THESIS

THE GEOLOGY, ALTERATION, & MINERALIZATION OF THE TURQUOISE LAKE AREA, LAKE COUNTY, COLORADO

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THE GEOLOGY, ALTERATION, AND MINERALIZATION OF THE TURQUOISE LAKE AREA, LAKE COUNTY, COLORADO

Submitted by

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Earth Resources Department

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY STEVEN D. CRAIG ENTITLED THE GEOLOGY, ALTERATION, AND MINERALIZATION OF THE TURQUOISE LAKE AREA, LAKE COUNTY, COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

THE GEOLOGY, ALTERATION, AND MINERALIZATION OF THE TURQUOISE LAKE AREA, LAKE COUNTY, COLORADO

The Turquoise Lake intrusive complex is located on the northeast flank of the Sawatch Range in Lake County, Colorado. The complex is centered on a 35 million year old subvolcanic stock of quartz latite porphyry. The intrusive rocks associated with the explosive emplacement of the stock includes an intensely brecciated border phase surrounding the porphyritic stock center, and dikes of similar composition. Other Oligocene intrusives include early dikes of latite and lake dikes of rhyolite.

North-trending structures reflecting the axis of the Sawatch Range are common throughout the Turquoise Lake area. The Central Fault, a major north-trending fault, is thought to have localized the stock at the juncture with inferred east-west trending structures. Radial faulting found in the Sugarloaf and St. Kevin Mining Districts formed during the emplacement of the Turquoise Lake stock.

Widespread and pervasive alteration halos including a propylitic zone, transition zone, phyllic zone, and quartz-topaz subzone are

centered on the stock. A late kaolinite-sericite zone is found at depth within the stock or in late dikes found above this zone.

Pervasive disseminated pyrite is found increasing up to 10 volume percent toward the stock. Molybdenite is found in the quartz-topaz subzone and in quartz veinlets outside this area.

The rocks surrounding the Turquoise Lake stock are geochemically anomalous in Cu, Mo, Pb, Zn, Sn, W and F. These elements form donut shaped dispersion halos centered on the stock. Two pulses of mineralization are inferred with double halos by the elements Cu, Pb, and Zn. Drillhole geochemistry finds Mo, Cu, and W displaying discrete halo boundaries and increasing values toward the bottom of the holes.

Studies of vein mineralogy relationships from the St. Kevin and Sugarloaf Districts find four episodes of mineralization. These include an early ore preparation stage, main ore stage, late ore stage, and supergene stage. The bulk vein mineralogy consists of a quartz gangue, pyrite, galena, sphalerite, and chalcopyrite. Samples from different locations throughout the mining districts were analyzed for Cu, Mo, Pb, Zn, Ag, Sn, W, and Bi. These metals formed distinct concentration halos spatially associated with the Turquoise Lake stock.

The Turquoise Lake stock has many features associated with known molybdenite ore bodies. These features suggest that potential exists for discovery of a molybdenite ore body at Turquoise Lake.

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INTRODUCTION

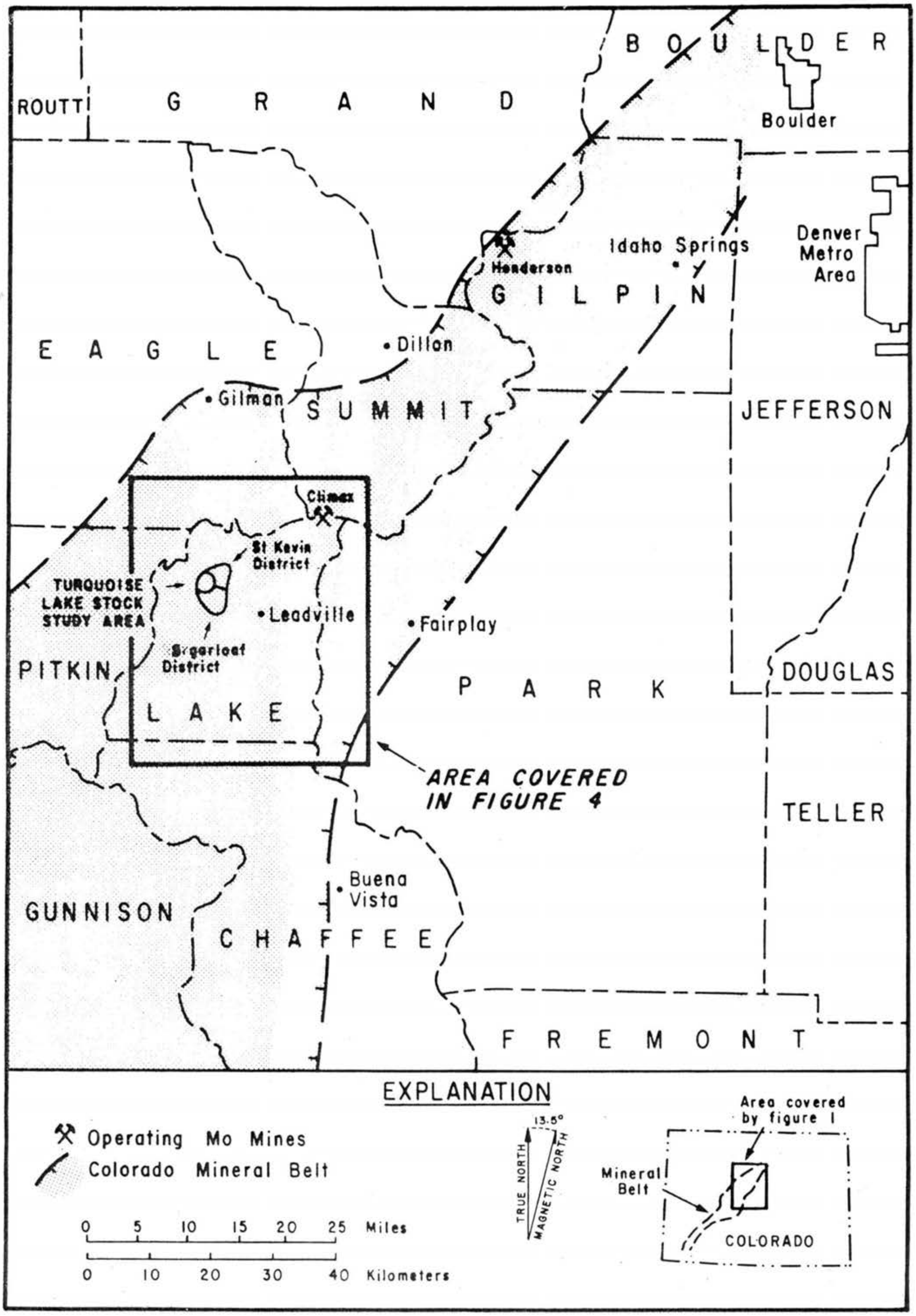
Purpose

Early reconnaissance of the Turquoise Lake area revealed a significant molybdenite occurrence spatially related to the quartz latite intrusive rocks of the Turquoise Lake stock. The purpose of this investigation was to study in detail the geology, alteration and trace element halos, and the potential for significant molybdenite mineralization at depth. A second purpose was to determine the genetic relationship of the vein systems in the St. Kevin and Sugarloaf Mining Districts to the Turquoise Lake stock. It was hoped that this study would provide additional knowledge to the understanding of mineralized mid-Tertiary intrusive systems that are found throughout the Colorado Mineral Belt.

Geographic Setting and Accessibility

The Turquoise Lake stock and adjacent St. Kevin and Sugarloaf Mining Districts (Figure 1) are located on the eastern flank of the Sawatch Range anticline in Lake County, Colorado, approximately six miles west to northwest of Leadville. The study area is found on the U.S. Geologic Survey Homestake Reservoir (1970), Leadville North (1970), and Mount Massive (1967) $7\frac{1}{2}$ minute topographic quadrangles.

Figure 1. Location map of the Turquoise Lake stock study area and adjacent St. Kevin and Sugarloaf Mining Districts. (Modified from Tweto and Sims, 1963.)



BOULDER
Boulder
ROUTT
GRAND
Henderson
Idaho Springs
Denver Metro Area
GILPIN
EAGLE
Dillon
Gilman
SUMMIT
JEFFERSON
Climax
St Kevin District
TURQUOISE LAKE STOCK STUDY AREA
Leadville
Fairplay
Sugarloaf District
PITKIN
DOUGLAS
PARK
LAKE
AREA COVERED IN FIGURE 4
TELLER
Buena Vista
GUNNISON
CHAFFEE
FREMONT
EXPLANATION
Operating Mo Mines
Colorado Mineral Belt
0 5 10 15 20 25 Miles
0 10 20 30 40 Kilometers
13.5°
TRUE NORTH
MAGNETIC NORTH
Area covered by figure 1
Mineral Belt
COLORADO

The hills of the St. Kevin and Sugarloaf Mining Districts start from a base elevation of 9,600 feet and rise to over 11,000 feet. Sharp changes in elevation are not common, with the greatest being 700-800 feet in the glaciated valley of the Lake Fork of the Arkansas Valley. The two mining districts (Figure 2) are separated by Turquoise Lake, a major water storage reservoir. The Turquoise Lake stock (Figure 3) is located on the north shore of the lake. In this area outcrop is not common and the bedrock is covered by glacial material and forest debris.

Main access to the study area from Leadville, Colorado can be obtained by driving west to the Sugarloaf Dam and following the paved Forest Service Road #104 around Turquoise Lake. The Turquoise Lake stock can be reached on foot after parking on the northwest shore of the lake near the Homestake water diversion tunnel. Access to the St. Kevin District is found by following various four-wheel drive roads off the Bear Lake Road or the lower Tennessee Park Road. The Sugarloaf District can be reached by four-wheel drive from the Public Service power line right-of-way one mile south of the Sugarloaf Dam.

History of Early Mining

The St. Kevin and Sugarloaf Mining Districts were known as early as 1878. However, there is evidence that some gold placer mining took place prior to that time in Colorado Gulch. Prospecting

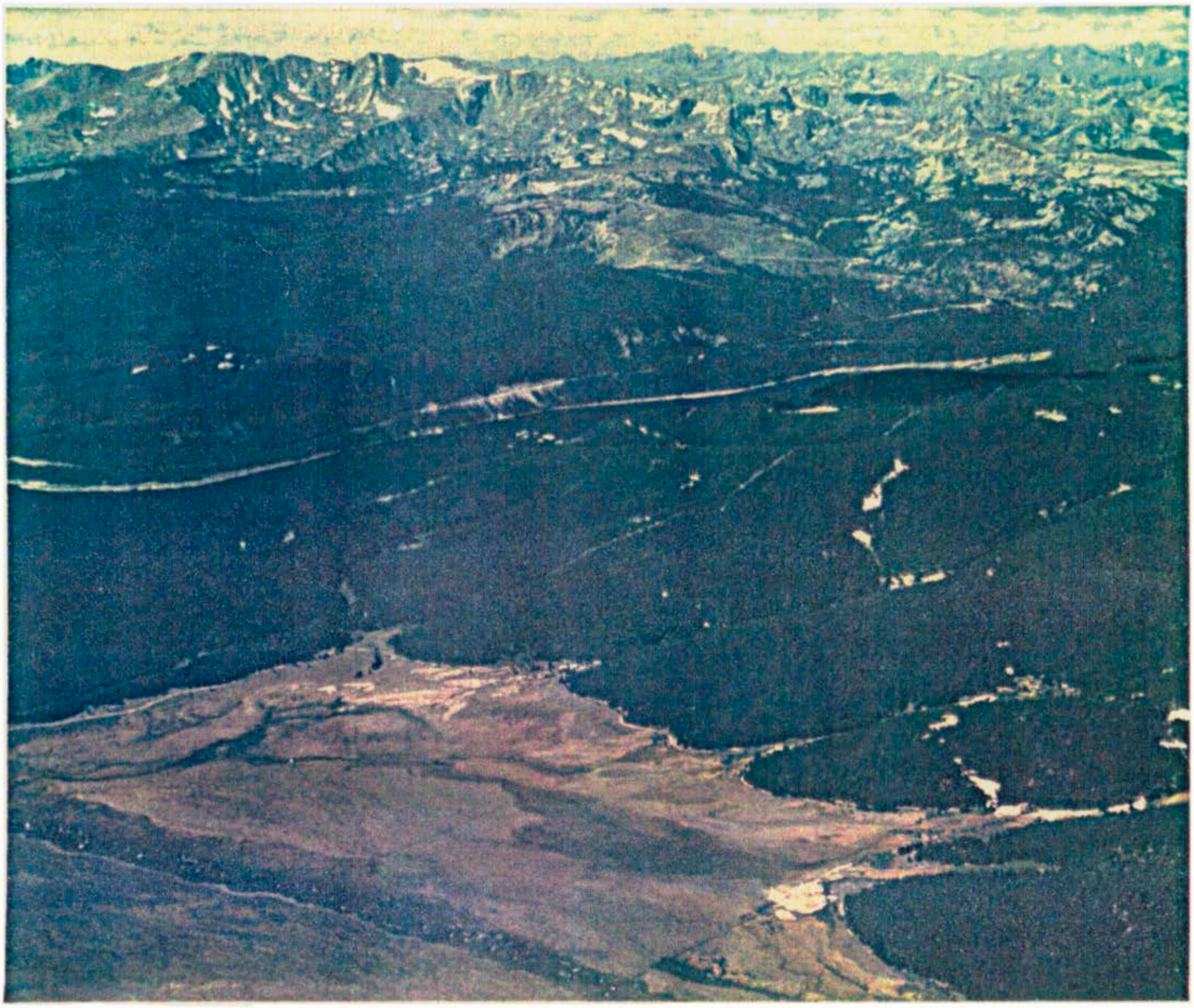


Figure 2. Oblique aerial photograph looking southwest toward St. Kevin Mining District, Turquoise Lake, and the Sugarloaf Mining District with Mt. Massive on the horizon.

Figure 3. Oblique aerial photograph looking northwest toward the Sugarloaf Mining District, Turquoise Lake and Turquoise Lake stock study area.

in the 1880's located most of the productive silver veins in the Sugarloaf and St. Kevin Districts. Tom Walsh, a local prospector, is credited for finding most of the veins that became important producers (Eberhart, 1974).

The period of maximum production for most of the mines occurred around 1890, just before the 1893 drop in silver prices. Presumably, a number of the smaller mines shut down following the silver collapse. However, some of the larger mines maintained continuous production up to World War I. The Dinero Mine, the biggest producer in the Sugarloaf District, continued operations into the 1920's. During the period between 1920 and 1942, mining operations declined with only intermittent work done at several mines. Since 1942 mining activities have virtually ceased with the exception of the tourist-oriented open pit mining at the Turquoise Chief Mine in the St. Kevin District.

Previous Investigations

The geology and mineralization of the St. Kevin and Sugarloaf Mining Districts were not studied by early geologists until after most of the mining activities had ceased. This was understandable since the districts combined production only contributed an estimated 10-15 million dollars (Singwald, 1955) to the state's economy. For comparison, the Leadville Mining District across the valley has produced 512 million dollars in mineral wealth through 1963 (Tweto, 1968).

The first brief mention of the existence of the two mining districts was in the comprehensive report on the Leadville District by Emmons et al. (1927). The master's thesis by Broughton (1938) was the first detailed work done on the St. Kevin and Sugarloaf Districts. Broughton produced a crude geologic map of the two districts along with a comprehensive report on the petrology of the rocks found in these areas. The first detailed description of the veins and the major mines of both districts was published in U.S. Geological Survey Bulletin #1027-E by Singewald (1955). This report had an accompanying geological map which was more detailed than previous work. Other early studies of minor importance included a report on granite alteration by Schwartz (1933) and an ore petrology study of the Sugarloaf veins by Sandburg (1935).

Early regional geologic investigations that included the Turquoise Lake study area were uncommon. The earliest completed was a report and map on Pliestocene glaciation by Capps (1909). The first geological maps and reports of the Sawatch Range were completed by Barnes (1935) and Stark and Barnes (1935). These maps became the basis for all other regional mapping to follow.

More recent regional work has been dominated by Ogden Tweto and his coworkers of the U.S.G.S. (1961, 1962, 1963, 1964, 1968, 1972, 1975 and 1976). Specific subjects include the geochronology of the Laramide Orogeny, age of Laramide porphyries near

Leadville, delineation and cause of the Colorado Mineral Belt, Cenozoic history of the Arkansas Valley, geology and related gravity and magnetic features of the Leadville quadrangle and geologic maps of a regional scope.

No studies dealing specifically with the Turquoise Lake stock have been published. Tweto's Holy Cross geologic map (1974) was the first published map to document the existence of the Turquoise Lake stock and associated alteration. Previous studies did not include the stock area with the adjacent mining districts and it is understandable it remained unknown until recently.

Following publication of Tweto's Holy Cross map in 1974, a major exploration mining company recognized the geologic significance of the Turquoise Lake stock and its associated alteration halo. They subsequently mapped, sampled, and drilled four holes in the stock area. Although none of this work has been made public, certain portions have been made available for use in this report.

Methods of Recent Investigation

Field and laboratory methods were used for this study with emphasis on the field work. Field observations were recorded from mid-June through August of 1978. Mapping was done on an enlarged topographic base map from the U.S. Geological Survey, Homestake Reservoir, Leadville North, and Mount Massive 7½ minute quadrangles with a scale of one inch to five hundred feet (1:6000). Air photos were used to assist in location of many mine workings.

Geologic mapping often had to be performed in large areas with no outcrop. Consequently, float rock and mine dump material had to be utilized and interpreted during the compilation of a geologic map. It is felt this mapping method is fairly accurate since observation of several prospect pits and caved shafts found bedrock approximately 1 to 5 feet below the surface.

Whenever possible, bedrock samples were collected for geochemical analysis. However, as previously mentioned, outcrops are not common and many samples were collected from prospect pits or mine dumps. Approximately 2 to $2\frac{1}{2}$ pounds of rock chips were collected at each sample site. The quartz-sulfide vein samples were collected from mine ore bins or from dumps.

Geophysical studies performed in the Turquoise Lake area included air and ground magnetometer surveys. All surveys were conducted by Bear Creek Mining Company with the author assisting in the ground magnetometer survey. The ground survey, using a Varian M-50 proton precession magnetometer, traversed section lines, roads, and claim lines. The air survey was flown in an east-west direction at a barometric elevation of 11,500 to 12,000 feet.

Laboratory investigations included the examination of 40 surface rock and 97 drill core thin sections and 30 polished vein ore sections by standard petrographic methods.

Rock and vein chip samples were analyzed by Barrenger Inc. and Bondar-Clegg Inc. for copper, molybdenum, lead, zinc, silver, manganese, tin, tungsten, fluorine, bismuth and potassium oxide.

One rock sample of the Turquoise Lake Porphyry was sent to Geochron Inc. in Cambridge, Massachusetts for an age date determination. A sericite concentrate was dated using the Potassium-Argon age dating method.

REGIONAL GEOLOGICAL SETTING

General Statement

The Turquoise Lake area is located in the center of the Colorado Mineral Belt near the northeast flank of the Sawatch Range uplift. The Arkansas Valley Graben, an extension of the Rio Grande Rift Zone dissected the eastern flank of the Sawatch Range during Miocene time, and now forms the eastern border of the range. These two major features have played a direct role in the present exposure level of the Turquoise Lake stock and related vein systems. Figure 4 shows the location of these features.

Precambrian Rocks

The exposed core of the Sawatch Range and Mosquito Range is composed of Precambrian metamorphic and igneous rocks. The metamorphic rocks in the region are largely metasedimentary gneisses consisting mostly of biotite gneiss, schist, and migmatite. Other less common varieties include hornblende gneiss, calc-silicate gneiss, and impure quartzites (Tweto and Case, 1972).

The granitic rocks include several varieties occupying different areas of the region. The St. Kevin Granite, a small batholith occupying 300 square miles, is host to the Turquoise Lake stock and adjacent mining districts. This granite, which intrudes

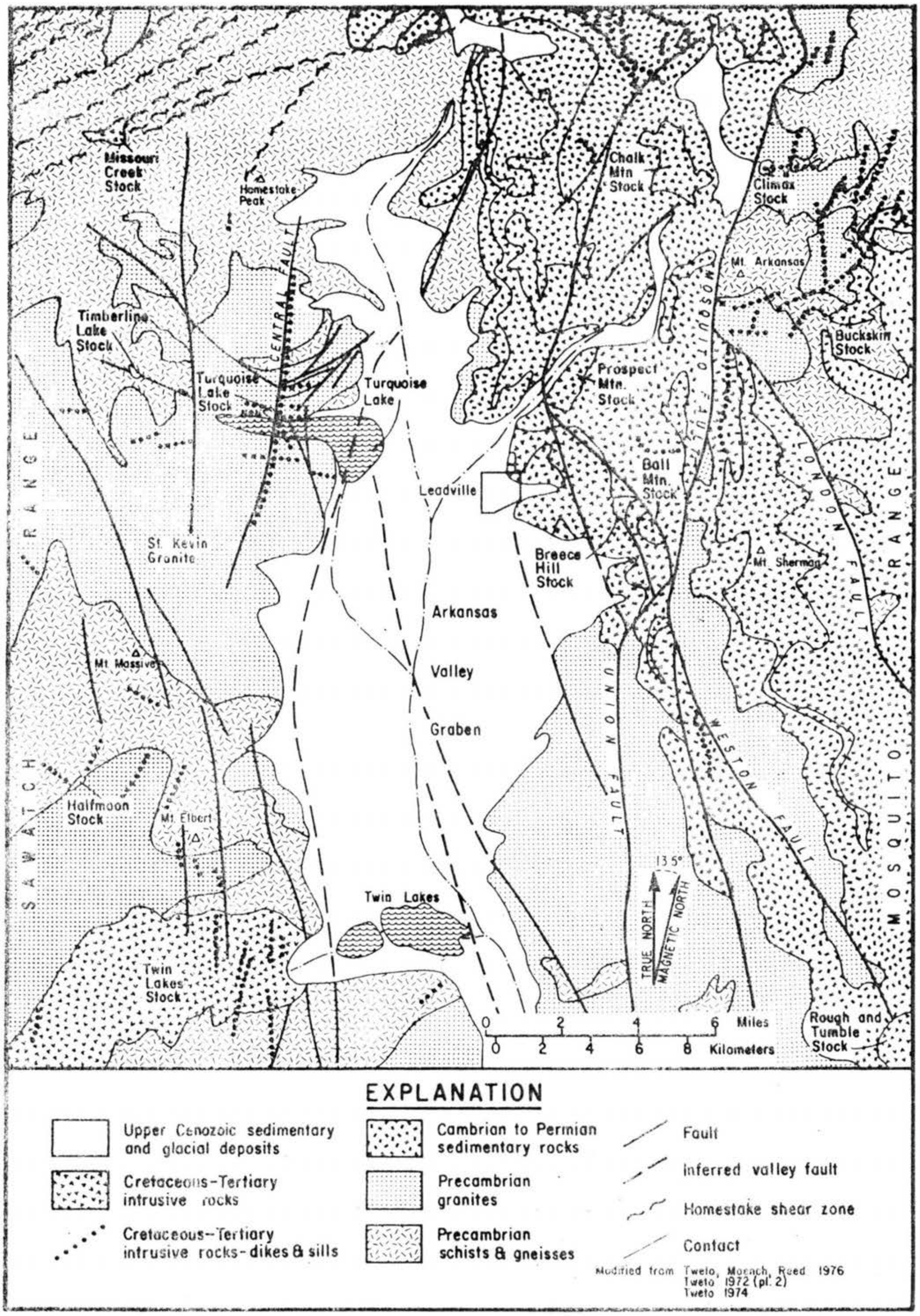

Missouri Creek Stock
Homestake Peak
Chalk Mtn Stock
Climax Stock
Mt. Arkansas
Buckskin Stock
Timberline Lake Stock
CENTRAL FAULT
Turquoise Lake Stock
Turquoise Lake
Prospect Mtn. Stock
MOSQUITO FAULT
Leadville
Ball Mtn. Stock
LONDON FAULT
St. Kevin Granite
Breece Hill Stock
Mt. Sherman
Arkansas
Valley
Graben
Mt. Massive
UNION FAULT
WESTON FAULT
SAWATCH RANGE
MOSQUITO RANGE
Halfmoon Stock
Mt. Elbert
13.5°
TRUE NORTH
MAGNETIC NORTH
Twin Lakes
Twin Lakes Stock
0 2 4 6 Miles
0 2 4 6 8 Kilometers
Rough and Tumble Stock
EXPLANATION
Upper Cenozoic sedimentary and glacial deposits
Cretaceous-Tertiary intrusive rocks
Cretaceous-Tertiary intrusive rocks-dikes & sills
Cambrian to Permian sedimentary rocks
Precambrian granites
Precambrian schists & gneisses
Fault
Inferred valley fault
Homestake shear zone
Contact
Modified from Tweto, Moench, Reed 1976
Tweto 1972 (pl. 2)
Tweto 1974

Figure 4

metasedimentary gneisses and schists, is locally characterized by complex interfingering and stoping along the borders. Other granitic rocks include the Silver Plume Granite found near Climax and the Denny Creek Granodiorite cropping out on Mt. Elbert.

Sedimentary Rocks

Sedimentary rocks of Paleozoic age flank the Sawatch Range on its western, northern, and northeastern margins. The eastern flank of the present range lacks these sedimentary units due to the downfaulting of the Arkansas Valley Graben. The nearest Paleozoic rocks are across the graben flanking the west side of the Mosquito Range.

Rocks of Cenozoic age consist of the upper Tertiary Dry Union Formation and many separate Pleistocene glacial deposits. These units fill the Arkansas Valley with clastic sediments derived from the Mosquito and Sawatch Ranges during uplift and erosion.

Structure

The Homestake shear zone, north of the study area, is the principal Precambrian structural feature in the region. It consists of many individual shear zones trending northeasterly in a belt 7 to 8 miles wide. Tweto and Sims (1963) consider this shear zone and three other recognized shear zones in Colorado to be a major crustal weakness responsible for the localization of the Colorado Mineral Belt.

Faults of Laramide age that were active into Miocene time include the Mosquito, London, Weston, and Union Faults which trend northerly in the Mosquito Range. Sawatch Range faults active during the same period include the Central Fault, the inferred east flanking Sawatch Range fault and other north trending faults. These faults later became elements in the basin-and-range type faulting associated with the formation of the Arkansas Valley Graben during Miocene time.

Upper Cretaceous and Tertiary Igneous Rocks

Two ages of intrusive igneous rocks are found in the Colorado Mineral Belt. The older igneous rocks of late Cretaceous and early Tertiary occur as sills and stocks on the western flank of the Mosquito Range. These include the Pando, Lincoln, Johnson Gulch and Evans Gulch Porphyries near Leadville, the Buckskin stock near Climax, and the Missouri Creek Granodiorite north of the study area (Pearson *et al.*, 1962 and Tweto *et al.*, 1976). The younger Tertiary rocks occur throughout the region mostly as stocks and dikes. The Twin Lakes stock of Eocene age (Ranta, 1974) is a quartz monzonite and may represent an exposed portion of an inferred batholith underlying the Colorado Mineral Belt. The Climax stock of Oligocene age (Wallace *et al.*, 1968) is a composite intrusion of granitic and rhyolitic rocks. Other Oligocene intrusions found in the region include the Chalk Mountain stock (Tweto and Case, 1972), the

Turquoise Lake stock (this report), the Timberline Lake stock (Tweto, 1974), and possibly the Halfmoon Creek stock.

The Colorado Mineral Belt

The Colorado Mineral Belt is characterized by intrusions and related mineral deposits of Laramide and Oligocene age in a belt trending northeasterly across Colorado. Tweto and Sims (1963) have suggested that the mineral belt actually follows several related northeast trending shear zones of Precambrian age. These zones of weakness reopened during Laramide time and allowed invasion of magma to form a wide belt of intrusives. In Oligocene time another widespread intrusive-extrusive event began. This igneous activity continued into late Oligocene to early Miocene time when the major molybdenum deposits of Climax, Henderson, and Mt. Emmons were formed in association with granitic composition rocks.

Recent work by Warner (1978) suggests that the Colorado Mineral Belt is a link in the Colorado Lineament. This structural zone constitutes a fault lineament at least 660 miles long by 96 miles wide trending from Arizona, through Colorado and Wyoming, and possibly into Minnesota. It was suggested that this lineament may represent a Precambrian wrench fault system that forms along continental plate margins during periods of mountain building. The approximate age of this shearing has been established to be from 1.7 to 1.95 billion years old.

GEOLOGY OF THE TURQUOISE LAKE STOCK AREA

General Statement

The limits of the area mapped in this report extend just beyond the extent of the igneous bodies associated with the Turquoise Lake stock (Plate 1). Tertiary intrusive rocks include the stock with related dikes and other dikes of unrelated origin. The host rocks of Precambrian age are granites of the St. Kevin Batholith and metamorphic rocks of sedimentary origin.

Precambrian Rocks

Metasedimentary gneisses and schists

Metasedimentary rocks (pєg) are not common in the study area. Only small isolated outcrops are found where the normal phase of the St. Kevin Granite (pє skn) persists. Many of these outcrops may actually represent xenoliths caused by upward stoping of the St. Kevin Granite during emplacement. Near the boundaries of the study area, these metasedimentary rocks occur with increased frequency and are very common in the Sugarloaf and St. Kevin Districts (Plate 1). These rocks can probably be correlated with the Idaho Springs Formation found in the Front Range.

