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TIN AND TUNGSTEN DEPOSITS AT SILVER HILL, SPOKANE COUNTY WASHINGTON

BY

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CONTENTS

ILLUSTRATIONS

TIN AND TUNGSTEN DEPOSITS AT SILVER HILL, SPOKANE COUNTY, WASHINGTON

By Lincoln R. Page

ABSTRACT

Tin and tungsten minerals occur in pegmatites and quartz veins at Silver Hill, in secs. 23 and 24, T. 24 N., R. 43 E., 11 miles southeast of Spokane, Wash.

Cassiterite, the only tin mineral present, is found in pre-Mesozoic sillimanite-andalusite pegmatite and feldspar-quartz pegmatite. Scheelite, rimmed with wolframite, occurs in quartz pegmatite and quartz veins, and in the schist adjoining them. These pegmatites and quartz veins cut sillimanite-biotite schist, graphite-andalusite schist, and quartzite. Small dikes and sills of Mesozoic (?) granitic rocks, including diorite, monzonite, granodiorite, and granite, accompanied by biotite-tourmaline pegmatites, aplites, and quartz veins, intrude both the schists and the early quartz veins and pegmatites. The pre-Mesozoic rocks were strongly folded, metamorphosed, and faulted before the intrusion of the granitic rocks. Basaltic lavas fill the Latah Valley to the west and reach the lower slopes of Silver Hill. They are in part covered by Pleistocene glacial debris, which extends to an elevation of about 2,550 feet.

No tin ore has been shipped from this area. The only tin ore body is from 1 to 6 feet thick and has been prospected for 40 feet along the strike and 60 feet down the dip. It is estimated to contain about 3 percent of metallic tin. Cassiterite is disseminated throughout the other pegmatites but mineralogic studies indicate that this rock contains less than 3 pounds of metallic tin per ton.

Eight small lenticular tungsten-bearing quartz veins have been prospected by the Bureau of Mines. In places these veins contain sufficient scheelite and wolframite to be of commercial grade.

INTRODUCTION

The tin and tungsten deposits of Silver Hill, Spokane County, Wash., are in secs. 23 and 24, T. 24 N., R. 43 E., on the east side of Latah Creek. (See fig. 16.) The mineralized area is owned by the Spokane Tin Co. Silver Hill may be reached by paved road from Spokane, 11 miles to the northwest, and an electrified branch of the Great Northern Railway crosses the property.

Cassiterite, the tin-bearing mineral, was first discovered and identified by Mr. Charles P. Robbins, now president of the Spokane Tin Co., and Mr. Richard Marsh [1] in the summer of 1906. The property was then being actively prospected for silver, and it was not until March 1907 that trenching and exploration of

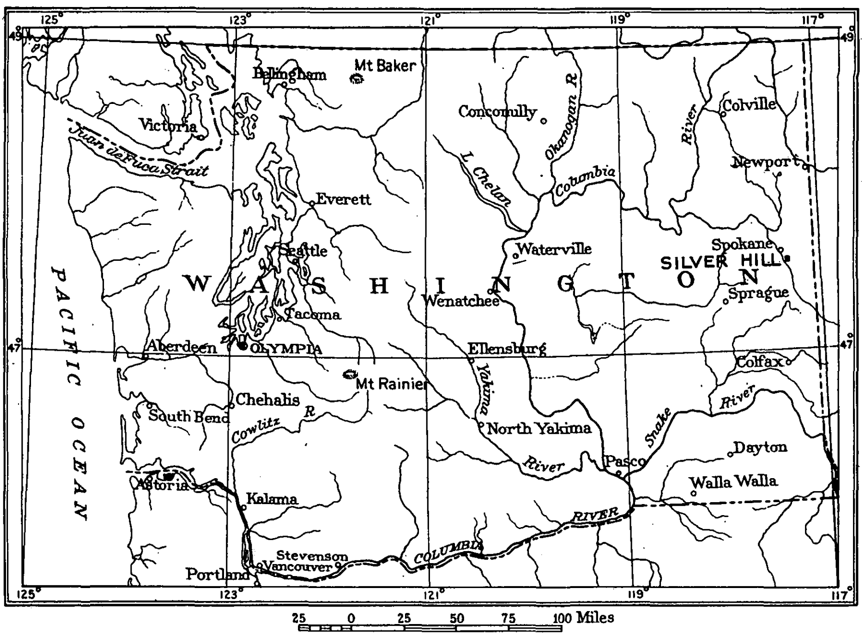

Figure 16.--Index map of Washington showing location of Silver Hill, Spokane County.

the tin-bearing pegmatites was started. Marsh soon discovered scheelite and wolframite also, in pegmatite, schists, and quartz veins, but these tungsten minerals were given little attention. The work done on the deposits was intermittent, and it ceased in 1912. About 150 tons of tin ore, estimated to contain 3 to 6 percent of metallic tin,[2] had then been mined and piled on the dump. No further work has been done since 1912 except that in

1/ Whitman, A. R., A tin deposit near Spokane: Min. and Sci. Press, vol. 94, p. 697, 1907; vol. 95, p. 49, 1907.

2/ Collier, A. J., Tin ore at Spokane, Washington: U. S. Geol. Survey Bull. 340, p. 304, 1907.

1938, under the direction of Mr. F. M. Handy, some trenches were cleaned out and outcrops sampled.

During July and August 1940, the writer, assisted by T. D. Lance, mapped the geology and topography of about half a square mile on the scale of 200 feet to an inch. Surface trenches, the main tin-bearing pegmatite zone, and underground workings were mapped on larger scales. The work was facilitated by Mr. Charles P. Robbins, who accompanied the writer in the field. In May and June 1941 the Bureau of Mines sampled the cassiterite pegmatites exposed in the old workings. The scheelite and wolframite veins were prospected by means of pits and trenches, and were sampled. In June 1941, the author examined these new prospects, and the descriptions of the tungsten veins are based largely upon information thus obtained. The writer is indebted to Mr. John W. Cole of the Bureau of Mines for cooperation during this examination. The writer is also indebted to several members of the Geological Survey: D. F. Hewett made available unpublished results of his field and laboratory investigations of 1938, and Miss Jewell Glass contributed mineral determinations. F. C. Calkins and H. G. Ferguson made many helpful suggestions during the preparation of this report.

GEOLOGY

The cassiterite-bearing pegmatites and scheelite-wolframite quartz veins of the district are pre-Mesozoic, and they cut schists and quartzites that were tentatively placed in the Archean by Collier.[3/] Mesozoic (?) granitic rocks, including diorite, monzonite, granodiorite, and granite,[4/] accompanied by pegmatites, aplites, and quartz veins, intrude the early quartz veins and pegmatites as well as the schists. Only small dikes

3/ Collier, A. J., op. cit., p. 298.
4/ Anderson, A. L., Genesis of the Silver Hill tin deposits: Jour. Geology, vol. 36, pp. 649-653, 1928.

and sills of these granitic rocks occur at Silver Hill. Basaltic lavas fill the Latah valley to the west and reach the lower slopes of Silver Hill. Pleistocene glacial sediments cover most of the basalt and extend up the slopes to an altitude of about 2,550 feet.

Before the intrusion of the granitic rocks, the pre-Mesozoic sediments were strongly folded and metamorphosed, and shear cleavage and granulation were produced in the earlier pegmatites and quartz veins. The granitic rocks produced contact metamorphism, which is distinguishable from the earlier, regional metamorphism.

A few small postmineral faults cut the quartz veins, pegmatites, and schists. One fault was found that offsets granite.

