The Geology of the Paradox No. 3 Mine Area

Thesis by

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ABSTRACT

The Paradox No. 3 mine, Atolia, California, was mapped and thin sections of the vein minerals and wall rock were examined.

Veins containing quartz, scheelite and carbonate occur along faults and fractures in Atolia quartz monzonite (Upper Jurassic ?), which is an orthoclase-biotite tonalite in the mine area. The mineralization occurs along three principle veins, named for convenience the main vein, north vein and west vein. Both the main and north veins occupy steeply dipping, northwest trending faults and fractures which dip 50 to 60 degrees southward from the surface and upper levels, but the main vein changes dip to the north near the 100 level, and the north vein changes dip to the north near the 200 level. Upward branching and changes in dip of the veins are common and are believed to be the result of nearly equal pressures on the different fracture surfaces at the time of mineralization. The west vein occupies a west to northwest trending thrust fault, which dips northward at 30 to 45 degrees, and an east trending strike-slip fault. The forces causing the faulting and fracturing are believed to be local vertical forces followed by regional compression oriented north to northeast. Localization of ore seems to occur at the junction of the thrust and strike-slip faults and at and above changes in dip of the north and main veins.

The vein matter consists of coarse grained scheelite, quartz, and calcite, deposited in that order as open space filling in the fractures. Crustification, comb textures and small filled cavities are common. Wall rock alteration in the quartz monzonite resulted in pervasive alteration of biotite to chlorite, and feldspar to white mica, carbonate and clays. Adjacent to the veins the wall rock consists of illite, calcite, quartz and minor clays, chlorite, pyrite and locally albite.

The deformation and mineralization are believed to have occurred during Miocene times at shallow depths. The ore forming fluids were probably not carbonated aqueous solutions carrying minor quantities of sulphur and tungsten and possibly silica and potash.

Suggested sites for exploration for ore are on the north vein at the 100 and 150 levels and the main vein at the east end of the 100 level.

TABLE OF CONTENTS

TABLE OF CONTENTS (con'd)

LIST OF FIGURES AND PLATES

GEOLOGY OF THE PARADOX NO. 3 MINE AREA

INTRODUCTION

The structure and mineralogy of the Paradox No. 3 tungsten mine, Atolia, California, were studied and described and certain conclusions were drawn concerning the origin and possible extensions of the deposit.

Location

The Atolia Mining district is situated at the northern edge of the Mojave desert near the line between the Kern and San Bernardino counties. (fig. 1). Hard surfaced highways (U.S. 6 and U.S. 395) connect the district with Los Angeles, 150 miles by road to the southwest.

The Paradox No. 3 mine is located in the eastern part of the Atolia mining district, 1800 feet south of the Surcease Mining Co. office (fig. 2). A dirt road connects the mine with U.S. highway 395, which passes 400 feet to the west.

PURPOSE AND METHODS OF STUDY

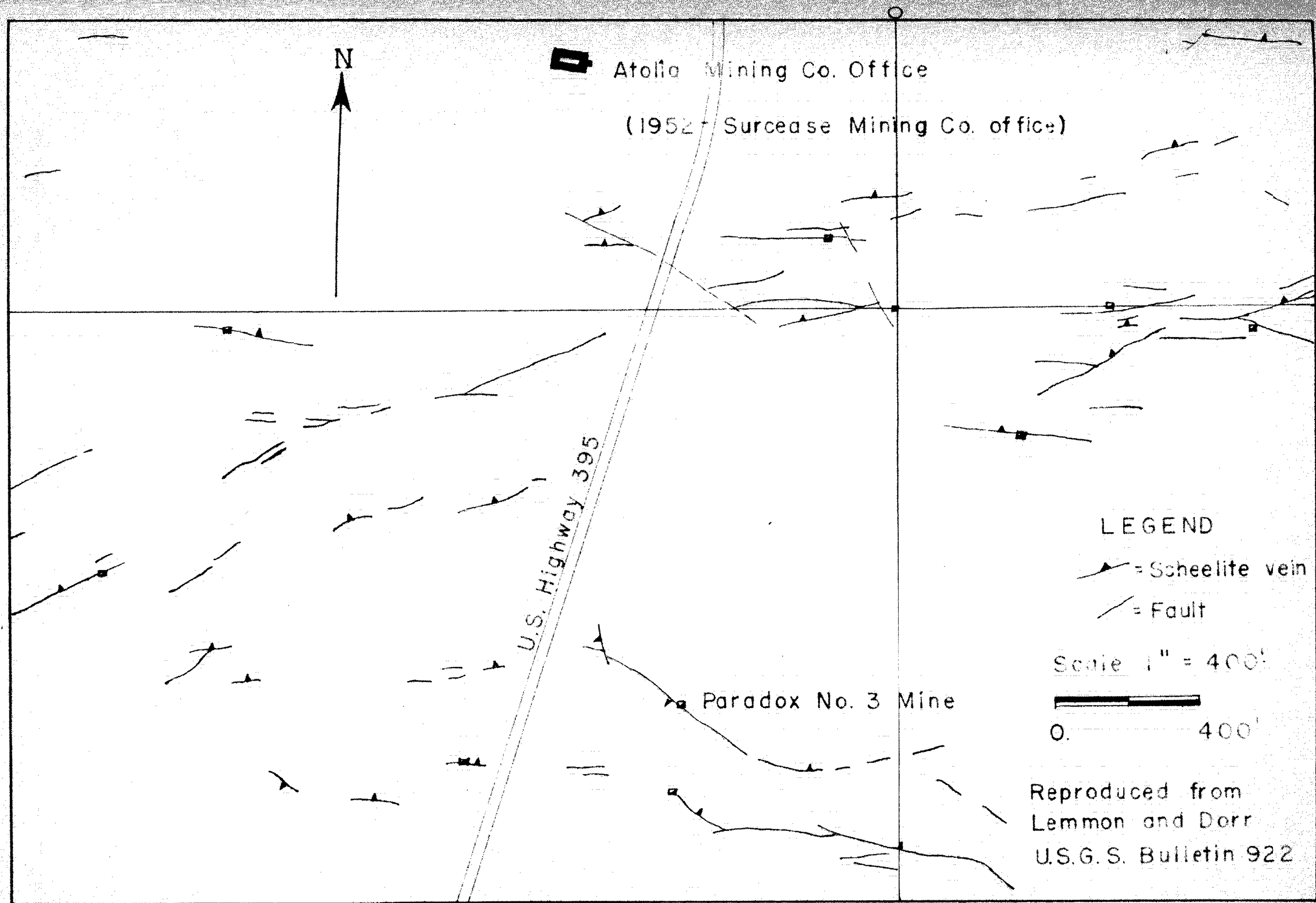
The Paradox No. 3 mine was mapped and studied and this report prepared in partial fulfillment of the requirements for the degree of Master of Science in Geology at the California Institute of Technology. It was hoped that the sudy would disclose the nature and possible extensions of the ore bodies.

A total of 16 days were spent at the mine between December 1951 and April 1952; of these, 15 were spent in mapping underground. The mine was mapped on a scale of one inch to twenty feet, using compass and tape and survey maps of the Surcease Mining Co. The open cut was mapped with a plane table and telescopic alidade. In the mine only level workings were mapped; inclined stopes, raises and winzes were generally inaccessible and were not examined. Samples of the wall rocks and vein minerals were taken during the mine mapping. Of these, 50 were sectioned and studied under the petrographic microscope. In addition oil immersion index determinations of a number of carbonate samples were made.

PREVIOUS WORK

The principal published geologic work in the Atolia tungsten mining district is by C. D. Hulin (1925) and by D. M. Lemmon and J. V. N. Dorr 2nd. (1940). Hulin's work, a survey of the entire Randsburg quadrangle, is more comprehensive but was prepared before the Paradox No. 3 mine was developed. Lemmon mapped all accessible underground workings (including the Paradox No. 3 mine) at a scale of 20 or 30 feet to one inch. The emphasis of the work was primarily economic--to determine the extent of the ore reserves.

