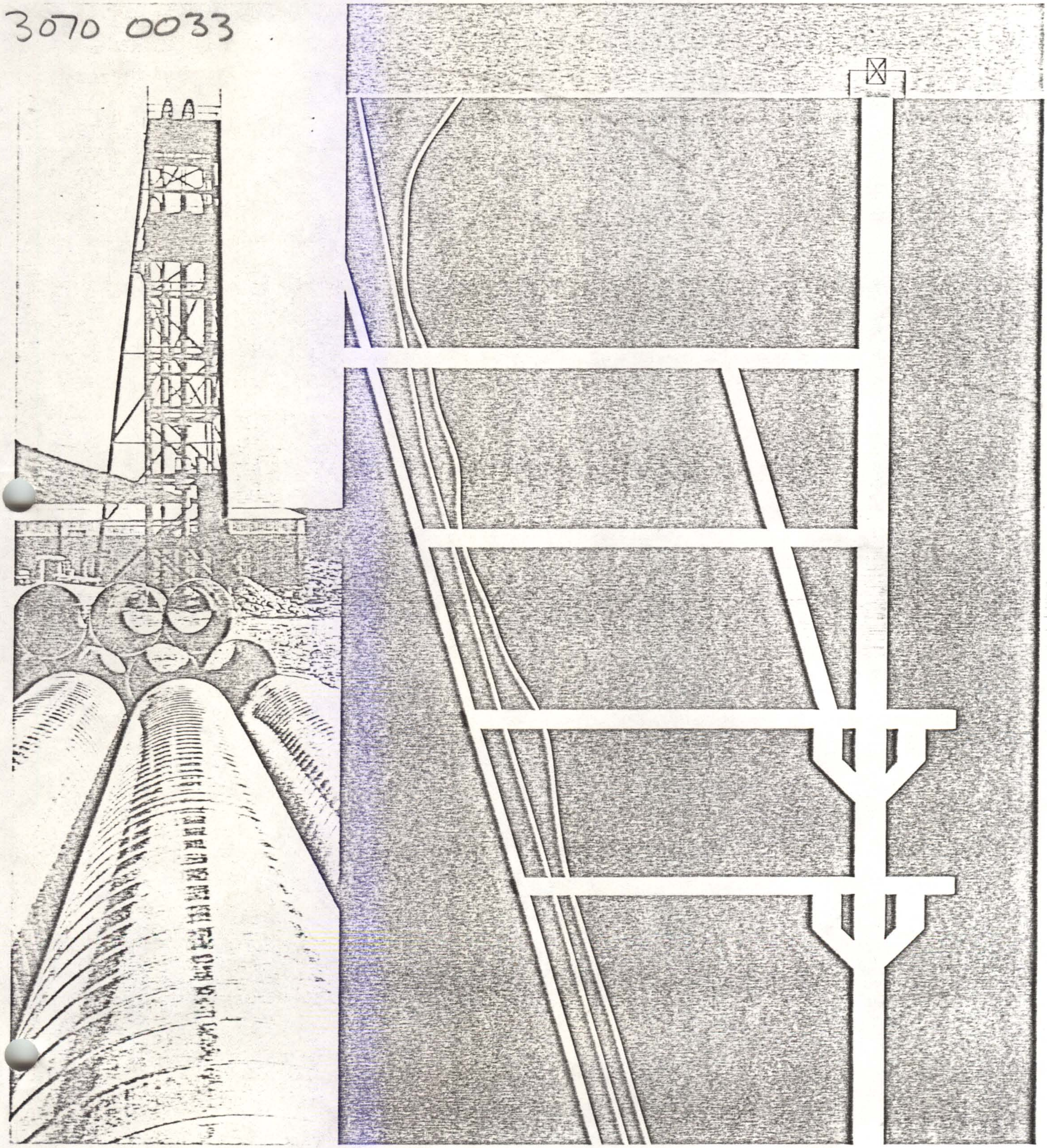
UTAH REPORT

AUG./SEPT. 1980



CONSTRUCTION PROGRESSES AT SPRINGER TUNGSTEN MINE

In early August 1979 the Utah International and General Electric Boards of Directors approved the construction of the Springer Tungsten Mine. The decision to proceed with the project culminated a $4.5 million program of exploration, reserves delineation, process development, preliminary engineering, and feasibility analysis begun in 1970 when General Electric exercised an option to evaluate and, subsequently, lease the properties controlled by Tungsten Properties Limited near the town of Mill City in northwestern Nevada.

After the Springer operation begins production in late 1981, the mine will produce approximately 350,000 tons of ore per year and will be the largest underground hard rock mine developed by Utah thus far in its history. The ore will be processed on site in a mill and chemical plant to produce annually approximately 100,000 short ton units of tungsten trioxide in the form of high purity ammonium paratungstate (APT). The product will be sold to General Electric's Refractory Metals Products Department for conversion to tungsten metal for use in light bulb filaments and to tungsten carbide powder for use in the manufacture of industrial cutting tools and drill bits.

At the mine site, work is now underway on three major aspects of construction: rehabilitation of the existing shaft and development of access tunnels; shaft sinking and construction of hoisting facilities; and construction of the mill, chemical plant and related surface support facilities. Referring to Figures 1 and 2 on these pages, let me explain the development of the shafts, access tunnels and hoisting facilities.

The Springer ore body consists of a series of thin mineralized beds which are inclined at a horizontal angle of about 70 degrees. In order to mine the ore in these beds, access from the surface must be provided by means of a vertical shaft in the hanging wall—that is, above the beds, as shown in Figure 1. The shaft will be rectangular in shape and will contain four compartments: two compartments containing skips (hoisting buckets) for hoisting ore; a service compartment containing a cage for hoisting personnel and supplies, and a utilities compartment containing pipes, cables and an emergency manway.

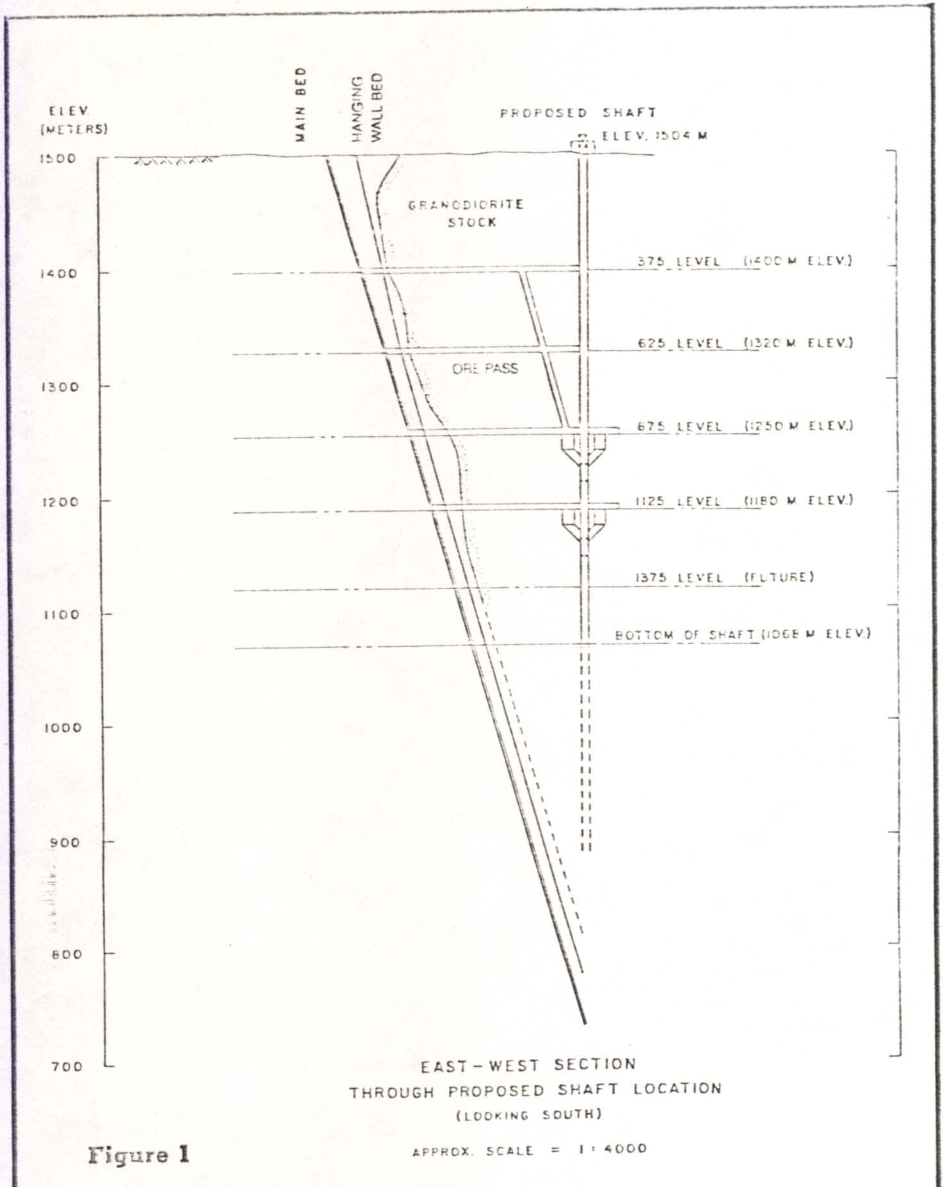


Figure 1

From the vertical shaft, horizontal access to the ore body will be provided by means of tunnels, called drifts, constructed at four levels. The total depth of the vertical shaft will be 1,430 feet and the access drifts will be tunneled at 375, 625, 875 and 1125-foot levels. There will be facilities at the bottom of the shaft for collecting spillage from the ore skips and for pumping water from the surrounding water table to the surface to prevent flooding of the mine.

From the access drift at each level, additional horizontal tunnels will be driven parallel to the ore body, either in the hanging wall bed or in the ore beds themselves. This is shown in Figure 2.

All of the drifts will be at least eight by nine feet in cross section to permit the installation of a narrow gauge rail system which will be used to haul ore from the mining areas back to dumping points—called transfer pockets—

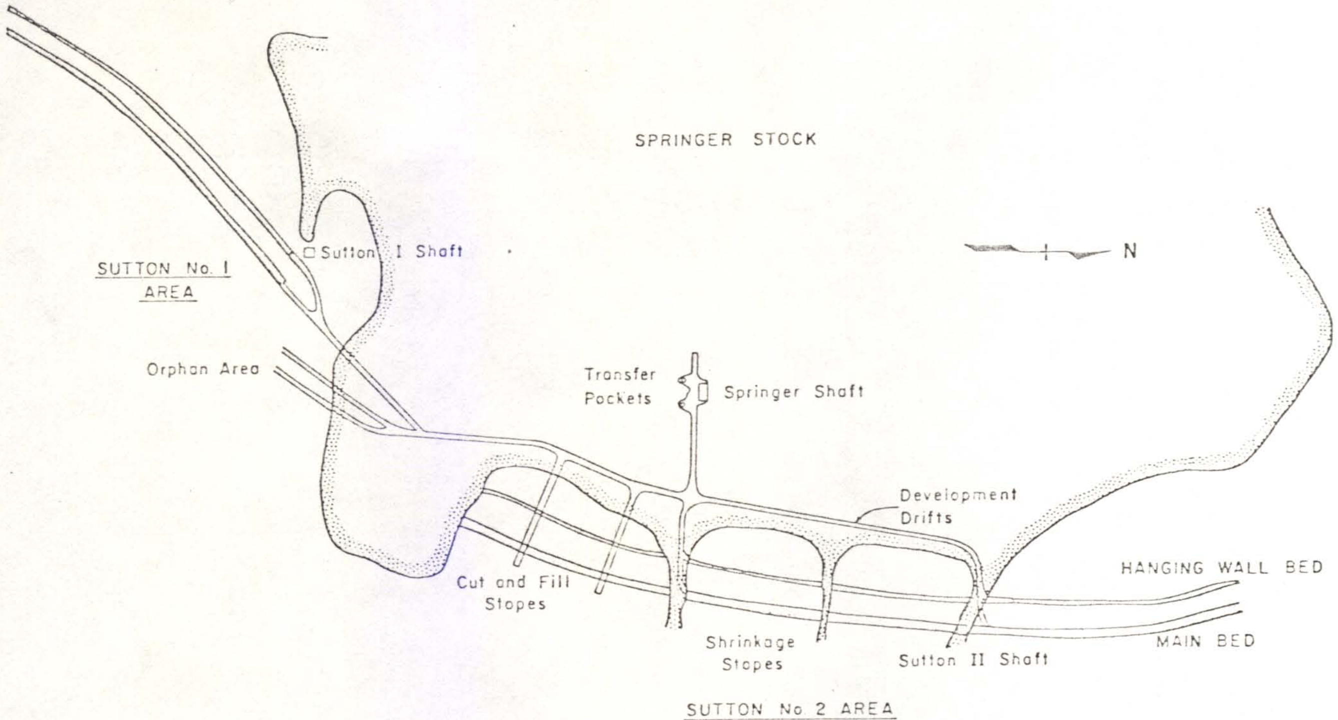


Figure 2 IDEALIZED MINE DEVELOPMENT PLAN

near the shaft. The ore, which ultimately will be hoisted from a loading station located below the 1125-ft. level, will be dropped to that loading station from the transfer pockets of all levels through a series of bored seven-foot diameter holes called ore passes. A certain amount of waste rock will have to be removed during the course of the mining operation and will be hoisted in a similar fashion but kept separate from the ore.

Ore will be extracted from the mining areas—called stopes—by one of two methods, depending on the stability of the surrounding rock. The distinguishing features of the two methods are illustrated in Figures 3 and 4, and I will discuss them now.

The shrink stope method of underground mining illustrated in Figure 3 is used when geophysical conditions indicate that surrounding rock will remain self-supporting even after ore has been removed. In such areas at Springer, a drift or tunnel will be driven into the ore bed and ore will be mined upward from one level to the next as miners take a series of ten-foot thick slices. After each slice has been blasted, enough broken ore will be drawn off from below, through a succession of chutes, to allow working room for those mining the next slice. Approximately 40 percent of the ore will be recovered in this manner—by being drawn off as swell (see glossary)—as mining progresses up the stope. The remaining ore will be drawn through the chutes as required until the stope is empty and there is a large, 250-ft. high hole in the rock.

The cut-and-fill mining method illustrated in Figure 4 is used when geophysical conditions are such as to require support of surrounding rock

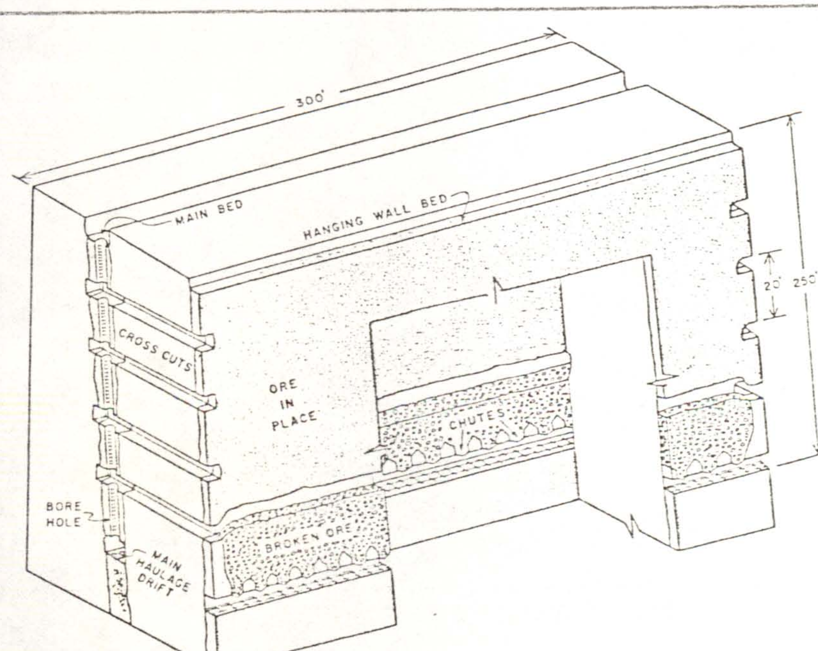


Figure 3 SHRINK STOPES

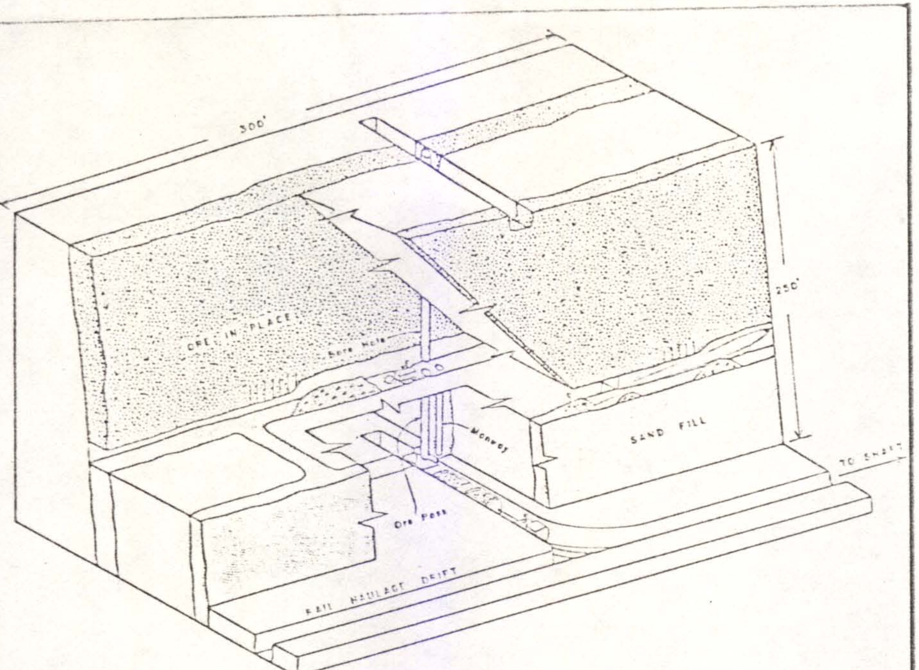


Figure 4

CUT and FILL STOPES

after ore has been removed. In such areas at Springer, the ore again will be drilled and blasted in ten-foot thick slices but, after it has been removed from the stope, the excavated area will be filled with waste—cycloned sand from Springer's mill tailings. The waste will provide structural support for surrounding rock and also will form a working platform from which the next slice can be taken. During the mining operation, mechanical equipment will be used to drag or carry broken ore to a centrally located ore pass, and the ore will be dropped to the rail haulage level for hoisting and removal.

When operations begin, it is expected that the underground tungsten mine will operate two shifts per day, five days a week to produce up to 1,400 tons of ore plus waste each day. This rate should satisfy easily the mill's requirements to produce 100,000 short ton units of ammonium paratungstate (APT) per year.

The processing plant at the mine site will operate three shifts per day, seven days a week. A generalized flowsheet of the conventional flotation mill and pressure leach chemical plant complex being built is shown in Figure 5. Let's go through it briefly.

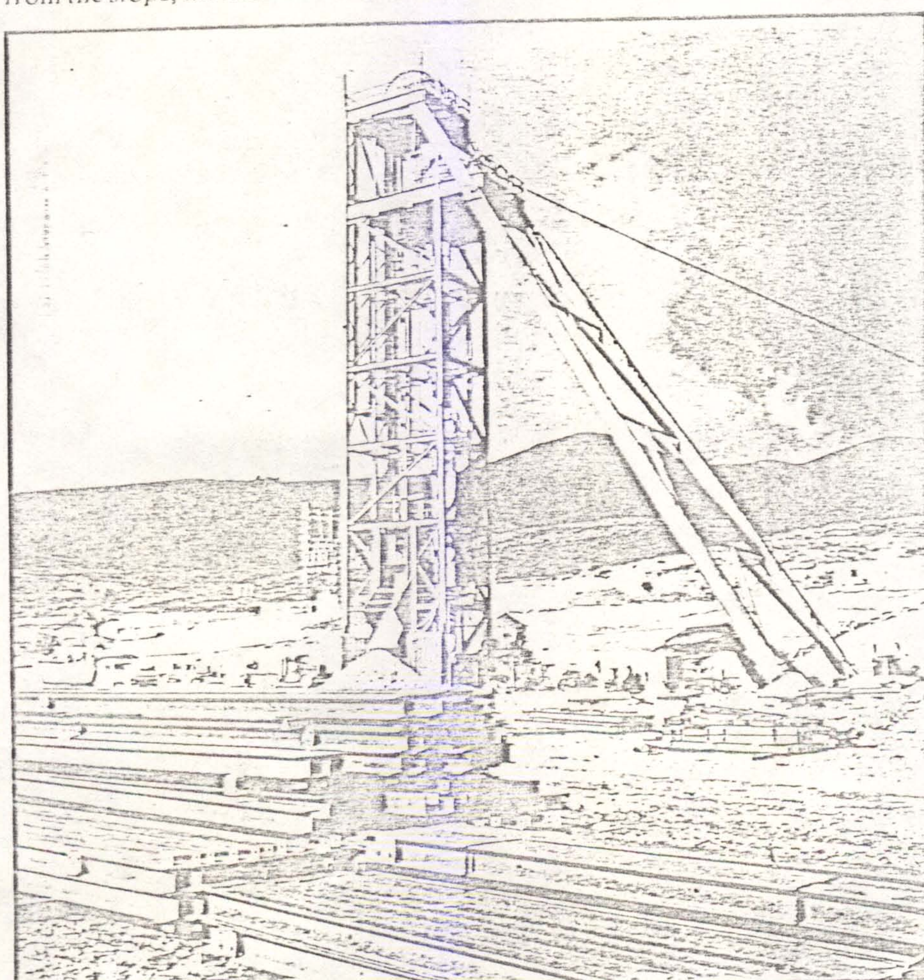
Following primary and secondary crushing in a gyratory crusher and a cone crusher, ore will be ground in a rod and ball mill featuring hydraulic cyclones to close the circuit. Next, sulfides will be removed by froth flotation prior to recovery of the tungsten mineral scheelite through a flotation process utilizing a fatty acid reagent.

At this point in the milling process, the resulting concentrate would not be of sufficiently high grade to sell directly. Therefore, the plant will include a pressure digestion process to solubilize the tungsten in preparation for separation and further upgrading. A soda ash leach will be used in the digestion process and will dissolve the tungsten mineral as well as a small amount of impurities.