The majority of schistose rocks in the region includes a variety of facies ranging from pure schist to migmatite. Biotite schist, the most common in the study area, is found as a foliated rock with mineral constituents of biotite, muscovite, quartz, and sillimanite. Quartz and sillimanite are subordinate in size to the mica. Due to oriented mica flakes, unaltered rocks appear lustrous in reflected light with a color range of medium to dark grey. Altered rocks range from a greenish grey, due to chloritization of the mica, to an off white when replacement by sericite occurs. In outcrop the rock weathers to slabby fragments with irregular or jagged outlines.

St. Kevin Granite - normal phase

Four varieties of granite included in the St. Kevin Batholith have been described by Tweto and Pearson (1964). Of these, only two were found in the study area. The oldest igneous phase of these two is the medium- to coarse-grained normal phase of the St. Kevin Granite (pє skn) which is found throughout the study area. In the central area of alteration, outcrops are rare and rock type had to be delineated by prospect pits and float material. However, two areas contain large exposures of the granite. The Silica Ridge area northwest of the stock (Plate 1) represents one of these areas while the long road cut on the south side of the lake provides a view of the granite in transitional contact with the fine-grained phase of the St. Kevin Granite (pє skf). When out of the area of phyllic alteration, the normal phase stands out in bold relief as large cliffs on steep slopes. These outcrops are found to the west and northeast of the stock.

The unaltered normal phase of the St. Kevin Granite (p€skn) ranges in color from light grey to pink. It is an even grained biotite-muscovite granite or quartz monzonite (Tweto and Pierson, 1964). When in close proximity with schists or gneisses, it contains abundant mica-rich streaks which sometimes grade into xenolith fragments. This feature closely suggests an incomplete process of assimulation during the upward stoping of the St. Kevin Granite magma body into metasedimentary rocks.

The normal phase of the granite exhibits a medium-grained, allotriomorphic-granular texture. Mineral constituents include interstitial anhedral quartz averaging 2 to 3 mm, microcline perthite as tabular subhedral to anhedral grains averaging 5 to 6 mm, anhedral plagioclase averaging 2 to 3 mm, with anhedral biotite and subordinate muscovite as streaky clots. Accessory minerals include anhedral zircon and minor apatite. For a more detailed description including whole rock analyses, norms, and modes, refer to Tweto and Pearson (1964).

The average absolute age of the St. Kevin Granite is 1390 ± 60 million years (Pearson *et al.*, 1966).

St. Kevin Granite - fine phase

The fine phase of the St. Kevin Granite (p€ skf) occurs over extensive areas throughout the study area. As before, float and dump material had to be utilized to delineate boundaries of the rock unit. Easily accessible outcrops occur along the highway north of the stock and along the road cut on the south side of the lake (Plate 1). Even though contacts appear to be transitional, the clean texture and map pattern indicates the rock was intruded some time shortly after the normal phase granite had crystallized.

Unaltered samples of the fine phase granite are grey in color with a fine-grained and equigranular texture. Although called granite, it is actually a biotite-muscovite quartz monzonite (Tweto and Pearson, 1964). Large muscovite flakes or clusters up to 1.5 cm across give the rock a spotted appearance when weathered. These large muscovite clots reflect sunlight and facilitate field identification. Phyllic altered specimens display a fine sugary texture which resembles a coarse-grained altered aplite.

In thin section the fine phase granite displays an allotriomorphic-granular texture. Minerals include anhedral quartz as discrete grains 0.5 to 1.5 mm in diameter with anhedral microcline and plagioclase ranging in size from 0.5 to 3 mm in diameter. Biotite forms anhedral flakes 0.5 to 1.5 mm across. Large poikilitic muscovite grains contain all other rock constituents in optically continuous crystals. Accessory minerals include zircon, apatite, and epidote.

For more detail, see Broughton (1938) who gives a detailed description of the St. Kevin Granite and metasedimentary rocks found in the Sugarloaf and St. Kevin Mining Districts.

Tertiary Intrusive Rocks

General Statement

The hypabyssal intrusive rocks of the Turquoise Lake area are considered to be Oligocene in age. The coarse phase of the Turquoise Lake Porphyry (Ttlpc) was age dated at 35.6 ± 1.4 million years (Appendix C). The method used to date the rock was potassium-argon derived from a sericite concentrate. This method actually dates the alteration episode that overprints the rocks after crystallization. Even though there are two possible heat sources, it is felt that the Turquoise Lake stock was the heat engine that caused most of the surrounding alteration, and therefore, the date presented closely follows the actual date of intrusion.

The earliest igneous activity at Turquoise Lake resulted in the passive emplacement of the rock mapped as latite (Tl) in narrow dikes in a pattern generally trending east-west (Plates 1 and 1A). This was then followed by the explosive emplacement of the Turquoise Lake stock and its related rocks of quartz latite composition. Evidence exists to indicate multiple pulsing of the magma chamber with cyclic emplacement, crystallization, and then stoping of the older rocks. The stock has three related phases defined upon texture and location. These phases are spatially related in time and appear to have transitional contacts. The Turquoise Lake Porphyry-breccia border phase (Ttlpbx) is characterized by inclusions of rock fragments, rock flour, and broken phenocrysts. The Turquoise Lake Porphyry-coarse phase (Ttlpc) forms the coarsely porphyritic central mass of the stock. The Turquoise Lake Porphyry-medium phase (Ttlpm) forms dikes characterized by a clean texture due to a more passive emplacement. In areas close to the stock are intrusive breccias (Tibx) where finger-like masses of magma penetrated in a continuous process into the country rock during stock emplacement. Another intrusive rock related to the Turquoise Lake Porphyry series, which is found only in drill hole BL-1, is the late feldspar porphyry (Tlfp). This rock was probably emplaced during a late pulse after cessation of the main episode of intrusive activity. The late rhyolite porphyry (Tlrp), the last intrusive unit emplaced in the area, is thought to be unrelated to the earlier intrusive rocks at Turquoise Lake. This rhyolite was intruded into the Central Fault possibly after late Tertiary movement.

Latite

The rock mapped as latite (Tl) is found as variable width dikes ranging from 6 inches to 10 feet. The dikes are found throughout the immediate study area and the St. Kevin and Sugarloaf Districts. Outcrops containing this rock are not common and float mapping had to delimit the extent of the intrusive. These dikes generally trend in an east-west direction near the stock with occasional exceptions further out from the stock center (Plate 1). Since no absolute cross-cutting relationships could be determined, the relative age to the other intrusive rocks can only be inferred. It is felt that perhaps early magma emplacement followed east-west structures parallel to an inferred fault system that follows the Lake Creek Valley. Due to lack of phenocrysts and an aphanitic texture, this magma must have been rapidly chilled as it was intruded along these planes of weakness. Consequently, no textural changes toward the stock can be discerned in the dikes which perhaps indicates prestock emplacement of the latite rock unit.

In hand speciman, the latite is light buff to light grey in color. Its aphanitic to very fine sugary texture is the most distinctive characteristic of the rock. Small phenocrysts of quartz are rare. The rock is quite dense and fracturing results in small angular shards and larger jointed blocks.

Microscopically, the latite consists of 1 to 2 percent phenocrysts set in an aphanitic groundmass. Generally, the rock contains no phenocrysts, but occasionally isolated quartz grains are present that reach a size of 0.03 mm in diameter. The groundmass consists of an interlocking mosaic of quartz and feldspar altered to sericite. These groundmass grains average 0.04 to 0.05 mm in diameter and have a micropoikilitic texture where sericite or clay overprint the quartz.

Turquoise Lake Porphyry - breccia border phase

In contact with the Precambrian granites and surrounding the coarse phase of the stock is the breccia border phase of the Turquoise Lake Porphyry (Ttlpbx) (Plate 1 and 1A). The breccia border phase also occurs around the east trending coarse phase dike east of the stock, and as dikes to the east and northeast of the stock. This unit is exposed in outcrops on the south side of the stock, as dump material of a few prospect pits, and as float. The rock is essentially an intrusive breccia but for reasons of genesis is separated from the other intrusive breccia (Tibx) unit described later in this chapter. The surface dimensions of the Turquoise Lake stock as defined by the breccia border phase are approximately 1,000 feet by 2,000 feet elongated along an axis trending northwest.

The megascopic appearance of the breccia border phase is quite variable due to its complex history of intrusion and its position relative to the stock border. The rock weakly resembles the coarse phase with major differences being that the phenocryst size is smaller, phenocryst volume is less and it is crowded with small rock fragments and rock flour. The large sanidine phenocrysts of the coarse phase are the most obvious feature lacking in the breccia border phase. Rounded xenoliths are mostly cognate with minor amounts of Precambrian granites and schists present.

Microscopically, the breccia border phase (Figure 5) is a microbreccia with a porphyritic-aphanitic texture and a felty microcrystalline groundmass consisting of quartz and sericite. The rock is fine- to medium-grained containing broken phenocrysts of feldspar, quartz, and biotite in various amounts. Accessory minerals include corroded and broken zircon and leucoxene.

<u>Turquoise Lake Porphyry - coarse phase</u>

The central portion of the Turquoise Lake stock and the east trending dike east of the stock are composed of the coarse phase of the Turquoise Lake Porphyry (Ttlpc) (Plate 1). In these areas the rock unit is found only as float and dump waste. The central portions of the stock and adjacent dike exhibit the largest phenocrysts of any porphyry in the area. When compared to the intensely brecciated borders of the stock and dike, this unit is distinctive and mappable. Surface rock evidence suggests that a stable crystallizing magma existed in the center of the stock and dike. In detail, however, the coarse phase as seen in diamond drill hole BL-2 (Plate 1A) passes into and out of finer-grained rock at least five times. The coarse phase may gradually change downward into a rock of finer grained texture and this fine-grained rock may exhibit chilled borders and autobrecciation. The development of this interesting feature can be explained by a magma chamber that continually pulses. After rapid growth of the cylindrical stock chamber due to explosive fracturing and penetration of overburden, the stock underwent a pressure quenching sequence associated with volatile loss. This mechanism allowed the magma to reintrude into itself in a retreating-advancing fashion. The finer grained portions of the drill hole approaches the texture defined by the medium phase of the Turquoise Lake Porphyry (Ttlpm).

The entire stock area has undergone phyllic alteration. As expected, the color of the rock is an off-white to light grey due to variable intensities of seritization and silicification. The coarse phase is a porphritic-aphanitic quartz latite porphyry with phenocrysts of sanidine, plagioclase, quartz and biotite. Feldspar type was based on size, habit, and comparison to unaltered versions of the Lincoln Porphyry which Tweto (1974) originally assigned to the Turquoise Lake Porphyry. Plagioclase is the most common mineral constituting up to 30 percent of the rock. The phenocrysts range in size from 1 to 5 mm and occur as subhedral individuals, twins, and clusters. Sanidine ranges up to 4 cm while comprising only 5 percent of the rock. Some of the smaller sanidine phenocrysts could easily be grouped with plagioclase and therefore yield a lower total volume. The large phenocrysts are all euhedral with some appearing to have had albite rims. Anhedral, rounded quartz exhibiting strong resorption makes up 15 percent of the rock and averages 3 mm in diameter within a range of 0.5 to 8 mm. Euhedral to subhedral biotite constitute 8 percent of the rock with a size range of 0.5 to 1.5 mm. The groundmass, although aphanitic, appears to be "trashy" and crowded with crystallites.

Microscopically, the texture of the coarse phase is porphyritic-aphanitic with a felty microcrystalline groundmass consisting of quartz, sericite, small rock fragments, and rock flour. Quartz grains are intensively fragmented, embayed, and display boundaries deeply corroded and partially replaced by sericite. Relict twinning of feldspars is often indicated by oriented sericite flakes under crossed nicols. Biotite appears ragged due to total replacement by sericite, leucoxene and pyrite. Accessory minerals include corroded and broken zircon and leucoxene.

Turquoise Lake Porphyry - medium phase

The medium phase of the Turquoise Lake Porphyry (Ttlpm) forms dikes extending as much as one mile away from the stock (Plate 1). These dikes, which sometimes exhibit flow foliation along their borders, occur in widths ranging from 2 feet to 500 feet. On the south side of the lake a wide pronglike mass of the medium phase parallels the Central Fault. The extreme southern portion of this dike exhibits chilling with loss of all megascopic phenocrysts while gaining prominent viscous flow lines. While this particular dike

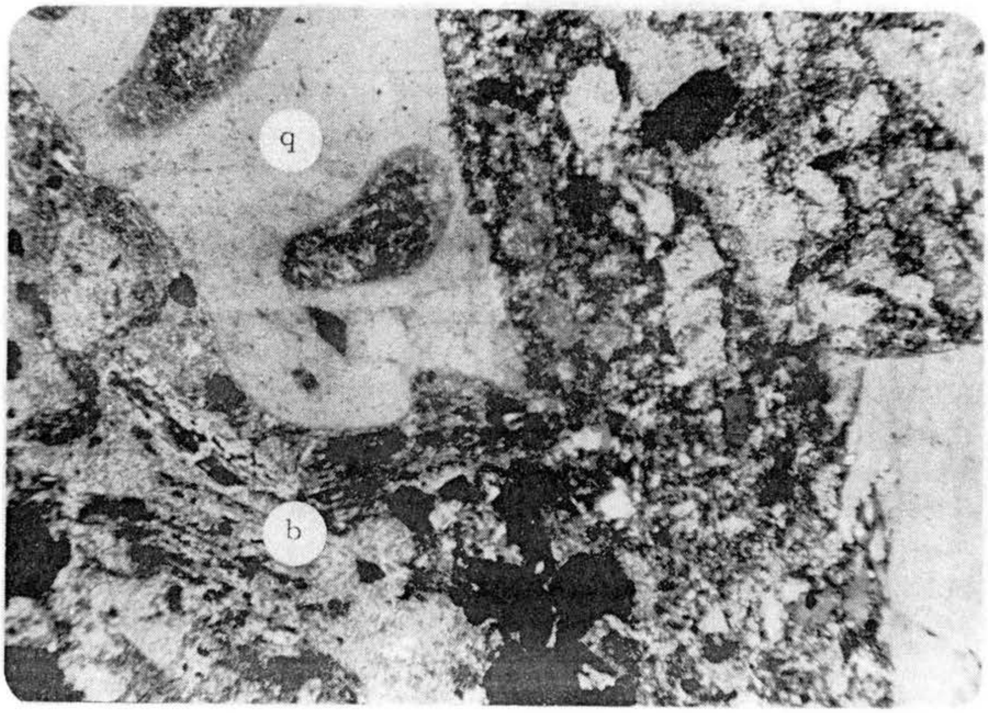


Figure 5. Photomicrograph of thin section no. BL2-36, crossed nicols. Photo dimensions are 1.7 mm x 2.5 mm. Turquoise Lake Porphyry-breccia border phase (Ttlpbx) with variable size groundmass materials due to auto brecciation. Note the embayed and corroded quartz phenocryst (q) and the three relict biotite books (b). The black spots represent pyrite. All minerals other than quartz have been altered to sericite.

increases in width toward the stock, its extent under Turquoise Lake is unknown. However, it appears that the dike was derived from the stock and localized along the Central Fault. A smaller mass of medium phase porphyry is found to the east of this large dike. It is found on a large dump surrounded by glacial debris and talus. Two dikes in outcrop were found; one on Silica Ridge (Plate 1) and the other along the shoreline east of the stock. These dikes exhibit chilled borders but rapidly grade into medium phase porphyry in their centers. Diamond drill hole BL-1 intercepted and bottomed in a possible dike of medium phase porphyry.

The medium phase porphyry (Figure 6) has several subtle characteristics in common with the coarse phase of the Turquoise Lake Porphyry. Foremost of these features are the similar phenocryst types and accessory mineral content. However, the phenocryst size is smaller and the density is less than its coarse grained counterpart. Exact volume percent of the total phenocrysts varies due to the width of the dikes and the amount of chilling which has taken place. The narrow chilled dikes exhibit about 10 percent phenocrysts while the larger dikes approach 30 percent by total volume. Feldspar usually dominates in size and volume over quartz and biotite. Subhedral feldspar constitutes from 8 to 25 percent of the rock with size range from 2 to 5 mm. Quartz comprises 2 to 8 volume percent of the rock and is present as 1 to 3 mm anhedral

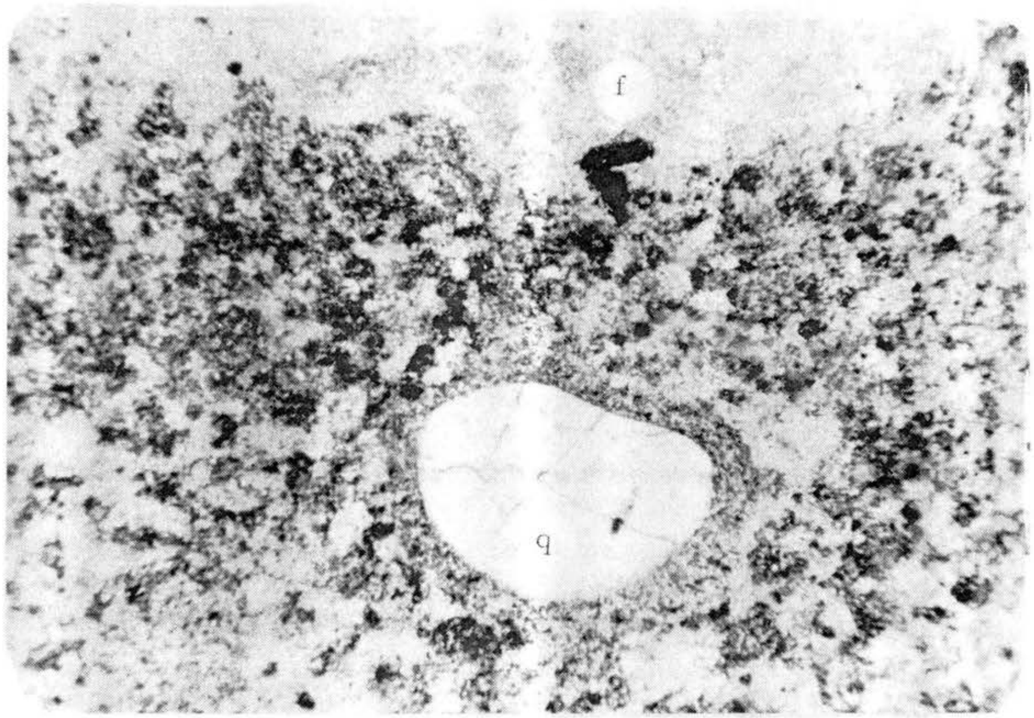


Figure 6. Photomicrograph of thin section no. 17311, crossed nicols. Photo dimensions are 1.7 mm x 2.5 mm. Turquoise Lake Porphyry-medium phase (Ttlpm) exhibiting general character of the rock. Note the reaction ring around the quartz (q) phenocryst and the subhedral feldspar (f). Sericite has replaced all minerals other than quartz.

resorbed grains. Biotite occurs as subhedral grains with volume ranging from 1 to 5 percent. Accessory minerals include euhedral to subhedral zircon and corroded leucoxene. The groundmass is free of xenolith material.

Intrusive breccia

The stock is surrounded by many isolated occurrences of intrusive breccia (Tibx). Only two of these were found in outcrop while the others were located on the basis of float distribution. The majority of the breccias were mapped on the east side of the stock (Plate 1) with one to the west and two others on the south side of the lake. It is thought that this breccia phase represents the upper distal portion of the Turquoise Lake stock during its initial explosive emplacement or during any one of its late pulses. It is also thought that with increasing depth this intrusive breccia possibly grades into wider dikes of the breccia border phase of the Turquoise Lake Porphyry (Plate 1A).

The breccia exhibits phyllic alteration with various intensities of silicification. Its color is an off white to grey with limonites filling fractures. The type of fragments found in the breccia depends upon the location relative to the stock. Breccia fragments include Precambrian granites and schists and coarse and medium phases of the the Turquoise Lake Porphyry. The fragments are cemented by a chilled version of the Turquoise Lake Porphyry or by silicified rock flour. The breccia fragments range in size up to 10 inches in diameter. The angularity of the fragments vary from well rounded to very angular, with each breccia dike having mixed representatives of both. Occasionally, the breccia dikes exhibit a vuggy texture indicating associated degassing of the deeper intrusive mass.

Late feldspar porphyry

The only occurrence of the late feldspar porphyry (Tlfp) is found in diamond drill hole BL-1 from 528 feet to 575 feet (Plate 1A). The rock is intensely altered with all feldspars and groundmass replaced by sericite and kaolinite. The contact of the late feldspar porphyry with Precambrian granites exhibits sharp chilled borders. Internally, the dike is "trashy" with many small phenocrysts, pyrite cubes, and grains of sphalerite and galena. These latter components yield a pronounced geochemical signature in the base metals. Even though no crosscutting relationships with the other Tertiary intrusive rocks were found, it is felt that the emplacement of this rock was the last igneous event associated with the Turquoise Lake stock. The intense kaolinization found in the late feldspar porphyry provides evidence that the rock was present during the late kaolinite alteration episode.

Microscopically, the late feldspar porphyry appears to be either a quartz latite or rhyolite in composition. However, this assumption is very tenuous due to the nature of intense alteration. Texture is porphyritic-aphanitic with phenocryst content increasing from 10 percent by volume on the margins to 50 percent in the central portion. Typically, the phenocrysts are sanidine, plagioclase, quartz, and biotite. The larger sanidine forms 1 to 4 mm euhedral individual and twinned phenocrysts up to 10 percent by volume in the rock. These have been altered to green sericite. The smaller plagioclase occupy approximately 30 percent of the rock and range in size from 0.5 to 1 mm. Embayed quartz occupy from 5 to 10 percent of the rock and range in size from 0.5 to 3 mm. Biotite occupies 1 to 2 percent of the rock as subhedral books. The groundmass is a felted mosaic of quartz, sericite and kaolinite.

Late rhyolite porphyry

The late rhyolite porphyry (Tlrp) was found only as float with larger concentrations being recorded as an expression of its bedrock location. It was found cutting the approximate southern border of the Turquoise Lake stock (Plate 1). On the south shore of the lake, it was also found separating and filling the eastern contact between the large dike-like mass of the medium phase of the Turquoise Lake porphyry and the host Precambrian granites. North of the study area on a ridge overlooking Porcupine Gulch, this rock was found filling the Central Fault. Since no outcrop was available, it is difficult to assign a relative age relationship with the other intrusives. However, because of its "cleaner" appearance and its characteristic blocky form, it is felt that the rock was emplaced in a quiescent period following the more explosive emplacement of the main stock. In the stock area, the rock is altered to kaolinite-sericite indicating it was at least present during the late kaolinite alteration activity. Tweto and Case (1972) thought this rhyolitic rock was emplaced close to the present erosion surface and is therefore very young.

The late rhyolite porphyry is a light grey to pinkish rock where unaltered and a buff color when altered. On the ridgeline overlooking Porcupine Gulch, the rock in outcrop forms a blocky, columnar jointed pattern normal to the contact. This type of jointing is distinctly characteristic of the rock and was observed in float near the stock and on the south shore of the lake.

The rhyolite consists of up to 20 volume percent phenocrysts of feldspar, quartz, and biotite set in an aphanitic groundmass. The feldspar, which in all cases is altered or weathered out leaving cavities, forms 5 mm euhedral phenocrysts or twinned and clustered aggregates occupying up to 15 percent of the rock. Quartz forms 1 to 4 mm, rounded and resorbed phenocrysts with a volume of 1 to 3 percent. Biotite occurs as thin euhedral books 1 to 3 mm wide comprising up to 5 percent of the rock. The groundmass is a fine mosaic of quartz and feldspar altered to sericite or clay.

Quaternary Deposits

Three types of Quaternary deposits have been mapped in the Turquoise Lake stock area. These include glacial drift, landslides, and ferrugenous breccia. For mapping simplicity, areas containing deep swampy soils and some alluvium were included with the glacial debris.

Glacial drift

Approximately half of the study area is covered by glacial drift (Qg) (Plate 1). These deposits consist of silt, sand, gravel and boulders that show little evidence of sorting or consolidation. Glacial drift forms lateral moraines on both sides of Turquoise Lake approximately 800 feet off the valley floor, and recessional moraines north of the study area toward Bear Lake. Other small deposits occur along the flanks of the valley or valley floor as thin coverings. Some of these deposits include rounded boulders with diameters up to 10 feet across that have rolled off the valley walls after retreat of the ice.

The hummocky lateral and recessional moraines mentioned above usually formed barriers across stream channels. These areas consequently filled up with fine silts and sands derived from the glaciers or later stream activity. The flat or swampy areas occur adjacent to the lateral moraines and in potholes of the recessional moraine.

Small areas of alluvium were included with the widespread glacial debris. These features include several small alluvial fans where modern streams deposited material onto the valley floor.

Landslides

Two landslides (Qls) occur in the mapped area. The larger one forms a basin on the southeast side of the lake (Plate 1). After glacial retreat, the combination of a steep valley wall, altered fault zones, and jointing parallel to the valley caused the rock mass to slump 500 feet into the valley. The second, smaller landslide is found flanking the east side of Silica Ridge. Both slides exhibit hummocky topography typical of slope failure.

Ferricrete

Ferricrete (Qf), also called ferruginous breccia, is found as several localized masses near the valley floor (Plate 1). This type of breccia reflects areas of high pyrite content, particularly where wide pyrite-quartz veins exist. This unusual rock is formed when oxidation of pyrite releases dissolved iron into surface waters. After certain reducing conditions take place, the iron is released as limonite and fills the interstices of gravel deposits, effectively cementing them into a breccia or conglomerate.

STRUCTURE

General Statement

The structural features in the Turquoise Lake region were formed during four periods of deformation and orogeny. The earliest is described by Stark and Barnes (1935) where Precambrian schists were deformed into overturned isoclinal folds and then intruded by igneous material. During late Cretaceous to early Tertiary time, mountain building of the Laramide Orogeny took place with uplift of the Sawatch Range. This was followed by further uplift of the Sawatch Range during Oligocene time along with the emplacement of the Turquoise Lake stock. Late Miocene to early Pliocene movement associated with the Rio Grande Rift in the upper Arkansas Valley completed the mountain building episodes as we know them.

Sawatch Range Structures

Uplift of the Sawatch Range occurred during the Laramide Orogeny and then either continued intermittently or dramatically uplifted again during Oligocene time. In Miocene and Pliocene time further movement took place giving rise to basin-and-range type faulting associated with the Rio Grande Rift. The Turquoise Lake area rests on the eastern flank of the Sawatch Range anticline where it is cut by many north-south trending faults formed by extensional stress parallel to the axis of the range. The principal fault through the study area is named the Central Fault due to its central proximity to the stock. This structure is traceable for many miles north and south of the stock area and is characterized by emplacement of porphyritic intrusive rocks along its extent. Post-intrusive movement with subsequent shearing of these porphyries offers evidence the fault was active over a large time span. Even though major movement seems probable along the Central Fault, the amount of throw is only speculative.

Many north-south trending, vertical to near vertical fault structures are exposed along the roadcut on the southside of the lake and in outcrop near the north shore line of the lake. Although small quantities of gouge and associated broken rock indicate movement, it is evident that the uplift of the Sawatch Range in this area formed in response to perhaps a combination of doming and stairstep faulting. However, with the lack of a convenient marker unit, the exact style and sequence of events during uplift can only be postulated.

The eastside boundary fault of the Sawatch Range nearly parallels the trend of the Central Fault. Although this fault is partly inferred and partly known from seismic studies (Tweto and Case, 1972), it is probably a major stairstep fault that follows the same pattern as that of the Central Fault. Furthermore, this fault is a major element in the basin-and-range type faulting that divides the Sawatch Range and Arkansas Valley Graben.

Faulting Due to Intrusive Emplacement

With the forceful emplacement of the Turquoise Lake stock, a radiating pattern of faults was produced. Figure 40 in the vein mineralization section presents the general strike and dip of these faults, many of which were subsequently mineralized. The character of this radial pattern changes to the west of the Central Fault. Detailed mapping by Tweto (1974) points out that the faulting west of the Central Fault in the Sugarloaf District is generally north-south and follows the axis of the Sawatch Range. However, the regional mapping done by Tweto et al. (1978) points out a radial and circular pattern of faults extending up to 5 miles from the stock in all directions. As pointed out in the vein mineralization section, the area west of the Central Fault lacks the same degree of mineralization as found east of the fault. It is possible that movement along the Central Fault uplifted the area west of the stock and subsequent erosion removed evidence of radial faulting and high grade mineralization.

Structural Localization of the Turquoise Lake Stock

It is felt that several local structural features controlled the localization of the Turquoise Lake stock. The most important of these features is perhaps the Central Fault. Since the fault existed before Oligocene time, its roots probably tapped the magma chamber at depth. Molten material forced its way along the fault, replacing the wall rocks for distances up to 4 miles north and south from the stock center.

Inferred east-west structures as evidenced by dikes of latite and Turquoise Lake Porphyry could be another localizing agent. These porphyry dikes trend in an east-west direction parallel to the Lake Fork Valley. Even though fault traces could not be found, east and west of the stock center are porphyry dikes trending into the stock. This suggests there might be subtle, parallel east-west faulting in the region with one of these faults localizing the main intrusive episode.

A third localization feature is tentatively attributed to doming in the Precambrian rocks. The doming occurred when the sequential intrusions of the St. Kevin normal and fine phase granites into schists and gneisses took place in Precambrian time. The Turquoise Lake stock is emplaced near the center of this broad structure; however, its location may be an instance of coincidence rather than one of actual causative relationship.