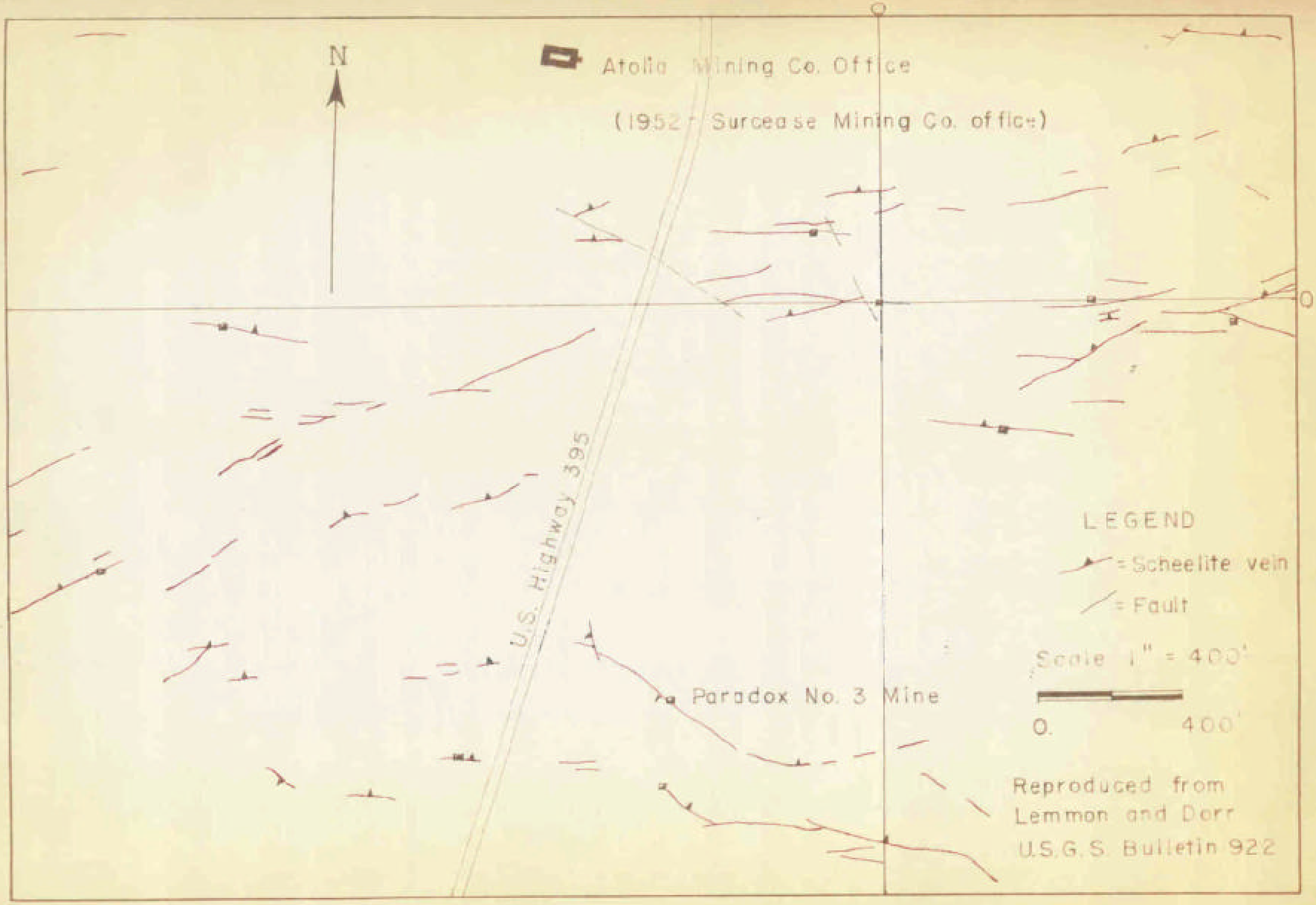
F. H. Frederick and Dion Gardner have separately mapped part or all of the Paradox No. 3 mine. Their maps are unpublished, the property of the Surcease Mining Co., and were not consulted during the preparation of this report.



INDEX & GEOLOGY MAP

of

THE EASTERN PART OF THE ATOLIA MINING DISTRICT, CALIFORNIA



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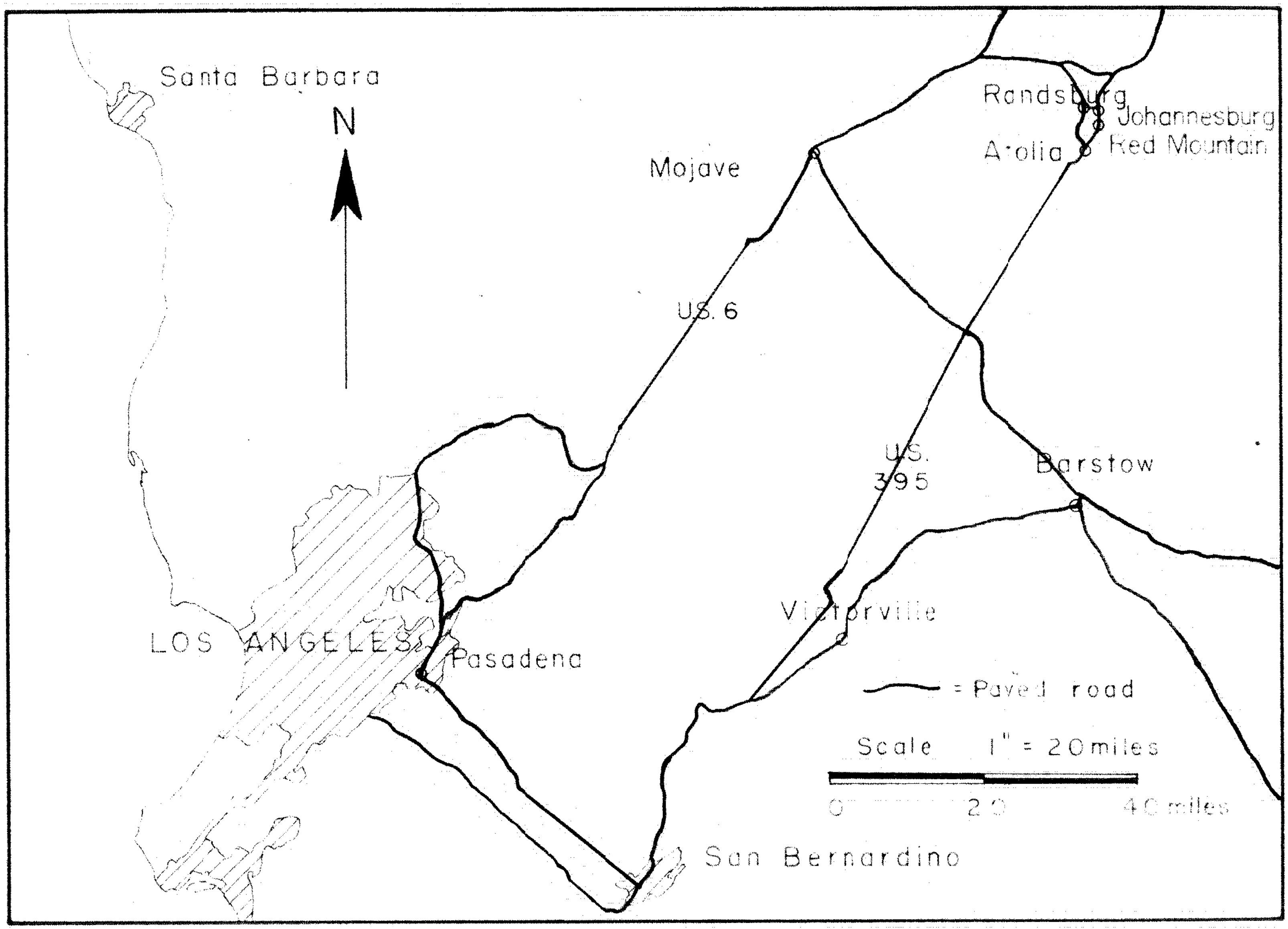

Santa Barbara
N
Mojave
Randsburg
Johannesburg
Atolia
Red Mountain
U.S. 6
U.S. 395
Barstow
LOS ANGELES
Pasadena
Victorville
= Paved road
Scale 1" = 20 miles
0
20
40 miles
San Bernardino

INDEX MAP

HISTORY

Tungsten was first discovered in the Atolia district in placer operations at the St. Elmo gold mine south of Atolia. The tungsten gravels were traced northward to the district, and within a few years almost all the large lode deposits so far known were discovered. Development of the Paradox No. 3 mine was begun in 1936 and was stopped in 1944. Since that time leasees have enlarged several of the stopes. From 1936 to 1944 a total of 7096 tons of ore was mined (most of it from the main vein) and 17,115 units* of WO_4 were recovered. According to Lemmon and Dorr (1940, p. 239) "the ore was of high grade, two feet thick in the widest part, but was much leaner on the bottom level than on the upper two level". At the present the ore reserves are practically nil, and mining is being carried on by two lessees on a small scale at the east end of the 150 level.

* One unit equals 20 pounds of WO_4

GENERAL DESCRIPTION

REGIONAL GEOLOGY

The Paradox No. 3 mine is in the southeast part of the Aolia tungsten mining district. The district is located on a pediment on the southeast flank of the Rand Mountains, a southward tilted fault block. The mountains consist of pre-Cambrian (?) metamorphic rocks which have been intruded by several igneous bodies. The pediment furface slopes toward Cuddeback Lake (eight miles to the east), and dips under the alluvial cover. The tungsten is carried as scheelite in quartz veins in the Atolia quartz monzonite, which is probably of Late Jurassic age (Hulin, 1925, p. 42). Dikes of diorite, splite, granite and diabase (none of which are exposed in the Paradox No. 3 mine) cut the quartz monzonite (Hulin, 1925, p. 38). The diabase dikes, which are Miocene in age, cut the veins. The Miocene (?) Rosamond Series of continental beds are reported by Gardner* to be faulted against the quartz monzonite in the east part of the district.

* Gardner, Dion, personal communication

ROCKS

Atolia Quartz Monzonite

The Atolia quartz monzonite is the only rock exposed in the Paradox No. 3 workings. As described by Hulin (1925, p. 34) the quartz monzonite is a light colored, medium grained rock with granitic texture. It is made up of approximately equal proportions of orthoclase, quartz and andesine-oligoclase. Biotite and hornblende each make up 10% of the rock. Asscessory minerals are sphene, magnetite and aptite. Hulin tentatively ascribes it to Nevadian (Upper Jurassic) time and relates it to the Sierra Nevada batholith which outcrops 15 miles to the north. The quartz monzonite is intrusive into pre-Cambrian (?) Rand schist and underlies uncomformably the Upper Miocene (?) Rosamond Series.

In the Paradox No. 3 mine the Atolia quartz monzonite has been moderately altered, but the nature of the original rock can be estimated with fair accuracy. In the sections examined the rock is more basic than quartz monzonite and has a composition of a basic granodiorite or acidic tonalite. However, Hulin's term, Atolia quartz monzonite, has been retained in this report, since the few sections examined by the present author are at best a poor sampling of the rock in the mine area and can not be taken as an indication of the composition of the intrusive as a whole.

