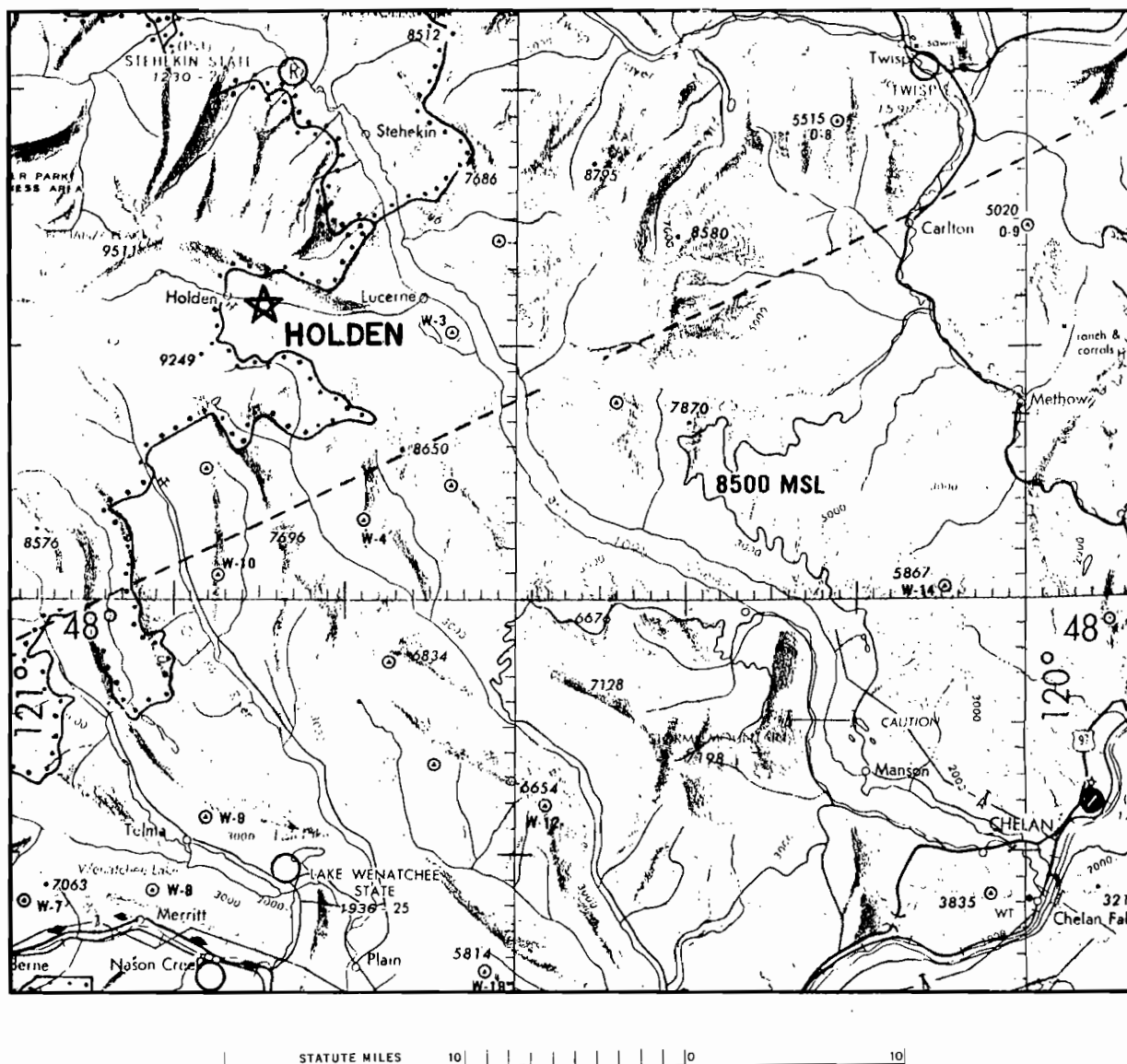


FIGURE 1. Location maps - Holden Mine, Chelan County, Washington.

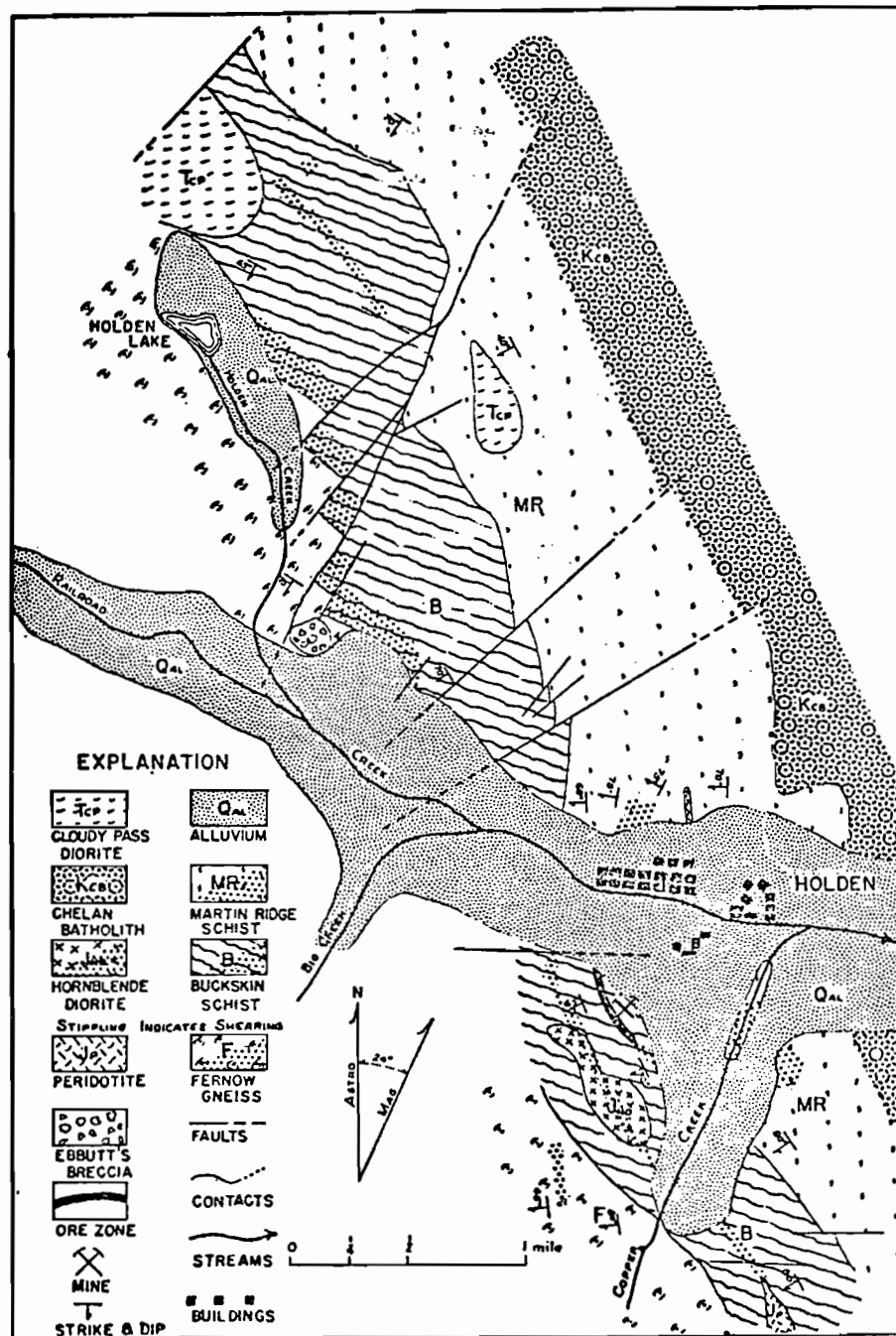


FIGURE 2. Geology of the Holden area (from Youngberg and Wilson, 1952).

ing bands of quartzite which vary in thickness to two inches. A persistent marble bed occurs above the contact of the Buckskin with the Martin Ridge formation. This bed varies in thickness from 2-10 feet. The total thickness of the Martin Ridge schist is about 3300 ft. The Buckskin schist is predominantly quartz-amphibole, but contains two horizons of intermittent marble beds and calcareous schists. In some areas the schist has been altered. The formation has a thickness of 3000 to 3500 feet. The Fernow gneiss has an appearance of granitic gneiss, but is made up of a thick series of quartz-amphibole gneisses. The total thickness of the formation was not reported. Youngberg and Wilson (1952) state,

"The sequence of deposition of the sediments is not clear. It would appear that the gneissic rocks of the Fernow unit are older than the less metamorphosed Buckskin schists and Martin Ridge argillites, which would require the beds to be overturned, as the Fernow gneisses now lie stratigraphically above the Buckskin and Martin Ridge schists."

The igneous rocks of the region are numerous and occur as plutons, dikes, sills, stocks, and extrusives. They vary in age from Jurassic to Pleistocene with three principal episodes during the Cenozoic. The compositional range of the intrusive rocks is broad, including peridotite, diorite, granodiorite, and aplite dikes. The three phases of Cenozoic igneous activity, as described by Tabor and Crowder (1969), are the quartz diorite Cloudy Pass batholith; andesitic to dacitic breccia, tuff, and lava of Gammo Ridge; and in late Pleistocene and Recent time, the growth of the dacitic Glacier Peak volcano, 15 miles southwest of Holden mine.

The peridotites are generally coarse-grained, massive, and hornblende-rich. They occur as dikes and elliptical bodies and cut the mine workings

at several levels. They are Jurassic in age, the oldest intrusives in the mine area.

The quartz-hornblende diorite varies in texture from medium to coarse grained and occurs as a massive body to the south of the mine ore zone. Youngberg and Wilson (1952) report the intrusive and the metamorphics around its periphery show evidence of granitization, biotization and chloritization.

The dioritic rocks, the most common plutonic rocks in the area, were intruded in two phases. The first phase, the Chelan batholith, which is Cretaceous in age, crops out on the surface east of the Holden mine area; a dike of Chelan diorite is exposed in the 1500 and 1600 foot levels of the mine. The second phase, the Cloudy Pass batholith, was emplaced in the Tertiary and is similar in composition to the Chelan batholith. It is exposed west of the mine, and at several levels in the mine, as are Cloudy Pass dioritic dikes.

Aplite and other dikes cut the dioritic rocks at numerous places in the mine. They are fine grained and vary in width from an inch to a yard. Other dikes are granodiorite and quartz diorite in composition and have chilled borders.

#### STRUCTURAL SETTING

The regional structure of the Holden mine and north Cascade area was described by Grant (1969) and Youngberg and Wilson (1952). The structural trend in the Holden mine area, part of the North Cascades, is predominantly northwesterly. The metamorphic rocks form the lower limb of an overturned fold with a northwest trending axis. Several small drag folds are present and some are overturned. The ore deposits are contained in the drag folds and are limited by the extent of folding. The fold axis plunges at about 60° southeast.

The region is transected by both normal and thrust faults. Figure 3 illustrates the broad regional structural trends and major faults. The Swamp Creek thrust fault is located west of the mining area, and the Lake Chelan transverse fault occurs south of the mine. Displacement on some of the normal or steeply dipping faults ranges from 60 to 1500 ft. Shear zones, which are the principal loci of mineralization, formed between the competent and incompetent metasedimentary units.

#### MINE GEOLOGY AND MINERALIZATION

The Holden mine ore deposit is in a roof pendant that has been intensely metamorphosed and overlies batholithic rocks. The pendant is made up of gneiss, schist, and quartzite, and is cut by granitic dikes. The rock is hard and abrasive and the geology complex. The deposits are of hydrothermal origin (Park, 1968) and are associated with the Cloudy Pass dioritic intrusions.

An idealized cross-section of the ore deposits and geology of the mine showing the 1400, 1500, and 1600 foot levels is illustrated in Figure 4. The copper-gold-silver ores are disseminated in the biotite schist and quartzite of the roof pendant. Ore minerals also occur in small quantities in the diorite. There are some masses of sulphide minerals, but, in general, the ore minerals are present as small scattered grains. The molybdenum primarily occurs in well-defined quartz veins cutting granitic rocks. Zinc mineralization is concentrated near the footwall of the ore body. Copper and gold are distributed throughout without any apparent relationship to levels or geologic structure. There has been little or no alteration of the host rocks at their contact with the veins.

The zone of mineralization has an average strike of N30°W with a dip of 60°-70°SW. The ore zone is 40 to 75 ft. wide and has an exposed length of 1400 to 1600 ft.

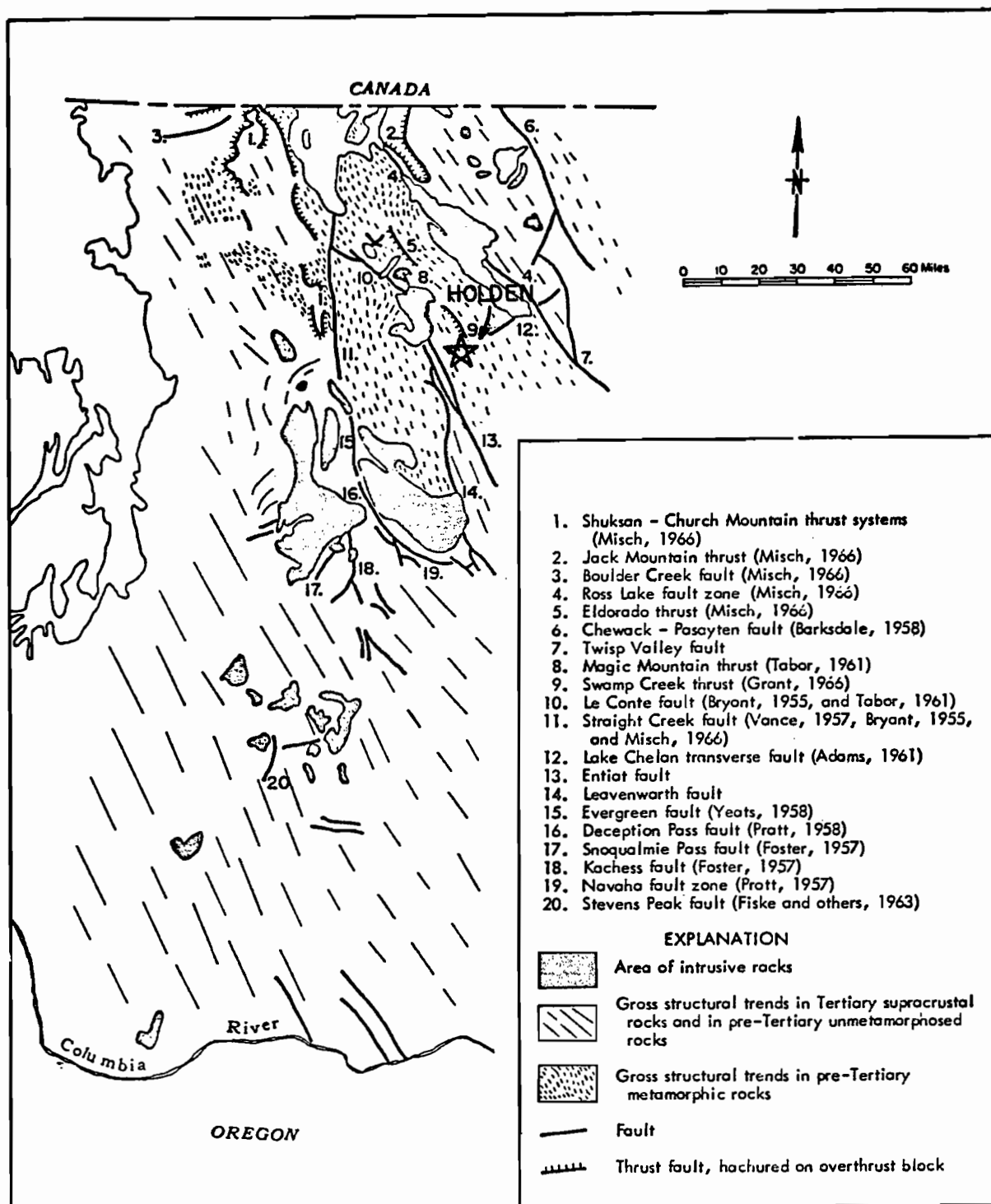


FIGURE 3. Gross structural trends and major faults in the North Cascade Range of Washington (after Grant, 1969).

