GEOLOGY AND MINERALIZATION OF THE LIGHTS CREEK STOCK, PLUMAS COUNTY, CALIFORNIA

by

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Abstract

The Lights Creek stock is located in northern California about 100 miles northwest of Reno, Nevada. It is within the Sierra Nevada physiographic province near its juncture with the Cascade and Basin and Range provinces. Structurally it is closely associated with Basin and Range-type features. The area is thought to lie within the influence of the Walker Lane structural lineament and may also be affected by the eastward projection of the Mendocino fracture zone.

The Lights Creek stock is of Late Jurassic to early Eocene age and was emplaced as a differentiated satellite of the Sierra Nevada batholith. The stock hosts at least three large porphyry-type copper-bearing zones. These zones are at the site of the old Superior mine and at the newly discovered Sulfide Ridge and Moonlight Valley areas. Geologic reserves at a 0.2% copper cutoff for the Moonlight Valley are estimated at 250 million tons of 0.35% copper. For the Superior mine, the reserves are approximately 100 million tons of 0.33% copper. An undetermined large tonnage of low-grade material in the Sulfide Ridge area is estimated to grade approximately 0.25% copper.

Petrographic studies indicate that the stock is of heterogeneous composition with a granodioritic center grading outwardly to a granitic periphery. The peripheral areas of the stock are also shown to be more fractured, exhibit the most copper mineralization, and have a higher content of potassium feldspar.

There is a most striking association of copper sulfides occurring with tourmaline as intergrowths in veinlets and disseminations. The abundant tourmaline suggests a late pneumatolytic vehicle for at least some of the ore.

There is a lack of characteristic alteration zonal patterns in the Lights Creek deposits. Alteration assemblages of minerals are present locally and occur overlapping in the ore areas; however, strong and discrete zonation is not apparent. The low sulfur content in the ore zones, as well as the possible contribution of late pneumatolytic copper to the ore zones rather than abundant hydrothermal ore, may account for the unusual mineral assemblages at Lights Creek.

It is suggested that the Lights Creek-type of copper occurrences are not easily recognized because of their unique mineral assemblages and that these low-grade types with relatively fresh appearing outcrops could become the orebodies of the future.

Introduction

The Lights Creek stock is located at the northern limit of the Plumas County copper belt in the Diamond Mountains (Fig. 1). The copper belt is about 18 miles long and has a northwesterly trend. It is defined by the Walker mine at the south and the Engels and Superior mines at the north. Numerous other smaller mines and copper showings occur scattered within the zone. The Walker mine, largest of the producers, recorded more than 80 million pounds of copper during about half of its active life between 1922 to 1930 (Smith, 1970). The Engels and Superior mines were jointly operated by the California Engels Mining Company during the years 1916 to 1930. Production from both of these mines was about 161.5 million pounds of copper recovered from 4.5 million tons of ore (Smith, 1970). This indicates an

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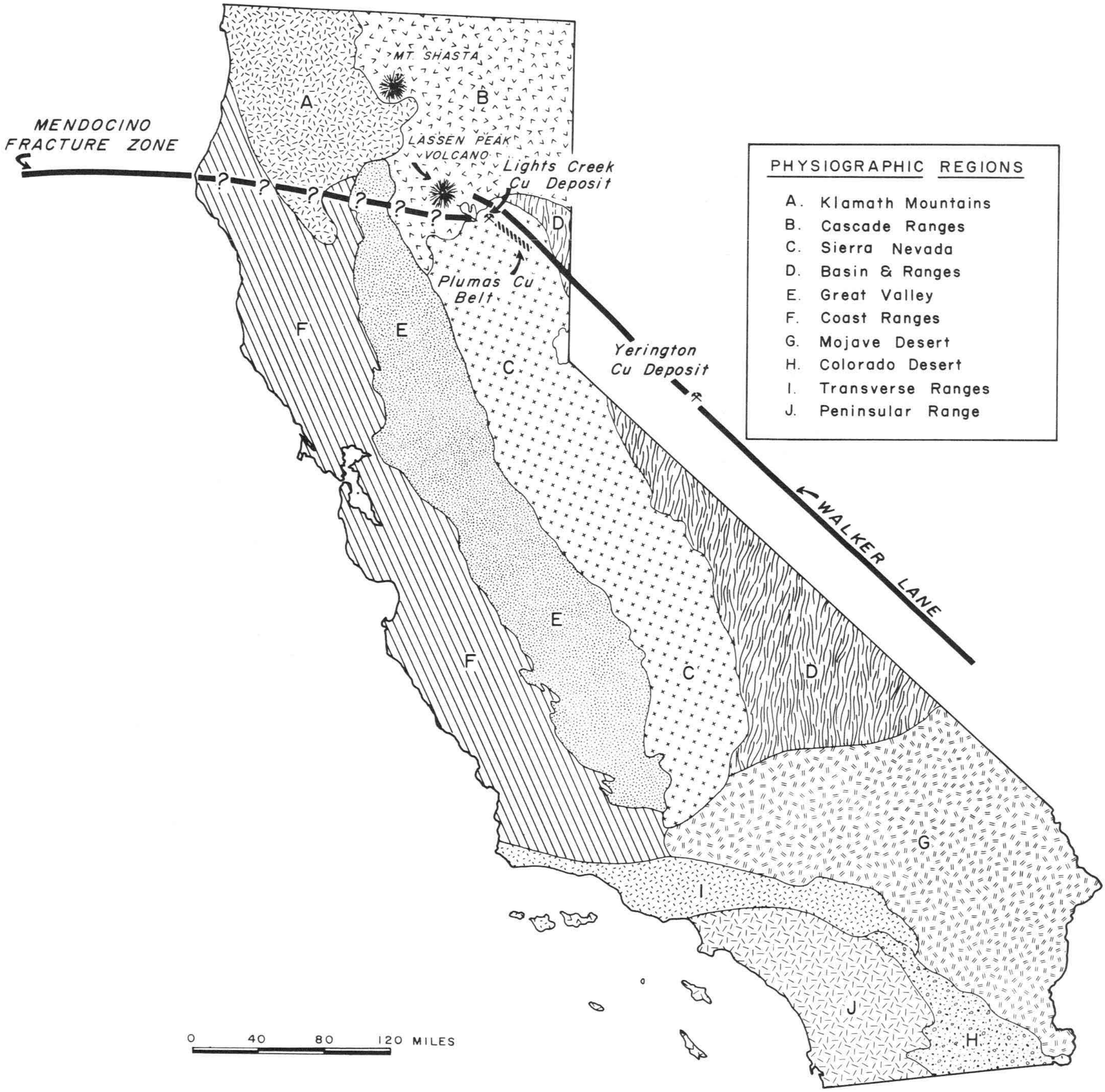