In the sections examined the rock contains on the average 20-30% quartz, 50-60% sodic andesine (An35), 5% orthoclase, 10-15% biotite and 5-10% combined augite, sphene, magnetite and apatite. The texture is meduum to coarse grained (average grain size 2-5mm) and the major constituents are anhedral except for subhedral plagioclase laths.

The andesine is unzoned but has much albite twinning. The quartz is strained and produces wavy extintions under crossed nichols. A few bubbles and minute inclusions are present. The biotite which occurs in irregular flakes, is pleochroic in colors from light to dark brown. The augite is pale green, non-pleochroic, and makes a maxumum extinction with the cleavage of 40 degrees. The spene occurs as wedge shaped crystals, the magnetite as octahedrons, and the apatite as minute hexagonal prisms.

Quaternary Pediment Gravels

Flat lying, unconsolidated Quaternary pediment gravels, 1 to 15 feet thick, overlie the Paradox No. 3 mine area, filling a channel which crosses the open cut from west to east, and veneering the pediment surface. The gravels contain a variety of rock and mineral fragments including quartz monzonite and vein quartz. No scheelite fragments were identified in the gravels at the mine, but farther east placer scheelite is recovered from similar gravels.

FAULTS, FRACTURES, AND VEINS

The tungsten-bearing fissure veins of the Atolia mining district are localized in a narrow east-west belt (Lemmon and Dorr, 1940 p. 217). The veins occupy pre-mineral faults which strike roughly east-west and dip northward at 45 to 90 degrees. The ore bodies are localized along the veins in triangular shoots which are broadest near the surface and narrow downward. The faults are grooved horizontally and are believed to be the result of compressional forces, giving strike slip movement. According to Lemmon and Dorr (1940, p. 222) the scheelite is localized along the main veins where those are cut by cross faults, along which movement occured both before and after mineralization.

The ore in the Paradox No. 3 mine is found primarily along three veins, named for convenience the main vein, the north vein, and the west vein. The main and north veins, which strike roughly northwest, dip steeply southward in the upper portions, but change to a northward dip in the lower levels. The west vein strikes east-west and dips northward. The veins, which occupy pre-mineralization faults and fractures, branch and change dip (or "roll over") throughout the mine. The ore occurs along the veins in shoots which may be similar in shape to those in the rest of the district. However little is known about the shape of the shoots except in plan along the drifts.

Main Vein

The main vein, the principle source of ore in the Paradox No. 3 mine, is exposed in the open cut, the 50 level, throughout the 100 level and in the central and eastern portions of the 150 level. The vein dips southward at 60 degrees from the surface to a line below the 100 level. The vein reverses the dip to the north along a line which rises at 12 degrees from the east end of the 150 level to the 100 level and dips steeply downward where the vein loops westward. The vein consists of straight segments offset by curved, "horsetail" sections. The straight segments trend in general northwest but in detail consist of segments with trends north-northwest and west-northwest respectively. At the "horsetail" intersections, called cymoid loops by McKinstry (1948, p. 316), the vein splits into gentle S-curved fractures which unite and reform the vein. The loop which is exposed in the central portions of the 100 level plunges steeply southward with the dip of the vein and is partially exposed in the 150 level workings.

The main vein appears to intersect the north vein along a line which plunges gently (about 15 degrees) from the east end of the 100 level to the east end of the 200 level. In the west workings of the 100 level the vein abuts against a vertical fault, which may be the upward extension of the north branch of the west vein. It is believed that the main vein was not cut by the fault but formed against it through the mineralization of a tension fracture.

A vein is exposed in the south drift of the east workings of the 150 level which strikes and dips roughly parallel to the main vein. The vein dips northward 45 to 55 degrees, branching upward along a line which rises at 12 degrees from the floor of the east end of the drift. One branch remains unchanges; the other dips southward 70 to 80 degrees. The vein may join the main vein somewhere below the 150 level.

Associated with the main vein are minor fractures which are either parallel to the vein or splay out from it. A few wedge shaped "feeder veins" or filled tension fractures abut against the main vein or its subsidiary fractures.

Ore occurs along the vein in shoots which appear to weaken or die out below the 100 level.

North Vein

The north vein is exposed along the northern workings of the 200 level. The north vein or a subsidiary fracture is exposed at the east end of the 100 level as a prominent fracture and vein, striking north-northwest and intersecting the main vein east of the shaft. The north vein dips steeply southward above the 200 level and northward below it. The line of change of dip plunges below the 200 level in the west and rises just above it in the eastern workings. The vein trends northwest, in detail striking from west-northwest to west-southwest.

The vein does not exhibit the cymoid loops characteristic of the main vein, but the branching of the north vein at the east end of the 200 level may be the beginnings of such a loop.

In the eastern workings of the 200 level the vein branches upward several times, one branch continuing steeply upward and the other branch rising less steeply (30 to 50 degrees) to the southwest. Some of the latter branches which may be related to the east and main veins, diverge from the vein and trend more westerly.

A northward dipping fracture set trending parallel to the north vein, which is mineralized to a minor extent, is exposed 30 feet north of the north vein on the 200 level. Other fractures, some of which are mineralized, are closely associated with the north vein and trend parallel to it.

Ore occurs in shoots along the vein separated by barren fractures.

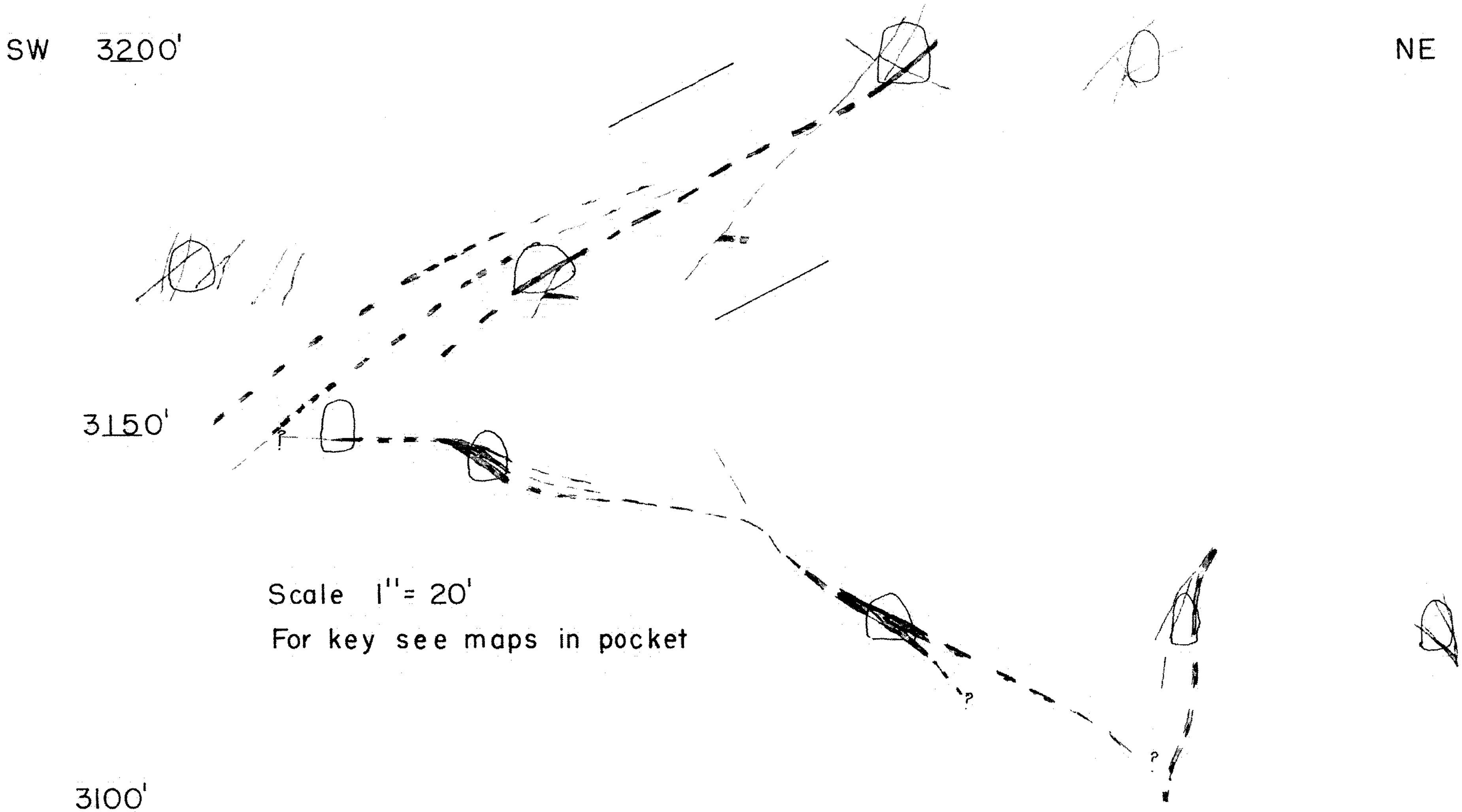
West Vein

The west vein is exposed along the east-west drift of the 200 level and in the western workings of the 150 level. The eastern portion of the vein below the 200 level dips 30 to 45 degrees northward, steepens upward in dip at the 200 level, and flattens at or below the 150 level (fig. 3). At the 200 level the vein branches downward, the flatter segment dipping 30 to 35 degrees and filled with heavy gouge (1 to 3 inches) but little quartz or scheelite, and the southern segment dipping 45 degrees and containing a vein of quartz and scheelite or barren quartz 4 to 8 inches thick. What happens to the two segments below the 200 level is unknown. The junction seems to be heavily mineralized, probably because of the diverting effect of the gouge zone on the mineralizing solutions. The flat dipping branch diverges in strike from the other branch 40 feet west of the manway on the 200 level and trends northwest. It is exposed in the northwest workings of the 200 level where it is unmineralized. It apparently steepens up dip and is exposed in the western workings of the 100 level where it terminates the main vein. The ore-bearing branch is exposed westerly from the junction with the other branch, dipping more steeply to the north and associated with a conjugate fracture set dipping southward. At the west end of the drift the vein intersects a northeast fracture and divides, forming nearly vertical, barren fractures. To the east the west vein joins the north vein at the 200 level as fractures and quartz veins which curve into and trend parallel to the north vein. Near the junction the north vein changes dip for a short distance and follows fractures which are parallel to the west vein and are probably related to it. In the cross cut from the shaft at the 200 level are exposed fractures with attitudes parallel to the south vein, which are apparently continuations of westerly trending branches of the north vein. These fractures are probably related to the south vein, the product of similar or identical forces.

