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SURVEY OF EXISTING UNDERGROUND OPENINGS FOR IN-SITU EXPERIMENTAL FACILITIES

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SUMMARY

In an earlier project, a literature search identified 60 underground openings in crystalline rock capable of providing access for an in-situ experimental facility to develop geomechanical and hydrological techniques for evaluating sites for radioactive waste isolation. As part of the current project, discussions with state geologists, owners, and operators narrowed the original group to 14. Three additional sites in volcanic rock and one site in granite were also identified. Site visits and application of technical criteria, including the geologic and hydrologic settings and depth, extent of the rock unit, condition, and accessibility of underground workings, determined four primary candidate sites: the Helms Pumped Storage Project in granodiorite of the Sierra Nevada, California; the Tungsten Queen Mine in Precambrian granodiorite of the North Carolina Piedmont; the Mount Hope Mine in Precambrian granite and gneiss of northern New Jersey; and the Minnamax Project in the Duluth gabbro complex of northern Minnesota.

Other granitic rock sites are considered to be of lower priority because they are too shallow, above or near the water table, have large water inflows, or are associated with a dam site where reservoir levels fluctuate and underground access is restricted. Rock masses at schistose rock sites are heterogeneous; and, in one case, the hydrologic setting is not favorable.

Volcanic rock sites and diversion tunnels at dams in the western Cascade Range of Oregon also have heterogeneous rock conditions in alternating andesitic or basaltic and tuffaceous sequences and are therefore not considered suitable for experimental facility sites. There appear to be no existing

underground openings in unmineralized tuffaceous rock with the exception of the "G" tunnel on the Nevada Test Site. Therefore, if experiments are to be conducted in basaltic rock or tuff, activities should be incorporated with future Department of Energy tests in facilities on the Hanford Reservation (in basalt) and at the Nevada Test Site (in tuff).

It is recommended that a program of horizontal core drilling be conducted which, combined with application of detailed logistical criteria, would determine two final candidate sites.

1. BACKGROUND

The initial effort to identify existing underground openings for in-situ experimental facilities in crystalline rock was a literature search conducted by LBL (Wollenberg et al., 1980). This search disclosed 26 mines and 4 underground civil works with potential as experimental facility sites ("Class 1") and 30 mines ("Class 2") that might have similar potential if more complete information could be obtained. The locations of these underground openings are shown in Figure 1. In this earlier investigation, we were constrained from contacting owners and operators of the underground workings to obtain the additional information needed to select the primary candidate sites from the list compiled.

The present investigation goes beyond the initial study in that its scope of work encompasses contacting state agencies and owners and operators of mines and civil works. We were able to obtain definitive information concerning the geologic and hydrologic settings of the sites, present operational status, and the extent and state of repair of surface and underground facilities and equipment. The present scope of work also expanded the categories of rock types to be investigated from crystalline rock (granitic and medium to high-grade metamorphic rock) to include tuffaceous rock and flood basalt.

As a result of contacting state geological survey groups, state divisions of mines, and owners and operators, the initial group of 60 sites was reduced to 14. To these were added three sites in volcanic rock and an additional granitic site, making a total of 18. A number of mines in the initial group, which had appeared promising because of their size and rock type, were removed

Key to location of underground workings identified in initial literature search as shown in Figure 1.

CLASS "1" MINES

Arizona
1. Lakeshore Mine
2. Miami East Mine
3. San Manual/Kalamazoo Mine

California
4. Pine Creek Mine

Colorado
5. Climax Mine
6. Schwartzwalder Mine
7. Urad/Henderson Mine
8. Colorado School of Mines, Experimental Mine

Idaho
9. Lost Packer Mine

Couer D'Alene District
10. Dayrock Mine
11. Star-Morning Mine
12. Coeur Mine

Maine
13. Black Hawk (Second Pond)-Blue Hill Mine

Minnesota
14. Minnamax Project

Montana
15. Black Pine Mine

Butte Mining District and Butte Underground Mines
16. Leonard Mine
17. Steward Mine

18. Granite-Bimetallic Mine

Nevada
19. Tem Piute District

New Jersey
20. Mount Hope and Scrub Oaks Mines

New Mexico
21. Questa Molybdenum Mine

New York
22. Balmat-Edwards District
23. Lyon Mountain District

South Dakota
24. Homestake Mine

Washington
25. Holden Mine

Wyoming
26. Sunrise Mine

CLASS "2" MINES

Arizona
27. Bagdad Mine
28. Oracle Ridge

California
29. Atolia District

Colorado
30. Black Cloud Mine

Idaho
31. Kentuck Mine
32. Silver City Region

Michigan
33. Indiana Mine
34. Iroquois Mine

Minnesota
35. Ely Prospect

Montana
36. Butte Highlands Mine
37. Dacotah Mine

Nevada
38. Gooseberry Mine
39. Mill City Mine
40. Ruby Hill Mine
41. Searchlight District
42. Summit King Mine
43. Sutton No. 2 Mine
44. Taylor Mine

New Jersey
45. Sterling Mine

New Mexico
46. Continental Underground
47. Groundhog Mine

North Carolina
48. Cranberry Magnetite
49. Tungsten Queen Mine

Tennessee
50. Ducktown District (Copperhill Mine)

Utah
51. Ontario Mine
52. Mayflower Mine
53. Park City Mine

Washington
54. Midnite Mine
55. Sherwood Mine
56. Sunrise Breccia Deposit

CIVIL WORKS

California
57. Helms Pumped Storage Project

Idaho
58. Dworshak Dam Site

Nevada
59. Nevada Test Site-Climax Stock

South Carolina
60. Bad Creek Pumped Storage Project

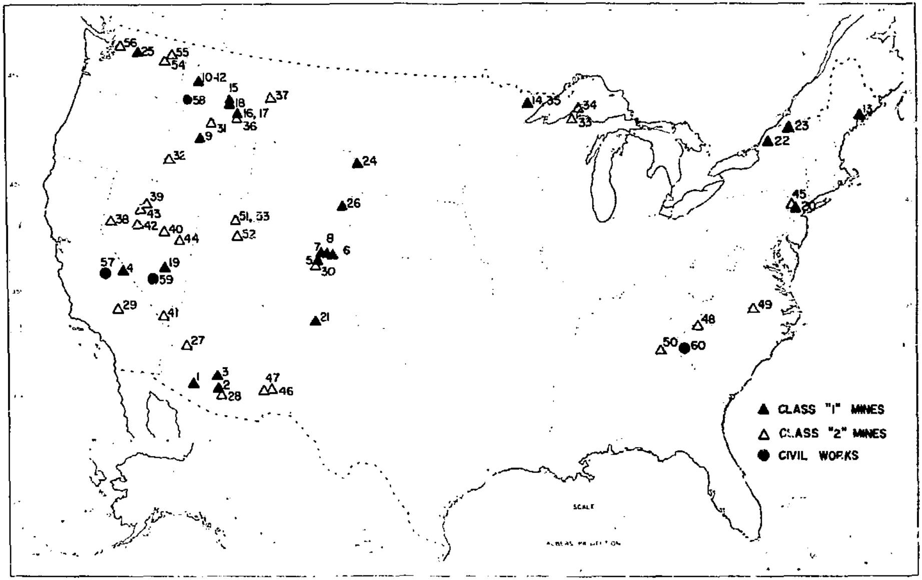

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Figure 1. Location of underground workings identified in initial literature search. Base map reproduced by permission of the Department of Geology, University of Chicago.

from the list because, after initial correspondence and telephone conversations with managers of these mines, it became apparent that the presence of an experimental facility would not be compatible with on-going mining activities. The other principal cause for eliminating some sites from further consideration was information from company geologists indicating that the geologic and hydrologic settings were not appropriate for an experimental facility. Direct contact with mine owners resulted in the addition of one mine to the list of 14 primary candidate sites in crystalline rock, and a mine was moved from "Class 2" into the group of four primary candidate sites. Underground openings deleted from further consideration and reasons for this deletion are listed in Table 1.

The 18 selected sites are shown on the map in Figure 2. Section 3, beginning on page 15, contains brief descriptions of these underground openings based on site visits; they are described in greater detail in the Appendix.

The goal of this phase of the project was to identify three to five primary candidate sites for in-situ experimental facilities. This identification would be followed by further investigations incorporating confirmatory drilling and application of technical and logistical criteria to select two final candidate sites. Concurrently, a program of experiments, a conceptual design of underground workings, and a preliminary cost estimate were prepared (Korbin et al., 1981).

Table 1. Underground openings deleted from further consideration.

State	Underground Opening	Owner or Operator	Reason for Deleting
Arizona	Bagdad Mine	Amoco Minerals Co.	Open pit only; no underground workings accessible.
	Bruce Mine	Amoco Minerals Co.	Extent of appropriate rock mass questionable; underground access questionable.
	Lakeshore Mine	Noranda Mining, Inc.	Highly fractured and jointed rock; interference with mining operations would preclude location of experimental facility.
	Miami East Mine	Cities Service Co. (Minerals Group)	Miami East operating at full capacity; no room for experiments.
	Oracle Ridge Mine	Continental Copper Inc.	Mining company not interested at this time.
	San Manuel Mine	Magma Copper Co.	Mining company is not interested in participating in this project.
California	Atolia District Mines	FCL Enterprises	Mines too shallow; some open pit; no production from area for 10-20 years.
	Helms Pumped Storage Project	Pacific Gas and Electric Co.	PG&E decided to withdraw site from consideration for research facility at this time.
Colorado	Black Cloud Mine	ASARCO	Black Cloud Mine is in limestone and dolomite.
	Climax Mine	Climax Molybdenum Co.	Mine company not interested; mine in full operation; no isolated tunnels.
	NORAD Site	Department of Defense	Complex has a sensitive national defense mission which will not permit research activities. All available space is being used.
	Schwartzwalder Mine	Cotter Corp.	Mining company will not participate at this time (based on the advice of the legal department).
	Urad/Henderson Mines	Climax Molybdenum Co.	Urad Mine is dangerous because of caving. Henderson Mine beneath the Urad Mine is in full operation; there is no available isolated tunnel; not practical at present.
Idaho	Bunker Hill Mine	Bunker Hill Co.	Mines are operating with marginally adequate entrance and service facilities; geologic setting questionable; company declines to participate in project because of both technical and philosophical objections.
	Coeur Mine	Coeur d'Alene Mines Corp., ASARCO	No suitable underground openings that will meet requirements.
	Crescent Mine	Bunker Hill Co.	See note for Bunker Hill Mine.
	Dayrock Mine	Day Mines, Inc.	Dayrock Mine closed.
	Galena Mine	ASARCO	No suitable underground openings that will meet requirements.
	Kentuck Mine	Gold Producers, Inc.	Mine has not operated since 1940s; environmental constraints will not permit mine runoff to flow into the Salmon River.
	Lost Packer Mine	Ivers Mining Co.	Lost Packer Mine is not accessible in winter.
	Silver City Region	Sidney Mining Co.	No reply from owner; state geologist indicates limited underground workings with questionable access.
	Star-Morning Mine	Hecla Mining Co.	Mine is in fractured and folded quartzites and argillites, requiring much roof support, mine workings are too busy to support any other activity; company not enthusiastically interested in use of part of their mine sites for in-situ testing.
Maine	Black Hawk-Blue Hill Joint Venture	Kerramerican, Inc.	Mine is sealed and flooded.
Michigan	Indiana Mine	State of Michigan	State is not willing to permit any research related to high-level waste disposal at this time.
	Iroquois Mine	UOP Inc.	
	Quincy Mine	Michigan Tech. Univ.	
Missouri	Pilot Knob Mine	Hanna Mining Co.	Mine closed; hoists and pumps removed; shaft capped with concrete; mine flooding.
Montana	Black Pine Mine	Black Pine Mining Co.	Mine less than 600 ft deep; workings are above water table in the area.
	Butte Mines	Anaconda Copper Co.	Proposed experimental facility not compatible with mining operations.
	Dacotah Mine	Bennett Mining Co.	Mine has poor access in winter and would probably not be suitable.

Table 1. Underground openings deleted from further consideration (continued).

State	Underground Opening	Owner or Operator	Reason for Deleting
Montana	Granite-Bimettalic Mine	Dr. William Antonioli	Mine closed for several years but head frame and hoist are in place; mine dry to 1000 ft level; needs some work around shaft collar; mine drained by 2-mile-long drainage tunnel to 1000 ft level, portal requires cleaning; winter access questionable.
	Taylor-Knapp Mine	Taylor-Knapp Mines	Mining company not interested at this time.
Nevada	Gooseberry Mine	West Coast Oil and Gas Corp.	The Gooseberry Mine is only 2 years old; heavy development work will continue for at least a year, shaft sinking is in progress; all workings presently being used.
	Mill City Mine	Utah International	Mining company is in the process of reactivating the mine and constructing a new milling facility; company has no interest in this mine being used for test facility.
	Mt. Wheeler Mine	Mt. Wheeler Mines, Inc.	Rock type, hydrologic conditions probably not suitable.
	Ruby Hill Mine	Hecla Mining Co.	Ownership and leasing are very complicated; probably not room for testing.
	Searchlight District	Multiple ownership	Old workings, depth and extent probably not suitable.
	Summit King Mine	Gilbert Ward	Not able to contact owner; letter returned.
	Taylor Mine	Silver King Mines Co.	Letter not received; no reply forthcoming.
New Jersey	Sterling Mine	New Jersey Zinc Co.	Mine in crystalline limestone (Franklin marble).
New Mexico	Continental Underground Mine	Sharon Steel Corp.	Unable to contact Victor Posner, President, who makes decisions; others in company not communicative.
	Ground Hog Mine	ASARCO	Mine is entirely in limestone.
	Lynchburg Mine	Cobb Resources Corp.	Above water table; depth of cover minimal.
	Questa Molybdenum Mine	Molycorp Inc.	Old underground workings closed and flooded for approximately 20 years; new mine is under development until 1983; by 1986, might have extra drifts that could be used for experiments.
New York	Chateaugay Mine 81 Mine	Republic Steel	Neither mine has been operated in the past 14 years.
North Carolina	Cranberry Magnetite Mine	Cranberry Magnetite Corp.	Mine has been closed for approximately 10 years.
South Carolina	Bad Creek Pumped Storage Project	Duke Power Co.	Company states that the Bad Creek Pumped Storage Project site would be unsuitable for a research facility.
South Dakota	Homestake Mine	Homestake Mining Co.	Mine very active; company not interested in test facility applications at this time.
Utah	Mayflower Mine Ontario Mine Park City Mine	Noranda Mining Co.	The mines are under active development and they do not have room for an experimental facility.
Washington	Holden Mine	Holden Village	The Holden Mine was closed in 1957, the portions of the mine below 600 ft are flooded. The mine site is very remote. All electric power available is used by the present owners.
	Knob Hill Mine	Day Mines, Inc.	The mine is limited in size. Present production and development program precludes research activities.
	Midnite Mine	Midnite Mines, Inc.	Mine is open pit.
	Sherwood Mine	Western Nuclear, Inc.	Mine is open pit.
	Sunrise Breccia Mine	International Brenmac Development Corp.	Mine is under development.

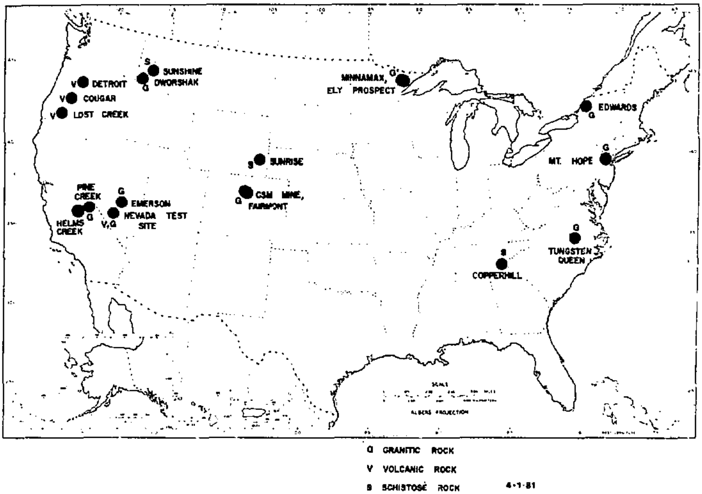

Figure 2. Location of underground workings visited in this phase of the investigation. Base map reproduced by permission of the Department of Geology, University of Chicago.