After the digestion product is filtered to separate the waste solids, two distinct precipitation processes, followed by additional filtration, will be used to remove principal impurities—silica and molybdenum. The resulting solution will be further purified and prepared by means of a solvent extraction circuit for crystallization as high purity APT. The APT crystals will be filtered, dried and packaged for shipment to General Electric's plant in Cleveland, where final conversion of tungsten wire or tungsten powder will be accomplished.

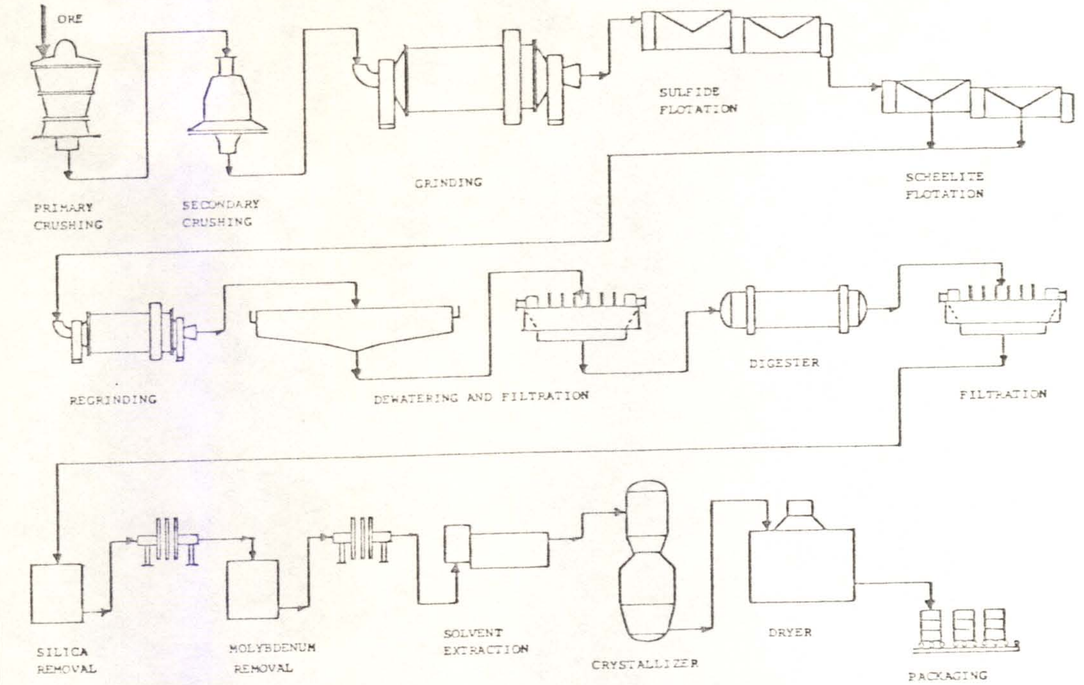
Design and construction of Springer's surface facilities have been

Construction work at Springer should be completed in late 1981.



SIMPLIFIED
MILL FLOWSHEET

Figure 5



contracted to an engineering group in Pasadena and are being carried out under the technical direction of Utah's Mining Technical Services Department. Construction started in May and is scheduled to be completed in September 1981.

Springer is a project unique among Utah's operations for several reasons. It is Utah International's sole hard rock underground mining venture to date and, as such, will require specialized crews to operate it effectively. It is the first mining venture between General Electric and Utah International, which gives it a high profile within both companies.

As with most new mining operations, the Springer mine has been staffed from scratch. Experienced underground miners are hard to find but, so far, Springer has been able to fill its present needs from local recruitment. As the work force expands, the local labor market will not be able to satisfy Springer's needs and the mine will have to recruit from outside and also to train as many people as possible. Extensive training also will be required to provide mill personnel with the specialized skills uniquely required by Springer's operations.

This article was written for Utah Report *by Project Engineer Bill Cline and Mine Manager Frank Metcalfe.*

A GLOSSARY OF UNDERGROUND MINING TERMS

Beds—Layers of minerals occurring between or in sedimentary rocks.

Chute—An inclined or vertical passage for the transfer of ore to a lower level. Also called an ore pass.

Cut-and-fill Stoping—An underground mining method through which ore is excavated by successive flat or inclined slices by miners working upward from a level. After each slice is blasted, all broken ore is removed and the excavated area then is filled with waste up to within a few feet of the back (to leave working space for the next slice to be taken out). The term cut-and-fill stoping implies a definite and characteristic sequence of operations: (1) breaking a slice of ore from the back; (2) removing the broken ore; and (3) introducing filling.

Drift—A horizontal passage underground. A drift follows the ore vein, whereas a crosscut intersects the vein and a level or gallery may do either.

Hanging Wall Bed—A secondary ore vein or bed on the upper side of the main inclined ore vein or bed.

Shrinkage Stoping—An underground mining method through which broken ore is excavated by removal of slices along the ore vein—from one end of an ore shoot to the other—by miners working on top of the previously blasted ore. No ore pillars are left to serve as supporting walls after the stope has been mined out completely.

Skip—A large hoisting bucket, constructed of boiler plate, which slides between guides in a shaft. The bail or handle usually connects at or near the bottom of the bucket so that its load may be dumped at the surface.

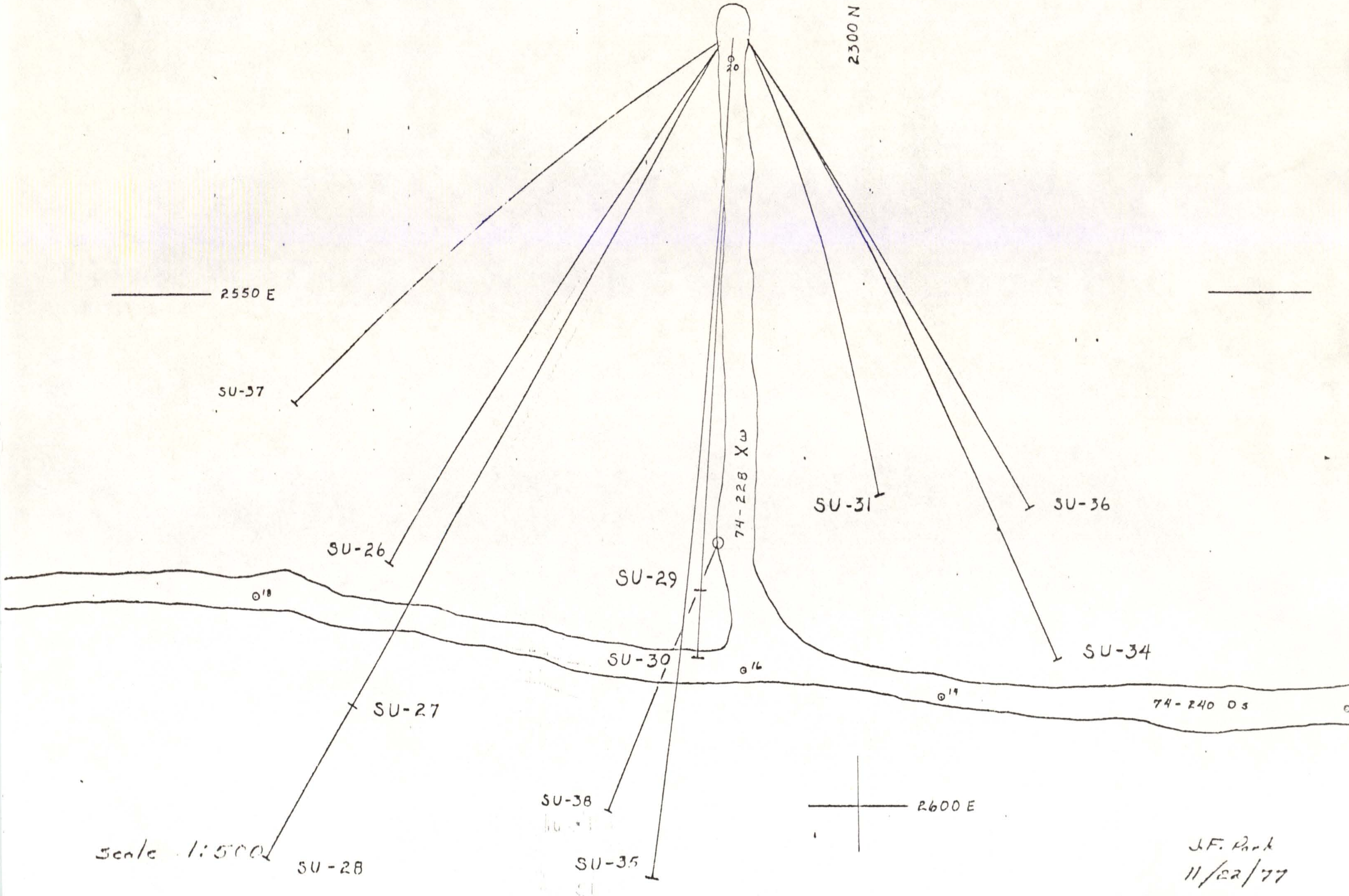
Stope—An excavation from which ore has been removed in a series of steps.

Stoping—In the broadest sense, the act of excavating ore by means of a series of horizontal, vertical, or inclined workings in veins or large, irregular bodies of ore. The term stoping covers the breaking and removal of ore from underground openings, except those driven for exploration and development purposes.

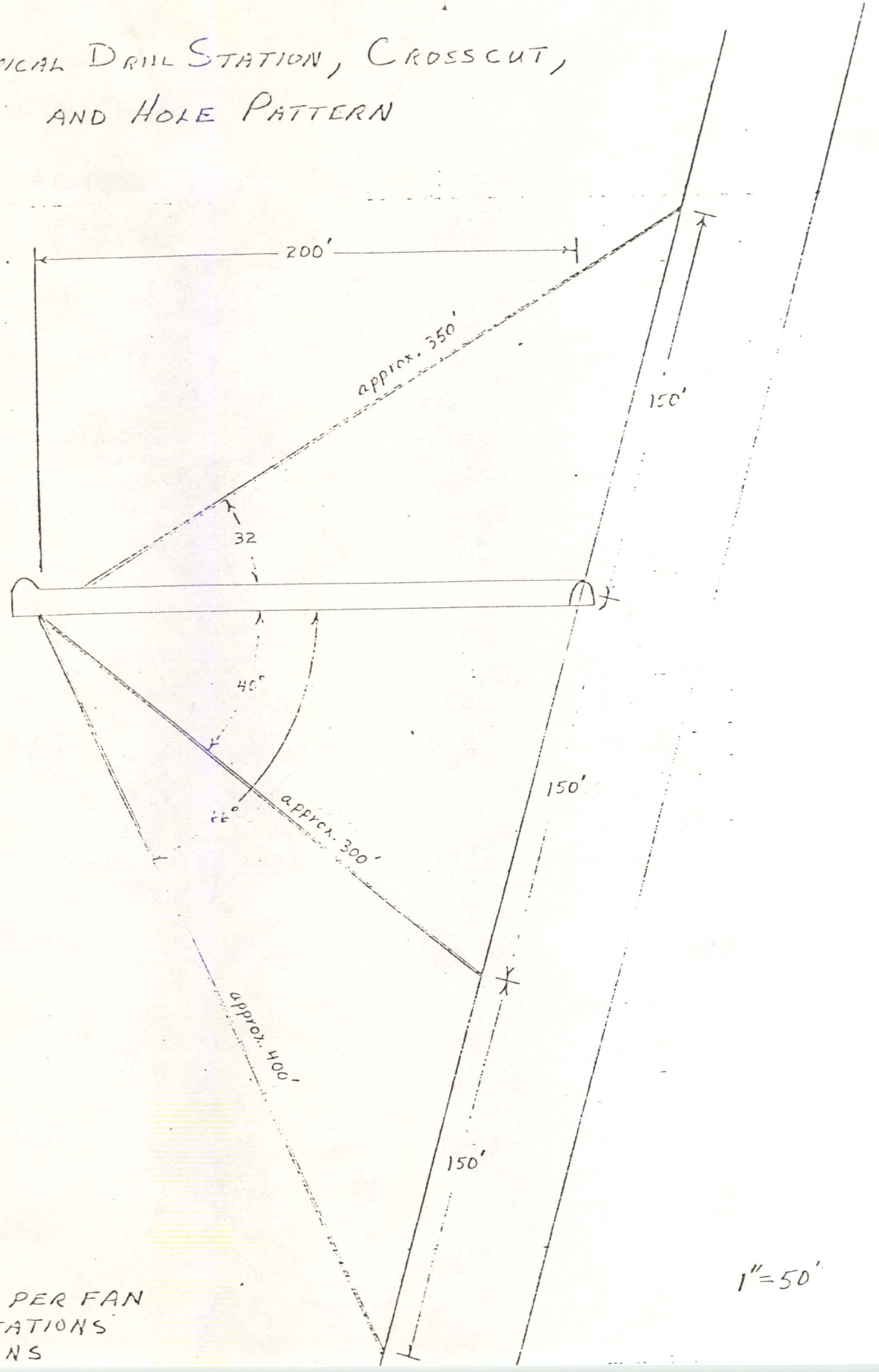
Swell—The tendency of soils or rock, on being removed from their natural, compacted beds, to increase in volume due to an increase in the space between soil or rock particles. The volumetric increase which occurs when material changes from bank (in situ) to loose (excavated) measure.

Diamond Drill Station No. 1

drill hole locations



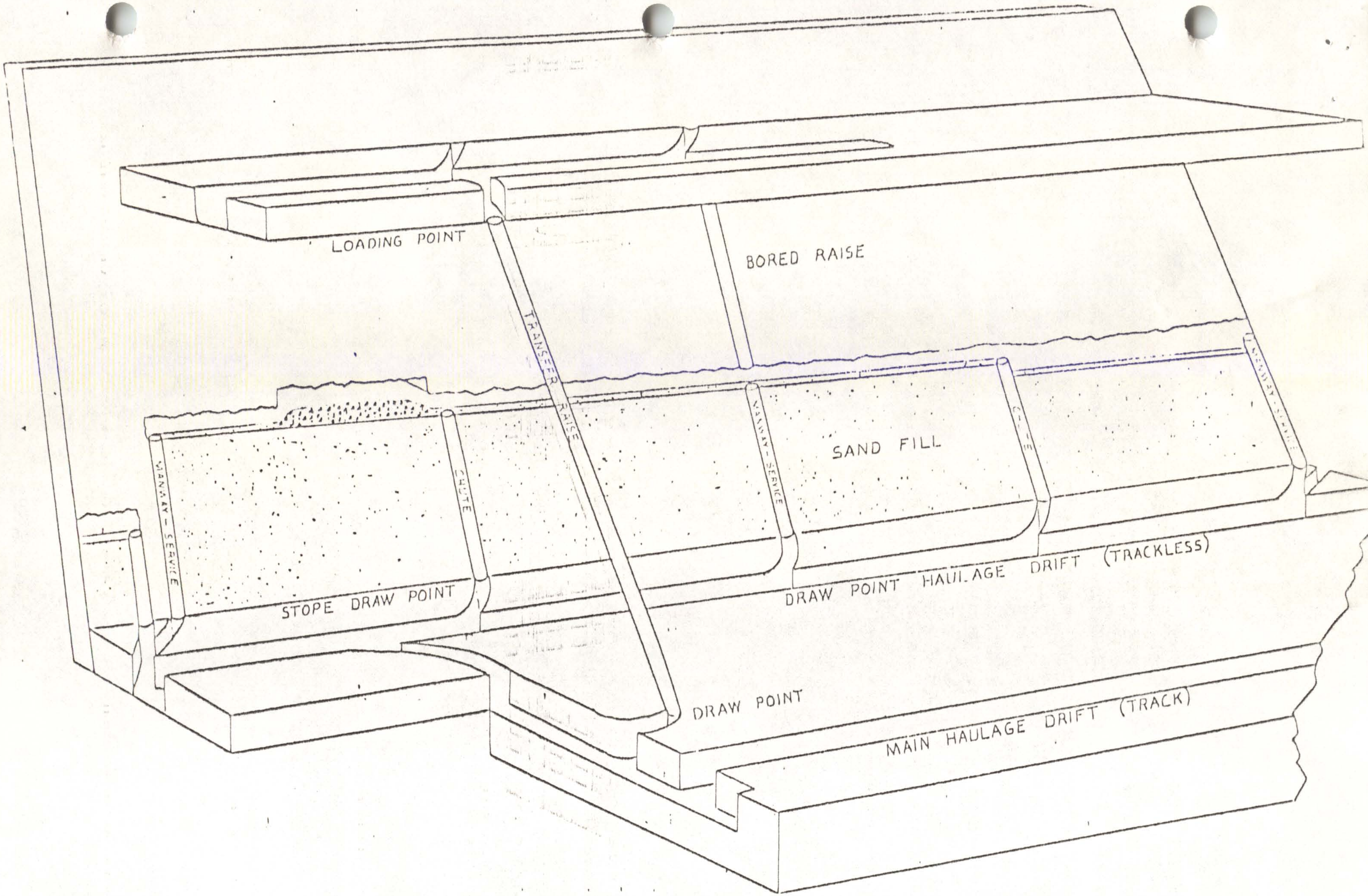
TYPICAL DRILL STATION, CROSSCUT, AND HOLE PATTERN



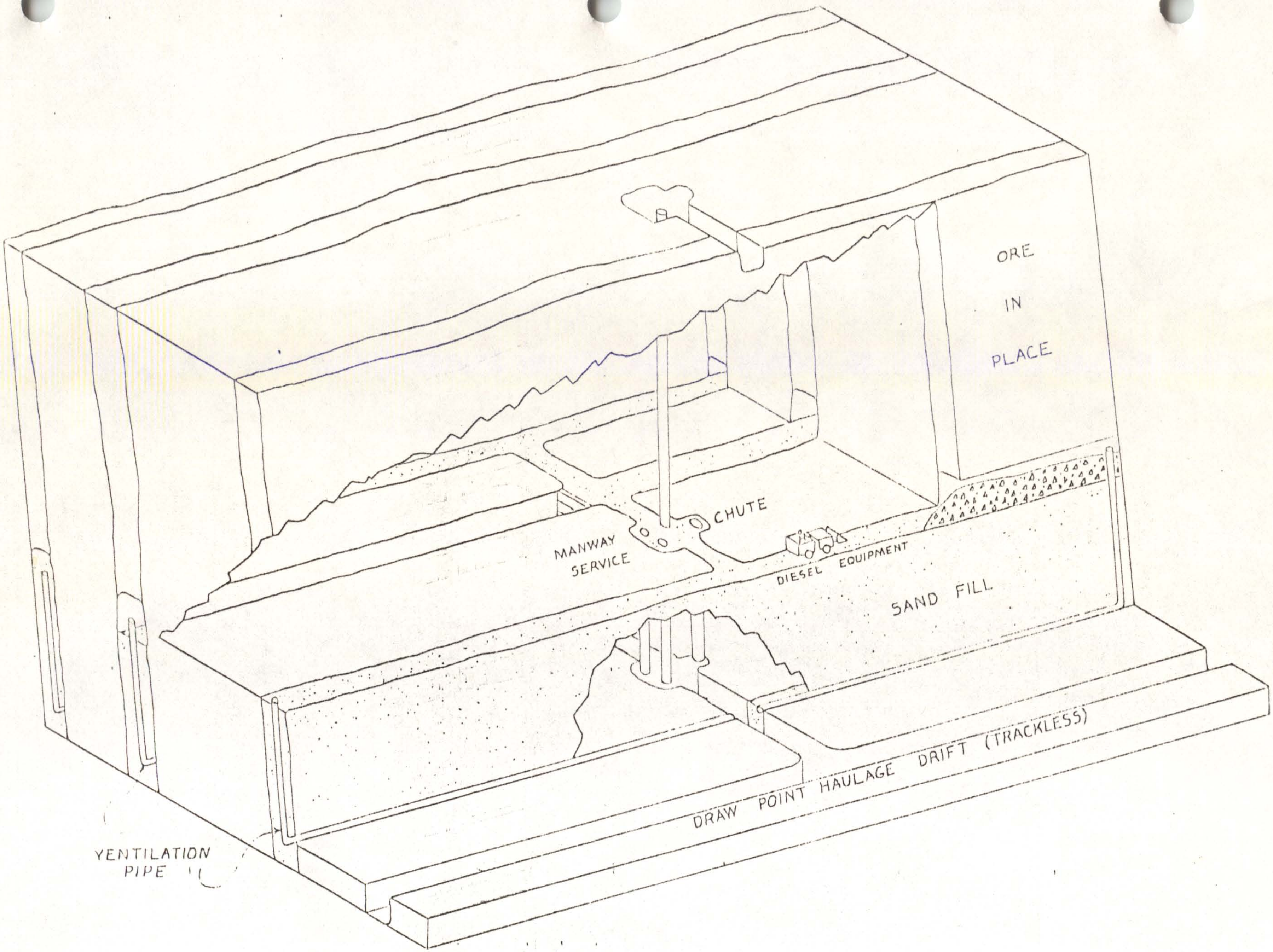
1" = 50'