Fig. 1. Location map of the Lights Creek copper deposit

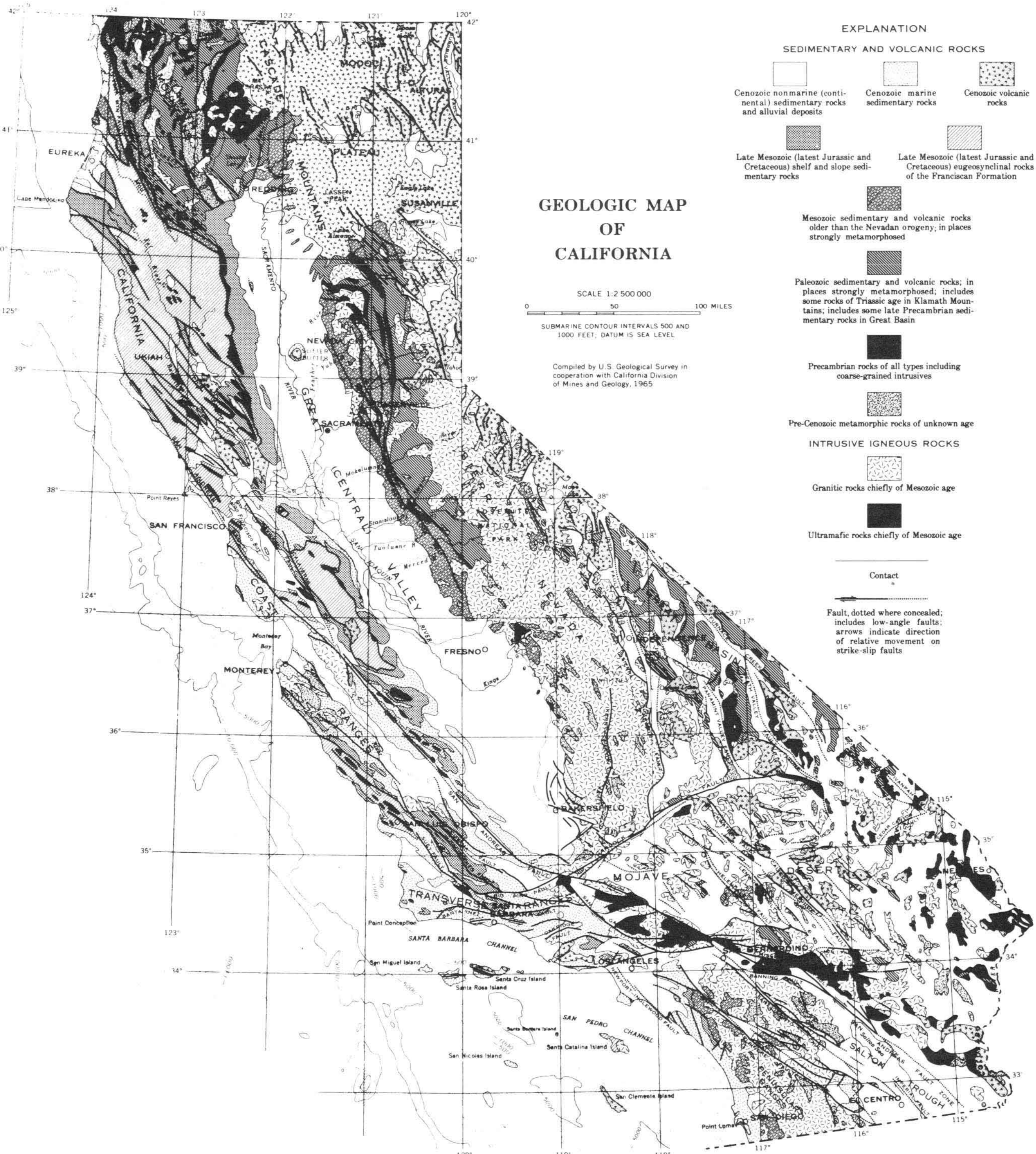

Fig. 2. Geologic map of California—from U.S.G.S. Map I-512

average recovery grade of 1.79% copper. The Superior mine is within the southern boundary of the Lights Creek stock, and the Engels mine is in a gabbroic complex just east of the stock.