HYDROTHERMAL ALTERATION

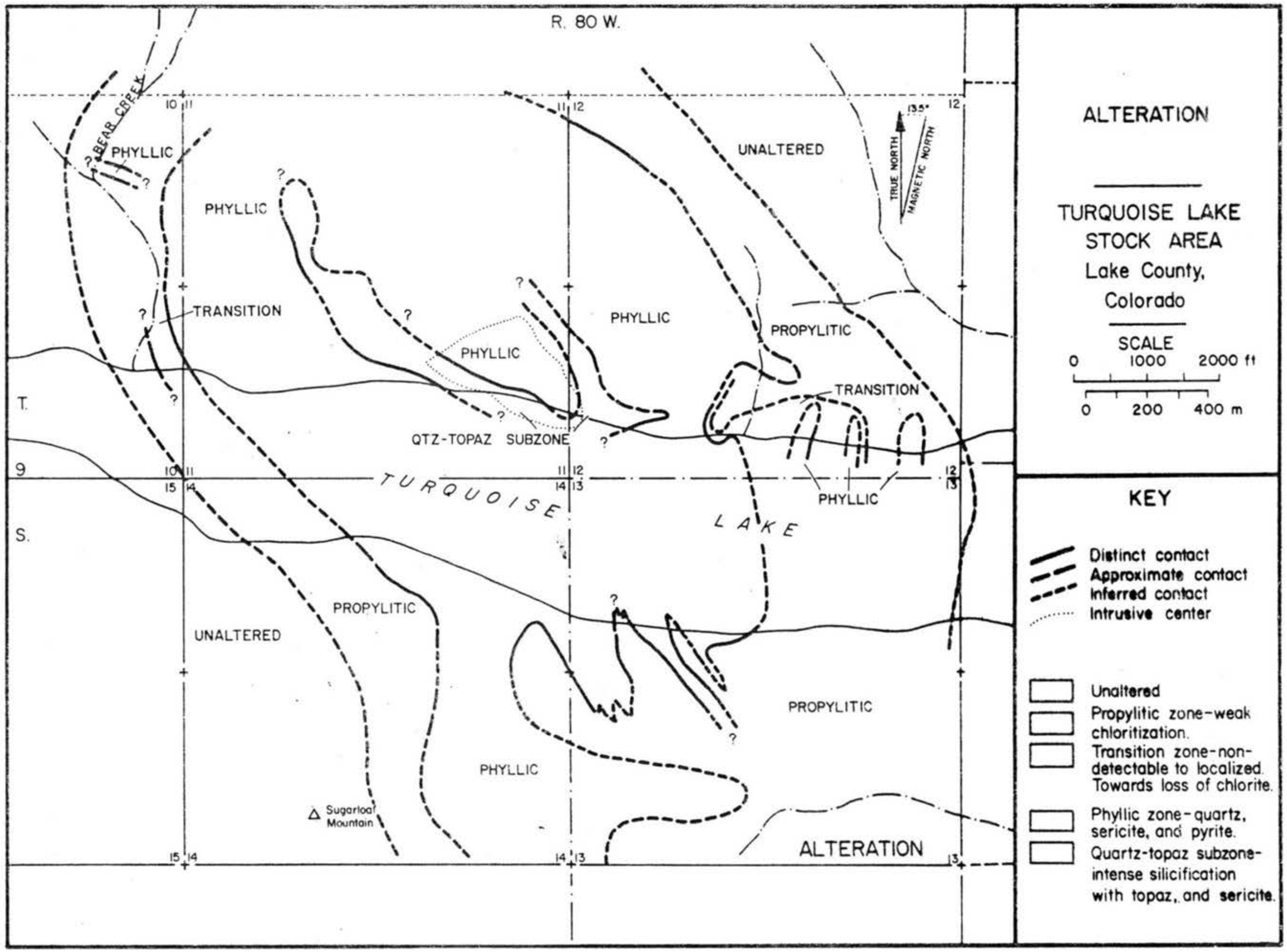
General Statement

Four hydrothermal alteration zones (Figure 7) of varying intensity are associated with and centered on the Turquoise Lake stock. These zones include a propylitic zone, a transition zone, a phyllic zone, and a quartz-topaz subzone. A fifth alteration zone, the kaolinite-sericite zone, is found at depth within the stock (Figure 8). Alteration zoning was observed and defined by field observation, petrographic study of representative specimens, and X-ray diffraction identification of representative and problem specimens.

Alteration modeling of this system included concepts presented by Lowell and Guilbert (1970), Hemley and Jones (1964), Mackenzie (1970), and many others.

Propylitic Zone

The propylitic zone is the outer alteration halo formed in response to the hydrothermal fluids associated with the Turquoise Lake stock (Figure 7). This zone is characterized by minor quantities of chlorite, epidote, sericite, magnetite and clay. Calcite is not present. The overall intensity of the propylitic alteration is considered to be weak. This property makes delineation of the outer



R. 80 W.
ALTERATION
TURQUOISE LAKE
STOCK AREA
Lake County,
Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
Distinct contact
Approximate contact
Inferred contact
Intrusive center
Unaltered
Propylitic zone-weak chloritization.
Transition zone-non-detectable to localized. Towards loss of chlorite.
Phyllic zone-quartz, sericite, and pyrite.
Quartz-topaz subzone-intense silicification with topaz, and sericite.
BEAR CREEK
PHYLLIC
UNALTERED
PROPYLITIC
TRANSITION
QTZ-TOPAZ SUBZONE
TURQUOISE
LAKE
TRUE NORTH
MAGNETIC NORTH
13.5°
T.
9
S.
Sugarloaf Mountain
ALTERATION

Figure 7

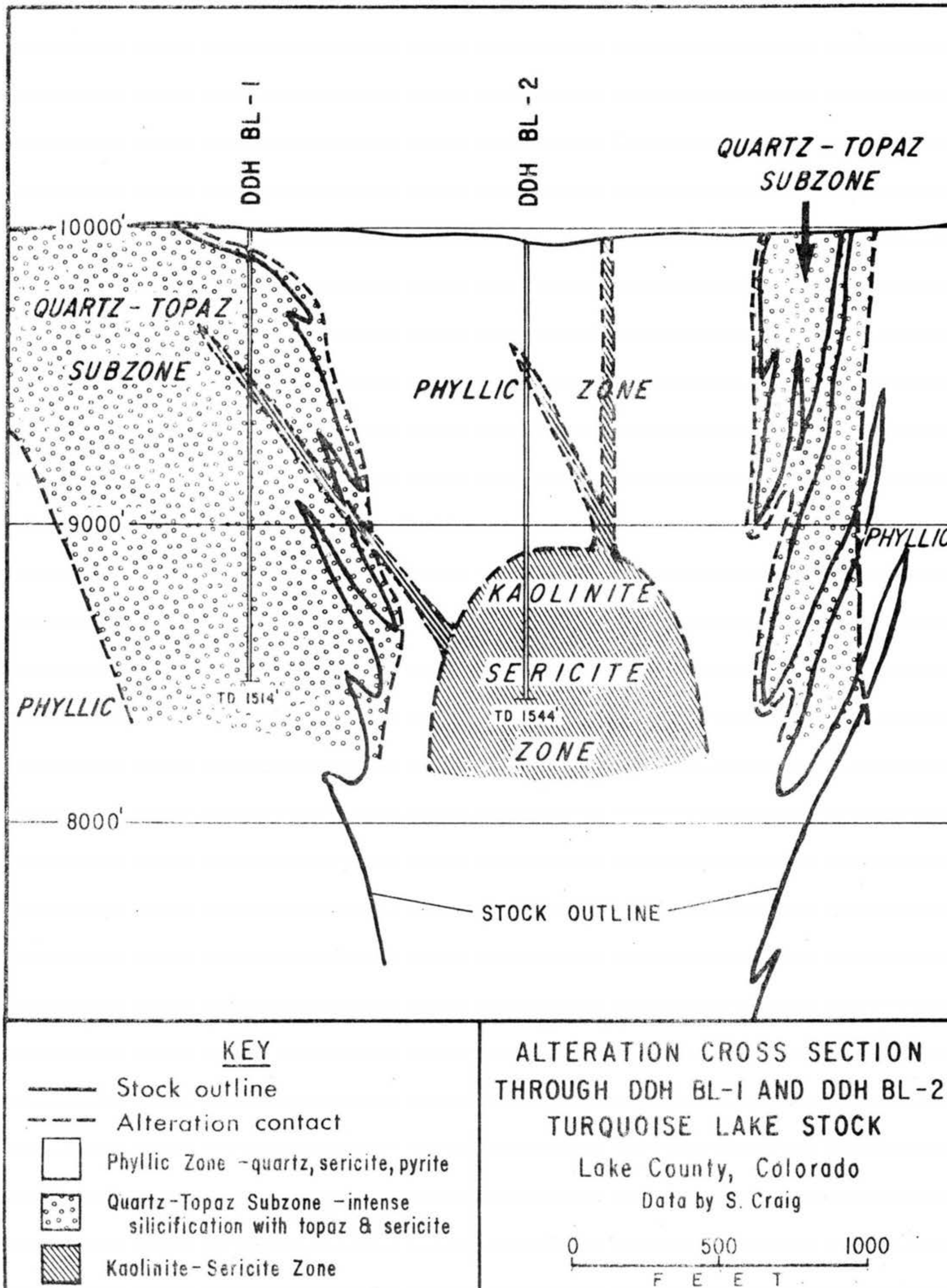

DDH BL-1
DDH BL-2
QUARTZ - TOPAZ
SUBZONE
10000'
QUARTZ - TOPAZ
SUBZONE
PHYLLIC ZONE
9000'
PHYLLIC
KAOLINITE
SERICITE
ZONE
TD 1514'
TD 1544'
PHYLLIC
8000'
STOCK OUTLINE
KEY
Stock outline
Alteration contact
Phyllic Zone - quartz, sericite, pyrite
Quartz-Topaz Subzone - intense silicification with topaz & sericite
Kaolinite-Sericite Zone
ALTERATION CROSS SECTION
THROUGH DDH BL-1 AND DDH BL-2
TURQUOISE LAKE STOCK
Lake County, Colorado
Data by S. Craig
0
500
1000
FEET

Figure 8

boundary difficult to interpret due to its fresh rock appearance. The inner boundary is defined by complete loss of chlorite and epidote.

The alteration products of chlorite and epidote are derived from biotite, plagioclase, and occasionally microcline. Sericite is found throughout the alteration zone partially replacing all minerals. In all cases, it is found in greater volumes replacing plagioclase than in biotite and microcline. Kaolinite is rare and replacement of feldspars is not common.

The separation of the propylitic zone from unaltered rocks and the more advanced alteration of the transition zone is based entirely on the chloritization of biotite. Brown biotite, a common mineral found in the fine and normal phases of the St. Kevin granite, was used as an indicator mineral to record advancing degrees of propylitic alteration. In early alteration brown biotite is pseudomorphously converted to green biotite initially along grain boundaries and then into the grain interior. As the alteration intensity increases, the green biotite is converted into chlorite. Simultaneously, aligned aggregates and lenses of magnetite and leucoxene are crystallized along the lattice of the relict biotite. Other products include sagenitic mats of rutile needles (Figure 9) that form during this replacement process. Magnetite is progressively replaced by pyrite as the inner boundary is approached.

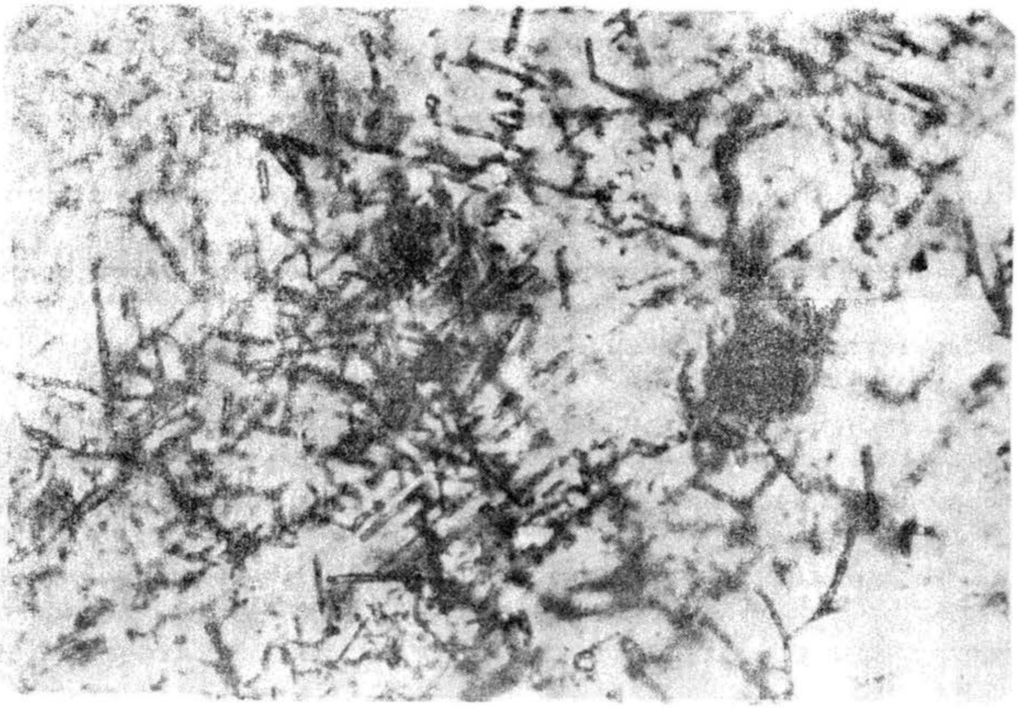


Figure 9. Photomicrograph of thin section no. 17326, uncrossed nicols. Photo dimensions are 0.11 mm x 0.16 mm. Sagenitic web of rutile needles in sericite formed during alteration of biotite in St. Kevin Granite-normal phase (p€ skn).

Transition Zone

Early field observations indicated an extensive zone of argillization where feldspars appeared to be replaced by kaolinite and smectite clays. However, petrographic and X-ray analysis eliminated the possible existence of an argillic zone at Turquoise Lake. It is felt that either clay products of argillization have been entirely replaced by sericite or more likely were never formed at all.

Between the weak propylitic zone and the stronger phyllic zones is a transition zone of limited and unknown extent (Figure 7). This narrow zone is characterized by the loss of chlorite and epidote common in propylitized rock, and the partial replacement of biotite and feldspars by sericite. Usually, microcline is stable longer than plagioclase which is more vulnerable to hydrothermal fluids. Broughton (1938) notes that as the zone of more intense alteration is approached, plagioclase exhibits more thorough sericitization. Once completely sericitized, these grains then seem to act as centers from which alteration spreads to other susceptible minerals. When complete sericitization takes place, the inner boundary of the transition zone and the beginning of the phyllic zone is recognized.

Phyllic Zone

The phyllic zone is the most extensive alteration envelope surrounding and including the Turquoise Lake stock (Figure 7). This type of alteration is characterized by the complete sericitization of all feldspars and mafic minerals. Quartz and zircon are the only minerals moderately unaffected. Strong pyrite mineralization is coextensive with this zone.

The phyllic alteration is pervasive with complete destruction of the original texture. Original orthoclase and plagioclase are replaced by felted mats of fine sericite and variable size granular quartz. Remnant twinning lines and cleavage planes of plagioclase and occasionally of microcline are preserved in oriented blades of sericite or sericite and quartz (Figures 10 and 11). Near the outer border, muscovite and biotite in Precambrian granites can be distinguished from each other by the presence of exsolved sagenitic webs of rutile and leucoxene in replaced biotite (Figure 9). Toward the interior of this alteration zone, coarse sericite replacement of the original micas is replaced by a fine mat of sericite and quartz. Original quartz exhibits extensive recrystallization as evidenced by abundant cracks found throughout the quartz phenocrysts. Borders of the quartz phenocrysts are deeply etched and partially replaced by fine needles of sericite. Rare diaspore, $HAlO_2$, occurs as fine discrete grains and clots randomly replacing alteration minerals. Diaspore probably represents areas in the phyllic zone where advanced hydrolytic leaching of cations occurred. Pyrite is extensively distributed throughout the phyllic zone as disseminated grains replacing all minerals. Volume percentages range from 1 percent near

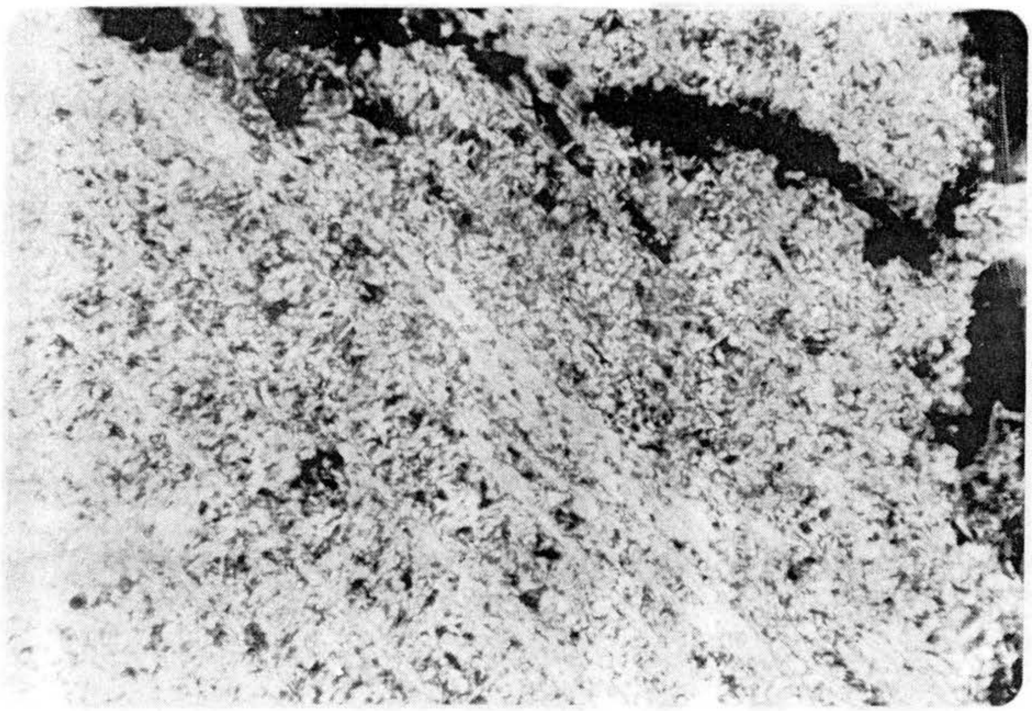


Figure 10. Photomicrograph of thin section no. 17326, crossed nicols. Photo dimensions are 0.41 mm x 0.63 mm. Oriented blades of fine sericite following twinning planes of destroyed plagioclase in St. Kevin Granite-normal phase (p€ skn).

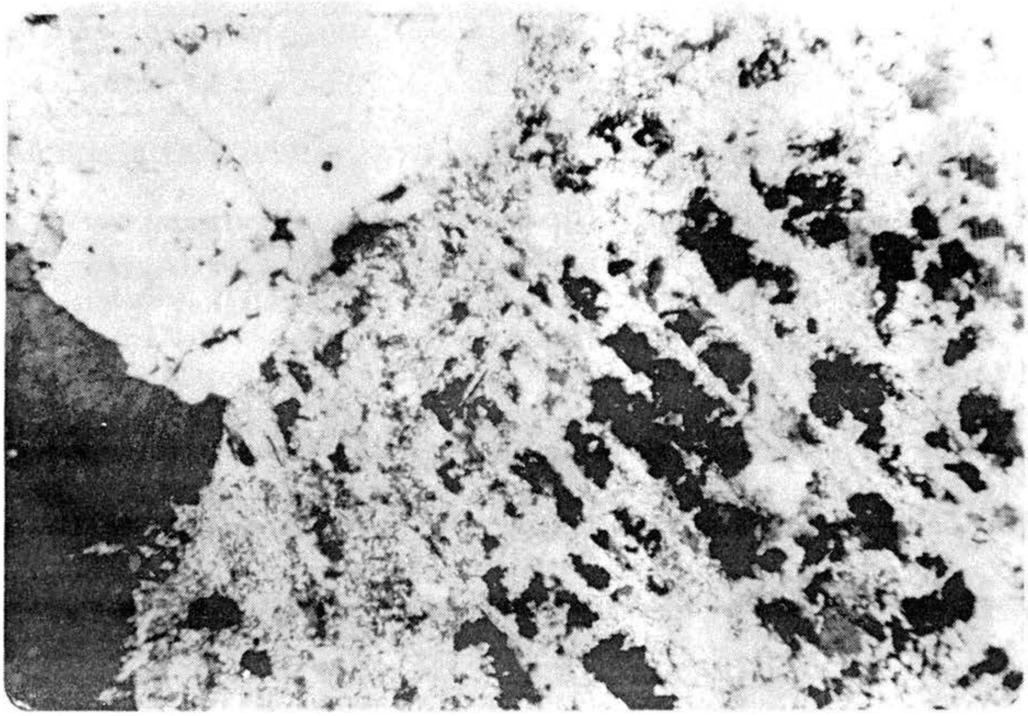


Figure 11. Photomicrograph of thin section no. 17329, crossed nicols. Photo dimensions are 1.7 mm x 2.5 mm. Blades of fine sericite and admixed quartz (dark patches) following grid texture of destroyed microcline perthite in St. Kevin Granite-normal phase (pϵ skn).

the outer phyllic border upward to 10 percent in a circular pattern centered on the northwest side of the stock. Figure 15 in the mineralization section presents the approximate distribution of pyrite as observed from field studies.

Quartz-Topaz Subzone

Two portions of the main phyllic zone exhibit more intense silicification. The first occurs bordering the Turquoise Lake stock where a silicified rind up to 500 feet wide occurs in Precambrian granites (Figure 7). This zone is characterized by advanced replacement of sericitized feldspars by quartz and topaz. Sericite is not entirely absent but its proportions seem to vary directly with the intensity of the silicification and formation of topaz. Anomalous fluorine and molybdenum mineralization are reflected along this zone.

Another area of quartz-topaz alteration occurs to the northwest of the stock. Quartz and topaz replace all feldspar sites previously occupied by sericite (Figure 12). The large volume of topaz is reflected geochemically by the high fluorine content (2%) in the area. Pyrophyllite is found within this zone indicating a possible mineral zonation with removal of potassium.

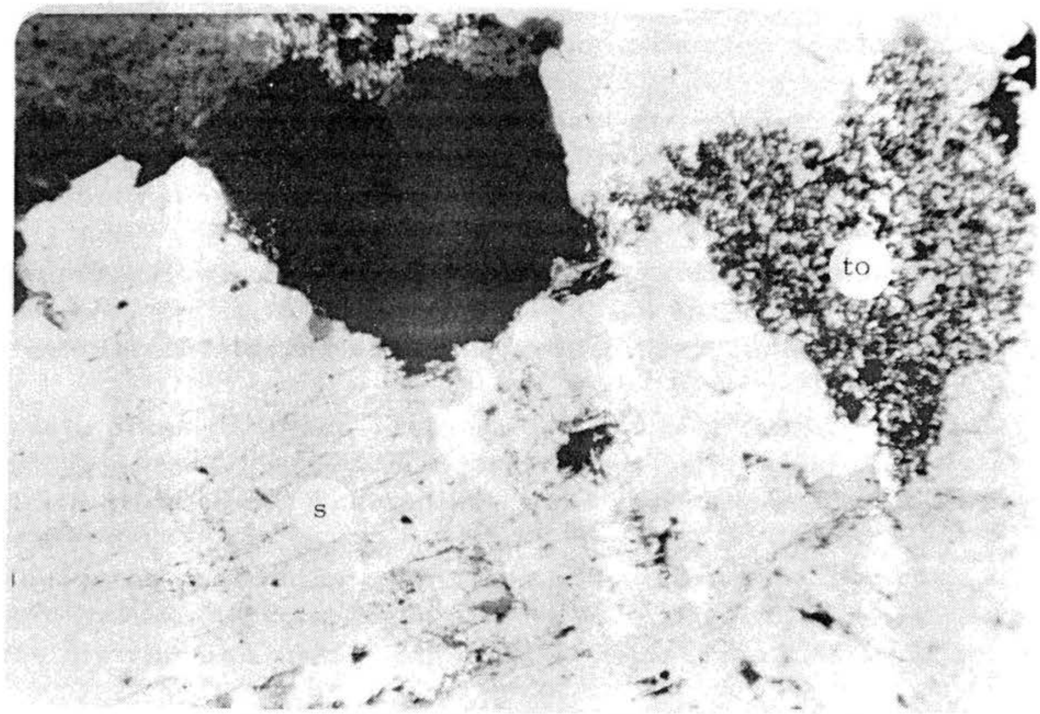


Figure 12. Photomicrograph of thin section no. 17287, crossed nicols. Photo dimensions are 1.7 mm x 2.5 mm. St. Kevin Granite-normal phase (p€ skn) exhibiting granular mass of topaz (to) replacing feldspar site. Coarse and fine sericite (s) replaces muscovite and feldspar.

Kaolinite-Sericite Zone

The phyllic alteration observed at the surface in the Turquoise Lake stock gives way to the kaolinite-sericite zone at depth (Figure 8). This zone is characterized by the crystallization of kaolinite in volume. Above the transitional contact at 1050 feet in drill hole BL-2, only spotty and weak occurrences of kaolinite are detected in the stock. However, below this contact kaolinite partially replaces sericite in all feldspar sites and groundmass, and coats fractures. The late dikes (Tlfp and Tlrp) above 1050 feet exhibit kaolinite-sericite alteration. These dikes were probably used as pathways by the hydrothermal fluids associated with this type of alteration. Due to the distribution of kaolinite and its replacement of sericite, it appears that kaolinite is a late mineral that overprints the earlier alteration suite of minerals.

The kaolinite alteration found at depth could be attributed to two possible events. One event permits formation of kaolinite during late stage alteration associated with the dying and collapsing hydrothermal system. This common type of alteration often overprints earlier alteration minerals and zones. However, due to the geometry of the kaolinite-sericite zone (Figure 8) at Turquoise Lake, a collapsing system is precluded and argillization may have taken place from a deeper, expanding alteration system associated with a blind intrusive. This intrusive would have its own alteration halos, and these halos would overprint all earlier alteration products.

Alteration Reactions

The changes in mineralogy due to hydrothermal fluids derived from depth and related to the Turquoise Lake stock is impressive. In this and any dynamic intrusive system, the hydrothermal fluids cause hydrolytic recrystallization of silicates to occur. According to Hemley and Jones (1964), as the fluids penetrate silicate rocks the resulting alteration reactions are controlled by pressure, temperature, and solution composition. This solution composition is controlled to a large extent by variations in the ratio of metal cations to hydrogen ions. As the activity of H^+ increases, hydrogen metasomatism and leaching of common metal cations from silicates takes place. These leached cations migrate with the hydrothermal fluid and in their passage act on other minerals to form new products, or they are flushed out of the system. Therefore, the purpose of this section is to reconstruct the probable chemical reactions that took place in each of the alteration zones.

In the phyllic zone alteration where sericite-quartz-pyrite constitute the stable assemblage, the following reactions occur according to the concepts of hydrogen metasomatism as presented by Hemley and Jones (1964).

Potassium feldspar alters to sericite and quartz with release of K^+

$$3\ KAlSi_3O_8 + 2H^+ \rightarrow KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+ \qquad (1)$$

Plagioclase alters to sericite in the presence of K^+ to form sericite with release of Na^+ and Ca^{2+}

$$0.75\ Na_2CaAl_4Si_8O_{24} + 2H^+ + K^+ \rightarrow$$

$$KAl_3Si_3O_{10}(OH)_2 + 1.5Na^+ + 0.75Ca^{2+} + 3SiO_2 \qquad (2)$$

In the quartz-topaz subzone where sericite-quartz-pyrite-topaz-diaspore and rare pyrophyllite are the stable assemblages, the following reactions would hold true:

Sericite alters to pyrophyllite with release of K^+

$$KAl_3Si_3O_{10}(OH)_2 + H^+ + 3SiO_2 \rightarrow 1.5Al_2Si_4O_{10}(OH)_2 + K^+ \qquad (3)$$

Sericite alters to topaz with the addition of fluorine

$$2KAl_3Si_3O_{10}(OH)_2 + 3F^- \rightarrow 3Al_2SiO_4(F)_2 + 2K^+$$

$$+ 2SiO_2 + 2H_2O + O_2 \qquad (4)$$

Sericite alters to diaspore with release of quartz and K^+

$$2KAl_3Si_3O_{10}(OH)_2 + 7H^+ \rightarrow 6HAlO_2 + 6SiO_2 + 2K^+ + 6H_2O\ . \qquad (5)$$

Even though the above reactions took place in a strong chemical leaching environment, it is difficult to explain the weak character of the fluid once it leaves the phyllic zone regime. It is known from petrographic and X-ray studies that the classic argillic zone does not exist in this alteration system. In its place is a transition zone between phyllic and propylitic rocks where the phyllic type alteration drops to insignificant levels. Due to the scarcity of alteration products, the rocks in the propylitic zone indicate that the hydrothermal fluid was unable to produce many chemical reactions. This fluid character suggests that the ability to leach cations probably declined due to decreased H^+ activity and increased cation concentration.

The stable mineral assemblage in the propylitic zone is chlorite-epidote-sericite. The following reactions to form this assemblage are described by Hemley and Jones (1964).