Metamorphic rocks

The metamorphic rocks are sillimanite-biotite schists interbedded with subordinate graphite-andalusite schists and quartzites. These rocks vary widely in color, texture, and mineral composition, partly because of initial differences of composition and partly because of additions of material from igneous sources.

Sillimanite-biotite schists.--Sillimanite-biotite schists crop out in the southern and eastern parts of the mapped area (pl. 32). In the contact zones of granitic intrusives, they are well-exposed on broadly rounded or spheroidally weathered surfaces. The less altered schist is much less resistant and weathers into platy fragments or a fine micaceous soil.

Fresh exposures of the schists are light to dark gray and usually show a definite schistose to gneissic structure. Layers of fine-grained, sugary-textured quartz, biotite, orthoclase, and oligoclase alternate with thin bands or lenses of sillimanite which probably represent original clayey beds. Andalusite, tourmaline, and muscovite occur in places. The proportions between the minerals not only differ greatly in adjacent bands but vary from place to place along the same band.

Graphite-andalusite schist and quartzite.--Graphite-andalusite schists interbedded with quartzite underlie the northwestern portion of the area. The schists are fine-grained and mostly dark gray to black; in some places they contain graphite enough to mark paper. They are more variable in composition than the sillimanite-biotite schists but less distinctly foliated, the beds being commonly several feet thick. The dominant minerals are quartz, graphite, andalusite, biotite, and muscovite. Tourmaline is abundant in some places. The andalusite forms radiating groups of metacrysts, some of them an inch or more in length, which are pinkish but clouded by numerous inclusions of graphite. Thin rims of muscovite flakes that stand perpendicular to the crystal surface surround the andalusite crystals. These metacrysts are limited to the bands that were originally rich in alumina. Aggregates of muscovite, graphite, and quartz, which apparently replace older metacrysts of andalusite or a similar mineral, are alined at an angle to the bands that contain the radial clusters of andalusite. Tourmaline crystals which occur in the same rock have a random orientation suggesting that they formed after the period of stress and at the same time as the metacrysts of andalusite.

The interbedded quartzites are dominantly massive, dark-gray to black, fine-grained rocks which grade into quartz or graphite schists. The dominant mineral, quartz, is accompanied by minor quantities of muscovite, biotite, feldspar, andalusite, sillimanite, and graphite. These rocks, with the accompanying graphite-andalusite schists, form the walls of the pegmatite dikes.

Small exposures of andalusite-tourmaline, hornblende-biotite, tourmaline-quartz, and biotite-feldspar schists were noted.

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Cassiterite-bearing pegmatites

Pegmatites are abundant in the area around Silver Hill, but the only ones in which cassiterite has thus far been found are the sillimanite-andalusite pegmatites and associated feldspar-quartz pegmatites of pre-Mesozoic age. The more abundant later biotite-tourmaline pegmatites of the surrounding region do not contain cassiterite. During the field work 26 outcrops of the pre-Mesozoic pegmatites were studied. Disseminated cassiterite was observed in about a fourth of these, but only one contained any appreciable concentration of this mineral.

The pre-Mesozoic pegmatites have had a very complex history, beginning with crystallization from a magma that had assimilated appreciable quantities of argillaceous wall rocks. The minerals formed at this time included muscovite, quartz, feldspar, cassiterite, and possibly andalusite. Regional metamorphism, prior to the intrusion of the granite, recrystallized and granulated the quartz and feldspar, converted muscovite to orthoclase and andalusite, and formed sillimanite from earlier aluminum minerals. Cassiterite, one of the earliest, and scheelite, one of the latest pegmatitic minerals to crystallize, were fractured and granulated. The contact metamorphism which resulted from the injection of the granite developed the andalusite metacrysts which cut preexisting andalusite and other aluminum silicates. At the same time biotite-tourmaline pegmatites cut across and merged with the tin-bearing varieties, causing a widespread introduction of tourmaline and other minerals.

The outcrops of pegmatite can be grouped in four zones trending roughly northwest and southeast and numbered in order from west to east (pl. 32). Those of zone 1 (see pl. 33) are characterized by sillimanite and andalusite; those in zones 2 and 3 are for the most part made up of feldspar and quartz, with only minor amounts of sillimanite and andalusite. Zone 4 is poorly represented, its best exposure being in the sillimanite-andalusite pegmatite cut by the vertical shaft. Two small exposures of similar rock lie east of the Scheelite adit. Cassiterite is most abundant in zone 1 and decreasingly abundant in zones 4, 3 and 2.

The size and shape of these pegmatite bodies is not well known; they are poorly exposed, they probably have been faulted, and they have been crisscrossed and offset by both diorite and granite dikes. Most of them dip from 10° to 65° westward, but a few dip eastward. The possibility that the pegmatites of the four zones originally constituted only four dikes has been considered, but it appears more likely that they were four groups of lenses that overlapped stepwise (en echelon) and tapered out both horizontally and vertically.

Three main types of pegmatite were recognized: (1) sillimanite-andalusite pegmatite; (2) feldspar-quartz pegmatite, and (3) massive quartz pegmatite which contains the tungsten minerals scheelite and wolframite but not cassiterite. On plate 33 distinctions are also made between cassiterite-rich and other varieties.

The pegmatites were originally coarse-grained, but deformation and metamorphism have partly transformed the grains to fine-grained aggregates, about as large as the original mineral grains, of feldspars, quartz, and aluminum minerals. Both the quartz and the feldspar aggregates have a sugary texture, and the larger quartz masses have shear-cleavage fractures one-eighth to one-sixteenth of an inch apart. Some patches consist of fine needles of sillimanite intergrown with irregular grains of other minerals and oriented parallel to what appear to be the cleavage planes of feldspar or muscovite. Large cassiterite grains, originally euhedral, are fractured and veined by later minerals. These textural features have been superimposed upon the original, very coarse pegmatitic texture and a gneissoid banding parallel to the contacts. Quartz masses, veinlike to irregular in shape and carrying tungsten minerals, cut across the bandings.

The textures are further complicated by the presence of irregular, medium coarse to very coarse grained, unsheared and unrecrystallized stringers and irregular masses of oligoclase, quartz, orthoclase, biotite, tourmaline, and coarse muscovite which in places merge with the pre-Mesozoic pegmatites. These are much younger than the sheared pegmatites and are probably related to the granites in origin.

Sillimanite-andalusite pegmatite.--Anderson [5] has described in detail the mineralogy of the pegmatites characterized by the presence of abundant sillimanite, andalusite, orthoclase, and by large subhedral to irregular cassiterite crystals which locally make up as much as 20 percent of the rock.

The mineralogy of these pegmatites is very unusual and complex. The dominant minerals are sillimanite and andalusite. Sillimanite surrounds small, irregular, pink grains of andalusite, which may be relicts of crystals formed from the pegmatitic magma, but most if not all of which were more probably products of regional metamorphism. Large euhedral andalusite crystals that cut across sillimanite and the other minerals were products of contact metamorphism due to the intrusion of the granite. Both sillimanite and andalusite have been partly altered to fine-grained muscovite. Cassiterite, as indicated in the table on page 192, is one of the few minerals present that were contained in the original pegmatites. It occurs as large subhedral crystals, which have been fractured and cut by veins of all the other minerals present. Quartz and orthoclase invariably accompany the cassiterite, sillimanite, and andalusite. Corundum, microcline, albite, apatite, magnetite, and graphite

5/ Anderson, A. L., op. cit., pp. 656-661.

occur sparingly in the pegmatites. Associated with these minerals are the Mesozoic (?) pegmatite minerals oligoclase, coarse muscovite, brown tourmaline, biotite, garnet (spessartite), orthoclase, and quartz, which in some places have the appearance of being an integral part of the early pegmatites. Stilbite veinlets cut the early pegmatite minerals.