~ 1200' PER FAN
10 STATIONS
~ 24 FANS

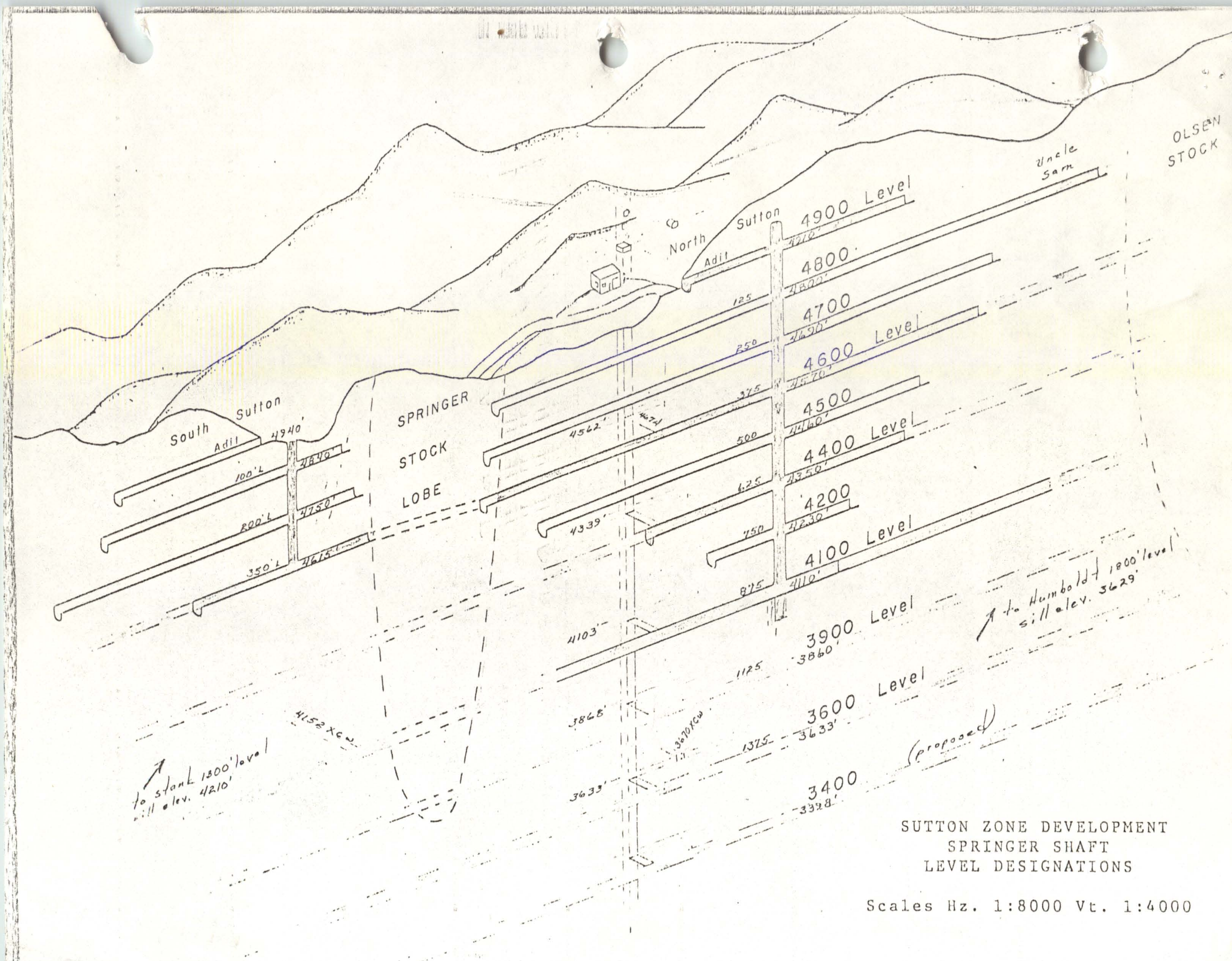
MINE DEVELOPMENT PLAN



<u>BACK STOPING - CUT & FILL</u>



CUT & FILL
Multiple Beds



SUTTON ZONE DEVELOPMENT
SPRINGER SHAFT
LEVEL DESIGNATIONS

Scales Hz. 1:8000 Vt. 1:4000

NEVADA-MASSACHUSETTS

YEAR	CRUDE ORE PRODUCED (MINED) S.T.	% WO_3	CONCENTRATES RECOVERED (R) UNITS SHIPPED (S)	SOURCE + REMARKS
1925		–	9,574 (S)	USBM Nev.-Mass.
1926	25,500	–	28,800 (S)	" "
1927		–	22,316 (S)	" "
1928	40,706	–	31,708 (S)	" "
1929	48,391	–	30,125 (S)	" "
1930	74,130	–	29,526 (S)	" "
1931	72,000	–	63,308 (S)	" "
1932	16,000	–	14,410 (S)	" "
1933	58,827	–	32,774 (S)	" "
1934	70,473	–	61,415 (S)	" " (Includes production from all N-M properties in other districts
1935	86,400	–	72,640 (S)	"
1936	123,505	–	97,775 (S)	" (also Rare Metals, Mill City
1937		–	121,700 (S)	" + Western T prop.)
1938	85,600	–	54,000 (S)	" "
1939	87,000	–	110,260 (S)	" "
1940	108,903 / 897435 [1,150,000]*	– [0.70]*	80,513 (S)	" " [Klepper 1943, " * Production 1917-1941]
1941		–	95,019 (S)	" "
1942		–	137,826 (R)	" (Golconda, Toulon)
1943	?	–	123,927 (R)	" " "
			1,217,619	

NEVADA - MASSACHUSETTS

YEAR	CRUDE ORE PRODUCTED S.T	% WO3	CONCENTRATES SHIPPED (S) Units RECOVERED (R)	SOURCE & REMARKS
1944		?	51,982 (R)	USBM
1944		?	15,341 9,160 (R)	" Rare metals Corp (Toulon plant
1944		?	21,780 (R)	" Golconda Syndicate (Golconda plant
1945		?	44,474 (R)	" Nev.-Mass. Co.
1945		?	12,124 (R)	" Rare metals Corp Toulon plant
1945		—	3,174 (R)	" "
1945		?	7,561 (R)	" Golconda Syndicate (Golconda
1946	144,179	0.47	50,263 (R)	" Nev.-Mass
1946	—	—	1,360 (R)	" " Rare metals + (Mill City & Toulon
1946	2,518		611 (R)	" Rare metals Corp (Toulon Plant
1947	140,897	0.43	59,206 12,677 (R)	" Nev.-Mass Co.
1948	142,675	0.40	58,090 (R)	" "
1949	65,470	0.40	27,764 (R)	" "
1950	140,924	0.40	52,091 (R)	" "
1951	152,456	0.35	47,376 (R)	" "
1952	146,786	0.30	40,870 (R)	" "
1953	157,577	0.3	44,236 (R)	" "
1954	151,577 37,692	0.37	57,637 (R)	" Mill City (Central).
1955	213,090	0.4	69,137 (R)	" Central
1956	212,393	0.44 est.	65,223. (R)	" Nev.-Mass.
1957	168,496	0.30	48,370	" "
1958	69,090	0.28	15,273	"
1959	1,945,770	—	813,732	nothing in USBM
1960	—	—	—	"
1961	—	—	—	"

…EV. – MASS.

YEAR	CRUDE ORE PRODUCED (MINED) S.T.	% WO_3	CONCENTRATES UNITS:	RECOVERED (R) SHIPPED (S)	SOURCE + REMARKS
1962	—	—	—		USBM
1963	—	—	—		" Mine idle
1964	—	—	—		" no activity. Surface plant liquid(?) + nearly compl. removed by purchaser Co. liquidating.
1965	10 est.	1.5 est.	15	R	" Maintainance + development
1966					nothing in USBM
1967					"
1968	—	—	—		USBM
1969					Nothing in USBM
1970					"
…otals	2,843,205		2,031,351		

14-047

IC 6284

Production

Chemically pure S contains 80.6% WO_3

Mining

Extraction 95%

Dilution 20%

RI 6902

Direct Cost milling 1.25

mining 3.15

Nev.-Mass Persh.

Klepper (1943):

... to date... 1,150,000 tons mined ... 800,000 units WO_3 recovered

Production (1917-1942):

Period	Company	Tons Ore	Tons Concent.	% WO_3	Units
1917-18	Pacific Tungsten	14,937	349.014	66.9	23,348
1917-18	Humboldt Corp.	20,774	271.531	68.9	18,669
1918	Mill City Tungsten	2,851	70.628	70.0	4,944
1924-25	Poole Lease	21,000 (?)	55.55 (?)	-	3,900 (?)
1925-42	Nevada Mass. Co.	1,087,341	9,127.525	75.6	688,343
1941-42	Tailing plant	-	822.9 est.	-	57,603
	Total	1,146,903	10,697.148		796,807 (*)

(*) Aver. recovery to date has been 13.895 lbs WO_3 per ton ore. Final recovery, after milling of tailings, is expected to be 16 lbs. WO_3 per ton, more than 90% of the tungsten contained in the ore.

Grade:

If final recovery is 90% WO_3, aver. grade ore mined to date will have been 0.875% WO_3.

Current ore from Humboldt-Springer mine aver. 0.75%; from Stank, 0.8-1.0%; and from North Sutton, 0.45-0.55%. A small tonnage of 0.25% ore is partly developed.

Reserves:

Substantial reserves of 0.4-0.5% are inferred in North Sutton. South end of Stank mine is inferred to contain 10,000-30,000 t. of 0.75%. Further more, worthwhile tonnages ... may be developed in Springer, George and Summit-O'Byrne beds

Low Grade:

About 150,000 tons ore estim'd at 0.25% are partly developed in Humboldt-Springer and Stank... Most of the low grade ore in the district occurs as fringes bordering commercial ore bodies, or a irregular blocks within them. There is little likelihood that any large minable bodies of low-grade ore will be found in the district.

IC 6250

Ore contains 1.10% S (CaWO4)

Product shipped: 70.43 WO3

Plant cap. 100 tpd (24hr), but operating @ 142 tpd

1.10% S = 0.9% WO3

4-6 oz Ag/t

and tr of Au

Carload shipment 35 t of 120 lb bags

Mill Recovery ave. 80%

lbs conc. produced 1928: 900,410

t ore treated ": 40,724

Chem analysis concent:

71.43	WO_3	0.12	Bi
0.43	S	none	Sn
0.03	Cu	0.13	Mo
none	As		
none	Sb		

Ag & Au roasted out.

Nev. - Mass

P.F. etc. files.

(1) Confid. King ( ).

To estim. reserves in outer and less explored beds, incl.

°East Beds
Sutton No. 2
Uncle Sam
Summit
Springer (Hard Luck, George Bed)
West Beds.

... Some water pumped from the operating Stank and Humboldt mines for milling purposes... domestic water from wells near Humboldt R., 3 mi away (mill water also from here)...

General Geology

Triassic (metamorphosed)... over 4000' thick... cut in various directions by dikes of granodiorite, aplite, quartz diorite and andesite.... beds N10° - 30°E w/ dip 60-70°W.... center granodiorite mass, 2500 X 3000' (Source of scheelite)... pre- and post-mineral faults... Triassic is hornfels, slate and limestone... limestone beds 2-15' thick — dk blue, gry or blk, often grading to marble....

East Beds... (described)

(OVER)

Summary of Results of Areas Explored

Area	Probable		Possible		Total	
	Tons Ore	Tons WO_3	Tons Ore	Tons WO_3	Tons Ore	Tons WO_3
Sutton No. 2	44,162	268.45	41,610	244.31	85,772	512.76
Uncle Sam	3,988	24.29	1,588	8.06	5,576	32.35
Springer	7,752	23.25	6,018	18.05	13,770	41.30
Summit	400	3.76	-	-	400	3.76
Total	56,302	319.75	49,216	270.42	105,518	590.17

Sutton No. 2

Tonnage & Grades of Ore

Block	Probable			Possible		
	Tons Ore	% WO_3	Tons WO_3	Tons Ore	% WO_3	Tons WO_3
A	6,346	0.70	44.38			
B				7,888	0.70	55.22
C	16,933	0.52	88.05			
D				12,157.	0.52	63.22
E	9,829	0.54	53.07			
F	11,060	0.75	82.95			
G				10,475	0.63	65.99
H				11,090	0.54	59.88
Totals	44,162	0.60	268.45	41,610	0.59	244.31

Uncle Sam.

Tonnage and Grades of Ore

Block	Probable			Possible		
	Tons Ore	% WO_3	Tons WO_3	Tons Ore	% WO_3	Tons WO_3
A	717	0.48	3.44			
B				717	0.48	3.44
C	1,743	0.53	9.24			
D				871	0.53	4.62
E		EXTREMELY DOUBTFUL.				
F	1,528	0.76	11.61			
Totals	3,988		24.29	1,588		8.06

Springer Area, Hard Luck, George Bed

Tonnage and Grade of Ore

A	7,752	.30	23.25			
B				2,220	.30	6.66
C				3,798	.30	11.39
Totals	7,752	23.25		6,018		18.05

Summit: ... estimate 400 tons of 0.94 % WO_3, probable ore

West Beds: ... no values found.

(2) 1 July 46 memo of L. B. Moon, U.S.B.M.

... exploration project ... 1940 and 1941 ... indicated a possible tonnage of 105,000 t. of ore containing 0.56 % WO_3.

Reserve Statistics: See single folded sheet in maps w/ rubberbands.

14-047

Nev-Mass

Persh.

King and Holmes (1941)

Ore reserves developed by USBM:

	Indicated			Inferred		
Area	Tons	% WO_3	Units	Tons	% WO_3	Units
Sutton No. 2	44,162	0.61	26,845	41,610	0.59	24,431
Uncle Sam	3,988	0.61	2,429	1,588	0.51	806
Springer	7,762	0.30	2,325	6,018	0.30	1,805
Summit	400	0.94	376	–	–	–
Total	56,302	0.57	31,975	49,216	0.55	27,042

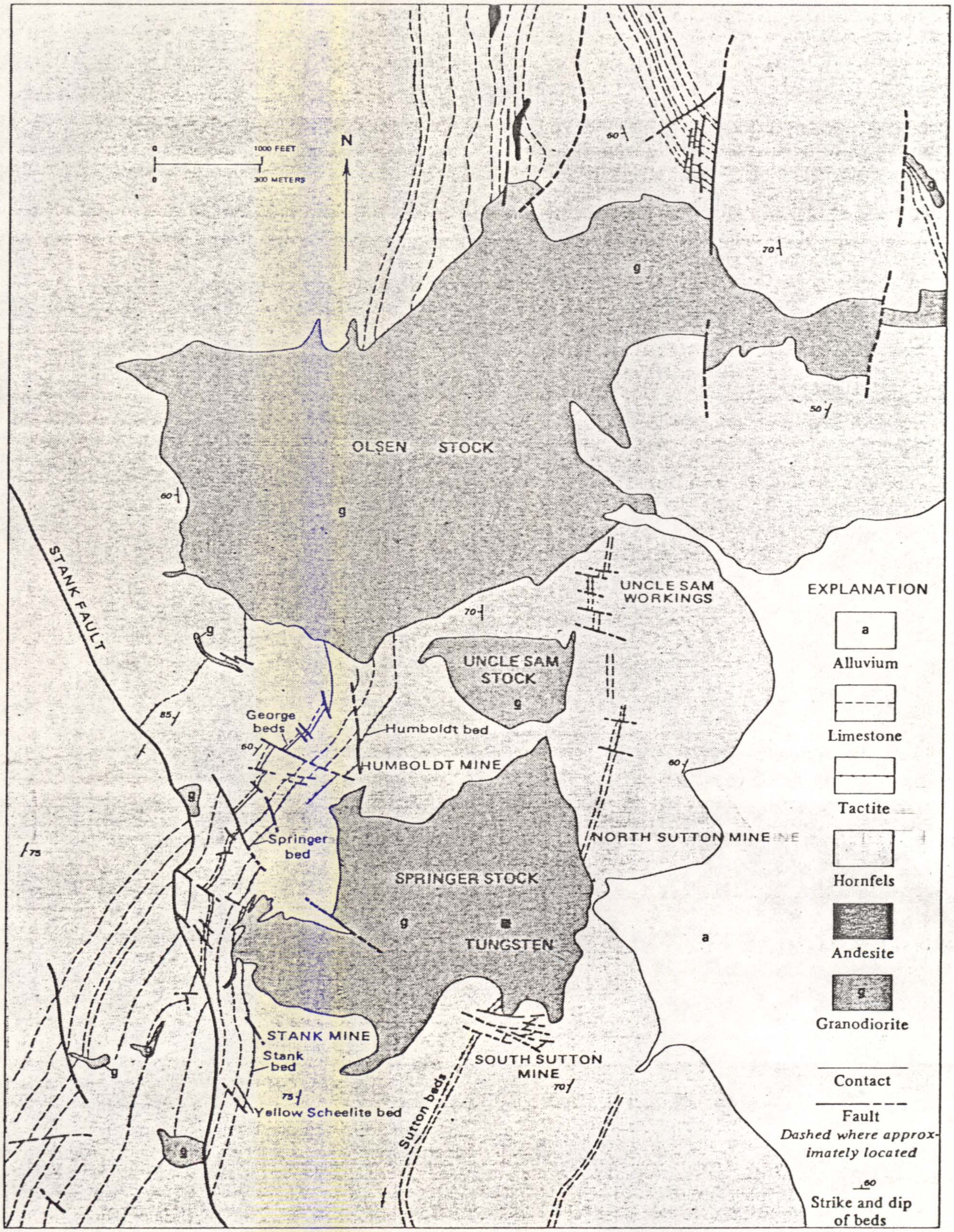
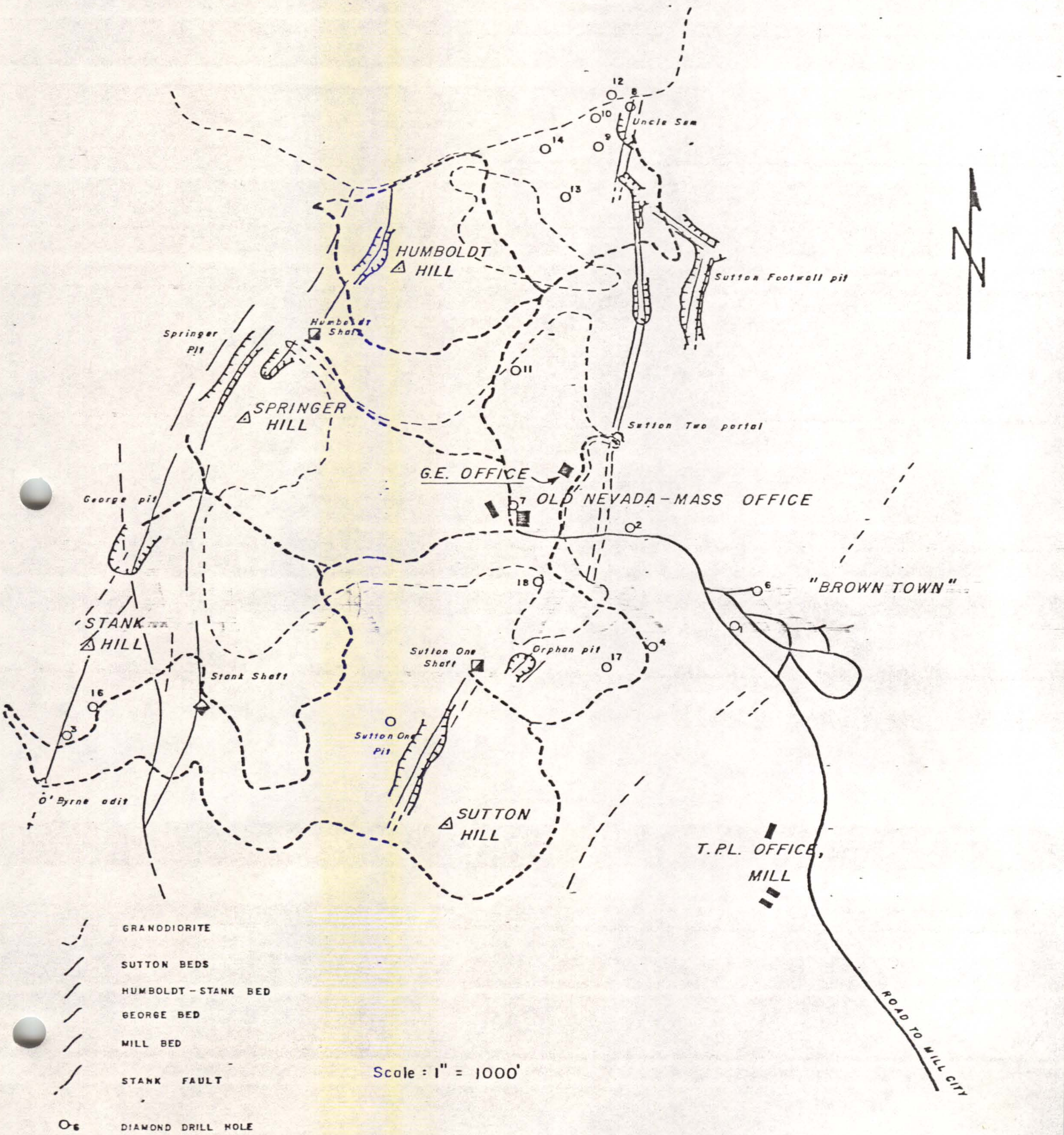


FIGURE 16. Geologic map of Tungsten and vicinity, Eugene Mountains.

Area Map

Nevada Massachusetts Property



GEOLOGY OF THE TUNGSTEN DEPOSITS NEAR MILL CITY, NEVADA

By PAUL F. KERR

INTRODUCTION

Mill City stands among the important tungsten producing districts of the world, and is at present the chief producing deposit in the United States.[1] In 1931 it produced 1,055 short tons of concentrates with 60% WO_3 equivalent, or about 75% of domestic production.[2] This amounted to approximately one-sixth the production of the Kiangsi tungsten mines in China, and about one-third the production of the Malay Peninsula for the same year. Geologic studies and mining estimates indicate that ore reserves are available to considerably increase this production and it is estimated by the operators that in normal times, with reasonable prices, sufficent concentrates could be produced to care for the demands of the United States.

The tungsten occurs in scheelite associated chiefly with quartz, garnet and epidote. The ore bodies are vein-like in form but have been produced by contact-metamorphism of thin limestone members in a siliceous sedimentary series. The associated sediments have been metamorphosed to hornfels, slate and quartzite. Extreme deformation, faulting and fracturing have separated the ore bodies into isolated nearly vertical segments arranged *en echelon* along a bearing of about N 20° E.

The contact metamorphism responsible for the ore is believed to be due to the intrusion of granodiorite. The later stages of instrusive action appear to be most closely related to the crystallization of scheelite. Progressive stages in the metamorphism of the limestone strata may be interpreted from detailed studies of various parts of the area and criteria are available to determine the mineral sequence.

During the summer of 1932 an opportunity was offered to examine the deposit in considerable detail. Both an underground

[1] Hess, Frank L., Tungsten; Minerals yearbook, U. S. Bur. Mines. 1932–1933. pp. 271–279.

[2] Fink, Colin G., Tungsten, Min. Ind. 1931, p. 559.

and a surface map were made and specimens were collected covering the various phases of mineralization. The property was revisited during the summer of 1933 for further study.