Biotite alters to chlorite and releases K^+ for H^+

$$2K(Mg, Fe)_3AlSi_3O_{10}(OH)_2 + 4H^+ \longrightarrow$$

$$Al(Mg, Fe)_5AlSi_3O_{10}(OH)_8 + (Mg, Fe)^{2+} + 2K^+ \quad (6)$$

Chlorite is altered to sericite releasing Fe^{2+} and Mg^{2+}

$$2Al(Mg, Fe)_5AlSi_3O_{10}(OH)_8 + 5Al^{3+} + 3Si(OH)_4 + 3K^+ + 2H^+$$

$$\longrightarrow 3KAl_3Si_3O_{10}(OH)_2 + 10(Fe, Mg)^{2+} + 12H_2 \quad (7)$$

In the kaolinite-sericite zone where kaolinite is overprinted on the phyllic alteration mineral assemblages, the following reaction would occur:

Alteration of sericite to form kaolinite with release of K^+

$$KAl_3Si_3O_{10}(OH)_2 + H^+ + 1.5H_2O$$

$$\longrightarrow 1.5Al_2Si_2O_5(OH)_4 + K^+ \qquad (8)$$

Late Hydrothermal Alteration

Evidence for a very late, low temperature alteration is found at depth in drill holes BL-1 and BL-2. Wavelite, $Al_3(OH, F)_3 (PO_4)_2 \cdot 5H_2O$, occurs as crusts of small radiating crystals filling vuggy fractures. Color varieties include white, pale green, pale brown and brown. The mineral is more common in BL-1 than in BL-2.

Supergene Alteration

Weathering and the resulting supergene alteration has played a very minor role in the Turquoise Lake area. Glaciation during recent times has limited the time for extensive weathering to occur on newly exposed bedrock. Consequently, any deep supergene effects are negligible.

The depth of the oxidized zone usually only penetrates a few feet into bedrock. This shallow depth is confirmed by drill holes BL-1 and BL-2 where unoxidized rock was found at 20 feet and 32 feet, respectively. Rocks on the surface have a limonite rind extending up to 1" into the interior of broken specimens. In this rind and along fractures pyrite has been converted to a goethite-jarosite mixture which results in a brown to yellow brown color. Only one small locality exhibited the bright red of hematite, and that was on "Silica Ridge" to the northwest of the stock.

Probable Alteration Temperatures

The various suites of minerals found in the Turquoise Lake alteration zones are stable under certain ranges of temperatures. By bracketing mineral pairs into their respective temperature ranges, it is possible to infer the formational temperature at the time of alteration.

The temperature of the quartz-topaz subzone adjacent to the stock is thought to have been from 400° C to 575° C. This range is based upon the mineral assemblage of sericite and topaz where sericite has a stability range of 200° C to 575° C (Creasey, 1966), and topaz has a range of 400° C to 850° C at 2kb (Bright and White, 1974).

The temperature of the propylitic zone on the fringes of the phyllic alteration would range from 200° C (from sericite) to an extreme of 500° C, the upper stability limits of chlorite and epidote (Creasey, 1966).

The temperature of formation in the kaolinite-sericite zone is based solely on kaolinite. The stability range of kaolinite is 50° C to 350° C (Creasey, 1966). Since this temperature is lower than the adjacent quartz-topaz subzone, it is felt that the kaolinite alteration is a late event.

FLUID INCLUSIONS

Three types of fluid inclusions were observed during petrographic studies in the rocks of the Turquoise Lake stock area. The classification of each type is based upon discussions by Nash (1976). Type 1 inclusions contain liquid and a small vapor bubble ranging from 10 to 40 percent of the enclosed volume. These usually indicate the presence of moderate salinity fluids during sericitic alteration episodes. Gas-rich type 2 inclusions contain liquid plus more than 60 percent vapor. Commonly, the vapor displaces all the liquid and the inclusion becomes a gas bubble (Figure 13). This phase character suggests the hydrothermal fluid boiled and the inclusions represent trapped steam. Type 3 inclusions contain liquid, vapor, and cubic halite (Figure 14). These primary-appearing inclusions generally contain salinities near 40 percent.

Although there was no attempt to observe strict zoning patterns of fluid inclusion types, a crude distribution pattern was noted in thin section. The type 3 inclusions were observed only in quartz phenocrysts of the Turquoise Lake stock. Type 2 inclusions were distributed throughout the alteration system with a very high proportion associated with the quartz-topaz alteration zone. This type of inclusion provides evidence of the high permeability of the rocks

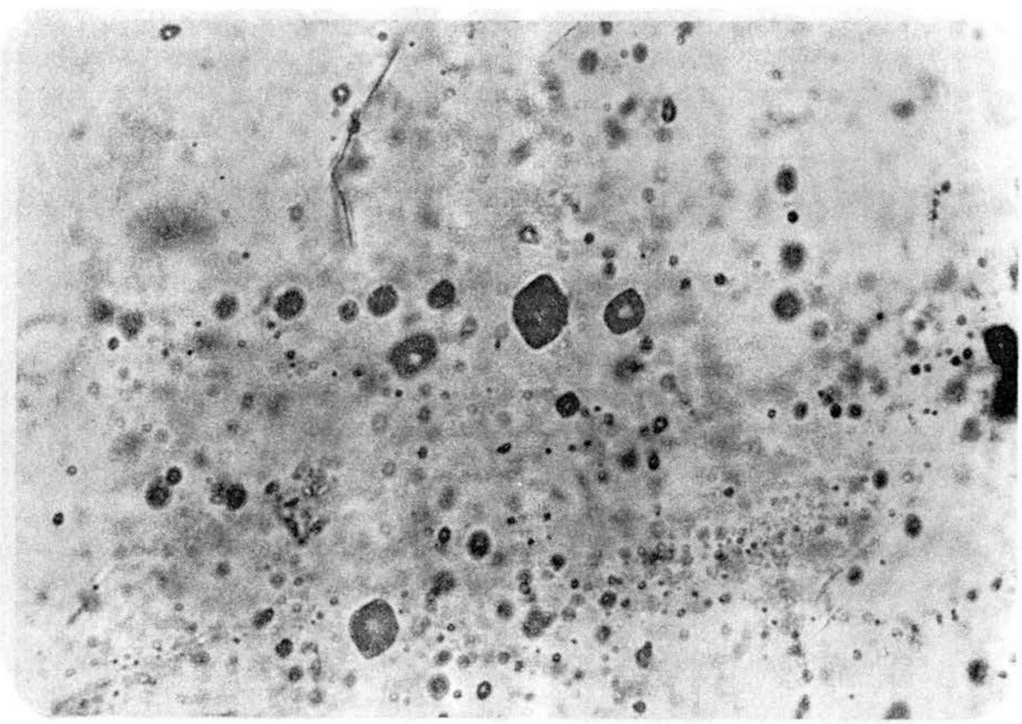


Figure 13. Photomicrograph of thin section no. 17251, uncrossed nicols. Photo dimensions are 0.11 mm x 0.16 mm. Gas rich, Type 2 secondary fluid inclusions in a quartz phenocryst from the St. Kevin Granite-fine phase (pϵ skf) in the quartz-topaz alteration subzone. Note the oriented planes of inclusions indicating the presence of healed microfractures.

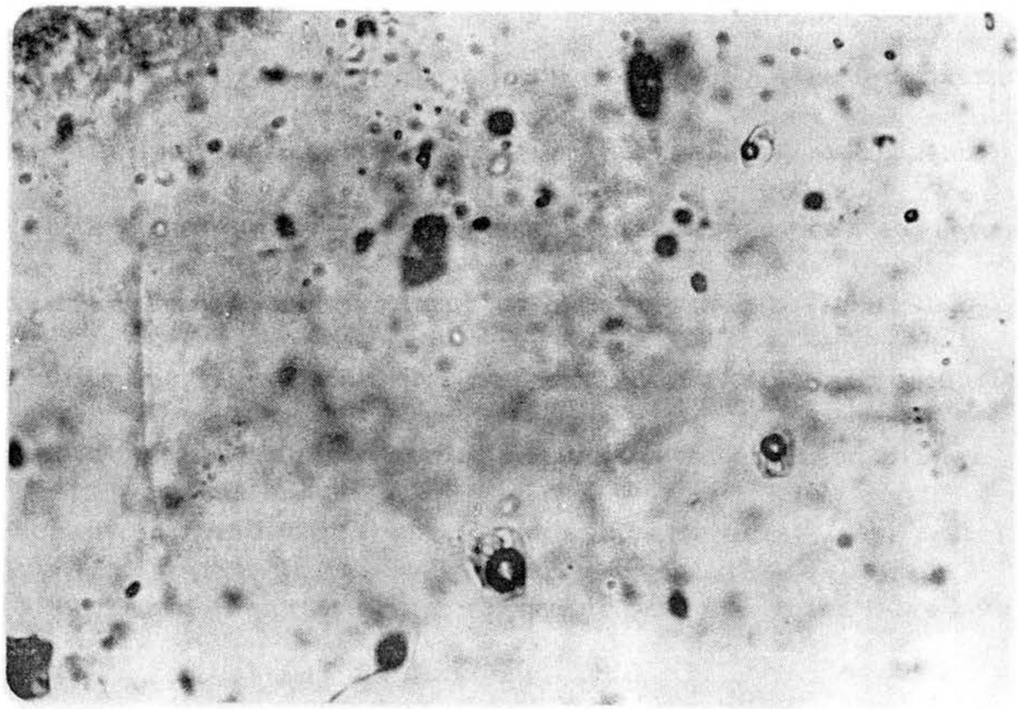


Figure 14. Photomicrograph of thin section no. 17256, uncrossed nicols. Photo dimensions are 0.11 mm x 0.16 mm. Type 3 primary fluid inclusions in quartz phenocryst from the coarse phase of the Turquoise Lake Porphyry (Ttlpc).

adjacent to the stock. The type 1 inclusions were also found throughout the alteration system with a higher proportion noted toward the cooler portions of the alteration system.

As shown in Figure 13 several criss-crossing planes of fluid inclusions are evident. Sprunt and Nur (1979) suggest that the cracking and healing of quartz in granitic and other related rocks is quite common and tectonic or thermal strains can easily induce this fracturing. Once fracturing occurs, then the cracks become conduits for silica and other hydrothermal fluids. Eventually, these fluids seal the cracks trapping inclusions in oriented planes. This mechanism implies that the formation, character, and distribution of the quartz-topaz alteration subzone was the "pipe" used by upward convective fluid flow adjacent to the stock.

Nash (1976) made comparisons between porphyry copper deposits in search of associated favorable fluid inclusion types. He found the presence of halite-bearing inclusions (type 3) coexisting with gas rich inclusions (type 2) to be most commonly associated with porphyry ore. Since the Turquoise Lake area exhibits these favorable inclusion characteristics, it is suggested that the right type of hydrothermal fluid existed at Turquoise Lake for creation of porphyry ore.

MINERALIZATION

The mineralization at Turquoise Lake is dominated by pyrite and molybdenite (Figure 15). Pyrite forms a large continuous halo with values that increase to 10 volume percent in a "bullseye" overlapping the stock. Pyrite values of greater than 4 percent coincide with the distribution of visible molybdenite in rock.

Pyrite

Pyrite is the most abundant sulfide mineral in the prospect area. The distribution of disseminated pyrite defines a large, oval shaped halo with dimensions exceeding 6,000 by 10,000 feet (Figure 15). Field estimates defined an increasing volume percentage toward the stock. The "bullseye" center, averaging +10 percent pyrite, cuts the stock on the northwest side. Even though contoured pyrite values generally form a concentric pattern, there are several exceptions found in the study area. On the south side of Turquoise Lake, pervasive mineralization starts to decline and pyrite distribution associated with the beginnings of the Sugarloaf vein systems extends in that direction. A lobe northeast of the stock could also be associated with the beginnings of a major vein trending into the St. Kevin District. The lobe east of the stock probably corresponds to the large east-west trending dike of Turquoise Lake Porphyry.

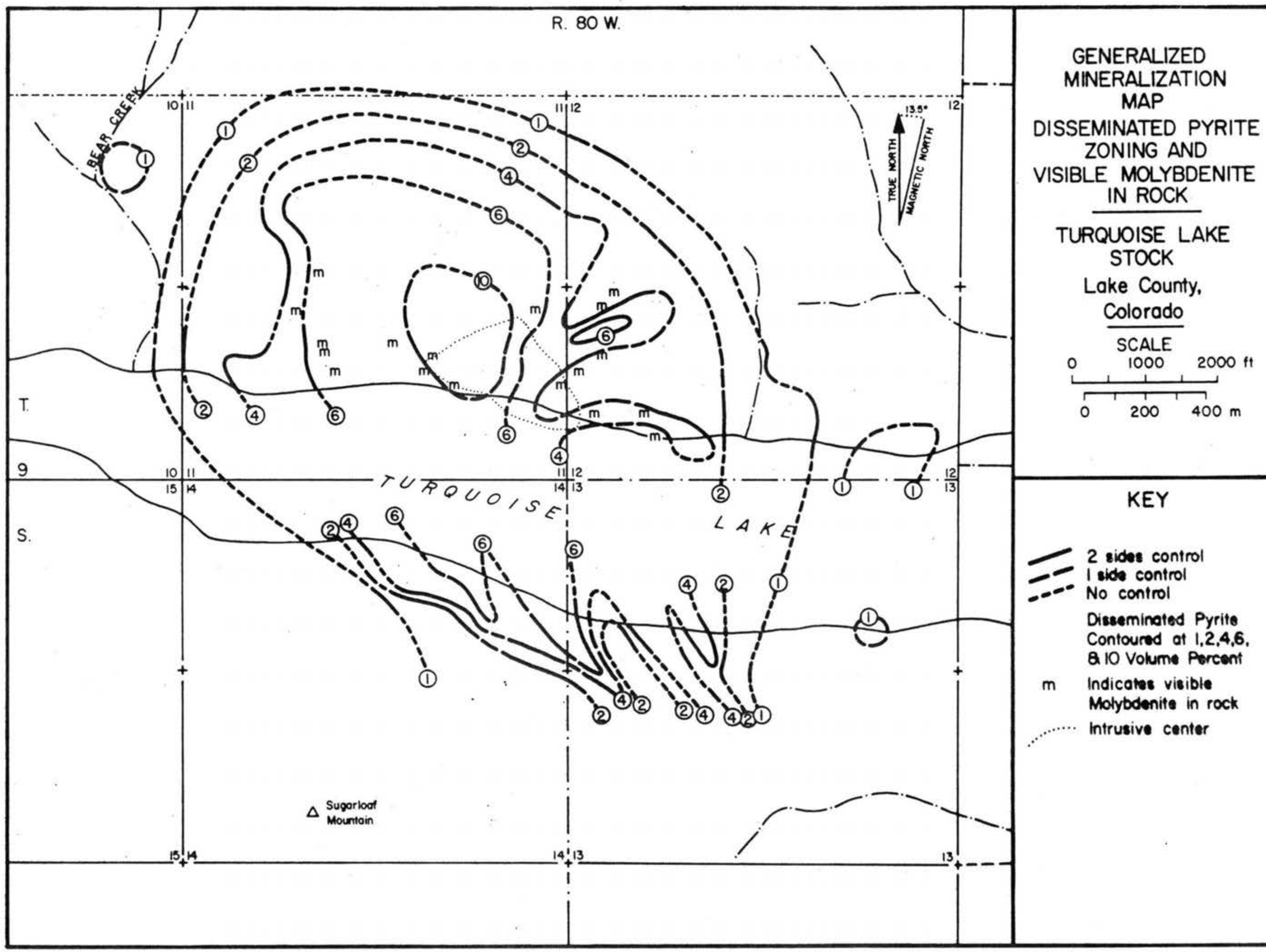

R. 80 W.
GENERALIZED MINERALIZATION MAP
DISSEMINATED PYRITE ZONING AND VISIBLE MOLYBDENITE IN ROCK
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
2 sides control
1 side control
No control
Disseminated Pyrite Contoured at 1,2,4,6, & 10 Volume Percent
m Indicates visible Molybdenite in rock
Intrusive center
TRUE NORTH
MAGNETIC NORTH
13.5°
BEAR CREEK
TURQUOISE LAKE
T.
9
S.
Sugarloaf Mountain

Figure 15

Other isolated occurrences of pyrite outside the main pervasive halo are attributed to mineralized fault zones.

The 1 percent contour of pyrite closely follows the phyllic-propylitic boundary. In propylitic rocks amounts ranging from trace up to 1 percent occur as fine disseminations scattered throughout the rock. Inside the phyllic boundary, pyrite occurs in increasing amounts as scattered grains throughout the rock and as partial replacement of biotite. Pyrite also occurs as fine-grained aggregates in quartz veins and as widely spaced fracture fillings.

No distinct vertical pyrite zoning was found in drill hole. The range of pyrite content in BL-1 was 6 to 12 percent with an average of 8 percent. Pyrite in BL-2 was less than BL-1 with a range of 3 to 8 percent and an average of 5 percent.

Oxidation of pyrite formed very subtle limonitic colors throughout the altered area. Vegetation ranging from lichen varieties to pine forest effectively mask the abundance of the mineralized rocks. Notable exceptions include the long road cut on the south side of the lake where light brown oxidation is quite strong, and the many large, yellowish mine dumps scattered throughout the area. For the most part, variable mixes of goethite and jarosite are the dominate limonites.

Molybdenite

Two forms of quartz-molybdenite mineralization have been noted in the vicinity of the stock (Figure 15). The first type of occurrence is associated with the quartz-topaz subzone which forms a rind on the stock margins. The molybdenite occurs as fine disseminated flakes, large rosettes, and fracture paint in close association with pervasive quartz alteration. Molybdenite grades up to 0.043 percent have been noted along the zone. Another type of molybdenite occurrence is in close association with quartz veining, particularly where the number of quartz veins increase into larger numbers. Figure 16 shows the distribution of quartz veins per linear foot as recorded in the field. Taken in conjunction with the mineralization (Figure 15), it is pointed out that a weak quartz-molybdenite halo occurs outside the quartz-topaz subzone. The molybdenite found in these veins is usually fine grained which gives the quartz a distinct bluish-grey cast. Unfortunately, most of the quartz veins have little or no molybdenite in them, and the quartz always predominates over molybdenite in the ones that contain it.

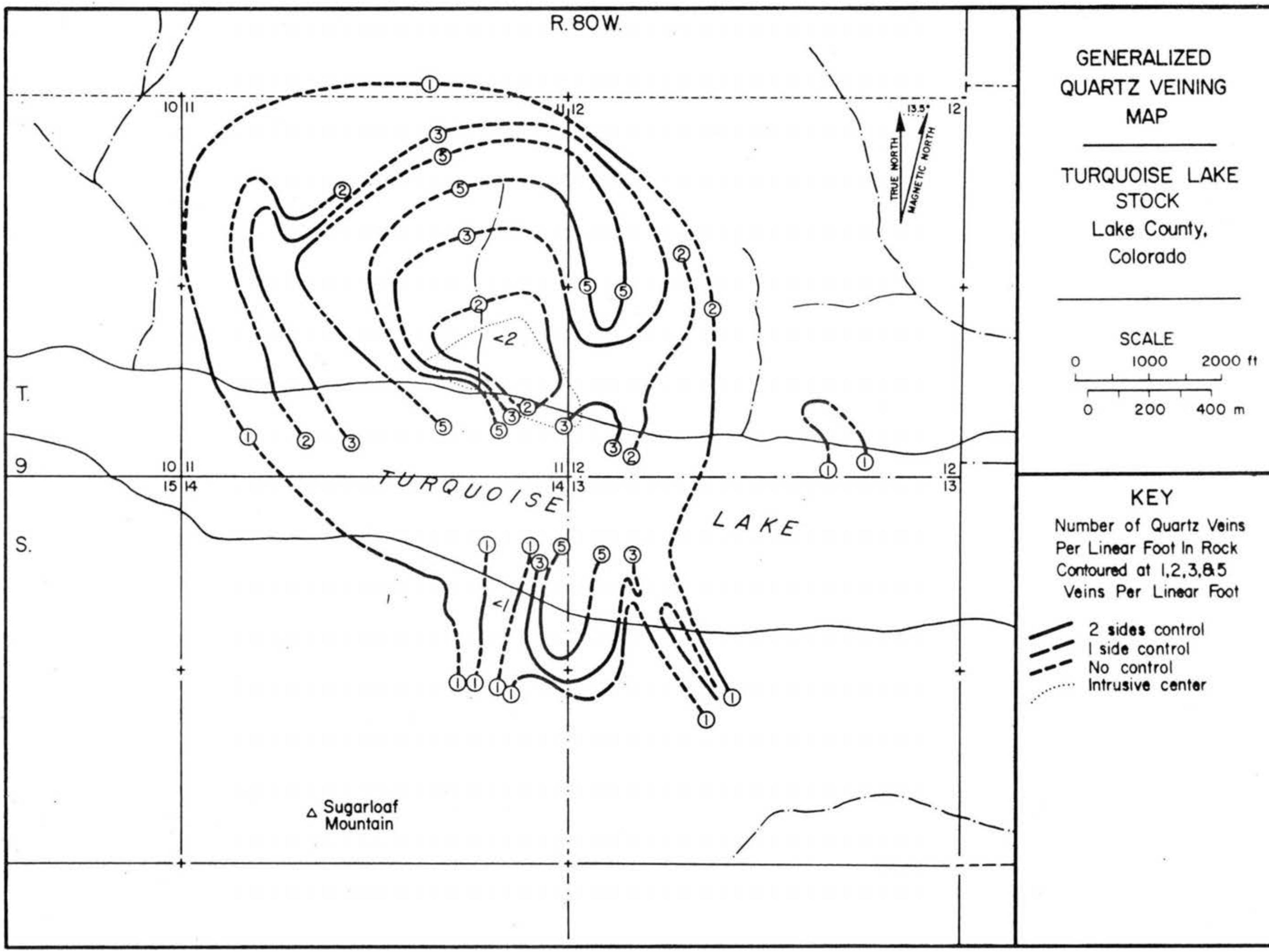

GENERALIZED QUARTZ VEINING MAP
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
Number of Quartz Veins Per Linear Foot In Rock Contoured at 1,2,3,&5 Veins Per Linear Foot
2 sides control
1 side control
No control
Intrusive center
R. 80 W.
T. 9 S.
TURQUOISE LAKE
TRUE NORTH
MAGNETIC NORTH
13.5°
Sugarloaf Mountain
<2
<1

Figure 16

TRACE ELEMENT GEOCHEMISTRY

General Statement

The use of trace element geochemistry in evaluating the economic potential of a mineralized area has become an important tool in exploration. At Turquoise Lake, this exploration technique involved systematic sampling of bedrock units followed by chemical analysis for selected trace elements. The results were then plotted to determine the distribution of elements in and adjacent to the hydrothermally altered rocks surrounding the Turquoise Lake stock. The objective of this procedure was to locate trace element anomalies and to make conclusions based on these data. A total of 109 rock chip samples and 32 composited drill pulp samples were analyzed from the Turquoise Lake stock area.

During formation of an ore deposit, certain trace elements will form with that deposit. These trace elements can then be used as pathfinders to aid in the search for other similar metal deposits. A number of published reports including Wallace et al. (1968), Corn (1975), John (1978), Sharp (1978, 1979), and others have reported trace elements and their dispersion pattern that are associated with porphyry copper and molybdenum systems. It was recognized early in the field reconnaissance that the Turquoise Lake area showed evidence of being a molybdenum exploration target. Consequently, nine pathfinder elements were chosen to help define a target for possible drill hole exploration. The pathfinder elements included molybdenum, copper, lead, zinc, manganese, tin, tungsten, fluorine, and potassium oxide.

Statistical Procedures

There are several statistical methods used to define background and anomalous geochemical values. It has been found that geochemical data generally follow a lognormal distribution (Lepelier, 1969). Therefore, the use of histograms and cumulative probability plots described by Lepelier (1969) and Sinclair (1974) allowed selection of threshold values from a wide range of geochemical results.

Appendix B contains the histograms and cumulative probability plots of the 109 surface rock samples. The 32 drill pulp samples were not included in the calculations.

Another statistical technique that is useful in analyzing large amounts of geochemical data is the correlation matrix. This method calculates a correlation coefficient (r) between all combination of variables as shown. The resulting numerical quantity measures the mutual relationship between elements that have similar or dissimilar characteristics in the geochemical environment. By using this technique in conjunction with the known behavior of an element, certain conclusions could be made about the intrusive system.

A correlation matrix for the 109 Turquoise Lake samples was calculated and is presented in Table 1. The table presents a tabulation of correlation coefficients equal to the measure of the degree of closeness between two variables. It follows that a coefficient equal to +1 indicates perfect positive correlation and a -1 coefficient indicates perfect negative correlation. No linear correlation is indicated whatsoever by a coefficient of zero.

Examination of Table 1 finds many of the correlations either weakly positive or weakly negative. The highest positive correlation exists between zinc and tin at $r = 0.458$ with many of the others falling between $r = \pm 0.3$. The only explanation offered for these low r values can be found by examining the contoured geochemistry figures following the description of each element. The halos around the Turquoise Lake stock are broad and sometimes occur in either single or double halo patterns which are probably due to multiple episodes of mineralization. This type of trace element dispersion probably nullifies strong positive or negative correlations which result in r values near zero.

Rules of Contouring

A brief description of the contouring rules need to be stated before discussion of each element takes place. Figures 17 through 25 present the geochemical data obtained at Turquoise Lake. In areas such as the wide expanse of Turquoise Lake and the deep

Table 1. Correlation coefficient matrix computed for seven elements in 109 Turquoise Lake samples.

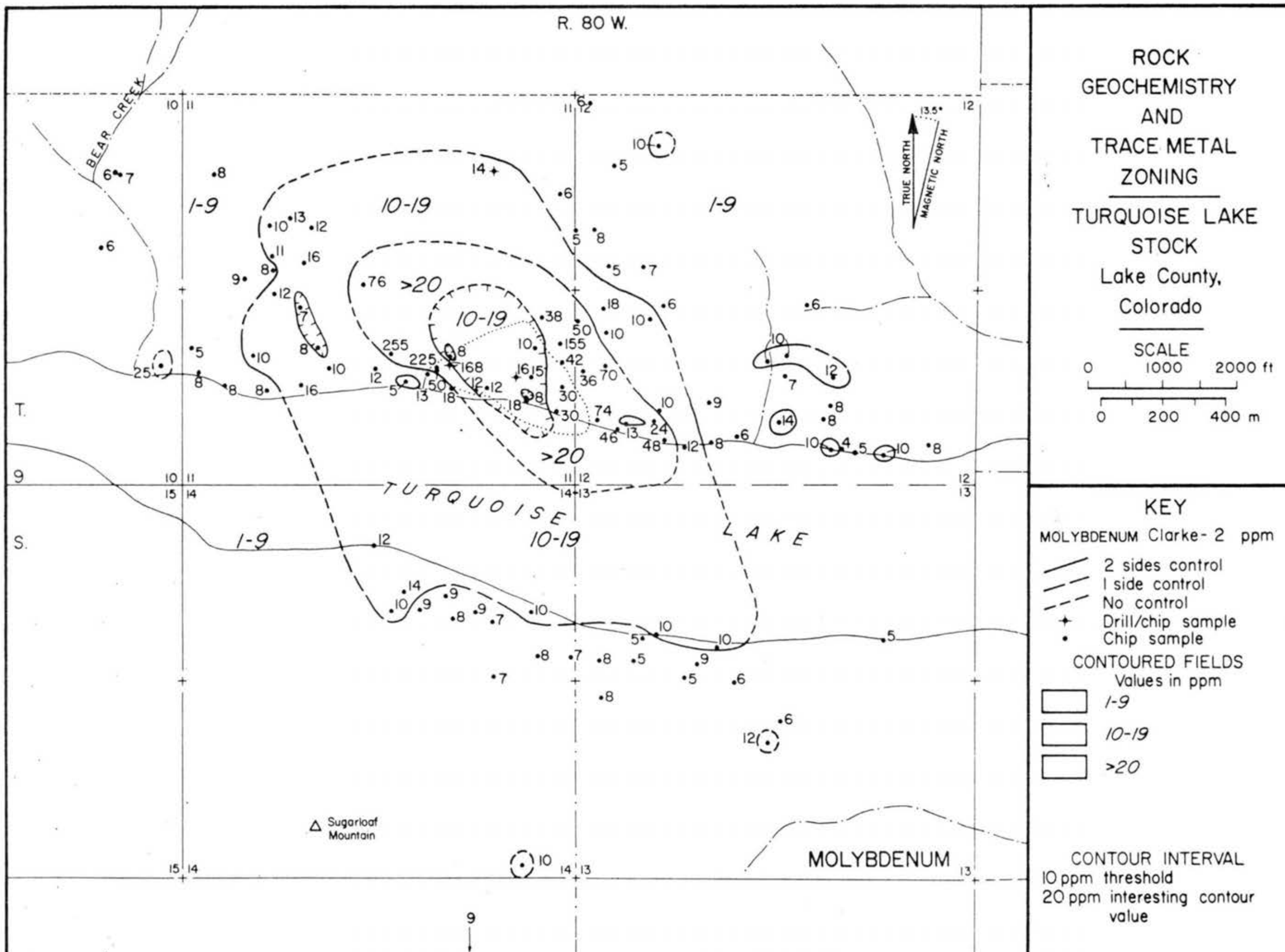
	Cu	Mo	Pb	Zn	Sn	W	F
Cu	1.000						
Mo	0.247	1.000					
Pb	0.363	-0.127	1.000				
Zn	0.209	-0.002	0.103	1.000			
Sn	0.032	0.188	-0.105	0.458	1.000		
W	-0.046	0.334	-0.053	-0.301	0.014	1.000	
F	-0.077	0.074	-0.018	-0.317	0.084	0.094	1.000

glacial cover north of the stock no sample coverage exists. Contour lines crossed these areas based on the assumption that the stock was the focal point that generated a circular dispersion pattern of trace elements. As stated on the explanation of the contoured figures, areas where no control exists are noted by change in line pattern. The same procedure was followed in contouring the geochemistry cross sections presented in Figures 26 to 28. Also, isolated single values that fell inside or outside a particular halo range were ignored in the cross sections. This procedure was used to help eliminate the "clutter" of isolated values and to emphasize the main dispersion pattern.