Some notable figures in American geology, including Turner, Diller, Tolman, Rogers, Graton, D. H. McLaughlin, C. A. Anderson, and A. Knopf are associated with early investigations of the Engels and Superior mines. Knopf and Anderson (1930) published one of the latest and most definitive accounts of the geology. Additional work by Anderson (1931) and Knopf (1933) were further contributions to the geologic knowledge. The areal mapping of the area by Anderson and the ore deposit geology by Knopf and Anderson provided the foundation for the Placer Amex geologic work. More recently, Smith (1970) and Putman (1972, 1975) have made significant contributions to the knowledge of the distribution of base metals within the stock.

American Exploration & Mining Co., now operating as Placer Amex Inc., began a regional study of the Plumas County copper belt in 1962. Underground workings at the Superior mine were visited and intravein wall rocks were noted to be mineralized. Subsequent sampling of crosscuts indicated large zones of >5% copper. Subsequent geochemical and geologic work delimited the strongly anomalous copper-bearing quartz monzonite stock.

Regional Geologic Setting

The Lights Creek stock lies near the intersection of the Cascade, Sierra Nevada, and Basin and Range provinces. According to Durell (1966) the Sierra Nevada crest is 25 miles to the southwest, and the area is shown within the geographical boundary of the Sierra Nevada province. Lassen Peak is about 50 miles northwest and is considered to be the southernmost volcanic cone of the Cascade province.

The regional structure of this part of northern California is very complex as would be expected from its position near the junction of three geologic provinces (Fig. 2). McMath (1966) summarizes the general features of the area saying it lies athwart the structural axis of the Nevadan orogenic belt characterized here by a northwesterly trending synclinorium composed of Paleozoic and Mesozoic strata. The Sierra Nevada batholith near Lights Creek cuts obliquely into the northeast limb of the synclinorium. The source of this Mesozoic intrusion and its attendant copper-bearing quartz monzonite stock may have been from deep within the eugeosynclinal sediments themselves as suggested by Bateman and Wahrhaftig (1966) or generated in the Benioff zone of subduction as suggested by Hamilton (1969).

Another major crustal feature, which projects just north of the Lights Creek area, is the Mendocino fracture zone. This system is recorded farther west in the Pacific basin and may influence this area.

It is thought that the Walker Lane shear system of right-lateral strike-slip movement projects into the Lights Creek area (Fig. 1). Some of the local structures appear to reflect this influence, and the northwesterly attitude of the Plumas County copper belt could also be a meaningful expression of this trend. According to Pease (1969), the Walker system is at least 100 miles wide, fanning out across the northeastern corner of California into southern Oregon.

Description of the Lights Creek Quartz Monzonite Stock

The Lights Creek stock has a surface area of about seven square miles (Fig. 3). It is thought to have been formed as one of a complex series of multiple intrusive satellites of the Sierra Nevada batholith. It intrudes low-grade metamorphosed Jurassic-Triassic volcanic and sedimentary rocks. The main Sierra Nevada batholith, east of the stock in the vicinity of Honey Lake, has been dated by the potassium-argon method as in the range of 97.4 to 101 m.y. (Evernden and Kistler, 1970). Nonmarine, gently dipping Eocene sedimentary rocks cover some northwestern portions of the stock, and they correlated with Diller's (1908) auriferous gravels of the same age. Therefore, the age of emplacement and subsequent mineralization of the stock is considered to be within the interval of Early Cretaceous to Paleocene. Most likely the age of mineralization would be closer to the intrusive age and would approximate 100 m.y., thus having the same general age as the copper deposit at Yerington, Nevada.

Early work by Anderson (1931) has defined five distinct Sierra Nevada batholith differentiates in the Lights Creek area. These are, in order of their emplacement from oldest to youngest:

1. Engels mine gabbro (main host to high-temperature Engels mine copper deposit).
2. Quartz diorite (also host to Engels mine ore).
3. Granodiorite (main batholith, nonmineralized).
4. Quartz monzonite (host to porphyry-type copper occurrences of intermediate temperature).
5. Coarse-grained granite (non-copper bearing with rare molybdenum occurrences).