The only published geological description of the tungsten deposits near Mill City is a short account included in the studies of the contact metamorphic tungsten deposits of the western United States published in 1931 by Hess and Larsen.[3] This account was written before the most important discoveries were made and while mining was largely confined to operations near the surface. It seems proper, therefore, to publish at this time

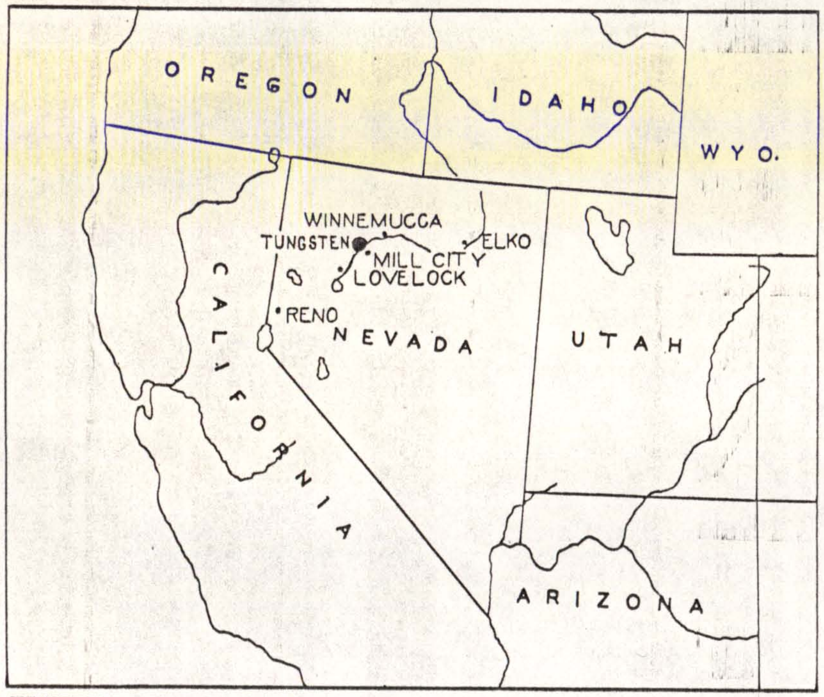


FIGURE 1. Sketch map showing the location of the Tungsten district, Nevada.

a more complete description of the district, outlining the development of the tungsten deposits and describing the geological conditions in greater detail.

Thanks are due to both Mr. Charles H. Segerstrom, President of the Nevada-Massachusetts Company, and to Mr. Ott F. Heizer, General Manager, for most cordial cooperation in allowing the use of the facilities at the tungsten camp and for permitting publication of this description. Mr. Heizer has supervised the

[3] Hess, F. L., and Larsen, E. S., Contact metamorphic tungsten deposits. U. S. Geol. Surv. Bull. 725, 1921.

mining operations throughout the recent development, and is thoroughly familiar with all of the workings, including portions no longer accessible. He has been particularly considerate in going over the underground workings and in discussing the mining development in its relationship to the geologic features.

The writer is also indebted to Mr. Powell Thompson for assisting in the preparation of the topographic map (Figure 7), and to the Stanford Geological Survey for the topographic base, upon which the map (Figure 2) has been drawn.

LOCATION AND HISTORY

The tungsten deposits are located at the mining camp called Tungsten (elevation about 5,000 feet), eight miles west of Mill City, Nevada (Figures 1 and 3). Tungsten is situated on the eastern slope of the Eugene Mountains (U. S. G. S. topographic map, Lovelock quadrangle), and is connected by a gravel road with the highway at Mill City. Mill City lies along the main transcontinental line of the Southern Pacific Railroad and the Victory Highway, 145 miles northeast of Reno, Nevada.

A map showing the location of the mine workings in the district is shown in Figure 2. The area shown in the map includes the working mines and important prospects distributed around the town of Tungsten, and shows their location with respect to the granodiorite intrusive. Three rounded hills with intervening canyons form the most prominent landmarks in the district and are known as Stank Hill (Figure 4), Springer Hill and Humboldt Hill (Figure 5). The three most important mines have similar names and extend beneath the hill of corresponding name. The mine workings reach a depth of 600 feet in the Humboldt mine and 800 feet in the Stank mine. Drifts and stopes trend northeast-southwest to north-south along steeply inclined segments of replaced limestone beds. The extreme distance between the opposite ends of the workings is about one mile, but the workings are by no means continuous for the entire distance, since the granitic intrusion intervenes for approximately 1,200 feet between the Springer mine and the Stank mine.

A small mine, the Summit mine (Figure 4), on the north side of Stank Hill, was worked for a time, but has been abandoned for several years. The Codd mine, south of the Stank ore body and presumably a continuation of that ore body, has produced some ore, but is also abandoned at present.

Among the most promising of the deposits not worked at the present time but offering possibilities of future development is the Sutton ore body (Figure 6). The Sutton ore body extends north-south on either side of the town of Tungsten and east of the area included in the map. Exploration of the Sutton ore body has never been completed, although ore has been found in isolated places throughout an extent of two miles, and successful mining operations have been carried on in the South Sutton mine. Altogether, approximately 1,000 feet of tunnel and numerous test

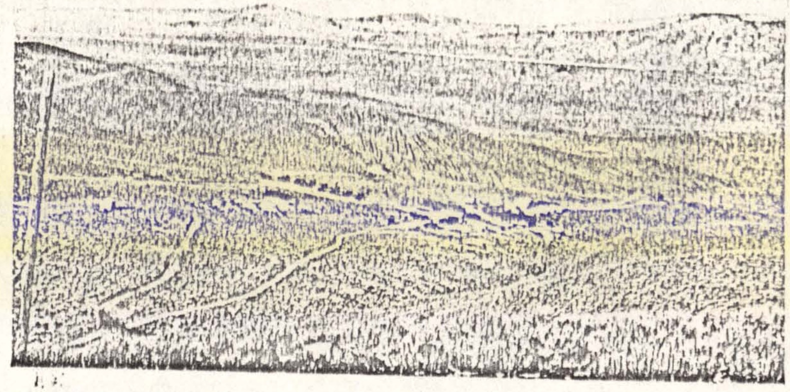


FIGURE 3. Tungsten, with the Humboldt River Valley in the background, looking northeast toward Winnemucca, Nevada.

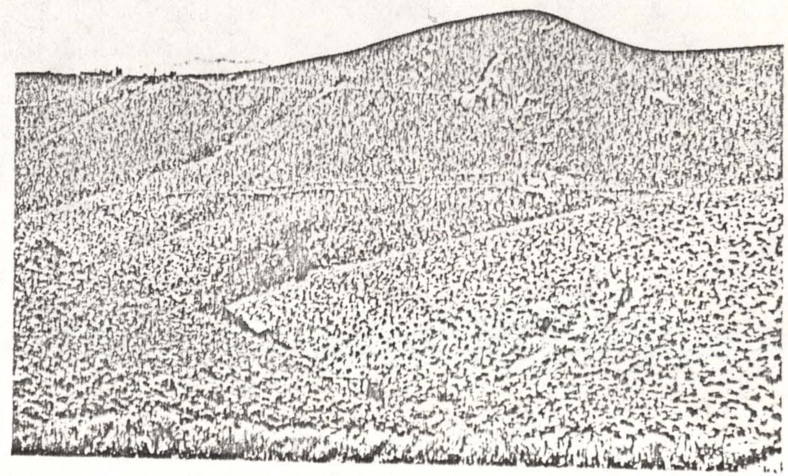


FIGURE 4. Stank Hill, looking south. The Springer mine is located in the canyon in the foreground. The head frame of the Stank mine is shown on the skyline at the left. The open pits on Stank Hill belong to the Summit workings.

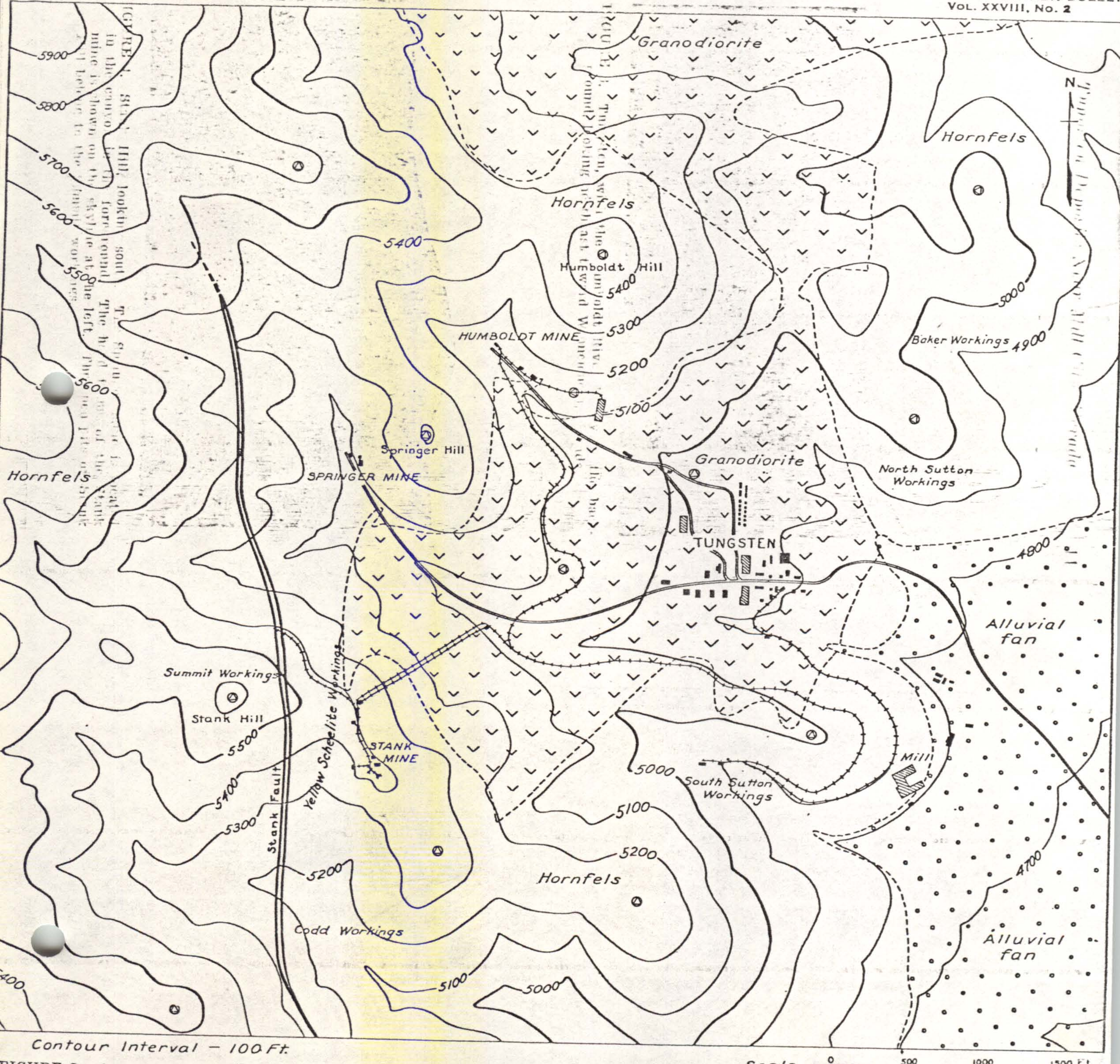


FIGURE 2. A general map of the mining district of Tungsten, showing principal scheelite bearing deposits and position of intrusive granodiorite.

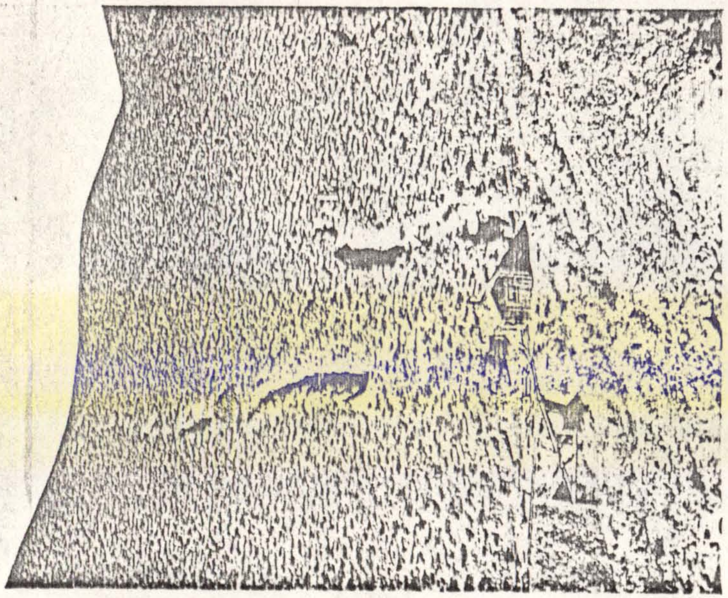


FIGURE 6. South Sutton workings looking south.

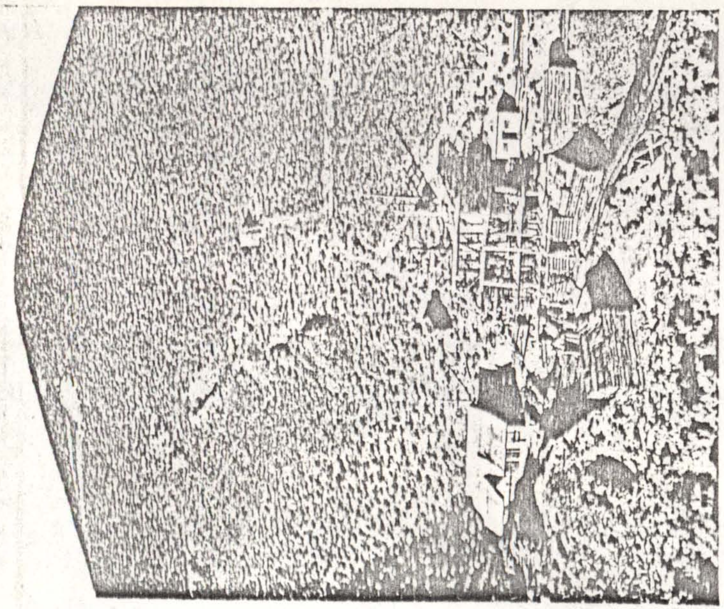


FIGURE 5. The Humboldt mine looking north. Pits along the hill indicate the trend of the ore body.

pits have been dug in prospecting two closely parallel limestone beds that constitute the Sutton ore body.

The tungsten deposits at Mill City were discovered in 1917.[4] In 1918 two mills were built—one by the Nevada-Humboldt Tungsten Mines Company, the other by the Pacific Tungsten Company. In 1926 the Nevada-Massachusetts Company took over the Pacific Tungsten Company and later acquired the Humboldt Tungsten mine. All of the claims in the group are now owned by the Nevada-Massachusetts Company. The property was in continuous operation from the time the Nevada-Massachusetts Company entered the business until 1932, when production was suspended from May to December, due to the lack of a market. A staff was kept on hand, however, in order to improve the mill and keep the mine workings in order. Advantage was also taken of the suspension of operations to install a new headframe and ore bin at the Humboldt mine. Mining was renewed in 1933, and operations have been continued at full capacity since that time. Over 300,000 tons of ore are reported to have been milled from the tungsten deposits at Mill City in the last eight years, and it is estimated by the management of the property that 2,000 tons of high grade scheelite concentrates could be produced per annum.

Until 1932 the normal ore contained about 1.10% scheelite. During that year, however, new discoveries were made which materially increased both the quality and the quantity of the ore reserves.

The ore ordinarily consists of fine-grained scheelite disseminated through a groundmass consisting largely of garnet, epidote, quartz and calcite, with scattered crystals of pyrite. A bulk concentrate consisting of garnet, scheelite and pyrite is produced on tables. The garnet is removed by means of a magnetic separator, and the pyrite by flash roasting and magnetic separation.[5] The concentrates are used in the production of tungsten steel, and fall within the following specifications:

WO_3	65–70%
Tin maximum	(trace)
Copper maximum	0.05
Sulphur maximum	0.75
Phosphorus maximum	0.05
Arsenic, Antimony and Bismuth, not over	0.035 each

The concentrates carry four to six ounces of silver and a trace of gold per ton, but no effort is made at the recovery of precious metals.

[4] Heizer, Ott F., U. S. Bur. Mines, I. C. 6284, June, 1930.
[5] Heizer, Ott F., U. S. Bur. Mines, I. C. 6280, June, 1930.

GENERAL GEOLOGY

The general geological relationships are shown on the map (Figure 7). Two principal formational units are shown, a metamorphosed sedimentary series and an intrusive granodiorite. The map indicates the outcrop portions of the unreplaced limestone strata within the sedimentary series and the probable projection of the strata. Scheelite bearing replacement zones along the strata are also indicated.

In addition to the main igneous area, isolated exposures of small intrusive masses of granodiorite are shown. No attempt has been made in mapping to distinguish the different phases of the granodiorite intrusion. A few dikes of hornblende andesite are indicated, but do not belong to the granodiorite stage of intrusion.

SEDIMENTARY SERIES

The sedimentary series in the vicinity of the tungsten deposits has an indefinite thickness, and it is uncertain in most cases whether the beds are normal or reverse in attitude. Metamorphism has obscured many of the original sedimentary features, and deformation has been intense, the average inclination of strata being about 70°. Part of the sedimentary series is Upper Triassic, although several thousands of feet of presumably overlying sediments may be much younger in age. Pseudomonotis subcircularis (Gabb) was identified by Dr. Simeon Muller in shaly strata south of the mill at Tungsten.

Several types of metamorphosed sedimentary strata occur in the Eugene Range. In the vicinity of the ore bodies the beds are at present chiefly hornfels, although quartzitic phases are also in evidence. A slaty phase occurs in several places, however, the slaty character of the rock appears to be accentuated by surface weathering. Underground the same strata appear compact and free from rock cleavage.

Erosion has removed the sedimentary cover irregularly, leaving exposed portions of the underlying granodiorite between blocks of cover rock. The contact between the two is sharp and free from cleavage to such an extent that fracture usually occurs across the contact rather than parallel, and numerous specimens may be collected with granodiorite on one side and hornfels on the other.

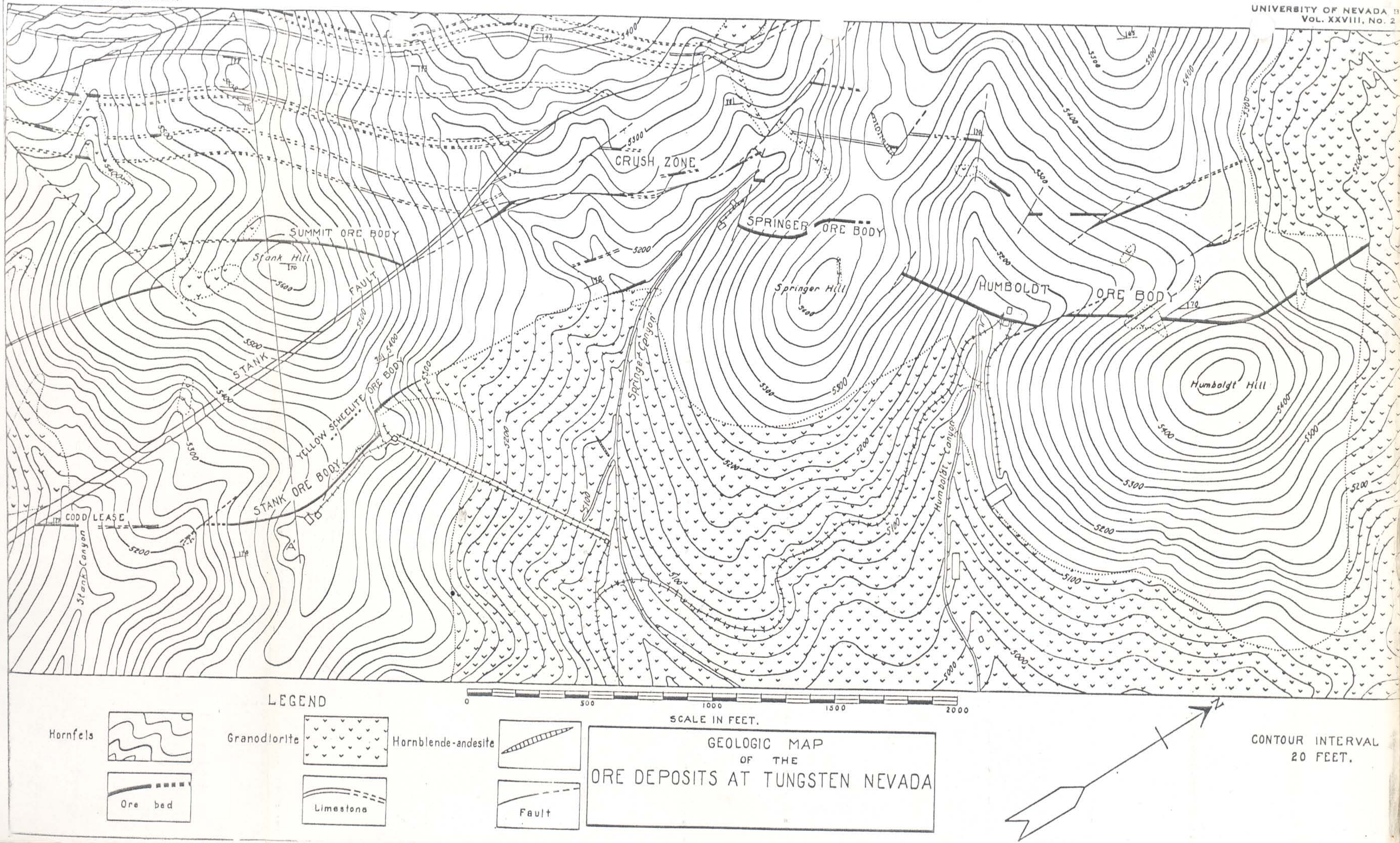
HORNFELS

The hornfels is a hard, extremely tough, olive-green or light gray rock which changes to brown on weathering. It is badly fractured, with joint planes extending in all directions (Figure 8). It weathers to rough angular blocks scattered loosely on the rounded surfaces of hills. Color bands in the rock frequently indicate the original planes of bedding and yield the most reliable criteria available for determining the attitude of the strata.

Hillsides underlain by hornfels may be frequently distinguished at a distance on account of peculiar rock streaks due to the concentration in straight vertical lines of small joint blocks (Figure 3). These streaks are from two to six feet in width, extend as straight downward drainage lines on rounded hillsides, and are arranged radially around the crest. They consist of shallow rock-filled depressions and contain virtually no soil. The rock blocks are usually from one to six inches in diameter and have been loosened from the hillside by storm action. The hornfels is so largely quartz that very little soil is produced, and any soil formed may be easily washed away during cloudbursts. It appears probable that the rapid erosion of desert storms concentrates the loose blocks and removes the soil. Frequently blocks are so angular and well formed that they appear on casual observation to imitate crystal forms. Such a joint block is shown in Figure 14. This block exhibits nine fracture planes, no two of which are parallel, and furnishes a fair illustration of the complexity of the fracture pattern.