Feldspar-quartz pegmatite.--Feldspar-quartz pegmatite containing a little sillimanite is prominent north of the main open pit (see pl. 33) and in the pegmatites of zones 2 and 3. Rock of this type occurs in the hanging wall of the pegmatite mass in zone 3. The sillimanite-andalusite variety forms a band in the center of this exposure. All the feldspar-quartz pegmatite has a sugary, granulated texture, superimposed in places on a gneissoid structure shown by the alinement of lenticular quartz patches, and in places it has a definite shear cleavage.

The mineral composition of this rock is simple. Orthoclase predominates and is accompanied by albite and quartz. Small quantities of andalusite give some portions a pink tinge. Sillimanite, muscovite, and closely associated tantalite-columbite, and cassiterite occur as widely scattered grains. Minerals of the late pegmatites are sparingly present.

Quartz pegmatite.--The veinlike to irregular masses of quartz which cut the layered sillimanite-andalusite pegmatite in the inclined shaft (fig. 17) are, where observed, entirely within the pegmatite. They are composed of granular quartz with small amounts of interstitial orthoclase, oligoclase, muscovite, and biotite. Scheelite, with irregular rims of wolframite, occurs in rectangular to irregular masses as much as 4 inches in diameter.

The micas are widely disseminated as flakes up to half an inch across, interstitial to rounded quartz grains. The feldspars are also interstitial to quartz and may have a uniform orientation over a square inch or more. The orthoclase is very

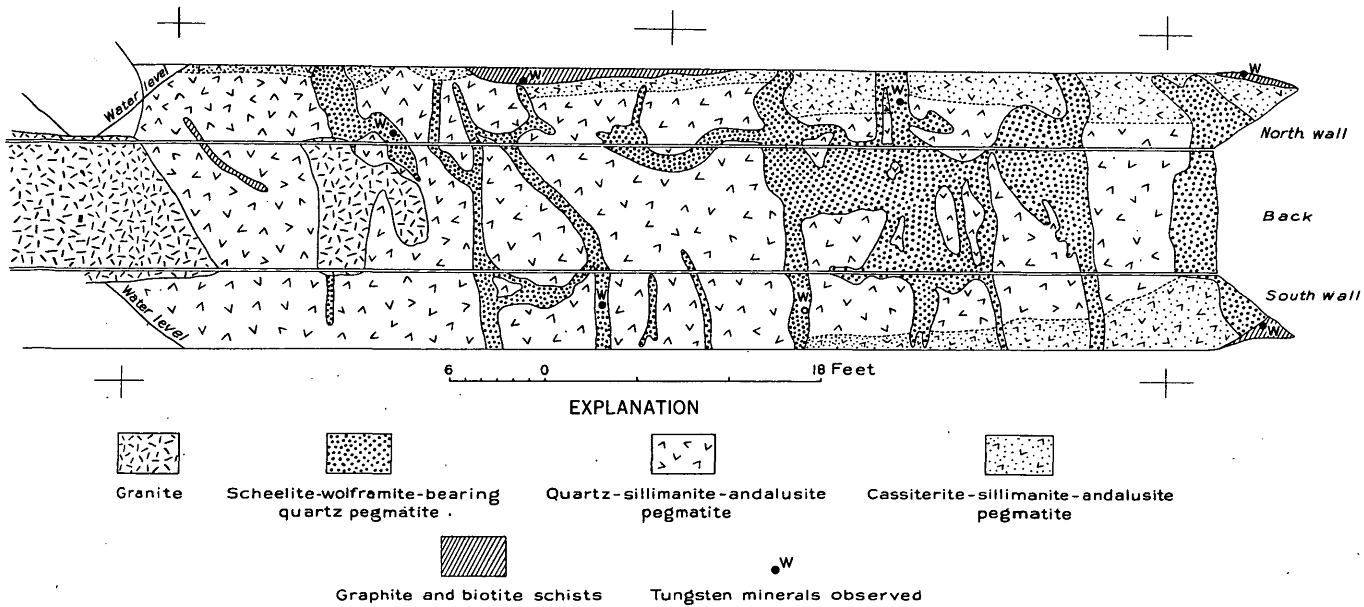


Figure 17.—Geologic map of the walls and back of the inclined shaft in the pegmatite of zone 1. The sections along the north and south walls are drawn so that they may be folded downward, at right angles to the map of the back, to form a three-dimensional picture. The correct inclination of the shaft is obtained if the "water level" is made horizontal.

dusty with alteration products, but the oligoclase, which is present in small amounts, is clear and unaltered. Tourmaline forms both interstitial grains and euhedral crystals that cut across quartz grains. The quartz pegmatite grades into veins in some of which quartz is the only gangue mineral present.

Quartz veins

Quartz veins containing scheelite and wolframite or galena are common in the area. The tungsten-bearing veins are best exposed in the Scheelite adit and near the top of the hill, where they have been exposed in trenches made by the Bureau of Mines. The veins are lenticular, and individual lenses range from a fraction of a foot to more than 10 feet in thickness. They are exposed from a few feet to more than 175 feet along the strike. All have a pronounced granulated texture and shear cleavage. Many show interstitial feldspar and scattered muscovite and biotite around coarsely granulated, well-rounded quartz grains. Scheelite and wolframite are more abundant in this granular aggregate than in the hard, glassy quartz which makes up the remainder of the vein material. In some places a little pyrite occurs with the tungsten minerals.

Most of the tungsten veins occur in schists, but small, irregular masses consisting of quartz, scheelite, and wolframite, or rarely of the tungsten minerals alone, are found isolated in the granite. These are considered to be inclusions of vein material, because both the quartz and the scheelite of the veins are cut in many places by dikes of granite a few inches thick. Such dikes are common along the walls of the veins, especially near the granular portions that contain the richest scheelite ore. Apparently the granite did not introduce the scheelite but emanations from it altered some scheelite to wolframite.

Galena, reported to contain a little silver, was found in a few small quartz veins, grains up to half an inch in diameter being widely scattered in hard, glassy quartz. If any other sulfides were present in the veins originally they have been completely oxidized. Feldspar is less abundant here than in the tungsten veins. No tungsten minerals have been observed in association with galena.

Postmineral intrusive rocks

Diorite.--Deeply weathered diorite dikes cut the tin-bearing pegmatites (pl. 33) and schists. Collier 6/ refers to this rock as kersantite. It is a fine- to medium-grained, dark-gray to purplish rock, composed of hornblende, oligoclase-andesine, and biotite with accessory orthoclase, quartz, magnetite, rutile (?), zircon and apatite.

The diorite is definitely older than the granites but younger than the sillimanite-andalusite pegmatites. Anderson 7/ mentions the presence of lamprophyre dikes, "older than the tin-bearing pegmatites," and refers to Collier's tentative identification of them as kersantite. Dikes of biotite-tourmaline pegmatite cut diorite, and presumably this is the pegmatite said by Anderson to cut the lamprophyre.

Granite.--The rocks mapped as granite (see pl. 32) include not only true granite but also a little monzonite and quartz monzonite, which have been described by Anderson 8/ but will not be further described here.

The granite, where exposed in the railroad cut, is weathered to a depth of more than 40 feet. Fresh surfaces are rare and the exposed rock is usually crumbly and iron-stained.