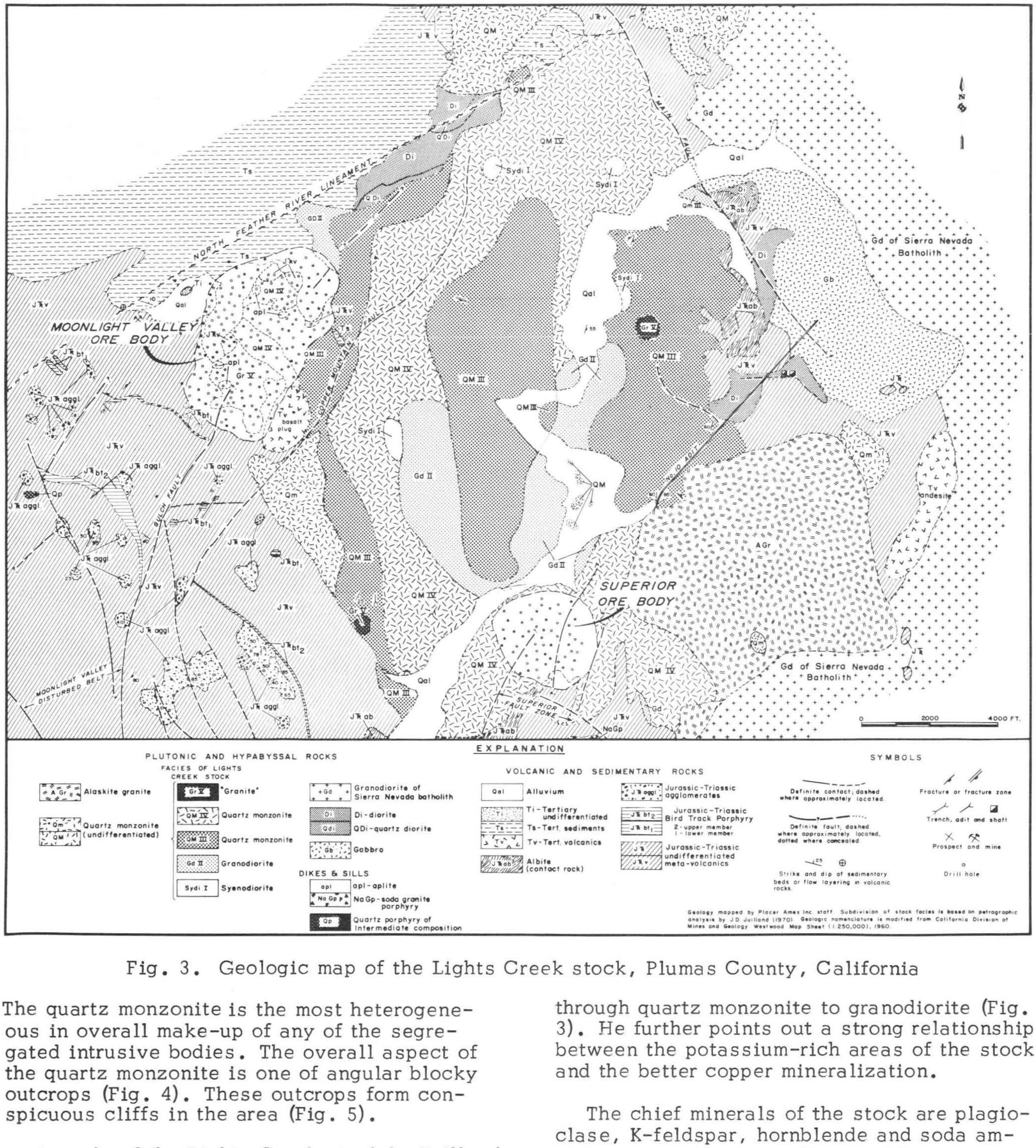

Fig. 3. Geologic map of the Lights Creek stock, Plumas County, California

The quartz monzonite is the most heterogeneous in overall make-up of any of the segregated intrusive bodies. The overall aspect of the quartz monzonite is one of angular blocky outcrops (Fig. 4). These outcrops form conspicuous cliffs in the area (Fig. 5).

A study of the Lights Creek stock by Juilland (1970) deals with the complex chemistry of the stock. He examined thin sections and polished sections, including samples taken from underground workings and drill core. By plotting the potassium feldspar to plagioclase feldspar ratio at various sample points and contouring the values he described several compositional zones within the stock. These zones range according to their modal analysis from granite through quartz monzonite to granodiorite (Fig. 3). He further points out a strong relationship between the potassium-rich areas of the stock and the better copper mineralization.

The chief minerals of the stock are plagioclase, K-feldspar, hornblende and soda amphibole, quartz, tourmaline, epidote, magnetite, and ilmenite with minute amounts of chalcopyrite, bornite, and pyrite. The rock is equigranular, fine to medium crystalline with few coarse crystalline zones. Aplitic and porphyritic textures are also recognized locally, especially in the Moonlight Valley area. Overall, the rock is weakly magnetic but in localized areas magnetite can be abundant, especially in the mineralized zones. Table 1 shows the