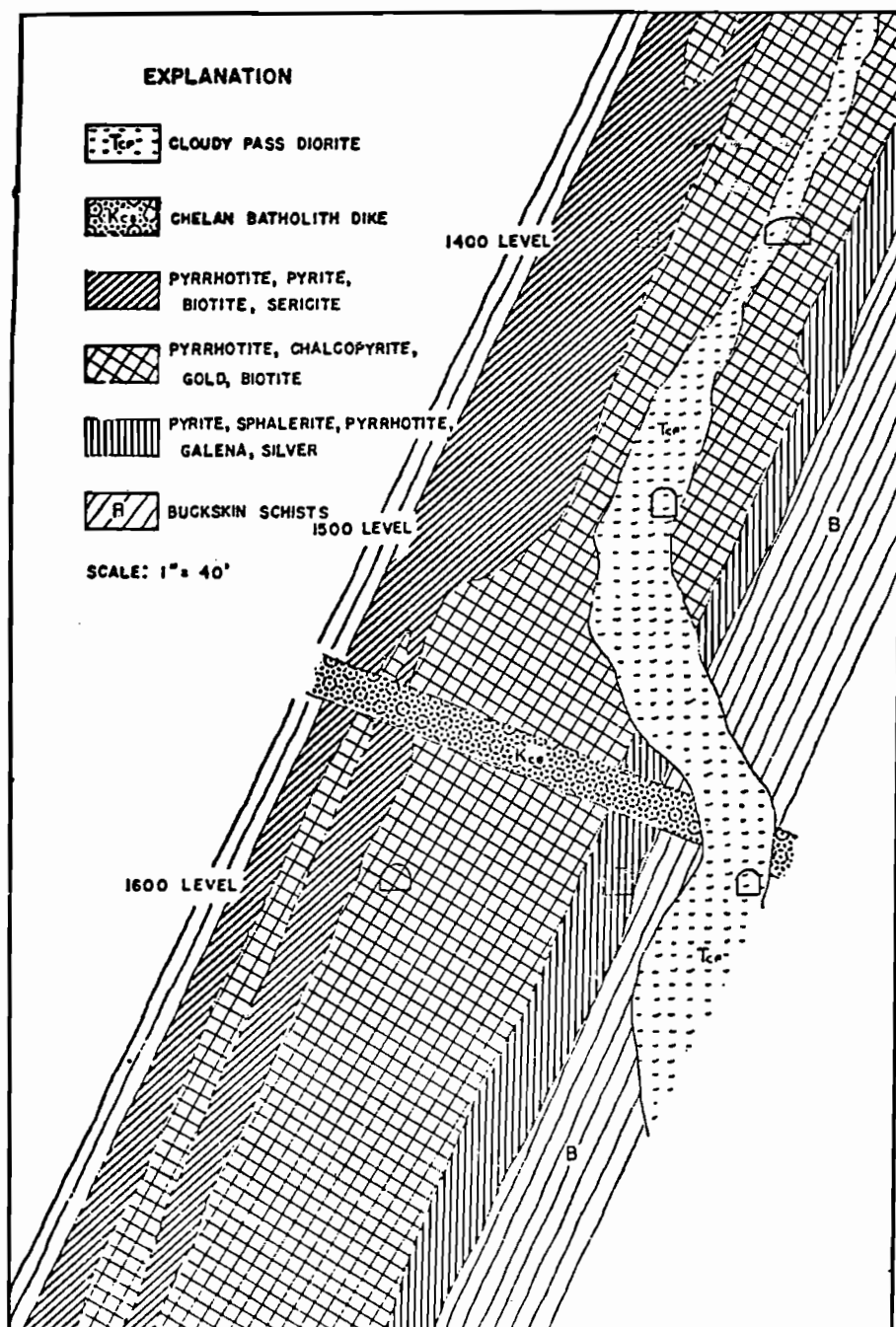


FIGURE 4. Idealized geologic cross section of the Holden ore body, showing ore zoning and its relationship to the wallrocks and intrusions. (After Youngberg and Wilson, 1952.)

## MINE CHARACTERISTICS

The mine is located below the groundwater table; however, several workings are in dry areas. The mine extends to a depth of 5200 ft.

Workings consist of a main adit, two shafts, a ventilation shaft, and over 18,000 ft. of workings at more than sixteen levels. The main adit is on the 1500 foot level, is 10 x 10 ft. in cross-section, and extends 4800 ft. into the mountain (Figure 5). The original mine development included several intermediate levels serviced by the No. 1 shaft, a vertical shaft about 936 ft. deep. These levels were connected by several main ore passes extending above the main haulage level. A second 4-compartment shaft, sunk in 1941-44, has a cross-section of 12 1/2 x 19 ft. The hoistroom for the No. 2 shaft is in good rock and has dimensions of 100 x 50 x 40 ft. The No. 2 shaft was driven as a raise full size for 170 ft. above the main haulage level. Below this level, a series of pilot raises were driven, connecting the 1500, 1600, 1775, and 1950 foot levels and the shaft was sunk to the 2800 foot level. There is a ventilation tunnel that extends westward from the No. 2 shaft for about 5000 ft. This tunnel is about 8 x 10 ft. in section and portals to the surface. There are at least 247,566 ft. of drifts, cross-cuts, and raises, and 231,922 ft. of diamond drill holes (Huntting, 1956). The mine has been closed since 1958; however, recent exploration work, in mid-1960's and mid- to late- 1970's, indicates that many levels are accessible and dry. Levels below 1400-1500 ft. are flooded.

## MINE FACILITIES

According to V.C. Stephens, consultant to Terra Tek, who managed the mine in the 1950's, the Holden Campsite is a beautiful camp consisting of sixteen large houses, six bunkhouses, hospital, large cookhouse and dining



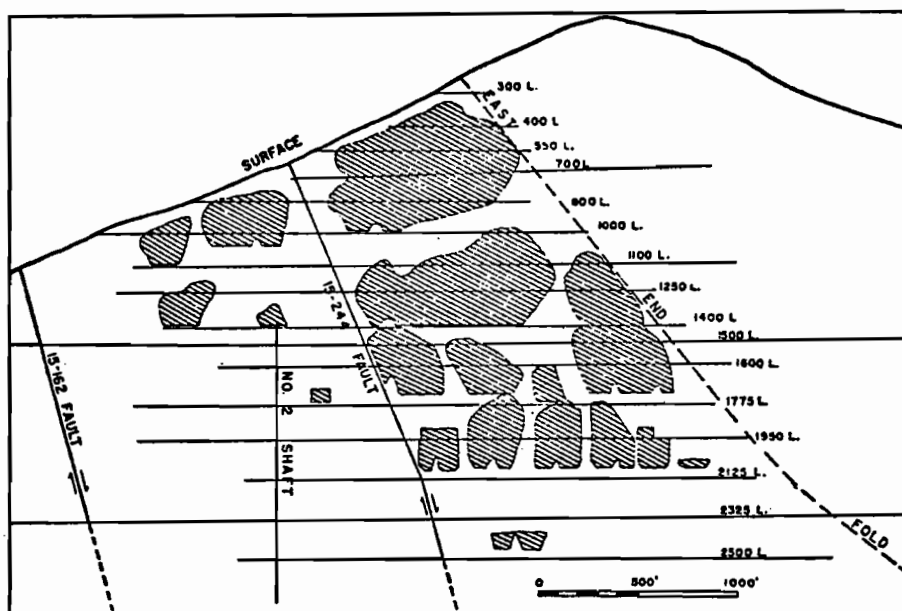


FIGURE 5. Geologic structure of a west-east section of the Holden Mine, showing mineralization, mine levels, and No. 2 shaft. (After Youngberg and Wilson, 1952.)

facilities, and a large recreation hall. The campsite is owned and operated by the Lutheran Church. Dock, tug, barges, and all necessary facilities are available on Lake Chelan, both at the town of Chelan and the village of Lucerne, Washington.

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## SUNRISE MINE

(OPERATED BY COLORADO FUEL AND IRON CORPORATION)

## LOCATION

The Sunrise mine is located in the Hartville-Sunrise district of Platte County, Wyoming, (Figure 1) approximately 7 miles north of Guernsey and 100 miles northeast of Cheyenne at 42°20'N, 104°42'W. The surface elevation is about 4870 feet, with several hundred feet of local relief.

## GEOLOGIC SETTING

Regional

The data describing the regional geologic setting were extracted from Carter (1963), Harrer (1977), and EMJ (1974).

The Precambrian rocks in the region, exposed in the Hartville uplift (oldest to youngest), are represented by the Whalen Group, which consists of the following sequence: Frederick schist, minimum thickness about 3000 feet; a massive blocky to schistose dark-green rock composed of quartz, chlorite, biotite, epidote, hornblende, and plagioclase, possibly an altered pyroclastic or series of lava flows; Whalen dolomite, thickness 400 to 2000 feet; a white to pink dolomite marble, cherty in places, with minor bands of quartzite and schist; Good Fortune schist, 500 to 1000 feet thick; a white to dark-gray quartz-sericite schist, often highly graphitic and pyritic; and the "Upper Blocky" schist, up to 100 feet thick, a dark-greenish blocky quartz-biotite-chlorite schist. The entire Whalen Group has been isoclinally folded and regionally metamorphosed to approximately the greenschist facies.

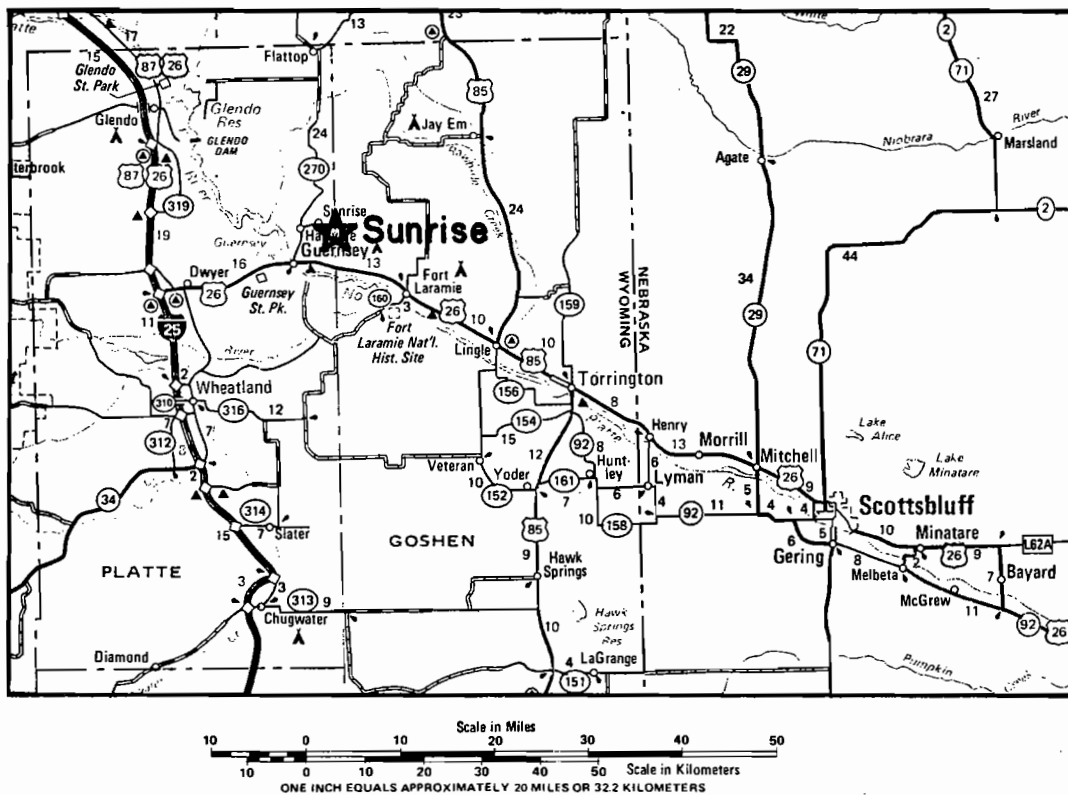


FIGURE 1. Location map of the Sunrise Mine, Platte County, Wyoming. Basic map reproduced by permission of the American Automobile Association, copyright owner.

Limestone and quartzite of the Carboniferous Guernsey and Hartville Formations cap the higher hills and mesas. Sandstone of the Miocene Arikaree Formations is present sporadically in the valleys. Figure 2 is a geologic map of the region.

#### Local Geologic Setting

The large hematite iron-ore bodies in the Hartville-Sunrise district are within a folded and faulted belt of steep to vertically dipping meta-sediments of Precambrian age that crop out along the east edge of the Hartville domal uplift between Guernsey and McCann Pass, seven miles north-east. Much of the iron formation is under a flat to gently dipping cover of Paleozoic limestones - dolomites, quartzites, and sandstones. The iron ores are principally red, earthy hematite and hard, steel-gray to bluish-black specular hematite. Wall rock contacts vary from gradational to sharply defined. Bands of gangue and low-grade hematite occur in the ore bodies and require separation. The schist walls are weak and cave readily.

At the Sunrise mine, the main ore body is an S-shaped lens in plan view, 50 to 600 feet thick and 1600 to 2100 feet long, occurring in a tight synclinal fold with a general south plunge. The hematite occurs in the lower part of the Good Fortune schist, usually close to the Whalen dolomite contact. It should be noted that the rocks at the Sunrise mine are apparently low-grade metamorphics.

#### Mine Facilities

Data concerning the mine facilities were extracted from EMJ (1974) and Harrer (1966).

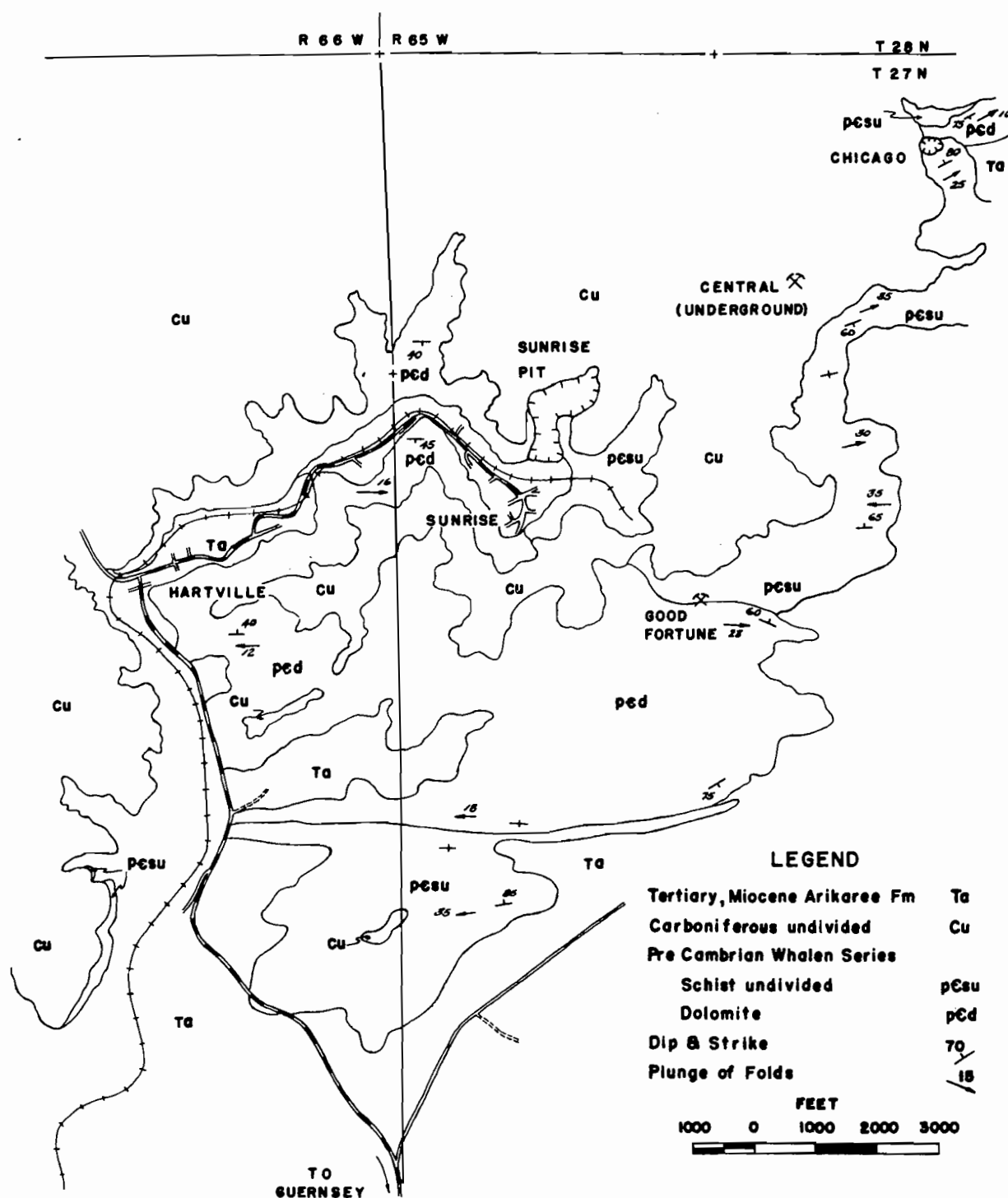


FIGURE 2. Geologic map, vicinity of Sunrise, Wyoming. (Carter, D.A., Sunrise Iron Mine, Wyoming, p. 264-266, Figure 1. From: Guidebook to the Geology of the Northern Denver Basin and Adjacent Uplifts, 1963, Rocky Mountain Association of Geologists, Denver.)

The Colorado Fuel and Iron Corporation acquired the Sunrise mine property in 1900. The mine was operated as an open pit until about 1930, when the mine was gradually converted to underground block caving with some sublevel caving. Approximately 500,000 tons of concentrates are currently produced annually at the Sunrise mine.

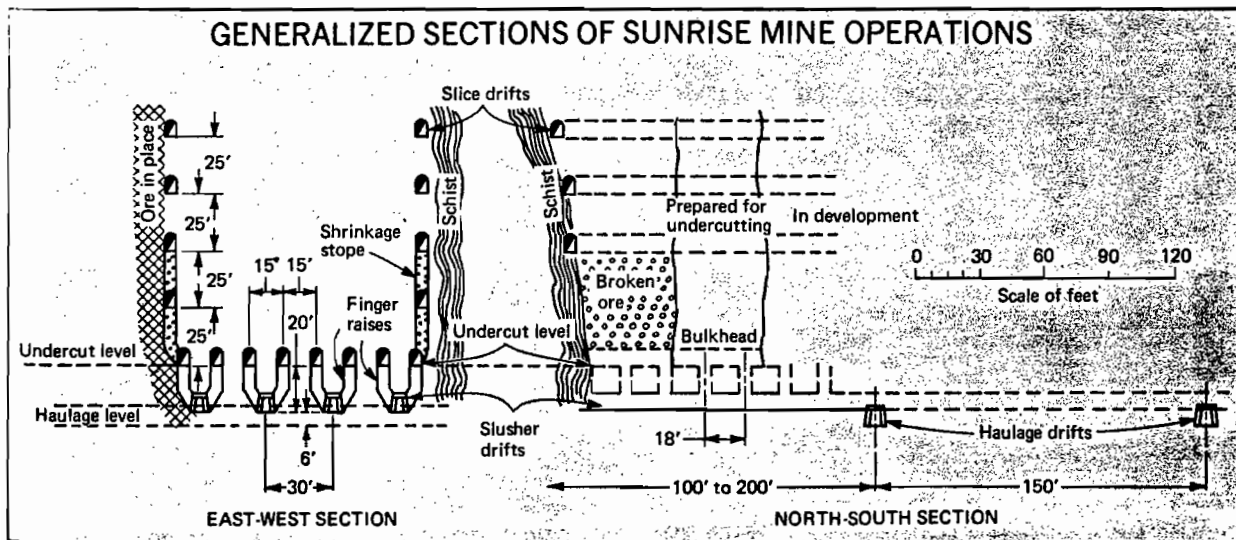
The deepest development is on the main ore body of the Sunrise mine. In 1966, mining was being conducted 750 feet below the surface, with known reserves continuing to greater depths.