2. CRITERIA

The criteria described below include site characteristics which are detailed in Tables 2, 3, 4, and 5 and are the basis for the ranking of the sites in Table 6.

2.1 GEOLOGIC SETTING

Characteristics include the rock type, homogeneity, character, and extent of rock mass. The rock mass should be of the type and have the physical properties generally suitable for a repository. The rock should be relatively homogeneous; sharp contrasts in rock properties should be avoided. In this respect, the rock mass encompassing the experiments should be extensive enough for contacts between rock units having significant contrasts in their properties to be at least hundreds of meters away from the experimental areas. The rock mass should contain distinct joint sets with favorable properties, i.e., character, spacing, persistence, orientation. Zones of closely spaced (inch-scale) joints, shear zones, and rubble zones should be avoided. The underground workings should be within rock with physical and mechanical properties capable of providing good support in new excavations, i.e., massive to blocky type rock, and with long-term access for the experimental program.

2.2 DEPTH

The site will be underground, at depths greater than 600 feet. This is considered to be the minimum depth at which relative stress and hydrologic conditions are comparable to those at planned repository depths.

2.3 HYDROLOGIC SETTING

Principal characteristics include depth of the workings below the water table and variations in water pressure. The workings should be located at least 150 to 200 meters below the water table although sites with workings both above and below the water table may provide access for tests of rock and hydrologic properties of the saturated and unsaturated zones.

A steady groundwater pressure field is desirable, preferably not near a source of major water pressure fluctuation such as a reservoir. Existing workings should have a three-dimensional configuration that is simple to model, enabling easy calculations of their effect on the hydrologic setting of the experiments. Furthermore, it should be possible to locate the facility sufficiently distant from the old workings to minimize their influence on the hydrologic regime.

2.4 WORKINGS

Characteristics include size of openings, appearance (stability) of workings, method of support, and locations for continued excavations.

1. The workings in existing mines should be of sufficient size to accommodate an in-situ testing facility similar to Stripa, Sweden. The Stripa facility required approximately 10,000 cubic meters of additional excavation for the experiments.

2. The workings should not be caved, sealed, or flooded or have been closed for over 10 years.

3. The workings should contain suitable locations for horizontal excavation, to enable the experiments to be isolated from the mechanical and hydrologic effects of old openings.

4. The underground environment should be suitable for good experimentation: dust and noise levels should be low, temperature and humidity reasonably comfortable, ventilation excellent. Generally, a safe working environment should prevail.

5. A reliable source of electric power and a high-quality water supply should be available.

2.5 ACCESSIBILITY

1. The site should be within reasonable distance of a labor supply and support facilities for personnel and equipment and within reasonable transporation distances of home bases of experimenters.

2. The site should be easily accessible to enable personnel and materials to be brought to and moved around the site without the use of helicopters.

3. In comparing sites, the ease of underground access provided by adits or tunnels should be compared with access by shafts. Furthermore, the size of the openings should be sufficient to provide a reasonable degree of mobility.

2.6 AMENABILITY OF OWNERS AND OPERATORS

Owners and operators should be enthusiastically interested in the application of a portion of their site to an in-situ experimental facility. They should also be reasonably confident that the establishment of an experimental facility will not cause reduced productivity or any other significant conflict with their operations during the next decade.

3. SITE CHARACTERISTICS AND RANKING OF SITES

Mines and civil works visited in the course of the investigation are grouped into four categories encompassing three broad rock types. The locations of these mines and civil works are shown in Figure 2. For the purposes of this project, granitic rocks were considered to include igneous intrusive rocks, ranging in composition from gabbro to alaskite, and high-grade metamorphic rocks, primarily gneiss. Schistose rocks include foliated to massive siliceous rocks of medium metamorphic grade, ranging from phyllite to quartzite and schist. The three sites in volcanic rocks were in basalt and andesite.

The characteristics of sites in granitic, schistose, and volcanic rock are summarized in Tables 2, 3, 4, and 5; the sites are described in some detail in Appendix A. Nine primarily geotechnical characteristics are described in these tables. The characteristics are considered to have equal weight in the rankings listed on Table 6. The numerical values, 0 through 5, assigned in this table reflect the degree that each site matches the specific characteristic: 0-1 indicates a negligible match, 2-3 a moderate match, and 4-5 a good match. The totals in Table 6 indicate the relative ranking of the sites, the most desirable sites having the highest scores.

3.1 PRIMARY GRANITIC ROCK SITES (TABLE 2)

Granitic rock sites include the Helms Pumped Storage Hydroelectric Project in California; the Tungsten Queen Mine, North Carolina; the Mount Hope Mine, New Jersey; and the Minnamax Project, Minnesota. Of the sites visited, these sites are considered to have the greatest potential of the sites visited for excavation and operation of an experimental facility.

Table 2. Characteristics of primary granitic rock sites.

	Helms Pumped Storage Project, California	Tungsten Queen Mine, North Carolina	Mount Hope Mine, New Jersey	Minnamax Project, Minnesota
Rock Type	Predominantly medium-grained, massive to moderately blocky hornblende-grandiorite of Sierra Nevada batholith; occasionally cut by felsic dikes and stringers and by fine-grained foliated bands of quartz diorite.	Precambrian granodiorite cut by occasional mafic fine-grained dikes.	Precambrian gneiss and granite.	Troctolitic gabbro of the Precambrian Duluth Complex with varying degrees of disseminated sulfide mineralization.
Homogeneity	Where viewed underground, the granodiorite is fairly homogeneous. The frequency of quartz dioritic bands should diminish in directions away from the granodiorite-quartzite contact.	Fairly homogeneous, based on observation of hanging wall granodiorite in east crosscut on 1700' level. Fine-grained mafic dikes may be present in hanging wall east of workings.	Good homogeneity with the exception of the Mount Hope fault zone, based on quarry and underground observations. Gneiss and granite probably have similar physical properties.	Fairly homogeneous. Grain size varies from medium to coarse. Degree of mineralization varies.
Character of Rock Mass	Massive to moderately blocky; joints generally spaced 1 to 3m apart; 3 principal sets.	Massive to slightly blocky; 3 major planar sets; 1 wavy horizontal set, closed partially or fully healed with quartz; some chlorite. Dikes highly jointed; joint spacing tens of cm.	Massive to slightly blocky; 4 major joint sets; spacing 1-10 m observed in quarry. Joints are planar, Fe-stained, closed. At depth, joints healed with calcite.	Massive to blocky away from contacts. Average joint spacing 2 ft. Joints are planar, tight and generally well healed. Three prominent joint sets. Average RQD of troctolite, 85%.
Extent	The granodiorite pluton extends westward tens of km from the site.	The granodiorite extends ~ 4 miles eastward.	Gneiss and granite extend well to the east under company-controlled land.	Workings in or near zone of basal contact of troctolite with underlying granulitic Virginia formation. Basal contact dips to southeast and troctolite effectively thickens in that direction.
Size of openings and method of support	Access tunnel ~ 30 ft wide 25 ft high (horseshoe). Crown is bolted; otherwise tunnel essentially unsupported except for steel sets and lagging in areas transected by shear zones and in blocky zones associated with fine-grained dikes.	Unsupported 8 ft x 8 ft drifts and crosscuts; bolting and mesh required only near dikes; rock bolting required at enlarged shaft station (30-40 ft wide).	Drifts 8 x 10 ft to 9 x 12 ft; unsupported except in Mount Hope fault zone.	8 ft wide by 9 ft high, with horseshoe cross section. Openings unsupported except in fault zone.
Method of Excavation and Appearance of Workings	Full-face excavations using conventional drill and blast methods. Some overbreak apparent in areas transected by shear zone.	Conventional drill and blast. Slight to moderate overbreak in crosscut due to blast damage.	Conventional drill and blast. Strong influence of foliation in gneissic areas. Moderate overbreak due to blasting damage.	Conventional drill and blast employing 3-arm jumbo. Minor overbreak associated with the horizontal joint sets and high horizontal stresses.

Table 2. Characteristics of primary granitic rock sites. (continued)

	Helms Pumped Storage Project, California	Tungsten Queen Mine, North Carolina	Mount Hope Mine, New Jersey	Minnamax Project, Minnesota
Most Likely Facility Location	Excavation westward in granodiorite from curving decline access tunnel ~ 450 ft west of generator chamber.	1700 ft level, eastward into hanging wall grandiorite.	1000 ft level; stub drift by New Leonard shaft, west of Mt. Hope fault; also possibly from North Carlton drift NW of Leonard Shaft.	(1) Excavation southeastward from end of 'C' drift into thicker zone of relatively unmineralized troctolite. (2) Excavation westerly from a new shaft station at an elevation well above base of the tractolite (1200–1500 ft depth).
Hydrology	Workings are 700 to 800 ft below the water table in a relatively tight granodiorite. Site geologist estimated that 50 gpm are produced from open fractures associated primarily with the shear zone and secondarily with contacts between granodiorite and mafic bands.	100–200 gpm from ~ 6500 ft of horizontal workings. Essentially dry on 1700 ft level; few drips from joints along drift; reservoir in vicinity fluctuates 12–20 ft seasonally.	400–600 gpm from workings, ~ 90% of water into mine believed to be from percolation through Elizabeth workings and open stopes. Drift wall rock damp to dry.	8 ft wide by 9 ft high with horseshoe cross section. Openings unsupported except in fault zone.
Access and Facilities	~1 km declining (8.25%) access tunnel capable of accommodating large diesel-powered vehicles. Road from Shaver Lake (~ 30 mi W) presently kept open in winter. After completion of construction in 1982, winter access will be by snow cat and helicopter.	Inactive mine; No. 6 shaft reaches a depth of 1700 ft, has a minimum hoisting capacity of 600 TPD. Mine is on standby, surface facilities are maintained.	Inactive mine; 2800 ft 3-compartment shaft with levels at 1000, 1700, 2100, and 2500 ft. Surface facilities are well maintained. Mine presently flooded to ~ 1200 ft depth but 1000 ft level is accessible.	Inactive mine; 1700 ft deep, 14 ft diameter shaft with fully operational hoist. Good surface facilities. The mine is presently inactive, following an initial evaluation phase. No significant underground work is contemplated by AMAX for the next few years.

3.2 SECONDARY GRANITIC SITES (TABLES 3A AND 3B)

On the basis of visits, underground observations and discussions, sites in this category were considered to have lower potential for an experimental facility in granitic rock. Sites included are the Dworshak Dam site, Idaho; the Edwards Mine, New York; the Pine Creek Mine, California; the Emerson Mine, Nevada; the Colorado School of Mines (CSM) student mine and the Fairmont Mine, Colorado; and the Nevada Test Site, Nevada. Principal detriments associated with these sites are listed below.

Dworshak Dam Diversion Tunnel: Fluctuating reservoir head; small size of entrance adit.

Edwards Mine: In the process of decommissioning, hoist and pump to be removed; limited underground access to gneissic rock well away from old mine workings.

Pine Creek Mine: Large water inflows through discrete joints; very rough surface topography; high elevation.

Emerson Mine: Above water table; relatively remote site.

CSM Student Mine: Above water table; shallow depth of cover; numerous old workings in the area.

Fairmont Mine: Very old workings; small cross sections; above water table; shallow depth of cover.

Climax Stock, Nevada Test Site: The experimental facility at the Climax Stock at the Nevada Test Site has been thoroughly discussed in the literature (including Wollenberg et al, 1980) and was not visited during the course of this investigation.

Table 3.A. Characteristics of Secondary Granitic Sites.

	Dworshak Dam, Idaho	Pine Creek Mines, California A. Main Workings	 B. Brownstone Adit	Emerson Mine, Nevada
Rock Type	Hornblende-biotite quartz-diorite gneiss, of Precambrian Orofino Formation, occasionally cut by quartz and feldspar-rich stringers.	Country rock predominantly Cretaceous quartz monzonite of the Sierra Nevada batholith, also some diorite-quartz diorite; numerous alaskite, aplite, pegmatite veins and stringers.	Southern half of ~3000 ft long adit in granitics, relatively dark granodiorite, cut by numerous felsic and pegmatitic dikes and stringers.	Medium to fine-grained quartz monzonite, southernmost of 2 stocks of probable Tertiary age.
Homogeneity	Gneiss strongly foliated, bands 1/4 to 1 ft thick; gneiss occasionally cut by shear zone parallel to foliation.	Quartz monzonite at contact with ore zone, cut by dikes and stringers of fine-grained felsic rock and pegmatite. Quartz monzonite may be more homogeneous several meters away from contact.	Similar to main workings.	Where viewed in contact zone with ore underground, quartz monzonite cut by numerous stringers; surface exposure 1000 ft east of contact in south stock also shows numerous easterly dipping pegmatite and felsic stringers.
Character of Rock Mass	Tunnel to crusher chamber: away from portal-unweathered to slightly weathered, joints spaced 4-8 ft apart, shear zones up to 10 ft wide with several ~ 1 ft clay seams.	Moderately blocky, intact; joints generally well healed by quartz, feldspar, sulfides. Tight fractures spaced at 2 to 3 ft intervals; open fractures tens of ft apart.	Similar to main workings.	Blocky to very blocky near contact, expected to be more massive toward center of stock. Fractures generally well healed with quartz, feldspar, sulfides; inch-scale spacing near contact; 2-3 ft in stock.
Extent	The extent of the Orofino Formation gneiss is essentially unlimited easterly from the dam site.	West of workings granites extend for tens of km.	Same as main workings.	Stock approximately one to two miles in diameter.
Size of Openings and Method of Support	(1) Access tunnel to crusher: ~20 x 20 ft horseshoe supported by roof bolts and zones of lagged steel sets. (2) 'G' inspection adit: ~6 x 6 ft horseehoe, self-standing (3) Diversion tunnel: ~40 ft diameter, fully concrete lined.	Haulage drifts ~7 x 8 ft. Mesh and rock bolts at stations: shop area in quartz monzonite on 1500 ft level - 30 x 60 ft plan w/15-20 ft back. Adit excavated in 1976-77; ~12 x 12 ft for trackless haulage; no support required.	Same as main workingr.	8 x 8 ft haulage drift on 6200 ft level requires very little bolt support in tactite. Some bolting required in drift and crosscut in quartz monzonite on 5600 ft level.
Method of Excavation and Appearance of Workings	(1) Access tunnel to crusher chamber: full-face excavation; overbreak from rockfalls in crown. (2) 'G' adit: full-face excavation, conventional drill and blast methods, very good appearance. (3) Diversion Tunnel: not available for inspection.	Conventional drill and blast. Some overbreak, most apparent near granitic ore zone contact and at open, water-bearing joints.	Same as main workings.	Conventional drill and blast; minimal overbreak in haulage drift on 6200 ft level, either in metamorphics or quartz monzonite.

Table 3.A. Characteristics of secondary granitic sites. (continued)

	Dworshak Dam, Idaho	Pine Creek Mines, California A. Main Workings	B. Brownstone Adit	Emerson Mine, Nevada
Most Likely Facility Location	Excavation southeastward from diversion tunnel, 1000-2000 ft into ridge supporting right abutment of dam.	Possibilities for drifting west into quartz monzonite. (1) North end of Easy Going (8100 ft) level. (2) North end of 1500 ft level. Presently water handling and shop and shaft facilities would conflict. (3) Zero level adit (1500 ft level) south of main shaft; presently ventilation access is from the south portal.	South end of adit is entirely in granitic rock; adit presently inactive, though there may be plans to put upper Brownstone workings into production.	5600 ft level almost entirely in blocky quartz monzonite in or near contact with tactite. Possible starting place for drifting eastward into less blocky quartz monzonite of south stock.
Hydrology	Diversion tunnel and area eastward are below water table; however, changes in reservoir level, 150-200 ft may influence experiments. Rock appears essentially tight except for a few joints which yield small amounts of water (<10 gpm); this despite proximity of reservoir with 400-500 ft of water at the dam.	Mine produces abundant water, 4000-6000 gpm, depending on season. A large component is from open joints in quartz monzonite and tactite. Away from such discrete sources, quartz monzonite appears reasonably tight; joints well healed.	Producing 100-150 gpm, mostly from horizontal drill holes southeast into tactite zone through quartz monzonite. Some seepage also from open joints.	All workings above the water table. Depth to water table unknown. Some seepage observed on back of 5600 ft level, but most water produced from mine is introduced for drilling.
Access and Facilities	(1) 'G' adit accessible from powerhouse deck, through 4 x 7 ft gate. Adit would have to be enlarged and dog-legs straightened to accommodate mining, drilling and experimental equipment. (2) Diversion tunnel could be used for muck disposal. (3) U.S. Corps of Engineers powerhouse facilities offer possible logistical base and Corps controls area encompassing most likely facility location.	Operating mine. Accessible by adit (2 miles); then raise 1500 ft to a level which has a surface portal accessible in summer. Track haulage.	Inactive adit. Portal near mine office area; trackless haulage; 2000 ft to south end area in granitic rock.	Operating mine. Approximately 1000 ft shaft from 6600 ft elevation to 5600 ft level; horizontal track haulage available in adit on 6200 ft level.