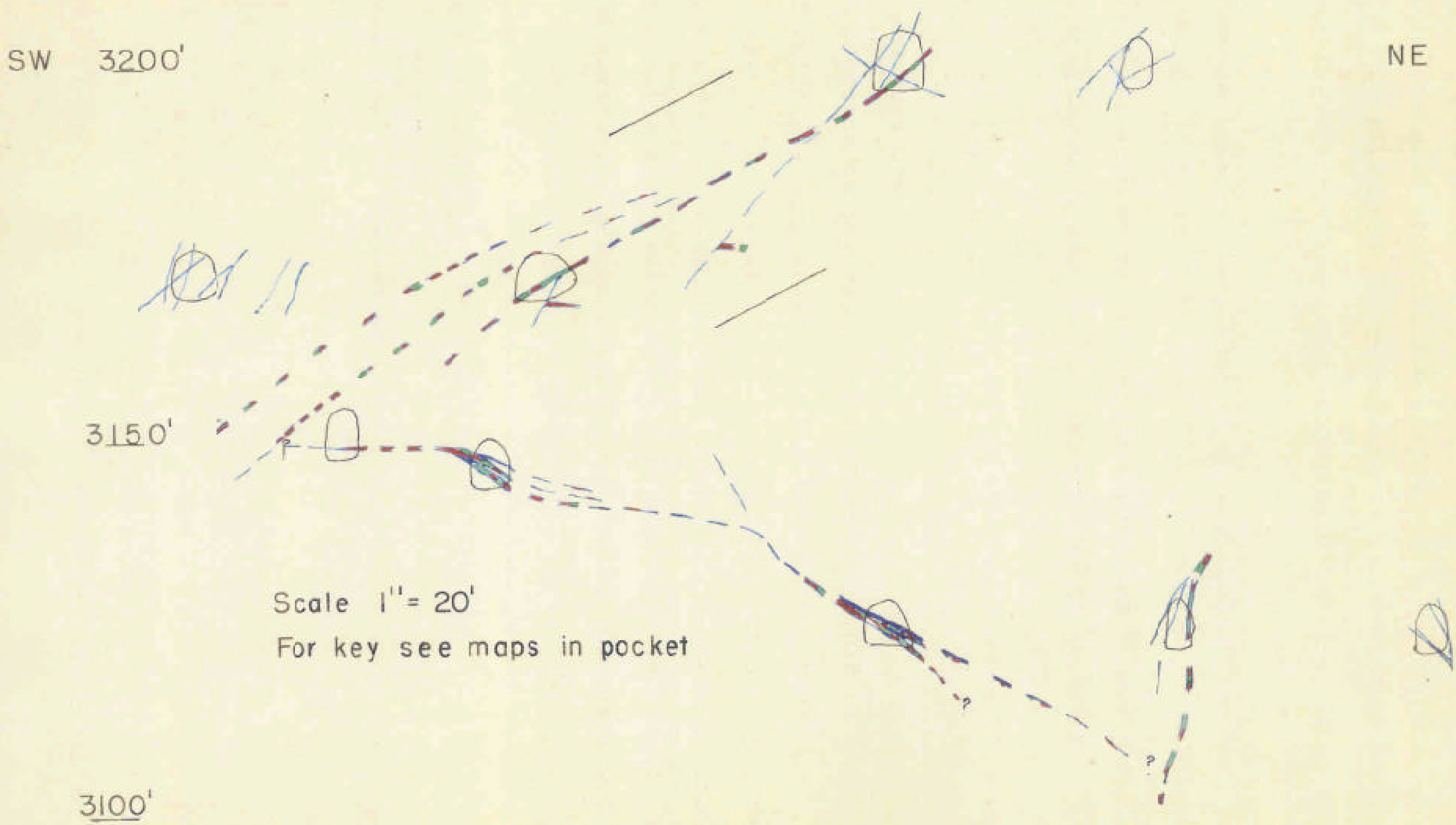
The relation between the west vein and the main vein is not known. The two intersect just south of the central 150 level drifts (fig. 3), but the only workings at the contact have been filled. The west vein apparently curves to the southwest near the filled workings and dies out.

The thrust fault described by Lemmon and Dorr (1940, p.239) may well be the south vein. In describing the paradox No. 3 mine they write:

CROSS SECTION (A), PARADOX MINE NO. 3, ATOLIA, CALIF.



CROSS SECTION (A), PARADOX MINE NO. 3, ATOLIA, CALIF.



> "The main vein dip . . . to a point below the first level where it is intersected by an irregular gently dipping fault, and the veins found on the second level . . . are apparently unrelated to the main vein".

It seems doubtful that the flat dipping branch of the south vein is a post-mineralization thrust fault. The ore is localized along it and is unfractured. The vein joins the north vein without offsetting or fracturing it and the wall rock alteration near the junction reflects shearing either prior to or contemporaneously with alteration (see section on Severe Zone of Alteration).

Subsidiary Fractures

In addition to the major veins there are minor fractures, most of which are unmineralized. The majority of these are either parallel to the major veins or diverge outward or downward from them. Most of the other subsidiary fractures trend parallel to the major veins but dip in the opposite direction. Thus the dominant fracture orientations strike northwest and dip 45 to 90 degrees northward and southward. A few cross fractures are exposed which strike northeast and dip 30 to 60 degrees east or west.

Vein Branching and Changes of Dip

The most characteristic attribute of the Paradox No. 3 veins is the frequent branching and changing of attitude of the veins. Such behavior reflects extreme variability in the attitude of the fractures and also changes in the paths of the mineralizing solutions from one fracture set to another of different attitude (fig. 3; Plate 3, cross section A; Plate 5, cross section C). These changes in the paths of solutions could result from either of two possible situations. Before mineralization those parts of the fractures which are mineralized could have undergone coordinated slippage. The path of the coordinated slippage could provide a fovorable path for later passage of solutions and for deposition. An alternative would be that at the time of mineralization the surfaces of different conjugate fracture sets were under nearly equal pressure. Slight variations in the attitude, degree of brecciation along the fractures, etc, would make first one and then the other set more permiable and hence more favorable to the passage of solutions and deposition. The second alternative appears to be the more likely. Where the branching and changing of attitude of the veins were observed, there was no fracturing and brecciation along a plane joining the two sets, such as would occur at the intersection of differently oriented fractures along which coordinated slippage took place.

Relative Age of Faulting and Mineralization

Lemmon and Dorr (1940, p. 239) describe the faulting in the Paradox No. 3 mine as being both pre- and post-mineralization.

> "Above the gently dipping fault the thick high-grade ore body was broken by numerous small faults"

It is believed that the faulting was pre-mineralization, except for displacements during and after mineralization measured in inches and fractions of inches, for the following reason:

1. The present spatial distribution of the veins can be

more readily explained by pre-mineralization faulting alone. The termination of veins against gouge filled fractures is believed to represent the abutment of tension fractures against contemporary shear fractures. These tension fractures have a constant orientation with respect to their associated shears throughout the mine.

2. The shears carry scheelite and quartz as unfractured fissure fillings and are flanked by typical illitized and carbonatized wall rock.

3. The shears curve into the veins with no apparent displacement or fracturing of the veins, and the orientation of the shears suggests a close causal relation to the veins.

4. The quartz-scheelite veins are not faulted and brecciated at the "faulted" end.

5. No clearly demonstrated offset of the veins were found in excess of one or two inches.

Small movements along the veins and related fractures between the phases of mineralization are shown by the texture of the vein minerals. Similar very small movements along veins and fractures after mineralization are shown by fractured vein material, now filled with iron oxides and chlorite.

Structural Control of Ore Deposition

Along the main vein ore is localized in shoots which continue upward from the 100 level but seem to diminish downward. The shoots apparently occur at and above the turning over of the vein. Similar localization at the turning over occurs along the small vein in the southeast drift of the 150 level. Small ore bodies occur along the veins of the cymoid loops. How far these ore bodies extend upward or downward is not known. The ore body associated with the central loop of the main vein continues from the 150 level through the 100 level and possibly to the 50 level. Small ore bodies, usually containing much quartz and little scheelite, are localized in tension fractures which abut the main vein or related fractures.

Along the north vein ore is localized in shoots, the structural control of which is not known.

Along the south vein the ore seems to be localized along steeper portions of the vein at the junction of the steep and flat segments. Moderately heavy barren quartz occurs along the flat portions of the vein at the 150 level.

Causal Forces

Dominantly dip slip movement along the north vein is indicated by grooving parallel to the dip direction. The sub-horizontal orientation of the tension fractures associated with the main vein also indicates dip slip movement, with movement of the south side upward relative to the north side i.e. a high angle reverse fault. The steep, variable dips of the north and main veins suggest origin from vertical forces, since horizontal forces could only produce reverse faults dipping less than 45 degrees.