The fresh granite is pink to gray, medium- to coarse-grained, and in part subporphyritic or gneissoid. It is composed essentially of orthoclase, microcline, oligoclase, quartz, and biotite. An accessory constituent is a brown tourmaline resembling

6/ Collier, A. J., op. cit., p. 300.
7/ Anderson, A. L., op. cit., p. 652.
8/ Idem, pp. 649-652.

that in the Mesozoic (?) pegmatites and the tourmaline-bearing schists.

Biotite-tourmaline pegmatites.--Dikes or irregular segregations of biotite-tourmaline pegmatite, rarely more than 2 feet across, are associated with the granite. Small dikes were observed which graded from granite on the walls to pegmatite in the center. Aplites and thin, unsheared quartz veins also cut the granite.

These Mesozoic (?) pegmatites are typically coarse-grained and not recrystallized or granulated. The larger dikes contain many cavities lined or filled with crystals of quartz, tourmaline, feldspar, and muscovite. Where the cavities have been completely filled, the quartz and tourmaline are graphically intergrown.

The dominant minerals plagioclase, orthoclase, and quartz are accompanied by biotite, tourmaline, garnet, and coarse muscovite. These minerals have been added to the tin-bearing pegmatites near Mesozoic (?) igneous rocks.

Structure

Although the structure of the area cannot, because of poor exposures, be determined in detail, attitudes of the bedding in the schists and quartzites indicate that these rocks have been highly folded. In general, the bedding strikes N. 35° E. and dips 35°-50° NW., but numerous small folds, faults, and granitic intrusions have caused many local variations. The schistosity, for the most part, is about parallel to the bedding in strike, but it dips more steeply to the west. The shear cleavage in the quartz pegmatite and the quartz veins usually strikes nearly north and dips from 50° W. to 80° E.

The area has been subjected to three periods of faulting, one that preceded introduction of vein material, one postmineral but pregranite in age, and another that followed the intrusion of the granitic rocks. The quartz veins that fill fractures formed during the premineral faulting may be separated, on the basis of their strike and dip, into the following groups: (1) Strike N. 10°-40° E., dip 55°-90° NW.; (2) strike N. 45°-50° E., dip 40°-45° NW.; and (3) strike N. 70°-80° E., dip 90°. Less prominent veins have other trends. The postmineral faults may be divided into similar groups, namely: (1) Strike N. 10°-30° E., dip 30°-45° NW.; (2) N. 60°-75° E., dip 30°-60° NW.; and (3) strike N. 40°-65° W., dip 35°-45° SW. One fault that strikes due east and dips 80° S. cuts granite and biotite-tourmaline pegmatite. Displacements on the faults appear to be only a few feet.

The tin-bearing pegmatites form sill-like, lenticular bodies, arranged stepwise in the schists. Their granulated and sheared appearance strongly suggest that they were injected prior to the folding. They strike N. 20°-55° W. and dip 10°-65° SW., although a few eastward dips have been recorded. These are cut by some of the postmineral faults, but their stepwise arrangement is probably due to their initial emplacement as overlapping lenses.

The granite bodies, although very irregular, have three dominant trends. The largest granite mass and some of the smaller ones strike N. 5°-20° E. and dip about 60° NW.; others strike N. 10°-20° W. and N. 80° E. and dip steeply to the west and north respectively. The dikes and sills of granite show in places a gneissoid banding parallel to the walls.

ORE BODIES

The Silver Hill tin deposits are confined to sillimanite-andalusite pegmatite and feldspar-quartz pegmatite of pre-Mesozoic age. Cassiterite is disseminated in both types of pegmatite, but the only ore shoot is in sillimanite-andalusite pegmatite.

The tungsten minerals scheelite and wolframite are found in the quartz pegmatite and quartz veins. Eight veins are exposed in the pits and trenches recently opened by the Bureau of Mines.

Mineralogy

Tin-bearing pegmatites.--Cassiterite, SnO_2, is the only tin mineral that occurs in the district. The crystals are black to dark brown in color, but the powdered mineral is light brown. The grains average over half an inch in length and some of them are as much as 4 inches long. They are subhedral to very irregular in outline, and most of them are shattered and veined. The grain boundaries are very ragged and show replacement by all the gangue minerals. (See table on p. 192.) Rarely, replacement is so nearly complete that scattered magnetite and cassiterite specks enclosed in silicates are all that mark the position of the original grain.

The gangue minerals that accompany the cassiterite include sillimanite, andalusite, orthoclase, and quartz, with subordinate plagioclase, microcline, muscovite, tourmaline, garnet, and biotite.

Tungsten-bearing pegmatites and quartz veins.--Scheelite, $CaWO_4$, is the most abundant tungsten mineral in the quartz pegmatite and veins. It occurs as yellow to brownish-gray, medium- to coarsely granulated crystals and masses of irregular shape, which average more than an inch in diameter, though masses more than 12 inches across were observed. These grains and masses have an irregular distribution in both the quartz pegmatite and the quartz veins. In the schists they occur apparently on the trend of veinlike masses of quartz within the pegmatite bodies and parallel to the walls of veins.

Most of the scheelite is partly or completely enclosed by a rim of the black, iron-manganese tungstate, wolframite. This mineral occurs sparingly along fractures and quartz veinlets

Mineral paragenesis at Silver Hill, Wash.[1/]

Mineral	Early pegmatite		Quartz veins	Late pegmatite
	Tin-bearing	Tungsten-bearing		
Cassiterite	O	....	......	....
Andalusite	X	....	......	....
Sillimanite	M	....	......	....
Corundum	X	....	......	....
Quartz	X	O	O	O
Orthoclase	X	X	X	O
Microcline	X	X	X	O
Oligoclase	I	I	I	O
Albite	X	....	......	O
Muscovite	X	X	X	O
Biotite	I	X	X	O
Tourmaline	I	I	I	O
Apatite	X	....	......	....
Titanite	X	....	......	....
Magnetite	M	....	......	....
Garnet	X	....	......	O
Graphite	O	....	......	....
Stilbite	I	....	......	....
Scheelite	....	O	O	....
Wolframite	....	I	I	....
Galena	....	....	O	....

1/ Original minerals designated by O; possibly original or formed by recrystallization, X; definitely formed by recrystallization, M; and introduced, I.

that cut the scheelite, and there it is intimately mixed with biotite, muscovite, and quartz.

A specimen of wolframite from the Scheelite adit was analysed in the chemical laboratories of the Geological Survey by Mr. W. T. Schaller. The gangue-free material contained 76.38 percent of WO_3, 20.74 percent of FeO (total iron reported as FeO), 1.72 percent of MnO, 0.47 percent of CaO, and 0.85 percent of MgO.

No tungsten minerals were noted in other types of pegmatite except within 2 or 3 inches of their contact with quartz pegmatite. Both scheelite and wolframite occur in the schists, where they are accompanied by tourmaline, aluminum silicates, feldspar, quartz, and micas. The grains are more irregular and appear more strongly intergrown in the schists than in the veins.

Origin

The cassiterite and scheelite are closely related in origin. Both were undoubtedly derived from the same igneous mass, for cassiterite pegmatite and scheelite-quartz pegmatite form parts of the same body. Gradation of pegmatite into quartz veins along the strike or dip was not observed, but the similarity in mineral composition and texture between the quartz pegmatite and some of the quartz veins suggests that such gradation may occur.

Cassiterite is the oldest mineral in the pegmatite and probably is one of the original constituents of the rock. The minerals originally associated with it, supposedly feldspar, quartz, muscovite, and perhaps even corundum and andalusite, have been so thoroughly granulated and recrystallized that all evidence of their age relations has been destroyed. If andalusite and corundum were original minerals, they probably developed as the result of assimilation of adjacent, aluminum-rich wall rock. The presence of a little graphite in the pegmatite also suggests assimilation. It is difficult, however, to imagine that all of the aluminum minerals could have originated by such a process. It seems more probable that an excess of alumina became available when the muscovite that crystallized from pegmatite magma was converted by metamorphism to orthoclase, though it is possible that some alumina was added from outside sources, or that removal of K_2O, Na_2O, or CaO from original feldspars by solutions produced an excess of aluminum silicates.