Table 3.B. Characteristics of secondary granitic sites.

	Edwards Mine, New York	Colorado School of Mines Student Mine	Fairmont Mine, Colorado
Rock Type	Precambrian gneiss and metamorphosed carbonate rocks.	Biotite-granite gneiss of Precambrian Idaho Springs Formation.	Biotite-granite gneiss of Precambrian Idaho Springs Formation.
Homogeneity	Possibly good, based on surface expression and drill core.	Gneiss is cut by numerous pegmatitic and aplitic dikes and stringers.	Gneiss is cut by numerous pegmatitic and aplitic dikes and stringers.
Character of Rock Mass	Massive to slightly blocky; ~10 ft fracture spacing in horizontal drillhole core.	Massive to slightly blocky; joints spaced 2-3 ft apart, most appear well healed.	Massive to slightly blocky away from old stopes; very blocky in vicinity of ore shoots and stopes.
Extent	Limited to several thousand ft, drill hole #1620 penetrates 550 ft into foot wall on 2500 ft level entirely in median gneiss.	Idaho Springs Formation is extensive in this area.	Idaho Springs Formation is extensive in this area.
Size of Opening and Method of Support	Haulage drifts 8 x 8 ft, subdrifts 4 x 7 ft, generally only roof bolts needed for support.	Drift size varies, ~7 x 7 ft, no support.	Drift size varies, generally less than 4 x 6 ft, no support.
Method of Excavation and Appearance of Workings	Underground workings not inspected; excavated by conventional drill and blast.	Conventional drill and blast, and smooth-wall blasting. Rock stands well with little overbreak.	Drill and blast, most excavation done in late 1800s.
Most Likely Facility Location	Possible starting points at shaft station on 900 ft level in hanging wall gneiss, or shaft station on 1500 ft level in foot wall gneiss.	Workings could be extended northward to reach adequate cover and be beneath the water table. Abandoned lower level may be accessible.	Questionable whether sufficient depth of cover is reachable by any additional excavation.
Hydrology	Water productivity from workings is unknown.	Present workings above water table. The mine appears to be essentially dry.	Well above the water table.
Access and Facilities	Inactive mine. Surface facilities are to be removed and shaft plugged in spring-summer 1981.	Active research mine. Access is by adit. Surface facilities are limited to those necessary for the present experimental facility.	Abandoned mine. Access is by adit. No existing surface facilities other than rail track and dump.

3.3 SCHISTOSE ROCK SITES (TABLE 4)

The three sites in schistose rocks which were visited are all considered to be of lower potential than the primary granitic sites. The schistose sites include the Copperhill Operations, Tennessee; the Sunrise Mine, Wyoming; and the Sunshine Mine, Idaho. Principal detriments associated with these sites are listed below.

Copperhill Operations: Frequent variation in rock character over short distances.

Sunrise Mine: Close proximity of water table and carbonate-rock aquifer; minimal depth of cover.

Sunshine Mine: Variations in rock type; high rock temperature.

Table 4. Characteristics of schistose rock sites.

	Copperhill Operations, Tennessee	Sunshine Mine, Idaho	Sunrise Mine, Wyoming
Rock Type	Meta-graywacke and schist.	Quartzite and phyllite.	Strongly foliated and tightly folded graphitic and sericitic schists.
Homogeneity	Variable, schistose zones alternate with zones of more massive graywacke.	Phyllitic zones are fairly extensive; quartzite bands range from 2 to 10 ft thickness.	From limited observations in the mine (due to intense timbering of haulage ways), schist appears to be relatively homogeneous.
Character of Rock Mass	In crosscut on 1400 ft level, graywacke is massive to slightly blocky. On ramp to 1000 ft level from 1400 ft level graywacke is blocky and and schistose. Joints planar, closed, and healed by quartz and calcite.	Quartzite blocky to schistose, phyllite strongly schistose.	Predominant bedding and foliation direction E-W to NW-SE. There are at least 3 principal joint sets. Where observed in the mine, the schist is blocky, friable in places where decrepitated; otherwise relatively hard.
Extent	Not well defined because of variability and lack of drilling information on rock of hanging wall or footwall.	Probably sufficient in phyllitic rock, based on observations in drift between Yankee Girl and Jewell Shaft.	Accessible schist zone in synclinal structure underlain by dolomite. Possible extensive zone (>1 km) laterally, east and southeast of main workings, (and south of drift between main and central workings to northeast) but dolomite < 200 ft below schist.
Size of Opening and Method of Support	12 x 12 ft to 14 ft crosscuts and drifts. Crosscuts on 1400 ft level unsupported Haulage drift (~ 16 x 16 ft) had pattern bolting in roof. Truck shop on 1800 ft level (~60 x 100 x 30 ft high) pattern bolt lined in back.	Drifts 7 x 8 ft, roof bolts and occasionally wire mesh required for roof support, bolts and steel bands required for walls where parallel to rock foliation.	7th level: main haulage drifts excavated at 10 x 10 ft cross section; 8 x 8 ft after timbering. Preponderance of drifts timbered with 12 x 12 in posts and stulls on ~14 in centers, board lagging between posts and rock. In the untimbered zones such as drift intersections, back is covered with mesh and bolted.
Method of Excavation and Appearance of Workings	Smooth-wall excavation in two stages. Little or no overbreak.	Conventional drill and blast; strong influence of foliation, some overbreak.	Conventional drill and blast. Some overbreak visible through timbering in drifts parallel to foliation. Abundant loose material retained by wire mesh and lagged timbering. Faces perpendicular to foliation appear to stand well with minimal support.
Most Likely Facility Location	Either 1000 or 1400 ft levels, drift between Boyd and Cherokee workings, east into hanging wall.	(1) From operator's standpoint, little-used drift on 2700 ft level connecting Jewell Shaft and Yankee Girl workings. (2) 6500 -long, 7 x 8 ft Nabob tunnel near Pinehurst suggested by mine geologist.	Possible starting point for excavation eastward into schist zone at SE curve on 7th level, east of #3 shaft station. However, depth to dolomite < 200 ft below 7th level.

Table 4. Characteristics of schistose rock sites. (continued)

	Copperhill Operations, Tennessee	Sunshine Mine, Idaho	Sunrise Mine, Wyoming
Hydrology	Essentially dry on 1400 ft level, a few drips in drift and ramp to 1000 ft level. 600-700 gpm from all Copper Basin mines; 200 gpm from Boyd.	Approximately 300 gpm of water produced by mine (from >100 miles of workings). 400-500 gpm added by operations; occasional small seeps observed in roof.	Water table reported to be between 5th and 7th levels, 550-750 ft below surface. Dolomite is the aquifer: in a few hours pumping time, mine produces 75,000-100,000 gpd from the dolomite for local domestic water supply.
Access and Facilities	Operating mine. Five shafts up to 2400 ft deep. Excellent surface facilities.	Operating mine. Access by Jewell Shaft to 2700 ft level then portion of drift between shaft and Yankee Girl in St. Regis formation; track haulage. Air temperature on 2700 ft level in the 90° F range.	Mine currently inactive. Two compartment shaft: large capacity hoisting works (3600 TPD). Electric rail haulage underground. Mine presently on standby. Surface facilities being maintained.

3.4 VOLCANIC ROCK SITES (TABLE 5)

After searching the literature and contacting state geological surveys, public agencies, and mining companies, it became evident that the only underground openings for excavation of experimental galleries in rock somewhat similar to the flood basalt of the Columbia River plateau were the Michigan Technological University (MTU) student mine in the Precambrian Keweenaw Basalt and diversion tunnels at dam sites in Tertiary volcanic rocks of the western Cascade Range, Oregon. The State of Michigan would not permit a visit to the MTU; but, through the cooperation of the Portland District, U.S. Army Corps of Engineers, we were able to visit three dam sites under their jurisdiction in the western Cascades: Detroit, Cougar, and Lost Creek.

We were not able to identify any potential accessible underground openings in extensive unmineralized tuffaceous rock other than those already used for experimental activities at the Nevada Test Site.

Table 5. Characteristics of volcanic rock sites.

	Detroit Dam Diversion Tunnel, Santiam River, Oregon	Cougar Dam Diversion Tunnel, McKenzie River, Oregon	Lost Creek Dam Diversion Tunnel, Rogue River, Oregon
Rock Type	Andesite, volcanic clastic rocks, and younger granodiorite.	Tuff, tuff breccia, lapilli, and younger basalt.	Basalt, basaltic dikes, andesite, and older tuff sequence.
Homogeneity	Andesite intruded by granodiorite near downstream portal of tunnel. Stratigraphic unit containing andesite also contains volcanic clastic rocks.	Tuffaceous rock variable, ranging from coarse breccia to fine lapilli over short distances (a few feet). Basalt relatively massive, but limited to an ~ 50-ft wide zone in accessible workings.	Flows up to 100 ft thick, separated by reddish baked zones and hydrothermally altered flow-breccia. Flows generally filled canyon; are underlain by tuffaceous sequence.
Character of Rock Mass	Blocky to very blocky. Andesite strongly fractured, joints spaced 1-3 ft apart. Two distinct joint sets: 1 subhorizontal, one nearly vertical. ~1/2 in wide crush zone at contact with granodiorite.	Blocky to very blocky. Tuff strongly fractured with joints spaced 1-6 ft apart. Slickensides and tuff bed offsets attest to post-depositional. faulting. Basalt also strongly fractured; spacings a few inches to 1 ft. Some open joints in tuff. Two predominant steeply dipping joint sets: N65°W and N50°E.	Diversion tunnel completely concrete lined. Inspection of spillway cut in left-abutment indicates blocky to moderately blocky rock. Three principal joint directions on right abutment: N20-50°E, N10-30°W, and N40 to 70°W; all nearly vertical. Joint surfaces in spillway cut have some copper mineralization.
Extent	Stratigraphic unit containing andesite is 800 to >1000 ft thick. However, lateral and vertical extent of individual andesite flows is variable.	Tuffaceous unit extensive over at least several square km. Basalt up to 800 ft thick, but overlies tuff, perhaps as a canyon-fill flow.	Basaltic flows filled old canyon; therefore are limited laterally and vertically, maximum thickness of sequence ~ 500 ft.
Size of Openings and Method of Support	~ 25-ft diameter horseshoe, supported by roof bolts. Large concrete plug presently separates accessible portion of tunnel from reservoir.	~ 25-ft diameter horseshoe, supported by bolts in roof and ribs. Concrete plug protects tunnel from reservoir.	~ 25-ft diameter horseshoe, completely concrete lined.
Method of Excavation and Appearance of Workings	Conventional drill and blast. Overbreak apparent in roof where intersecting joint sets are parallel to tunnel axis.	Conventional drill and blast. Appreciable overbreak apparent in roof and ribs where joints intersect.	Conventional drill and blast. Tunnel not inspected.
Most Likely Facility Location	Necessary to excavate 1200-1500 ft from tunnel into left abutment to reach sufficient thickness of cover. However, thickness of andesite flow is questionable.	Basalt probably not reachable by excavation into canyon wall of left abutment from diversion tunnel. Excavating incline upward to reach basalt would result in insufficient thickness of cover.	Relatively low relief in diversion tunnel area would require ~ 3000 ft of lateral excavation to reach depths greater than 600 ft in basalt.

Table 5. Characteristics of volcanic rock sites. (continued)

	Detroit Dam Diversion Tunnel, Santiam River, Oregon	Cougar Dam Diversion Tunnel, McKenzie River, Oregon	Lost Creek Dam Diversion Tunnel, Rogue River, Oregon
Hydrology	Occasional seeps in crown of tunnel. Probable variations in hydraulic head due to changes in reservoir level.	Abundant seeps in crown and ribs, localized by joints. Probable variations in hydraulic head due to changes in reservoir level.	Expect variations in hydraulic head due to changes in reservoir level.
Access and Facilities	Diversion tunnel presently partially flooded by tail-waters, accessible from downstream portal by boat. U. S. Corps of Engineers facilities at dam; area accessible by all-weather roads.	Diversion tunnel partially flooded, accessible along crumbling wooden walkway. U. S. Corps of Engineers facilities at dam accessible by all-weather road.	Access to diversion tunnel portal difficult at this time. U. S. Corps of Engineers facilities at dam accessible by good roads.

It is evident from these descriptions that sufficient thickness of relatively homogeneous basaltic or andesitic rock is not available for excavation of experimental galleries from the diversion tunnels under adequate depth of cover. It is expected that similar geologic settings would be found at other dam sites in andesitic and basaltic rock of the Pacific Northwest. Furthermore, the hydrologic problems associated with the fluctuating head in response to seasonal variations in reservoir levels would be of concern.

4. RECOMMENDATIONS

Three granitic rock sites that rank high in Table 6--the Tungsten Queen Mine, the Mount Hope Mine, and the Minnamax Project--are recommended for consideration as primary candidate sites. These sites should be investigated further to select two final candidates. (Subsequent to our initial investigations, the Helms site was deleted when Pacific Gas and Electric Co. indicated that its facility should no longer be considered for NRC-sponsored experiments.) Further investigations should include the drilling of continuously cored horizontal holes into the wall rock in the direction of the proposed excavation for experimental areas. Site evaluations will also include the development and application of detailed logistical criteria which, when combined with the results of the technical investigations, will provide the basis for the final selection.

Horizontal drilling is required because, in the case of mines, almost all existing detailed information is confined to the ore body or to exploration for potential ore zones. In mines, the area of our interest, the wall rock away from the ore, is purposely avoided in excavation and drilling and therefore is essentially unexplored. This is also true at the Helms Pumped Storage Project where the nature of the granodiorite west of the powerhouse area is presently not well known.

In each of the primary candidate sites, there is access at appropriate depth to a starting point for excavation for a research facility. Furthermore, the wallrock appears to be of appropriate composition, texture and structure. However, the nature of the rock between the existing workings and a zone 200-300 meters into the wall, a distance that might encompass experimental drifts and galleries, is not adequately known. Therefore, it is necessary to

Table 6. Ranking of Sites.

SITE	SITE CHARACTERISTIC									TOTAL
	Rock Type	Homogeneity	Character of rock mass	Extent of rock mass	Size of openings	Appearance of workings and support	Hydrology	Access and facilities	Depth	
Helms Creek*	5	4	4	5	5	5	5	4	5	42
Tungsten Queen	5	4	4	5	4	4	5	4	5	40
Mt. Hope	5	4	4	5	4	4	4	4	5	39
Minnamax Project	5	4	4	3	5	4	5	4	5	39
Pine Creek (Brownstone)	5	4	4	5	5	4	3	4	5	39
Dworshak Dam	5	4	4	4	3	4	2	4	3	33
Edwards Mine	4	4	4	3	4+	4+	5	0	4	32
CSM Student Mine	5	4	4	3	4	4	2	4	2	32
Emerson Mine	5	4	3	4	4	4	0	3	4	31
Fairmont Mine	5	4	3	4	1	1	0	2	0	20
Copperhill Opns.	3	1	3	4	5	5	5	4	5	35
Sunshine Mine	3	1	3	4	4	4	5	3	5	32
Sunrise Mine	3	3	3	2	4	3	2	3	3	26
Detroit Dam	3	1	3	2	3	4	2	3	2	23
Cougar Dam	3	1	3	2	3	3	2	3	3	23
Lost Creek Dam	3	1	3	2	3	3	2	3	1	21

* Excluded following notification by Pacific Gas and Electric Co., 4 May 1981.