The flat dipping gouge-filled segment of the south vein probably resulted from thrusting as the result of compressional forces from the north or northeast. The attitude of the other segment of the south vein (east strike and steep north dip) is similar to the prevailing attitude of the veins throughout the rest of the district. According to Hulin (1925, p. 71) and Lemmon and Dorr (1940, p. 215) the veins throughout the district occupy strike slip faults, the south sides of which have moved east relative to the north sides. They ascribe the origin of the faults to "regional compression"-- presumably oriented northeast or northwest. No clue was found in the mine to the relative movement on the steep segment of the south vein, but strike slip movement is not incompatable with the field relations.

Thus northeast compressional forces could have caused the observed features of the south vein fractures. The northwest fractures throughout the mine could have been formed under vertical stresses alone, but whether they could have formed under combined vertical and horizontal forces is questionable. The reverse movement on the main vein seems to support combined forces. However the extreme irregularity of the fracture surfaces neccessitates increase in volume of the rocks involved and hence implies low confining pressures--I.E. shallow depth and low compressional forces. The curing nature of the junction between the south vein and the north vein and the apparent lack of offset at the junction could arise either form contemporaneous fracturing or sequential fracturing--vertical stresses followed by horizontal compression with partial relief along earlier formed northwest fractures.

The most coherent and reasonable explanation of the forces which caused the faulting in the mine area seems to the writer to be local vertical stresses followed by regional northeast compressional forces.

VEIN MINERALS

The mineralogy of the vein minerals is fairly simple, as the only ore mineral is scheelite and the gangue is dominantly quartz with subordinate calcite and minor chlorite and pyrite. Angular fragments of quartz monzonite, completely replaced by quartz, illite, calcite, pyrite and chlorite, makes up 10% to 90% of the material between the vein walls. In most of the veins quartz and scheelite are closely associated, but a few barren quartz stringers were found in the flat dipping portion of the south vein on the 200 and 150 levels. In each vein the vein matter is roughly symmetrical about a central plane. Usually subhedral crusts of scheelite are adjacent to the vein wall, and these are coated by cloudy quartz as fine, anhedral grains and coarse combs. The center of the vein is filled with fine grained, anhedral clear quartz with a few druses filled with calcite. In many of the veins the symmetry has been destroyed by irregularly distributed inclusions of wall rock and by veinlets of quartz and calcite which follow the vein walls and cut the vein matter.

Quartz

In each vein quartz occurs in two forms, cloudy and clear. The milk white, "cloudy" quartz occurs as small, anhedral grains adjacent to the vein walls and as comb quartz, coating the anhedral quartz, and made up of elongate, subhedral quartz prisms up to 7 mm in length. The cloudy quartz grains and prisms also surround scheelite and wall rock fragments in the vein. Microscopically the cloudy quartz is observed to contain numerous minute bubbles and clay particles which are irregularly distributed or, in a few instances, outline chevron growth patterns in the individual prisms.

The colorless to slightly milky "clear" quartz fills the central portions of the veins and veins cloudy quartz and scheelite along irregular fractures. The clear quartz which rims calcite-filled druses in the vein centers occurs as terminated prisms, but elsewhere the clear quartz occurs as small, anhedral grains. The clear and cloudy quartz have been recrystallized subsequent to deposition to irregular grains which bear no relation to the original grain boundaries and contain both varieties of quartz. The quartz is cut by a few veinlets of calcite and chlorite.

Scheelite

The scheelite is medium grained (1-5mm in diameter) and white to cream-colored. The mineral can sometimes be distinquished megascopically from quartz, calcite or altered wall rock by the color, hardness (4,5-5), and distinct cleavage, and can always be distinquished by its blue-white fluorescence under ultra-violet radiation. The scheelite occurs as incrustations on the vein walls and as angular fragments surrounded by quartz and calcite. The scheelite grains are anhedral toward the vein walls and euhedrally terminated toward the center of the vein, and are cut by a few veinlets of quartz, calcite and chlorite.

Calcite

Vein calcite is colorless to white, anhedral and fine grained. Coarsely crystalline calcite was observed in only one small veinlet at the west end of the 100 level. Minor quantities of calcite cut quartz, scheelite and altered wall rock and fill cavities in the clear quartz.

Chlorite and Iron Oxides

Very minor quantities offine grained, blue-green, green and colorless chlorite cuts quartz, scheelite, calcite and wall rock fragments al ong irregular fine veinlets. With the chlorite is orange brown and black iron oxides as irregular stains, dendritic growths and small circular spots. The chlorite isorange brown and black iron oxides as irregular stains, dendritic growths and small circular spots. The chlorite-iron oxide veinlets either cut completely across the veins or terminate in the veins, and probably represent either the last phase of mineralization or weathering.

In addition to the minerals identified in the Paradox No. 3 mine, cinnabar, stibnite, gold, dolomite, ankerite and siderite have been reported from Atolia tungsten veins by Hulin (1925) and by lemmon and Dorr (1940). Kerr (1946) reports adlaria and fluorite. The possible presence of carbonates other than calcite was tested by acid reaction tests and oil immersion index determinations. The different colors and textures of the carbonates were found to be the result of admixtures of calcite with quartz, illite and iron oxides.

WALL ROCK ALTERATION

Three zones of wall rock alteration are distinquished--an outer "fringe" zone, an "intermediate" zone, and a zone of "severe alteration" adjacent to the veins.

Fringe Zone Alteration

Throughout the Paradox No. 3 mine area the quartz monzonite has been altered to chlorite, white mica, carbonate and clays. Megascopically, dark green chlorite replaces brown biotie, the feldspars are cloudy, and white clay pseudomorphs replace sphene. Under the microscope it was observed that the sphene has completely altered to leucoxene, most of the biotite has altered to chlorite and leucoxene, much of the orthoclase and andesine has gone to white mica, carbonate and clays, and most of the augite has altered to clays, carbonate, leucoxene and magnetite. Quartz, magnetite and aptite are unaltered except for minor veining of the quartz by carbonate.

White mica is the dominant alteration product of the feldspars, occurring as minute plates and felted masses scattered through the feldspar grains and concentrated along fractures, favorable twin directions and the periphery of grains. The mica is colorless to pale green and has parallel extinction and birefringence colors up to first order red and blue. Whether the mica is illite, sericite or paragonite is not known. Chlorite occurs as coarse flakes replacing biotite. Birefringence is anomalous blue and first order gray, and some of the chlorite is pleochroic from dark green to tan. The index of the clays, which occur as infrequent patches in the feldspar, is slightly above that of andesine suggesting that the clay may be kaolin. However the minute size of the grains prevented positive identification by optical means. The carbonate was checked by reaction with acid, and is thought to be predominantly calcite.

Alteration in the Intermediate Zone

The wall rock of the intermediate zone of alteration, usually one to three feet from the vein walls, is greenish grey in color. The feldspar is chalky white, quartz grains are rounded, and veinlets of chlorite and carbonate cut the rock. The feldspars have been completely altered to white mica and minor carbonate and clay. Most of the biotite has gone to chlorite, much of which has been altered to coarse illite and minor clay. A minor amount of the quartz has recrystallized to fine grained quartz along fractures and grain boundaries and has been replaced along grain boundaries by fine grained quartz, white mica, carbonate and clays. Veinlets of carbonate cut feldspar and quartz, and chlorite, quartz and illite veinlets cut feldspar, quartz and carbonate.

The coarse illite is colorless with birefringence colors as high as second order green. Properly oriented flakes yield optic axis figures which are uniaxial negative or biaxial negative with a very small optical angle. The clays derived from feldspar and chlorite have indices less than that of balsam, and may be montmorillonite. Many of the veinlets which consist of chlorite where they cut feldspar are quartz where they cut quartz, the transition occurring at the grain boundaries. Therefore the veinlet minerals represent at least in part reconstitution of material from adjacent mineral grains with little or no transportation of material along the veinlets.

Severe Zone of Alteration

The wall rock immediately adjacent to the veins has been severly altered in a zone up to 12 inches wide to an olive-green to gray-green rock with prominent rounded quartz grains and veinlets of dark green chlorite. The quartz has been changed to a moderate extent along the periphery of grains and along fractures either to fine grained anhedral quartz or to a fine grained mixture of quartz, white mica and calcite. Most or all of the fledspar has altered to coarse flakes (1/10-1/5mm in diameter) of illite and minor clacite, clay and chlorite. In more than one half of the slides examined part or all of the plagioclase (andesine) has been replaced by albite. Part of the coarse illite derived from chlorite has altered to chlorite, and minor pyrite (1-2%) has formed in association with chlorite and leucoxene. Veinlets of illite, quartz, chlorite and calcite cut the quartz and feldspar, occurring in albite along fractures which displace twin lamellae.

Polysynthetic twins of albite give maximum extinction angles of 17 degrees, indicating compositionally pure albite. The grains are fresh and unaltered except for a few remnent (?) illite flakes and minor veinlets. The clays are thought to be similar to those in the Intermediate Zone--i.e. montmorillonite.

In the 200 level near the junction of the south and north veins, the altered wall rock adjacent to the north vein is banded chalky white and gray. Microscopically it differs from typical altered rock because of a gneissoid structure produced by elongate lenses of strained quartz. The lens shape has been produced by alteration of the quartz at the periphery of the grains together with shearing and brecciation of the grains and recrystallization of the quartz along fractures. The matrix consists of illite, clays (montmorillonite) and calcite plus pyrite (5%) and minor chlorite derived from illite. Veinlets of illite, calcite, quartz and chlorite traverse the rock. The alteration seems to represent chemical conditions of formation similar to those elsewhere immediately adjacent to the veins, but modified by intense shearing of the rock prior to or contemporaneous with alteration.