Whatever its origin, the rock has the character of a pegmatite. The cassiterite is concentrated on the footwalls and hanging walls. The extent of the ore bodies vertically or horizontally will be unpredictable as in other pegmatite deposits.

The tungsten-bearing quartz pegmatite was the last facies of the pegmatite to form, for it cuts across earlier facies as irregular dikelets extending outward from irregular quartz masses in the centers of the pegmatite bodies. All of these dikelets, so far as observed, terminate close to the schist walls, but tungsten minerals are found near them in the schists. Some of these quartz dikelets may extend beyond the limits of the pegmatite as veins, but none was observed to do so.

The mineralogy and texture of the tungsten-bearing quartz veins indicate that they are closely related to the pegmatites in origin and age. The veins, however, occur at some distance from the pegmatites and along different trends, and it is probable that they were deposited by ore-forming solutions escaping directly from the parent magma rather than from the crystallizing pegmatite. The lead-silver quartz veins are probably related to the same igneous source.

Size and grade of ore bodies

Because of the complicated geologic relations of the potential ore bodies and the absence of assays, any estimates of possible tonnage and grade can at best be only rough approximations.

Pegmatites of zone 1.--A pegmatite body in zone 1 (see pl. 33) contains the richest ore shoot of cassiterite; the pegmatites of this zone also contain the largest tonnage of sillimanite and andalusite and the largest amount of tungsten-bearing quartz pegmatite.

Pegmatite crops out in this zone over a distance of 425 feet, between 2,685 and 2,755 feet in altitude. Possible outcrops at 2,630 feet, south of the main open pit, may extend the length by 200 feet. The outcrops are not continuous, and it is likely that they represent at least four lenticular bodies arranged stepwise (en echelon), for while the general trend of the zone is about N. 25° W. the individual bodies appear to strike N. 35°-45° W. Most of them dip 35°-55° SW. The footwall of one thin lens in the northernmost exposure shows a dip of 25° SW., but its hanging wall shows gentle dips both east and west. In the second trench north of the shaft, the exposed part of the contact dips east.

These deposits are explored by one large open pit, 100 by 30 by 10 feet, from which a shaft (fig. 17) inclined at 37° to the southwest was driven on the footwall of the pegmatite. This shaft was originally about 125 feet deep but has been filled to the 75-foot level, (fig. 18), where a drift extends northward 165 feet. Fifty-five feet north of the shaft, a 15-foot winze from the drift level passed out of the cassiterite pegmatite into schist. At 45 feet, on the drift, north of the shaft, a 35-foot crosscut and drift were made in the footwall. The surface outcrops were explored by several trenches.

The main ore shoot, exposed in the open pit and the inclined shaft, is from 1 to 6 feet thick, roughly wedge-shaped, and thickest near the upper edge. It is exposed for 40 feet along the strike in the open pit and for approximately 60 feet above the drift, and it extends about 10 feet below the drift level. A channel sample 2½ feet long was taken across the ore body 24 feet below the collar of the shaft and is believed to indicate the approximate grade of the ore. This sample, analyzed in the chemical laboratories of the Geological Survey by R. C. Wells, contained 3.6 percent metallic tin. Quantitative mineralogical studies indicate that pegmatite beyond the limits of the ore shoot contains on the order of 2 pounds of tin to the ton.

The gangue of the high-grade cassiterite ore is more than 50 percent sillimanite and andalusite, and perhaps 10 percent tungsten-bearing quartz pegmatite. The pegmatite beyond the limits of the ore shoot contains about 20 percent of sillimanite and andalusite.

Pegmatites of zone 2.--The feldspar-quartz pegmatites of zone 2 are explored by a 15-foot shaft, now caved, and by cross trenches and pits. Outcrops occur over a distance of 400 feet

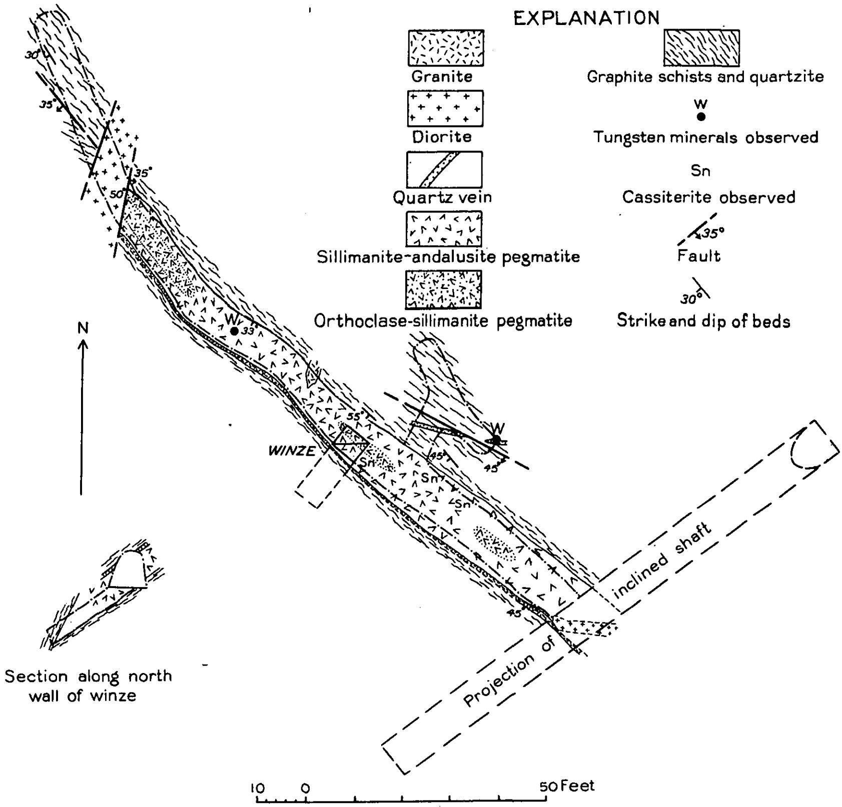
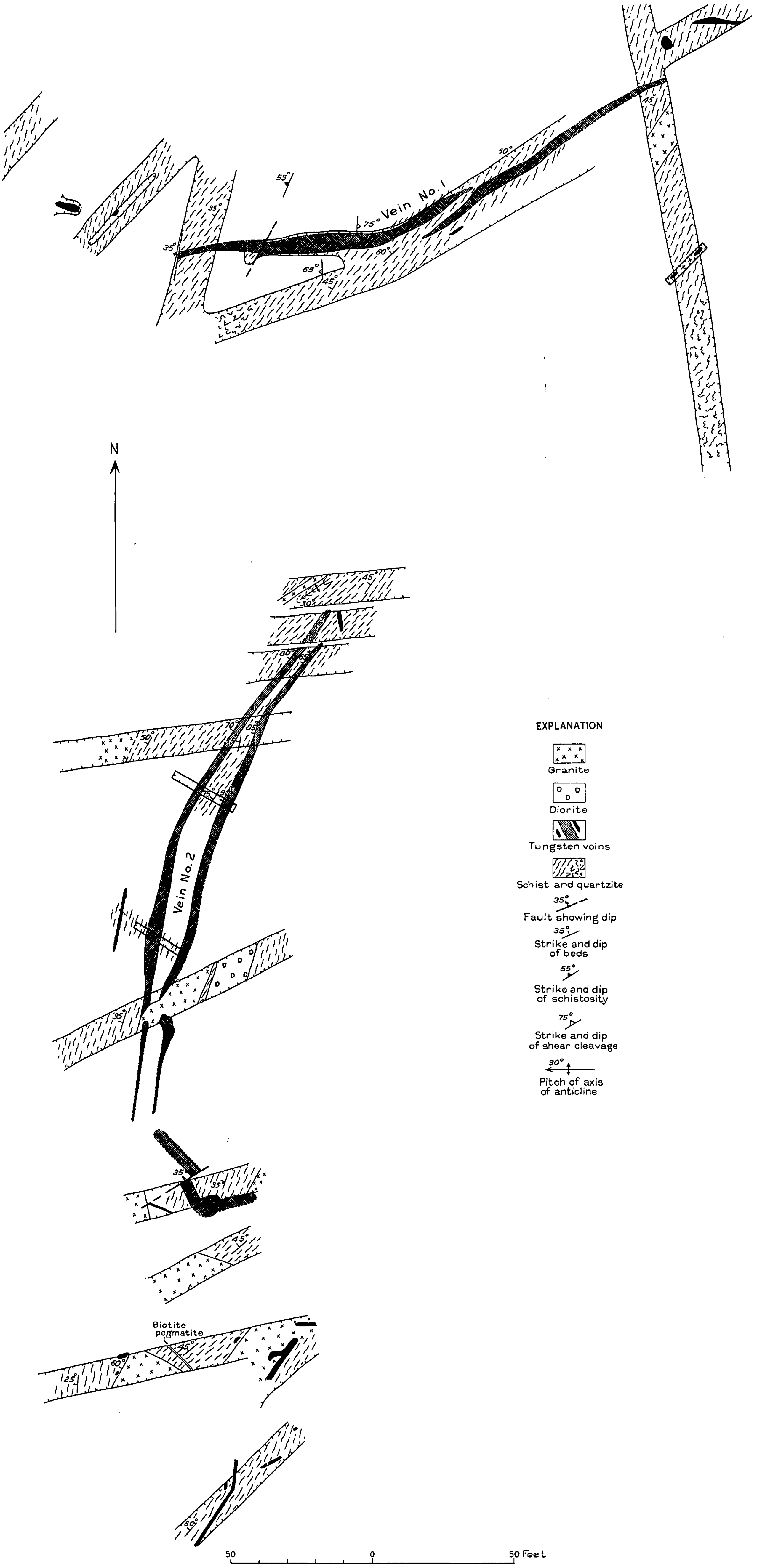