\+ Indicates assumed value because workings were not inspected.

drill continuously cored horizontal drill holes from accessible underground locations to aid selection of two final candidate sites. The core would be examined for its lithologic continuity and fracture frequency. A zone near the bottom of the hole would be packed off, and the hydraulic pressure measured to determine the hydrostatic head. Subsequent laboratory tests would be conducted on selected samples to determine rock physical properties.

It is recommended that the investigations of the three primary candidate sites be performed sequentially. Initially, the most immediately accessible site, the Tungsten Queen Mine, would be studied. A hole would be drilled approximately 800 feet eastward from the stub drift on the 1700-foot level, at the location shown in Figures 15 and 17. If this site was found to be unacceptable, the next most accessible site, the Mount Hope Mine, would be investigated. In the unlikely event that, for one reason or another, both sites proved to be unacceptable, the primary remaining candidate site, the Minnamax Project, would be investigated. By ordering the site investigation program in this sequence, the total cost and time required to carry out the program would be kept to a minimum.

APPENDIX A: DESCRIPTION OF SITES VISITED

In the descriptions that follow, granitic rock sites are divided into two categories. First, four primary candidate sites are described in detail; and, second, the remaining six granitic sites of lesser desirability are briefly described. Short descriptions of sites in schistose and volcanic rocks follow.

A.1 PRIMARY GRANITIC SITES

A.1.1 Helms Pumped Storage Project, California (Pacific Gas and Electric Co.)

Location and Accessibility

The Helms Pumped Storage Project of the Pacific Gas and Electric Co. (PG&E) is located on a tributary of the north fork of the Kings River, approximately 60 miles east of Fresno, California at 37°02'N, 118°58'W (Fig 3). The underground powerhouse shown in Figures 4 and 5 is situated between two reservoirs, Courtright at an elevation of 8200 feet and Wishon at 6500 feet. The project will produce over 1000 MW of electricity during periods of peak demand and will pump water back to the upper reservoir during off-peak periods.

From Shaver Lake, the site is accessible by a 30-mile road, the last 15 miles of which are controlled by PG&E. The road is presently kept open in winter. However, after completion of construction in 1982, winter access for permanently stationed PG&E employees may be limited to snow cat and helicopter. The topography in the vicinity of the project is mountainous,

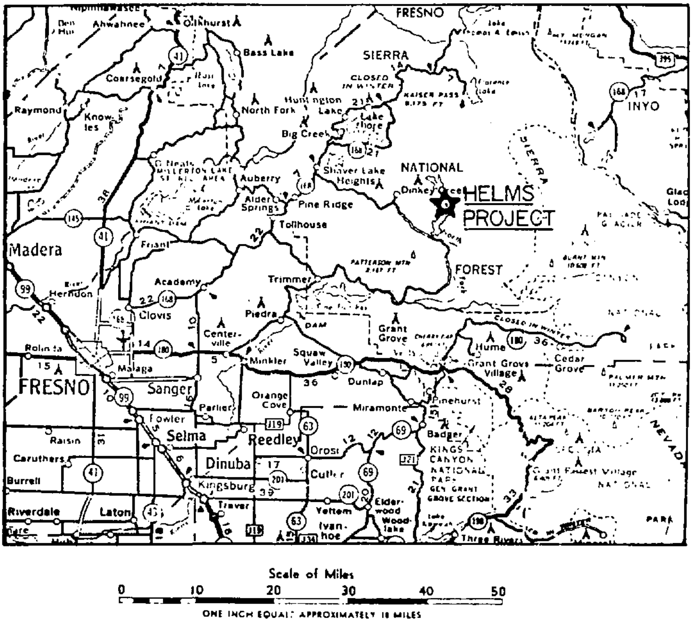

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Figure 3. Location of Helms Pumped Storage Project, 60 miles east of Fresno, California. (Base map reproduced by permission of the American Automobile Association, copyright owner)

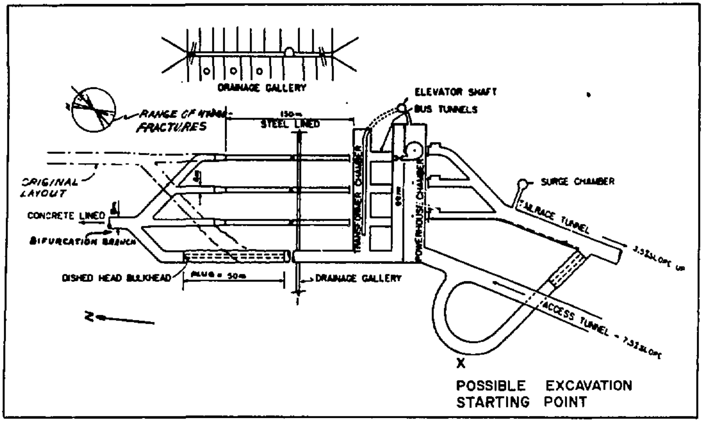

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Figure 4. Original and modified layout of underground powerhouse complex, Helms Pumped Storage Project. Diagram reproduced by permission of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.

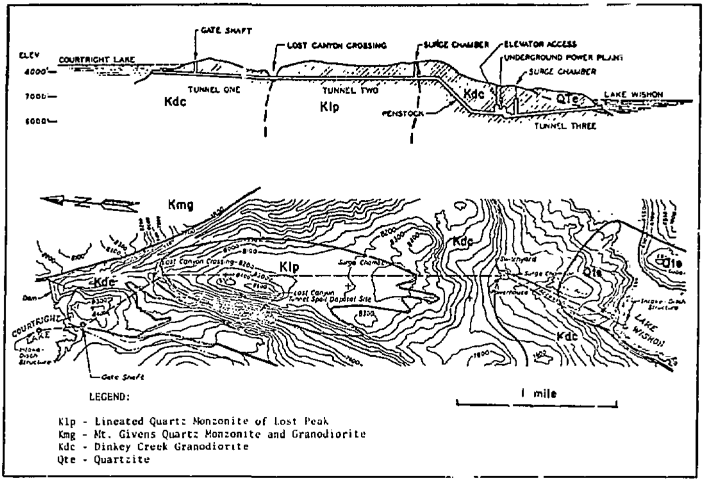

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Figure 5. Plan and profile, Helms Pumped Storage Project. Base map and section provided by Pacific Gas and Electric Company; geology after Bateman (1965)

with changes of several thousand feet in elevation over distances of several miles.

The underground power station is served by a 3000-foot long access tunnel, approximately 30 feet in diameter, declining from the portal on an 8.25% grade (the portal is shown in Figure 6). Only diesel-powered vehicles with scrubbers are permitted in the access tunnel.

Facilities

Upon completion of construction, the access tunnel will remain open. Underground utility systems and permanent office, residence, and garage buildings, which are located about one mile south of the tunnel portal, will remain intact. Wishon Reservoir is presently open in summer and fall months for public fishing and boating and is expected to remain so after start of pumped storage operations.

Geologic Setting

Areal Geology. The distributio. of rock units in the Helms Project area (Fig. 5) was taken from the U. S. Geological Survey's geologic map of the Blackcap Mountain Quadrangle (Bateman, 1965). The predominant rock unit is the Dinkey Creek hornblende granodiorite (Kdc in Figure 5). The Dinkey Creek pluton, one of the largest in the Sierra Nevada batholith, is of Cretaceous age and covers several hundred square miles (Bateman et al., 1963). A small pluton in the project area, the lineated quartz monzonite of Lost Peak (Klp), probably intruded the Dinkey Creek granodiorite. The Dinkey Creek granodiorite is in contact with a large, more felsic pluton, the Mt. Givens

Figure 6. Portal to access tunnel, Helms Pumped Storage Project.
(XBC 813-2174)

granodiorite (Kmg) near the dam that impounds Courtright Reservoir, about three miles north of the powerhouse site. A pendant of quartzitic rock (Qte), which predates the plutonic rocks, underlies the north end of Wishon Reservoir, south of the underground powerhouse. The underground powerhouse workings are outside the zone of poor rock conditions associated with the contact between the granodiorite and the quartzite (Haimson, 1976).

The geological quadrangle map (Bateman, 1965) indicates that the foliation in the Dinkey Creek granodiorite, evident primarily by alignment of hornblende laths, strikes northwesterly and dips from 55° northeasterly to nearly vertically in the powerhouse area. This attitude generally holds to the north and south; but, within a half mile to the west of the powerhouse area, the foliation strikes northeasterly, with steep northwesterly dips.

Analyses of the Dinkey Creek granodiorite (Bateman, 1965) indicate that its quartz content in the project area ranges from 19 to 31 percent, potassium feldspar from 6.5 to 31 percent, plagioclase from 35.5 to 59.5 percent, and mafic minerals (predominantly hornblende) from 6 to 29 percent.

Local Geology. PG&E geologists (PG&E Co., private communications, February, 1981) have recognized three principal plutonic rock types exposed in the underground workings. In the area considered most likely for an experimental facility excavation, the rock types are quartz monzonite, granodiorite, and meta-quartz diorite. The quartz monzonite is described as a fresh, light gray, medium-grained rock showing some lineation. The granodiorite is a fresh, gray, coarse-grained rock having a slight northwest trending lineation.

The granodiorite also contains xenoliths of darker, more mafic plutonic rock, probably the meta-quartz diorite. The meta-quartz diorite is a fresh, dark gray to black, fine- to medium-grained rock, having a strong northwesterly lineation that grades locally into schistose zones. Structurally, the quartz diorite appears as localized dikes, although this may not be its mode of emplacement. Contacts between these three major rock types are sharp and well defined. The rocks are occasionally cut by felsic dikes and stringers. Contacts between the granodiorite and bands of quartz diorite are occasionally the loci of water-producing open fractures.

The underground workings are transected by a north-south trending shear zone, dipping nearly vertically, with a width varying from one-half to four feet. Rock surfaces in the shear zone are slickensided, and gouge material is present. The majority of the bedrock along the project line is exposed at the ground surface.

Rock Mass Character and Rock Properties. Sweeney and Hovland (1981) describe the rock as blocky to massive. Where cbserved underground, joints in the granodiorite away from contacts and shear zones are spaced three to ten feet apart. Three principal sets of joints are evident: one subhorizontal, one striking northwesterly with a steep dip, and one striking northeasterly, also steeply dipping. Open fractures are only associated with the north-south shear zone and occasionally with contacts between rock units.

Properties of the granodiorite have been summarized by Strassburger (1981):

Compressive strength	15,000 to 20,000 p.s.i.
Tensile strength	1,450 to 2,340 p.s.i.
Specific gravity	2.64 and 2.88 g/cm^3

Stresses were measured in situ in a test drift (Sweeney and Hovland, 1981) and by hydraulic fracturing in boreholes (Haimson, 1976). Measurements in the test drift by overcoring methods provided the following values:

	Stress (p.s.i.)	Bearing (degrees)	Inclination (0° = vertical)
σ (max.)	~ 2,200	~ 188	~ 67
σ (inter.)	~ 1,100	43–65	29–37
σ (min.)	880–970	~ 107	104–118

Stress values obtained by hydraulic fracturing (Sweeney and Hovland, 1981) are:

	Stress (p.s.i.)	Bearing (degrees)	Inclination (0° = vertical)
σ (max.)	1,380	205	90
σ (inter.)	1,190	-	0
σ (min.)	780	115	90

Hydrology

The workings are well below the water table along the project line; water levels in holes drilled from the surface were recorded by PG&E before and during the course of construction. These recorded levels indicate that the groundwater surface elevation is probably 700 to 800 feet above the elevation of the proposed experimental areas. Precipitation in the region averages 40-50 inches per year, mostly during winter-spring months.

Most of the water derived from the workings is from the north-south shear zone; it has been estimated by PG&E geologists to produce about 50 gpm. The ~20°C temperature of this water, ~10°C warmer than ambient, suggests that the water circulates deeper than its depth of emanation in the workings, 1000 feet below the surface. The high pH of the water (~9.5) and its chemical content indicate a significant difference from most other groundwaters sampled in the central part of the Sierra Nevada batholith (Ivan Barnes, U.S. Geological Survey, private communication, March 1, 1981). Most of the remainder of the water produced in the workings is from open fractures associated with the fine-grained mafic rock and its contacts with the granodiorite; otherwise, the tunnel walls are mainly dry to damp.

Underground Openings--Workings

The main access tunnel, about 3000 feet long, descends on an 8.25 percent grade. The horseshoe shaped section is 30 feet wide and 25 feet high with a straight 15-foot high sidewall. Most of the tunnel crown is reinforced with grouted rock bolts installed in a spile pattern, i.e., approximately 30° to the tunnel axis. The tunnel stands essentially unsupported, except for steel sets and lagging installed in areas transected by the shear zone and in blocky zones associated with the fine-grained quartz diorite and mafic dikes. Some overbreak is apparent in these areas. Excavation of the access tunnel was conducted full-face by conventional drill and blast methods. Because controlled methods of excavation were not effectively employed, the tunnel wall rock appears more blocky and shattered than it would have if more effective methods had been used.

An impressive demonstration of the generally high quality of the rock is the powerhouse gallery, a chamber 336 feet long, 83 feet wide and 144 feet high, at a depth of 1000 feet. The gallery roof is reinforced with radial rock bolts, wire mesh, and a thin layer of shotcrete.

Possible Experimental Facility Location

The most likely location for excavation for an experimental facility is westward from the downward-curving spiral tunnel, which connects the main access tunnel with the tailrace tunnel. This location is shown in Figure 4. Excavation 500 to 1000 feet westward from this point would place the experiments at depths greater than 1000 feet, well away from any hydrological or mechanical effects of the operation of the powerhouse. A vertical profile along this alignment is shown in Figure 7. Conversely, at this distance, excavation of the drift to and galleries for the experimental areas should have no appreciable effect on hydroelectric or pumping operations.

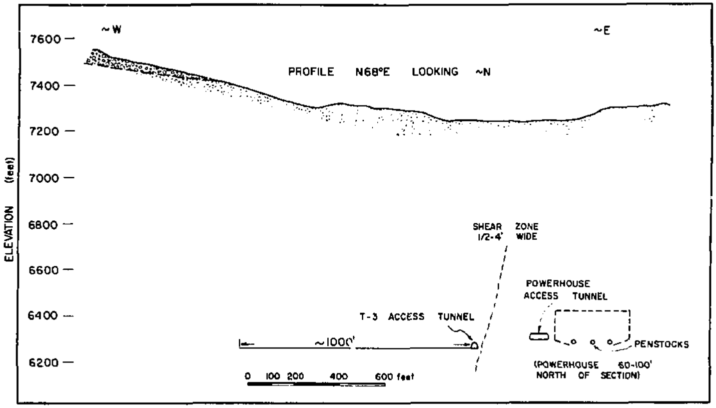

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Figure 7. Profile along possible alignment of access drift to experimental facility, Helms Pumped Storage Project.

A.1.2 Tungsten Queen Mine, North Carolina (Ranchers Exploration and Development Co.)

Location and Accessibility

The Tungsten Queen Mine (formerly known as the Hamme Mine) is located in the Hamme tungsten district which spans the North Carolina-Virginia border in the vicinity of Kerr Reservoir (Fig. 8). The mine, in Vance County, North Carolina, is reached by a paved road, about 13 miles NNW of Henderson, North Carolina, which is approximately 50 miles by expressway and freeway (I-85) from the Raleigh-Durham airport. The nearest town is Townsville.

The land surface in the vicinity of the mine is flat to gently rolling; elevations range from 350 to 450 feet. Small valleys are incised 50 to 150 feet into this surface by the Roanoke River and its tributaries. The valleys have been flooded by the impoundment of the Roanoke River at Kerr Dam.

Mine Facilities

The Tungsten Queen Mine is owned and operated by Ranchers Exploration and Development Co. with headquarters in Albuquerque, New Mexico. The mine has been inactive since 1971; although the surface and underground facilities are being kept in good order.