Locally the wall rock along faults has been brecciated and isolated from the walls of the fault by deposition of quartz and scheelite. This wall rock, incorporated into the vein itself, has been completely altered to calcite, quartz and illite and minor chlorite, clay and pyrite. The severity of the alteration probably was related to the accessibility of the fragments to mineralizing solutions prior to the deposition of quartz and scheelite. Equally severe alteration of wall rocks adjacent to veins was observed only very locally. Wall rock incorporated in the vein at the west end of the 100 level has been altered to calcite which has been veined and replaced by illite, which in turn has been partially replaced by fine grained quartz.

Chemical Changes Involved in the Wall Rock Alteration

A consideration of the chemical changes involved in the wall rock alteration in the Paradox No. 3 mine, based on the information contained in the preceding section, must of neccessity be very generalized. No chemical analyses of the altered wall rock are available; the exact proportions of minerals in the altered rock has not been determined; and the chemical composition of the clays, chlorite and white micas is not known.

In the fringe zone the formation of chlorite, white mica, clays and carbonate from andesine and biotite calls for the addition of only water and carbon dioxide. In the intermediate and severe zones the formation of illite from chlorite and andesine neccessitates the addition of potash, and the local formation of albite form andesine would require the addition of soda. The formation of pyrite was probably from iron derived from chlorite and magnetite but calls for the addition of minor sulphur. The local complete alteration to illite, calcite and quartz would require the removal of almost all original constituents, and in all the altered rocks the addition of some constituents and the reduced specific gravity would require the removal of some of the silica, alumina and bases. The net changes involved in alteration would be the addition of water, carbon dioxide, minor sulphur, and locally potash and soda. The losses would be in all other components--silica, alumina, and possibly minor magnesia, soda iron and calcium. Most of the magnesia, iron and calcium was probably stabilized as chlorite, pyrite and clacite in veinlets which cut the altered rocks. The soda lost by illitization of the andesine may balance that gained by albitization. The formation of chlorite near the vein presents a special problem. In the fringe zone chlorite replaces biotite, in the intermediate zone illite replaces chlorite, and in the severe zone minor chlorite apparently replaces illite, and chlorite veinlets cut the rock. The apparent reversal of replacement in the severe zone may be only the result of inadequate sampling, and the veinlets may represent reduced temperatures or chemical intensities in the last phase of mineralization.

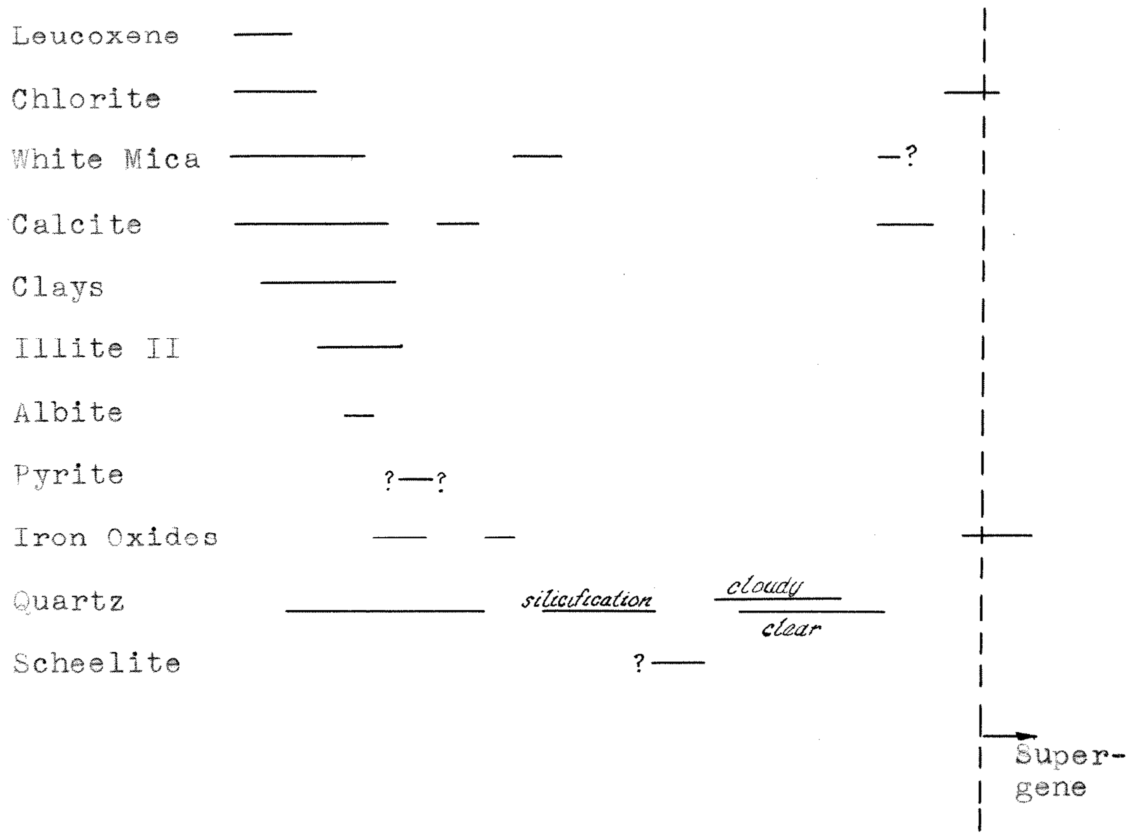
PARAGENSIS

The paragenesis of the wall rock alteration minerals and vein minerals was determined from mineral relationships observed microscopically. Criteria used in determining the paragenesis were veining, pseudomorphism and oriented growth patterns (e.g. needle quartz radiating from scheelite and pyrite). Certain relationships were not satisfactorily determined and are represented by question marks. The sequence of wall rock alteration may not represent a sequence in time but in space. Silicification of wall rock in the vein may have occurred contemporaneously with chloritization of the outermost wall rocks.

The paragenesis of the wall rock alteration minerals and the vein minerals is outlined on figure 4.

PARAGENESIS OF VEIN AND WALL ROCK ALTERATION MINERALS

PARADOX NO. 3 MINE, ATOLIA, CALIFORNIA



ORIGIN

Environment of Deposition

The quartz-scheelite mineralization was predominantly cavity filling, producing crustification and comb textures and crystalline, calcite filled cavities. Such open space deposition would indicate formation at low confining pressures. The complexity and irregularity of the individual faults neccessitates an increase in volume upon deformation and therefore low confining pressures. The conclusion is that both faulting and mineralization occurred at shallow depths. Hulin (1925, p. 77) estimates total erosion since the Miocene as less than 300 feet, but does not state how he arrived at this figure.

No vein minerals identified from the paradox No. 3 mine would provide an indication of the temperatures at which the vein minerals were deposited. In other Atolia tungsten vein the scheelite is accompanied by cinnabar and sibnite--both low temperature minerals. The scheelite was deposited at the same low temperatures is not known.

The textures of the vein minerals indicate that mineralization proceded in phases separated by movements along the faults and fracturing of the vein matter. The occurrence of quartz stringer with scheelite in the flat dipping portions of the south vein suggests that some of the movements along the fault which made sites favorable for deposition took place after the scheelite phase of the mineralization.

Age of Deposition

In the Paradox No. 3 mine no relationships were found which establish the age of the mineralization. The deposit certainly formed after the intrusion of the Atolia quartz monzonite, which is believed to be Nevadian in age. Formation of the deposit at shallow depth neccessitates long continued erosion following emplacement of the quartz monzonite. Lemmon and Dorr (1940, p. 213 and 234) believed that tungsten veins in the Union mine were cut by diabase dikes believed to be pre-Late Miocene in age, but Hulin (1925, p. 72 and 77) considered the mineralization to connected with the nearby late Miocene vulcanism. Noble* reports the occurrence of scheelite in nearby gold-quartz veins which cut the Rosamond formation (Late Miocene ?).

* J. A. Noble, oral communication

SUGGESTIONS FOR EXPLORATION

Undeveloped ore may occur along the north vein at the 100 and 150 levels and along the main vein east of the end of the 100 level. At the 100 level the north vein could be explored by cross cutting a short distance from the end of the cut east of the shaft, to be certain the north vein has been reached, and then drifting to the northwest along the strongest shear. Southeast of the shaft the main vein may be beginning a cymoid loop. If such is the case the vein should lie to the east of the end of the drift.