Molybdenum

The calculated threshold for molybdenum (Figure 17) in the Turquoise Lake area is 10 ppm (Appendix B, Figure 53). The dispersion halo forms an ellipsoid pattern with dimensions of 5,000 feet by 9,000 feet spatially surrounding the stock. Inside this halo stronger mineralization ranging from 20 ppm up to 255 ppm coincide with the quartz-topaz subzone. Within the stock molybdenum mineralization drops to near threshold values. Sporadic, isolated high molybdenum values occur outside the primary halo along structures.

Molybdenum values in drill hole (Figure 26) closely follows the same pattern as observed on the surface. Low values ranging from 3 to 27 ppm occur in the stock with the quartz-topaz zone giving



ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
MOLYBDENUM Clarke- 2 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-9
10-19
>20
CONTOUR INTERVAL
10 ppm threshold
20 ppm interesting contour value
R. 80 W.
T. 9 S.
BEAR CREEK
TURQUOISE LAKE
TRUE NORTH
MAGNETIC NORTH
13.5°
Sugarloaf Mountain
MOLYBDENUM

Figure 17

higher values ranging from 38 to 130 ppm. DDH BL-2 offers an encouraging increase in molybdenum values with increasing depth. This, taken in conjunction with the appearance of quartz-molybdenite veining at the bottom of the hole, offers encouragement for further exploration drilling in the stock center.

As expected molybdenum correlates with tungsten, copper and tin. This supports the known relationship of these elements at the Henderson mine (Bright and White, 1974) and at the Questa mine (Martineau et al., 1978). Negative or neutral correlation occurs against lead, zinc, and surprisingly fluorine.

Molybdenum is contained in visible molybdenite (see Figure 17) found within the quartz-topaz subzone as dusted disseminations and in quartz veins. It is also probably absorbed on limonites and contained in ferrimolybdite.

Copper

Copper (Figure 18) forms two distinct primary dispersion halos elongated in the same direction as molybdenum. The inner halo coincides with the quartz-topaz subzone that surrounds the stock while the outer halo forms a discontinuous ring 2,000 to 3,000 feet from the stock. A threshold value of 18 ppm (Appendix B, Figure 54) was calculated with inner halo values ranging upwards to 135 ppm and outer halo values approaching that of the threshold.

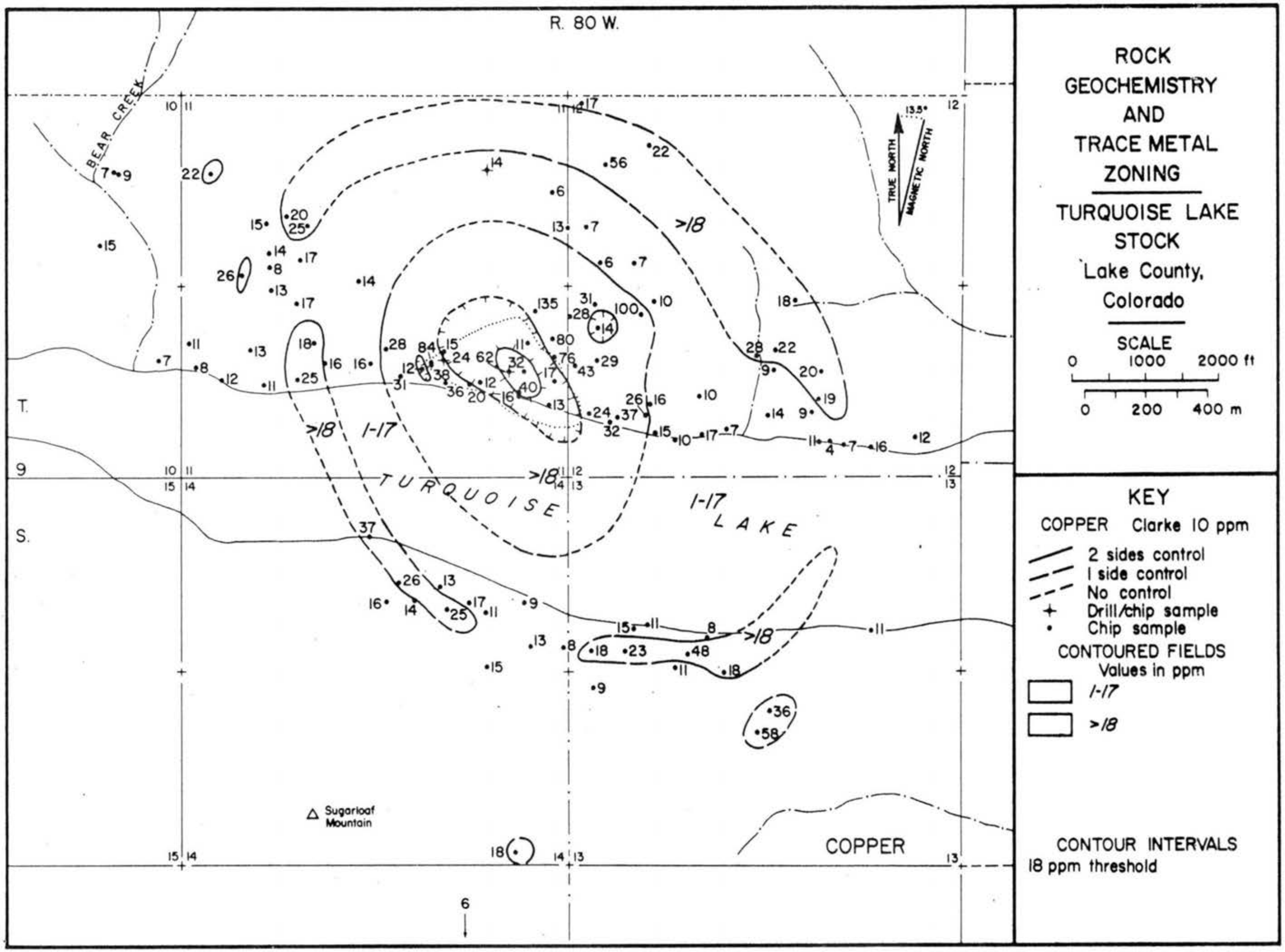

ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
COPPER Clarke 10 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-17
>18
CONTOUR INTERVALS
18 ppm threshold
R. 80 W.
T.
9
S.
BEAR CREEK
TURQUOISE LAKE
TRUE NORTH
MAGNETIC NORTH
Sugarloaf Mountain
COPPER
6

Figure 18

In cross section (Figure 26) the inner halo of copper closes with depth in BL-2 forming a broad bowl shaped feature. A weak remnant halo closes near the top of BL-2 indicating the existence of an eroded third halo or the down dropped central portion that could be part of the outer halo. Values in drill hole range from 10 ppm to 128 ppm with one high interval at 3500 ppm. This isolated high value is attributed to chalcopyrite in a fissure vein with sphalerite and galena.

Copper correlates with lead, molybdenum and zinc. A neutral or negative correlation exists with tin, tungsten and fluorine.

Rare trace amounts of copper oxide minerals were found on the surface in the stock area. Chalcopyrite grains were observed disseminated in portions of the drill holes.

Lead

With a calculated threshold of 100 ppm (Appendix B, Figure 55), lead (Figure 19) forms two dispersion halos either located over the stock or widely dispersed away from the stock. The outer halo forms an elongate, northwest-southeast trending dispersion halo of broad dimensions. Surface geochemical values range from a low of 13 ppm up to 1000 ppm. The quartz-topaz subzone around the stock is low in lead.

In cross section (Figure 26) the inner halo of lead forms a shallow zone that bottoms 300 feet below the surface. It is possible

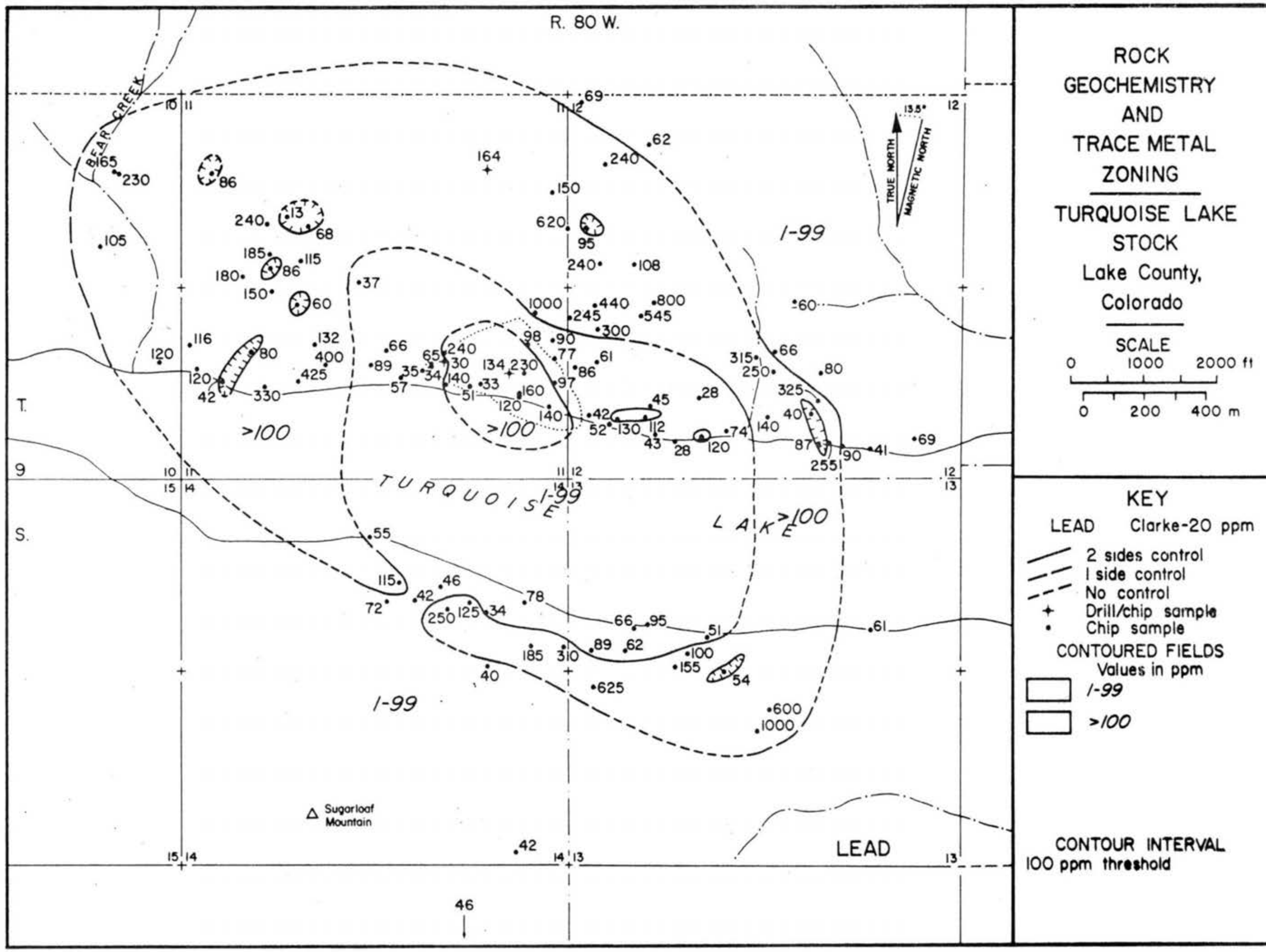

R. 80 W.
ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
LEAD Clarke-20 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-99
>100
CONTOUR INTERVAL
100 ppm threshold
LEAD
TRUE NORTH
MAGNETIC NORTH
BEAR CREEK
TURQUOISE LAKE
Sugarloaf Mountain
T. 9 S.

Figure 19

that this inner halo connects with the outer halo, but unfortunately erosion has removed the evidence of continuity. Other than isolated high values, geochemistry values in drill hole remain less than 100 ppm.

Lead correlates with copper at r = 0.363. Examination of the surface halos of copper and lead find that the outer halos of both elements overlap. The other elements form neutral or negative correlations with lead.

Lead minerals were found only in drill holes as galena. The late feldspar porphyry (Tlfp) contained disseminated galena in BL-1 while a fissure vein in BL-2 contained smeared galena.

Zinc

Zinc (Figure 20) forms a very complex set of dispersion halos centered on the Turquoise Lake stock. As demonstrated from the zinc threshold plot in Appendix B, Figure 55, double inflection points exist indicating the mixing of two widely separated data populations. No attempt was made to separate each population, and the inflection points at 33 ppm and 230 ppm were used as contour values. Two distinct dispersion halos exist with the inner halo overlying the quartz-topaz subzone and the outer halo straddling the outer edge of the phyllic alteration zone. The halos are formed by stairstep increase in geochemical values up to 430 ppm. They are separated by a band of lower zinc values in the 20 ppm range. To the northwest

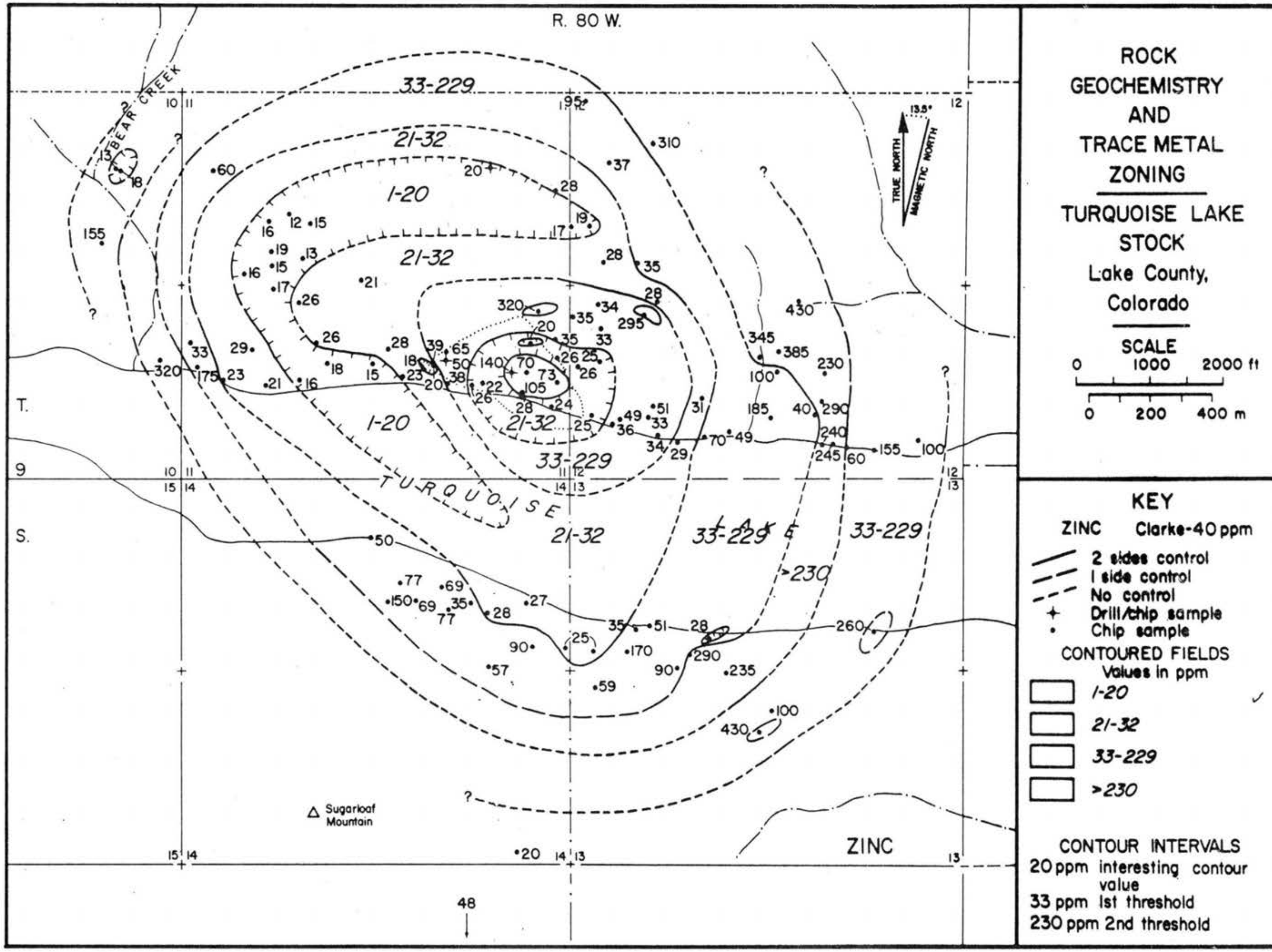

R. 80 W.
ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
TRUE NORTH
MAGNETIC NORTH
13.5°
KEY
ZINC Clarke-40 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-20
21-32
33-229
>230
CONTOUR INTERVALS
20 ppm interesting contour value
33 ppm 1st threshold
230 ppm 2nd threshold
BEAR CREEK
TURQUOISE LAKE
T. 9 S.
Sugarloaf Mountain
ZINC
48

Figure 20

of the stock an anomalous zone of leached zinc values less than 20 ppm form a broad band between the two main halos.

In cross section (Figure 28) zinc does not offer any distinct zoning profiles. All geochemical values in drill holes are above 33 ppm, the lower threshold value, with the range from below 100 ppm up to 3200 ppm.

Of all the metals, zinc makes the strongest correlation with tin at r = 0.458 and with molybdenum. This correlation is unusual since zinc is normally associated with lead and their high mobility has a tendency to form peripheral halos. Due to the complex dispersion pattern of trace elements at Turquoise Lake, overlapping of inner and outer type elements have occurred. This mixing of characteristically different elements allows the unusual correlations to occur as mentioned above.

Other than the occurrences mentioned under the discussion on lead, no zinc minerals were identified.

Manganese

A limited manganese survey (Figure 21) was performed with 33 samples. As with zinc a double threshold was calculated with inflection points plotted at 400 and 1000 ppm (Appendix B, Figure 58). Generally, the stock area is depleted in manganese with increasing values toward the edges. This increase, which ranges from lower

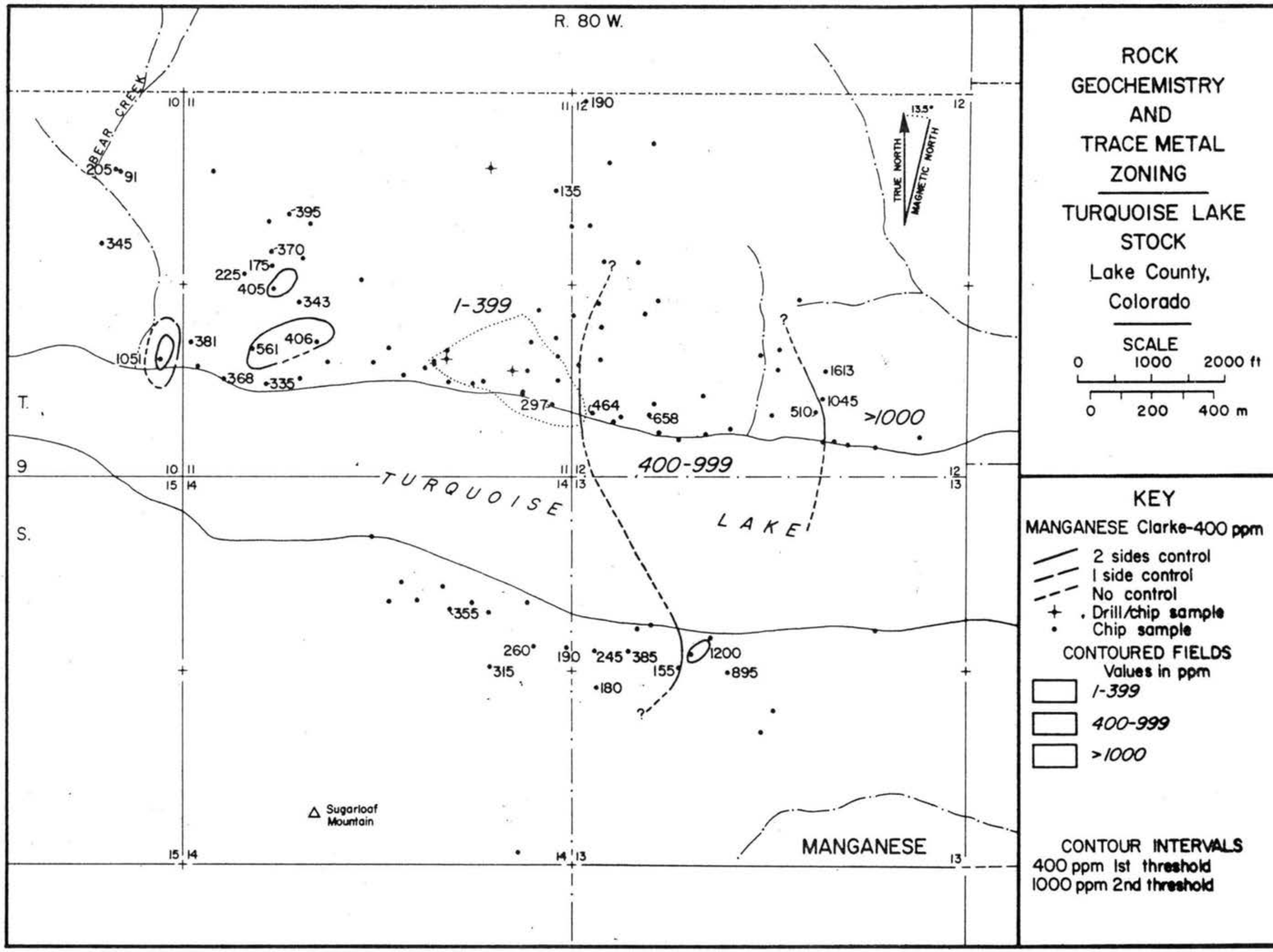

ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
R. 80 W.
T. 9 S.
TRUE NORTH
MAGNETIC NORTH
BEAR CREEK
TURQUOISE LAKE
Sugarloaf Mountain
MANGANESE
1-399
400-999
>1000
KEY
MANGANESE Clarke-400 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-399
400-999
>1000
CONTOUR INTERVALS
400 ppm 1st threshold
1000 ppm 2nd threshold

Figure 21

values of 300 ppm upward to 1600 ppm, is expected due to its high mobility which allows it to form peripheral halos.

The geochemical cross section (Figure 28) of manganese indicates a downhole range of values from 16 to 268 ppm with no pattern towards increasing values. Originally, it was hoped that a manganese halo of the type occurring over the Henderson ore body might exist at depth.

No correlation with other elements was made due to incomplete analyses.

Pyrolusite was the only manganese mineral found in the stock area. It occurred coating fractures in propylitic rocks on the eastern side of the alteration halo.

Tin

The dispersion halo of tin (Figure 22) forms an elongate, off-centered pattern with dimensions of 7,000 by 10,000 feet. As with zinc, the threshold calculations yield double inflection points in the probability plot at 4 ppm and 40 ppm (Appendix B, Figure 53). The lower threshold value of 4 ppm follows that of the established clarke of tin at 3 ppm (Krauskopf, 1967). Geochemical values greater than 20 ppm surround the stock area while an adjacent arcuate zone up to 97 ppm is centered to the northeast of the stock on Silica Ridge.

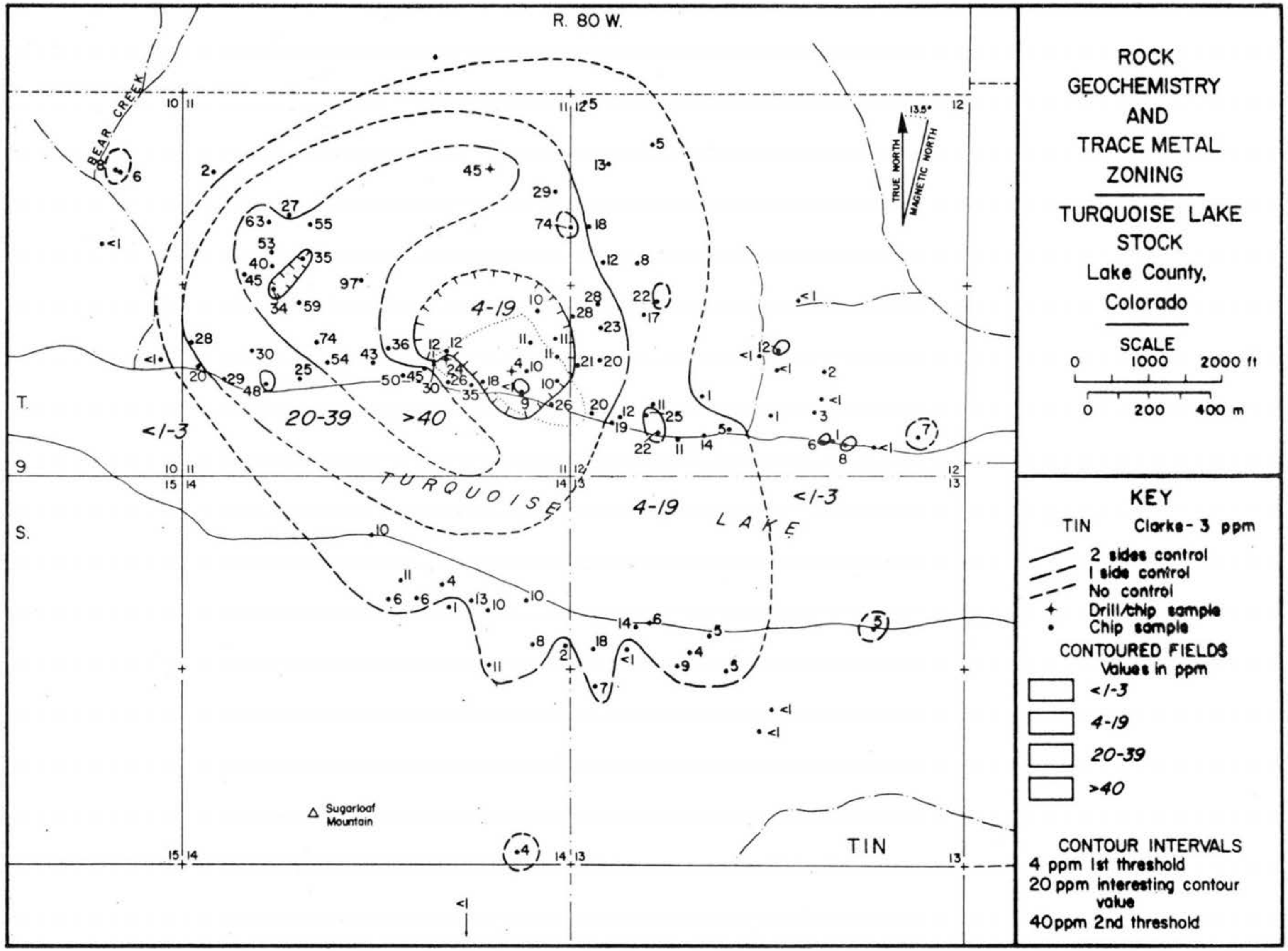

ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
TIN Clarke - 3 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
<1-3
4-19
20-39
>40
CONTOUR INTERVALS
4 ppm 1st threshold
20 ppm interesting contour value
40ppm 2nd threshold
R. 80 W.
T. 9 S.
BEAR CREEK
TURQUOISE LAKE
TIN
Sugarloaf Mountain
TRUE NORTH
MAGNETIC NORTH
13.5°

Figure 22

Tin in drillhole (Figure 27) offers no meaningful pattern as that found on the surface. Values range from less than 5 ppm up to 30 ppm with BL-1 containing a continuous series of higher numbers than in BL-2.

Correlation of tin to other elements yields a positive compatibility with zinc and molybdenum. There is a neutral or negative correlation with the other elements.

No tin minerals were recognized during field work.

Tungsten

As with the other major elements, tungsten (Figure 23) forms a continuous, ellipsoid shaped halo of large dimensions around the stock. Threshold was calculated at 8 ppm (Appendix B, Figure 54). A ring of higher values (+15 ppm) falls just outside the quartz-topaz subzone with the stock area containing near threshold values.

Tungsten, along with molybdenum, offers the best evidence for deeper exploration potential when compared to the other trace elements. This encouragement is found in drillhole BL-2 (Figure 27) where geochemical values increase with depth from 8 ppm to 18 ppm. Although BL-1 contains consistant values up to 25 ppm, it is felt that these values reflect the higher trace metal content characteristic of the quartz-topaz subzone.