Geologic Setting

Regional Lithology and Mine Geology. The geologic setting of the Hamme district was described in detail by Parker (1963), and the structural control of the mineralization by Gair (1977). The district is located in the

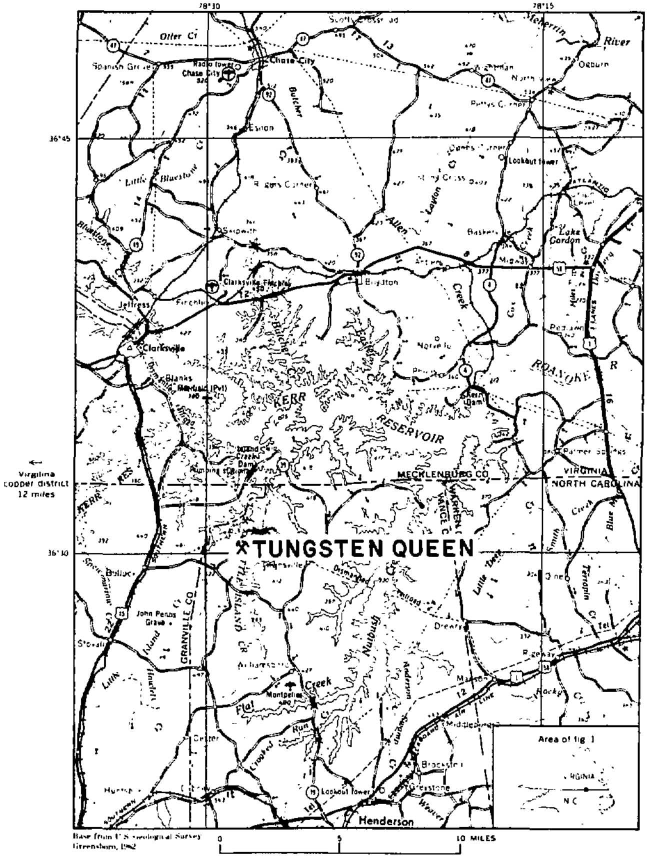

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Figure 8. Location of the Tungsten Queen Mine, Vance County, North Carolina. (After Gair, 1977)

Carolina slate belt of the Piedmont physiographic province. As shown in Figure 9, mineralization at the Tungsten Queen Mine occurs near the western border of a NNE-trending pluton of albite granodiorite in contact with sericite-chlorite phyllite of the slate belt (Parker, 1963). The slate belt host rocks are of late Precambrian and Cambrian ages, while the pluton is considered to have intruded the slates in the lower Paleozoic (595 to 520 m.y.) (Gair, 1977). The pluton is foliated, generally conformably with the NNE-trending foliation of the slate belt rocks. Where observed on the 1700-foot level near the mineralized contact, the appearance of the granodiorite changes over a span of 10 feet from relatively massive rock away from the ore to strongly foliated rock near its contact with the ore zone. The albite granodiorite is medium- to coarse-grained and dark gray; the average composition is 50 percent albite, 20 percent potassium feldspar, 25 percent quartz and 5 percent mafic and accessory minerals (Parker, 1963).

The principal mineralization, vein quartz containing the manganese tungstate mineral, huebnerite, occupies an ESE-dipping sericitized shear zone which strikes NNE from the phyllite into the granitic pluton. The surface geologic map by Parker (1963) indicates that the pluton is at least five miles wide in the vicinity of the Tungsten Queen Mine, affording ample room for excavation and experiments in the plutonic rock eastward from the existing underground workings.

Rock Mass Character. The hanging wall granodiorite observed on the 1700-foot level is massive to slightly blocky in character (Figs. 10 and 11).

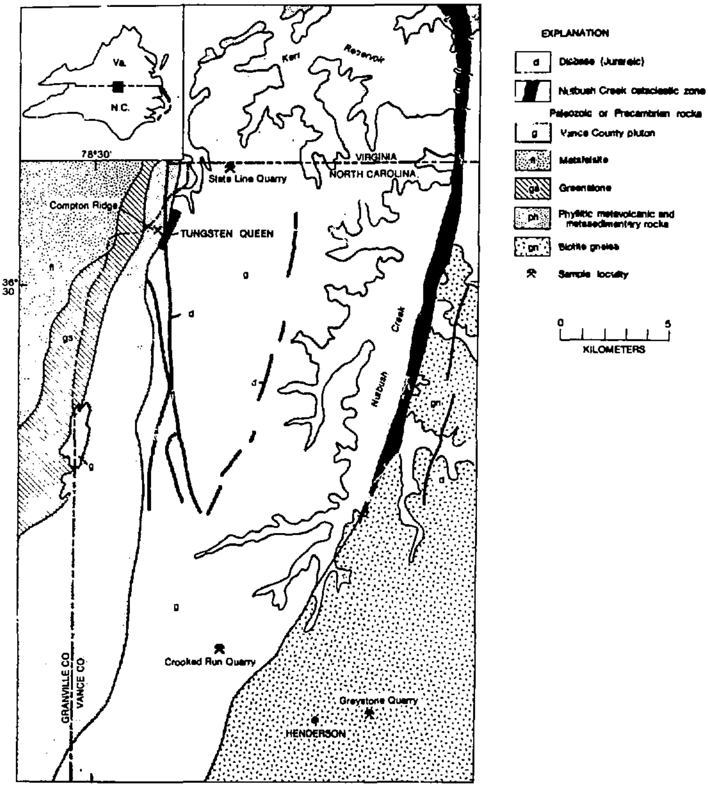

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Figure 9. Generalized geologic map of the Hamme Tungsten District, North Carolina. (After Casadevall and Rye, 1980. Reproduced by permission of the Department of Geologic Sciences, University of Texas, El Paso)

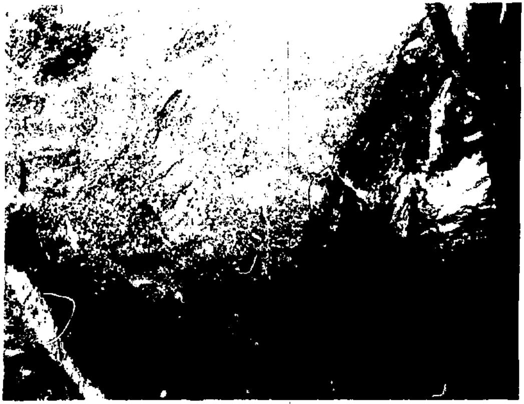

Figure 10. Tungsten Queen Mine, moderately foliated granodiorite. Note white quartz joint-filling material. (XBC 811-275)

Figure 11. Tungsten Queen Mine, 1700-foot level shaft station roof. (XBC 811-271)

Average joint spacing of several feet was noted in at least three major joint sets. The discontinuities are planar, tight, and partially or completely healed with quartz (Fig. 10). Occasionally, a thin chlorite coating was also noted, although this may be associated with the proximity of the granodiorite to the mineralized contact.

From a drill station on the 1700-foot level, a 200-foot long horizontal drill hole (No. 6-17-2) was drilled to the SE, the preferred direction for an experimental facility. The hole was within the granodiorite and revealed additional minor zones of mineralization to a distance 80 feet from the collar. Beyond this point, the granodiorite was relatively massive, with the exception of a shear zone at a distance of 160 to 166 feet. This 5- to 10-foot wide zone was described as highly jointed with areas of sericite schist and chlorite-coated or filled joints (see Table 7). The presence of additional shear zones, farther into the granodiorite pluton away from the mineralized contact and phyllite, can only be assessed with the aid of a long (700 to 1000 foot) horizontal drill hole.

The phyllite and granodiorite are cut by fine-grained diabase dikes, probably of Triassic age (Parker, 1963). Near the mineralized contact, the dikes are spaced at roughly 500 feet and are from several inches to several feet wide. As shown in Figures 12 and 13, the dikes are more fractured than the wall rock and can lead to minor overbreak where they strike nearly parallel to the axis of the drift and are more than one foot wide. Orientation of the dikes is variable, although several were observed to be closely aligned with the strike of the ore zone.

Table 7. Horizontal diamond drill hole, eastward from 1700 foot level (#6-17-2), Tungsten Queen Mine, North Carolina.[a]

Interval (feet)	Rock Type	Description
0 - 4	Quartz	Some sericite schist at start
4 - 7	Gneiss	Pyrite increases with depth, appears to be sheared granodiorite
7 - 8 1/2	Sericite schist	Pyrite along foliation
8 1/2 - 22	Gneiss	Abundant pyrite
22 - 23	Sericite schist	Abundant pyrite
23 - 49	Granodiorite	Fracture at 42'
49 - 51	Sericite schist	0.2' quartz at 50'; slight gneissic texture
51 - 51 1/2	Granodiorite	Abundant pyrite
51 1/2 - 51 1/2	Sericite schist	Abundant pyrite
52 1/2 - 54 1/2	Quartz	Huebnerite at 53'
54 1/2 - 56 1/2	Sericite schist	Moderate pyrite
56 1/2 - 59 1/2	Gneiss	Sericite schist with pyrite at 57 1/2'
59 1/2 - 61	Schist	Abundant pyrite
61 - 66	Granodiorite	0.2' of schist at 64'
66 - 67	Sericite schist	Abundant pyrite
67 - 68	Granodiorite	
68 - 70 1/2	Cal (?) schist	Possible phyllite?
70 1/2 - 78 1/2	Granodiorite	Fracture at 75'; many phyllite inclusions
78 1/2 - 80	Granodiorite	Purple fluorite at 79', silicified, tendency toward cleavage
80 - 165	Granodiorite	Small, very fine grained basic intrusive at 89'; 0.1' quartz at 122'; 0.2' quartz at 139 1/2 and 142'; 0.2' quartz with 1/4" pyrite crystals and muscovite at 150'; gneissic structure 155-157'; small sericite schist at 158'; micro (?) across small schist at 158 1/2'; pyrite 155-163'; small schist 161 1/2 to 162'; broken with chlorite along fracture at 163'
165 - 166 1/2	Lost core	
166 1/2- 200	Granodiorite	0.2' quartz at 174, 185, 186, and 193'.

[a] Information from the drilling records of Ranchers Exploration and Development Co., obtained on a site visit, Jan. 8, 1981

Figure 12. Tungsten Queen Mine, diabase dike in drift crown. (XBC 811-306)

Figure 13. Tungsten Queen Mine, diabase dike in drift crown. (XBC 811-273)

Underground Openings/Workings

Access to the mine workings is by 1700-foot deep shaft #6, serviced by the headframe pictured in Figure 14. The workings consist of mine levels spaced at roughly 200 feet with a bottom level 1700 feet below the shaft collar (Fig. 15). Mining of the steeply dipping, relatively narrow ore body was by open cut and fill stopes. Although the workings extend approximately 6000 feet along strike of the ore body, the region of major development is restricted to eight lodes, each less than 600 feet long. Between the lodes relatively extensive sections of rock remain unexcavated (Fig. 17). The stope widths range from 8 to 30 feet and are generally sand filled.

Drifts and haulage roads are approximately 8 feet high by 8 feet wide and are roughly rectangular in cross section (Fig. 13). Aside from the previously described dike intersection and enlarged shaft stations, the openings are largely unsupported. Where support is employed, it usually consists of rock bolts, as shown at the 1700-foot level shaft station (Fig. 11), or bolts and wire mesh.

All openings were excavated by drill and blast without the aid of controlled blasting techniques. Consequently, most of the minor overbreak observed probably was the result of excavation damage. The openings on the 1700-foot level show no signs of instability or excessive stress.

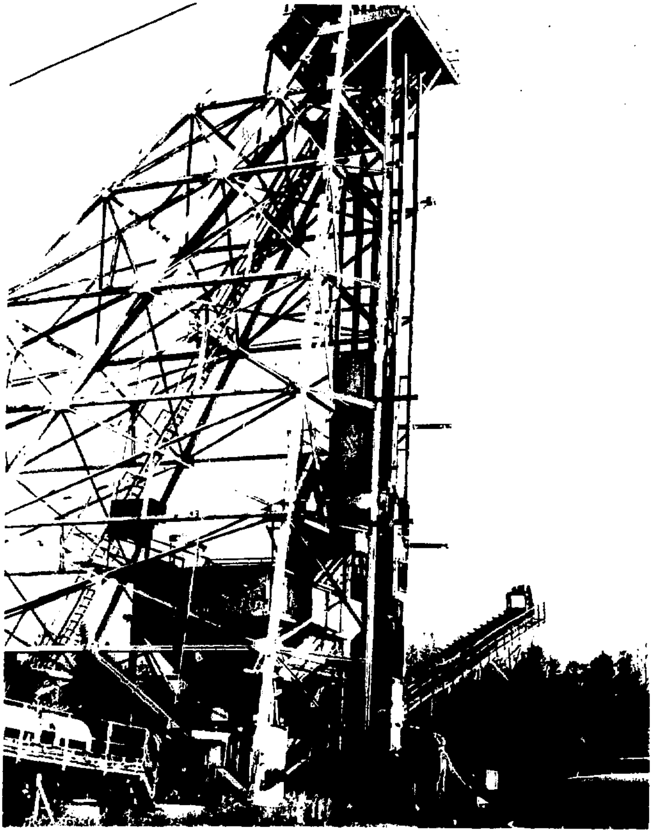

Figure 14. Tungsten Queen Mine headframe, Shaft #6.
(XBC 811-269)

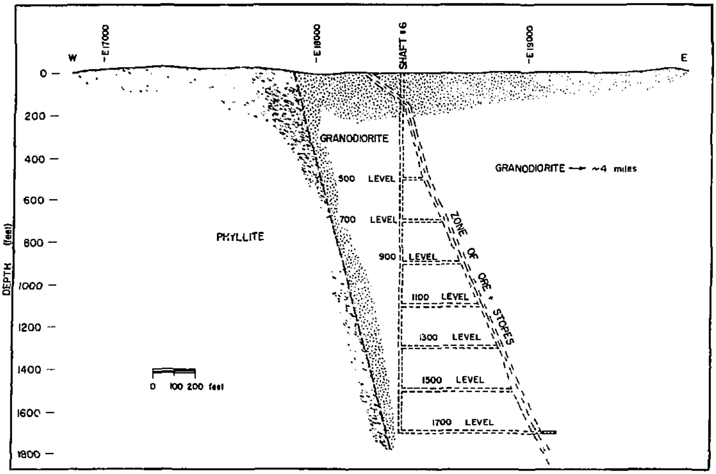

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Figure 15. Simplified geologic cross section through the Tungsten Queen Mine, centered on operating shaft #6.

Hydrology

The groundwater table in the vicinity of the mine is believed to be close to the surface due to the abundant rainfall (averaging 47 inches annually, approximately evenly distributed throughout the year), numerous rivers and marshes in the area, gentle topography, and proximity to the large Kerr Reservoir. Although the main reservoir is several miles to the north of the mine, Townsville Lake below Island Creek Dam is less than one mile from the shaft. The water level of Kerr Reservoir fluctuates 12 to 20 feet seasonally.

A total of 100 to 200 gpm of water are presently being pumped from the 1700-foot level. It is probable that a large proportion of the water is from the surface, having percolated through the stopes and old shafts. However, the total quantity of water produced by the mine is small considering the extent of the workings.

As viewed from the 1700-foot level, the openings are essentially dry. Only a few drips were noted from joints intersecting the drifts. Occasionally, the wall rock surrounding a joint was stained, as shown in Figure 16.

Possible Experimental Facility Location

Excavation from the 1700-foot level, to the east or southeast into the hanging wall rock, should provide access to relatively massive and homogeneous granodiorite well away from the existing mine workings at sufficient depth of cover (Figs. 15 and 17). In addition to providing excellent cover, placing the experimental facility access on the 1700-foot level as an extension of the main cross-cut would locate the facility approximately 600 feet from major

Figure 16. Tungsten Queen Mine, water-stained joint (presently dry) at end of drift stub, 1700-foot level.
(XBC 811-280)

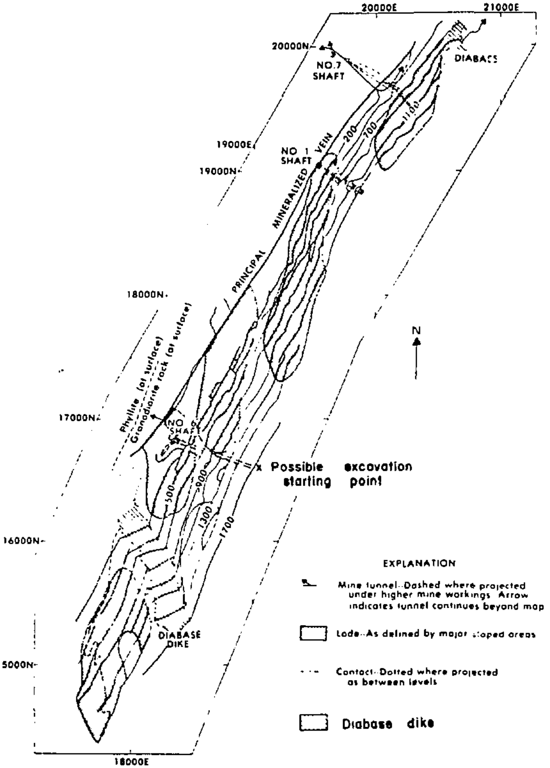

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Figure 17. Horizontal projection of mine workings and principal geologic features of the Tungsten Queen Mine, Hamme District, Vance County, North Carolina. Principal mineralized vein underground corresponds closely to mine drifts. Mine coordinates are in feet north and east of an arbitrary origin established by the U.S. Bureau of Mines, 1943. (Modified from Gair, 1977; after Casadevall and Rye, 1980)

mine stopes. Depending on hydrologic considerations, this location could help reduce the amount of horizontal drifting needed to reach a relatively undisturbed section of rock mass for the experimental facility proper.