As of 1974, new mine projects have been underway to enhance the mine's capabilities. While production has been coming from the seventh and third levels, another associated but separate ore body is also under development on the seventh level. Access to this area is being developed by a decline equipped with conveyor belt haulage. A ventilation shaft 9 feet in diameter was completed in 1974.

Block caving was introduced at Sunrise in 1929. Blocks 350 ft. sq. by 200 ft. high are undercut and blasted. Ore is then drawn out through a pattern of finger raises below the undercut level, as shown in Figure 3. Approximately 3600 tons of ore are hoisted daily to the surface by two 10-ton capacity skips.



FIGURE 3.



(Eng. Mining J. v. 175, (11), p. 151, 1974)

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## CIVIL WORKS

## INTRODUCTION

Large underground galleries and related shafts and tunnels comprise several hydroelectric generation facilities. Where they are described in the literature, the geologic settings of these facilities are usually treated in less detail and the engineering aspects given greater coverage than those of mines, because lithology and structural setting are key factors in ore location. Hydroelectric facilities incorporating underground galleries are generally located in tectonically stable regions, in relatively homogeneous crystalline rock bodies.

Among hydroelectric installations, pumped storage facilities often utilize underground powerhouses. In 1974 there were 25 pumped storage facilities in the United States with 10 more under construction (Stout, 1974). In this section of the report, we briefly describe as examples two pumped storage sites in crystalline rock; Bad Creek of South Carolina in granite and Helms of California in quartz monzonite; which may contain openings accessible for in situ tests. The Dworshak dam site, Idaho, in gneiss, is also described. At Dworshak, test adits in the abutments of the dam and a large underground crushing chamber may still be accessible.

Also considered in the category of civil works is the underground spent-fuel test facility, presently under construction at the Nevada Test Site.

To assess the number, location, and availability of openings in underground hydroelectric projects, it will be necessary to contact the appropriate governmental agencies, utility companies, and/or company associations such as the Electric Power Research Institute.

## REFERENCE

Stout, J.J., 1974, Potential pumped storage projects that would use existing reservoirs: in Engineering Foundation Conference, Converting existing hydro-electric dams and reservoirs in pumped storage facilities, Franklin Pierce College, Rindge, N.H., published by Amer. Soc. Civil Engineers, New York, p. 221-252.

## CIVIL WORKS

HELMS UNDERGROUND POWERHOUSE - PUMPED STORAGE PROJECT  
(Pacific Gas and Electric Co.)

## LOCATION

The Helms project of the Pacific Gas and Electric Co. (PG&E) is located on the North Fork of the Kings River, about 60 miles east of Fresno, California, at  $37^{\circ}02'N$ ,  $118^{\circ}58'W$ , the project location is shown in Figure 1. The pumped-storage project is expected to ultimately produce 1000 MW. The underground powerhouse, as shown in Figure 2, is situated between two reservoirs: Courtright, at an elevation of 8200 feet; and Wishon, at 6550 feet (a profile of the project is shown in Figure 3). The depth to the powerhouse is approximately 1000 feet.

## GEOLOGIC SETTING

The geologic setting of the Helms project area was mapped by Bateman (1965). The predominant rock unit is the Dinkey Creek hornblende granodiorite (Kdc in Figure 3). The Dinkey Creek pluton of the Sierra Nevada batholith is of Cretaceous age, and covers several hundred square miles. A small pluton, the lineated quartz monzonite of Lost Peak (Klp), intruded the Dinkey Creek granodiorite. The Dinkey Creek granodiorite is in contact with a more felsic pluton, the Mt. Givens quartz monzonite (Kmg), at the vicinity of the dam impounding Courtright Reservoir. A pendant of pre-batholithic quartzite (Qte) lies just south of, and above, the underground powerhouse workings. The workings are reportedly outside the zone of poor rock conditions associated with the contact between the granodiorite and the quartzite (Haimson, 1976). Bateman's map (1965) indicates that the foliation of the Dinkey Creek granodiorite in the vicinity of the powerhouse strikes northwesterly and dips nearly vertically.

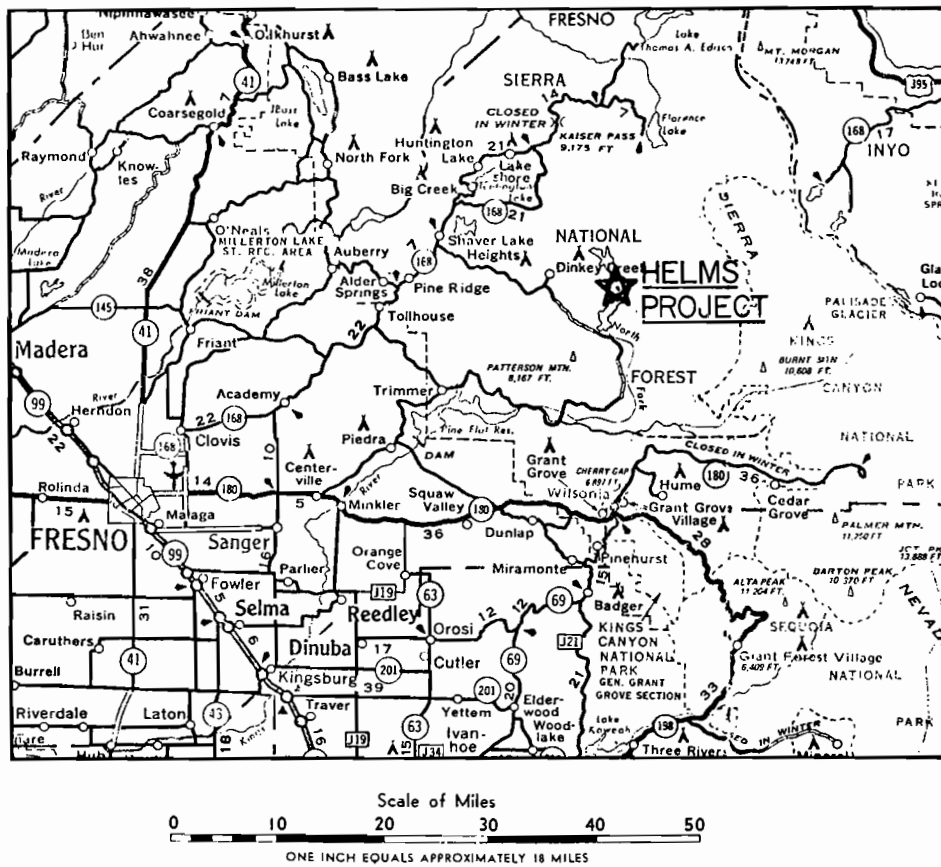


FIGURE 1. Location of Helms Project in California, 60 miles east of Fresno. Basic map reproduced by permission of the American Automobile Association, copyright owner.

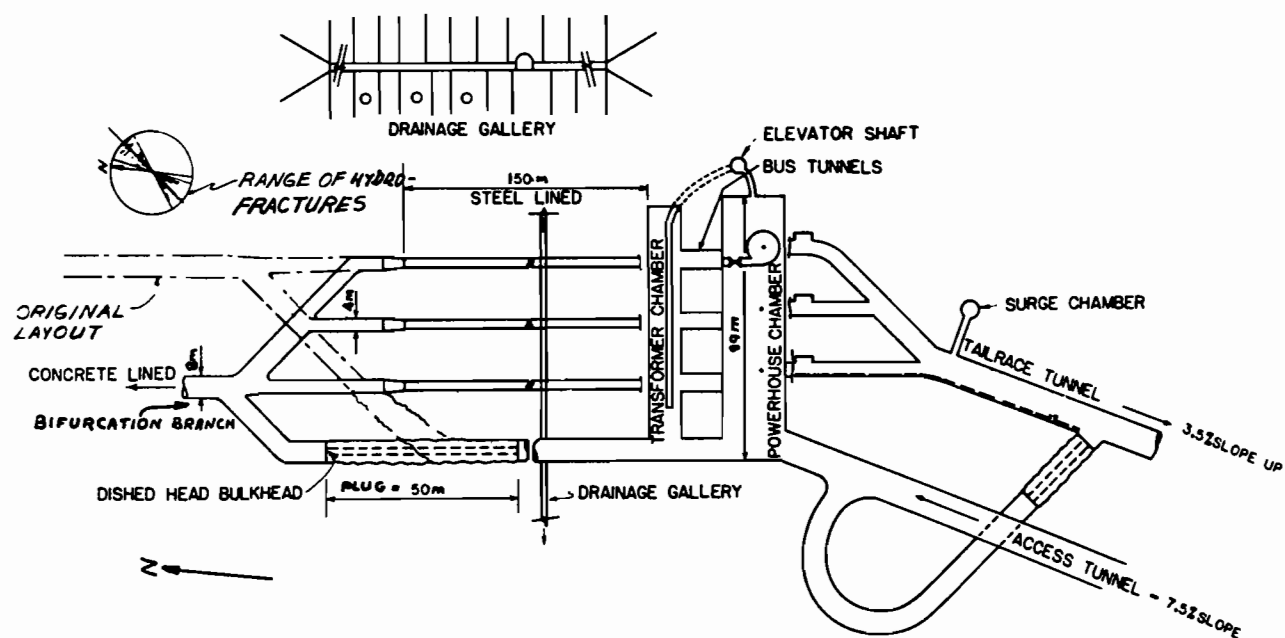
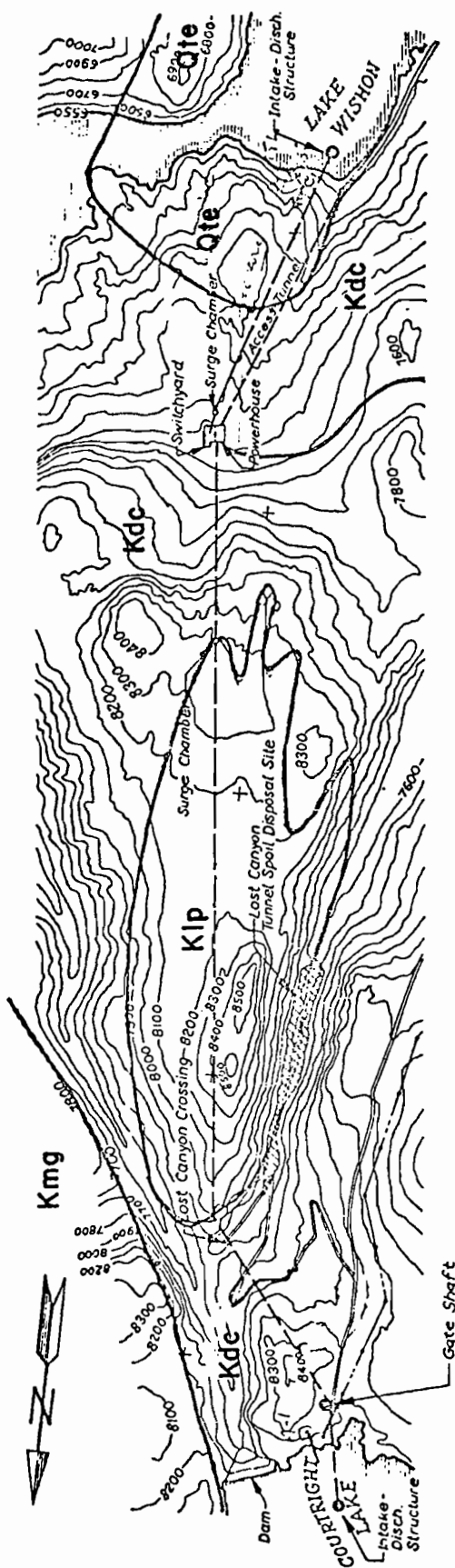
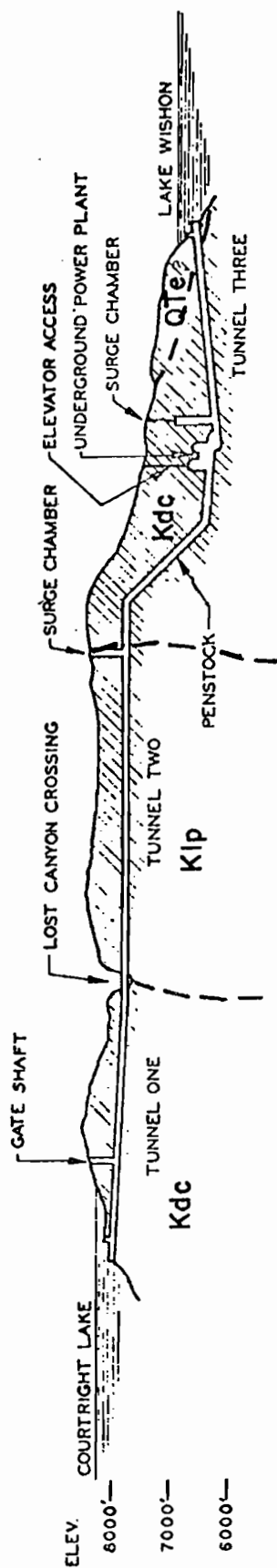


FIGURE 2. Original and modified layout of underground powerhouse complex--Helms Pumped Storage Project (Haimson, 1976).





## PLAN AND PROFILE HELMS PUMPED STORAGE PROJECT

FIGURE 3.

LEGEND:

ATTACHMENT 2  
ENG. EST. NO. 3120

- Klp - Lineated Quartz Monzonite of Lost Peak
- Kmg - Mt. Givens Quartz Monzonite and Granodiorite
- Kdc - Dinkey Creek Granodiorite
- Qte - Quartzite

(Geology after Bateman, 1965)

Geotechnical parameters are listed in Table 1. Rock structure and rock properties in this table were obtained from the paper by Haimson (1976). Thomas Doe, staff hydrogeologist at LBL, as a student of Haimson at Wisconsin, participated in field investigations at the Helms Project. Discussions with Doe indicate that, since the Helms pumped-storage project is still under construction (Summer, 1979), there may be access at present and in the near future for further studies of the mechanical and hydrologic properties of the granodiorite. It is also possible that discussions with PG&E may indicate that some openings will be accessible for long-term studies.

## T A B L E 1

Structure - Cubic joint system (2-8 m spacing)

Rock Properties -  $\sigma_{unc} = 1-1.3 \text{ kb}$ ,  $E = 4-8 \times 10^5 \text{ bars}$ ,  
 $\nu = 0.2-0.3$ ,  
 tensile strength = 100-150 bars

Stress -  $\sigma_H(\text{max}) = 95 \text{ bars}$ ,  $N25^\circ E$   
 $\sigma_H(\text{min}) = 54 \text{ bars}$ ,  $N65^\circ W$   
 $\sigma_v = 82 \text{ bars}$

Hydrology - below water table

Project Characteristics

Depth - 300 m

Volume -  $98 \text{ m} \times 25 \text{ m} \times 36 \text{ m} = 88,000 \text{ m}^3$  (powerhouse),  
 $93 \text{ m} \times 15 \text{ m} \times 15 \text{ m} = 21,000 \text{ m}^3$  (transformer  
 chamber).

(Data from Haimson, 1976).

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J., and Conlon, R. J., ed., Proc. 1976: Rapid Excavation and  
Tunneling Conference, Las Vegas, Nevada, June 14-17, 1976,  
American Inst. of Mining, Metallurgical and Petroleum  
Engineers, New York.



## CIVIL WORKS

## DWORSHAK DAM SITE

(U.S. Bureau of Reclamation)

## LOCATION

The Dworshak Dam site is located on the North Fork of the Clearwater River, near the town of Orofino, Idaho (40 miles east of Lewiston), at  $46^{\circ}31'N$ ,  $116^{\circ}18'W$  (Figure 1). The dam, with a crest length of 3000 feet and a height of 673 feet, was completed in 1972. It was built by the U.S. Corps of Engineers and is presently under the jurisdiction of the Bureau of Reclamation.

Prior to construction, rock-mechanics tests were done at depths of 300 to 700 feet in adits in the abutments to determine in-situ deformation properties (Deere and others, 1969). Some of these workings may still be accessible as well as a large "glory hole" and underground crushing facility for preparation of concrete aggregate from dam-site crystalline rock.