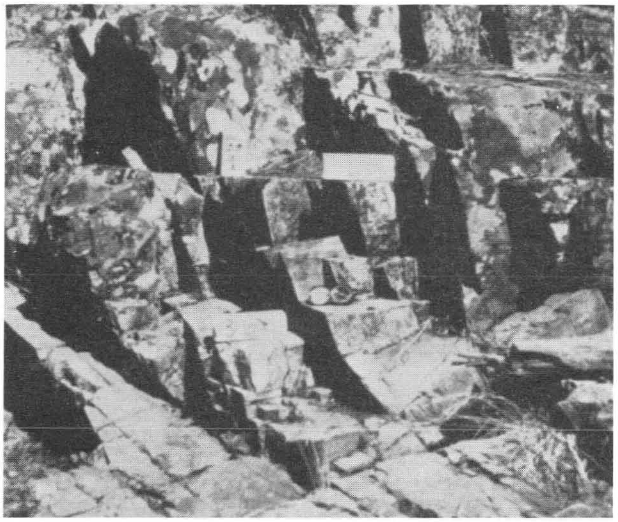

Fig. 4. Quartz monzonite showing angular blocky outcrops

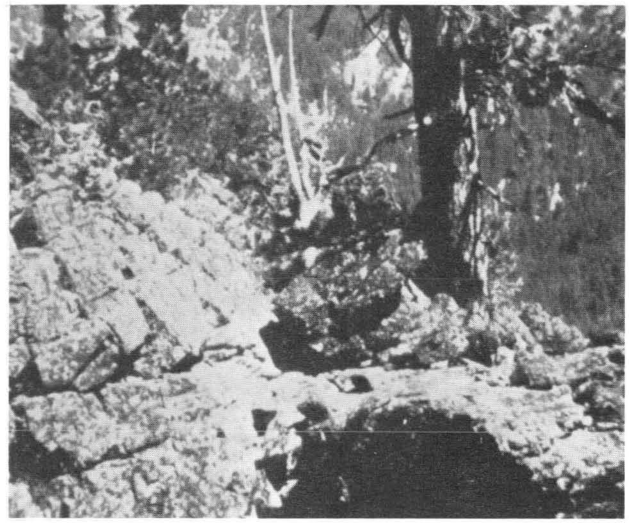

Fig. 5. Quartz monzonite forms prominent cliffs in the area

generalized composition of the stock after Juilland (1970).

Table 1. Lights Creek Stock—After Juilland (1970)

	Volume Percent		
Mineral	Maximum	Minimum	Average
K-feldspar	56.2	20.4	32.9
Plagioclase	42.0	23.0	31.4
Quartz	43.2	18.1	21.4
Totals	94.7	80.5	85.7
Mafics	27.7	0.4	11.0
Metallics	12.2	0.3	3.3

Mapping in the stock area has shown three dominant structural trends, which are northwest, northeast, and north-south (Fig. 3). Mineralization is most commonly associated with the northeast and north-south structural directions. Northwest structures commonly enhance the mineralization and/or cut it off.

Copper Mineralization in the Stock

The Lights Creek stock appears to be unique in the area in that it hosts porphyry copper-type mineralization. Putman (1975) shows by statistical analysis that copper mineralization has been introduced on a large scale and that it is not merely a small-scale segregation of magmatic-stage constituents. He further suggests a largely magmatic source for the metals in the stock.

At least three zones of copper mineralization have been delimited, two of which contain economically significant grades of copper. Over 200,000 feet of diamond drilling and 3,550 feet of rotary drilling have helped to define these zones. The site of the old Superior mine is the southernmost of the areas, having an estimated geologic reserve of 100 million tons of 0.33% copper at a 0.2% copper cutoff. The Moonlight Valley deposit, 1.9 miles northwest of the Superior deposit, is estimated to have a geologic reserve of 250 million tons grading 0.35% copper at a 0.2% copper cutoff. The Sulfide Ridge area, 1.7 miles northeast of the Superior mine, indicates an undetermined large tonnage of material, which could average 0.25% copper.

These three major mineralized zones occur entirely within the quartz monzonite stock near its contact with the older intruded rocks. Each of these areas show a greater degree of fracturing than elsewhere within the stock. Mineralization is found as disseminations and fracture fillings. Juilland (1970) has postulated at least two generations of copper mineralization. The first is of magmatic stage origin no later than pneumatolytic, while the second is of hydrothermal origin and has taken place after crystallization of the stock when fractures were formed and sustained.

Alteration of the Quartz Monzonite

Typical porphyry copper-type alteration zoning as illustrated by Lowell and Guilbert (1970) is nonexistent. Recognizable hydrothermal alteration of the Lights Creek deposits is unimpressive compared with that accompanying most porphyry copper deposits in the southwestern United States.

Of the three mineralized zones, the Moonlight Valley deposit resembles other porphyry systems. However, sericitic and argillic alteration occur most typically only in the fracture zones and not pervasively throughout the rock. Chlorite is apparent at each of the mineralized areas and has formed at the expense of some of the ferromagnesian minerals. Although the stock is more potassium-rich in the Moonlight area, Juilland (1970) considers only the K-feldspar that occurs in veinlets to be positively hydrothermal and that which occurs as disseminations to have formed during crystallization of the magma (Fig. 6). If this is correct, potassic alteration would also be considered as minimal. However, the nearly complete absence of primary biotite in the stock has led Juilland to further conjecture that it may have been completely destroyed by late deuteric alteration from K-feldspathization and he cites the work of Hemley (1959) and Rutherford (1969) to support this hypothesis.