A positive tungsten correlation exists with molybdenum at $r = 0.334$. Negative correlations with copper, lead, and zinc support

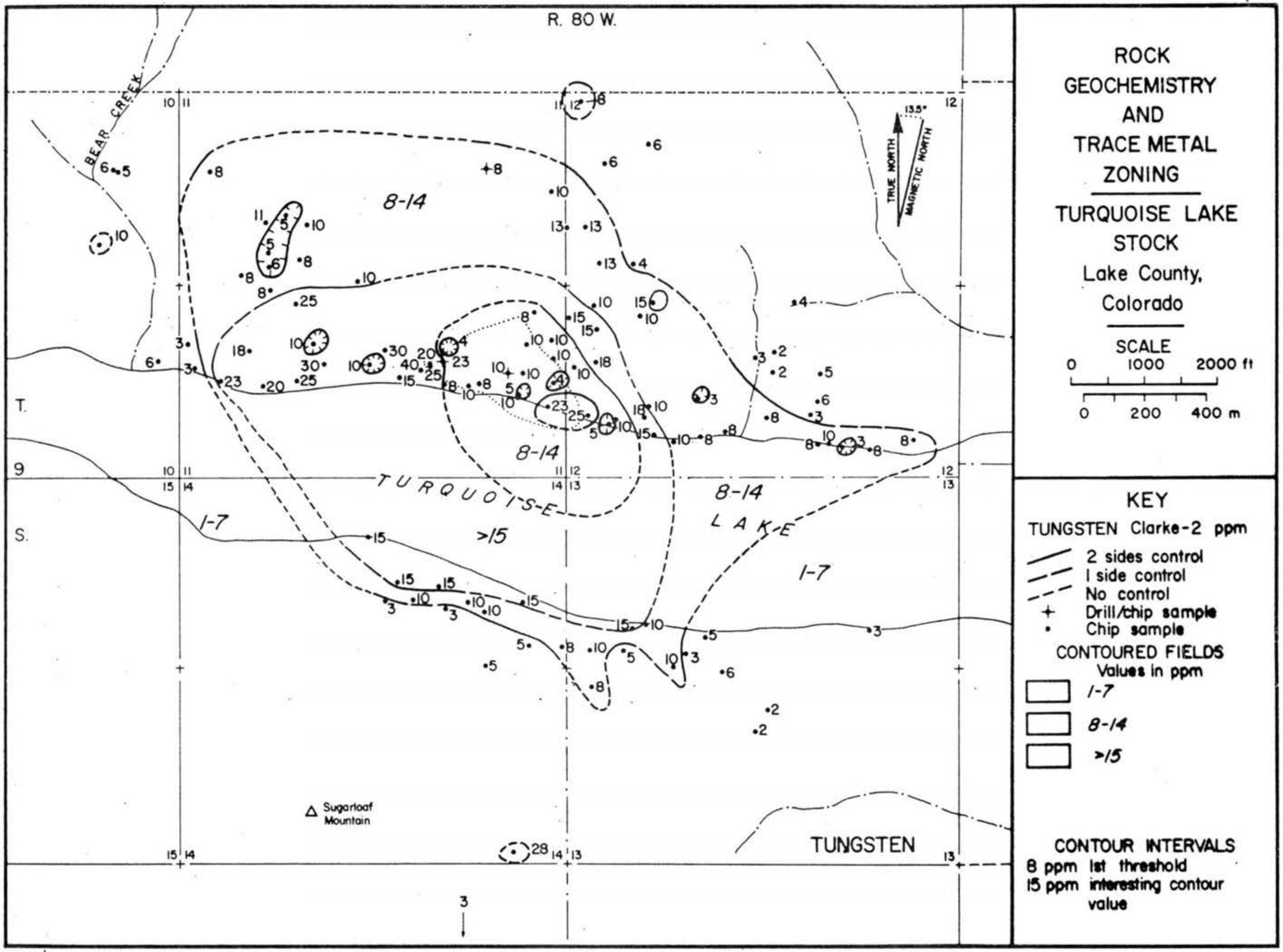

ROCK
GEOCHEMISTRY
AND
TRACE METAL
ZONING
TURQUOISE LAKE
STOCK
Lake County,
Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
TUNGSTEN Clarke-2 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-7
8-14
>15
CONTOUR INTERVALS
8 ppm 1st threshold
15 ppm interesting contour value
R. 80 W.
T.
9
S.
BEAR CREEK
TURQUOISE
LAKE
TRUE NORTH
MAGNETIC NORTH
13.5°
Sugarloaf Mountain
TUNGSTEN

Figure 23

the established inner halo geochemical character of the element versus those of outer halo characteristics.

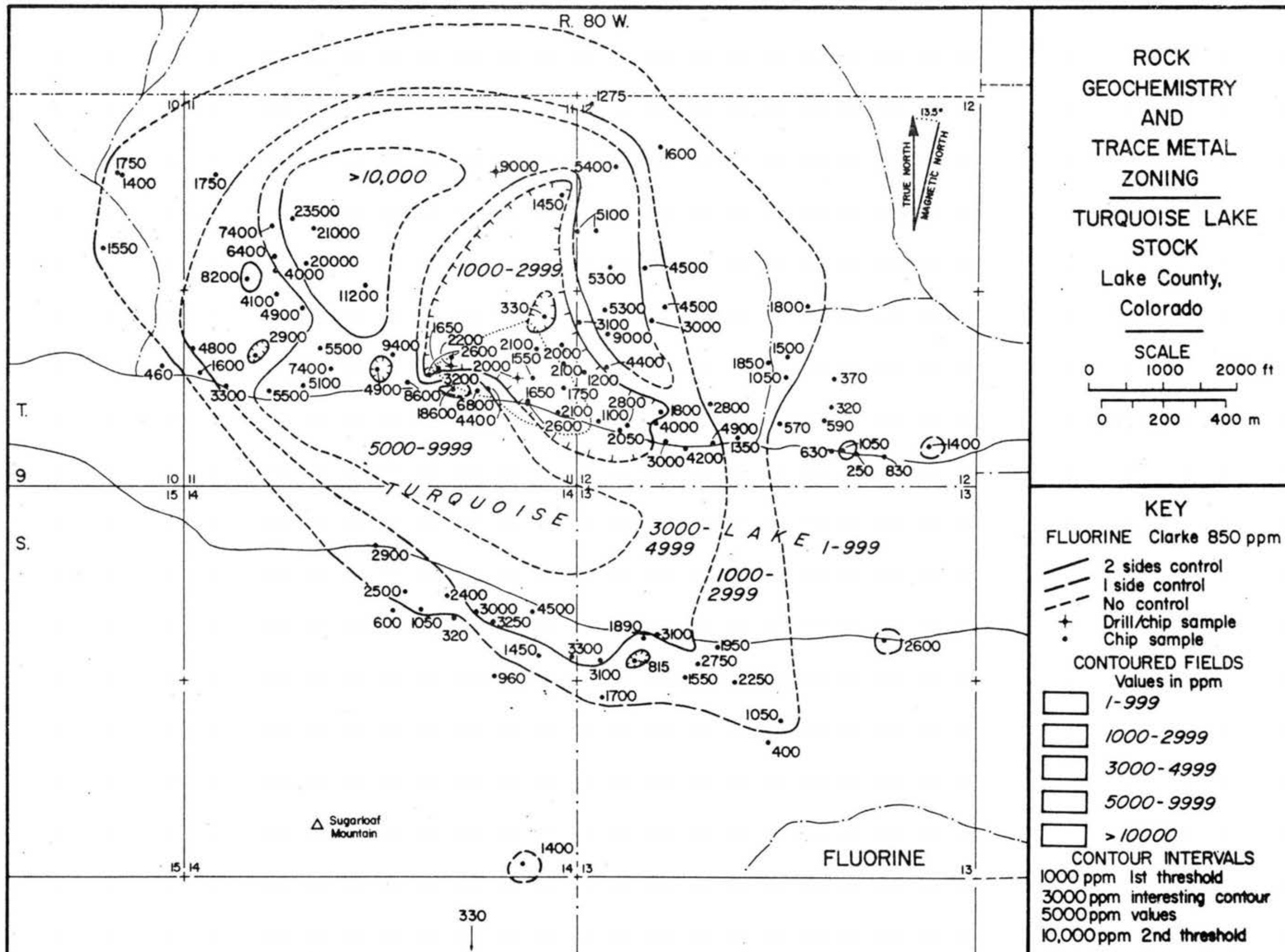
No tungsten minerals were identified in the field work.

Fluorine

The dispersion halo of fluorine (Figure 24) follows the same northwest trending, elongate pattern that is characteristic of all the trace elements. Double threshold values were calculated at 1000 ppm and 10,000 ppm (Appendix B, Figure 56). Generally, anomalous fluorine values (+1000 ppm) are found inside the propylitic-phyllic alteration boundary. The stock area exhibits values in the range of 1000 to 3000 ppm while the adjacent areas exhibit significantly higher values. To the northwest of the stock on Silica Ridge a zone of high fluorine values up to 23,500 ppm occur in relation to an area of abundant topaz.

Fluorine in cross section (Figure 27) defines meaningless halo trends. Geochemical values range from 2200 ppm to 7000 ppm. The quartz-topaz zone penetrated by BL-1 contains higher fluorine values than BL-2 in the stock center.

The correlation matrix indicates that fluorine is not strongly compatible with any element. This is unusual since it is considered to be an inner halo element that forms with molybdenum, tungsten, and tin. However, it does show a negative or neutral correlation



R. 80 W.
T.
9
S.
ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
TRUE NORTH
MAGNETIC NORTH
13.5°
>10,000
1000-2999
5000-9999
3000-4999
1000-2999
1-999
TURQUOISE LAKE
Sugarloaf Mountain
FLUORINE
KEY
FLUORINE Clarke 850 ppm
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in ppm
1-999
1000-2999
3000-4999
5000-9999
>10000
CONTOUR INTERVALS
1000 ppm 1st threshold
3000 ppm interesting contour
5000 ppm values
10,000 ppm 2nd threshold

Figure 24

with copper, lead, and zinc which are considered to be outer halo elements.

Minerals containing fluorine are rare in the Turquoise Lake area. Only one occurrence of fluorite was noted in thin section, and it was from a dike of Turquoise Lake Porphyry-medium phase (Ttlpm) near the eastern phyllic-propylitic boundary. It is felt that the high fluorine concentrations found throughout the altered rocks of the Turquoise Lake area are lattice substitutions into sericite and topaz. Due to the abundance of sericite and topaz, fluorine substitutions for hydroxide molecules in these minerals yield a high geochemical "fingerprint" of the element.

Potassium (K_2O)

The analysis of potassium oxide (Figure 25) was to facilitate the recognition of a potassic alteration zone. This type of enrichment is common in rocks near or within ore and is sometimes a useful guide in exploration. The threshold value of K_2O was calculated at 3.4 percent (Appendix B, Figure 57) which resulted in contoured zones that offered no meaningful surface trends in the study area. Furthermore, the writer feels that a number of samples were inconsistently analyzed giving undependable results.

In cross section, K_2O (Figure 28) forms several bands alternating above and below the threshold value with increased depth. These weak zones indicate an absence of a potassic alteration zone in the drilled portion of the stock. The lack of this potassium enriched area offers encouragement for deeper drilling in search of a blind molybdenite target.

No correlation matrix was calculated for K_2O.

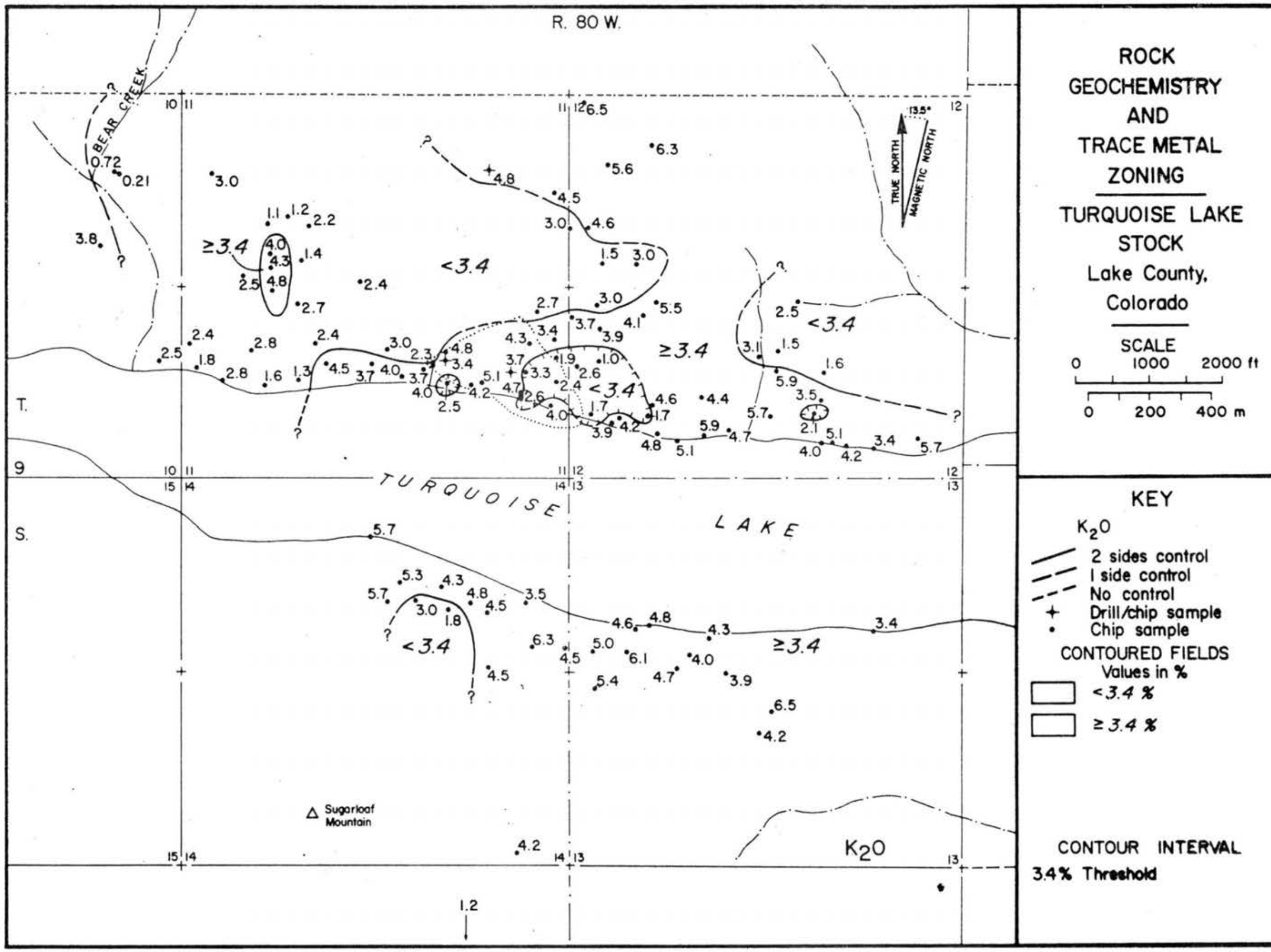

ROCK GEOCHEMISTRY AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
SCALE
0 1000 2000 ft
0 200 400 m
KEY
K_2O
2 sides control
1 side control
No control
Drill/chip sample
Chip sample
CONTOURED FIELDS
Values in %
<3.4 %
≥3.4 %
CONTOUR INTERVAL
3.4% Threshold
R. 80 W.
T. 9 S.
BEAR CREEK
TURQUOISE LAKE
TRUE NORTH
MAGNETIC NORTH
Sugarloaf Mountain
K_2O

Figure 25

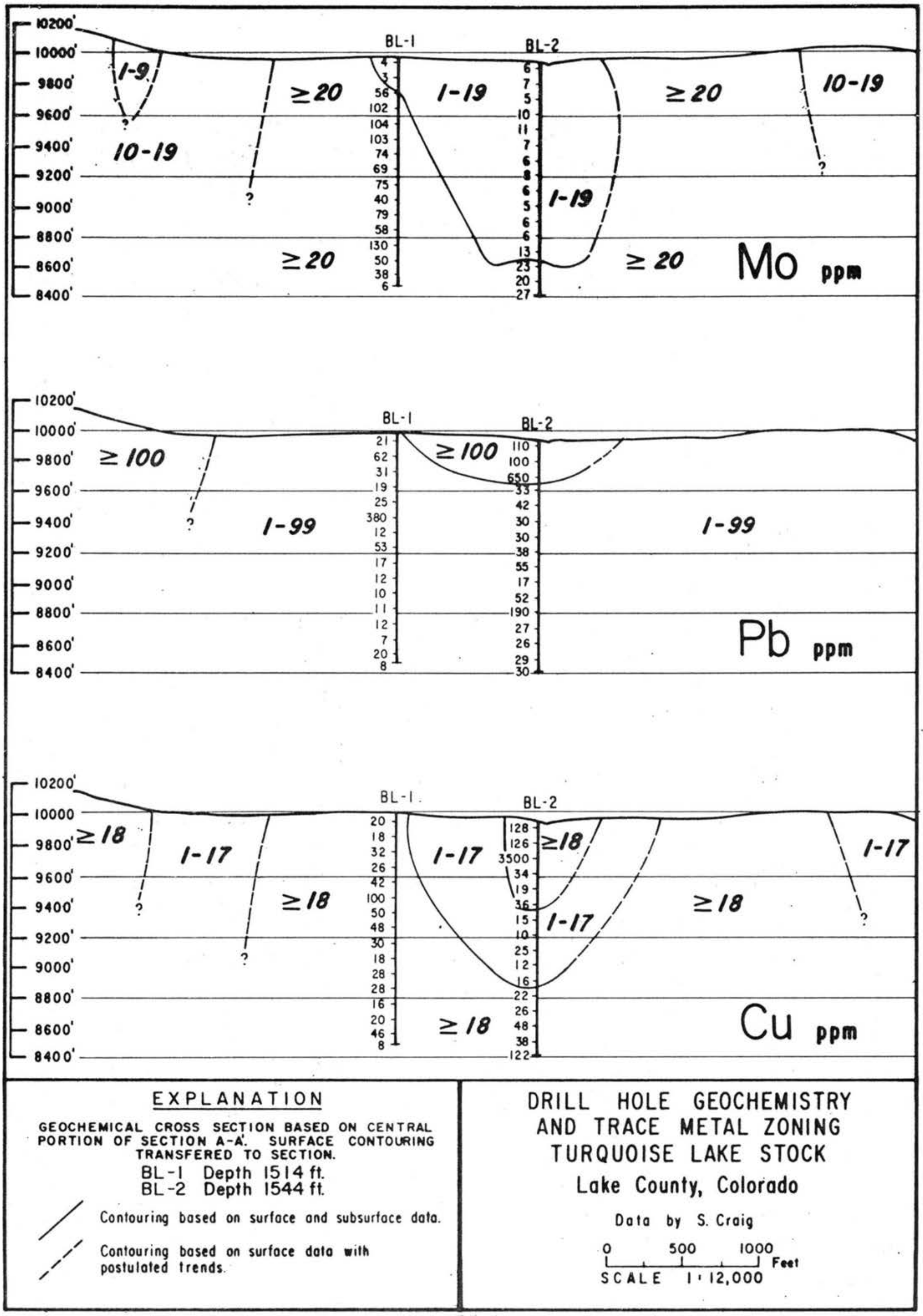

10200'
10000'
9800'
9600'
9400'
9200'
9000'
8800'
8600'
8400'
BL-1
BL-2
1-9
10-19
≥20
1-19
≥20
10-19
1-19
≥20
≥20
4 3 56 102 104 103 74 69 75 40 79 58 130 50 38 6
6 7 5 10 11 7 6 8 6 5 6 6 13 23 20 27
Mo ppm
≥100
1-99
≥100
1-99
21 62 31 19 25 380 12 53 17 12 10 11 12 7 20 8
110 100 650 33 42 30 30 38 55 17 52 190 27 26 29 30
Pb ppm
≥18
1-17
≥18
1-17
≥18
1-17
≥18
1-17
≥18
20 18 32 26 42 100 50 48 30 18 28 28 16 20 46 8
128 126 3500 34 19 36 15 10 25 12 16 22 26 48 38 122
Cu ppm
EXPLANATION
GEOCHEMICAL CROSS SECTION BASED ON CENTRAL PORTION OF SECTION A-A'. SURFACE CONTOURING TRANSFERED TO SECTION.
BL-1 Depth 1514 ft.
BL-2 Depth 1544 ft.
Contouring based on surface and subsurface data.
Contouring based on surface data with postulated trends.
DRILL HOLE GEOCHEMISTRY AND TRACE METAL ZONING TURQUOISE LAKE STOCK
Lake County, Colorado
Data by S. Craig
0 500 1000 Feet
SCALE 1:12,000

Figure 26

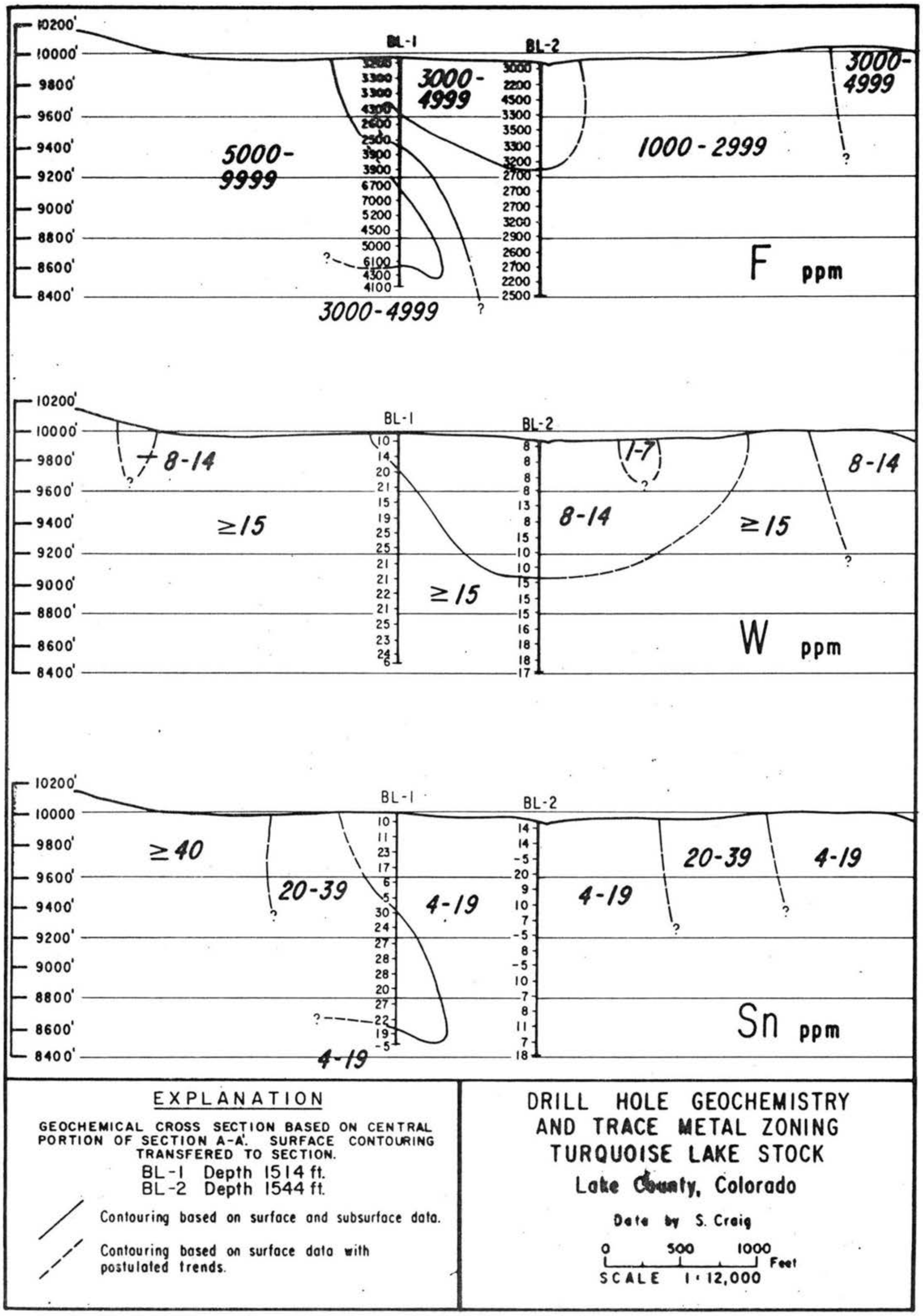
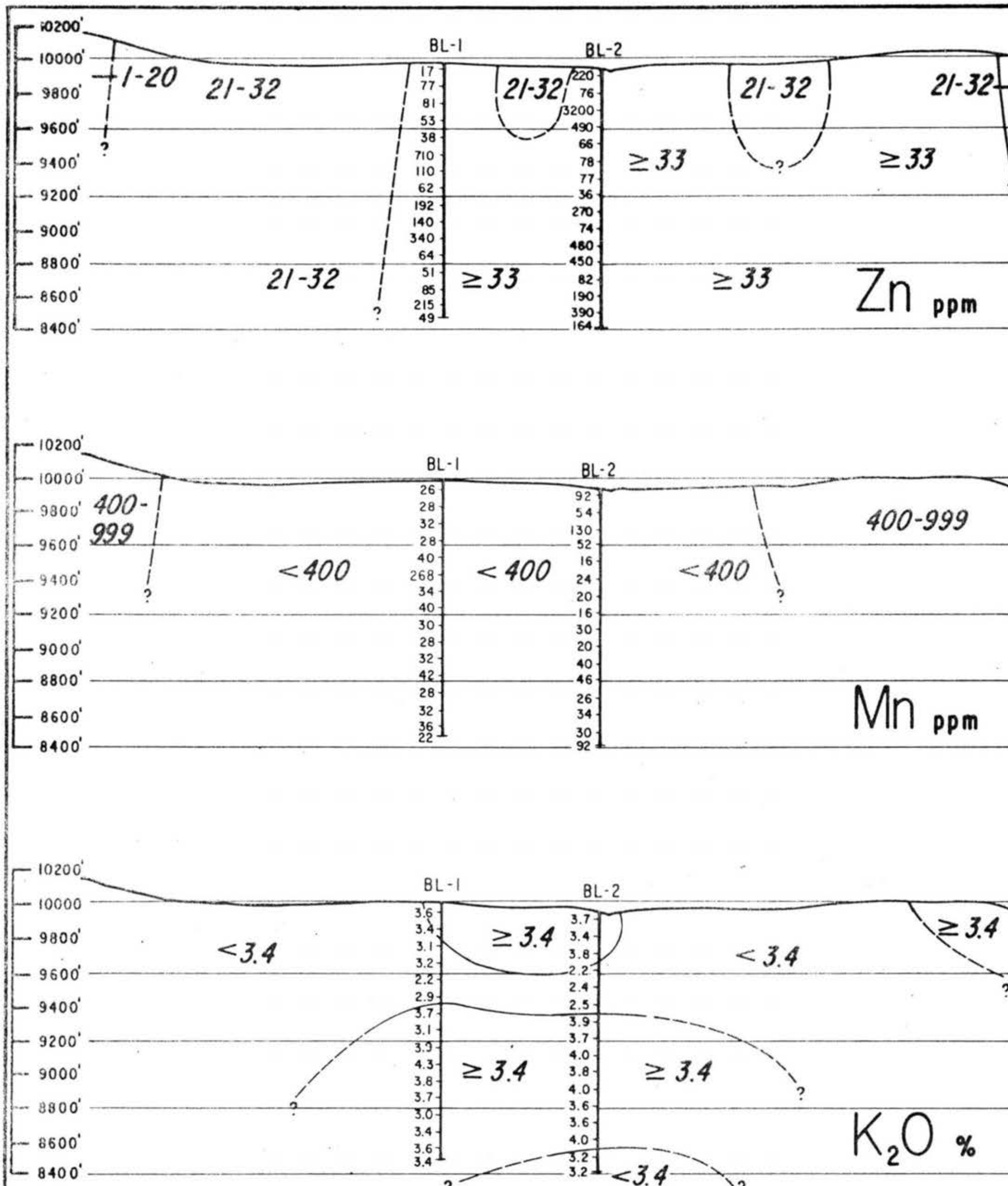

BL-1
BL-2
3000-4999
5000-9999
1000-2999
F ppm
8-14
≥15
1-7
W ppm
≥40
20-39
4-19
Sn ppm
EXPLANATION
GEOCHEMICAL CROSS SECTION BASED ON CENTRAL PORTION OF SECTION A-A'. SURFACE CONTOURING TRANSFERED TO SECTION.
BL-1 Depth 1514 ft.
BL-2 Depth 1544 ft.
Contouring based on surface and subsurface data.
Contouring based on surface data with postulated trends.
DRILL HOLE GEOCHEMISTRY
AND TRACE METAL ZONING
TURQUOISE LAKE STOCK
Lake County, Colorado
Data by S. Craig
0 500 1000 Feet
SCALE 1:12,000

Figure 27



EXPLANATION

GEOCHEMICAL CROSS SECTION BASED ON CENTRAL PORTION OF SECTION A-A'. SURFACE CONTOURING TRANSFERED TO SECTION.

BL-1 Depth 1514 ft.
BL-2 Depth 1544 ft.

Contouring based on surface and subsurface data.

Contouring based on surface data with postulated trends.