Earlier fractures in the hornfels have been filled in places with quartz and also with epidote. Later fractures are open. During metamorphism thermal solutions evidently penetrated the sedimentary series in all directions. Thin sections demonstrate that all of the rock has been recrystallized and now consists for the most part of a fine mosaic of quartz and actinolite, varying in places to a quartz-biotite mixture (Figure 24). Fine cordierite, apatite, zircon, rutile, and pyrite occur as accessory minerals. The microstructure of the rock is commonly poikilitic with quartz in amphibole or mica.

In places black bands three or four feet thick occur intercalated with light greenish layers. The black layers consist of microscopically fine elongated hornblende crystals in random arrangement in quartz. The surrounding layers are composed of fine needle-like aggregates of the same material in a quartz groundmass. On the whole, the sedimentary series, aside from the limestone members, is comparatively free from concentrations


CRUSH ZONE
SUMMIT ORE BODY
Stank Hill
STANK FAULT
SPRINGER ORE BODY
Springer Hill
HUMBOLDT ORE BODY
Humboldt Hill
YELLOW SCHEELITE ORE BODY
STANK ORE BODY
CODD LEASE
Stank Canyon
Springer Canyon
Humboldt Canyon
LEGEND
Hornfels
Granodiorite
Hornblende-andesite
Ore bed
Limestone
Fault
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ORE DEPOSITS AT TUNGSTEN NEVADA
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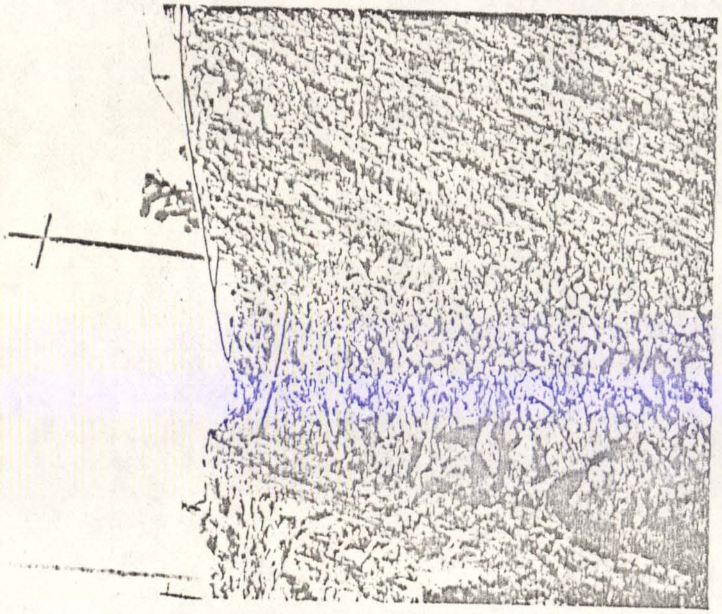


FIGURE 9. Open pit above workings, showing width of Stank ore body and inclination of hornfels walls.

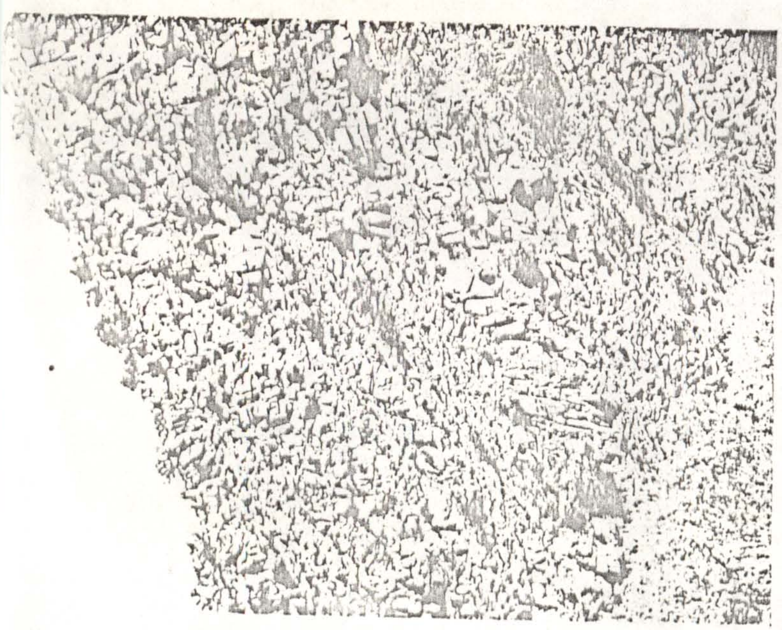


FIGURE 8. Outcrop of hornfels in Springer Canyon showing jointing.

of epidote and garnet. The garnet and epidote are confined to small segregations in intensely silicified areas, to small veinlets, and to extremely fine, isolated microscopic crystals occasionally found along the old bedding planes.

The intensity of the silicification in the hornfels appears to have been greater in the vicinity of the present prominent hills, and it is not unlikely that Humboldt Hill, Springer Hill and Stank Hill may correspond in a general way at least to more intense zones of silicification in the sedimentary series. Intensity of silicification may be in turn connected to intensity of the contact metamorphic action resulting in the crystallization of scheelite. Thus the highly silicified hornfels of Humboldt Hill, Springer Hill and Stank Hill may be a natural accompaniment to the ore formation in the adjacent mines.

LIMESTONE

Limestone strata occur in isolated beds at irregular intervals in hornfels. The strata have the same attitude as the hornfels above and below (Figure 9). The best limestone exposures near the mines occur along the ridge west of Stank Hill.

The beds in the area studied may be divided into two groups separated by the Stank fault, as shown on the map (Figure 7). One group occurs west of the Stank fault, and throughout this group the effects of contact metamorphism have been less severe at the surface (Figure 27). The second group occurs east of the Stank fault, and throughout this group contact metamorphism has been active and the beds have been largely replaced. The beds of the second group contain the principal high grade ore.

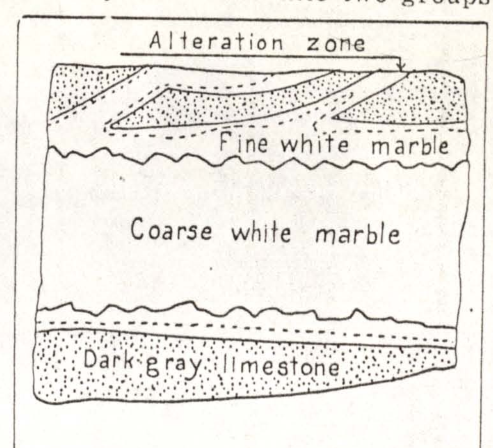


FIGURE 10. Diagram illustrating the original dark gray limestone bounded by an alteration zone and fine white marble. The fine white marble has been penetrated by coarse white marble.

The beds east of the fault vary from 3 to 15 feet in thickness, although the normal thickness is from 3 to 6 feet. Faulting has been pronounced and the beds have been broken into so many segments that it is not certain whether two or three parallel beds occur. It seems certain, however, that at least two exist, and there is a probability that several isolated exposures shown on the surface belong to a third bed.

West of the Stank fault nine beds may be counted within the area mapped (Figure 27). These appear to cross the least deformed portion of the area, and several can be traced for a considerable distance by means of occasional outcrops and scattered pieces of float occurring on the soil of the hillside. Four more prominent limestone beds measure fifteen feet, ten feet, thirty-three feet, and six feet in thickness and are of sufficient

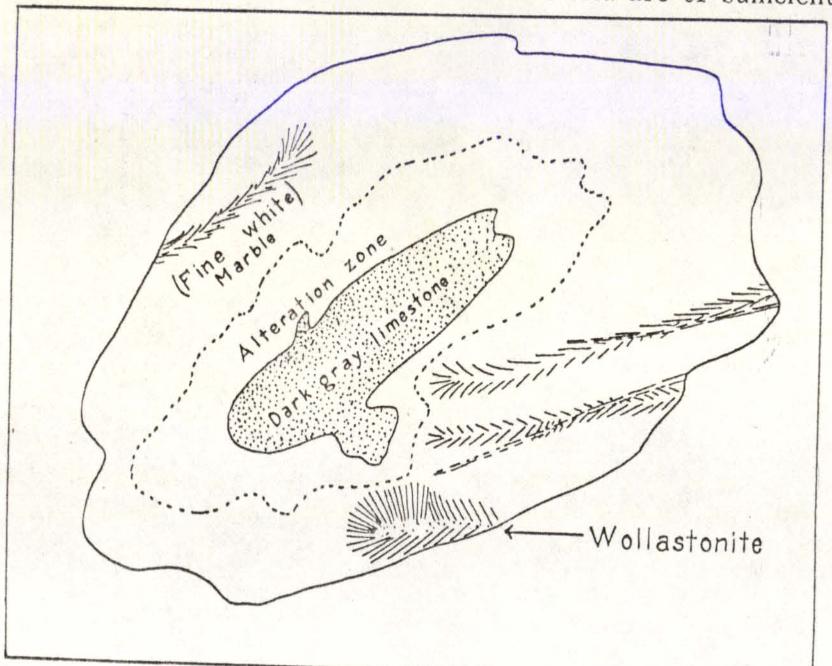


FIGURE 11. Diagram showing the alteration of dark gray carbonaceous limestone with the subsequent formation of white marble, the marble being penetrated by radial wollastonite and cut in turn by later calcite veinlets.

thickness to permit profitable mining if mineralized at depth. A fifth, the summit bed, shows mineralization at the surface. Thus far no exploration has been made to determine the extent of metamorphism below the surface in buried portions of the limestone beds nearer the underlying granodiorite. It is probable that at some time these beds will be prospected at depth for scheelite. A crosscut normal to the strike or horizontal drill holes from the Stank workings intersecting the limestone beds at depth should indicate the extent of mineralization in other beds parallel to the Stank ore body.

The limestone is commonly blue-gray in color, although in some exposures it is almost black. It usually weathers to a light gray color, and several outcrops show a ribbon-like brown and gray banding due to weathering. Some of the strata are also somewhat sandy. The color of the limestone is probably due to a large amount of included carbonaceous matter. Small tremolite crystals are also widely distributed (Figure 21). These crystals occur in the beds west of Stank Hill and may indicate an increase in the magnesium content of certain of the limestone strata.

Contact metamorphism appears to have produced an alteration of the limestone by stages. First a greenish-white alteration zone

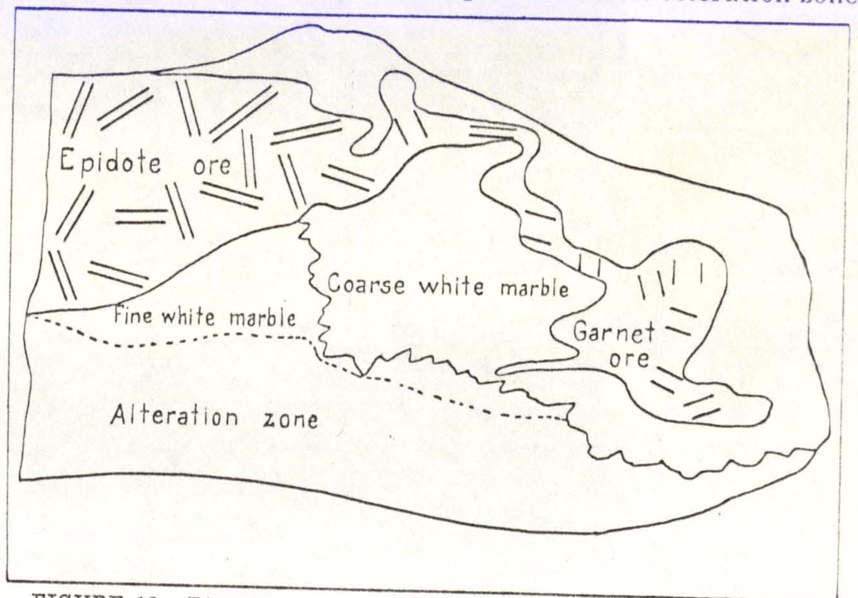


FIGURE 12. Diagram showing epidote and garnet (dark brown variety) invading coarse white marble.

has been produced (Figure 10) with the accompanying destruction of the dark gray limestone. Numerous examples of dark gray limestone remnants entirely surrounded by the greenish alteration zone occur in the vicinity of ore bodies. Following the greenish alteration recrystallization to fine white marble occurred, frequently accompanied by the formation of white fibrous wollastonite (Figure 11). The final stage in the metamorphism resulted in the formation of coarse white marble accompanied by the introduction of garnet or epidote (Figure 12).

Tremolite appears to be replaced during this metamorphism and carbonaceous matter entirely disappears ...

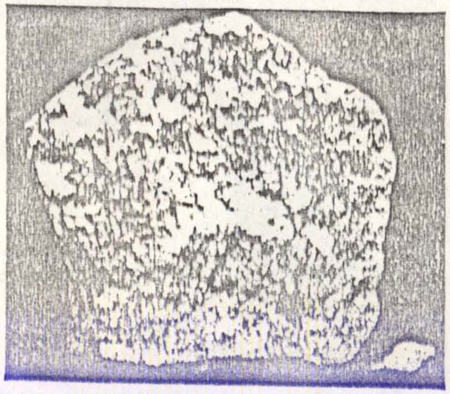


FIGURE 13
Scheelite in a quartz-epidote groundmass. (One-third natural size.)

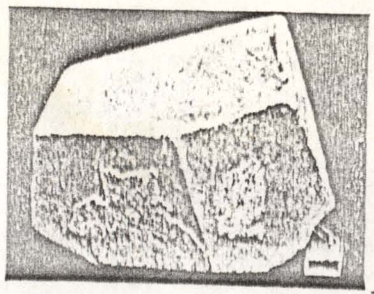


FIGURE 14
Fracture block of hornfels. (One-third natural size.)

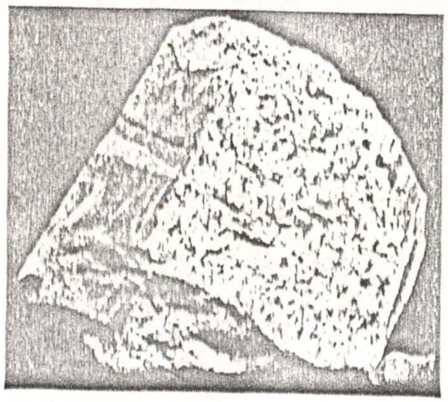


FIGURE 15
Portion of an end-stage altered granodiorite dike. (One-third natural size.)

formed. Ore has not been found in the gray portions of the limestone beds, and it is only where the limestone has become altered to marble that the ore-bearing mineralization occurs. Numerous remnants of gray limestone, however, occur in the mineralized portions of the beds.

THE ORE BODIES

The principal ore bodies including the Humboldt-Springer and Stank ore deposits are distributed along the western margin of the granodiorite intrusive (Figure 2). The Sutton beds, not worked at present, lie in a position more or less parallel to the main ore bodies, but on the east of the intrusive. For the most part the surface exposures of the ore are restricted to an area within 2,000 feet of the margin of the intrusive, as outlined on the areal map (Figure 7). The ore values, however, vary considerably, even within this limited area. It is only in cases of unusual concentrations that extremely high grade ore is found, and these may occur either immediately adjacent to the igneous mass or considerably removed from it. Portions of the replaced beds may be found in contact with the granodiorite, either terminated by the granodiorite mass or cut by intrusive dikes.

The thickness of the ore body is usually uniform in an individual bed (Figure 9). Beds now worked are normally about five or six feet thick and continue with only minor variations in thickness for distances of several hundred feet along the strike. In places the ore zone is twice the normal thickness, due to faults of 20 to 40 feet displacement that cut the strata at an angle of about 15° to the strike. Where the beds are mineralized there appears to be little change in ore value with depth. In the southern part of the Stank workings, however, the ore values have been better in the lower levels, apparently because the mineralization has been more intense.

The outstanding characteristics of the mineralized beds are a prominent display of the contact metamorphic minerals garnet and epidote, together with an unusual concentration of vitreous quartz. The scheelite is obvious to the eye in only a few places in particularly high grade portions of the deposit. Elsewhere it appears as minute specks disseminated through the garnet and epidote. Other minerals occur in the ore beds, but garnet, quartz and scheelite are the most prominent. The contact, metamorphic product, consisting of masses of contact metamorphic minerals formed in limestone has been called "tactite" by Hess.[6]

[6]Hess, F. L., Tactite, the product of contact metamorphism. Am. Jour. Sci.,

Several types of ore are distinguished in mining operations. These may be described as garnet ore, garnet-epidote ore and quartz-epidote ore. The garnet ore occurs more frequently in the Stank mine and to a lesser degree in the Springer and Humboldt mines. Garnet-epidote ore is distributed throughout the entire deposit and may occur with either of the other two types. The highest grade ore concentrations belong to the quartz-epidote type, as illustrated in Figure 13. The high grade concentrations of scheelite in both the garnet ore and garnet-epidote ore are usually highly silicified and appear glassy.

In the lower levels of the Humboldt mine and at places in the Stank mine the ore has been pulverized by movement along the beds. Powdered ore of this type is dark gray, but appears to contain as much scheelite as uncrushed ore in adjacent portions of the deposit. A slip zone is frequently encountered in the hanging wall within a few feet of the unreplaced bed. There is no parting, however, between the mineralized portion and the hornfels.

The best ore values appear to favor the footwall side of the vein-like bed. The complete bed is not always replaced, even in high-grade portions of the deposit, but where replacement has not taken place no ore values are found.

MINERALS PRESENT IN THE ORE BODIES

CALCITE

Calcite may be found in the ore beds in all of the different forms in which it occurs in the region, varying from the unreplaced gray limestone to the most highly metamorphosed and recrystallized marble. Portions of the gray limestone containing carbonaceous matter occur in the ore beds in several places as remnants that have not been replaced. In addition to its occurrence in the gray limestone, calcite occurs as fine white marble, as coarse white marble, in secondary veinlets, and in euhedral crystals in cavities. Apparently all of the carbonate of the deposit is calcite. Qualitative tests show a decidedly minor amount of magnesium and all of the X-ray diffraction patterns taken of different types of carbonate have given the calcite diffraction pattern. Dolomite and magnesite have not been observed.

The significance of the importance of calcite as a source of calcium in the crystallization of scheelite may be inferred from the fact that all specimens of ore that have been examined contained small amounts of that mineral.

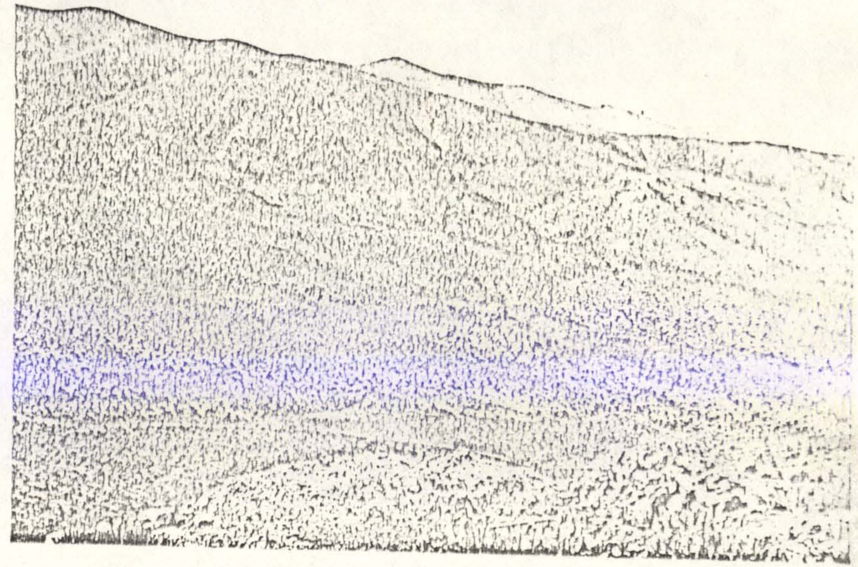


FIGURE 16. Resistant granodiorite knob due to silicification in veins, surrounded by weathered granodiorite east of Humboldt Hill.

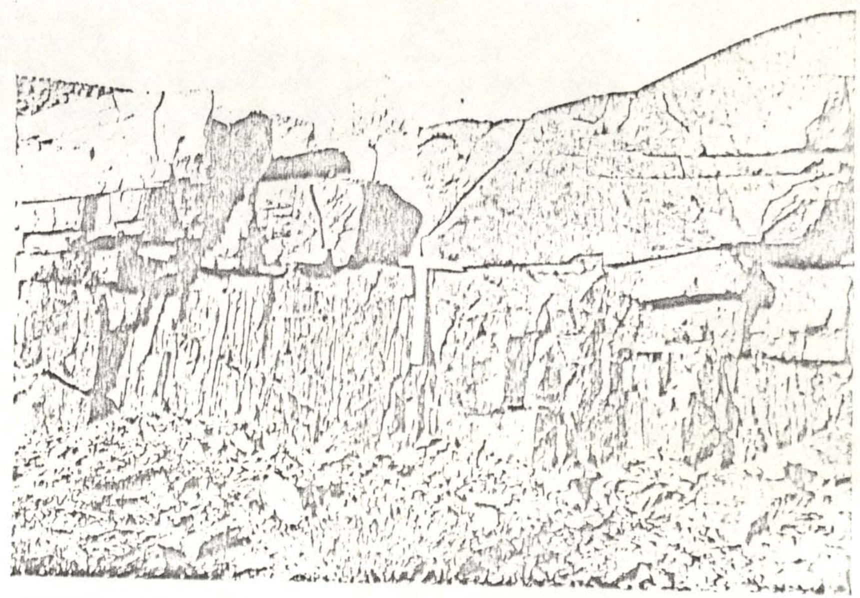


FIGURE 17. An outcrop of hornblende-andesite in contact with hornfels. Hornblende-andesite above white line, hornfels below.

Figure 20 illustrates an isolated patch of intergrown calcite and scheelite in a groundmass of quartz. It is assumed that the scheelite replaced part of the calcite in the first place and the scheelite-calcite mixture suffered invasion and isolation by quartz.

TREMOLITE

Two varieties of tremolite are found in the deposit, probably widely separated from the standpoint of origin. The first tremolite is early tremolite that occurs in small crystals scattered in irregular arrangement throughout the gray limestone (Figure 21). Tremolite crystals have been found in abundance in limestone beds more than a mile from the nearest tungsten prospect. The crystals show characteristic rhombic cross-section when examined in thin section, and fragments have the proper optical properties for tremolite. In addition, small crystals from the limestone have been concentrated by treatment with acid. X-ray diffraction patterns of the concentrated residue have been taken and compared with X-ray diffraction patterns of tremolite from several known localities, making use of the method of multiple comparison for identification.[7]

The second tremolite is radial tremolite that occurs in association with actinolite, apparently formed during the cooling of solutions following the main contact metamorphic mineralization. The early tremolite is restricted to the gray limestone, while the late tremolite occurs in minor amounts in the coarse white marble. The late tremolite is fibrous and matted, in contrast to the isolated small crystals of the early tremolite, and does not appear to be a residual of the earlier mineral.