Tourmaline is the most remarkable mineral associated with the copper deposition. It is found principally as the iron-rich dark variety, schorlite, in both fracture vein fillings and as sunburst blebs throughout the rock. Interesting intergrowths with bornite and chalcopyrite are often associated with both forms of tourmaline (Fig. 7). Quartz commonly occurs with tourmaline in the mineralized veinlets. Epidote occurs throughout the stock in patches and veins and is particularly abundant within the zones of sulfide mineralization. It appears to increase in density closer to the contacts with the intruded rock or where xenoliths are abundant in the quartz monzonite.

Pyrite is relatively scarce in the Lights Creek stock. The predominant sulfides of the system are chalcopyrite and bornite. Magnetite and hematite are present as disseminations and in veins. However, hematite, generally occurring as specularite, is much more prominent in the Moonlight Valley area than magnetite. Specular hematite appears to be more pervasive on the southwest end of the Moonlight Valley deposit where it plunges under the older volcanic cover. This occurrence may represent a flooding front of iron out from the copper mineralized center into the overlying volcanic rock. The absence of pyrite and abundance of hematite at Moonlight Valley is evidence of a low sulfur environment and probably would account for the lack of supergene clay alteration.

Copper Occurrences

Moonlight Valley Deposit

The main ore minerals occurring in the Moonlight Valley deposit are bornite and chalcopyrite with lesser amounts of covellite and chalcocite. Important gangue metallic minerals found with the ore are magnetite, hematite, and lesser amounts of pyrite. Nonmetallic vein minerals accompanying the copper mineralization are quartz, tourmaline, siderite, dolomite, calcite, epidote, chlorite, and rarely actinolite. Typically, there are centers with best copper mineralization which show abundant bornite and minor amounts of chalcocite. As the grade decreases, chalcopyrite increases and bornite decreases. Farther away from the

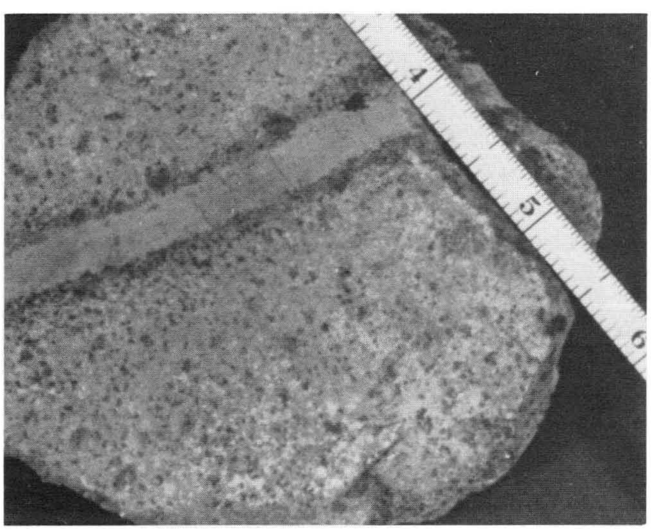

Fig. 6. Veinlet in quartz monzonite showing hydrothermal K-feldspar

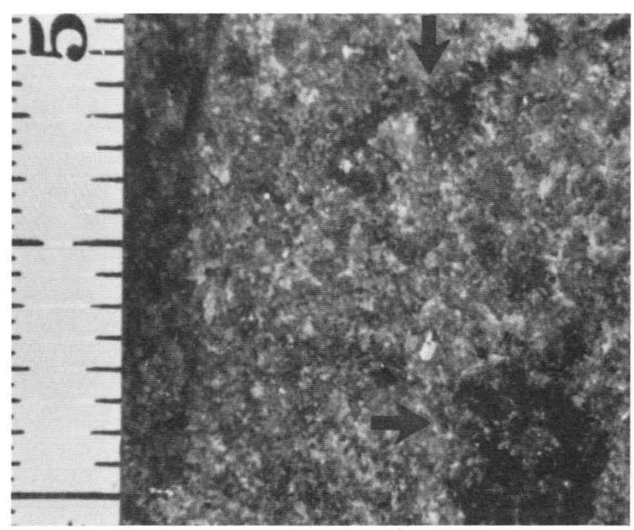

Fig. 7. Quartz monzonite specimen showing an interesting intergrowth of bornite and chalcopyrite associated with tourmaline

high-grade centers, the appearance of increased pyrite indicates even lower grades. Chalcopyrite occupies an intermediate position and perhaps makes up the greatest bulk of the ore. The chalcocite, with few exceptions, is believed to be hypogene. Under the microscope it appears to form exsolution textures with bornite and to replace bornite (Bryner, 1972). Bornite and chalcopyrite also commonly exhibit exsolution features (Bryner, 1972).

Other minerals occurring in very minor amounts are pyrrhotite, molybdenite, sphalerite, galena, tetrahedrite-tennantite, and luxonite. None of these minerals contributes economically recoverable metals with the exception of possibly the tetrahedrite-tennantite, as silver values for the deposit average $\pm$ 0.1 oz per ton.