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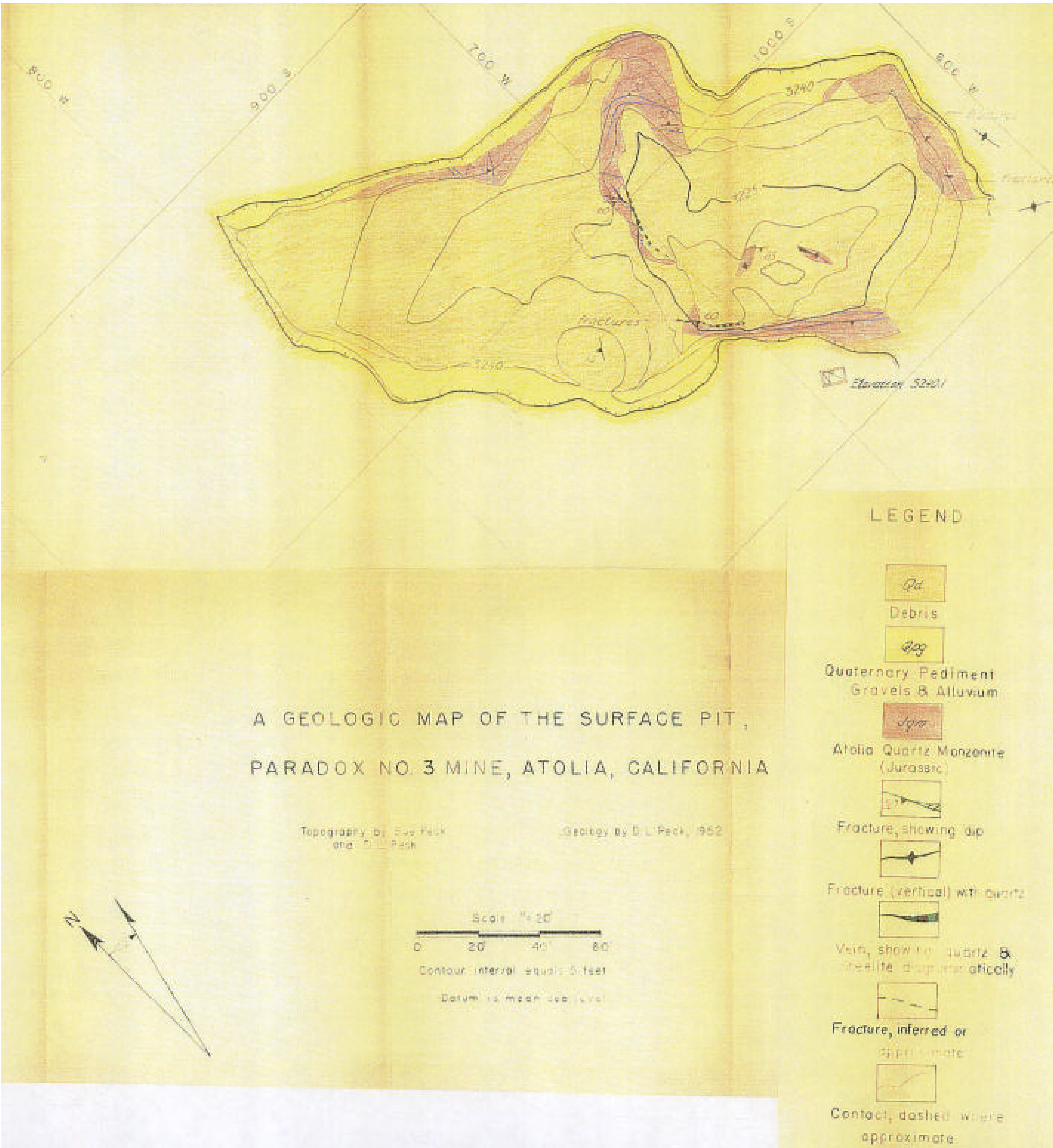
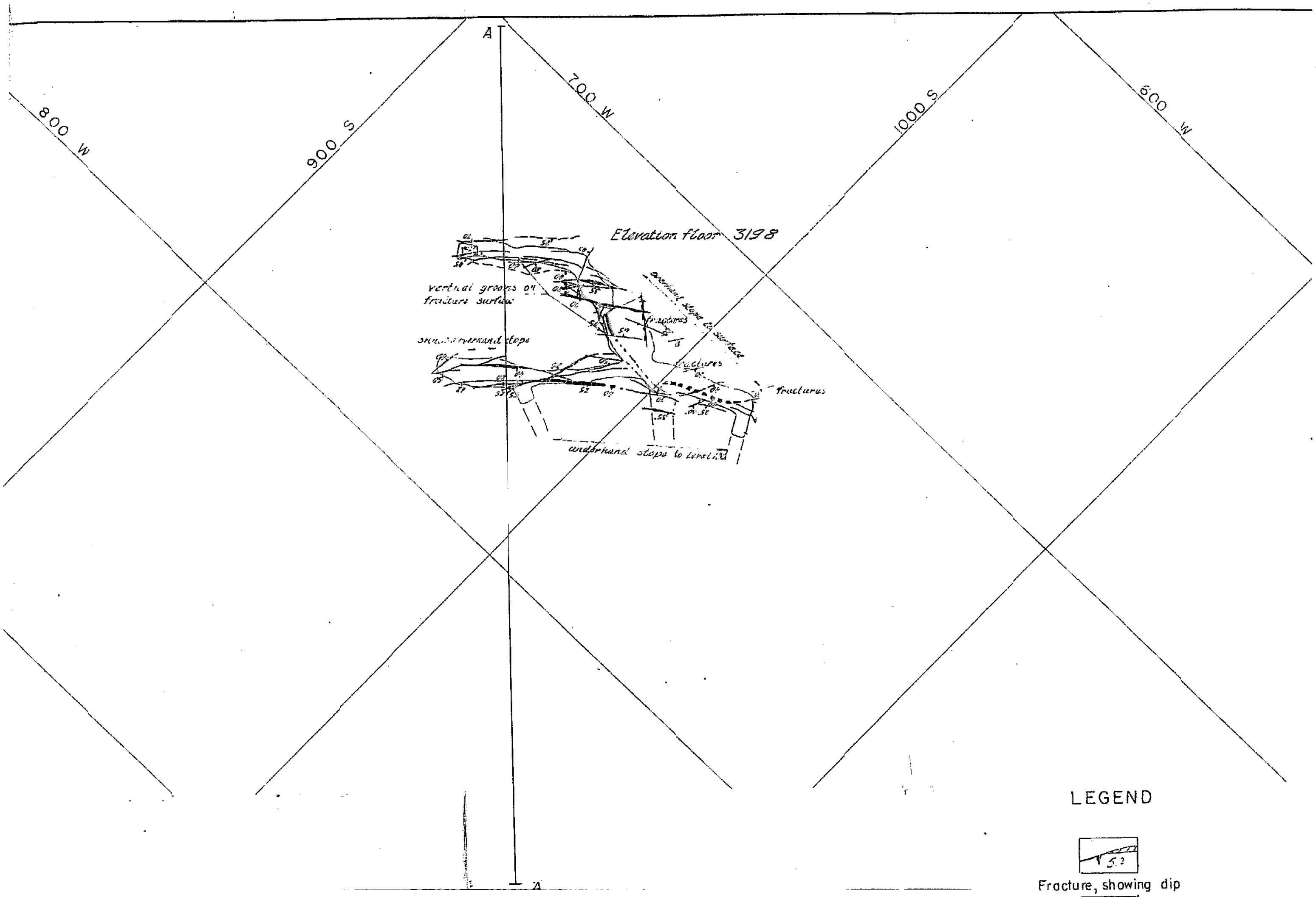

900 W
900 S
700 W
1000 S
800 W
5240
5225
Fractures
Elevation 5240.1
A GEOLOGIC MAP OF THE SURFACE PIT,
PARADOX NO. 3 MINE, ATOLIA, CALIFORNIA
Geology by D. L. Peck, 1952
N
Scale 1" = 20'
0 20' 40' 60'
Contour interval equals 5 feet
Datum is mean sea level
LEGEND
Qd
Debris
Qpg
Quaternary Pediment Gravels & Alluvium
Jqm
Atolia Quartz Monzonite (Jurassic)
Fracture, showing dip
Fracture (vertical) with quartz
Contact, dashed where approximate



LEGEND

Fracture, showing dip

Fracture (vertical) with quartz

Vein, showing quartz & Sheelite diagrammatically

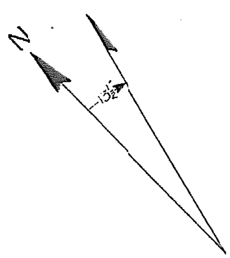
Fracture, inferred or approximate

Wall rock is Atolia Quartz Monzonite

A GECLOGIC MAP OF THE 50 LEVEL
PARADOX NO. 3 MINE, ATOLIA, CALIFORNIA

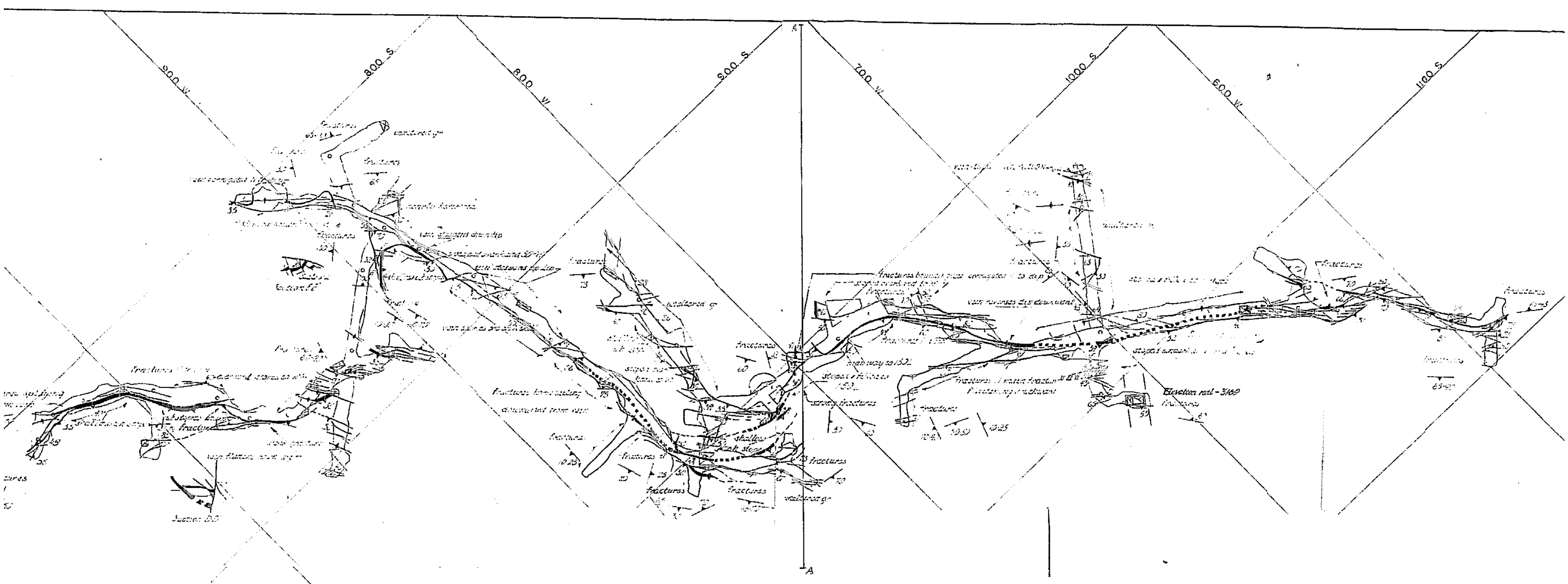
Mine workings surveyed by D. L. Peck

Geology by D. L. Peck, 1951-2



Scale 1" = 20'