## GEOLOGIC SETTING

The geologic setting of the region surrounding Dworshak Dam was described by Johnson (1947) and is illustrated in Figure 2. The rock at the site is granodiorite gneiss of the Orofino Series, considered by Johnson to have originally been a siliceous sedimentary rock of Beltian (Late-Precambrian) age, metamorphosed in the Mesozoic to its present crystalline form by hydrothermal solutions associated with the Idaho Batholith. The granodiorite gneiss is schistose and banded, its color is light to moderate gray, its granularity ranges from fine to coarse. Microscopic examination is needed to distinguish the granodiorite gneiss from hornblende and biotite quartz-diorite gneisses which also occur in the region. Occasionally quartz veins and basaltic dikes

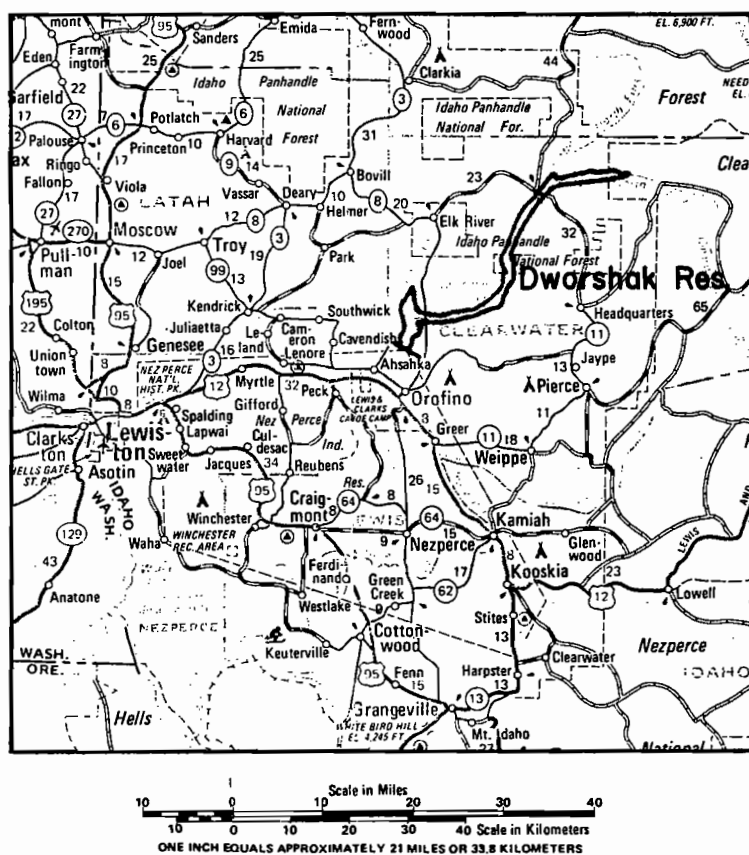


FIGURE 1. Dworshak Dam Site in Idaho, approximately 40 miles east of Lewiston. Basic map reproduced by permission of the American Automobile Association, copyright owner.

[illegible]

FIGURE 2. Geologic map of the Orofino region, northern Idaho (reprinted from: Igneous Metamorphism of the Orofino Region, Idaho, by C. H. Johnson, in *Journal of Geology*, v. 55 (6), p. 490-507, 1947; by permission of The University of Chicago Press).



cut the granodiorite gneiss. Petrographic examinations reported by Deere and others (1969) showed that the dam-site gneiss was foliated with biotite flakes aligned parallel to the foliation. Johnson (1947) observed that bedding in the Orofino Series was not completely obliterated by metamorphism. Regional strike ranges from nearly east-west to N45°W; dips are to the north and vary from 15° to nearly vertical. At the site, foliation strikes roughly parallel to the cross-stream axis of the dam, and dips ~50° upstream. A prominent joint set dips at ~90° to the foliation.

Rock-property data is summarized from in-situ and laboratory measurements at depths of 300 to 700 feet by Deere and others (1969):

Unconfined compressive strength: 23500 psi

Tensile strength: 1000 psi

Tangent modulus:  $4.05 \times 10^6$  psi at an axial  
stress of 130 psi

Dilatational wave velocity: 12,340 ft. per second

Because of the possibility of access to test adits and the glory-hole-crusher workings, their availability for in-situ mechanical and hydrologic testing in crystalline rock at appropriate depths should be investigated.

## REFERENCES

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## NEVADA TEST SITE-CLIMAX STOCK

(U.S. GOVERNMENT/DOE)

## LOCATION

The Climax Stock at the Nevada Test Site (NTS) is located approximately 5 miles from Area 12 camp, ~40 miles north of Mercury, Nevada, and 90 air-line miles northwest of Las Vegas, Nevada, at 37°14'N, 116°04'W. Figure 1 is a location map showing the Climax Stock, NTS and geographical landmarks.

## GEOLOGIC SETTING

Data for these sections were extracted from Terra Tek (1975), Eckel (1968), and Ramspott (1978).

The generalized geologic setting is illustrated in Figure 2, which includes a cross section through the Climax Stock.

The NTS site is located on the northeast side of the Las Vegas-Walker Lane shear zone in a region of thick Paleozoic miogeosynclinal sedimentary accumulation. Sedimentary rocks account for approximately 30 percent of the outcrops in the region, while the remainder consists of intrusives overlain by volcanics. Regional structure is expressed in generally north trending mountain ranges in the northern part of the NTS. Several different geologic settings occurring in the region are characterized as follows:

- (1) Mesozoic intrusives are represented by the granodioritic quartz monzonite Climax and Gold Meadow Stocks, each exposed over several square miles.
- (2) The Ranier and Pahute Mesas are examples of a thick sequence of Tertiary volcanics overlying an eroded Paleozoic sedimentary basement. The Tertiary volcanics range up to 5,000 feet in thickness and may be capped by a resistant welded tuff. The tuff units range from ash-flow and ash-fall tuffs to highly welded tuffs.

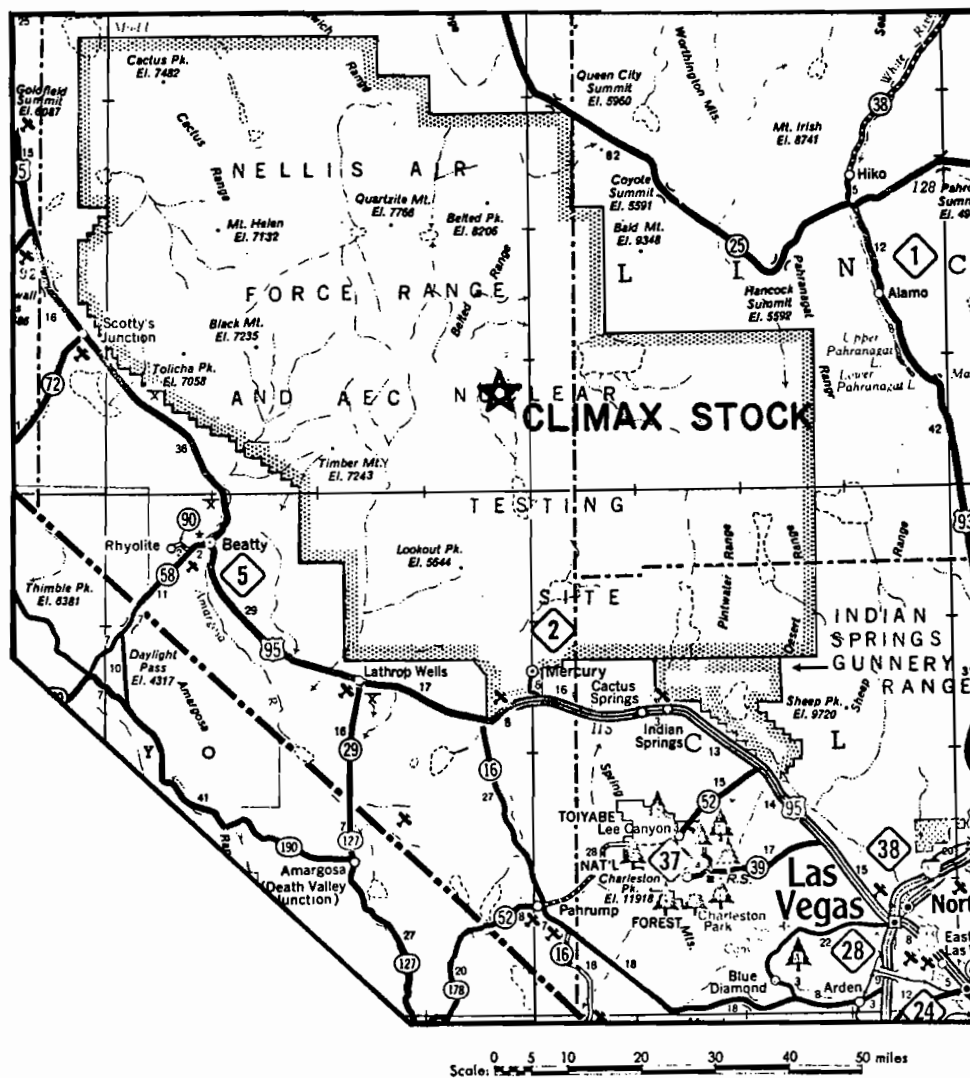


FIGURE 1. Location map - Climax Stock, Nye County, Nevada.  
Base map used with the permission of the Nevada  
Department of Transportation.

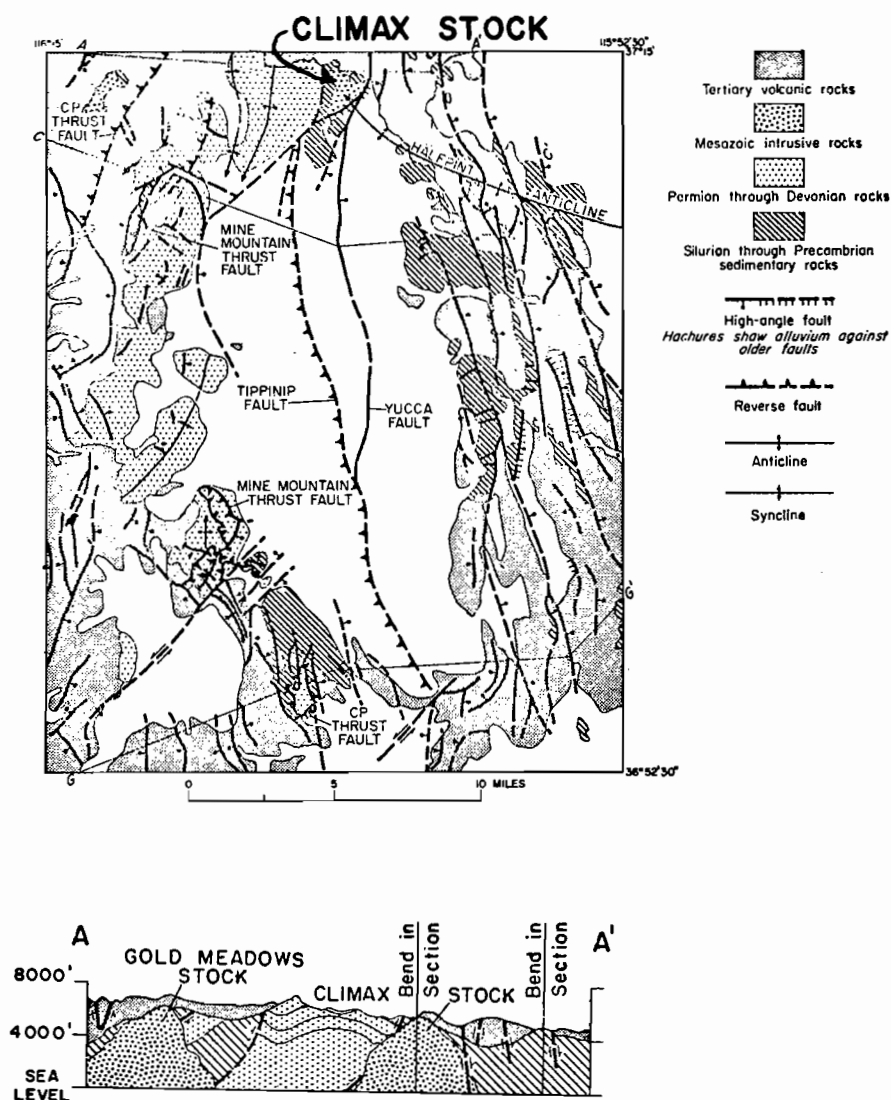


FIGURE 2. Generalized geologic map of the Yucca Flat Area and cross section through the Climax Stock. Unpatterned areas are surficial deposits. (Hinrichs, 1968). (Courtesy, the Geological Society of America.)

- (3) Alluvial valleys are characterized by a thick sequence of underlying sedimentary rocks. At Yucca Flat the alluvium and tuff reach a thickness of 3,500 feet, and overlie Paleozoic carbonate rocks and some intrusives at depth.

The geologic structure of the region is somewhat typical of the Basin and Range province: alluvial valleys bounded by high angle normal faults. Normal faulting associated with volcanic structures occurs beneath the alluvial valleys. Several major thrust faults have been identified as significant features with respect to the distribution and movement of ground water.

A great deal of geological and geophysical work has been performed at NTS, in the form of geological mapping, joint frequency maps, geophysical borehole logging, and gravity, magnetic and seismic surveys. Much of this work has been summarized in a compendium of reports (Eckel ed., 1968).

The area is located in earthquake zone 2.

#### Climax Stock

The underground opening being considered as a candidate site is located in the Climax Stock. As shown on Figures 2 and 3, the stock, of Mesozoic age, intruded Precambrian and Paleozoic clastic and carbonate rocks. Geophysical evidence suggests that the Climax stock expands conically from a surface area of several square miles to an area of approximately 60 square miles at a depth of three thousand feet. The Climax stock is structurally controlled, elongate in the north-south direction, and bounded on the east and west by faults. Minor faults transect the intrusive joints typically spaced from several inches to several feet apart. The 420 m level is apparently above the regional water table, and the rock at that level appears to be unsaturated. Approximately 1 to 2 wt % water is localized in fractures and pores.

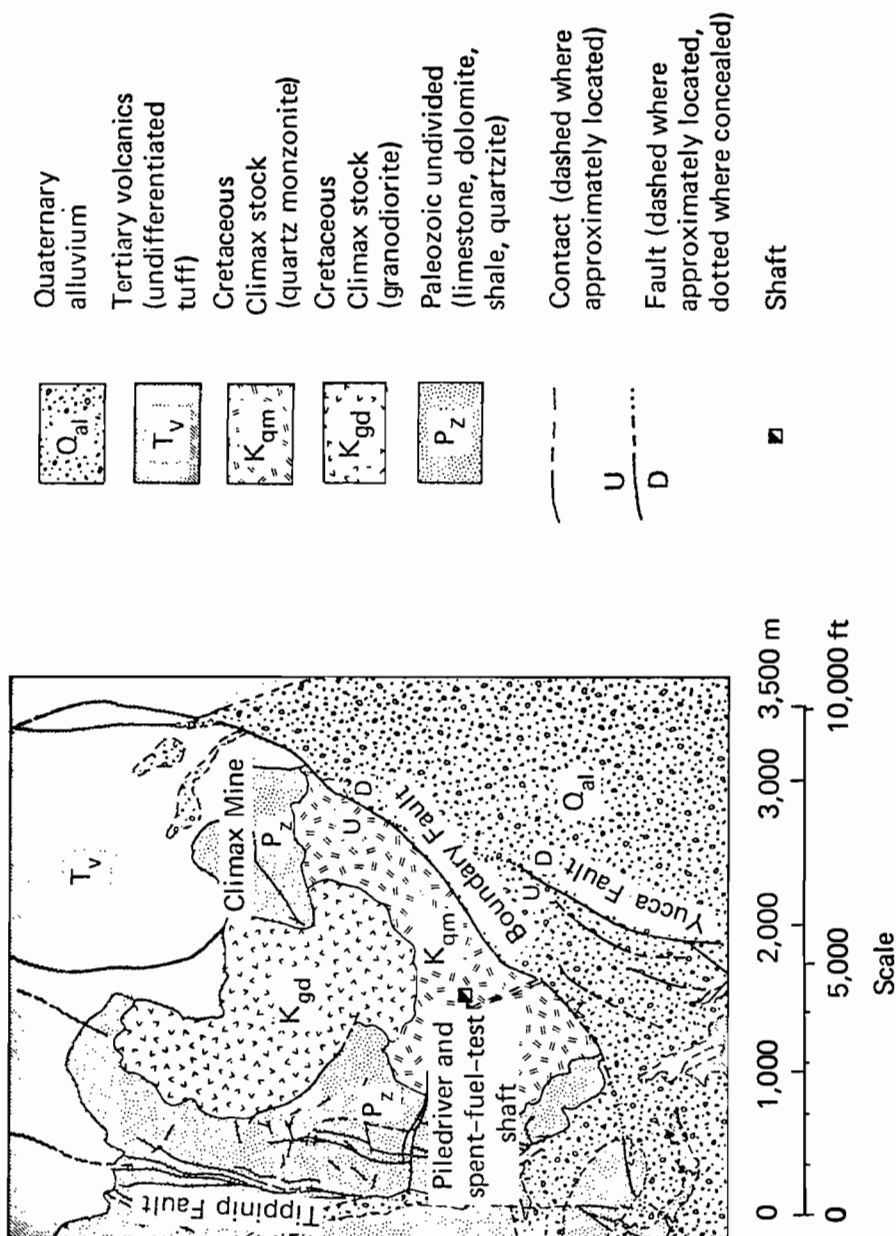


FIGURE 3. Geologic map of the Climax stock area (modified from U.S.G.S. map by Barnes et al.), (Ramspott, 1979).



Laboratory tests of rock properties of the Climax Stock granodiorite and quartz monzonite, conducted by the Lawrence Livermore Laboratory are summarized in Table 1 and figures 4 and 5.

#### Underground Opening Facilities

The layout of the underground facilities and the current testing program have been described by Ramspott (1979). The shaft and tunnel complex previously constructed for the PILEDRIVER underground nuclear test, are presently being utilized for a spent fuel test facility. As shown in Figure 6, further excavation on the 420 m level has been done by Lawrence Livermore Laboratory in preparation for the spent fuel tests.

Mechanical equipment at the site includes hoist and ventilation apparatus to service the 1,400 ft. shaft and drifts on the 420 m level.

TABLE I

SUMMARY OF LABORATORY TESTS ON CLIMAX STOCK QUARTZ MONZONITE

<u>PHYSICAL PROPERTIES</u>	<u>SAMPLE SOURCE</u>		
	<u>G-1</u>	<u>G-2</u>	<u>LARGE CORE</u>
Dry Bulk Density (gm/cm <sup>3</sup> )		2.635 ± .036	
Grain Density (gm/cm <sup>3</sup> )		2.723 ± .027	
Total Porosity (%)		3.221 ± .716	
Permeability (μd)	0.12	0.10	
<u>THERMAL PROPERTIES</u>			
Conductivity (watt/m-°C)			
versus pressure <sup>2</sup>	3.6	3.7	
versus temperature			2.92 @ 25°C
			2.76 @ 100°C
			1.95 @ 200°C
<u>MECHANICAL PROPERTIES</u>			
Compressive Strength (GPa)			
@ σ <sub>3</sub> = 0 MPa	0.20 ± .03	0.20 ± .03	
@ σ <sub>3</sub> = 3.4 MPa			0.275 ± .007
@ σ <sub>3</sub> = 6.9 MPa			0.282 ± .044
@ σ <sub>3</sub> = 10.3 MPa			0.337 ± .027
@ σ <sub>3</sub> = 20.7 MPa			0.452 ± .016
@ σ <sub>3</sub> = 41.4 MPa			0.569 ± .032
<u>YOUNG'S MODULUS (GPa)</u>			
@ σ <sub>3</sub> = MPa <sup>1</sup>	48 ± 5	51 ± 5	
σ <sub>3</sub> = 3.4 MPa			66.7 ± 5.9

<sup>1</sup> Taken from previous test results on G-1 and G-2 core.