Very little supergene enrichment has occurred at the Moonlight Valley deposit. Surface exposures and the tops of some holes show meager oxidation and leaching with limited limonite, manganese oxides, malachite, azurite, chrysocolla, and native copper. Sparse sooty chalcocite is found in some holes but certainly does not express a significant enrichment to the orebody.

Although it is difficult to map structure in the Moonlight Valley area because of lack of surface outcrops, it is quite evident from drill-hole information that the better copper mineralization is closely associated with a higher degree of shattering and fracture fillings. Strong structural control for the ore is very apparent. The deposit is broadly arch shaped, conforming to a domelike feature with a long dimension northeast-southwest (Fig. 8). From a limited few deep drill holes it is indicated that the orebody has several roots, with the largest and most persistent under the volcanic cover to the southwest. Geologic surface mapping has suggested a dome in the older volcanics conformable to both the Superior mine and the Moonlight Valley ore zones. Bryner (1972) postulated the occupancy of these domal structures by local apophyses into the roof by the stock. This would mean that these deposits are positioned in the uppermost portions of the stock.

Strong northeast, northwest, and north-south sets of shears in the Moonlight Valley area appear to be important for the overall structural plumbing system for the ore; however, the local brecciation and crackling which is apparent in the best ore zones may be closely related to the plutonic emplacement, perhaps as late resurgence into a semiconsolidated rim. This is substantiated by the fact that there is much less fracturing developed toward the center of the stock than near its margin.

Superior Mine

The Superior Mine mineralization is thought to be of a higher temperature of formation than Moonlight Valley. Anderson (1931) has given good descriptions of the Superior orebody. He has considered the ore-forming minerals to have been introduced under hydrothermal conditions into previously formed higher temperature pneumatolytic gangue minerals.

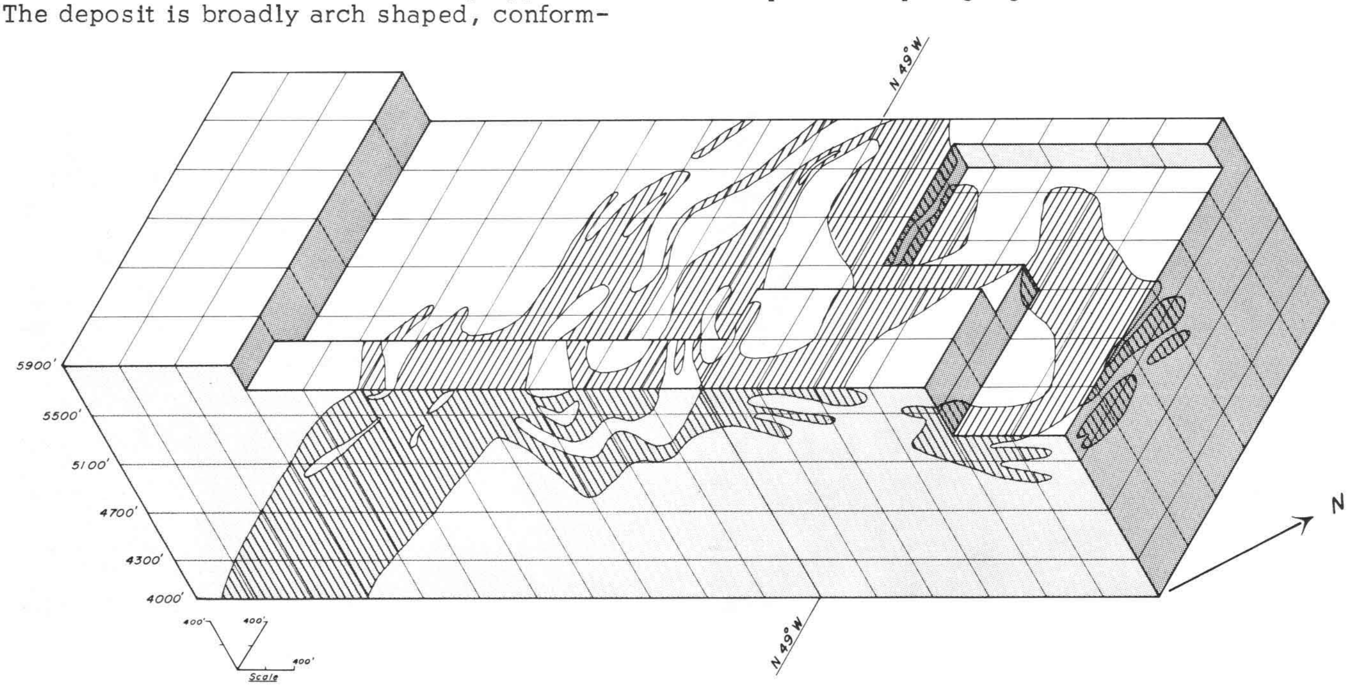

Fig. 8. Block diagram of the Moonlight Valley orebody (from Moonlight Valley drill sections)