The proposed location of the start of the experimental facility access drift is roughly 600 feet from the 1700-foot level shaft station. Because the mine is presently not in production, there would be no interference with mine operations. The proposed location also appears to be compatible with mining should production resume in the future.

A.1.3 Mount Hope Mine, New Jersey, (Halecrest Co., Inc.)

Location and Accessibility

The Mount Hope Mine is 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 approximately 35 miles WNW of New York City, is 18 miles long and 4-5 miles wide. The Mount Hope Mine is at Mount Hope, three miles north of Dover. The approximate location is 40°54'N and 74°35'W (Fig. 18). The region has a network of good primary and secondary roads, and all areas are readily accessible.

Mine Facilities

The Mount Hope Mine is owned by the Halecrest Company, Inc. of Edison, New Jersey. It is located in a rural, hilly area on a three-square-mile site. The mine has had several different owners and was inactive from 1959-1977 (SRI, 1976).

The Mount Hope Mine was considered as a potential site for a pumped-storage hydroelectric or compressed-air energy facility by the Jersey Central Power and Light Co. As described by Richert (1974), a surface reservoir would be connected with an underground powerhouse and reservoirs which would be excavated from workings. The mine was re-opened in October 1977 but closed in February 1978 because of lack of capital (Engineering and Mining Journal, 1978).

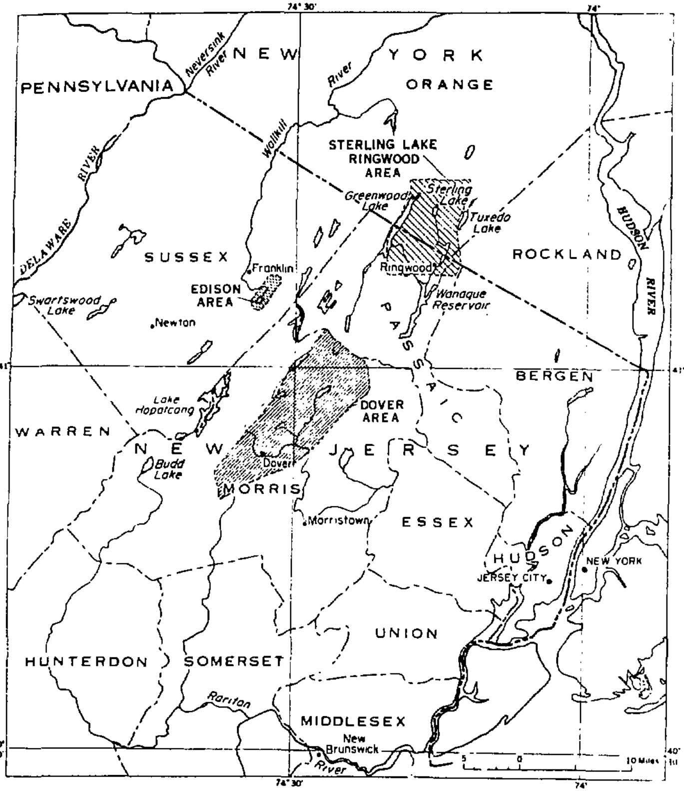

Figure 18. Index map showing the location of the Dover District, New Jersey. (Sims, 1958)

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The mine has flooded to a depth of roughly 1200 feet. If flooding were to continue, the water level would inundate the 1000-foot level workings within the year. Due to a water shortage, however, the mine water is being pumped for local distribution. Aside from this activity, the mine is not in use at this time, and there are no future plans. The New Leonard Shaft hoist is operable (Fig. 19), and general utilities are available on the surface and underground. Surface offices, shops, and other facilities are in good repair.

Geologic Setting

Regional Lithology. The geological setting of the Dover district, (Fig. 20) was described by Sims (1958) and summarized by Smith (1974). The district is in the New Jersey Highlands, a belt of Precambrian rocks about 20 miles wide which strikes in a NE-SW direction across the northern part of the state. 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. Elevations are 500 to 1100 feet. The Wisconsin glacial terminal moraine crosses the central part of the district.

Bedrock consists of Precambrian metasedimentary rocks, migmatites, and intrusive igneous rocks, all of which are cut by Triassic diabase dikes. In the northwestern portion of the district the Precambrian rocks are disconformably overlain by steeply dipping early Paleozoic sedimentary rocks. Quaternary surficial deposits cover the bedrock in a discontinuous and usually thin layer.

Figure 19. Mount Hope Mine, headframe over New Leonard Shaft.
(XBC 811-293)

The oldest Precambrian metasedimentary rocks are widely distributed and make up about 25 percent of the bedrock. They are of high metamorphic grade: marble, pyroxene gneiss, skarn, amphibolite, biotite-quartz-feldspar gneiss and oligoclase quartz-biotite gneiss. 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.

Regional Structure. 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 most prominent fault in the district. Smaller faults, most exposed only in the mines, cause some mining problems. With reference to regional trends, the smaller faults are classified as transverse, longitudinal, and oblique. The transverse Mount Hope Fault (Fig. 20), striking N78°W and dipping 80°SW, is the only major fault transecting the mine area.

In the Dover district, the Precambrian rocks generally trend northeast and dip steeply southeast with considerable local variation. This pattern is produced by northeastward-trending isoclinal and open folds (from Proterozoic time) and by conformable granite sheets on the fold limbs. The folds, ranging in width from a few feet to over a mile, plunge to the northeast. Metasedimentary rocks form 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 preintrusive carbonate

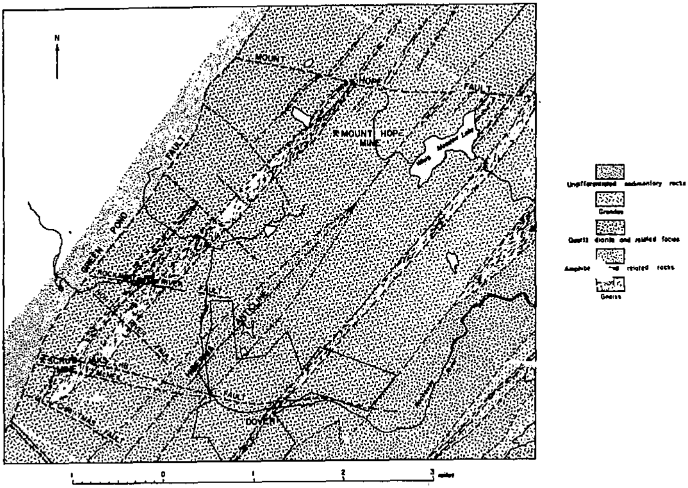

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Figure 20. Geologic map showing the location of the Mount Hope and Scrub Oaks mines in the Dover Mining District, Morris County, New Jersey. (After Sims, 1958)

rocks. Foliation developed in the granitic rocks before the final crystallization of the magma, and in some places secondary foliation is superposed on the initial foliation.

Smith (1974) points out that,

> "in the vicinity of the Delaware River, some forty miles southwest of the project, the Precambrian rocks are part of an overturned huge fold (technically known as a nappe), and this structure has been so deeply eroded that the present surface exposes rocks on the underside of this structure. One result is that, in places, upside-down Paleozoic rocks on the under side of the nappe are now exposed to view..... the significance of this is that if the Precambrian rocks are not true basement, Paleozoic rocks might be encountered if one went deep enough,......"

He concludes that such depths would be below the 2500-foot level of the Mount Hope Mine.

Mine Geology. The Dover district contains 91 mines, 58 of which produced iron ore. All but the Mount Hope Mine are abandoned. Of the seven ore s in the district, the Wharton ore belt, which contains the Mount Hope ine, is 10 miles long and 900-3000 feet wide.

The 300-year old Mount Hope Mine has workings in nine ore bodies. It is considered to be the oldest operating mine in the United States, with production dating back to 1710; it may have been worked as early as 1665.

Bedrock at the Mount Hope Mine consists of mixed metamorphic rocks and granites. The most abundant metamorphic rock, oligoclase-quartz-biotite gneiss of metasedimentary origin, is exposed at the surface as well as throughout most of the mine. Alaskite (albite-oligoclase granite) is the most widespread rock type. Mine rocks were deformed into isoclinal folds trending and plunging northeast. The most prominent fold is the overturned Mount Hope syncline (Fig. 21); its axial trace trends N45°E and its axis plunges 12-20°NE. Oligoclase-quartz-biotite gneiss and ore deposits occupy the limbs of the syncline. Aside from the Mount Hope Fault, longitudinal faults also present can cause mining problems, although they are not continuous for long distances.

The Mount Hope iron ore deposits are of Precambrian age and occur in both metasedimentary and granitic rock. Massive magnetite ore containing 35-60% iron comprises most deposits. The ore occurs in belts containing steeply dipping veins. The veins, conforming essentially to the gneissic wall rock structure, strike and dip parallel to the foliation of the gneiss and plunge parallel to the lineation.

Rock Mass Character. With the exception of the magnetite ore zones and the Mount Hope Fault zone, the granite-gneiss is reported to be fairly uniform in composition and in physical properties. Surface exposures at a nearby quarry, approximately 1/2 mile NW of the mine surface facilities, appear to have similar characteristics.

Exposures of granite-gneiss in the quarry indicated four principal joint orientations: two nearly vertical (one north-westerly probably controlled

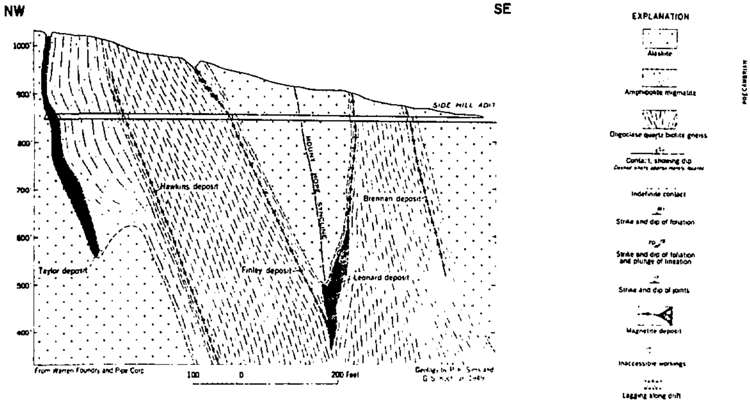

Figure 21. Geologic section through Side Hill adit, Mount Hope Mine. (Sims, 1958)

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by foliation), one subhorizontal, and one dipping at 45-70° (Fig. 22). In general, all joints are planar and appear tight, except where loosened by blasting. It is expected that the four principal joint sets continue at depth and would be observed on all levels of the mine. Overall, the average spacing of major joint sets was observed to be on the order of 1 to 10 meters.

Where observed underground, at the 1000-foot level near the New Leonard Shaft, average joint spacing appears to be closer to one meter. Most of the joints were healed with calcite and were occasionally coated with what appeared to be chlorite (Figs. 23a and b). Near mineralized contacts viewed in the North Carlton drift, the alaskite was highly jointed but again well healed (Fig. 24). This high intensity of jointing, with spacing of less than 0.3 m, is most likely associated with the contact.

As previously described, the predominant granitic rock types in the mine area include alaskite, hornblende granite, and oligoclase-quartz-biotite gneiss. The alaskite and the hornblende granite are similar in their petrologic character (Sims, 1958). The alaskite is a light-colored, medium- to coarse-grained rock occasionally gneissic in texture. A modal analysis of alaskite from the Mount Hope Mine indicates that quartz and plagioclase are in roughly equal abundance, 31 perent by volume; potassium feldspar (microperthite) makes up 30 percent. The remainder of the rock is composed primarily of accessory minerals and biotite. The hornblende granite is light-colored, medium- to coarse-grained, equigranular and occasionally gneissoid. Quartz content averages about 25 percent; potassium feldspar ranges from 35 to 65 percent; and plagioclase is generally present in inverse proportion to

Figure 22. Panoramic view across the north face of the quarry near the Mount Hope Mine area, showing joint sets and general rock conditions.
(XBC 811-302 and XBC 811-303)

Figure 23. Mount Hope Mine, closeups of joint surfaces in quartz-biotite gneiss.
(XBC 813-3257 and XBC 813-3258)

Figure 24. Medium to coarse alaskite, east side of North Carlton drift, near face, Mount Hope Mine, New Jersey. (XBC 813,3255)

Figure 25. Stub drift in Mount Hope mine near New Leonard Shaft, general cross section. (XBC 813-3248)

the amount of potassium feldspar. Hornblende makes up from 5 to as much as 11 percent of the rock. The oligoclase-quartz-biotite gneiss was described by Sims (1958) as a greenish-gray, medium-grained, equigranular rock, strongly foliated where biotite is an abundant constituent. A sample from the 1000-foot level of the Mount Hope Mine (Sims, 1958) contained 71.5 percent plagioclase and 26 percent quartz; biotite was absent. However, other samples from elsewhere in the Dover district contained from 2 to 12 percent biotite.

Underground Openings and Workings

The underground workings are serviced by the New Leonard Shaft, a 2800-foot deep three-compartment shaft with levels at depths of 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 (Acres, 1975). Drifts and haulage ways are generally from 8 x 10 to 9 x 12 feet in cross section with larger stoped areas. Several types of mining methods have been employed, in chronological order: (1) open pit, (2) underground open stopes (stull timbered), (3) shrinkage stoping, and (4) sublevel stoping.

Drifts and haulage roads are largely unsupported except within fault zones. An example is the stub drift near the New Leonard Shaft on the 1000-foot level (note the near vertical joint set striking parallel to the axis of the drift in Figure 25). Given the appearance of the surface and underground exposures, the rock mass can be generally characterized as blocky to massive.

A further indication of the competence of the rock mass is provided by the engineering report on the proposed pumped hydroelectric scheme (Jersey Central Power and Light Co., 1975). Based on inspection of the underground workings, it was estimated that chambers could be excavated 75 feet high and 50 feet wide with support generally limited to surface rock bolting and wire mesh for safety.

Hydrology

Historically, water inflow into the Mount Hope Mine has been 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 (Halecrest Co. engineers, personal communication). More recently, the Acres report (1975) indicates that the inflow into the Mount Hope Mine is 400 gpm above the 1700-foot level. Discussions with mine personnel, however, indicate that the majority of this water is from a connecting drift to an adjacent mine and percolation from the surface through the old open stopes (Halecrest Co. engineers, personal communication, January 7, 1981).

Sims (1958) states that the Mount Hope Fault in the mine workings is a shattered brecciated zone. This zone may be capable of producing water where the fault is intersected by the workings. However, where observed on the 1000-foot level on March 16, 1981, the fault zone appeared relatively tight with only minor inflows (i.e., drips) of water. Walls of nearby drifts within the massive to blocky bedrock generally were dry to damp.

As a further indication of the impervious nature of the rock mass, it was proposed that chambers be excavated within the granite-gneiss for compressed air energy storage. This usually requires a hydraulic conductivity equal to or less than 10^{-8} cm/sec for favorable economics with respect to air leakage.

The presence of the Mount Hope Lake and Pond directly above the workings indicates that the water table is near the surface.

Possible Experimental Facility Location

Areas most suited for use as an experimental facility are located on the 1000-foot level, below mine datum. Underground observations, mine maps, sections, and a model indicate that the North Carlton drift on the 1000-foot level is a possible location to begin excavation, with access from the New Leonard Shaft (Fig. 26). Another candidate location, also offering access to unmineralized rock, is a stub drift near the New Leonard Shaft, crossing the Mount Hope Fault zone.