<sup>2</sup> Not pressure dependent in the range of 0 to 34.5 MPa.

	<u>G-1</u>	<u>G-1</u>	<u>LARGE CORE</u>
@ $\sigma_3 = 6.9$ MPa			54.4 $\pm$ 5.1
@ $\sigma_3 = 10.3$ MPa			61.8 $\pm$ 7.0
@ $\sigma_3 = 20.7$ MPa			63.7 $\pm$ 6.4
@ $\sigma_3 = 41.4$ MPa			66.8 $\pm$ 1.9
DYNAMIC	82.8	73.3	67.2 $\pm$ 3.9
<u>POISSON'S RATIO</u>			
@ $\sigma_3 = 0$ MP <sup>1</sup>	0.21 $\pm$ .02	0.22 $\pm$ .02	
@ $\sigma_3 = 3.4$ MPa			0.35 $\pm$ .02
@ $\sigma_3 = 6.9$ MPa			0.27 $\pm$ .06
@ $\sigma_3 = 10.3$ MPa			0.31 $\pm$ .05
@ $\sigma_3 = 20.7$ MPa			0.31 $\pm$ .05
@ $\sigma_3 = 41.4$ MPa			0.28 $\pm$ .05
DYNAMIC	0.240	0.253	0.245 $\pm$ .012
<u>BULK MODULUS (GPa)</u>			
Static			
Dynamic	53.2	49.4	44.5 $\pm$ 4.4
<u>ULTRASONIC VELOCITIES</u> ( km/sec)			
P-wave	6.058	5.767	5.501 $\pm$ .208
S-wave	3.541	3.317	3.185 $\pm$ .080
TENSILE STRENGTH (MPa) <sup>3</sup>	16 $\pm$ 2	14 $\pm$ 2	

<sup>3</sup>Brazil test.

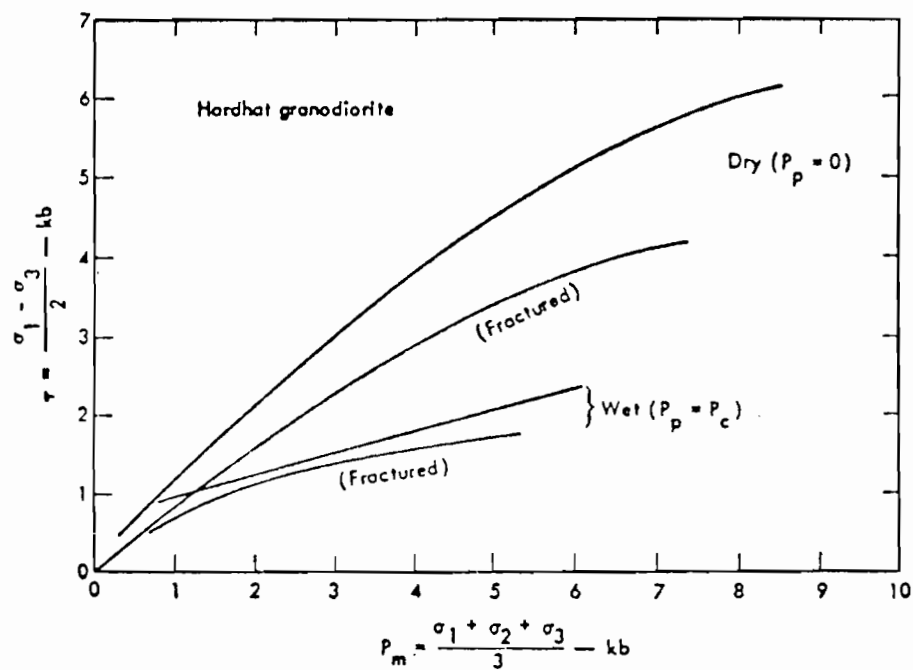


FIGURE 4. Failure envelopes of both intact and fractured Climax Stock granodiorite under dry and saturated conditions 240-m level. (Heard, 1971).

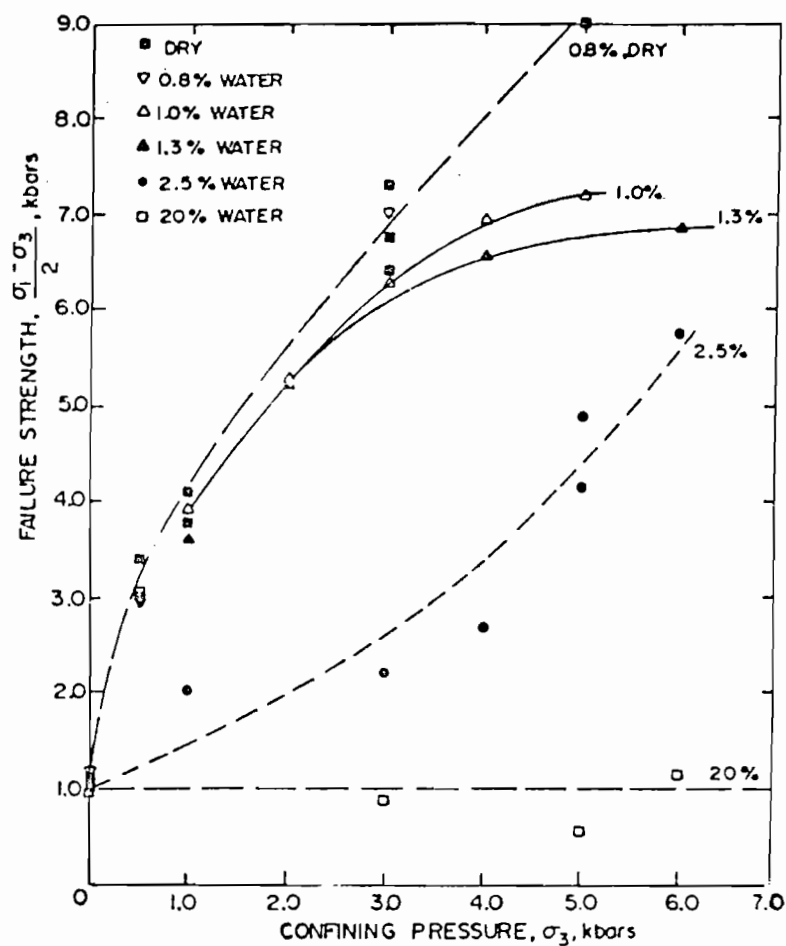


FIGURE 5. Failure strength as a function of confining pressure for dry samples and samples with excess water. 240-m level. (Duba and others, 1974).

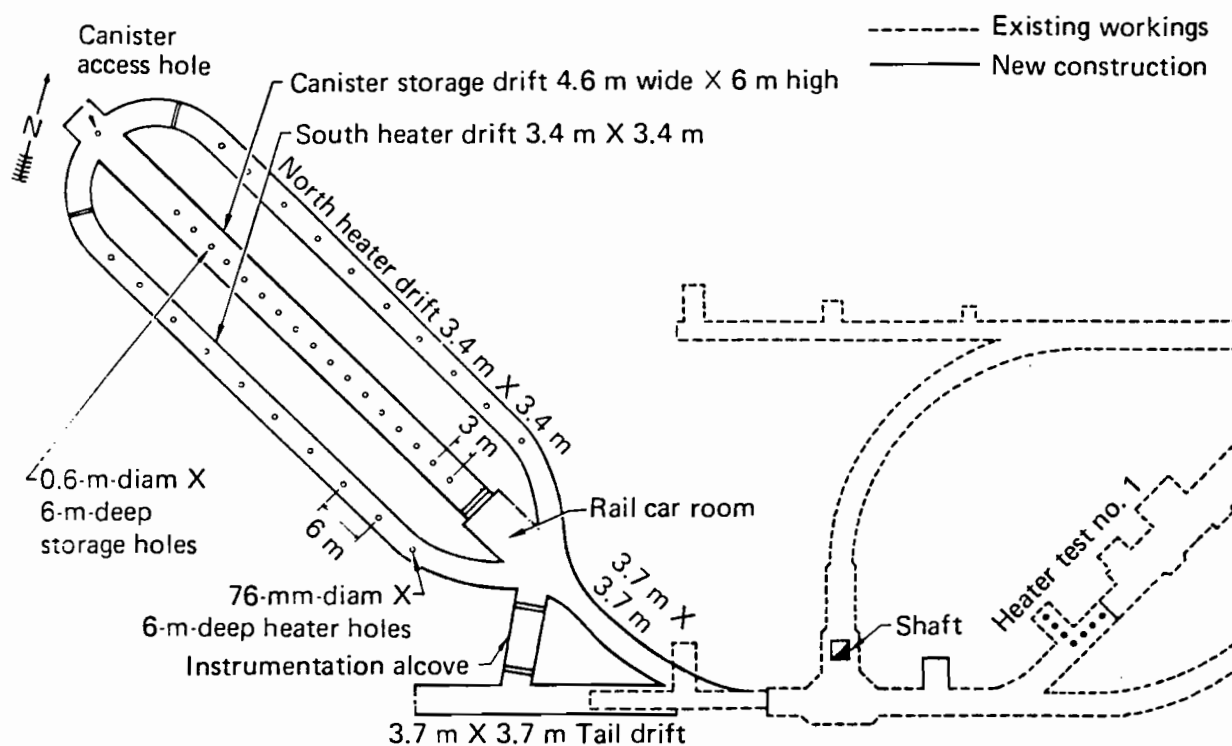


FIGURE 6. Layout of 420-m level, Climax granite, showing new construction for spent-fuel test, (Ramspott, 1979).

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## CIVIL WORKS

THE BAD CREEK PUMPED STORAGE PROJECT  
(Duke Power and Light Co.)

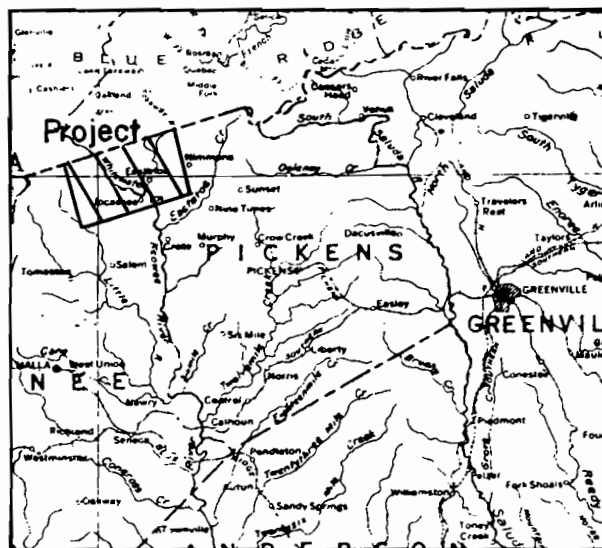
## LOCATION

The Bad Creek project of Duke Power and Light Co., described by Hester and Edmonds (1974), is located on the southeastern edge of the Blue Ridge escarpment, approximately 40 air miles WNW of Greenville in Oconee County, South Carolina, at  $34^{\circ}57'N$ ,  $83^{\circ}04'W$ . As shown in the location map (Figure 1) and the cross section (Figure 2), the underground workings are immediately west of the Whitewater River arm of Lake Jocasee. The pumped-storage project's upper reservoir is formed by impounding Bad Creek and West Bad Creek at an elevation of 2310 feet; Lake Jocasee, at an elevation of  $\sim 1100$  feet, serves as the lower reservoir. The underground powerhouse is situated at a depth of  $\sim 900$  feet, its dimensions are 90 x 445 feet in plan, its height 130 feet.

## GEOLOGIC SETTING

Geologic descriptions of the site are sparse in the open literature. According to Haimson (1976), the powerhouse chamber is excavated in the Toxaway gneiss, a medium- to coarse-grained, well-foliated rock. However, plotting the location of the project on the geologic map of the crystalline rocks of South Carolina (Overstreet and Bell, 1965) indicates that the underground workings are in the Whiteside granite of the Blue Ridge belt. Overstreet and Bell (1965) describe the Whiteside granite as typically faintly to strongly gneissic, but massive in some places. It is primarily a white to light-gray biotite - muscovite granite, but phases of muscovite granite, biotite granite, and, rarely, mica-free granite are also present.





0 25 miles

FIGURE 1. Location map of Bad Creek Project in Oconee County, South Carolina (from Overstreet and Bell, 1965).

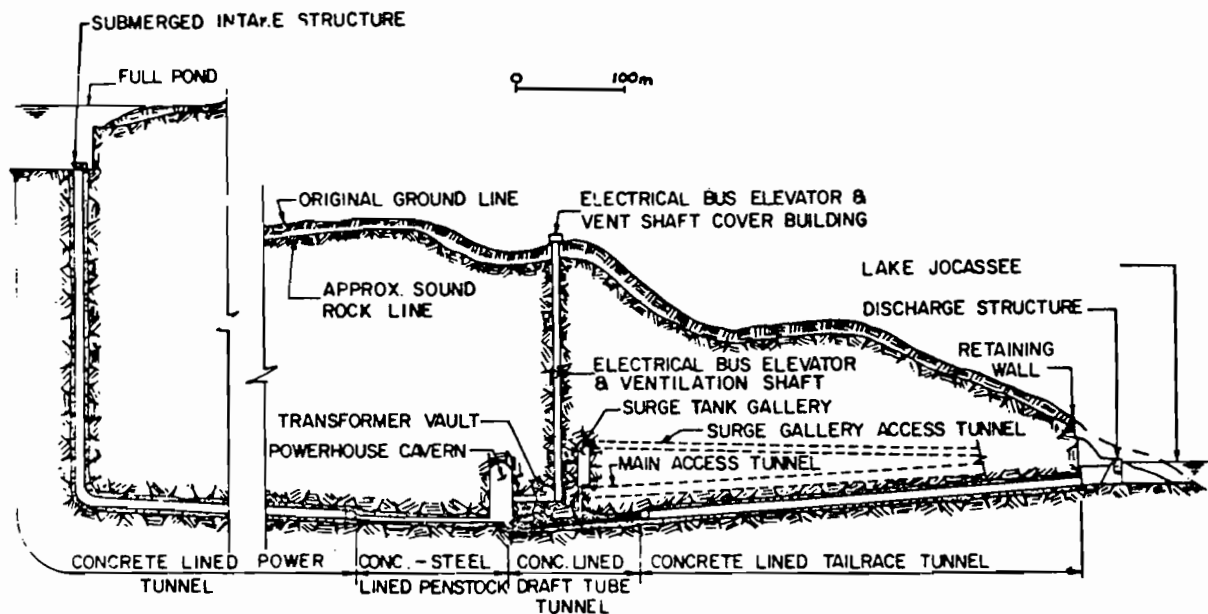


Figure 2. Vertical section through the waterways--Bad Creek Pumped Storage Project (from Hester, J.G., and Edmonds, R.F., Bad Creek Pumped Storage Project, in: Electric Power and the Civil Engineer, Conference Papers, Specialty Conference, Boulder, Colorado, 1974, American Society of Civil Engineers, New York).

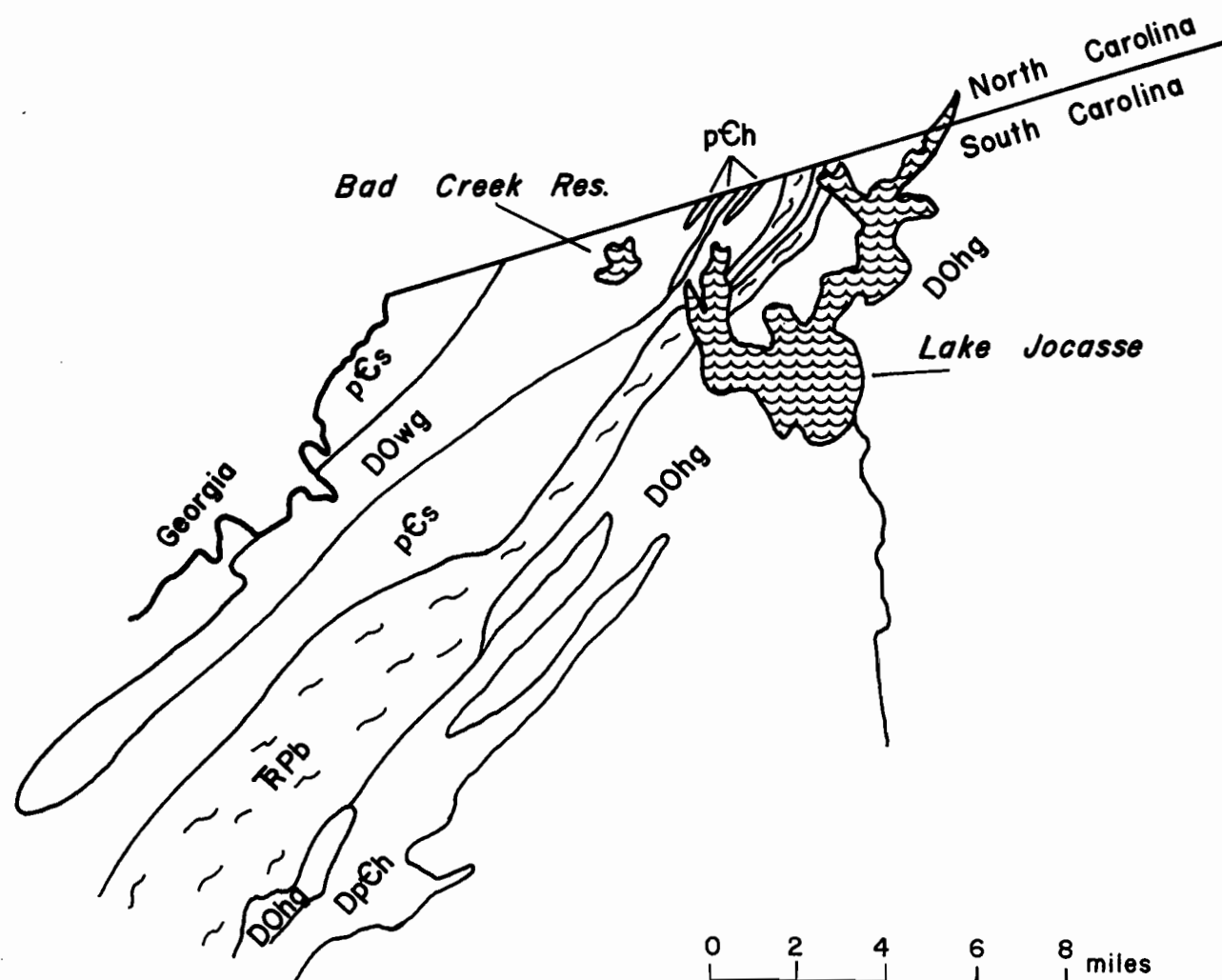


FIGURE 3. Simplified geologic map of the Lake Jocassee area (Overstreet and Bell, 1965).