Figure 18.--Geologic map of the tin-bearing pegmatite of zone 1 on the 75-foot level.

between altitudes of 2,700 and 2,760 feet. Exposures south of the shaft appear to be part of one pegmatite body 200 feet in length and as much as 40 feet in width. Cassiterite is sparingly disseminated in this body, which is estimated to contain about a pound of tin to the ton.

Tantalum-columbium minerals have been reported from the shaft but were not observed by the writer. Andalusite and sillimanite are limited to narrow zones on the walls and are not abundant enough to be of economic value.

Pegmatites of zone 3.--The feldspar-quartz and sillimanite-andalusite pegmatites of zone 3 are exposed in 10 shallow pits.



GEOLOGIC MAP OF VEINS NOS. 1 AND 2

Outcrops occur in a zone 560 feet long and 120 feet wide between the 2,700- and 2,820-foot contours. The observed pegmatites have various dips, and there are probably several dikes in this zone. The largest outcrop is 40 by 100 feet, and here the hanging wall strikes N. 10° W. and dips 65° SW. A hundred feet to the north the observed contact strikes N. 80° E. and dips 47° NW. A contact, perhaps along a fault, at the southernmost pit strikes N. 65° W. and dips 40° NE. The author estimates that the pegmatites of zone 3 may contain about a pound of tin to the ton and some minable sillimanite and andalusite. No tungsten was observed in this zone.

Pegmatites of zone 4, vertical shaft area.--Five outcrops of pegmatite occur in zone 4. Two have been trenched, and a 6- by 8-foot vertical shaft was sunk in the largest to a depth of 25 feet. The shaft started at the hanging wall and was bottomed in sillimanite-andalusite pegmatite. The lowest outcrop, at an altitude of 2,600 feet, is 850 feet from the highest, at 2,820 feet. Scattered cassiterite was observed in all exposures. Boulders carrying as much as 15 to 20 percent of cassiterite were observed in the gulch to the east and were perhaps derived from this zone, but their source was not found.

The pegmatite at the shaft will probably average 30 percent or more of sillimanite and andalusite. No tungsten minerals were seen there. A few small outcrops of sillimanite-andalusite pegmatite, present as small blocks enclosed in and cut by granite, were observed east of the gulch but no tin minerals were seen.

Tungsten veins.--The largest tungsten veins have been designated on the map (see pl. 32) by numbers, which are referred to in the text. Because of obvious relationships two or more quartz lenses have, in some cases, been grouped as one vein.

Vein No. 1 (see pl. 34) is exposed for 185 feet at altitudes of 2,860 to 2,885 feet. It is made up of two overlapping lenses, each 100 feet in length, which contain patches of scheelite a few inches in diameter, scattered throughout hard, glassy or granular vein quartz. Thin rims of wolframite surround the scheelite. The eastern lens strikes N. 58° E. and averages about 30 inches in thickness. The western lens strikes N. 86° E. and averages about 4 feet, although in places it is 6 feet thick. Both lenses are essentially vertical and crosscut the enclosing schists and quartzites. The depth to which these lenticular bodies will be found is problematical but it appears likely that they will extend 30 to 50 feet below the center of the present outcrop. Two postmineral faults cut the vein.

Vein No. 2 (see pl. 34) is 200 feet south of No. 1 and at altitudes of from 2,840 to 2,860 feet. It consists of two roughly parallel quartz veins, which probably merge at depth but are separated at the surface by 3 to 10 feet of schist and quartzite. These veins are exposed continuously for 175 feet but are cut by granite near their southern end. South of this point the veins narrow and eventually pinch out. The strike and dip of the veins is not uniform throughout their length. The strike ranges from N. 10° E. to N. 35° E. and the dip from 65° NW. to 90°. The average thickness is 30 inches but the western vein attains a thickness of 6 feet in one place. Scheelite and a little wolframite occur in patches scattered throughout hard, glassy, milky-white quartz with which some feldspar is associated.