One objection to locating an experimental facility on the 1000-foot level is the existence of workings at lower levels down to 2100 feet, although the major stopes are somewhat removed from the proximity of the New Leonard Shaft. As far as can be ascertained, several drifts are directly below the areas of interest on the 1000-foot level. It appears, however, that with a horizontal drift to the east or southeast, the experimental facility would be outside the region of significant hydrologic or geomechanical disturbance.

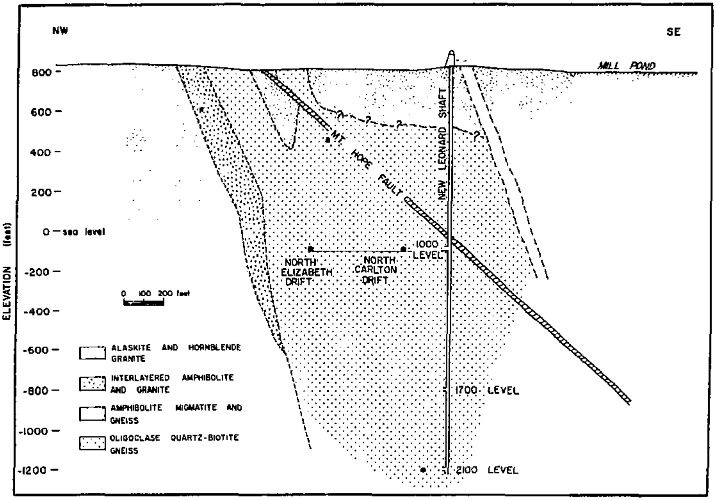

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Figure 26. Simplified geologic cross section through the Mount Hope Mine, New Leonard Shaft. Note: the fault through this section complicated locating the mined areas, based on available information. However, the mined areas probably extend above the indicated drifts, with a dip of between 55° and 80°.

A.1.4 Minnamax Project, Minnesota (Operated by American Metals Climax Inc.)

Location and Accessibility

The Minnamax Project site is located approximately 5 miles SSE of Babbitt and about 60 miles north of Duluth, Minnesota (Fig. 27) at 47°37'N, 91°52'W. The elevation of the area averages 1600 feet; small lakes and marshes are prevalent. The Babbitt area is reached by good roads from Duluth by way of Aurora or through Two Harbors on the north shore of Lake Superior. As shown in Figure 28, there is a taconite mining area immediately north of the Minnamax Project.

Facilities and Status

The Minnamax Project is operated by American Metals Climax, Incorporated (AMAX). A shaft was sunk to a depth of 1700 feet, and roughly 3400 feet of drifts were excavated for exploration of copper - nickel mineralization in the late 1970's; the shaft and drifts remain accessible. Surface facilities including a mine office, core storage building, hoist house, dry, and shops are in excellent condition. The mine is presently inactive, following an initial evaluation phase. No significant underground work is presently contemplated by AMAX for several years. A final evaluation phase may involve limited mining to produce some tonnage for pilot plant operation. This may lead to sinking a production shaft and concurrent development of an open pit, followed by commercial production in the 1990's.

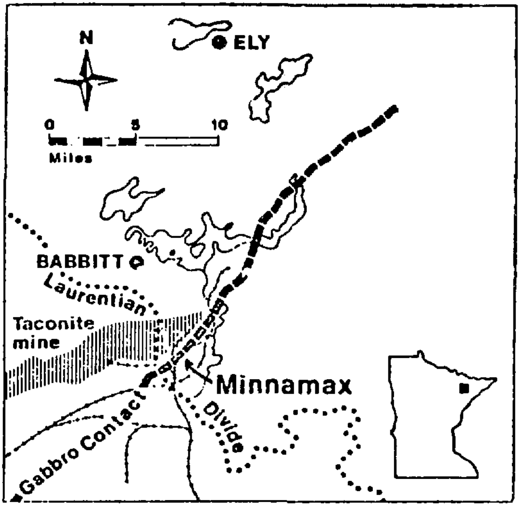

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Figure 27. Location map of Minnamax Project, St. Louis County, Minnesota. (Reproduced by permission of Engineering and Mining Journal)

Geologic Setting

Regional Geology. The principal sources of geologic information on the region are articles by Bonnichsen (1972), Listerud and Meineke (1977), and Phinney (1972). The Duluth Complex of northeastern Minnesota covers about 2500 square miles and is comprised of a series of Upper Precambrian mafic intrusive rocks: anorthosite, troctolite and gabbro. The complex extends in an arc from Duluth northeastward into the north-easternmost tip of Minnesota, a distance of 150 miles. The base of the complex dips southeastward, with the rock units thickening in that direction. The complex was intruded along an unconformity between the overlying volcanics (the North Shore Volcanic Group, mainly rhyolite) and underlying older rocks of Early and Middle Precambrian ages (the Virginia Formation metasediments of granulitic facies, Biwabik Iron Formation, and the granite of the Giant Range batholith). Radiometric dating indicates that the age of the Duluth Complex intrusives is approximately 1120 $\pm$ 15 million years.

The Minnamax Project is located in the Babbitt-Hoyt Lakes region, approximately midway along the northwest border of the Duluth Complex, as shown in Figure 28. The geologic setting of the Babbitt-Hoyt Lakes region and the location of the Minnamax Project are shown in Figure 29.

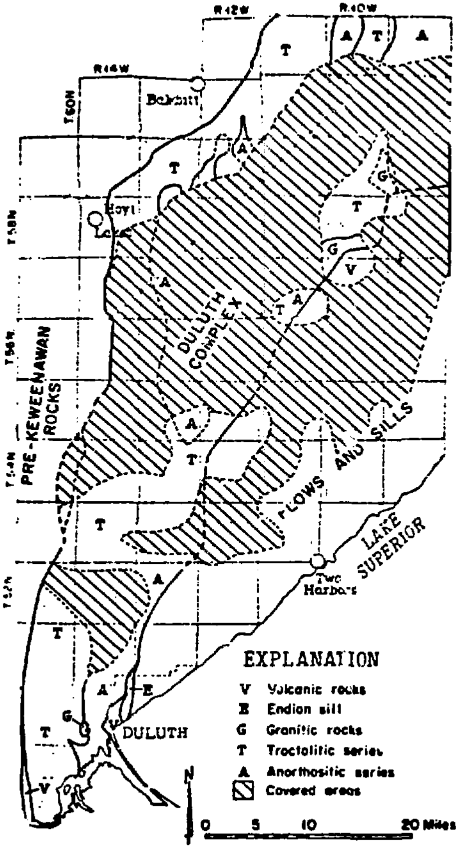

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Figure 28. Geologic map of southern part of Duluth Complex, Minnesota. (Bonnichsen, 1972)

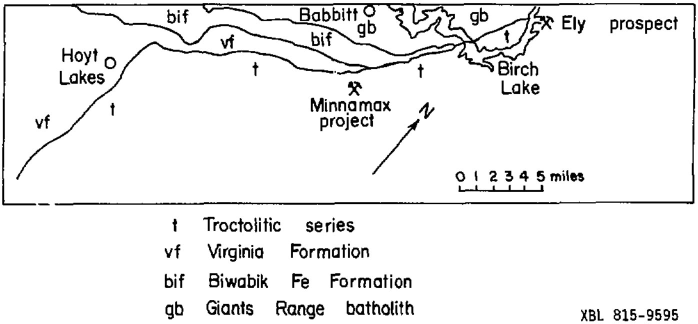

Figure 29. Simplified geologic map of the Babbitt-Hoyt Lakes area, Minnesota. (After Bonnichsen, 1972)

The Duluth Complex contains two major rock groups: a troctolitic series and an anorthositic 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 crops out near the western margin of the complex and is generally located west and northwest of the anorthositic series. Numerous inclusions of fine-grained, generally granular hornfels, 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 rock appear to be most abundant.

Mine Geology. The geologic setting of the mine area was described by Phinney (1972). The host rock, basal troctolitic gabbro of the Duluth Complex, varies in grain size, mineral proportions, structural attitude, and texture. The exploration shaft and accessory drifts of the Minnamax Project are predominantly in the Duluth Complex intrusive, though near its base the shaft is in granulitic rock of the Virginia Formation (Fig. 30). The principal rock type in the underground workings is medium- to coarse-grained troctolite with occasional pegmatitic zones. The copper/nickel mineralization occurs predominantly as disseminated sulfide minerals near the base of the troctolitic intrusive; zones of massive sulfide mineralization are also present. Prominent

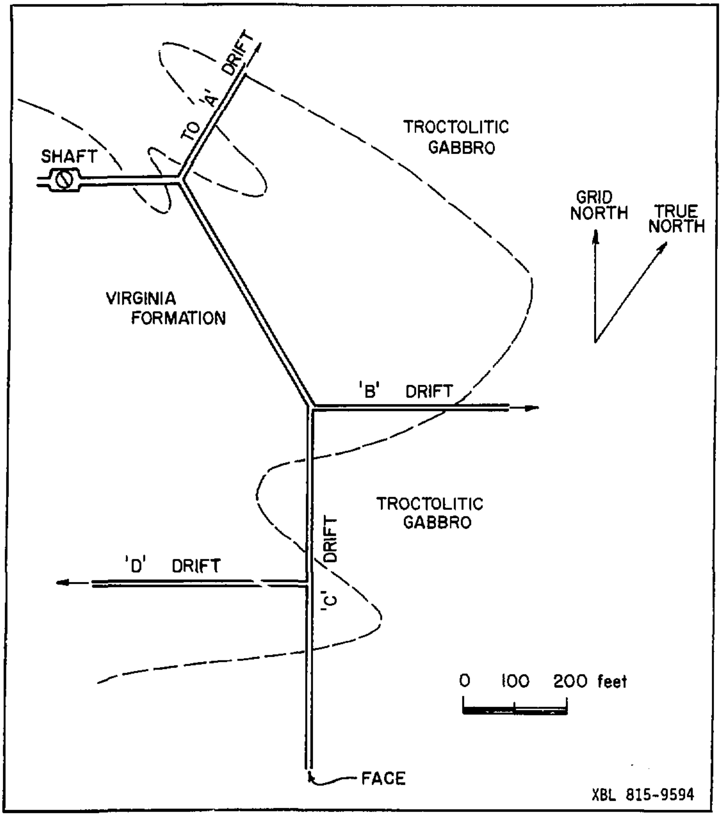

Figure 30. Schematic layout of 1700-ft level, Minnamax Project; dashed line is approximate location of contact between Virginia formation and gabbro. (Information from inspection of 1700-ft map)

ore minerals are cubanite, chalcopyrite, pyrrhotite, and pentlandite; ore grades range to over 1 percent copper by weight; extensive zones of disseminated mineralization may contain 0.1 to 0.2 percent copper; total sulfide mineralization ranges from approximately 0.1 t 0 percent.

The shape of the deposit is tabular, approximately 6000 meters in length, 115 meters in width, and 100 meters in thickness. The ore body strikes northeastward; the undulating plunge and dip are to the northeast and southeast, respectively. The depth to the top of the ore body is about 400 meters.

Rock Mass Character. Where observed underground, especially away from contacts with the Virginia Formation, the troctolitic gabbro is massive to blocky. Joints are spaced approximately two feet apart and appear to be well healed, predominantly with carbonate minerals. Three prominent joint sets were observed: one striking approximately north-south and dipping nearly vertically, another nearly vertical set striking approximately east-west, and a third set which is sub-horizontal with dips undulating roughly parallel to the contact between the gabbro and the underlying Virginia Formation (Figs. 31 and 32). Two steeply dipping north-south striking fault zones transect the workings; they are each about 3 feet wide, slickensided, and are spaced roughly 800 feet apart.

Alteration of the gabbro is confined essentially to the joint surfaces. Away from zones of intense sulfide mineralization,

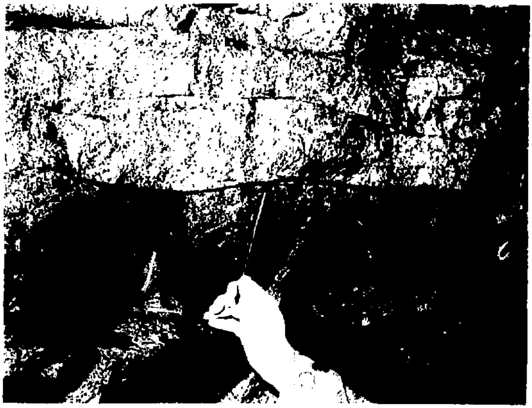

Figure 31. Closeup of drift wall, subhorizontally jointed troctolite, Minnamax Project, Minnesota. (XBC 813-3271)

Figure 32. 'C' drift face area; approximately N-S vertical joints, Minnamax Project, Minnesota. (XBC 813-3273)

alteration is predominantly saussuritization. The average rock quality designation (RQD) of the gabbro, 85 percent, was determined by surface drilling (S. Watowich, Amax geologist, private communication, March 19, 1981).

The ranges in composition of gabbro from the layered series were expressed by modal analyses of the abundance of minerals by Bonnichsen (1972). Plagioclase (predominantly calcic) ranges from 44 to 81 percent by volume; clinopyroxene from less than 1 to 37 percent; orthopyroxene from less than 1 to 9 percent; and olivine (predominantly forsterite) from 4 to 20 percent.

The workings are predominantly in gabbro that is sulfide-mineralized to varying degrees. However, relatively unmineralized gabbro was observed at the southeast end of the 'C' drift (Fig. 33); the location is shown in Figure 30. Because the exploratory drilling does not extend further to the southeast, it is not known if this "barren" gabbro extends beyond the workings in that direction or if more mineralized zones might be encountered. However, the workings are in or near the zone of basal contact between the gabbro and the Virginia Formation and are a few hundred feet vertically above the Biwabik Iron Formation. This basal contact dips southeastward, and the gabbro effectively thickens in that direction. Therefore, less mineralized gabbro should be encountered in a southeastward direction from the workings at 1700 feet or shallower depths.

Figure 33. 'C' drift face area; closeup of troctolite surface, Minnamax Project, Minnesota (XBC 813-3276)

Underground Openings and Workings

The mine workings are reached by a 1700-foot deep, 14-foot diameter circular shaft. The headframe is shown in Figure 34. Approximately 3400 feet of drifts on the 1700-foot level were excavated by conventional drill and blast methods, employing a 3 - arm drilling jumbo. The horeshoe-shaped drifts are approximately 8 feet wide and 9 feet high in cross section and provide access for extensive radial drilling of the orebody from enlarged drill stations approximately 15 by 15 feet in cross section. The openings are unsupported, except where the fault zones transect the drifts, and show little sign of deterioration. Some minor overbreak is associated with the nearly horizontal joint set and apparently high horizontal stresses. The minimum horizontal stress is significantly greater than overburden pressure, and the maximum horizontal stress is approximately twice the minimum stress (S. Watowich, private communication). These relatively high stresses contributed to the formation of "Gothic arch" shaped drift cross sections in the massive gabbro (Fig. 35).

Hydrology

The water table in the Babbitt area is probably close to the surface, as indicated by the presence of numerous lakes and streams, moderate rainfall (25 - 30 inches per year), and relatively gentle topography. The unlined shaft reportedly produces 5 to 6 gallons per minute, and the 3400 feet of drifts produce an approximately equal amount (Minnamax personnel, private communication). Several gallons per minute were

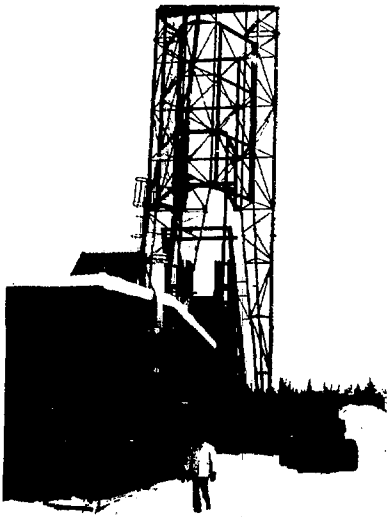

Figure 34. Headframe hoist house, Minnamax Project, Minnesota. (XBC 813-3266)

Figure 35. Looking down 'C' drift, Minnamax Project; "Gothic arched" cross section is indicative of high horizontal stress. (SBC 813-3277)

observed to be flowing into the workings from some of the exploration holes (up to 500 ft long) drilled in a radial pattern from stations along the drifts. Packers were set in several of the holes producing excessive water, a few gallons per minute. With the exception of these drill holes, surfaces of the underground workings in both the Virginia Formation and the gabbro appeared essentially dry. Minnamax personnel indicated that the mine water contains up to 1000 ppm chloride, in contrast to near-surface and surface water of much lower chloride and total-dissolved-solids contents. The high chloride content of Minnamax mine waters is comparable with high salinities of other mine waters in the Canadian Shield (P. Fritz, private communication). More detailed chemical analyses of Minnamax waters have been requested from the company.