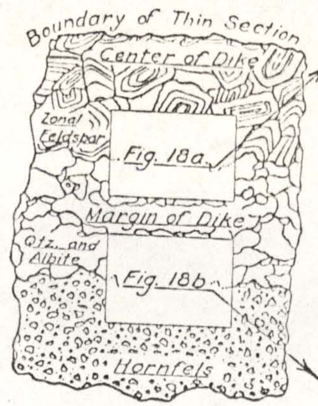
WOLLASTONITE

Wollastonite occurs in streamers and radial aggregates (Figure 11). These are snow-white in color, and extend throughout the fine white marble. The mineral does not appear to be present in the coarse white marble phase. It occurs in patches of fine white marble that have been produced by alteration of the gray limestone and have not yet suffered recrystallization to the coarse white marble. It is probable that wollastonite is an earlier mineral produced at a stage prior to the recrystallization of the main contact metamorphic minerals, garnet, epidote, and scheelite.

GARNET

Several types of garnet may be found in the ore beds. Garnet occurs as a light pale pink mineral in association with radial

[7]Kerr, Paul F., Econ. Geol., Vol. XXVII, No. 7, November, 1932, p. 621.



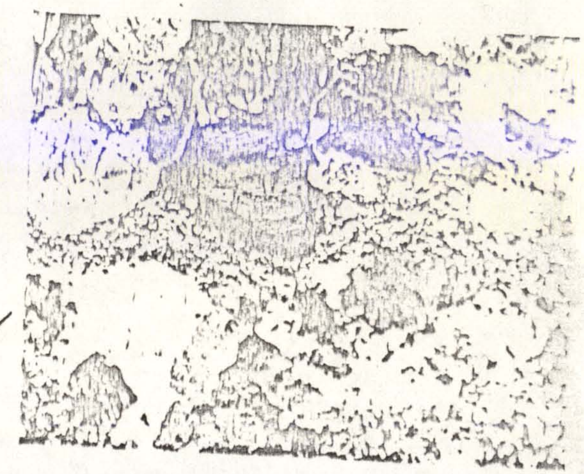


FIGURE 18

Phases of the granodiorite intrusion (photomicrograph x 20).

(a) Central portion of a dike showing zonal feldspar.

(b) Quartz - albite margin in contact with hornfels.

aggregates of wollastonite apparently formed as an early alteration of the limestone. Garnet of this type does not appear to be associated with scheelite, and no epidote occurs along with it. It is usually found in areas immediately adjacent to unreplaced patches of gray limestone and is assumed to be prior to the ore deposition.

Reddish-brown garnet, probably grossularite, occurs in all parts of the deposit (Figure 26). Garnet of this type is associated with scheelite. A very dark brown garnet, probably andradite, occurs in the middle of the Stank mine associated with molybdenite (Figure 25). It appears that this is slightly later in origin than the grossularite.

In thin sections the various varieties of garnet show strong anomalous birefringence between crossed nicols characteristic of garnet formed by replacement of calcite due to contact metamorphism.[8] All types of the garnet in the deposit are probably of the "ugrandite" series of Winchell[9] and the phenomenon of birefringence does not appear restricted to any particular species. X-ray diffraction photographs of grossularite and andradite from ore beds have been taken. Both appear to be isometric in crystallization in spite of the anomalous optical properties.

EPIDOTE

Epidote is found in interlacing crystals that vary from microscopic grains to crystals a quarter of an inch in thickness and about an inch in length. Such crystals are usually suspended in quartz (Figure 22) or protrude from the walls of small openings. Another form of epidote of much finer crystallization appears to occur as a later phase. This type of epidote occurs as finely disseminated crystals scattered through quartz, and imparts an olive-green cast to the rock. Microscopic evidence of the earlier coarse generation of epidote being broken down and replaced by the fine-grained second generation is abundant. Scheelite appears to be associated with both generations, although it is probable that the coarse high grade concentrations of scheelite occurred with the second generation. The coarse crystals of scheelite in the Humboldt mine are found suspended in a glassy epidote-quartz matrix made up of finely disseminated crystals of epidote scattered through the quartz with traces of calcite (Figure 23).

[8] Illustrated in Rogers, A. F., and Kerr, P. F., Thin-section mineralogy, McGraw-Hill, New York, 1933, p. 118, fig. 113.

[9] Winchell, A. N., Elements of optical mineralogy, John Wiley & Sons, New York, 1927, p. 257.

SCHEELITE

Scheelite occurs in pure white imbedded crystals with a characteristic greasy luster. The crystals vary in size from a fraction of a millimeter to several centimeters in diameter. Scheelite is frequently not easily seen in the ore even in high grade specimens. The miners often wet the surface of the rock in order to make the mineral stand out from the quartz. The scheelite fluoresces blush white in ultra-violet light.[10] An excellent effect is given by scheelite subjected to the radiation from a spark gap arc. Recently an ultra-violet light installation consisting of an iron spark gap arc operating on a high voltage transformer and utilizing a mica plate condenser has been found to have practical value. It is useful both for the examination of mill products and in the study of the ore.

Although the normal color of the scheelite throughout the deposit is white, a few samples of coarse crystallization have been found in the Stank mine in which the scheelite is pale brown. In one bed west of Springer Canyon yellow scheelite occurs, the color probably being due to traces of tungstite.

Scheelite is for the most part anhedral or subhedral in form (Figure 19) and is not found free from a matrix of embedding minerals. As previously stated it is usually associated with quartz, calcite, epidote or garnet.

ACTINOLITE

Actinolite is not only a prominent constituent of the country rock, but is found throughout the ore body. In the ore beds, however, it appears to have been formed as a later mineral, following the crystallization of the coarse epidote and scheelite. It may have been in part contemporaneous with the crystallization of the fine epidote and part of the scheelite. On the whole, however, it appears to have been somewhat later than the minerals previously mentioned.

ZEOLITES

The most prominent zeolite found in the deposits is stilbite. It occurs in radial aggregates and in plates. Stilbite is found as vein-filling material along the cracks and fissures in dikes and within the ore body. It was probably crystallized at a late stage following the crystallization of the intrusive mass. In

[10] Scheelite from Mill City was not examined by Van Horn in his study of fluorescence. The fluorescence of the Mill City scheelite, however, is similar to the effect he observed in scheelite from a number of other localities. Van Horn, F. R., Amer. Min. Vol. 15, No. 10, Oct., 1930, pp. 461–469.

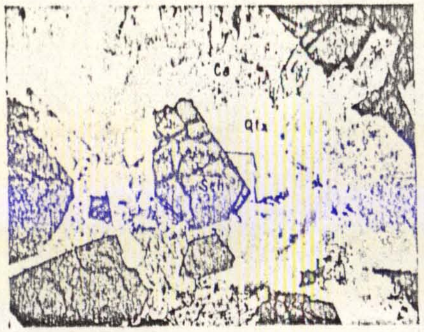


FIGURE 19
Scheelite in a groundmass of quartz and calcite. (Photomicrograph x 20.)

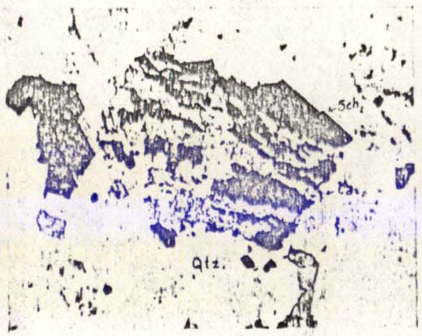


FIGURE 20
Isolated scheelite and calcite in quartz. (Photomicrograph x 20.)

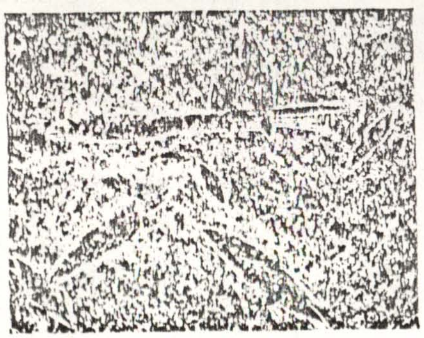


FIGURE 21
Tremolite in gray limestone. (Photomicrograph x 20.)

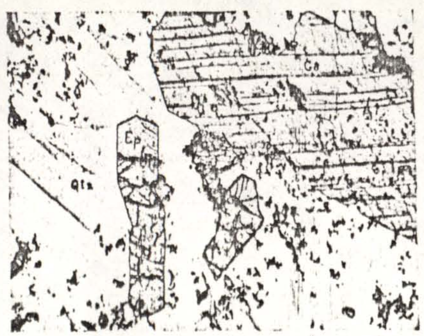


FIGURE 22
Euhedral epidote associated with calcite in quartz.

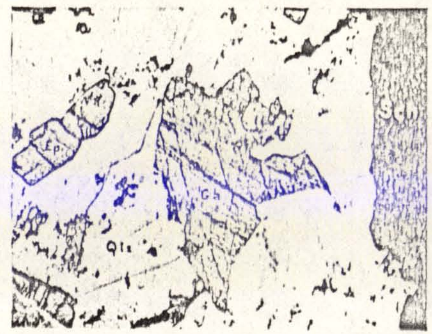


FIGURE 23
Epidote and calcite associated with scheelite in quartz. (Photomicrograph x 20.)

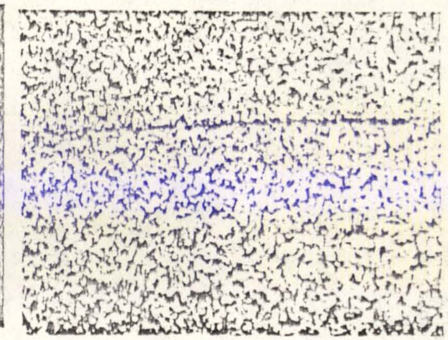


FIGURE 24
A typical thin section of the hornfels. (Photomicrograph x 20.)

FIGURE 25
Molybdenite (black) in garnet and epidote.

FIGURE 26
Subhedral garnet in quartz. (Photomicrograph x 20.)

the yellow scheelite bed stilbite occurs in abundance and contains traces of a yellow mineral, possibly nontronite. Stilbite also occurs in the high grade portion of the Humboldt ore body.

OTHER MINERALS

Pyrite and quartz are found in profusion throughout the ore body and extending in all directions throughout the country rock. Pyrite occurs in small crystals disseminated through quartz and virtually all of the other minerals produced by the contact metamorphism. Quartz was formed at numerous stages during the mineralization, and has been replaced, broken, fractured, and recrystallized time and again. Even following ore deposition, veins of quartz were formed cutting the ore body at right angles. Molybdenite and pyrrhotite occur as minor constituents of the ore. Chalcopyrite specimens are also occasionally found. Molybdenite is found in a small concentration a few feet long and about six inches in width occurring on the 300 level in the Stank mine just north of the shaft. In addition it is widely distributed in small amounts in the lower levels of both the Stank and the Humboldt ore bodies.

Molybdenite fills fractures, cutting the earlier generations of garnet, epidote and scheelite (Figure 25). Traces of bismuth have been reported in analyses of the concentrates. It is possible that small specimens reported occasionally as stibnite are bismuthinite.

INTRUSIVE GRANODIORITE

Granodiorite occurs both in the main intrusive mass and in dikes extending outward and cutting the hornfels. The granodiorite probably underlies most of the Eugene Range. Isolated occurrences a number of miles apart may be found around the boundaries of the mountains. In the vicinity of Tungsten several square miles of granodiorite are exposed. The hornfels resting upon the granodiorite is normally not merely a thin veneer but is a pendant having considerable depth. The contour of the upper surface of the granodiorite is uncertain. Mining operations, however, indicate that it is extremely irregular and that the sedimentary cover is much thicker than surface mapping would lead one to believe. Where remnants of hornfels remain upon the overlying granite surfaces, and have been penetrated during mining operations, they have been found to extend almost vertically without interruption for 600 to 800 feet in depth. The hornfels - granodiorite contact across the strike of the Stank ore body is probably inclined between sixty and seventy degrees (Figure 29). Even in places where the

granodiorite has cut the ore bed at right angles the inclination is steep. Nevertheless, in spite of the high angle of contact, it is hazardous to predict any considerable extension of the ore beds beneath the present mining levels.

The weathering of the granodiorite is apparently influenced to some extent by the abundance of quartz veinlets and fracture blocks. On the whole, the granodiorite appears to weather much more easily than the hornfels and forms the valleys, while the hornfels forms the ridges and hilltops. In a few places small pyramid-like hills of granitic rock stand out because of greater resistance to erosion due to a large number of intersecting quartz veinlets in the rock (Figure 16).

The granodiorite is an even grained holocrystalline rock composed of quartz, soda, and soda-lime plagioclase, amphibole, biotite, and accessory minerals including orthoclase. It was classified by Larsen[11] as a granodiorite, although further examination indicates that some phases may be more nearly a quartz diorite. Thin sections demonstrate the presence of the following essential minerals: quartz, andesine (zoned and corroded), albite, hornblende (partially altered to chlorite), and biotite (partially altered to clear biotite and chlorite). The biotite also contains included zircon crystals. The accessory minerals in the granodiorite are epidote, titanite, calcite, magnetite, apatite, pyrite, zircon, leucoxene. Dikes radiate outward from the granodiorite in a number of places. These vary from less than an inch in diameter to several that are about 100 feet in thickness. The length of the dike exposed at the surface, however, seldom exceeds 300 to 400 feet.

The dikes cut all phases of the hornfels and the ore beds. They show two types of mineralization, one containing a concentration of albite and quartz which occurs along the margins and sometimes constitutes the entire dike. The other phase is the granodiorite or quartz diorite phase which makes up the centers of many of the dikes and forms the main mass of the major intrusives. The marginal portions of the dikes appear to have been forced outward from the intrusive mass either as the central phases were being crystallized or closely following their crystallization. Shear lines appear along the walls of the dikes and along the contact between the margins and the centers. The shear cracks have been filled by later quartz and are associated with quartz-albite mineralization.

It is generally recognized that soon after the solidification of

[11]Hess, F. F., and Larsen, E. S., Contact metamorphic tungsten deposits

an igneous rock the rock may be *self-injected.*[12] A diorite or granodiorite, for example, may be invaded by quartz and albite; an upward penertation due to end-stage emanation from the same diorite or granodiorite magma which produced the original rock. The granodiorite both in dikes and in the intrusive mass associated with the tungsten deposits has suffered such invasion. This is apparently reflected in the topography of the intrusive in the area east of Humboldt Hill (Figure 16). In areas of otherwise deeply eroded granodiorite several resistant knobs stand out. These appear to have resisted erosion on account of the concentration in a small area of end stage mineralization in the form of erosion resistant quartz.

Evidence of end stage action may be observed to best advantage in thin sections. Figure 18 illustrates this relationship. The two views (Figures 18a and 18b) are photomicrographs of portions of a large thin section sawed at right angles to a small dike of the type illustrated by Figure 15. The central area of the dike, the marginal quartz-albite area and the hornfels wall rock were all retained in one unbroken section and are related as shown in Figure 18. Comparison of the two photomicrographs with the key sketch in Figure 18 should bring out the relationship.

SILICIFICATION

Silicification appears to have occurred as an additional end stage effect of the intrusion. Presumably this started with the quartz-albite invasion and increased as the end stage solutions cooled. Vein quartz invasion appears to have filled fractures following the quartz-albite invasion and the earlier more massive silicification. Multiple banding of alternate quartz-albite layers and quartz layers in some of the dikes indicates a close relationship between the albitization and the silicification.

Vein quartz cuts across the high grade garnet-epidote-scheelite bodies at right angles and it is naturally concluded that the crystallization of scheelite ore occurred prior to the quartz veins. The quartz of the quartz-albite stage, and massive glassy quartz closely associated but presumably slightly later, appear to have been closely related to the ore mineralization. The massive vitreous quartz contains fine epidote crystals associated with scheelite, while the later veins consist of barren quartz.

Silicification appears to have been more intense in certain zones than in others. These zones do not appear to follow the strike of

[12]Colony, R. J., The crystallization of an igneous rock, Jour. Geol. Vol. XXXI. No. 3, Apr.-May, 1923, pp. 169-178.

the sedimentary series, nor are they related in any apparent fashion to the intrusive contact. The west side of Humboldt Hill, the vicinity of the Baker prospect, the crest of the hill above the South Sutton workings, Springer Hill, the vicinity of the Stank workings at the surface, the crest of Stank Hill and several minor localized areas appear to have been more highly silicified than adjacent areas. These zones are irregular in shape; in fact, the outlines are so obscured by gradation into the normal hornfels that the zones can only be indicated and not accurately mapped. The chief significance of the zones of silicification lies in the fact that in several of the areas mentioned high grade ore deposits are found, and in all the indications of ore appear to be of economic importance. In each case in which limestone beds happened to fall within the zone of silicification intense replacement appears to have taken place.

HORNBLENDE-ANDESITE

The hornfels and limestone beds and also portions of the granodiorite are occasionally cut by small dikes of hornblende-andesite (Figure 17). The hornblende-andesite appears to be an entirely later phase of igneous intrusion, and is probably not related to the processes of ore formation. The hornblende-andesite is composed essentially of soda-lime feldspar varying from extremely fine crystals to moderate-sized phenocrysts. Abundant hornblende crystals varying considerably in dimensions are scattered indiscriminately throughout the rock. The common hornblende is green, although a brown variety occasionally occurs as an alteration. The accessory minerals are magnetite, ilmenite, leucoxene, apatite, and titanite. Zonal banding is common in the plagioclase which is chiefly andesine with some laboradorite. Later veinlets of chlorite cut the hornblende-andesite in places and also penetrate the previous rocks.

STRUCTURAL FEATURES

The Eugene Range in which the Tungsten district is located constitutes a fault block of the basin and range type with the west side more elevated than the east. The structures of the range of importance to the mining problems, however, are not the comparatively recent displacements of the margins of the mountain block, but the complex and earlier structures of lesser magnitude that occur within the range.

The general strike of the sedimentary strata as indicated by traces of the old lines of sedimentation is approximately N 20 E. Locally the strike may vary to north-south or N 30 E. The rocks of the entire district are badly fractured along the numerous planes, and the fracturing is so complex that no definite pattern has been interpreted.

The principal fault in the area mapped is the Stank fault, which extends for a distance of about a mile and a half in an almost north-south direction, cutting across the eastern slope of Stank Hill. The strata west of the Stank fault (Figure 27) are inclined toward the east; east of the Stank fault in the vicinity of the operating mines the beds dip about 70° W. The zone of faulting varies in width from about fifty feet in the vicinity of the Codd workings to twenty-five feet near the Summit workings and apparently disappears on the western boundary of the area mapped. Near the Springer ore body the fault becomes associated with a crush zone several hundred feet in width in which all of the limestone beds have apparently been broken into short isolated segments. In spite of several dozen small prospect pits and short tunnels dug into the hillside throughout the crush zone, no definite set of beds can be traced. Segments twenty or thirty feet in length are apt to be terminated with faults on each end, and in places the segments themselves have become fault zones containing fragments of broken ore along a plane of movement.

Post-mineral faults cut all of the geologic units and apparently much local displacement took place after the cooling of the igneous mass and before the present topography was developed. The fault lines are not reflected in the surface topography, and are only traceable by careful study of the limestone beds and zones of brecciation encountered in the underground workings.

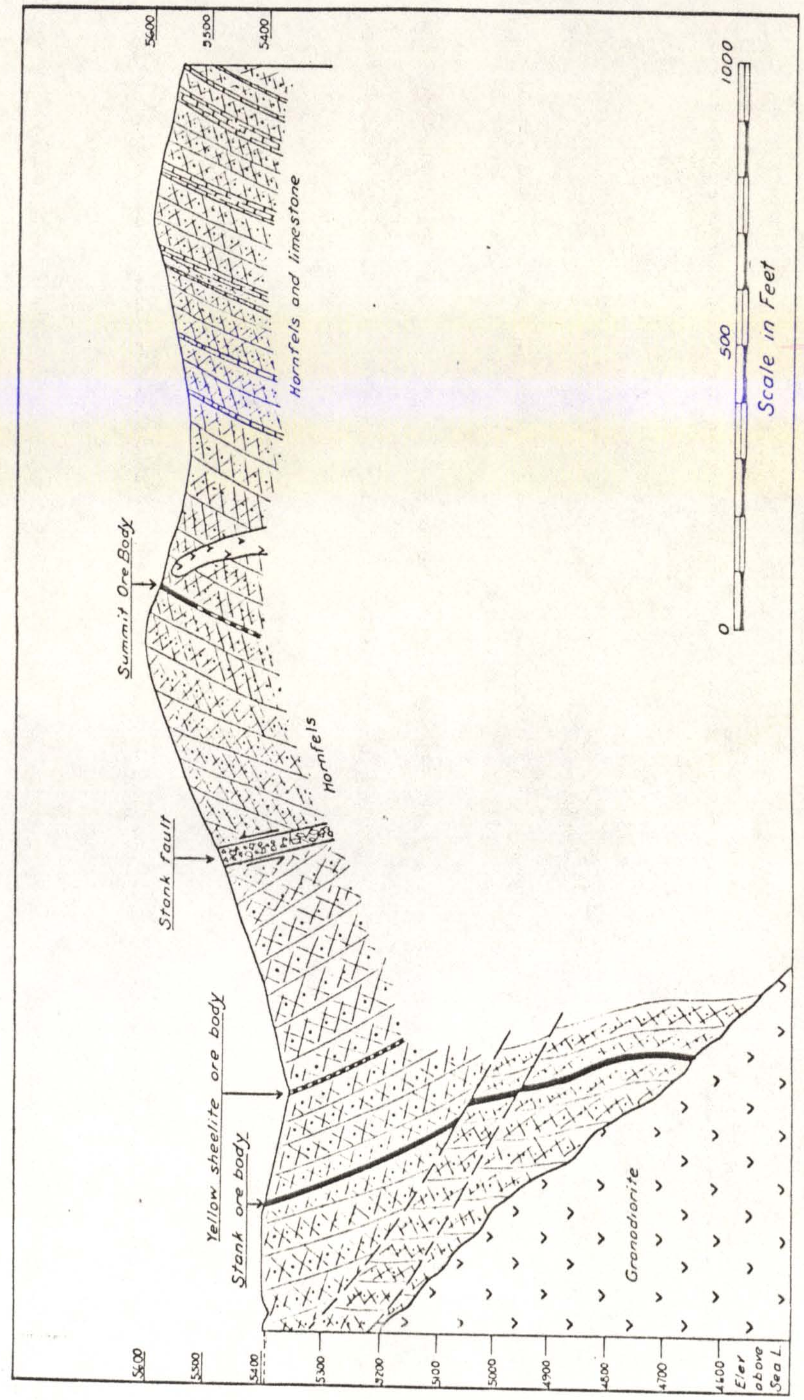


FIGURE 27. Cross-section of Stank Hill looking south. (See AA', Figure 7, also Figure 4.)