#### LEGEND

- R Pb - Brevard fault zone
- DOwg - Whiteside granite
- DOhg - Henderson gneiss
- DpCh - Hornblende gneiss
- pCh - Hornblende schist and gneiss
- pEs - Biotite schist and gneiss

Three principal directions of foliation in the gneiss were observed by Haimson and his co-workers (Haimson, 1976). Two foliation directions conform well to the direction of measured horizontal principal stresses. Rock properties are summarized from the paper by Haimson (1976) in Table 1.

Table 1

Maximum horizontal stress: 228 bars at a depth of 230 m.;

(direction N60°E)

Minimum horizontal stress: 159 bars (direction N30°W)

The third foliation direction is approximately E-W.

Vertical stress: 62 bars (roughly corresponds to  
overburden pressure).

More detailed information on the geologic setting, resolution of the uncertainty in nomenclature of the bedrock at the Bad Creek site, as well as information on ease of access to, and availability of, underground workings for geotechnical tests, can only be obtained by discussion with company and government geologists.

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The bibliography, while large, is not exhaustive. It was compiled for the specific needs of this report.

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I N D E X

This index serves as a subject key to the Bibliography. The index begins with headings of a general nature. Following these listings, the index uses as subjects primarily state, region, county, mining district, and mine names. Included are listings of underground workings not in classes 1 and 2.

To make the Bibliography easier to use, author and year of publication identify each reference dealing with a specific area or site. Page numbers where given refer to information on an underground working described in the body of this report.

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## Utah (cont.)

Page

Crowder, 1959  
 Grant, 1969  
 Huntting, 1943  
 Huntting, 1956  
 Moen, 1976  
 Park, 1968  
 Purdy, 1954  
 Soderberg, 1948  
 Tabor, 1969  
 Youngberg, 1952  
 Metaline District  
   McConnel, 1968  
 Middle Fork  
   Grant, 1973  
 Midnight Mine  
   Becraft, 1963  
   Nash, 1978  
   Weissenborn, 1974  
 Sunrise Breccia Deposit  
   Pierce, 1977  
 United Copper Claim  
   Bancroft, 1914  
   Bennington, 1951  
   Clark, 1968  
 Van Stone Mine Area  
   Cox, 1968

## Wisconsin

Bur. Min., 1973  
 Dutton, 1970  
 Hubbard, 1975  
 Sims, 1976  
 Tri-State Geol. Field Conf., 1953  
 Yardley, 1975B  
 Menominee Iron-Bearing District  
   Bayley, 1966

## Wyoming

Bur. Min., 1973  
 Hanley, 1950  
 Osterwald, 1966  
 Wyoming Dis. of Manf. and Mining, 1978  
 Wyoming Geol. Assoc., 1971  
 Wyoming Inspector of Mines - Annual Rep., 1972  
 Wyoming Inspector of Mines - Annual Rep., 1973  
 Wyoming Inspector of Mines - Annual Rep., 1974  
 Wyoming Inspector of Mines - Annual Rep., 1975  
 Wyoming Inspector of Mines - Annual Rep., 1976  
 Wyoming Inspector of Mines - Annual Rep., 1977  
 Wyoming Inspector of Mines - Annual Rep., 1978  
 Wyoming Mineral Division, 1978

## Wyoming (cont.)

## Atlantic City District

Bayley, 1968

Eng. Min. J., 1965

## Big Horn Basin

Lowry, 1976

## Granite Mountain Area

Love, 1970

Peterman, 1978

## Mountain Province

Tweto, 1968

## Sunrise Mine .....307

Ball, 1907

Carter, 1963

Eng. Min. J., 1974

Harper, 1966

Hedderly-Smith, 1975

MAS

Rupp, 1939



## APPENDIX I - SOURCES OF INFORMATION

### The MAS Data Base

The Minerals Availability System (MAS) data base of the U.S. Bureau of Mines is used for storage and retrieval of mineral deposit information. As described in the MAS Deposit Information Manual, 1978:

"The system provides an auditable procedure to continuously monitor the present and potential availability of mineral supplies to the United States in the context of many parameters that impinge upon supply, such as mining costs, beneficiation, smelting, refining, transportation, infrastructure, environment, land use, labor, productivity, technology efficiencies, supply specifications, operating capacities, deposit life, and political factors, including taxation, ownership, access, and international relations. MAS classifies the identified resources that are reserves and systematically outlines the factors that limit other known resources from being reserves. Resource and reserve nomenclature is used according to joint U.S. Geological Survey and Bureau of Mines agreement as published in USGS Bulletin 1450-A in 1976."

Information in the MAS data base is grouped into five data sets. These categories are: deposit location, deposit definition, development plan, product definition, and environmental assessment. Information from the first two data sets--deposit location and deposit definition--were utilized. Those data sets which are complete contain the following information, as described in the MAS Deposit Information Manual 1978:

- "a. The deposit location base data set encompasses location, topography, and name of the deposit. Backup data sets include information on additional names, ownership, public land survey, references and comments.
- b. The deposit definition base data sets contain information on commodities, quantities of resource, and assays of commodities in the resource. Backup data includes published reserve information, exploration and production histories, deposit geometry, lithology, and mineralogy."

The MAS data base was queried for information on all mines having data on rock type. This request produced printouts of 5929 mines, both surface and underground. Exhibit 1 is an example of the MAS printout for the San Manuel mine.

#### The CRIB Data Base

The U.S. Geological Survey's Computerized Resources Information Bank (CRIB) is available for public use through Information Systems Programs at the University of Oklahoma by means of the General Electric Mark III Service.

"The Mineral Resources Data Book of the U.S. Geological Survey" User's Guide (1976) describes the data base as,

"Information in the record consists of descriptive text, numeric data, codes, and certain key words. Some topics accommodated are: Name, Location, Commodity Information, Description of deposit, Geology, Production, Reserves, Potential resources, and References. Approximately 400 data items are available, although all 400 data items are never used in a given record. Some 40 percent of the data items are organized into fixed-length fields or contain controlled information, such as key words. The remaining 60 percent contain free text entries."

General queries made to the CRIB data base included:

- 1) mines in crystalline rock with workings deeper than 600 feet, and
- 2) all information on the mines researched in detail.

A sample CRIB printout is shown in Exhibit 2.

GEOREF, the Geological Reference file compiled by the American Geological Institute, covers the geoscience literature from 3000 journals, as well as conferences, symposia and monographs, in the areas of geology, economic geology, engineering-environmental geology, geochemistry, geochronology, geomorphology, igneous and metamorphic petrology, solid earth geophysics and stratigraphy.

Coverage also includes books, government documents, special reports and theses, as well as citations from the Bibliography and Index of Geology.

The characterization of GEOREF was extracted from Orbit, A World of Information, and Orbit User Manual for GEOREF, published by SDC Search Service, Santa Monica, California.

GEOREF was queried for information on specific mine sites. A sample citation is shown in Exhibit 3.

#### Other Sources of Information

Other sources of information included the following publications with a list of items covered by each.

- 1) 1977 E/MJ International Directory of Mining and Mineral Processing Operations, Mining Information Services, Engineering and Mining Journal, McGraw-Hill, New York, N.Y.

All underground mines were listed, regardless of commodity mined.

Information includes:

- mine name
- mine location
- mine status
- number of employees
- kind of operation (mine, mill, concentrator, etc.)
- products
- underground mine
  - number of shafts
  - haulage
  - ore tonnage
  - daily ore capacity
  - ore grade
  - mineralization
  - reserves
- personnel in charge
  - mine manager
  - geologists

- 2) Published State Directories of Mining Operations.

Various items of information - usually commodity mined and mine location.

- 3) Survey of Active and Inactive Mines for Possible Use in In Situ Test Facilities Y/OWI/SUB-76/16514, Cobbs Engineering, Geotechnical Consulting, 5200 South Yale, Tulsa, Oklahoma.

Data on all mines listed in this report as being in crystalline or high-grade metamorphic rock were extracted. Complete data sheets include the following information:

- mine location by state and county
- owner
- mine name
- present service (example: inactive, active, propane storage)
- country rock type
- mineral mined
- depth in feet
- volume of mine in cu. ft.
- entries (type and number)
- mining plan (example: room and pillar)
- water production
- first mining
- last mining
- general description (example: "The block caving will eventually reach the surface.")

- 4) Jamison report, U.C. Berkeley, 1978, Inventory of Mines.

Complete data sheets include the following information:

- mine name
- location (state and county)
- ore
- country rock
- location and direction from nearby town or city (or section, township, and range)
- owner
- wells
  - altitude to Land Surface Datum (approx. land surface elevation of the collar of each well, given in feet above mean sea level)
  - depth to water table (from LSD, in feet)

>>>> MILS - DATA SET <<<<  
(MINERAL INDUSTRY LOCATION)

STATE: ARIZONA  
COUNTY: PINAL  
TYPE OF OPERATION: UNDERGROUND  
CURRENT STATUS: PRODUCER  
LATITUDE: N 32DEG 40MIN 34SEC  
LONGITUDE: W 110DEG 40MIN 41SEC  
UTM - ZONE: 12  
HEMISPHERE: NORTHERN  
EASTING: 3615237  
NORTHING: 530185  
POINT OF REFERENCE: ORE BODY  
PRECISION: 100 METERS  
ELEVATION: 976 METERS  
PRECISION: 100 METERS

YEAR FIELD CHECKED: 1978  
QUADRANGLE: TUCSON  
RIVER BASIN NAME:  
SAN PEDRO RIVER  
RIVER BASIN CODE: 60E  
HYDROLOGIC UNIT CODE:  
DATA OF ELEVATION: SEA LEVEL  
MAP NAME: MAMMOTH  
SCALE: 7.5 MIN  
DOMAIN: PRIVATE  
TYPE OF MINERAL HOLDINGS:  
PATENTED  
STATE LEASE

MINE MAP REPOSITORY:  
TYPE OF EVALUATION: C  
EVALUATOR: SMITH  
YEAR OF INFORMATION ENTRY: 1978  
MAINTAINING FIELD CENTER:  
INTERMOUNTAIN  
MINERAL PROPERTY FILE:  
CORE LIBRARY:  
MINES IDENTIFICATION:  
GEOLOGICAL SURVEY CRIB:  
LAST MILS MODIFICATION:  
AUG 09, 1978  
LAST DEPOSIT MODIFICATION:  
DEC 12, 1978

--PUBLIC LAND SURVEY--  
PRINCIPAL MERIDIAN:  
GILA & SALT R  
TOWNSHIP: 008 S  
RANGE: 016 E  
SECTION: 35  
SECTION SUBDIVISION:  
S1/2.  
SURVEY STATUS: SURVEY

>>>> COMMODITY - DATA SET <<<<

RECORD NO.	COMMODITY	MODIFIER	MARKETABILITY	STANDARD INDUSTRIAL CODE	DATE OF LAST MODIFICATION
01	COPPER	SULFIDE	PRIMARY		AUG 09, 1978
02	COPPER	OXIDE	PRIMARY		DEC 04, 1978
03	MOLYBDENUM		BYPRODUCT		AUG 09, 1978
04	SILVER		BYPRODUCT		DEC 04, 1978
05	GOLD		BYPRODUCT		DEC 04, 1978

>>>> OWNERSHIP - DATA SET <<<<

RECORD NO.	NAME OF OWNER	STATUS	PERCENT OF OWNERSHIP	LOCATION OF HOME OFFICE	YEAR OF LAST INFORM. MODIFICATION
01	MAGMA COPPER CO	OWNER-OPERATOR	100 %	USA ARIZONA	1978 AUG 09, 1978

EXHIBIT 1. Printout of data on the San Manuel/Kalamazoo mine from the MAS data base.  
(U.S. Bureau of Mines Minerals Availability System)



DATE PRINTED: MAR 22, 1979

DEPOSIT NAME: SAN MANUEL / KALAMAZOO

MINERALS AVAILABILITY SYSTEM  
DEPOSIT LISTING

PAGE 561

448

SEQUENCE NUMBER: 0040210001

>>>> PUBLISHED RESERVES/RESOURCES <<<<  
QUANTITY (NONCUMULATIVE) AND GRADE

RESERVES	: REC 1	: REC 2	: REC 3	: REC 4	: REC 5	: REC 6	: REC 7	: REC 8	: REC 9
MEASURED	: 416000	: 512500	:	:	:	:	:	:	:
INDICATED	: 416000	: 512500	:	:	:	:	:	:	:
INFERRED	: 416000	: 512500	:	:	:	:	:	:	:
**UNDETERMINED	: 416000	: 512500	:	:	:	:	:	:	:
*EXPONENT	: 3	: 3	:	:	:	:	:	:	:
UNITS	: MT ORE	: MT ORE	:	:	:	:	:	:	:
MATRIX REF.	: 1	: 2	:	:	:	:	:	:	:
COLUMN REF.	: 1	: 1	:	:	:	:	:	:	:
YEAR O. INFO	: 1978	: 1978	:	:	:	:	:	:	:
DATE OF LAST	:	:	:	:	:	:	:	:	:
MODIFICATION	: 780809	: 780809	:	:	:	:	:	:	:

\*ALL QUANTITIES ARE EXPRESSED TIMES 10 TO THIS POWER FOR A GIVEN COLUMN.

\*\*UNIDENTIFIABLE AS MEASURED, INDICATED, OR INFERRED

GRADE ASSAY/FORM	: REC 1	: REC 2	: REC 3	: REC 4	: REC 5	: REC 6	: REC 7	: REC 8	: REC 9	GRADE UNITS	MINERAL	DATE OF LAST MODIFICATION	LINE NO.
CU	: .70	:	:	:	:	:	:	:	:	WT-PCT	9-SULFIDE	JUL 03, 1978	01
MO	: .02	:	:	:	:	:	:	:	:	WT-PCT	9-SULFIDE	JUL 03, 1978	02
AG	: 1.091	:	:	:	:	:	:	:	:	G/MT		DEC 05, 1978	03
AU	: .0612	:	:	:	:	:	:	:	:	G/MT		DEC 05, 1978	04
CU	:	: 0.72	:	:	:	:	:	:	:	WT-PCT	9-SULFIDE	AUG 09, 1978	01
MO	:	: 0.02	:	:	:	:	:	:	:	WT-PCT	9-SULFIDE	AUG 09, 1978	02
AG	:	: 1.091	:	:	:	:	:	:	:	G/MT		DEC 05, 1978	03
AU	:	: .0612	:	:	:	:	:	:	:	G/MT		DEC 05, 1978	04

RESERVES - REMARKS

COL: 01 SAN MANUEL OREBODY  
COL: 02 KALAMAZOO ORE BODY

%

MINERALS AVAILABILITY SYSTEM  
DEPOSIT LISTING

DATE PRINTED: MAR 22, 1979

PAGE 562

DEPOSIT NAME: SAN MANUEL / KALAMAZOO

SEQUENCE NUMBER: 0040210001

>>>> GEOMETRY - DATA SET <<<<

MATRIX NUMBER: 1 COLUMN NUMBER: 1

TYPE OF ORE BODY: DISSEMINATED: STOCKWORK  
MODE OF ORIGIN: HYDROTHERMAL : OXIDATION  
SHAPE OF ORE BODY: MASSIVE  
ORE CONTROLS: IGNEOUS : FAULTING  
DEGREE OF WALLROCK ALTERATION: MODERATE  
TYPE OF WALLROCK ALTERATION:  
POTASSIC

DEPTH TO MINERALIZATION (IN METERS)  
AVERAGE: 201 MINIMUM:  
THICKNESS OF UNCONSOLIDATED MATERIAL (IN METERS)  
AVERAGE: MINIMUM:  
AVERAGE DIMENSIONS OF MINERALIZATION (IN METERS)  
LENGTH: 2440 WIDTH: 1140 THICKNESS: 366  
STRIKE AND DIP OF MINERALIZED ZONE: N61S:50S

MATRIX NUMBER: 2 COLUMN NUMBER: 1

TYPE OF ORE BODY: DISSEMINATED: STOCKWORK  
MODE OF ORIGIN: HYDROTHERMAL : OXIDATION  
SHAPE OF ORE BODY: MASSIVE  
ORE CONTROLS: IGNEOUS  
DEGREE OF WALLROCK ALTERATION: MODERATE  
TYPE OF WALLROCK ALTERATION:  
POTASSIC

DEPTH TO MINERALIZATION (IN METERS)  
AVERAGE: 750 MINIMUM: 854  
THICKNESS OF UNCONSOLIDATED MATERIAL (IN METERS)  
AVERAGE: 213 MINIMUM:  
AVERAGE DIMENSIONS OF MINERALIZATION (IN METERS)  
LENGTH: 2440 WIDTH: 1140 THICKNESS: 366  
STRIKE AND DIP OF MINERALIZED ZONE: N55E:15S

>>>> LITHOLOGY - DATA SET <<<<

MATRIX NUMBER: RECORD NUMBER: 1

FORMATION NAME: IGNEOUS INTRUSIVE  
AGE O FORMATION: U CRET  
DENSITY (IN SITU): 2.6

RELATIONSHIP OF MINERALIZATION TO DEFORMATION: MIN PRECEDING DEF  
DEFORMATION DESCRIPTION: MAJ FAULTING  
AGE OF DEFORMATION: PALEOC

>>>> MINERALS - DATA SET <<<<

MAT #	RFC NO.	AGE OF MINERALIZATION	OVERALL GRAIN SIZE	NAME	CLASS	GRAIN SIZE	AMOUNT	UNITS
	02	PALEOC	VARIABLE	CHALCOCITE	SULFIDES	VARIABLE		WT-PCT
	03	PALEOC	VARIABLE	CHRYSOCOLLA	SILICATES	VARIABLE		WT-PCT
	04	PALEOC	VARIABLE	CUPRITE	OXIDES (EXCLUDING SiO2)			WT-PCT
	05	PALEOC	VARIABLE	MOLYBDENITE	SULFIDES		0.02	WT-PCT
	06	PALEOC	VARIABLE	GOLD			13	G/MT
	07	PALEOC	VARIABLE	SILVER		UNKNOWN	294	G/MT
1	01	PALEOC	VARIABLE	CHALCOPYRITE	SULFIDES	VARIABLE	0.70	WT-PCT
2	01	PALEOC	VARIABLE	CHALCOPYRITE	SULFIDES	VARIABLE	0.72	WT-PCT

>>>> BIBLIOGRAPHY - DATA SET <<<<

SET REFERENCE LINE NO.