Possible Experimental Facility Locations

Two possible locations for excavation for experimental facilities were identified in the Minnamax workings. It is expected that both areas will be well away from any future mining activities.

One possibility would be excavation southward from the end of 'C' drift at a depth of approximately 1700 feet (Fig. 30) into an area where mine maps and a model suggest that the gabbro is relatively unmineralized. As indicated in Figure 30, the base of the gabbro lies about 100 feet below the end of 'C' drift, and the top of the Biwabik Iron Formation is approximately 220 feet below the floor of the drift. The general south to southeasterly dip of the gabbro suggests that, if mineralization follows the basal contact in approximately the same position observed in the explored area, experimental workings developed from a southerly extension of 'C' drift would be above rock of possible future economic interest.

A second possible location, more certain to be in relatively "barren" gabbro and farther away from contacts, could be reached by drifting westward from a station that would be excavated from the shaft of 1200 to 1500 feet below the surface. Inspection of mine maps and sections indicates that gabbro in that direction may be relatively unmineralized, and the base of the gabbro beneath the workings would be 200 to 400 feet, or deeper. The favorability of these or other excavation directions can only be confirmed by horizontal drilling from the selected starting locations.

Ely Prospect. A possible site for an underground experimental facility in the Duluth Gabbro, identified in our earlier search (Wollenberg and others, 1980), was the Ely Prospect of the International Nickel Company (INCO), located approximately 13 miles southeast of Ely, Minnesota, and about 12 miles northeast of the Minnamax Project (Figs. 27 and 28). The geologic setting of the Ely Prospect is probably similar to that of Minnamax because both are in the troctolitic gabbro of the Duluth Complex. However, mineralization at the Ely Prospect is somewhat shallower than at Minnamax.

The underground workings at the Ely Prospect consist of the approximately 1000-foot deep Maturi Shaft; a 400-foot long, 8-foot wide drift; and a 40-foot wide, 180-foot high stope. A limited description of the site and description of hydraulic fracturing tests in the gabbro were given by Von Schonfeldt (1970). Recent discussions with INCO indicate that the underground workings were developed for exploration of copper/nickel mineralization and to obtain sufficient material for a pilot plant. Within the past year the shaft has been sealed and the hoist and head frame removed.

A.2 SECONDARY GRANITIC SITES

A.2.1 Dworshak Dam Site

Location: On North fork of Clearwater River, Clearwater County, near Orofino, Idaho.

Jurisdiction: U.S. Army Corps of Engineers, Walla Walla District.

Rock type: Strongly foliated quartz diorite gneiss of Precambrian age.

Description: An underground crushing chamber beneath the quarry area, approximately 1/2 mile from the reservoir, is served by an approximately 1000-foot long access drift roughly 25 feet in diameter. Extending the drift 700-800 feet southeastward beneath and beyond the quarry might provide access for experiments. However, sufficient depth of cover and position of the water table are questionable.

Three exploration adits in the gneiss beneath the dam are still accessible. In two, flat-jacking tests were conducted prior to construction of the dam. A pressure chamber to test the response of the gneiss to the dam and reservoir loading is also accessible. The third adit intersects the diversion tunnel in the left abutment. This adit offers the most likely access for experimental facility excavation at this site. However, its cross section would have to be enlarged to accommodate mining and experimental equipment. Excavation could originate in the diversion tunnel and extend into the canyon wall under sufficient depth of cover. The hydrologic regime beneath and close to the dam is strongly affected by the reservoir (over 500 feet of head at the dam) and its seasonal fluctuations.

A.2.2 Balmat-Edwards Mines, St. Lawrence County, New York

Owner: St. Joe Zinc Company.

Rock Type: Precambrian quartz-biotite gneiss wallrock; the ore occurs in dolomitic marble.

Description: The Edwards Mine has underground access to starting points for excavation into the gneiss of the hanging wall on the 900-foot level, and into the footwall gneiss on the 1500-foot level; level depths are below mine surface datum. However, the Edwards Mine is being closed and, lacking indications of encouragement for future use, will be sealed. The hoist and head frame will be removed in the late spring or early summer of 1981. We were unable to inspect the underground workings, but observation of surface exposures of the gneiss and discussion with company geologists indicated that the rock at depth is probably acceptable for our purposes, although somewhat limited in extent.

The Balmat Mine is entirely in carbonate rock of good character. However, to reach the wallrock gneiss would require nearly 3000 feet of horizontal excavation from accessible mine levels.

A.2.3 Pine Creek Mine, Inyo County, California

Owner: Union Carbide Company

Rock type: Predominantly Tungsten Hills quartz monzonite of the Sierra Nevada batholith, cut by veins, stringers, and dikes of aplite, pegmatite and alaskite, and in contact with prebatholithic siliceous and carbonate metasedimentary rocks. The tactite of the contact zone contains the tungsten mineralization.

Description: Possible access areas for excavation of experimental facility galleries in the quartz monzonite are the north ends of haulage levels at 8100 and 9600 feet above sea level. The highest levels of the mine are over 11,500 feet above sea level. The lowest and main haulage level of the mine is the "Easy Going" adit on the 8100-foot level; the portal is approximately 2 miles south of the shaft. Haulage is by electric-powered railroad in the ~8 x 8 foot adit. Another possible access area in quartz monzonite is an adit on the 1500-foot level (9600 feet elevation), presently only used as an intake for ventilation.

There is appreciable water inflow into and through the mine; total water production varies seasonally, ranging from 4000 to 9000 gpm. Relatively little water is introduced by mining operations; nearly all is from flow through old workings and through open joints, often at pegmatite-quartz monzonite contacts. Some joints were observed to be producing on the order of 100 gpm of water or more.

The Brownstone adit, driven south-southwestward nearly 2000 feet to explore and develop a separate ore zone, has its portal at an elevation of 8100 ft near the mine offices. The Brownstone is presently inactive but is easily accessible by foot. The southern third of the adit is entirely in granodiorite which is cut by numerous felsic and pegmatitic dikes. The adit was excavated in 1976-77; it is approximately 12 x 12 feet in cross section. Rock was hauled by rubber-tired vehicles. As with the actively mined areas, rock conditions on the back and walls of the Brownstone appear to be good. The total water outflow from the granitic rock zone is 100 to 150 gpm; most water issues from drill holes and open joints, less from a circular raise driven into an upper ore zone.

A.2.4 Emerson Mine, Lincoln County, Nevada

Owner: Union Carbide Metals Division

Rock type: Medium to fine-grained quartz monzonite of a stock of probable Tertiary age, 1 to 1 1/2 miles in diameter, in contact with Paleozoic metasedimentary rocks. The ore zone being mined occurs at and near the contact between the western margin of the stock and the metasediments.

Description: Possible access for excavation eastward into the quartz monzonite, under sufficient depth of cover, is provided by workings on the deepest level of the mine. This level is served by about a 1000-foot shaft from the surface. Where observed on the surface and underground, the quartz monzonite appears to be highly fractured at the contact; surface exposures indicate that the quartz monzonite is more massive at a position approximately 1000 feet into the stock.

All of the mine workings are above the water table, a setting somewhat similar to that of the Climax Stock workings at the Nevada Test Site. The mine produces less than 100 gpm of water, most introduced by underground operations.

A.2.5 Colorado School of Mines Student Mine, Clear Creek County, Colorado

Rock type: Biotite-granite gneiss of the Precambrian Idaho Springs Formation. The gneiss is cut by numerous pegmatitic and aplitic dikes and stringers. Joint and fracture surfaces are often lined with pyrite.

Description: The CSM Mine is entered by an adit whose portal, at an elevation of approximately 7400 feet, is about 1/4 mile north of the town of Idaho Springs. The mine is used to train students in the practical aspects of mining engineering and geology. Presently, there are three DOE sponsored geotechnical projects underway: a heated, jointed block test, an air and water permeability test in three parallel holes intersecting a common fracture, and detailed characterizaton and synthesis of fracture orientations in and around the experimental room. In addition to the DOE-sponsored tests, the U.S. Geological Survey is conducting a block test at ambient temperature to evaluate instrumentation.

Most of the presently accessible workings are under a less than acceptable thickness of cover and are above the water table. Discussion with Professor W. Hustrulid indicates that, to accommodate an NRC sponsored experimental facility, the workings could be extended northward into the mountain, reaching a position under sufficient cover and below the water table. However, numerous old workings penetrate the area, and the undetected presence of these workings would be of some concern if they were too close to an experimental area. Furthermore, the depth below the water table is probably not adequate.

A.2.6 Fairmont Mine, Clear Creek County, Colorado

Owner: Moritz Mining Company.

Rock Type: Idaho Springs gneiss, essentially of the same character as the CSM Mine.

Description: This mine is located about 3 miles north of the CSM Mine and approximately 2000 feet higher on Pewabic Mountain.

The adit and crosscuts are old; some were driven in the late 1800's. Their cross sections are roughly from 4 x 4 to 4 x 6 feet. Any use for an experimental facility would require significant enlargement of the adit and crosscuts. This, coupled with the position of the mine well above the water table and under a minimal depth of cover, makes this site less desirable than the CSM Mine or others we have visited which are located in granitic rock.

A.3 SCHISTOSE ROCK SITES

A.3.1 Copperhill Operations, Polk County, Tennessee

Owner: Cities Service Company, Chemical and Minerals Group.

Rock types: Metamorphosed Precambrian graywacke and quartz-sericite schist, containing zones of intense sulfide mineralization.

Description: A number of mines in the district, which are interconnected at depth, are being worked by Cities Service. The company personnel suggested that the most likely access for experimental facility excavation would be from drifts connecting the Boyd and Cherokee mines on either the 1000- or 1400-foot levels. The Boyd Mine will be deactivated this year; its shaft and hoisting works could accommodate experimental facility excavation and operations. Examination of drifts and crosscuts indicated that relatively homogeneous zones in either the graywacke or the schist are not extensive; the widest zone of non-schistose homogeneous graywacke, observed in a crosscut on the 1400-foot level, did not exceed 30 feet. Mine maps suggest that this also holds for other workings. Rock texture varies from relatively massive and homogeneous to intensely schistose over distances of only a few feet. With respect to lithology and homogeneity, this rock may be less desirable for a facility to develop tests and methodologies than the gneissic or granitic country rock of the other eastern U.S. mines visited.

A.3.2 Sunrise Mine, Platte County, Wyoming

Owner: CF&I Steel Corp.

Rock type: Strongly foliated and tightly folded graphitic and sericitic schist of the Whalen Group of Precambrian age, in contact with older Precambrian dolomite.

Description: The Sunrise Mine is presently on standby after a protracted strike. A maintenance crew keeps the shaft, hoist, ventilation and underground haulage ways in good repair.

Where observed underground, the schist is blocky, relatively hard, and breaks readily along the principal east-west foliation direction. Bedding surfaces are often slick, due to the weak sericite-graphite minerals.

The water table is reported to be between the 5th and 7th levels, approximately 550 to 750 feet below surface datum. The dolomite which stratigraphically underlies the schist is a principal aquifer in the region. The dolomite in the mine provides 75,000 to 100,000 gallons per day to the local domestic water supply.

If the site were suitable for an experimental facility, excavation in the schist to the east would be required from the lowest working level, about 750 feet below surface datum, to achieve a minimum thickness of cover. The thickness from the schist zone to the top of the dolomite is minimal; geologic data on the configuration of the schist-dolomite contact indicate that it is within 200 feet of the 7th level.

A.3.3 Sunshine Mine, near Kellogg, Idaho

Owner: Sunshine Mining Company.

Rock type: Strongly foliated Revett quartzite and St. Regis phyllitic quartzite of the Precambrian Belt series. The silver bearing veins are controlled by approximately east-west striking faults. Where they are the most uniform, phyllitic zones extend over tens of feet, interrupted by quartzite bands 1 to 2 feet wide.

Description: A little used drift, nearly 7 x 8 feet in cross-section, on the 2700-foot level (below mine datum) was considered by the mine geologist as the most likely access for an experimental facility. The area is served by the 3-compartment Jewell Shaft, which is the main vertical access for the active silver mine. Ventilation in the area appears to be adequate although the air temperature is about 90°F and humidity nearly 100 percent. Water production from the entire mine is approximately 300 gpm, with over 100 miles of workings contributing.

A pump room near the Jewell Shaft on the 2700-foot level in the St. Regis phyllitic quartzite is approximately 20 x 40 feet in plan and about 12 feet in height. The back is supported by wire mesh with rockbolts; roughly 6 inch-wide steel bands are bolted to the walls for support.

The mine geologist suggested that the nearby Nabob Tunnel, driven from the surface in the 1940s to explore mineralization west of the Sunshine Mine, might offer better access for our purposes than the operating mine. The tunnel is in the St. Regis formation and extends nearly 6400 feet at an approximate 45° angle to the regional strike. Although we did not enter the tunnel, inspection of the portal indicates that it is in good condition and electric power is available.

A.4 VOLCANIC ROCK SITES

A.4.1 Oregon Dam Sites, U.S. Corps of Engineers, Portland District

Detroit Dam Diversion Tunnel, North Fork, Santiam River, east of Salem.

Rock: Strongly fractured andesite of the western Cascades Range, intruded by massive fractured granodiorite. The andesite is considerably different in its appearance from the Columbia River flood basalt.

Description: A 25-foot diameter diversion tunnel in the left abutment is flooded to a depth of about 5 feet and therefore is accessible only by boat from the downstream portal. A concrete plug blocks the tunnel beneath the axis of the dam approximately 900 feet in from the portal. If it were desirable to conduct tests in andesite, an excavation from the diversion tunnel 1200 to 1500 feet into the canyon wall of the left abutment would reach a sufficient depth of cover. However, it is questionable whether the andesite flow is adequately thick for an experimental facility.

Cougar Dam Diversion Tunnel, McKenzie River, east of Springfield

Rock: The rock visible in the accessible portion of the diversion tunnel is predominantly flat-lying tuff, tuff breccia, and lapilli of the western Cascade Range. The tuff sequence is transected in one place by a 50-foot wide basalt zone. The tuff is fractured and faulted, and numerous seeps occur on the back and walls. The tunnel geologic section provided by the Corps of Engineers shows columnar basalt in contact with the tuff upstream from the concrete plug. It is questionable whether the basalt could be reached by excavation into the left abutment walls from the diversion tunnel or whether excavations would remain in tuffaceous rock.

Description: A roughly 25-foot diameter diversion tunnel is accessible by a crumbling wooden walkway from the downstream portal. A concrete plug beneath the axis of the dam blocks the tunnel approximately 700 feet in from the portal.

Lost Creek Dam Diversion Tunnel, Rogue River, north of Medford

Rock: Fairly massive andesite and basalt of the western Cascade Range. Inspection of the vertical walls of the spillway cut on the left abutment indicated that flows are up to 100 feet thick and are separated by 1- to 2-foot wide reddish baked zones containing some ash. The flows are interbedded with coarse flow breccia units which have been hydrothermally altered in some places. Steeply dipping to nearly vertical shear zones cut the flows and transect flow boundaries.

Description: A concrete-lined diversion tunnel in the right abutment is accessible from its downstream portal. However, because of the relatively low topographic relief in that area, considerable excavation (about 3000 feet) would be required to reach depths greater than 600 feet in basaltic rock.

It is evident from these descriptions that a sufficient thickness of relatively homogeneous basaltic or andesitic rock is not available for excavation of experimental galleries from the diversion tunnels under adequate depth of cover. It is expected that similar geologic settings would be found at other dam sites in andesitic and basaltic rock of the Pacific Northwest. Furthermore, the hydrologic problems associated with the fluctuating head in response to seasonal variations in reservoir levels would be of concern.

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