DRILL HOLE GEOCHEMISTRY AND TRACE METAL ZONING TURQUOISE LAKE STOCK

Lake County, Colorado

Data by S. Craig

0 500 1000 Feet

SCALE 1:12,000

Figure 28

GEOPHYSICS

Aeromagnetic and ground magnetic surveys from Turquoise Lake were made available to the author by Bear Creek Mining Company. The surveys were conducted to discover the position of anomalous high or low magnetic areas associated with the Turquoise Lake system.

Aeromagnetics

Regional aeromagnetic studies have disclosed the existence of a magnetic low over the valley of the Lake Fork of the Arkansas River and the low hills of the St. Kevin Mining District (Tweto and Case, 1972). This low is attributed to a combination of three factors: (1) low topography, (2) reversed remanent magnetism in the St. Kevin Granite, and (3) extensive alteration of the rocks in the St. Kevin District.

Recent detailed aeromagnetic studies by Bear Creek Mining Company have located three salient features of this magnetic low (Figure 29). The center of the magnetic low is found one mile southwest of the surface expression of the stock. This suggests that the low is related to a feature other than the alteration associated with the Turquoise Lake stock. This feature may possibly be a deeper, more extensive portion of the Turquoise Lake stock, or perhaps

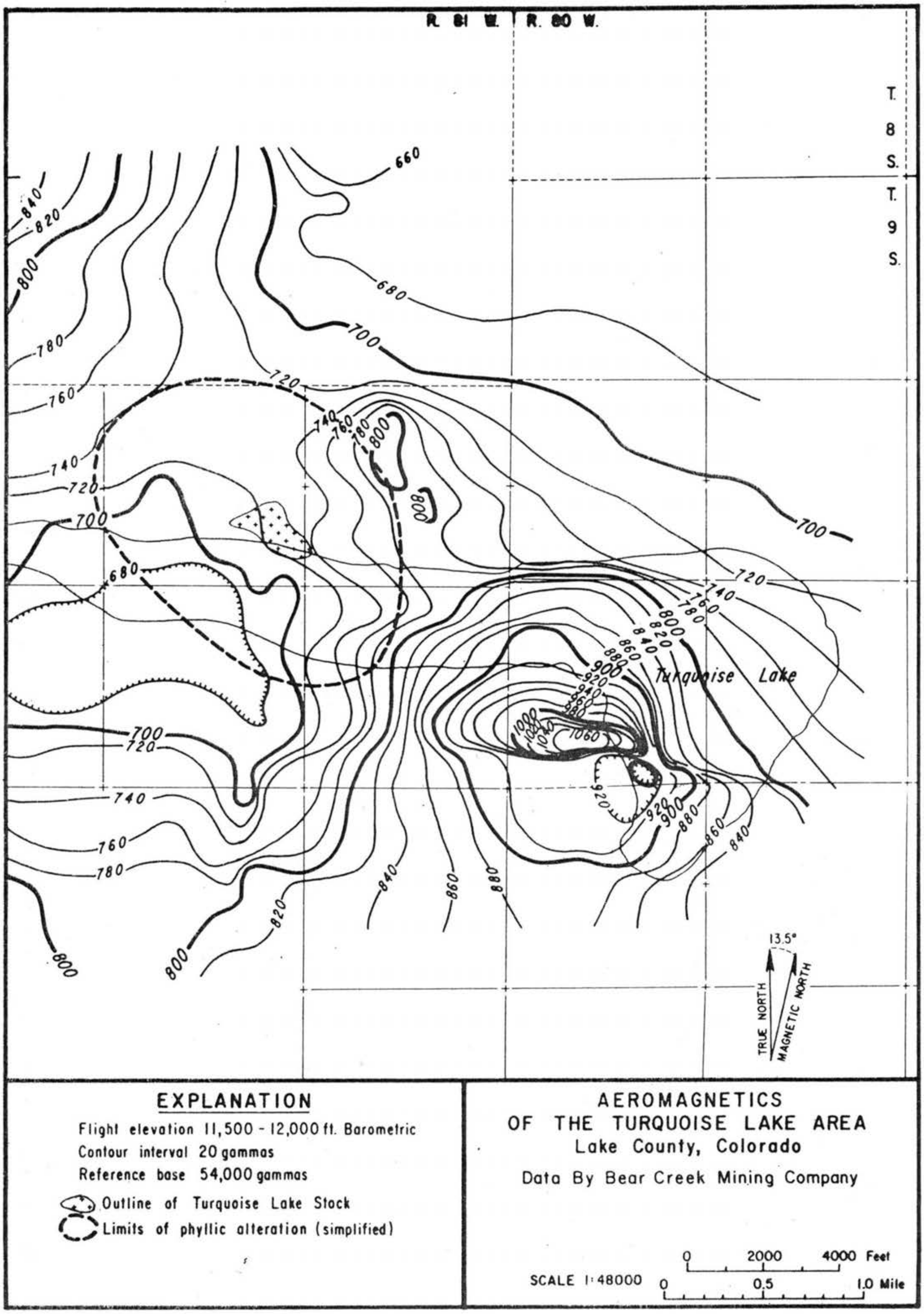

R. 81 W.
R. 80 W.
T. 8 S.
T. 9 S.
660
680
700
720
740
760
780
800
820
840
860
880
900
920
1000
1020
1040
1060
Turquoise Lake
13.5°
TRUE NORTH
MAGNETIC NORTH
EXPLANATION
Flight elevation 11,500 - 12,000 ft. Barometric
Contour interval 20 gammas
Reference base 54,000 gammas
Outline of Turquoise Lake Stock
Limits of phyllic alteration (simplified)
AEROMAGNETICS
OF THE TURQUOISE LAKE AREA
Lake County, Colorado
Data By Bear Creek Mining Company
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 29

the center of a magnetite poor, Tertiary batholith responsible for the Turquoise Lake stock. A magnetic high is located to the southeast of the stock in the Sugarloaf District with a lobe trending northwest to an area adjacent to the phyllic alteration east of stock. Although the cause of the magnetic high in the Sugarloaf District is not known, the high in the St. Kevin District is attributed to the magnetite halo found outside the phyllic alteration boundary.

Ground Magnetics

The main objective of the ground magnetic survey was to determine the position of the magnetite halo along the fringes of the phyllic alteration. A proton precession magnetometer was used along roadways, section lines, trails, and ridgelines with readings taken every 100 feet. The limits of the survey and results are presented in Figure 30.

A magnetic high "ridge" was located on the northeast side of the phyllic alteration. This "ridge" extended southeastward across the lake and expanded into a wide lobe. North and west of the stock definite magnetic halos are not evident. The absence of the magnetic halo in this area is attributed to two phenomena: (1) deep glacial drift effectively reduces the anomaly in this zone, or (2) the Central Fault uplifted the magnetic halo and subsequent erosion has removed the bulk of the once existing magnetic rocks. West of the stock only random, high magnetic readings were obtained indicating a possible continuation of the halo around the alteration margins. Southwest of the stock, a magnetic low dominates with no trace of the halo evident. On the southeast side of the alteration zone across the lake, many north-south structures may account for the scattering of high and low magnetic readings.

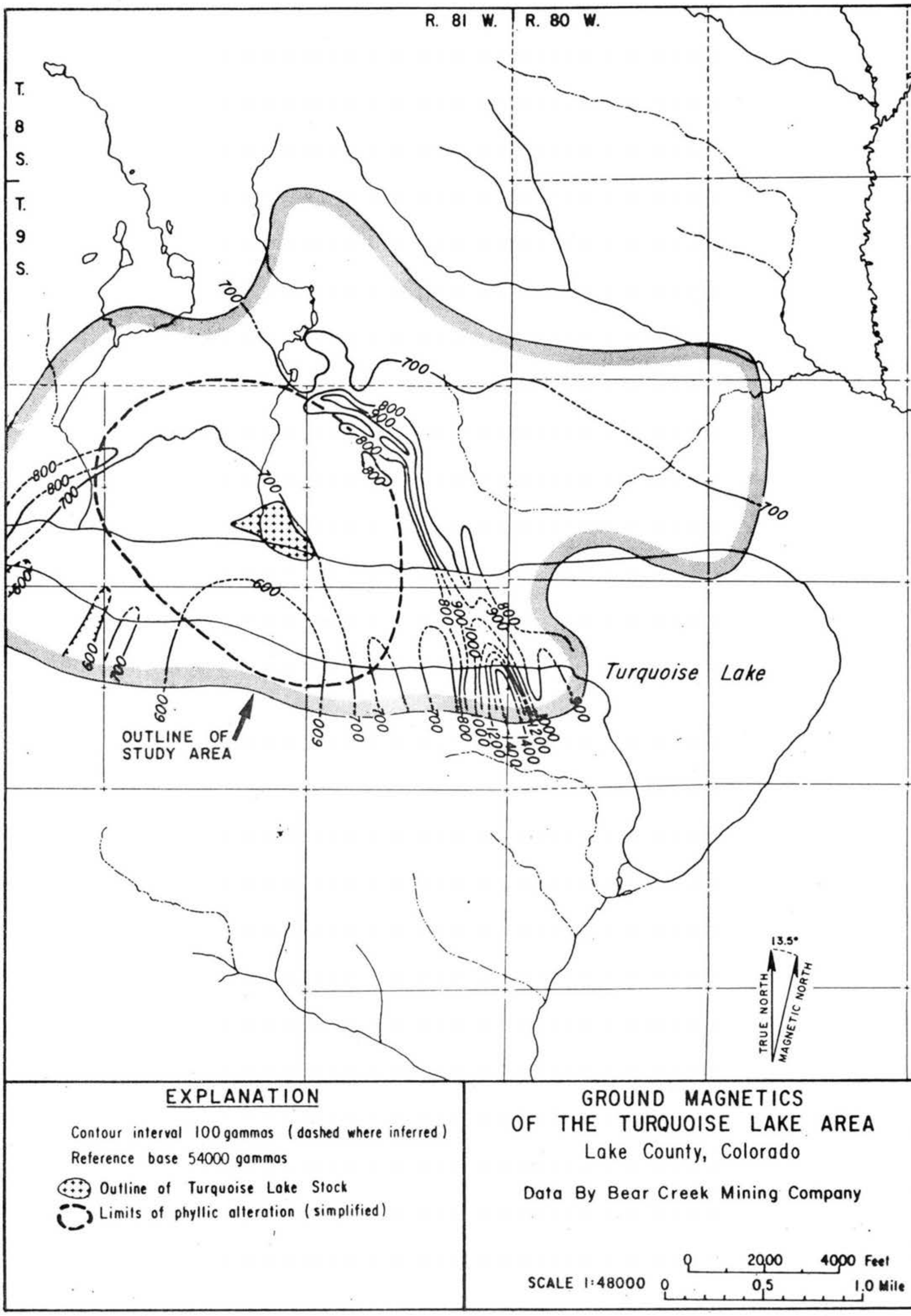

R. 81 W.
R. 80 W.
T. 8 S.
T. 9 S.
Turquoise Lake
OUTLINE OF STUDY AREA
TRUE NORTH
MAGNETIC NORTH
13.5°
EXPLANATION
Contour interval 100 gammas (dashed where inferred)
Reference base 54000 gammas
Outline of Turquoise Lake Stock
Limits of phyllic alteration (simplified)
GROUND MAGNETICS
OF THE TURQUOISE LAKE AREA
Lake County, Colorado
Data By Bear Creek Mining Company
0 2000 4000 Feet
SCALE 1:48000 0 0.5 1.0 Mile

Figure 30

THE ST. KEVIN AND SUGARLOAF DISTRICTS

General Statement

The St. Kevin and Sugarloaf Mining Districts were the subject of numerous studies over the past 45 years. A number of writers made detailed reports and/or maps on the ore petrography (Sandburg, 1935), the vein systems (Pierson and Singwald, 1954; Singwald, 1955), and regional setting (Tweto, 1974). The writer does not intend to repeat this earlier work but to make needed reevaluations and additions to the bulk of knowledge already in existence. Changes include a reevaluation of the ore minerals and their paragenesis through ore petrography techniques, while additions include a new section on vein geochemistry and metal zonation patterns.

Vein Mineralogy

During reconnaissance of the Sugarloaf and St. Kevin Districts, it was noted that all the underground workings were inaccessible and direct observation of veins was impossible. Consequently, vein specimens were collected from ore chutes and dumps found throughout the two districts. The descriptions that follow will apply to these specimens with inferences to the whole vein system.

The bulk vein mineralogy of the Sugarloaf and St. Kevin Districts consists of a quartz gangue with sulfide minerals of pyrite, galena, sphalerite and chalcopyrite. Minor amounts of marcasite, polybasite, molybdenite, and a manganiferous calcite gangue occur locally throughout the districts. Secondary minerals in the zone of weathering include pyrargyrite, chalcocite-digenite, and iron oxides. Sandburg (1935) reports the presence of tetrahedrite and argentite, but the writer could not find them in polished section.

Quartz is the most common gangue mineral and appears in two forms. A transparent-grey, crystalline to massive variety is the most common and appears to be associated with the majority of sulfide minerals. This type of quartz forms drusy linings in vugs, veinlets, and amorphous masses that appear to have been emplaced during early crystallization. Sulfides caught in this "gel" appear to be rolled like a snowball. A second type of quartz is a white, massive to chalcedonic variety found in the distant portions of the veins. This quartz may be the cooler manifestation of the crystalline quartz after the vein fluid dropped all its sulfides. Usually, this variety is barren of sulfides but occasionally fine disseminations of pyrite can be found.

Carbonate gangue is not common in either mining district with its only occurrence found at the Fanchon Mine in the Sugarloaf District. Sandburg (1935) analyzed this carbonate and found it contains 67 percent $MnCO_3$ and 33 percent $CaCO_3$. The mineral was found filling vugs lined with drusy quartz.

Pyrite is found throughout the vein systems either as the only sulfide mineral present or as small scattered subordinate grains to the other ore minerals. Pyritohedrons were the only crystal form observed, and these were usually rolled and broken. Large, massive grains were common and these were usually mildly broken by tectonism during vein emplacement. Two types of pyrite mineralization were found in the veins. Separation of each type was difficult except that pyrite I had numerous inclusions when compared to pyrite II, and pyrite I often had overgrowths of the later pyrite II (Figure 31).

Galena appears as a vug filling mineral and therefore massive in form. In a number of specimens, cleavage triangles indicate multiple crystals grew together to form a continuous mass. Some of these crystals also showed considerable curvature and distortion due to later movement of the vein (Figure 32). As with pyrite and sphalerite, later vein fluid movement carried broken fragments of galena in a partially crystallized mush.

Sphalerite forms a dark massive, early fracture filling and a light brown to greenish brown, late crystalline vug filling. The early sphalerite was found in some locations as rolled and broken grains up to 1 cm across mixed in a quartz-pyrite-wallrock mush. As with pyrite, this mode of occurrence indicates that movement of the ore-bearing fluids through fissures was taking place during crystallization.

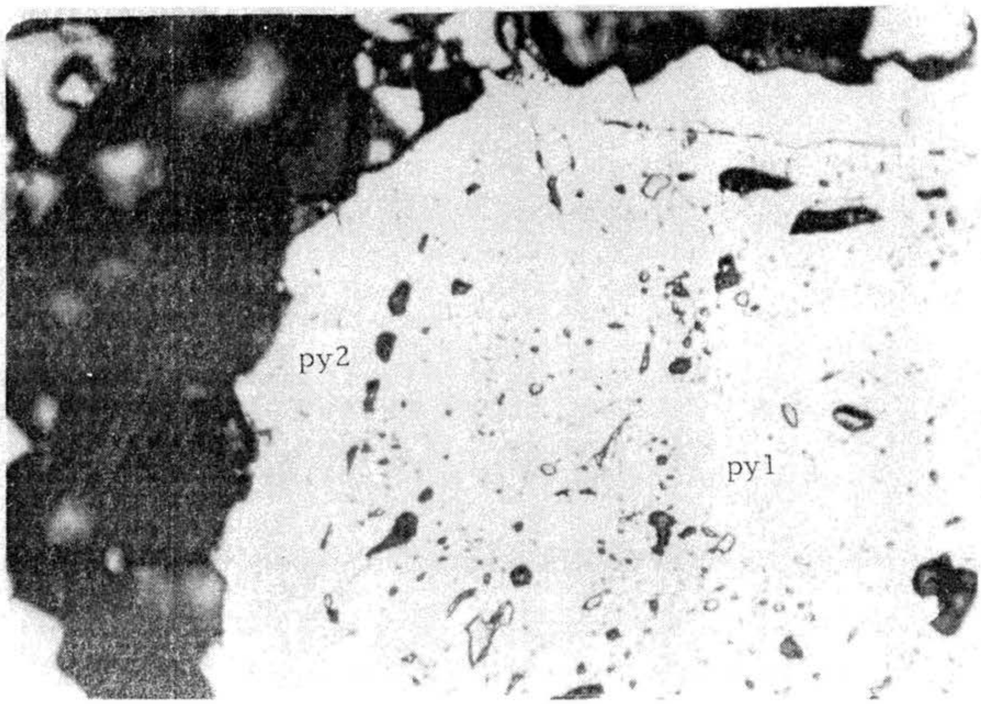


Figure 31. Photomicrograph of vein material, sample no. 17349. Photo dimensions are 0.17 mm x 0.26 mm. Early pyrite I (pyl) exhibiting pyritohedron crystal form with overgrowth of later pyrite II (py2).

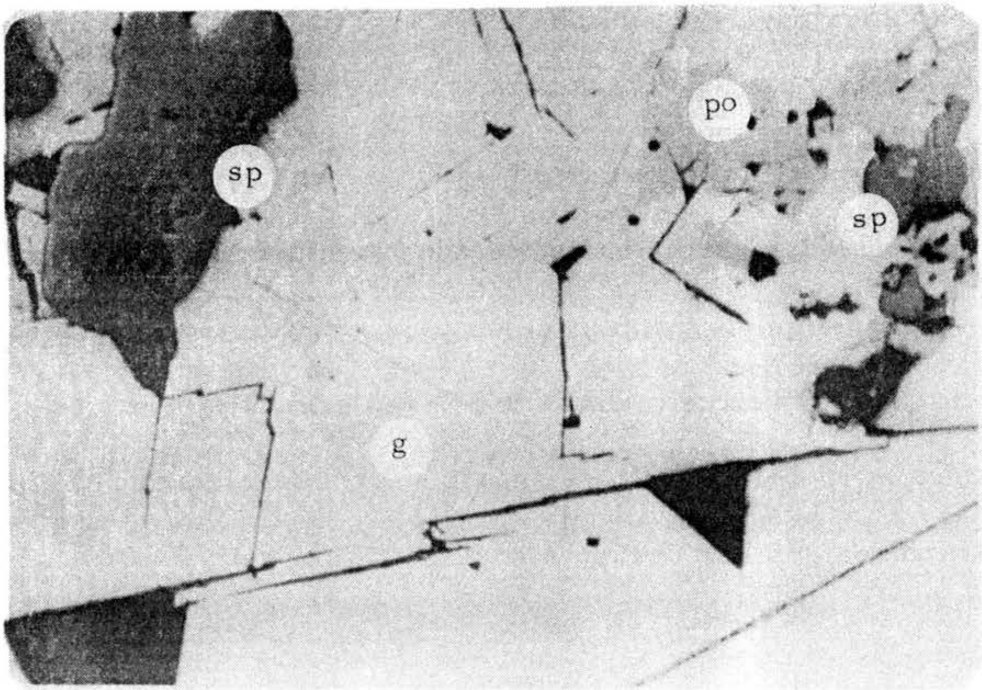


Figure 32. Photomicrograph of vein material, sample no. 17256A. Photo dimensions are 0.17 mm x 0.26 mm. Galena (g) cleavage plane exhibiting curvature due to later movement of fissure vein. Polybasite (po) replaces galena near a replacement front with sphalerite (sp).

The later sphalerite usually formed numerous crystals in vugs, sometimes completely filling the opening.

Chalcopyrite is not an abundant mineral in the vein systems. Usually, it was found in dark sphalerite as exsolved rods and beads (Figure 33) and only rarely in light sphalerite in this form. Occasionally, small grains were found replacing galena near a replacement front between sphalerite and galena. Late chalcopyrite-pyrite-quartz veining was also noted in other specimens.

Polybasite (Figure 34) was the only primary silver mineral found. It either formed rare grains singly isolated in galena or was present with chalcopyrite in galena adjacent to a replacement front between sphalerite and galena.

The occurrence of marcasite in a quartz-pyrite-marcasite breccia (Figure 35) is the only instance of this mineral noted. Small broken fragments of marcasite were found mixed with fragments of pyrite and quartz xenocrysts from the Reese tunnel in the St. Kevin District.

Molybdenite was observed in quartz-pyrite veins as small isolated flakes or as smears. A zone close to the stock in the Lake Fork valley exhibited this type of mineralization.

A small number of supergene minerals were found in polished section. Chalcocite-digenite occurred as either small veins following fractures or as a localized replacement of chalcopyrite. Pyrargyrite

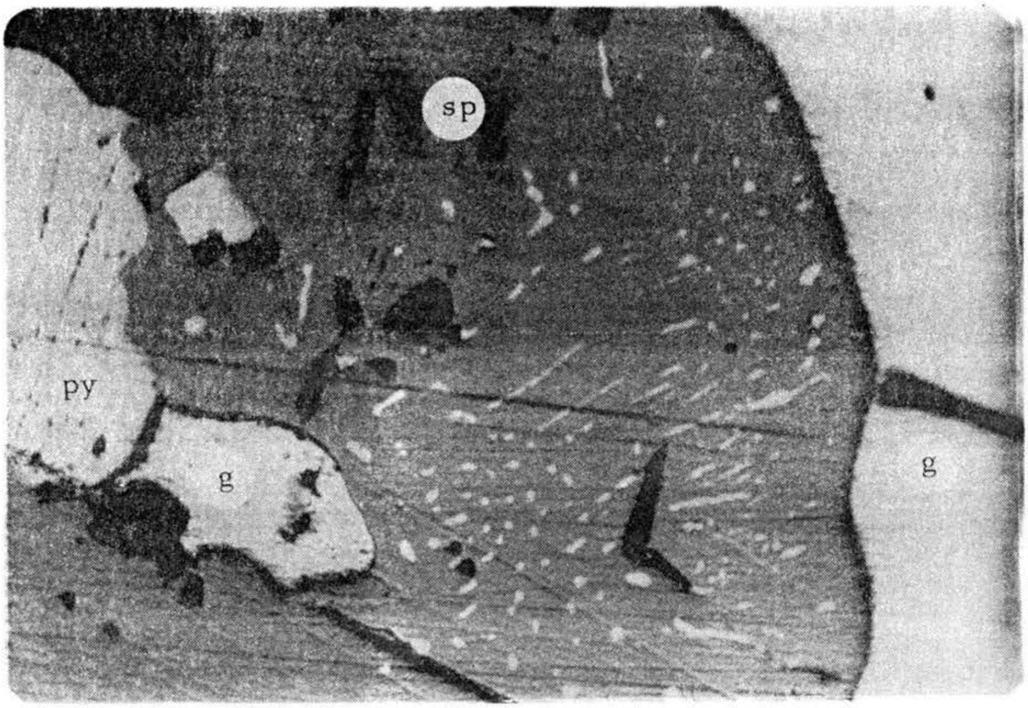


Figure 33. Photomicrograph of vein material, sample no. 17354. Photo dimensions are 0.17 mm x 0.26 mm. Rod and bead exsolutions of chalcopyrite in early sphalerite (sp). Sphalerite is replacing galena (g) and pyrite (py).

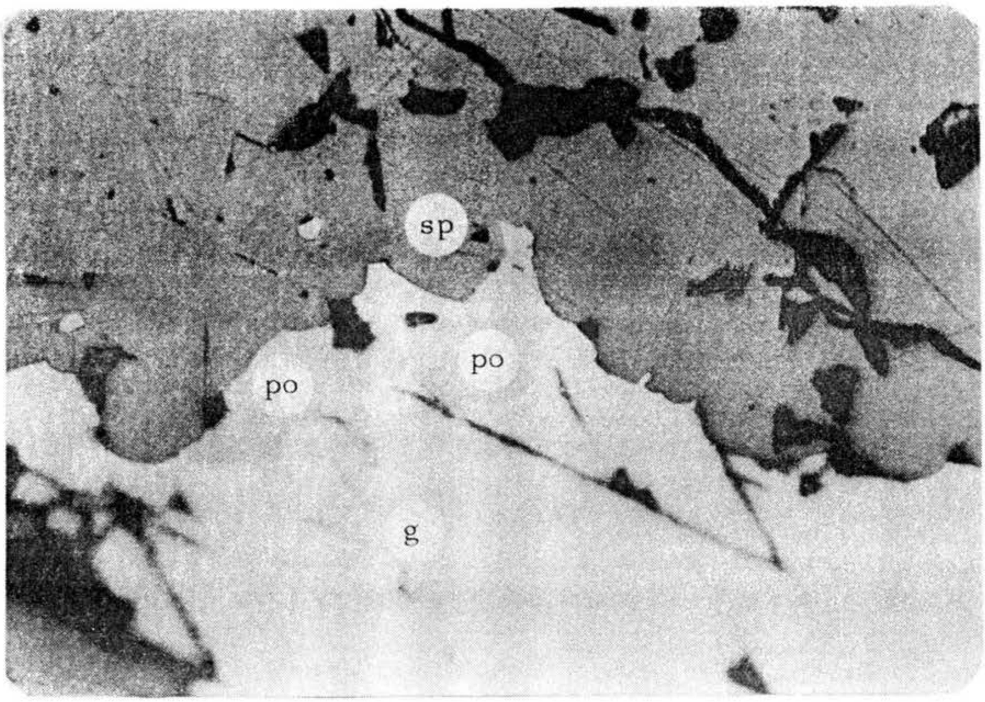


Figure 34. Photomicrograph of vein material, sample no. 17256. Photo dimensions are 0.17 mm x 0.26 mm. Polybasite (po) replacing galena (g) at replacement front with sphalerite (sp).

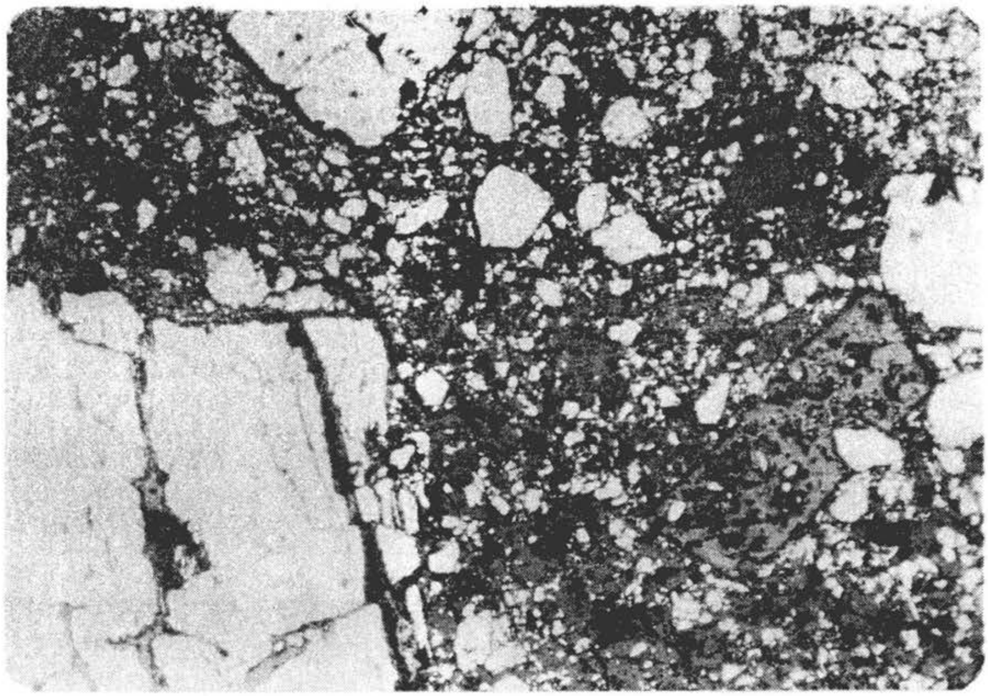


Figure 35. Photomicrograph of vein material, sample no. 17374. Photo dimensions are 0.42 mm x 0.63 mm. Mixture of pyrite-marcasite (white grains) fragments in a quartz and rock breccia.