Vein No. 3 is exposed in the Scheelite adit. The drift (see fig. 19) follows a quartz vein 6 to 60 inches thick that contains appreciable quantities of scheelite and wolframite. At the portal two other small veins, truncated by granite, carry some scheelite and wolframite, which also occur in the nearby schist mixed with more or less granite. The main vein is exposed in surface trenches for 70 feet horizontally and 25 feet vertically. It apparently pinches out at the southwestern end of the exposure but its northeastern end is not known. The vein has an average strike of N. 15° E. and dip of 35° NW. It is very irregular in thickness and the small faults and dikes of granite which cut the vein accentuate its irregular shape. Scheelite occurs mainly in patches up to 8 inches across, sur-

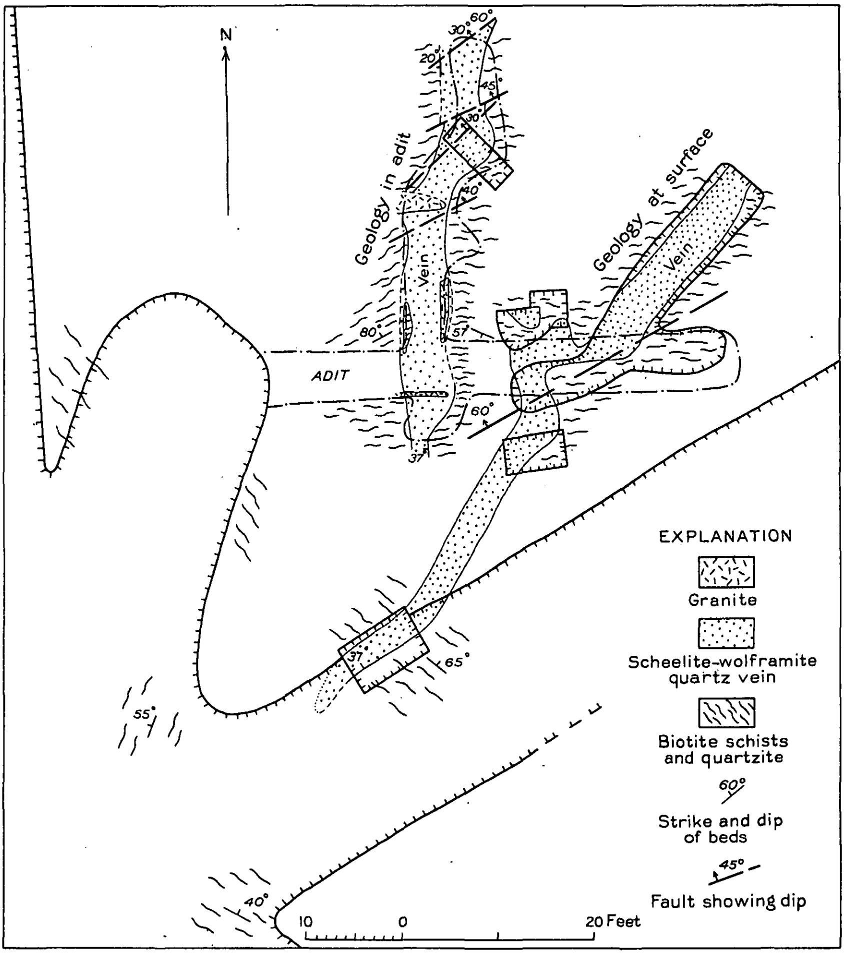


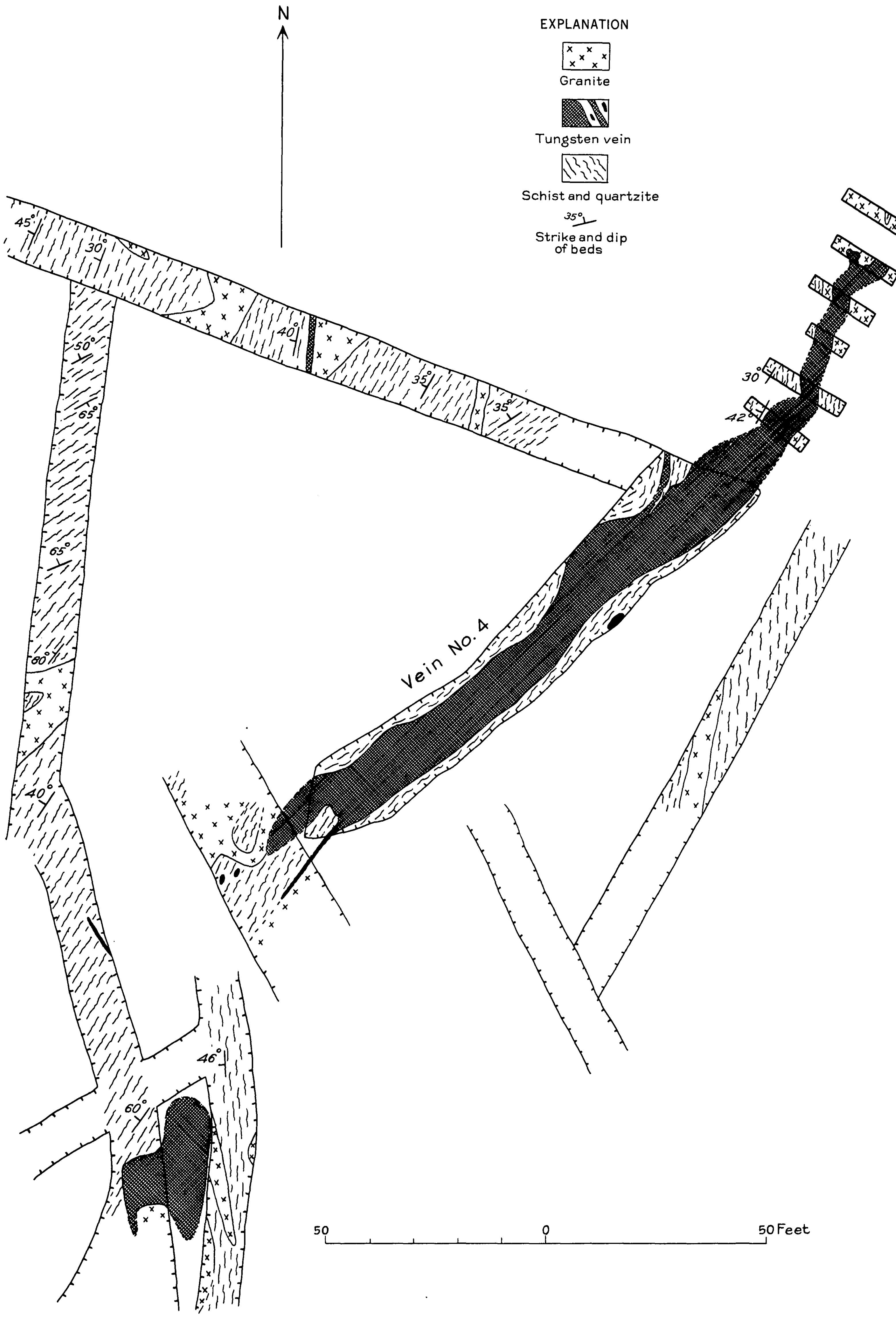
Figure 19.—Geologic map of vein No. 3.

rounded by rims of wolframite; both are accompanied by pyrite. Scheelite is less abundant, however, than wolframite near the granite, and even scarcer in inclusions of vein material in the granite.