SAN MANUEL'S NEW PROCESS FOR THE RECOVERY OF MOLYBDENITE

001

%

DATE PRINTED: MAR 22, 1979

DEPOSIT NAME: SAN MANUEL / KALAMAZOO

MINERALS AVAILABILITY SYSTEM  
DEPOSIT LISTING

PAGE 563

450

SEQUENCE NUMBER: 0040210001

>>>> BIBLIOGRAPHY - DATA SET <<<<

SET REFERENCE LINE NO.

002 BY HARRY K. BURKE AND JOSEPH F. SHIRLEY, SOCIETY OF MINING  
003 ENGINEERS, PREPRINT NO. 65810, 1965.  
004 NEWMONT MINING PROSPECTUS, 5-5-69. TONS AND GRADE  
005 FROM PUBLIC RELATIONS DEPT.: "THE PLANT" AND "THE MINE"  
006 GENERAL INFORMATION PUBLICATIONS - EXCELLENT INFORMATION  
007 MAGMA FACTS - 7-1-77, COMPANY LITERATURE  
008 LATERAL AND VERTICAL ALTERATION-MINERALIZATION ZONING  
009 IN PORPHYRY ORE DEPOSITS BY J. DAVID LOWELL AND JOHN M.  
010 GUILBERT FROM ECONOMIC GEOLOGY, JUNE-JULY, 1970, NO. 4.  
012 ORE TRANSPORTATION AT SAN MANUEL BY C.F. CIGLIANA,  
013 MAY, 1958, MINING ENGINEERING.  
014 MINING, MILLING, AND SMELTING METHODS, SAN MANUEL COPPER  
015 CORP., PINAL COUNTY, ARIZONA, BY V.B. DALE, BUREAU OF MINES  
016 I.C. 8104, 1962.  
017 HISTORY AND DEVELOPMENT OF THE SAN MANUEL MINE BY JOHN F.  
018 BUCHANAN AND FRANK H. BUCHELLA FROM: AIME VOL. 217,  
019 FEBRUARY, 1960.  
020 SAN MANUEL-ENGINEERING AND MINING JOURNAL, APRIL, 1956, P.75

## 18 MINERAL RESOURCES FILE 10

## RECORD IDENTIFICATION

RECORD NO..... W019536  
RECORD TYPE..... L  
COUNTRY/ORGANIZATION. USGS  
DEPOSIT NO..... 147  
MAP CODE NO. OF REC..

## REPORTER

NAME: MILLER, PAT J.  
DATE: 74 04

## NAME AND LOCATION

DEPOSIT NAME..... CRESCENT MINE  
SYNONYM NAME..... HOOPER TUNNEL

MINING DISTRICT/AREA/SUBDIST. COEUR D' ALENE DISTRICT

COUNTRY CODE..... US

STATE CODE..... 16

COUNTY..... SHOSHONE

DRAINAGE AREA..... 17 BIG CH., COEUR D' ALENE R

PHYSIOGRAPHIC PROV..... 08 COEUR D' ALENE MTNS

LAND CLASSIFICATION..... 01

QUAD SCALE QUAD NO OR NAME  
1: 250000 SPOKANE

LATITUDE LONGITUDE  
47-30-20N 116-04-23W

ALTITUDE.. 2691 FT

UTM NORTHING UTM EASTING UTM ZONE NO  
5261560. 569800. +11

TWP..... 048N  
RANGE..... 003E  
SECTION.. 16 17  
MERIDIAN. ROISE

POSITION FROM NEAREST PROMINENT LOCALITY: ADJOINS NW OSBURN

## COMMODITY INFORMATION

COMMODITIES PRESENT: U CU AG PB ZN

## SIGNIFICANCE:

MAJOR..... AG CU  
MINOR.....

EXHIBIT 2. Printout of data on the Crescent Mine from the CRIB database, compiled by U.S. Geological Survey, computer searches by University of Oklahoma, Norman, Oklahoma.

452      COPRODUCT..  
          BYPRODUCT..  
          POTENTIAL..  
          OCCURRENCE.    U

ORE MATERIALS (MINERALS, ROCKS, ETC.):

PITCHBLFNDE OR URANINITE; CHALCOPYRITE; TETRAHEDRITE; GALENA; SPHALERITE

COMMODITY COMMENTS:

MINE IS IN THE PAGE - GALENA MINERAL BELT. AVERAGED 55 OZ. AG/TON ON  
3300 - 3500 FT LEVELS.

ANALYTICAL DATA (GENERAL)

2 CHANNEL SAMPLES BY USGS ASSAYED 0.026 % U AND 0.048 % U; 0.633 % U3O8  
HIGHEST ASSAY; 0.19 % U3O8 AVERAGE U CONTENT.

INERAL ECONOMICS FACTORS

ECONOMIC COMMENTS:

BECAUSE OF CONTINUING DECLINE IN GRADE OF ORE MINED, B. H. EXPECTS  
CRESCENT MINE OPERATIONS DISCONTINUED AT END OF 1975

XPLORATION AND DEVELOPMENT

STATUS OF EXPLOR. OR DEV.

4

PROPERTY IS ACTIVE

YEAR OF DISCOVERY..... 1888 ?

NATURE OF DISCOVERY..... A

PRESENT/LAST OWNER..... THE BUNKER HILL CO.

PRESENT/LAST OPERATOR.... THE BUNKER HILL CO.

WORK DONE BY USGS

YEAR    WORK TYPE    GEOLOGIST AND RESULTS

1) 1953    GEOCHEM    F. C. ARMSTRONG

2) 1958    RECON    WEIS AND OTHERS, BULL. 1074 - B

3) 1964    OTHER    V. C. FRYKLUND, PROF. PAPER 445

WORK DONE BY OTHER ORGANIZATIONS

YEAR    WORK TYPE    ORGANIZATION AND RESULTS

1) 1975    COMPILE    USBM, 1974 MINING ACTIVITIES LIST

EXPLOR. AND DEVELOP. COMMENTS:

7 PATENTED CLAIMS.    DIAMOND DRILLING

DESCRIPTION OF DEPOSIT

DEPOSIT TYPES:

VEIN

FORM/SHAPE OF DEPOSIT:

SIZE/DIRECTIONAL DATA

SIZE OF DEPOSIT..... LARGE

DEPTH TO BOTTOM..... 5100    FT

MAX LENGTH..... 750    FT

MAX THICKNESS..... 2    FT

STRIKE OF OREBODY.... N 75 DEG W

453

DIP OF OREBODY..... 80 DEG S

COMMENTS(DESCRIPTION OF DEPOSIT):

LOWER ALHAMBRA VEIN (SIDERITE - TETRAHEDRITE) FIRST DISCOVERED 400 FT  
BELOW SEA LEVEL

DESCRIPTION OF WORKINGS  
UNDERGROUND

DESCRIP. OF UNDERGRND WORKINGS

DEPTH OF WORKINGS BELOW SURFACE. -1400 FT

LENGTH OF WORKINGS..... 2452 FT

DESCRIP. OF OPEN WORKINGS (SURFACE OR UNDERGRND)

COMMENTS(DESCRIP. OF WORKINGS):

DEPTH OF WORKINGS 1400 FT BELOW SEA LEVEL. MINE DEEPENED TO 4000 FT  
LEVEL IN 1970 . LENGTH OF WORKINGS GIVEN ABOVE FOR DEVELOPMENT BY 1966

PRODUCTION

YES

MEDIUM PRODUCTION

ANNUAL PRODUCTION (ORE AND COMMODITIES)

ITEM	ACC	AMOUNT	THOUS.UNITS	YEAR	GRADE OR USE
1 AG	ACC 00001400	OZ		1967	
2 AG	ACC 0816.771	OZ		1966	
3 ORE	ACC 00000025	TONS		1967	
4 ORE	SML			1966	40 OZ AG/TON

SOURCE OF INFORMATION.. SPOKANE CHRONICLE, JAN. 20 , 1969 ; MAY 20 . 1968 ;  
MAR. 17 , 1967

RESERVES ONLY

ITEM	ACC	AMOUNT	THOUS.UNITS	YEAR	GRADE OR USE
1 ORE AG	EST 00000023	TONS		1974	28.4 OZ AG/TON; PROVEN
2 ORE AG	EST 000036.5	TONS		1974	28.4 OZ AG/TON; PROBABLE
3 ORE AG	EST 000027.6	TONS		1973	34.3 OZ AG/TON; PROVEN
4 ORE AG	EST 000012.3	TONS		1973	34.3 OZ AG/TON; PROBABLE
5 ORE AG	EST 000031.1	TONS		1972	29.4 OZ AG/TON; PROVEN
6 ORE AG	EST 000024.3	TONS		1972	29.4 OZ AG/TON; PROBABLE

SOURCE OF INFORMATION GULF RESOURCES 1974 ANNUAL REPT.

GEOLOGY AND MINERALOGY

AGE/NAMES OF HOST ROCKS..... PREC QUARTZITE

PERTINENT MINERALOGY..... CALCITE; QUARTZ; SIDERITE

IMPORTANT ORE CONTROL OR LOCUS..... FAULT

## GEOLOGY (SUPPLEMENTARY INFORMATION)

## REGIONAL GEOLOGY

MAJOR REGIONAL STRUCTURES.. OSBURN FAULT

## LOCAL GEOLOGY

## AGE/NAMES OF FORMATIONS OR ROCK TYPES

- 1) PREC ST. REGIS FORMATION - QUARTZITE, ARGILLITE
- 2) PREC WALLACE FORMATION - CALC. QUARTZITE, ARGILLITE

## SIGNIFICANT LOCAL STRUCTURES:

ALHAMBRA FAULT, BRECCIATION

## SIGNIFICANT ALTERATION:

FE - OXIDES, SERICITE, PYRITE

## GENERAL REFERENCES

- 1) COOK, E. F., 1955 , PROSPECTING FOR URANIUM, THORIUM, AND TUNGSTEN IN IDAHO: IDAHO BUR. MINES AND GEOLOGY PAMPH. 102 , 53 P.
- 2) WEIS, P. L., ARMSTRONG, F. C., AND ROSENBLUM, S., 1958 , RECONNAISSANCE FOR RADIOACTIVE MINERALS IN WASHINGTON, IDAHO, AND WESTERN MONTANA, 1952 - 1955 : U.S. GEOL. SURVEY BULL. 1074 - B, 48 P.
- 3) FRYKLUND, V. C., JR., 1964 , ORE DEPOSIT OF THE COEUR D' ALENE DISTRICT, SHOSHONE COUNTY, IDAHO: USGS PROF. PAPER 445 , 103 P.
- 4) USRM, 1975 , ACTIVITY OF IDAHO MINING PROPERTIES, 1974 , USBM, BOISE, 61 P.
- 5) SPOKANE CHRONICLE, FEB. 24 , 1972 ; MAY 25 , 1970 ; AP. 18 , 1967; MAR. 27, 1975
- 6) WESTERN MINING NEWS, 1974 - 75 DIRECTORY OF MINES IN IDAHO (COEUR D' ALENES) AND WASHINGTON, P. 33

-1-  
 ACCESSION NUMBER 77-39103  
 TITLE Preliminary geologic map of the Leadville 1 degrees X 2 degrees quadrangle, northwestern Colorado  
 AUTHORS Tweto, O.; Moench, R. H.; Reed, J. C., Jr.  
 SOURCE U. S. Geol. Surv., Misc. Field Stud. Map (USA) (XMFSDD), No. MF-760, unpaginated p., 1976, geol. map, SCALE: 1:250,000  
 DOCUMENT TYPE S (Serial); MON (Monographic)  
 ISSUE 77-37721 (Bibliography and Index of Geology)  
 CATEGORY CODES 2-14 (Areal geology, maps & charts)  
 INDEX TERMS Grant County; Garfield County; Eagle County; Lake County; Summit County; Mesa County; Pitkin County; Rio Blanco County; \*Colorado; areal geology; \*maps; northwest; Leadville Quadrangle; United States; geologic.  
 COORDINATES N390000; W1060000; W1080000.

-2-  
 ACCESSION NUMBER 77-33023  
 TITLE Preliminary map of landslide deposits, Leadville 1 degrees by 2 degrees quadrangle, Colorado  
 AUTHORS Colton, R. B.; Holligan, J. A.; Anderson, L. W.; Patterson, P. E.  
 SOURCE U. S. Geol. Surv., Misc. Field Stud. Map (USA) (XMFSDD), No. MF-701, unpaginated p., 1975, environ. geol. map, SCALE: 1:250,000  
 DOCUMENT TYPE S (Serial); MON (Monographic)  
 ISSUE 77-33696 (Bibliography and Index of Geology)  
 CATEGORY CODES 2-14 (Areal geology, maps & charts)  
 INDEX TERMS Chaffee County; Delta County; Eagle County; Garfield County; Grand County; Gunnison County; Lake County; Mesa County; Park County; Pitkin County; Rio Blanco County; Routt County; Summit County; \*Colorado; environmental geology; geologic hazards; landslides; \*maps; northwest; Leadville Quadrangle; United States.  
 COORDINATES N390000; W1060000; W1080000.

-3-  
 ACCESSION NUMBER 77-31991  
 TITLE Gravitational spreading of steep-sided ridges ('sackung') in Colorado  
 AUTHORS Radbruch-Hall, D. H.; Varnes, D. J.; Colton, R. B.  
 ORGANIZATIONAL SOURCE U. S. Geol. Surv. Menlo Park, Calif. USA  
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EXHIBIT 3. Bibliographic references dealing with the Leadville quadrangle, Colorado (from the GeoRef database on SDC Search Service).





APPENDIX 2. MINES IN CRYSTALLINE ROCKS  
CONSIDERED FOR STUDY

Table 1 lists by state the numbers of underground mines, mines in rocks other than crystalline and metamorphic, and mines in crystalline or metamorphic rock. Also listed are the numbers of class 1 and class 2 mines and civil works by state.

The 285 mines and mining districts considered for study for this report are listed in table 2 in alphabetical order by mine name. Also included are the state and county in which each mine is located.

TABLE 1. Quantitative summary by state of underground sites reviewed and selected for study.\*

State	Original total	Surface and underground mines	Mines not in crystalline rock	Mines in crystalline rock	Total mines in crystalline rock (from all sources)†	Sites selected based on criteria			Total sites
						Class 1 mines	Class 1 civil works	Class 2 mines	
ALABAMA	93	39	6	33	33	-	-	-	-
ALASKA	62	40	2	38	38	-	-	-	-
ARIZONA	92	58	10	48	52	3	-	2	5
ARKANSAS	26	19	3	16	3	-	-	-	-
CALIFORNIA	351	258	53	205	210	1	1	1	3
COLORADO	1444	1312	1088	224	238	4	-	1	5
CONNECTICUT	8	7	-	7	7	-	-	-	-
DELAWARE	--	--	--	--	--	-	-	-	-
FLORIDA	104	--	--	--	--	-	-	-	-
GEORGIA	21	2	--	2	3	-	-	-	-
HAWAII	4	--	--	--	--	-	-	-	-
IDaho	163	155	53	102	128	4	1	2	7
ILLINOIS	52	47	46	1	1	-	-	-	-
INDIANA	10	10	10	--	--	-	-	-	-
IOWA	5	5	5	--	--	-	-	-	-
KANSAS	53	53	53	--	--	-	-	-	-
KENTUCKY	55	49	45	4	4	-	-	-	-
LOUISIANA	4	4	4	--	--	-	-	-	-
MAINE	44	15	1	14	15	1	-	-	1
MARYLAND	26	14	2	12	12	-	-	-	-
MASSACHUSETTS	4	1	--	1	2	-	-	-	-
MICHIGAN	33	29	4	25	27	-	-	2	2
MINNESOTA	83	2	--	2	4	1	-	1	2
MISSISSIPPI	1	--	--	--	--	-	-	-	-
MISSOURI	313	245	240	5	15	-	-	-	-
MONTANA	265	224	4	220	228	-	-	2	6
NEBRASKA	4	4	--	--	--	-	-	-	-
NEVADA	168	128	49	79	97	1	1	7	9
NEW HAMPSHIRE	7	6	--	6	6	-	-	-	-
NEW JERSEY	11	10	1	9	10	2	-	-	3
NEW MEXICO	214	182	50	132	133	1	1	2	3
NEW YORK	15	11	6	5	7	2	-	-	2
NORTH CAROLINA	82	60	--	60	61	-	-	2	2
NORTH DAKOTA	--	--	--	--	--	-	-	-	-
OHIO	16	11	11	--	--	-	-	-	-
OKLAHOMA	119	116	116	--	--	-	-	-	-
OREGON	67	43	14	29	32	-	-	-	-
PENNSYLVANIA	36	26	12	14	14	-	-	-	-
RHODE ISLAND	--	--	--	--	--	-	-	-	-
SOUTH CAROLINA	8	4	--	4	4	-	-	-	-
SOUTH DAKOTA	85	66	25	41	41	1	1	1	1
TENNESSEE	209	137	132	5	10	-	-	1	1
TEXAS	14	11	8	3	3	-	-	-	-
UTAH	1318	1223	1056	167	172	-	-	3	3
VERMONT	9	6	--	6	8	-	-	-	-
VIRGINIA	28	24	16	8	8	-	-	-	-
WASHINGTON	92	80	47	33	41	1	-	3	4
WEST VIRGINIA	6	6	6	--	--	-	-	-	-
WISCONSIN	19	12	8	4	4	-	-	-	-
WYOMING	86	29	22	7	9	1	-	-	1
TOTALS	5929	4783	3225	1558	1679	26	4	30	60

\*Table based on data primarily from MAS and from: E/NJ Directory, 1977; Milne, 1978; Cobbs Engineering, 1976; Jamison, 1978; and CRIB, 1979.