The post-mineral faulting just described constitutes the principal structural disturbance of the area. Pre-mineral faulting, however, occurred previous to the contact metamorphism of the limestone beds. These faults are evidently displacements of the ore beds that occurred prior to metamorphism. The mineralizing solutions penetrating the country rock and ore beds completely recrystallized the gouge along the fault lines and sealed all openings to such an extent that the usual indications of fault movement were obliterated. The pre-mineral faults are only located by tracing the offset ore beds. Because of the difficulty in locating these faults and the sealed character of the fault planes, the pre-mineral faults cause the most trouble in mining operations. Two pre-mineral faults that cut ore beds are indicated in Figures 28 and 29. One fault cuts the Stank ore body, reaching the surface at the head of the tramway, while another cuts the Humboldt ore body north of the shaft.

DESCRIPTION OF INDIVIDUAL ORE BODIES

The three principal ore beds of the Tungsten district extend in an irregular N 20° E line for a distance of approximately a mile. This line is broken in a number of places, and the chief ore bodies now being worked may represent one continuous ore bed or may be composed of segments of two beds. In any event the replaced limestone strata have been broken by numerous faults, and have also been completely eliminated in places by the intrusive granodiorite. The faulting and the intrusion have produced gaps in the ore deposition which have rendered the problem of following the ore difficult. The two mines on the north are connected underground, but may be operated on two different beds, although development work has not proceeded to such an extent that this can be considered proven. A considerable offset exists at the junction between the Humboldt mine and the Springer mine, and the relation between the ore beds of the two mines has not been clearly established. The Stank mine farther south is isolated from the Springer mine, being separated by a considerable area of granodiorite (Figure 7). It is possible, however, that the replacement producing the ore in the three mines may have followed what was once the same limestone bed. Other metamorphosed strata exist in isolated segments roughly parallel to the main ore beds. These have not as yet been thoroughly explored even at the surface, in spite of the fact that in many cases surface indications are quite promising and in several places scheelite ore can be found in outcrops. An abundance of ore reserves in the mines now working has made extensive exploration and development unnecessary in recent years.

The underground workings of the Humboldt, Springer and Stank mines present an interesting variety of geological problems of a decidedly practical nature. The distinction between the two generations of faults is particularly important since the pre-mineral faults have in general different criteria for detecting the direction of displacement than the post-mineral faults. The extent and intensity of the contact metamorphism appears important in governing the tenor of the ore. Zones of silicification must be followed since these zones appear to indicate the most intense metamorphism. The extent and depth of the igneous intrusive is important, since when the intrusive is encountered mining will cease.

THE HUMBOLDT-SPRINGER ORE BODIES

The Humboldt-Springer workings are shown both in a plan view and a projected vertical section in Figure 28. The Humboldt mine extends underground for six levels or approximately 600 feet below the collar of the shaft. The 300 level is connected by means of a crosscut and a short raise with the 200 level of the Springer mine, and all operations from the Springer mine are now carried on through the Humboldt 300 level. The ore bed upon which the Humboldt mine has been developed dips approximately 70° to the northwest, and strikes N 20° E. The thickness throughout most of the workings is from five to six feet; in one place, however, where the highest grade ore occurs on the 300 level north it is fifteen feet. The ore body is cut by several fault zones and also by both granodiorite and hornblende-andesite dikes. No ore is found in the dikes. High grade ore occurs on either side, however, even within a fraction of an inch of the margin of the dike. It appears that the penetrating end stage solutions which followed the dikes rather than the dikes themselves were the controlling factors in ore deposition. In computing ore reserves, the dikes are merely considered as gaps in the ore body, and in mining operations are left as pillars.

Recent development work has exposed two unexplored ore bed segments. One segment is shown in the plan (Figure 28) on the Humboldt 300 level south at the northern end of the Springer workings, where the junction between the two mines occurs. An ore bed five feet in width, and averaging three percent scheelite has been exposed along a tunnel for approximately four hundred feet. Whether this ore bed extends to the surface or not and how far it penetrates below the 300 foot level can only be established by future exploration. It is a fair assumption, however, that the new development represents a considerable addition to the ore reserves of the Humboldt-Springer mine.

The other recently discovered ore bed segment is located at the north end of the 300 level north in the Humboldt mine. About three hundred feet of an ore bed fifteen feet in width and probably averaging between five and ten percent scheelite has been exposed. The new ore body has also been cut one hundred feet beneath on the extreme northern end of the 400 level, but development work has not as yet been completed. Whether this new Humboldt ore body extends all the way to the surface and how far it penetrates below the 400 level will need to be established by future development. Also, the distance to granite on the north is unknown, although it is probably at least 700 feet horizontally, judging from surface exposures. The prospect of a considerable extension of this ore body would appear to be unusually good from the geological standpoint. It is probable that certain outcrops west of Humboldt Hill containing contact metamorphic minerals and scheelite represent the surface exposure of this bed. Since the main ore body in the Humboldt mine has been worked to the 600 level, it is probable that the newly discovered ore bed may extend at least to a similar depth. Additional pre-mineral faulting has been encountered in lower levels,[13] however, and it is not likely that the ore body will be entirely worked out until additional data is secured for the solution of the fault system in the Humboldt mine.

The ore of the high grade stope on the 300 level north consists chiefly of coarsely crystalline masses of scheelite in a groundmass of fine quartz and epidote. Both garnet-epidote masses and garnet masses containing quartz and coarse scheelite are also occasionally encountered. The ore of this stope contains much more visible scheelite than is usual for the Humboldt mine as a whole. For the most part the scheelite is disseminated in fine specks through the contact metamorphic minerals. The ore in the lower and north end of the Humboldt mine contains fine black pyrite and is more finely granulated than in the upper levels, but it appears to contain as much scheelite.

As the mine has been deepened from level to level the operators have been in fear that the underlying mass of granodiorite might be encountered and the bottom of the mine would be reached. No bottom has as yet been encountered, however, and it is clear from the depth to which mining has been carried that the sedimentary cap on the granodiorite mass represents a pendant-like mass rather than a thin veneer as was supposed by the early operators who greatly underestimated the size of the deposit. No indication of the main granodiorite mass has been encountered in the lower levels, the granodiorite cut being the continuation of the same dikes or offshoots encountered at the surface. One granodiorite dike extends from the surface just south of the Humboldt shaft downward at an angle varying from 30° to vertical at the end of the 500 level south of the shaft. The same dike has been penetrated on each successive level as the mine was deepened.

[13]Encountered in development work since the original text was written.

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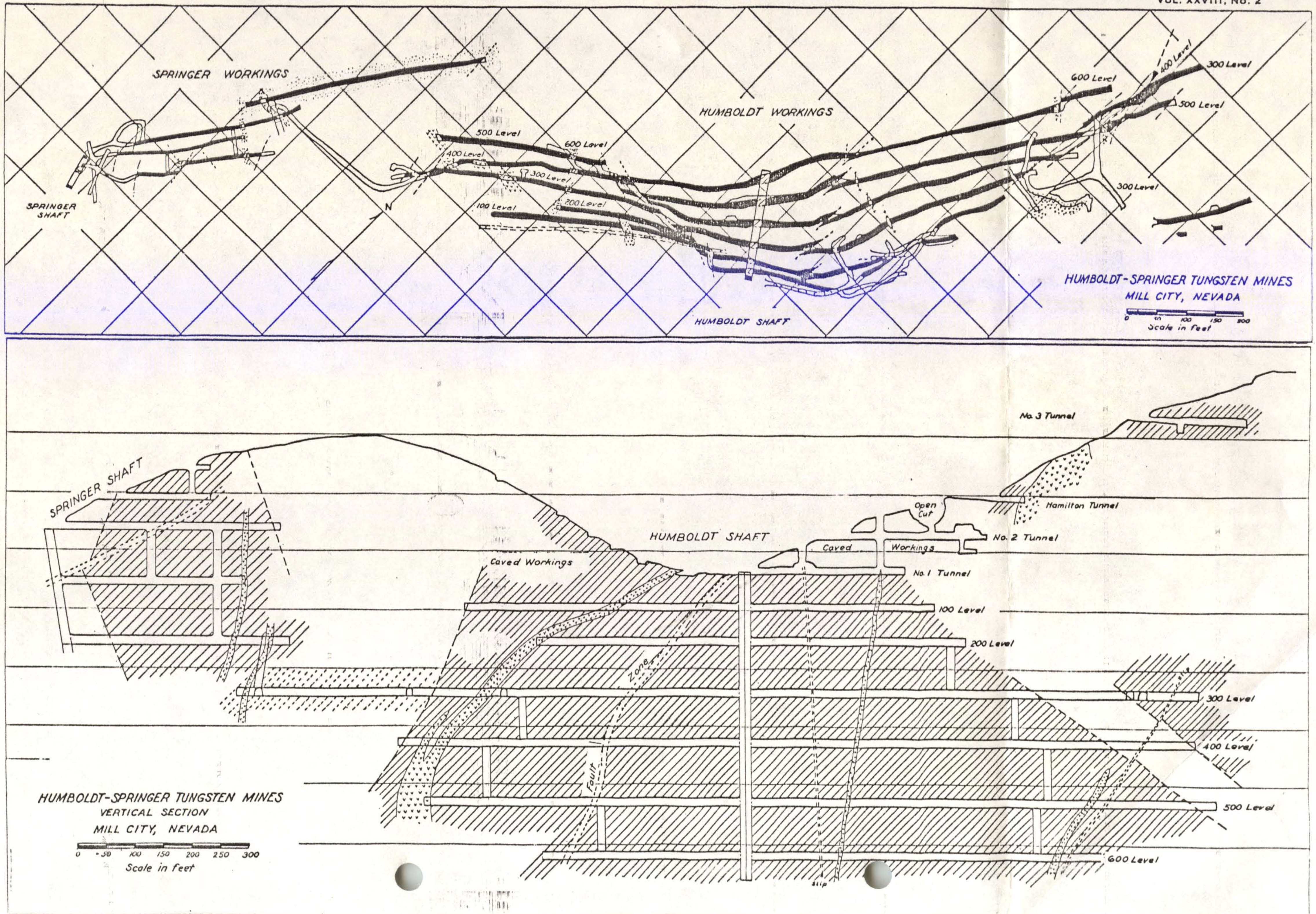

FIGURE 28.—Plan and projected vertical section of the Humboldt and Springer

A thin hornblende-andesite dike cuts the mine workings almost vertically on the north side of the Humboldt shaft. There appears to be no information to be gained from the study of these dikes, however, to indicate whether the bottom of the mine will be a few feet or many feet below the 600 level.

As previously mentioned, the faults cutting the Humboldt ore body are both pre-mineral and post-mineral. The pre-mineral faults appear to have caused an original displacement of the limestone before metamorphism took place; the post-mineral faults represent a more recent movement after the mineralization. The pre-mineral fault planes have been completely silicified, all traces of gouge or fracture having been obliterated by the silification. It is only by careful study of polished slabs of the rock and a detailed inspection of the walls that the planes can be located by changes in mineralization. The limestone beds, however, were offset by such movement in places as much as two hundred feet.

The post-mineral faults are easily followed by the usual indications of gouge and drag of ore fragments, together with brecciation of the hornfels. The movements along the post-mineral faults appear to have been of less importance in the Humboldt mine than the pre-mineral movements. The chief problems involved in following the ore body have had to do with the location of faulted segments on the pre-mineral faults.

The operations in the Springer mine have been much more restricted than the Humboldt mine, and mining has not extended below the 300 level where the connection between the two mines occurs. On the south of the Springer mine an extended area of complicated post-mineral faulting has been encountered and no attempt has been made to drive tunnels south, below the bottom of Springer gulch. The shaft of the Springer mine penetrates a broad breccia zone of post-mineral faulting, and prospect pits on the hill opposite disclose such a complicated group of small isolated ore segments separated by faults that the zone does not appear to justify mining operations.

THE STANK ORE BODY

A geologic section cut at right angles to the strike of the Stank ore bed is shown in Figure 27. This section follows the line AA′ of the map, Figure 7, and indicates the relationship between the sedimentary strata on the two opposite sides of the Stank fault. One portion of the workings along the Summit ore body cuts across the Stank fault. The crosscut in this place shows zones

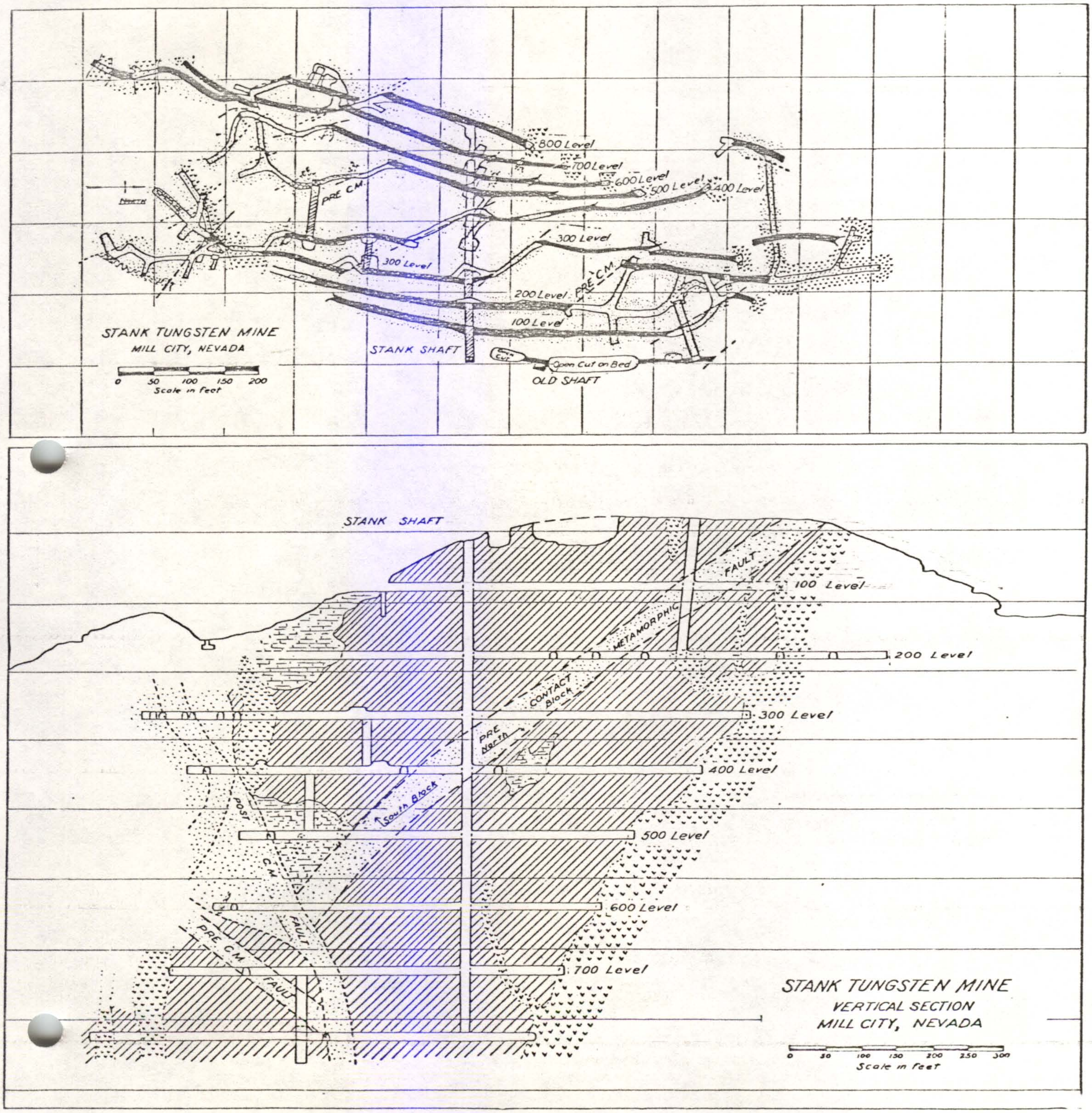

FIGURE 29. Plan and projected vertical section of the Stank mine.

of brecciation containing blocks of granodiorite, limestone, and hornfels. The blocks measure from a few inches to several feet in diameter, and are disarranged in a heterogeneous mass of fault brecciation. The Summit ore body, together with the adjacent hornfels and unreplaced limestone beds, appears to represent a block west of the Stank fault, while the Humboldt, Springer and Stank ore bodies, together with the adjacent granodiorite mass, represent another block east of the fault. The unreplaced beds of limestone are shown in the section west of the Summit ore body. These limestone beds present a problem of importance to the future of the Mill City district. Adjacent exposures of ore demonstrate that the limestone, although unreplaced, is within the area of contact metamorphic action. The Summit ore body has yielded some fairly good ore which was apparently cut off at the bottom by a pre-mineral fault, and the off-faulted segment has not yet been located.

East of the Stank fault is the Stank ore body and a small parallel ore bed characterized by scheelite of a yellowish tint responsible for the name "yellow scheelite ore body." The Stank ore body has been opened to the 800 level with a dip varying from 70° to the west to vertical. In the lower levels, however, the dip is reversed and the ore body inclines at an angle of about 80° to the east.

The Stank ore body is shown in both plan and elevation in Figure 29. The best exposure of the contact between the granodiorite mass and the ore body may be found underground along the northern margin of the Stank workings. The contact has been exposed from the surface downward to the 800 level with several off-shoots penetrating a few hundred feet outward and cutting the ore bed. The contact between the ore bed and the granodiorite is irregular, with numerous bench-like extensions of the igneous mass exposed along the open workings. The ore has been removed for a vertical distance of eight hundred feet, a narrow open stope eight or ten feet in width remaining, and the hanging wall standing for the most part without support (Figure 9). All of the workings are not accessible, but in many places the granodiorite can be observed in contact with the hornfels of the adjacent hanging wall and foot wall of the ore bed, and in the lower part of the workings, where ore still remains, a sharp contact is visible. The scheelite in the ore bed extends to within a few inches of the granodiorite without either increase or loss of ore value. This is typical of the situation which appears to hold true throughout all of the contact areas between the ore body and the intrusive in the district as a whole.

Several fair-sized blocks of unreplaced limestone or limestone so poorly replaced that it would not constitute ore have been encountered in the Stank workings. Likewise in one place an underground limestone cavern about forty feet in length and four feet wide was penetrated. The cavern was apparently produced by secondary leaching of unreplaced limestone. It occurs at the south end of the Stank workings where the limestone has not been replaced and contact metamorphic action was apparently absent.

The same two generations of faulting are found in the Stank mine that have been described in the Humboldt-Springer workings. One prominent pre-mineral fault cuts diagonally across the ore bed, extending from a point on the surface five hundred feet north of the Stank shaft underground to a point on the 600 level about two hundred feet south of the shaft. This fault line shows no recent gouge or evidence of open fault movement. On the other hand, slabs of rock broken from the line of faulting and later polished show the contact metamorphic minerals on one side and quartzite on the other. The off-faulted segment of the ore bed has been located on each successive level as the mine has been deepened and crosscuts were run in each instance intersecting the ore body at the proper point. The proper projection point was established by geometric projection by Mr. Heizer, the displaced segments being located during the course of operations.

In the lower levels of the Stank mine on the south end the pre-mineral fault is cut by a post-mineral fault system apparently having several branches. The movement along one of these faults appears to have been rotational, and it is probable that the pre-mineral fault plane was rotated by movement of the blocks on the south side of the post-mineral fault. The situation produced on the south side of the Stank mine in the lower levels is consequently somewhat complicated, and development work has not proceeded to such a point that the extension of the ore body can be definitely established. A fair supply of blocked out but unmined ore reserves exists in the lower levels on the southern end of the Stank mine, in spite of the faulting; and it is possible that future exploration conducted with parallel geologic study may yield worthwhile knowledge concerning the continuation of the ore bed. The upper levels of the Stank mine have been worked out, and the portion near the surface on the southern extension is so poorly replaced and so badly broken that the section does not appear to justify the expense of mining operations.

The lower levels will be called upon, therefore, to provide ore

during future operations along the beds now being worked. Southward extension is possible in the lower levels and a considerable area of unexplored sedimentary rock exists between the present south end of the Stank mine and the Codd prospect.

The same problem regarding the granodiorite floor beneath the sedimentary series exists in the Stank mine that has been discussed in connection with the Humboldt mine and the answer is equally uncertain. Operations have followed the replaced limestone bed in the Stank mine to a depth of over 800 feet, and indications of striking the underlying granodiorite are no more abundant than at the surface.

THE SUTTON BEDS

Mining operations were conducted during the early history of the district along the Sutton beds. These consist of two closely parallel limestone beds, about forty feet apart, nearly vertical in attitude, and exposed intermittently along a north-south line on either side of the town of Tungsten, for a total distance amounting to about 5,000 feet between the extreme north and south operations (Figure 2). The two beds may be traced by occasional exposures south from the southernmost operation for at least an additional mile. The east bed is normally from 2½ feet to 5 feet thick, while the west bed varies from 2 feet to 4 feet in thickness. The Sutton beds are Upper Triassic in age, and furnish one of the few fossil horizons in the area. Hornfels occurs both between the two beds and on either side.

Exposures along the Sutton beds are intermittent due to hillslopes covered with soil and loose rock debris, areas of intrusive granodiorite and faulting which has displaced certain portions several hundred feet. The rounded hillslopes yield poor exposures, which make surface mapping difficult, and leave many gaps without reliable field evidence. Two large areas of intrusive granodiorite and a number of dikes cut the beds. One intrusive area on which the town of Tungsten is situated, eliminates approximately 2,000 feet of strata. East of Humboldt Hill is another large area of intrusive granodiorite which terminates the Sutton beds on the north. Faults almost at right angles to the strike of the sedimentary strata have offset portions of the Sutton beds for several hundred feet in a number of instances. Unfortunately, from the standpoint of mining, the beds have not only been offset but have been broken into numerous small isolated segments seldom exceeding 60 feet and frequently not more than 20 feet in length. The faults are not restricted to vertical and horizontal displacements, but include diagonal displacements as well, with the result that the broken blocks of the Sutton beds are so irregularly distributed in the faulted zones that normal mining operations under present economic conditions are unprofitable, even where the limestone blocks have been replaced with the formation of scheelite.