0 20' 40' 60'



A GEOLOGIC MAP OF THE 100 LEVEL
PARADOX NO. 3 MINE, ATOLIA, CALIFORNIA

Mine workings modified from Surcease Mining Co. data

Geology by D. L. Peck, 1951-2

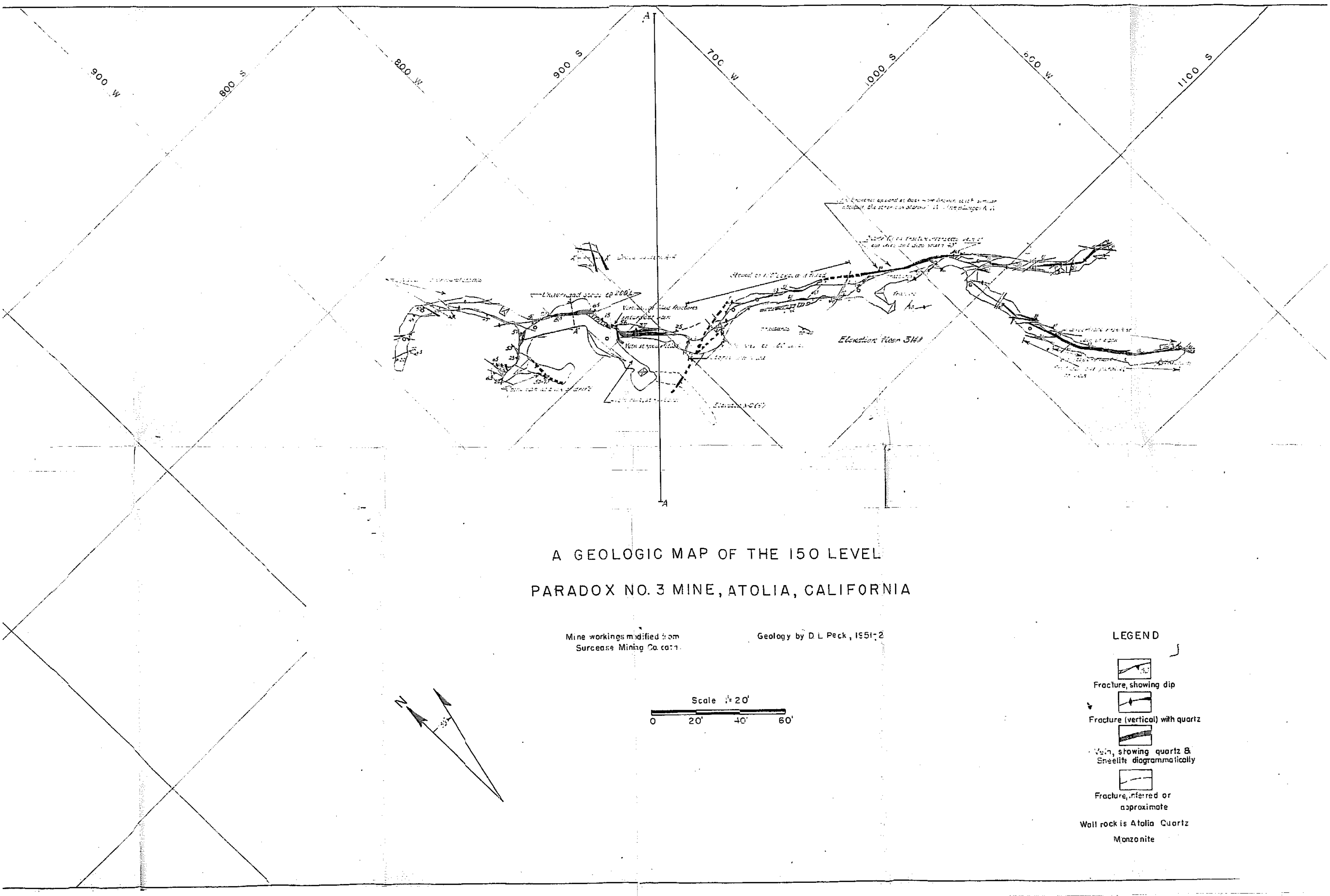
Scale 1" = 20'

0 20' 40' 60'

LEGEND

- Fracture, showing dip
- Fracture (vertical) with quartz
- Vein, showing quartz & Sheelite diagrammatically
- Fracture, inferred or approximate

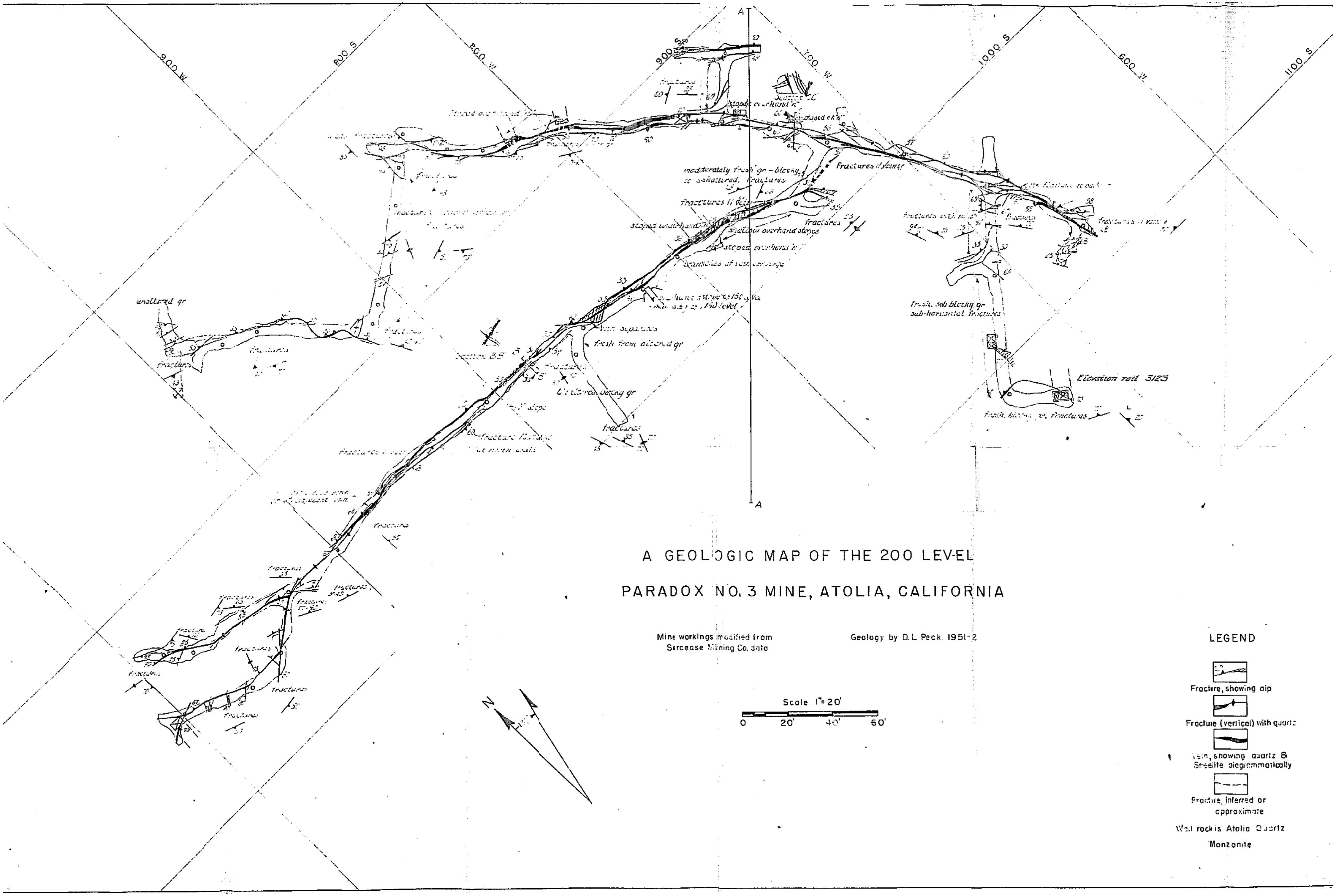
Wall rock is Atolia Quartz Monzonite



A GEOLOGIC MAP OF THE 150 LEVEL
PARADOX NO. 3 MINE, ATOLIA, CALIFORNIA

Mine workings modified from Surcease Mining Co. cat'n.

Geology by D. L. Peck, 1951-2



A GEOLOGIC MAP OF THE 200 LEVEL

PARADOX NO. 3 MINE, ATOLIA, CALIFORNIA

Mine workings modified from Surcease Mining Co. data

Geology by D.L. Peck 1951-2