†Includes information from the literature, private communications, and other sources.

‡Ducktown District

Mines considered for study, listed alphabetically along with state and county.

Allouez Conglomerate No. 1., Michigan, Houghton Co.  
Allouez Conglomerate No. 2., Michigan, Houghton Co.  
Alta Mine, Montana, Jefferson Co.  
Amador Mine, Montana, Mineral Co.  
Amalgamated Larder Mine, Nevada, Lincoln Co.  
Amazon Mine, Idaho, Shoshone Co.  
Amry Prospect, Nevada, Esmeralda Co.  
Apex Standard Mine, Utah, Utah Co.  
Arctic Camp, Alaska, Ambler River Co.  
Ashland Mine, Oregon, Jackson Co.  
Atlantic & Brighton, Colorado, Gilpin Co.  
Atlantic Mines, Wyoming, Fremont Co.  
Atolia District, California, San Bernardino, Kern Cos.  
Babbitt Lake Exploration Prospect, Minnesota, St. Louis Co.  
Babbitt Mine, Montana, Sanders Co.  
Bagdad Mine Area, Arizona, Yavapai Co.  
Balmat-Edwards District, New York, St. Lawrence Co.  
Balmat, New York, St. Lawrence Co.  
Baltic Amygdaloid, Michigan, Houghton Co.  
Banner Mine, Idaho, Boise Co.  
Bartholomae, Alaska, Fairbanks Co.  
Baxter Mine, Nevada, Mineral Co.  
Black Cloud, Colorado, Lake Co.  
Black Hawk (Second Pond) - Blue Hill Mine, Maine, Hancock Co.  
Black Pine Mine, Montana, Granite Co.  
Black Rock Mine, California, Mono Co.  
Blackbird Mine, Idaho, Lemhi Co.

**Block P Mine, Montana, Judith Basin Co.**

Boise-Rochester Mine, Idaho, Elmore Co.

**Borianna Mine, Arizona, Mohave Co.**

Bornite, Alaska, Ambler River Co.

Boyd Mine, Tennessee, Polk Co.

Brushy Creek Mine, Missouri, Reynolds Co.

Buffalo Mine, Idaho, Elmore Co.

Buick Mine, Missouri, Iron Co.

Bulldog Mountain Project, Colorado, Mineral Co.

Bullion District, Nevada, Lander Co.

Bunker Hill Mine, Idaho, Shoshone Co.

Burgin Mine, Utah, Utah Co.

Burra Burra Mine, Tennessee, Polk Co.

Burro Chief Mine, New Mexico, Grant Co.

Butte Manganese District, Montana, Silver Bow Co.

Butte Highlands Mine, Montana, Silver Bow Co.

Butte Mining District and Butte Underground Mines, Mont., Silver Bow Co.

Cago No. 12, Idaho, Lemhi Co.

Calera Mine, Idaho, Lemhi Co.

Calloway Mine, Tennessee, Polk Co.

Calumet, No. 1, Michigan, Houghton Co.

Calumet, No. 2, Michigan, Houghton Co.

**Campbird Mine, Colorado, Ouray Co.**

Canisteo Mine, Minnesota, Itasca Co.

Carr Fork Mine, Utah, Tooele Co.

Centennial, No. 3-6, Michigan, Houghton Co.

Cherokee Mine, Tennessee, Polk Co.

Chief Mine, Utah, Juab Co.

Christmas Mine, Arizona, Gila Co.  
Clayton Mine, Idaho, Custer Co.  
Climax Mine, Colorado, Lake Co.  
Coeur Mine, Idaho, Shoshone Co.  
Colorado School of Mines Mine, Colorado  
Conjecture Mine, Idaho, Bonner Co.  
Consolidated Silver, Idaho, Shoshone Co.  
Constitution Mine, Idaho, Shoshone Co.  
Continental Underground, New Mexico, Grant Co.  
Copper Camp, Idaho, Valley Co.  
Copper Hill Operations, Tennessee, Polk Co.  
Copper King, Arizona, Yavapai Co.  
Cornwall Mine, Pennsylvania, Lebanon Co.  
Cranberry Magnetite, North Carolina, Avery Co.  
Crescent, Idaho, Shoshone Co.  
Croton Magnetite Iron Mine, New York, Putnam Co.  
Crowell Mine, Nevada, Nye Co.  
Culchote, Tennessee, Polk Co.  
Cuyuna Range Exploration Prospect, Minnesota, Crow Wing Co.  
Dacotah Mine, Montana, Cascade Co.  
Dan Tucker Mine, Nevada, Churchill Co.  
Darwin Mine, California, Inyo County  
Dayrock Mine, Idaho, Shoshone Co.  
Deep Creek Mine, Washington, Stevens Co.  
Deer Trail Mine, Utah, Juab Co.  
Douglas Mine, Idaho, Shoshone Co.  
Ducktown District, Tennessee, Polk Co.  
Eagle Mine, Colorado, Gilman Co.

East Tennessee, Tennessee, Polk Co.  
Edwards, New York, St. Lawrence Co.  
Elizabeth Mine, Vermont, Orange Co.  
Elmwood No. 1, Tennessee, Polk Co.  
Ely Prospect, Minnesota, Lake Co.  
Eureka Bullion Mine, Utah, Utah Co.  
Eureka Lily Mine, Utah, Utah Co.  
Eureka Mine, Tennessee, Polk Co.  
Eureka Standard Mine, Utah, Utah Co.  
Fletcher Mine, Missouri, Reynolds Co.  
Florence Mine, Montana, Cascade Co.  
Frisco Mine, Idaho, Shoshone Co.  
Galena Unit, Idaho, Shoshone Co.  
Galt-Queen, Montana, Cascade Co.  
Georgia Mine, Georgia, Chatsworth Co.  
Germania Mine, Washington, Stevens Co.  
Getchell Mine, Nevada, Humboldt Co.  
Gilman Mine, Colorado, Eagle Co.  
Gold Hunter Mine, Idaho, Shoshone Co.  
Golden Sunbeam, Idaho, Custer Co.  
Gooseberry Mine, Nevada, Storey Co.  
Grace Mine, Pennsylvania, Berks Co.  
Granite-Bimetallic Mine, Montana, Granite Co.  
Gregory, Montana, Jefferson Co.  
Grey Eagle, California, Siskiyou Co.  
Grey Eagle Mine, Montana, Jefferson Co.  
Ground Hog Mine, New Mexico, Grant Co.  
Hall-Interstate Mine, Idaho, Valley Co.

Hamme Tungsten District, Tungsten Queen, North Carolina, Vance Co.

Hanover Mine, New Mexico, Grant Co.

Hecla Mine, Idaho, Shoshone Co.

Henderson, Colorado, Grand & Clear Creek Cos.

Hercules Mine, Idaho, Shoshone Co.

Highland-Surprise Mine, Idaho, Shoshone Co.

Hillside Mine, Arizona, Yavapai Co.

Holden Mine, Washington, Chelan Co.

Homestake Mine, South Dakota, Lawrence Co.

Hoo Doo, Idaho, Custer County

Houghton No. 1., Michigan, Houghton Co.

Hyatt, New York, St. Lawrence

Idarado Mine, Colorado, Ouray & San Miguel Cos.

Ilmenite Mines on Anorthosites, New York

Ima Mine, Idaho, Lemhi Co.

Imuruk Basin Graphite, Alaska, Teller Co.

Independence Mine, Nevada, Lander Co.

Indian Creek Div., Missouri, Washington Co.

Indiana, Michigan, Ontonagon Co.

Iron Dyke Mine, Oregon, Baker Co.

Iron King Mine, Utah, Utah Co.

Iron Mountain, Missouri, St. Francois Co.

Iroquois, Michigan, Keweenaw Co.

Isabella, Tennessee, Polk Co.

Jefferson City Mine, Tennessee, Polk Co.

Johnson Mine, Vermont, Lamoille Co.

Jualin, Alaska, Juneau Co.



Kalamazoo, Arizona, Pinal Co.

Kearsarge Amygdaloid No. 1., Michigan, Houghton Co.

Kearsarge Amygdaloid No. 2., Michigan, Houghton Co.

Kentuck Mine, Idaho, Lemhi Co.

Kerr American Blue Hill Joint Venture, Maine, Hancock Co.

Keystone Mine, Colorado, Gunnison County

Kingston, Michigan, Keweenaw Co.

Kingston, No. 1, Michigan, Houghton Co.

Kingston, No. 2, Michigan, Houghton Co.

Lakeshore Mine, Arizona, Pinal Co.

Last Resort Vein, Idaho, Custer Co.

Latest Out Mine, Idaho, Lemhi Co.

Leadville Unit, Colorado, Lake Co.

Liberal King Mine, Idaho, Shoshone Co.

Little Pittsburg Mine, Idaho, Shoshone Co.

London, Tennessee, Polk Co.

Lost Packer Mine, Idaho, Custer Co.

Lost Pilgrim Mine, Idaho, Valley Co.

Lost River, Alaska, Teller Co.

Lower Mammoth Mine, Utah, Juab Co.

Lucky Friday Mine, Idaho, Shoshone Co.

Lyon Mountain District New York, Clinton Co.

Magma, (Superior) Mine, Arizona, Pinal Co.

Magmont Mine, Missouri, Iron Co.

Mary, Tennessee, Polk Co.

Mather Mine, Michigan, Marquette Co.

Mather B. Mine, Michigan, Marquette Co.

Mayflower Mine, Utah, Wasatch Co.

McCarty, Alaska, Livengood Co.

Mermac Mines, Nevada, White Pine Co.

Miami East, Arizona, Gila Co.

Middle Fork Property, Washington, King Co.

Midnite Mine, Washington, Stevens Co.

Mill City, Nevada, Pershing Co.

Minnamax Site, Minnesota, St. Louis Co.

Minnie Moore Mine, Idaho, Blaine Co.

Miscellaneous Amygdaloids No. 1, Michigan, Houghton Co.

Miscellaneous Amygdaloids No. 2, Michigan, Houghton Co.

Miscellaneous Fissure No. 1, Michigan, Houghton Co.

Miscellaneous Fissures No. 2, Michigan, Houghton Co.

Monarch Mine, Idaho, Elmore Co.

Monitor Mine, Idaho, Shoshone Co.

Morning Mine, Idaho, Shoshone Co.

Mt. Hope Iron Mine, New Jersey, Morris Co.

New Light Mine, Washington, Whatcom Co.

New Market Mine, Tennessee, Jefferson Co.

North Lily Mine, Utah, Utah Co.

North Pole-Columbia Lode Mine, Oregon, Baker Co.

Old Dick, Arizona, Yavapai Co.

Old Tennessee, Tennessee, Polk Co.

Old Timer Mine, Nevada, White Pine Co.

Ontario Mine, Utah, Summit Co.

Ophir Mine, Utah, Tooele Co.

Oracle Ridge, Arizona, Pima Co.

Ore Knob Mine, North Carolina, Ashe Co.

Oriental Mine, California, Sierra Co.  
Osceola No. 1, Michigan, Houghton Co.  
Osceola No. 2, Michigan, Houghton Co.  
Ozark Mine, Missouri, Reynolds Co.  
Pacific, Utah, Utah Co.  
Page Mine, Idaho, Shoshone Co.  
Pan American Mine, Nevada, Lincoln Co.  
Park City Mine, Utah, Summit Co.  
Patapsco Mines, Maryland, Carroll Co.  
Pend Oreille Mine, Washington, Pend Oreille Co.  
Pewabic No. 1, Michigan, Houghton Co.  
Pewabic No. 2, Michigan, Houghton Co.  
Phi Kappa Mine, Idaho, Custer Co.  
Piedmont Manganese Belt, Ga - Sc., Georgia, Lincoln Co.  
Pilot Knob Mine, Missouri, Iron Co.  
Pine Creek Mine, California, Inyo Co.  
Pittsburg-Idaho Mine, Idaho, Lemhi Co.  
Polk County, Tennessee, Polk Co.  
Poorman Mine, Idaho, Owyhee Co.  
Questa Mine, New Mexico, Taos Co.  
Records Vault, Utah-Little Cottonwood Canyon, Salt Lake Co.  
Red Bluff, Idaho, Valley Co.  
Red Mountain, Montana, Lewis & Clark Co.  
Red Mountain Property, Arizona, Santa Cruz Co.  
Resurrection Mine, Colorado, Lake Co.  
Rich Gulch Mine, Idaho, Owyhee Co.  
Robinson District, Nevada, White Pine Co.

Rock Creek, Montana, Sanders Co.  
Ruby Hill Mine, Nevada, Eureka Co.  
Safford Phelps Dodge, Arizona, Graham Co.  
San Francisco District, Utah, Beaver Co.  
San Manuel, Arizona, Pinal Co.  
San Pedro Mine, New Mexico, Valencia Co.  
Schwartzwalder Mine, Colorado, Jefferson Co.  
Scrub Oaks, New Jersey, Morris Co.  
Searchlight District, Nevada, Clark Co.  
Seneca, Michigan, Keweenaw Co.  
September Group, California, Mono Co.  
Sherman Mine, Colorado, Lake Co.  
Sherman Mine, Idaho, Shoshone Co.  
Sherwood Mine, Michigan, Iron Co.  
Sherwood Mine, Washington, Stevens Co.  
Shrine Mine, New Mexico, Grant Co.  
Sidney Mine, Idaho, Shoshone Co.  
Silver City Region, Idaho, Owyhee Co.  
Silver Crystal Mine, Idaho, Shoshone Co.  
Silver Dyke, Nevada, Mineral Co.  
Silver King Mines, Nevada, Lander Co.  
Silverton Operations, Colorado, San Juan Co.  
Sixteen-to-one Mine, Nevada, Esmeralda Co.  
Snowbird, Idaho, Valley Co.  
Soudan Mine, Minnesota, Saint Louis Co.  
South Mountain Mine, Idaho, Owyhee Co.  
Springfield Mine, Maryland, Carroll Co.

St. Patrick Mining Co., Nevada, Lincoln Co.  
Standard-Mammoth Mine, Idaho, Shoshone Co.  
Star-Morning Mine, Idaho, Shoshone Co.  
Star Mine, Idaho, Shoshone Co.  
Steen Mine, Idaho, Lemhi Co.  
Sterling Mine, New Jersey, Sussex Co.  
Success Mine, Idaho, Shoshone Co.  
Sullivan Operations, Missouri, Washington Co.  
Summit King Mine, Nevada, Churchill Co.  
Sunbeam Mine, Utah, Juab Co.  
Sunrise Breccia Deposit, Washington, Snohomish Co.  
Sunrise, Wyoming, Platte Co.  
Sunset Mine, Idaho, Shoshone Co.  
Sunset Mine, Washington, Snohomish Co.  
Sunshine Mine, Idaho, Shoshone Co.  
Superior Mine, Arizona, Pinal Co.  
Sutton No. 2 Mine, Nevada, Pershing Co.  
Tag Mine, Nevada, Pershing Co.  
Tamarack Mine, Idaho, Shoshone Co.  
Taylor Mine, Nevada, White Pine Co.  
Tem Piute Operations, Nevada, Lincoln Co.  
Tennessee Mines Div., Tennessee, Knox & Jefferson Co.  
Thomas "W" Mine, Nevada, Lander Co.  
Tiger-Poorman Mine, Idaho, Shoshone Co.  
Tilly Foster Magnetite Mine, New York, Putnam Co.  
Tintic Standard Mine, Utah, Utah Co.  
Trixie Mine, Utah, Utah Co.  
Troy Mine, Montana, Lincoln Co.

Tungsten Group, Nevada, Pershing Co.  
Tungsten Queen Mine, North Carolina, Vance Co.  
Twenty-one Mine, New Mexico, Valencia Co.  
Twenty-seven Mine, New Mexico, Valencia Co.  
United Copper Claim, Washington, Stevens Co.  
Unity Mine, Idaho, Idaho Co.  
Urad Mine, Colorado, Ouray Co.  
Viburnum Div., Missouri, Iron Co.  
Ward Mountain Mine, Nevada, White Pine Co.  
White Pine Mine, Michigan, Ontonagon Co.  
Whitedelph Mine, Idaho, Bonner Co.  
Woodrat Mountain Kyanite Prospect, Idaho, Idaho Co.