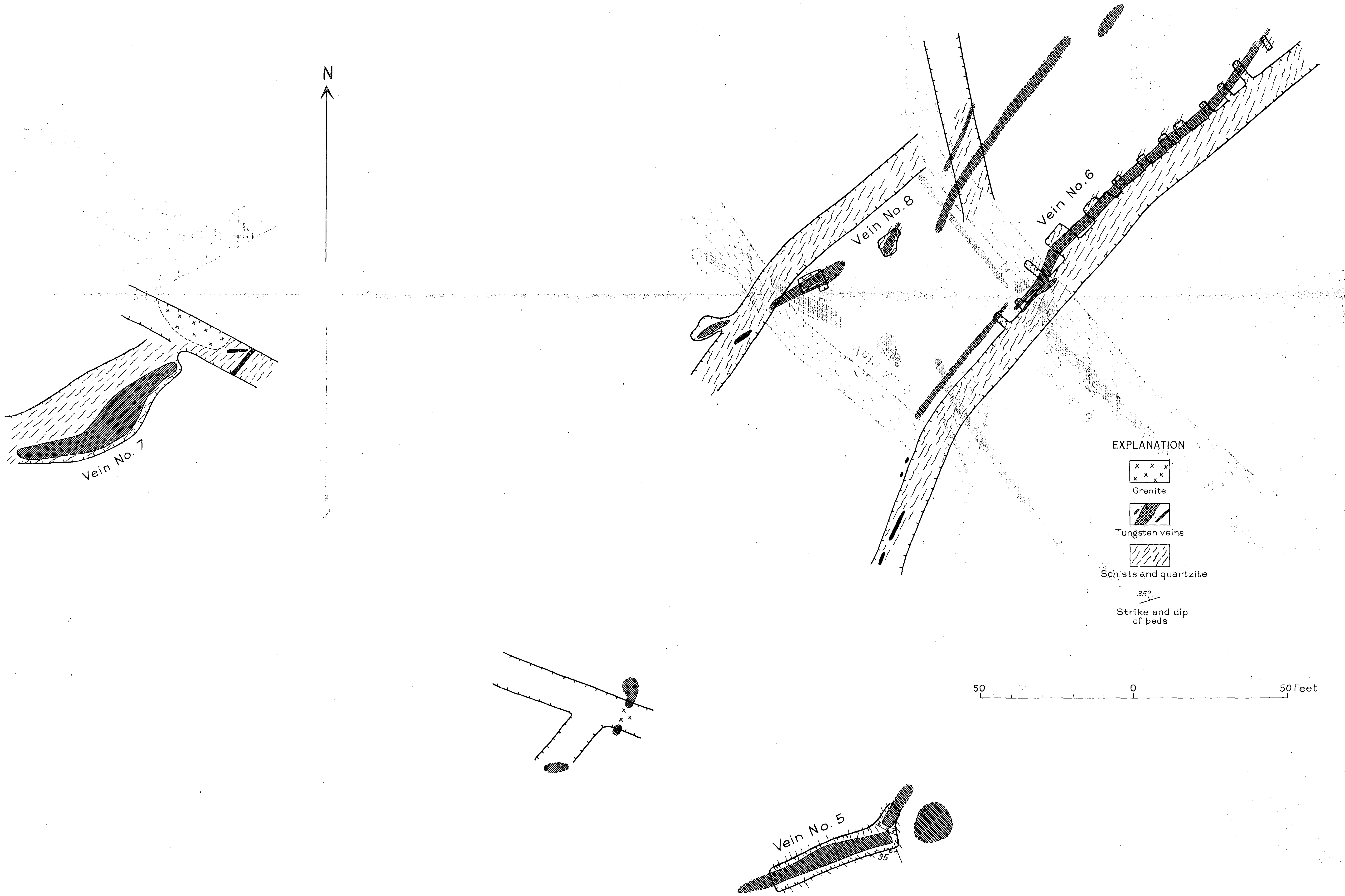
The largest vein in the area, vein No. 4 (see pl. 35), is 450 feet northeast of the Scheelite adit. It is 190 feet long, has a maximum width of 15 feet, and averages 10 feet in thickness for more than 125 feet along the strike. The vein pinches out abruptly at the southwest end and is truncated by granite on the northeast. The strike, N. 40° E., and the dip, approximately 40° NW., are parallel to that of the schists. The abrupt pinching of the vein at the western end suggests that it may terminate abruptly at depth. It is also possible that the lens may pitch to the southwest or northeast rather than directly down the dip. In any case it is doubtful whether the vein will extend downward much more than 50 feet. Large masses of high-grade ore are scattered throughout the vein. One such mass, on the footwall, is 10 feet long and 2 feet wide. Scheelite patches a few inches in diameter are found throughout the length of the vein, which consists for the most part of granular quartz with interstitial feldspar and micas, although in places the quartz is hard and glassy. Small granite dikes cut both the quartz and the scheelite, and in places they are so abundant that the vein has the appearance of a breccia.

Vein No. 5 (see pl. 36) lies east of the section line near the north end of Silver Hill. It trends N. 70° E. for 60 feet but its eastern end trends N. 30° E. for 15 feet. It averages 4 feet in thickness and is vertical. Additional work might show further extensions of this vein, but it is probable that these will be limited to rather small isolated lenses. Although scheelite was observed in this vein it is questionable whether it is present in commercial quantities.

Vein No. 6 (see pl. 36) has been exposed by pits and trenches for 165 feet horizontally and 25 feet vertically. The vein consists of two main lenses, which had not been completely exposed at the time of the writer's visit. They strike N. 30°-45° E. and dip from 70° to 90° NW. The larger one is from 3 to 4 feet thick and the smaller averages 2 feet in thickness. Large patches of scheelite and wolframite are scattered through-



GEOLOGIC MAP OF VEIN NO. 4



GEOLOGIC MAP OF VEINS NOS. 5, 6, 7, AND 8

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out the granular to glassy quartz. It is possible that this vein may extend 50 to 75 feet down dip before pinching out. The observed tungsten content and its possibilities for extension in depth indicate that it is one of the more promising veins of the area.

West of vein No. 6, on the northwest slope of the hill, vein No. 7 (see pl. 36) is exposed for 60 feet. This vein is 3 feet thick but appears wider on the map because it has been exposed along the dip. Examination in ultraviolet light indicates that it is of higher grade than the other veins discussed and the scheelite is finer grained and more evenly distributed in the quartz.

Vein No. 8 (see pl. 36), 50 feet north of vein No. 6, includes a number of discontinuous lenses, and at the time of the writer's visit was incompletely exposed. These lenses average about 30 inches in width and have a total length of about 125 feet. The longest individual lens may be 70-75 feet long. High-grade scheelite occurs in masses up to 1 foot in diameter. Surface exploration indicates that these lenses thin rapidly in depth and will probably not extend more than 20 to 30 feet below the present exposures.

A large number of smaller veins outcrop or have been uncovered in trenching operations by the Bureau of Mines. Many of these, especially in the eastern half of the area, contain large patches of scheelite and wolframite but the individual quartz lenses are of very small size. Few are more than 10 feet long and in many cases they were completely removed during the trenching operations, and additional ones were exposed. Some high-grade tungsten ore could be obtained from these scattered lenses, but the total amount would be small.

RESERVES

One body of pegmatite contains an ore shoot 100 feet long, 20 feet wide, and 2 to 3 feet thick that is estimated to contain approximately 3 percent of metallic tin; and cassiterite is disseminated in other pegmatites.

Placer tin might be recovered from the slopes of Silver Hill, especially from the gulch on the southern side, but appreciable quantities are not likely to be found. Production from placer deposits in the stream valley to the south is not to be expected, since cassiterite concentrated there in pre-Tertiary time has been covered either by basaltic lavas or Pleistocene glacial debris.

The sillimanite and andalusite of the tin-bearing pegmatites may be of economic value. These minerals, where present, usually make up 20 to 50 percent of the rock. Recent metallurgical developments may make it possible to mine and mill much of the pegmatite in zones 1 and 4 for these minerals and to recover the tin and tungsten minerals as byproducts. The low iron content of these pegmatites would help make them desirable ores of aluminum silicate.

Surface trenching by the Bureau of Mines has exposed 8 veins, which the author estimates contain approximately 0.5 percent of WO_3. This estimate, based on the examination of exposures with an ultraviolet lamp, is believed to approximate the average of all the veins but small portions of individual ones are of much higher grade. However, any estimate of the grade of these ore bodies is subject to rather large errors because the tungsten minerals are irregularly distributed throughout the vein in grains and masses of widely different size. The reserves of ore are small and estimates of tonnages contained in these lenticular ore bodies would be subject to large errors. It is probable that the veins do not maintain their present dimensions more than a few feet below the surface and it appears quite possible that none will extend much more than 50 feet.

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