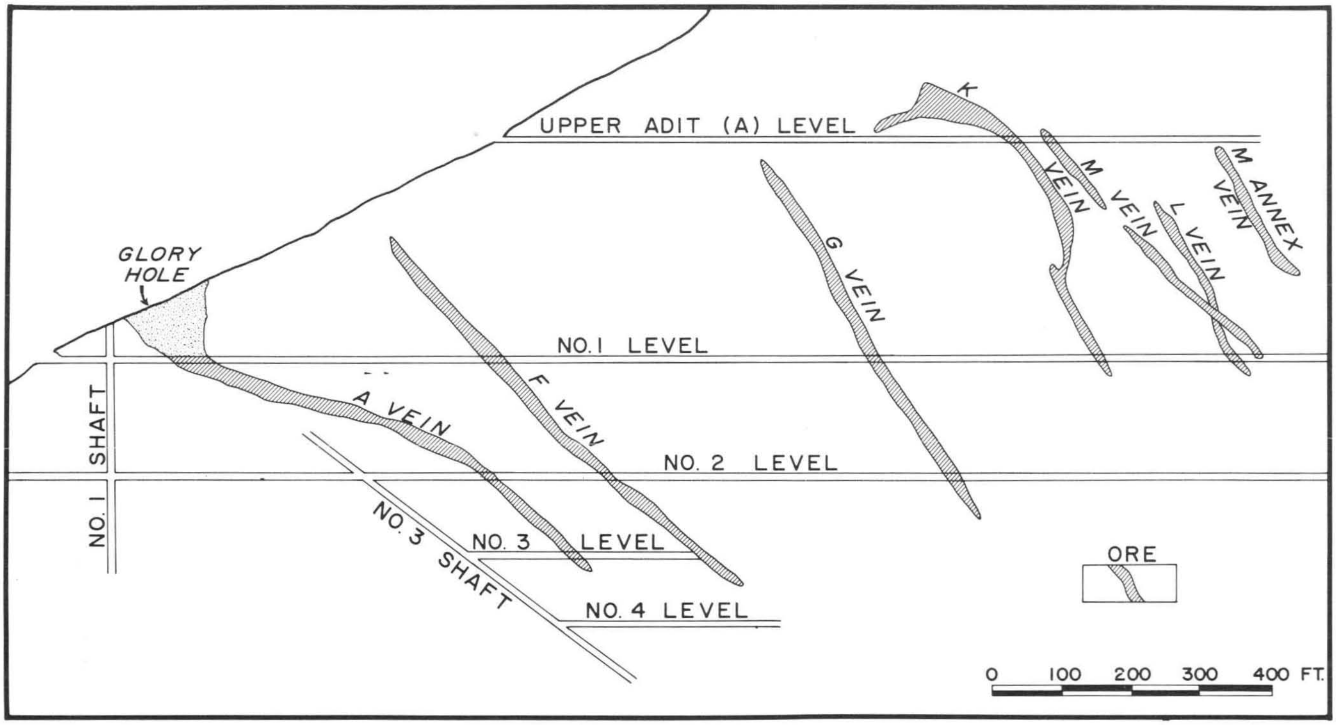

Fig. 9. Diagrammatic cross section of the Superior mine—after Anderson (1931)

The Superior deposit occupies a stockwork around seven parallel, northerly striking, easterly dipping (8 to 10 feet thick) vein zones with accompanying sheeting and brecciation (Fig. 9). Strong N. 30° E. shear zones dipping 55° E. limit the high-grade veining in an east-west direction. Mineralization is enhanced and/or cut off by northwest-striking, southwest-dipping shear zones superimposed on the vein system. The typical mineralized vein zone contains chiefly chalcopyrite with smaller amounts of bornite, magnetite, and pyrite in a dark gangue of black schorlite, green mica, actinolite, quartz, epidote, chlorite, sericite, apatite, titanite, and siderite. Intervein wall rock is also mineralized with disseminations and fracture fillings.

Magnetite is much more prevalent in the Superior area than at Moonlight Valley; however, specularite, which is very strong at Moonlight Valley, is nearly nonexistent at the Superior mine.

Sulfide Ridge Deposit

The Sulfide Ridge copper occurrence is more like the Superior mine than the Moonlight Valley deposit. However, the only subsurface information available for the area is from diamond drill cores. Outcrops show the strong influence of structural control for the mineralization (Fig. 10).

Summary and Conclusions

In summary, it can be stated that the Lights Creek quartz monzonite stock contains large concentrations of copper. These copper-bearing zones are of sufficient cohesion to qualify them as porphyry copper systems. However, some of the features commonly associated with the copper porphyry deposits of the southwestern United States are missing at Lights Creek. Most conspicuously absent are

Fig. 10. View looking east of Sulfide Ridge

the zonal alteration assemblages usually found with such a system. A combination of low sulfur and pyrite with some pneumatolytic rather than hydrothermal introduction of at least a portion of the copper sulfides may have helped to obscure more pervasive alteration. Also, very little supergene activity together with minimal surficial clay alteration has given outcrops a relatively fresh appearance. Some of these and other unique features at Lights Creek may indicate more subtle mineral assemblages that perhaps will lead to copper deposits in the future. The successful exploration results at Lights Creek should encourage the pursuit of nonconventional copper systems. Perhaps this will result in additional new districts being found.

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