After eliminating the areas of intrusive granodiorite, and the extremely faulted portions of the Sutton beds, approximately 2,500 feet remain. This length is divided into two portions, one portion north of the town of Tungsten including the north Sutton tunnel (shown on the hill just beyond Tungsten in Figure 3) and the Baker prospect; the other portion south of the town including the South Sutton workings and the hill beyond (Figure 6). These two segments as exposed on the surface or in the underground workings are largely unreplaced limestone. Portions, however, are said by the operators to contain workable ore bodies, and in view of the history of the district it is possible that the mineralization may increase with depth. The extent of this increase can only be determined by future prospecting.

HISTORY OF THE GEOLOGIC PROCESSES

The history of the geologic processes may be expressed in terms of a rather simple sequence of events. Between the period of Triassic deposition and the time the present topographic development began the important processes were metamorphism, igneous intrusion, and deformation. The periods of each process are indicated according to the following order:

(1) Widespread metamorphism of the sediments throughout the district.

(2) Deformation either before or accompanying igneous intrusion.

(3) Igneous intrusion and accompanying contact metamorphism with end-stage alteration.

(4) Later andesitic intrusion.

(5) Post-intrusive deformation.

1. Evidence of the first alteration in the Triassic sediments is found in the limestone. A widespread metamorphism of the sediments must have taken place throughout the district, since abundant tremolite needles occur widely scattered through the gray limestone. Although the metamorphism produced tremolite, it did not destroy the carbonaceous matter in the limestone.

2. Following the early metamorphism, there was widespread fracturing of the tremolite crystals in the limestone and recementation by calcite. Mining operations also demonstrate displacement of the limestone strata at some stage between the early metamorphism and the formation of the ore beds. This may have occurred accompanying the early stages of the intrusion, although it probably happened before, since there is no evidence that the intrusive followed planes of faulting.

3. The igneous intrusion and accompanying contact metamorphism was responsible for the concentration of scheelite. The principal ore formation appears to have occurred toward the end of the intrusive action prior to the formation of quartz veins and accompanying end stage effects consisting of quartz-albite invasion and silicification. The processes of metamorphism appear to have been connected with the end-stage effects of the intrusion, starting with the quartz-albite phase and extending into the stage of silicification. As metamorphism progressed decarbonization of the limestone occurred, together with replacement of the tremolite and the development of two types of marble. The first type

of marble to be formed was a fine white marble varying to pale green on the margins of unaltered blocks of gray limestone. The white marble was later cut by a second marble of coarse recrystallized calcite due to more intense contact metamorphism. Accompanying the coarse calcite were garnet, epidote, and scheelite essentially crystallized in the order named. It is clear, however, that the periods of crystallization overlapped, and it is only in general that garnet crystallized before epidote, and epidote before scheelite. The chief ore forming period appears to have partly overlapped and closely followed the end-stage quartz-albite invasion of the intrusive. Following the garnet-epidote-scheelite stage occurred a second epidote stage with extensive silicification and continued crystallization of scheelite. This was closely followed by the formation of actinolite and some tremolite. Silicification was continued and terminated in numerous quartz veins. As the contact metamorphism was concluded, the intrusive cooled, and during the cooling zeolites were formed in cracks along the margins of the granodiorite mass and even in adjacent rocks within the ore bodies.

4. The hornblende-andesite appears to have intruded the area after the cooling of the previous intrusive. Dikes of the andesite cut all previously formed rocks in various directions.

5. The post-intrusive deformation appears to have resulted chiefly in faulting. The faults of this generation of movement cut all of the rock types associated with the ore bodies, and displace the pre-mineral fault planes as well.

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TABLE 13. Summary of recorded production, Kennedy mining district.

[0, no production; blank, no data]

Year	Ore sold or treated (short tons)	Total value when sold $	Placer gold (ounces)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1903–1906	1,752	22,563	0	720	13,440	0	0
1910–1911	139	7,051	0	143	5,846	0	21,564
1914	40	820	0	37	116	0	0
1917–1924	203	11,117	34	107	8,410	141	12,316
1926–1928	29	2,992	0	16	4,243	172	2,147
1931–1932	40	1,813	0	36	2,123	236	12,000
1934–1942	3,462	140,227	0	2,811	47,221	61,590	32,752
1949–1950	646	8,001	0	55	3,177	300	20,700
Total	6,311	194,584	34	3,925	84,576	62,439	101,479

carbonate rocks of the Triassic Natchez Pass Formation overlies the Koipato at the eastern edge of the district.

The gold-silver veins in the vicinity of the site of Kennedy are a network of intersecting quartz-pyrite veins that trend north and northwest and dip west and southwest. The veins mined at the Sunnyside and Imperial groups of claims are in a basic facies of the Tertiary granodiorite; the veins mined at the Gold Note group of claims are in metamorphic rocks of the Pumpernickel Formation. The metallic minerals are galena, sphalerite, chalcopyrite, arsenopyrite, pyrite, tetrahedrite, and pyrrhotite; the galena is argentiferous, and native gold is present locally (Muller and others, 1951).

The oxidized zone, ranging in depth to 50 or 125 feet down dip from the surface, contained 0.75 oz of gold and 12.0 oz of silver per ton (Klopstock, 1913). The secondary sulfide zone varies from 50 to 75 feet in depth below the oxidized zone and contains some copper, lead, and zinc with high-grade gold-silver values. The primary sulfide zone averages 65 feet in depth below the secondary sulfide zone and contains 0.52 oz gold and 10.0 oz silver with traces and occasional enrichments of lead, zinc, and copper. The mines are extensively developed by tunnels and drifts that cut at least 15 veins. Underground workings total about 5 miles.

The ore at the Henrietta mine is in a quartz-sulfide vein that varies from a few inches to 4 feet in thickness in a thrust(?) fault in greenstone and schist of the Havallah sequence. In the upper part of the fault zone, the vein has been completely oxidized and the ore minerals are earthy oxides and carbonates of lead and zinc. In the lower levels, below 400 from the surface down the dip of the vein, sulfides predominate over oxidized material—principally galena, sphalerite, and pyrite, with minor chalcopyrite as narrow bands or ribbons generally on the foot and hanging walls of the fault, occasionally at a few places within the vein. At depth, the banded structure of the vein is less apparent; quartz and sulfides appear to be in more or less intimate mixture. The mine is developed by four tunnels that follow the fault zone from which the ore was stoped; total development is about 5,000 feet.

Mill City District

By Dwight M. Lemmon

The Mill City district, originally called the Central district, includes the southern three-quarters of the Eugene Mountains (in Tps. 33 and 34 N., Rs. 33 and 34 E.) within north-central Pershing County.

Tungsten deposits in the Eugene Mountains in the vicinity of Tungsten, 8 miles north-northwest of Mill City, are among the largest known in North America. The Humboldt, Springer, Stank, North Sutton, and South Sutton mines have been the principal producers and have long been under common ownership. Occurrences elsewhere in the Eugene Mountains appear to be small and have had little production.

The mines in the district are easily accessible by paved, improved, and unimproved roads that lead north and west from Interstate Highway 80 at Mill City. A paved road extends from Mill City to Tungsten (former settlement and mill of the Nevada–Massachusetts Co. mines). Other roads, mostly unimproved roads and jeep trails, extend up the canyons into the interior of the Eugene Mountains.

HISTORY

Copper deposits were discovered in the Eugene Mountains in 1856 and the Central district was organized 1861. The first location was the 56 copper mine; other base and precious metal deposits were located and mined between 1856 and 1917. Prior to 1900 production was at least 935 tons valued at $14,648 (Couch and Carpenter, 1943, p. 127) from the 56, Marietta, Keystone, and other mines, including the Blackbird mine in the Humboldt County part of the Eugene Mountains. Subsequently the Keystone mine and 56 copper mine were worked intermittently to 1966. Production from these deposits yielded only a few hundred to a few thousand dollars for each year mined.

Scheelite was found here in 1917; by 1918, three companies were mining ore: the Humboldt Corp., the Pacific

Tungsten Co., and the Mill City Tungsten Mining Co. Operations ceased in 1919 because of low prices for tungsten and were not resumed until 1924. In 1925, Nevada–Massachusetts Co. purchased holdings of the Pacific and Mill City companies, and in 1928, those of the Humboldt Corp. Under the consolidated ownership, operations were continuous until 1958, except for 4 months in 1932. Forced by economic conditions to close in 1958, the company dismantled the mill and housing settlement. In 1971, Segerstrom Brothers built a pilot mill for retreatment of accumulated tailings. Details of early development and operations are described by Hess and Larsen (1922), Heizer (1930a, b) and Kerr (1934, 1946).

Total production is approximately 1.5 million short-ton units of WO_3 in scheelite concentrates.

DEVELOPMENT OF MINES OF THE NEVADA–MASSACHUSETTS CO.

In 1945 (the time of the last detailed geologic study of the district), mine workings in the district amounted to about 13 miles of drifts and crosscuts, 4,650 feet of shafts, and 3½ miles of core-drill holes, nearly a third of the level workings crosscuts. Half the workings were in the Humboldt–Springer mine, which provided about 60 percent of the total amount of ore produced in the district between 1917 and 1943.

The Humboldt–Springer mine is open to a vertical depth of 1,420 feet (1,700 level) through the inclined, two-compartment Humboldt shaft. Three parallel beds are worked in the mine—the Humboldt, the Springer, and the George. The Humboldt and Springer beds were originally developed as separate mines. Below the 300 level, where the mines were connected, the Springer bed was worked from the Humboldt shaft.

The Stank mine is open to a vertical depth of about 1,200 feet (1,300 level) through an inclined shaft to the 700 level, a winze from the 700 to the 1,200 level, and a second winze to the 1,300 level. Most of the workings are in the Stank bed, which is probably equivalent to the Humboldt bed. In 1944–45, crosscuts were extended west to the Yellow Scheelite bed on the 300 and 400 levels. The Yellow Scheelite bed is the probable equivalent of the Springer bed.

The South Sutton (Sutton No. 1) mine, in the Sutton beds at the south edge of the Springer stock, is opened by 950-foot adit along the beds, an inclined shaft 215 feet deep, and drifts on the 100 and 200 levels extending 300 and 250 feet south of the shaft. The grade of the ore is about 0.5 percent WO_3. Between the South Sutton mine and the Springer stock, the Sutton beds are broken into many small segments by faulting. Some of these segments were opened by short adits and open cuts (the Orphan workings); about 10,000 tons of 0.75 percent ore were mined.

The North Sutton mine is opened by an adit, about 720 feet long, on the west bed and an internal shaft sunk from a point 550 feet within the portal. By 1958, the shaft, inclined at 67°, had reached the 850 level. Although the main workings are in the West Sutton bed, parallel drifts follow the East Sutton bed for long distances.

The deep mines, 850, 1,300, and 1,850 feet on the incline, still have ore on the bottom levels and offer opportunities for future exploration. Exploration at depth might find additional mineralized offsets of beds such as the Humboldt and beds that were not present on the upper levels. Some calcareous beds that do not have surface ore might be mineralized at depth.

GEOLOGY

The scheelite deposits occur in tactite replacing thin beds of limestone in a thick hornfels sequence. The principal deposits are closely related to three small irregular stocks of granodiorite; the Olsen stock has an outcrop area of 0.5 square mile, the Springer stock with an outcrop of 0.2 square mile, and the Uncle Sam stock with an outcrop of 0.04 square mile (fig. 16). The walls of these stocks and of other, smaller intrusive bodies appear to dip steeply outward, and the area of the intrusives is only slightly greater in the deepest mine levels than at the surface. In general, the limestone beds are altered for 1,500 to 2,000 feet from the main intrusives, although large remnants of only slightly altered limestone are found within this zone.

The sedimentary rocks are of Triassic and Jurassic age and consist of shale, largely metamorphosed to hornfels, with intercalated beds of limestone and sandstone. The predominant type of hornfels is a brown, compact, blocky rock that can be scratched with a pick and consists largely of quartz, biotite, and hornblende. A type of hornfels abundant in highly altered areas near ore bodies is a gray and green, dense, hard, banded, chertlike rock composed of quartz, actinolite, and tremolite, and locally epidote and pyroxene. The thickness of the sedimentary rocks is unknown; it is probably at least a mile.

The dozen or more known limestone beds range in thickness from 1 to 30 feet. Most of the individual beds tend to be fairly continuous and of uniform thickness, but some thin or even pinch out entirely. Within the contact aureole, the limestone beds may be unaltered, bleached, recrystallized to marble, or replaced by tactite. The tactite is a medium- to coarse-grained crystalline rock composed of garnet, epidote, and quartz, with small amounts of calcite, scheelite, and pyrite.

The intrusive rocks are granodiorite, quartz diorite, and aplite, all related, and a younger hornblende andesite that cuts across the older rocks. The main granodiorite stocks are composed of a medium-grained holocrystalline rock containing quartz, orthoclase, andesine, albite, hornblende, and biotite as essential minerals, and apatite, sphene, pyrite, zircon, and epidote as accessories. The associated acidic dikes are variable in composition and texture. Many contain only a small amount of dark minerals and some consist almost entirely of quartz and albite.

Much of that part of the district underlain by sedimentary rocks is covered by mantle rock 1 to 10 feet deep consisting of angular fragments of hornfels with some soil. On slopes, this mantle may completely obscure thick dikes.

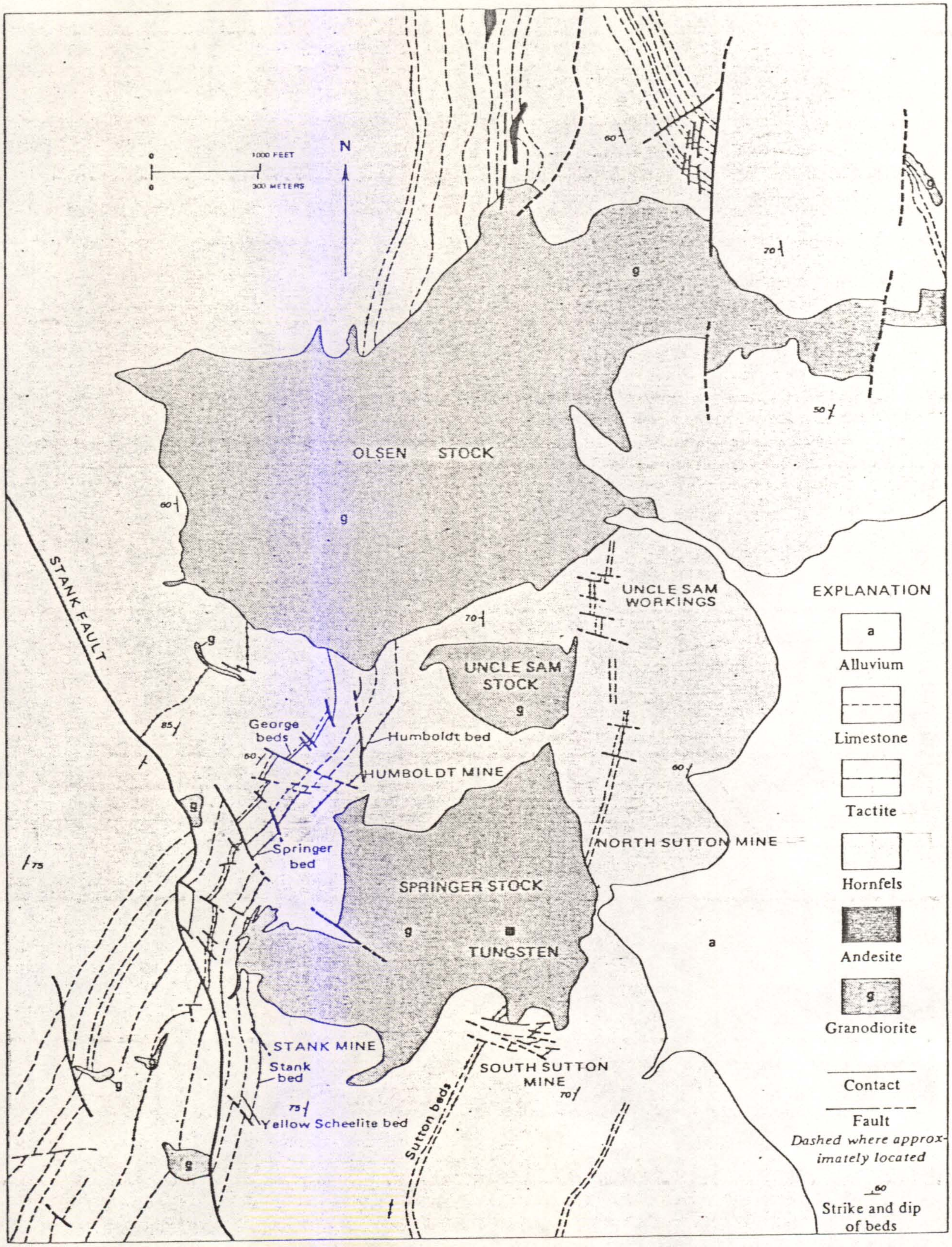

FIGURE 16. Geologic map of Tungsten and vicinity, Eugene Mountains.

The poor exposures, coupled with lack of distinctive stratigraphic markers, make the solution of fault problems difficult, for surface geologic information is at best generalized. The Triassic and Jurassic rocks strike N. 10°–30° E. and dip steeply. East of the Stank fault, the beds dip west, west of the fault, east. The beds west of the fault are right side up, as shown by minute crossbedding in sandy beds found beneath Codd Hill in the 400-level workings of the Stank mine. The beds east of the Stank fault are probably overturned, as indicated by crossbedding in the Sutton and Mill beds 2 miles south of Tungsten.

The Stank fault is the major structural feature. Originally postulated on change in dip of the beds, the fault was subsequently found underground in the south workings of the Stank mine. The fault strikes northwest, dips southwest, and appears to be a thrust with both pregranodiorite and postgranodiorite movement. Limestone beds on opposite sides of the fault are mineralized but cannot be correlated. Where exposed on the Stank 400 level, the fault dips 45°–55° W. and consists of two zones of gouge and breccia 12 and 6 feet thick separated by a 30-foot width of granodiorite and phyllite. The Stank bed is cut off by the fault, and a different sedimentary sequence is exposed in workings to the southwest. The Stank fault cuts through the Codd granodiorite dike at the surface and on the 400 level but offsets it only a few hundred feet. The major displacement apparently took place before intrusion of the granodiorite.

Many other pregranodiorite and postgranodiorite faults are exposed in the mines. The pregranodiorite faults are largely obliterated by later metamorphism; it is difficult to distinguish a faulted bed from a lenticular one. The only absolute proof of faulting is the discovery of the offset segment, as the fault surface itself is not recognizable, and the attitude of the fault is determinable only after three or more points on it are identified. These faults make wedge-shaped terminations to ore beds and are usually characterized by broad zones of silication and silicification. The offset segments beyond several of the sealed faults in the Humboldt, Springer, and Stank mines were discovered after considerable exploration. Several other offsets are not yet solved. The south end of the Humboldt bed, cut off below the eighth level, has not been found despite extensive exploration. Some geologists believe this cutoff was caused by lack of sedimentation; others believe it represents a pregranodiorite fault with greater displacement than that on other sealed faults.

Postgranodiorite faults are recognizable underground by gouge on the fault surface and by lack of mineralization. Offsets are generally small, ranging to 100 feet. Both transverse faults and strike faults are found. The strike faults in places cut the ore beds at angles acute to both strike and dip, making stoping by the usual shrinkage method difficult.

ORE DEPOSITS

The scheelite ore bodies occur in shoots that are largely coextensive with tactite. The ore shoots rake steeply south along dikes that cut the ore beds. The bodies that have been mined to depth appear to have greater vertical extent than lateral. The Humboldt ore body, the largest mined, was 1,500 feet long at its greatest extension, and by 1958 had been mined to a vertical depth of 1,637 feet (the 1,850-foot level on the incline). The average width was about 6 feet. The Springer ore body had a maximum length of 700 feet, an average width of 3 feet; by 1945, it had been mined to a depth of 1,000 feet. The Stank ore body, opened to the 1,300-foot level (about 1,200 feet vertical) with an average width of 4 feet and maximum length of 800 feet, contained sizable blocks of marble within the ore body. The North Sutton ore body, opened to the 850-foot level on a 67° incline, was explored for 3,600 feet along the strike, including dikes, on the 125-foot level, and ranged in width from 5 to 25 feet.

The average grade of all ore mined from the district from 1917 to 1944 was about 0.875 percent of WO_3, the grade of individual stopes, 0.4 to 10.0 percent. In general, ore from the Stank mine is richer than the average, that from the North Sutton, leaner. Ore from the North Sutton, the principal output since World War II, probably yielded less than 0.4 percent WO_3.

The tungsten-bearing tactite ores contain the following minerals, given in approximate order of abundance: quartz, garnet, epidote, calcite, pyrite, scheelite, actinolite, and at places molybdenite and pyrrhotite. The proportions of the various minerals differ widely from mine to mine and even within single ore shoots. Most of the ore is a medium- to coarse-grained aggregate of quartz, garnet, and epidote with scattered crystals of scheelite. Some of the best ore consists of scheelite crystals embedded in glassy quartz and fine-grained epidote. In the North Sutton mine, much of the scheelite occurs along joints in tactite. In general, the scheelite forms crystals 1 to 2 mm in diameter; some are a few centimeters. Most of the scheelite fluoresces blue white, but some of it locally in the Stank, Yellow Scheelite, and South Sutton beds fluoresces pale yellow.

Mineral Basin District

The Mineral Basin district is in south-central Pershing County, and, as generally defined, extends south into Churchill County. This district, one of the largest iron-producing areas in Nevada, includes mines in the Buena Vista Hills (T. 25 N., R. 34 E.), a north-trending spur of the Stillwater Range, and in the low-lying hills 2 miles northeast (T. 26 N., R. 34 E.) in Buena Vista Valley. The largest mines are the Segerstrom–Heizer, Thomas (fig. 17), Ford, and Nevada Iron Ore Co. (Hematite) mines in the Pershing County part of the district and the Buena Vista mine in the Churchill County part of the district. The mines are accessible from the Coal Canyon road, a paved access road from Colado to the mines.

Most of the mines are owned by Southern Pacific Co. and were leased to various operating companies throughout the years of development. The mines are currently held under lease by Standard Slag Co. The geology and ore deposits of the area have been studied by geologists, geophysicists, and engineers of the U. S. Geological Survey,

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