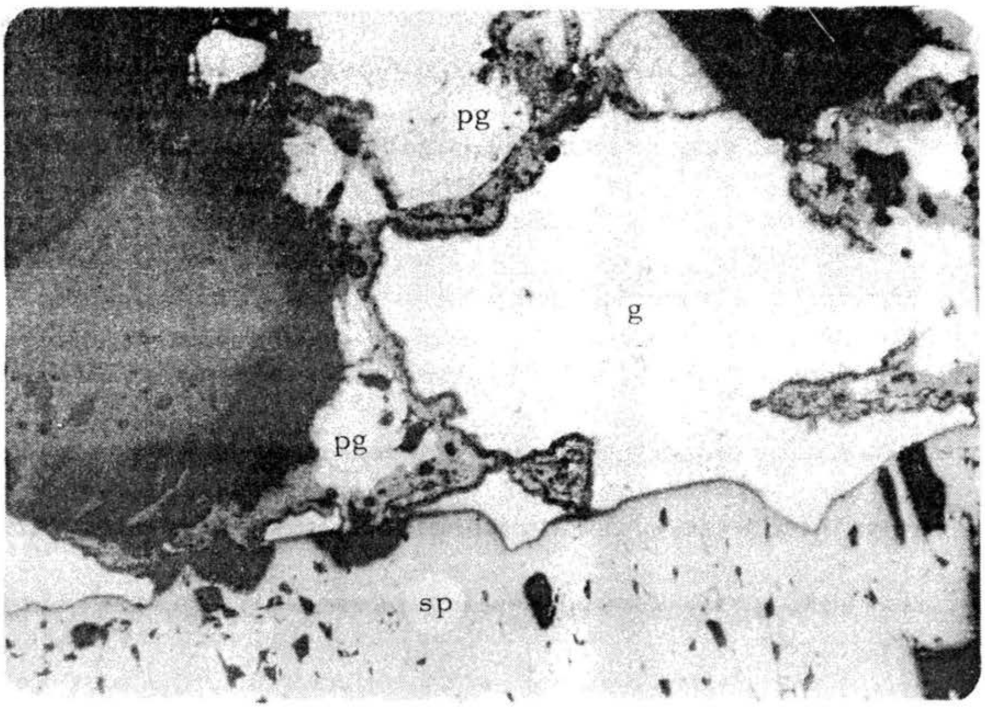


Figure 36. Photomicrograph of vein material, sample no. 17374. Photo dimensions are 0.42 mm x 0.63 mm. Pyrargyrite (pg) replacing galena (g) and sphalerite (sp) adjacent to drusy quartz (q) in vug.

was found replacing galena and sphalerite (Figure 36). Finally, iron oxides were found replacing pyrite.

Paragenesis

The mineral paragenesis of the St. Kevin and Sugarloaf veins can be divided into four stages. The early stage is an ore preparation episode involving massive introduction of gangue quartz. The main ore stage followed depositing the bulk of the economic metals. The late stage represents a second pulse of weak mineralization crosscutting the main ore stage minerals. Supergene deposition formed the final stage recognized in the mineral-forming sequence. Figure 37 presents the paragenetic sequence along with relative abundance of each mineral at time of appearance.

The early stage saw massive introduction of quartz with minor amounts of molybdenite and abundant pyrite I in pyritohedron form. Later in this episode continued introduction of quartz concurrently with overgrowths of pyrite I by pyrite II took place (Figure 31). Both pyrite types were then replaced by ore minerals (Figure 38) during the main ore stage. The minor appearance of marcasite (Figure 35), is presumed to have taken place sometime during this episode. Evidence for cataclasis and vein fluid movement is common in this early stage.

The main ore stage had galena, sphalerite, chalcopyrite, polybasite and more quartz deposited in the fissure veins. Galena filled

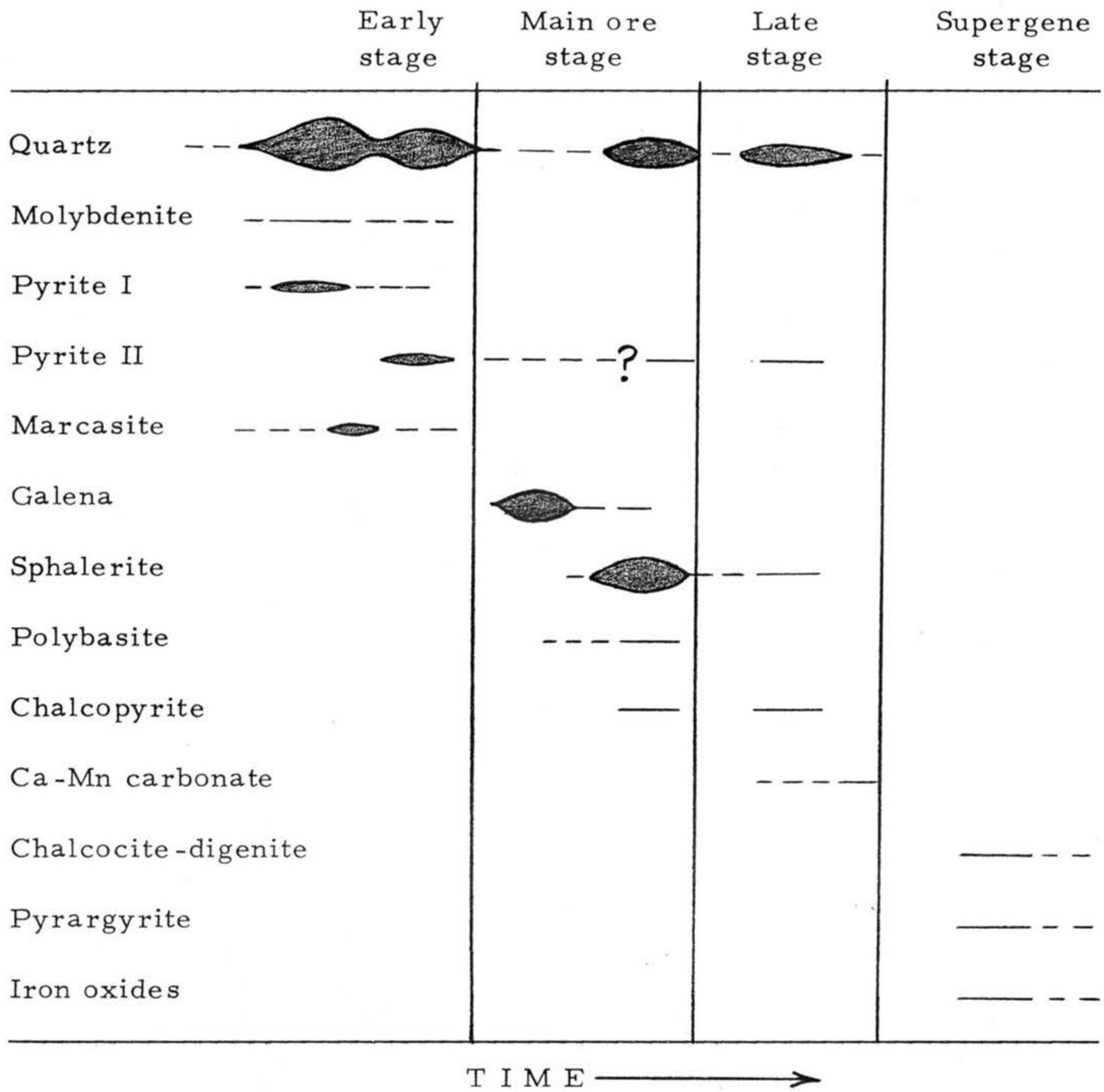


Figure 37. Generalized paragenetic sequence and relative abundance of ore and gangue minerals in veins; width of bars are proportional to abundance.

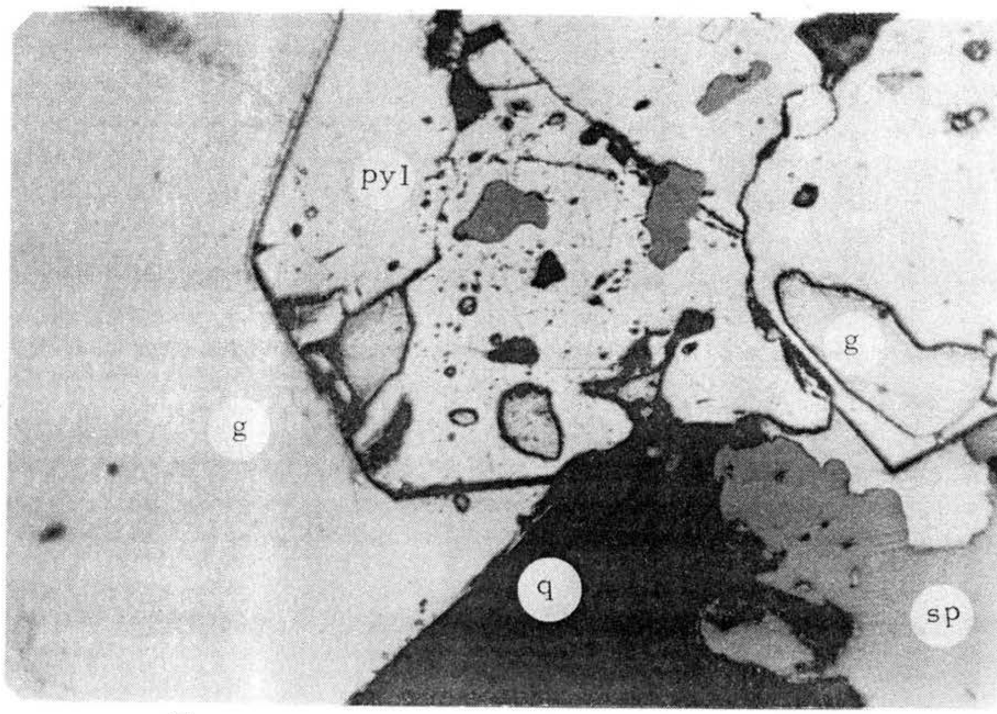


Figure 38. Photomicrograph of vein material, sample no. 17352. Photo dimensions are 0.17 mm x 0.26 mm. Pyrite 1 (pyl) exhibiting pyritohedron crystal form being replaced by galena (g). Sphalerite (sp) replaces galena and quartz (q).

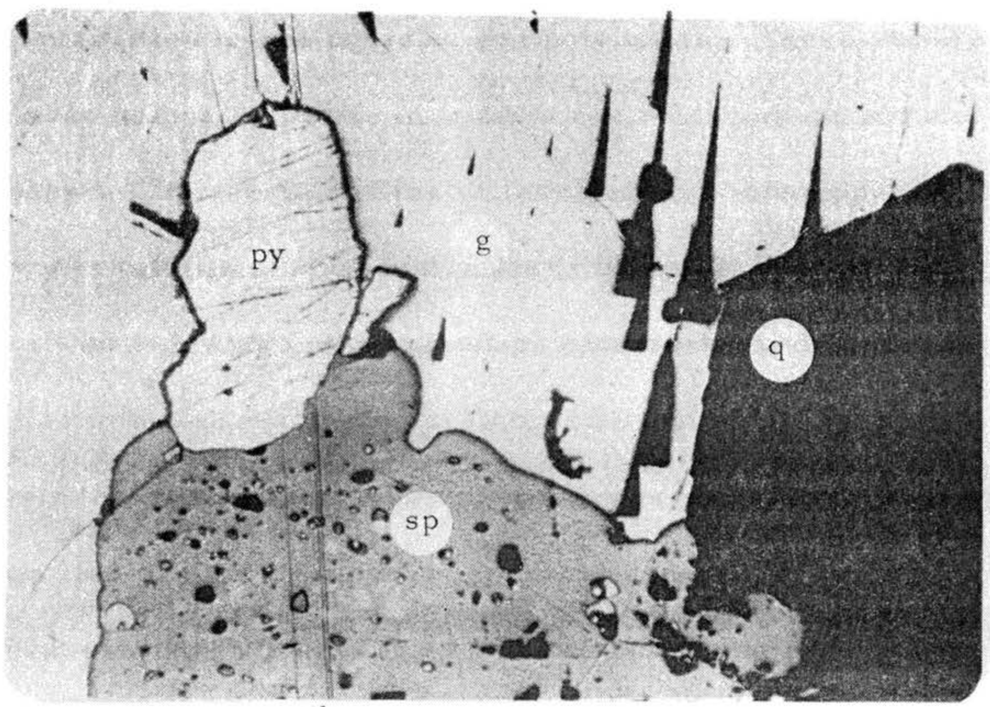


Figure 39. Photomicrograph of vein material, sample no. 17355. Photo dimensions are 0.42 mm x 0.63 mm. Sphalerite (sp) replaces pyrite (py), galena (g) and quartz (q). Galena originally filled open vug filled with drusy quartz.

vug spaces, replaced earlier pyrite and did not replace quartz. Sphalerite followed galena in abundance. It replaced all earlier minerals including quartz (Figure 39). Associated with sphalerite mineralization is chalcopyrite and polybasite. These minerals replaced galena or pyrite in front of the replacement boundary of sphalerite (Figure 34). Finally, exsolution of chalcopyrite took place during crystallization of sphalerite (Figure 33).

The late stage mineralization saw weak veining cutting all earlier minerals. Quartz, chalcopyrite and pyrite formed at approximately the same time. Possibly associated with this event was the deposition of light brown sphalerite in reopened vug spaces. The manganese-calcium carbonate was the last event and it filled any remaining open spaces.

The supergene stage saw development of secondary copper sulfide minerals of chalcocite-digenite and the ruby silver mineral of pyrargyrite (Figure 36). Iron oxides formed as a gossan on shallow ores.

Vein Geochemistry and Metal Zonation

A unique opportunity to study the linear dispersion of metals along vein systems associated with a point source intrusive is present in the St. Kevin and Sugarloaf Mining Districts. Twenty-nine samples (Figure 40) were high graded from ore chutes and dumps over a wide area in both districts. After analysis and plotting of data points,

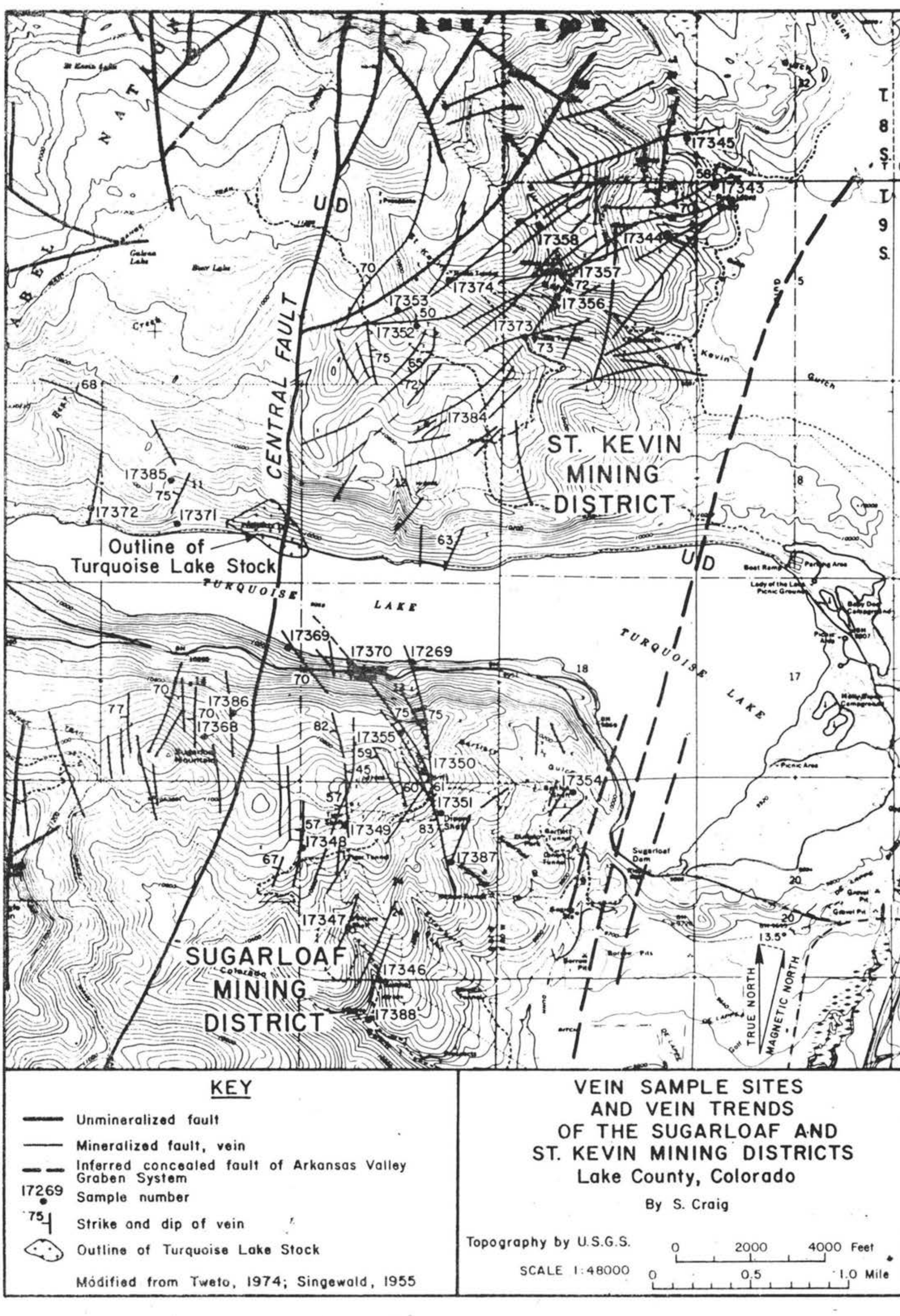

CENTRAL FAULT
U D
ST. KEVIN
MINING
DISTRICT
SUGARLOAF
MINING
DISTRICT
Outline of
Turquoise Lake Stock
TURQUOISE LAKE
T 8 S
T 9 S
TRUE NORTH
MAGNETIC NORTH
13.5°
17345
17343
17358
17344
17357
17374
17353
17356
17352
17373
17384
17385
17372
17371
17369
17370
17269
17386
17368
17355
17350
17354
17351
17349
17348
17387
17347
17346
17388
KEY
Unmineralized fault
Mineralized fault, vein
Inferred concealed fault of Arkansas Valley Graben System
17269 Sample number
75 Strike and dip of vein
Outline of Turquoise Lake Stock
Modified from Tweto, 1974; Singewald, 1955
VEIN SAMPLE SITES
AND VEIN TRENDS
OF THE SUGARLOAF AND
ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
Topography by U.S.G.S.
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 40

several interesting facts were revealed. Not only was it possible to get the "average" metal content of a vein in a particular place, but to also delineate zones of metal concentration around the stock. Manipulation of data into metal ratios also yielded definable ratio zones centered on the stock, the apparent source of the metals.

As with the rock geochemistry, the vein geochemistry values were tabulated in histogram form and threshold values were calculated. Although these data were not used in contouring the metals, it is presented in Appendix B as supportive information.

A statistical correlation matrix was performed for 8 elements in 29 samples. Table 2 presents the matrix with discussion under the individual metals.

Contouring Rules

While analyzing the plotted results of the vein geochemistry, it became evident that values ranged over wide intervals. Consequently, logarithmically progressing contour intervals such as 1, 10, 100, 1000, etc. were chosen to delineate broad zones of dissimilar numbers. Usually, this gave consistent results in locating zones of similar metal concentration.

It must be noted that the writer took considerable liberty in extending similar metal concentration zones across a 2 mile gap over Turquoise Lake. Since it is believed the metals were derived from a central point source, enough geochemical control exists in both mining

Table 2. Correlation matrix for eight elements in 29 vein samples from the St. Kevin and Sugarloaf Mining Districts.

	Cu	Mo	Pb	Zn	Ag	Sn	W	Bi
Cu	1.000							
Mo	-0.144	1.000						
Pb	0.356	-0.245	1.000					
Zn	0.551	-0.210	0.560	1.000				
Ag	0.409	-0.294	0.310	0.221	1.000			
Sn	0.555	-0.076	0.062	0.031	0.711	1.000		
W	-0.239	0.410	-0.291	-0.298	-0.462	-0.226	1.000	
Bi	0.366	-0.066	-0.047	-0.121	0.285	0.758	-0.122	1.000

districts to allow this procedure with confidence. Also, as noted on the figures, line pattern changes where a lack of data points exist.

Some samples may reflect poor sampling in the field due to a disproportionate result with some metals. In particular, the bismuth sample of 4900 ppm in a field of numbers less than 100 ppm calls attention to the problem. However, the consistency of the overall geochemical dispersion patterns lends credibility to the results.

Copper

The study of polished sections found that copper minerals are not abundant. This fact is reflected in the overall copper values found throughout the two districts. In Figure 41, copper zoning is nearly nonexistent except for a decline into lower numbers on the distant portions of the veins.

Curiously, even though the spread of values appeared uniform, subtle shifts allowed copper to correlate with lead, zinc, silver, tin, and bismuth. Negative correlation existed with molybdenum and tungsten.

Molybdenum

High molybdenum geochemical values were found surrounding the stock area (Figure 42). Except for isolated occurrences of other high values, molybdenum also forms a wide band in the southeast

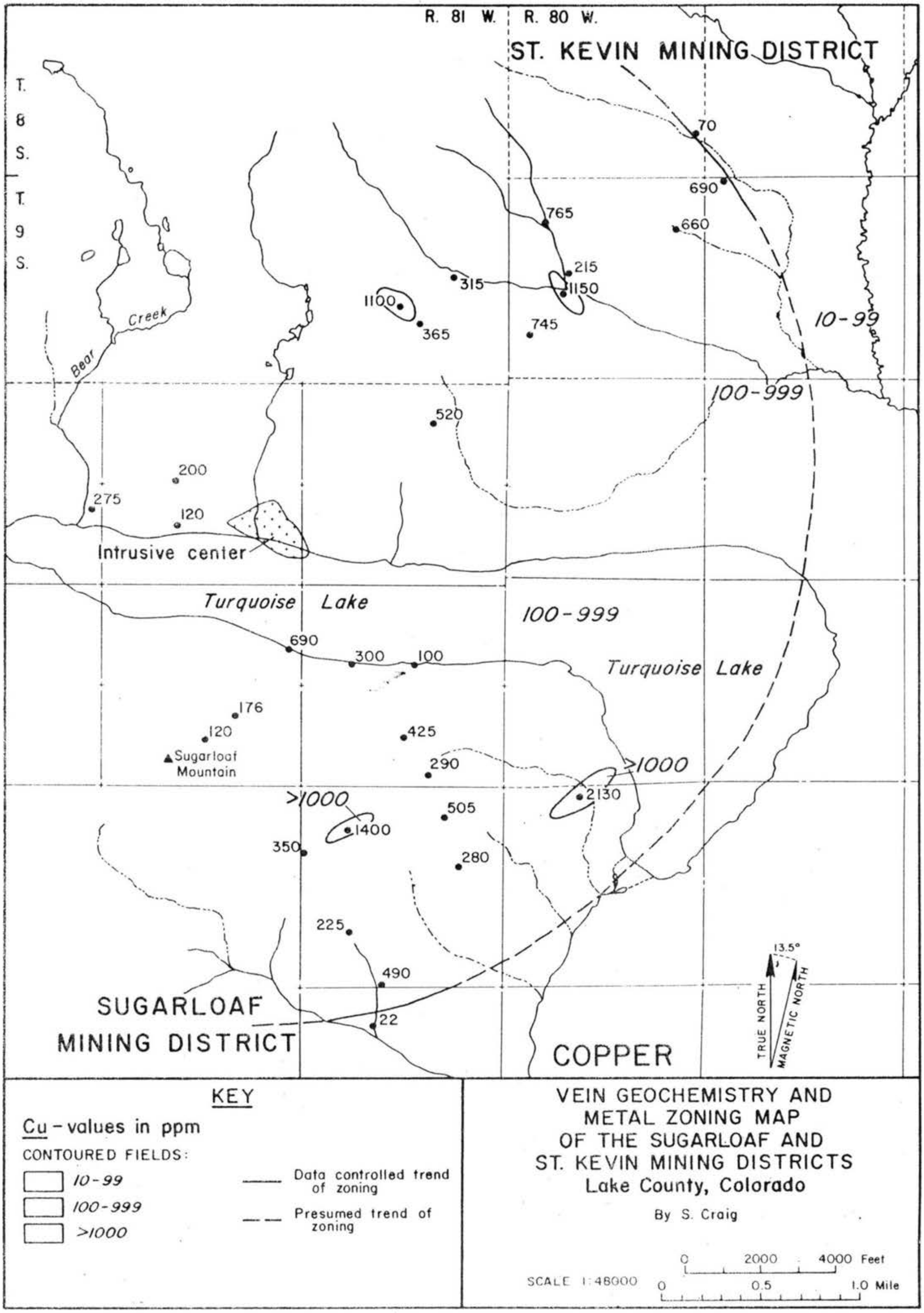

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
70
690
765
660
215
1150
315
1100
365
745
10-99
100-999
520
200
275
120
Intrusive center
Turquoise Lake
100-999
690
300
100
Turquoise Lake
176
120
Sugarloaf Mountain
425
290
>1000
>1000
2130
505
1400
350
280
225
490
22
SUGARLOAF MINING DISTRICT
COPPER
13.5°
TRUE NORTH
MAGNETIC NORTH
KEY
Cu - values in ppm
CONTOURED FIELDS:
10-99
100-999
>1000
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 41

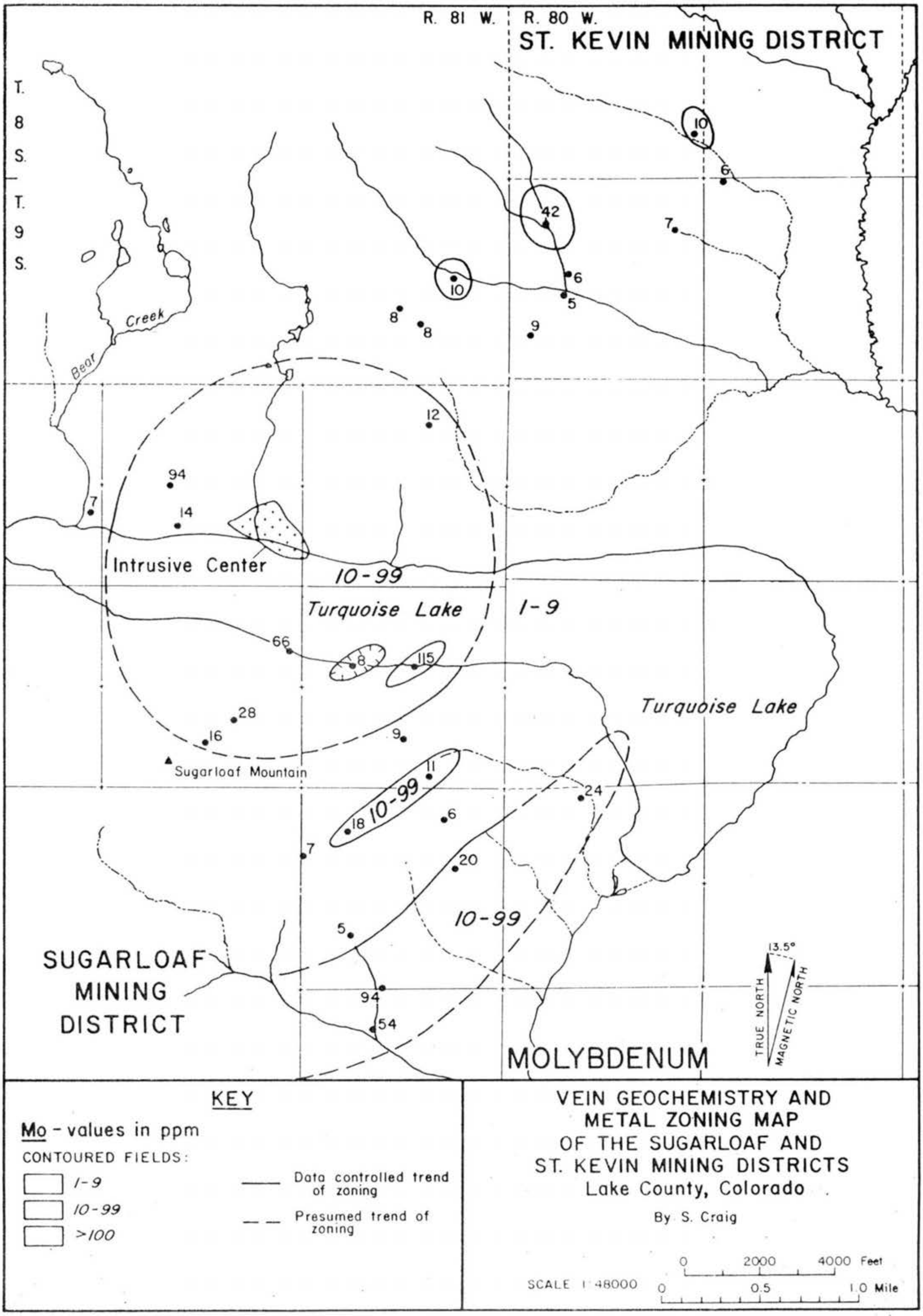

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
Intrusive Center
10-99
Turquoise Lake
1-9
Turquoise Lake
Sugarloaf Mountain
10-99
10-99
SUGARLOAF MINING DISTRICT
MOLYBDENUM
TRUE NORTH
MAGNETIC NORTH
13.5°
KEY
Mo - values in ppm
CONTOURED FIELDS:
1-9
10-99
>100
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 42

portion of the Sugarloaf District. This same zone is found in the contoured maps of tin and tungsten. This zone is an anomaly considering that the geochemical behavior of molybdenum allows it to form inner halos. Two explanations can be offered: (1) this peripheral mineralization represents early stage dispersion with a sub-halo forming at a great distance due to rapid flushing of Mo-Sn-W rich fluids; (2) a hidden intrusive is expressing itself beneath the sampled veins that fall within this elongate zone. Following the reasoning presented in the first alternative, the halo surrounding the stock represents the later, main ore stage mineralization that is associated with the dispersion of lead, zinc and silver minerals. Tin and tungsten generally follow this same pattern with high values surrounding the stock.

The only element that molybdenum correlates with is tungsten. All other metals show negative correlations.

Lead

The geochemistry of lead (Figure 43) allows contouring of four levels of logarithmically increasing values. The lowest metal values fall in the stock area and the distant portions of the mining districts with the higher values between. The width of the halo in the St. Kevin District is wider and contains significantly higher mineralization than the Sugarloaf District. These features also hold true for zinc and silver. Perhaps during the main ore stage mineralization movement

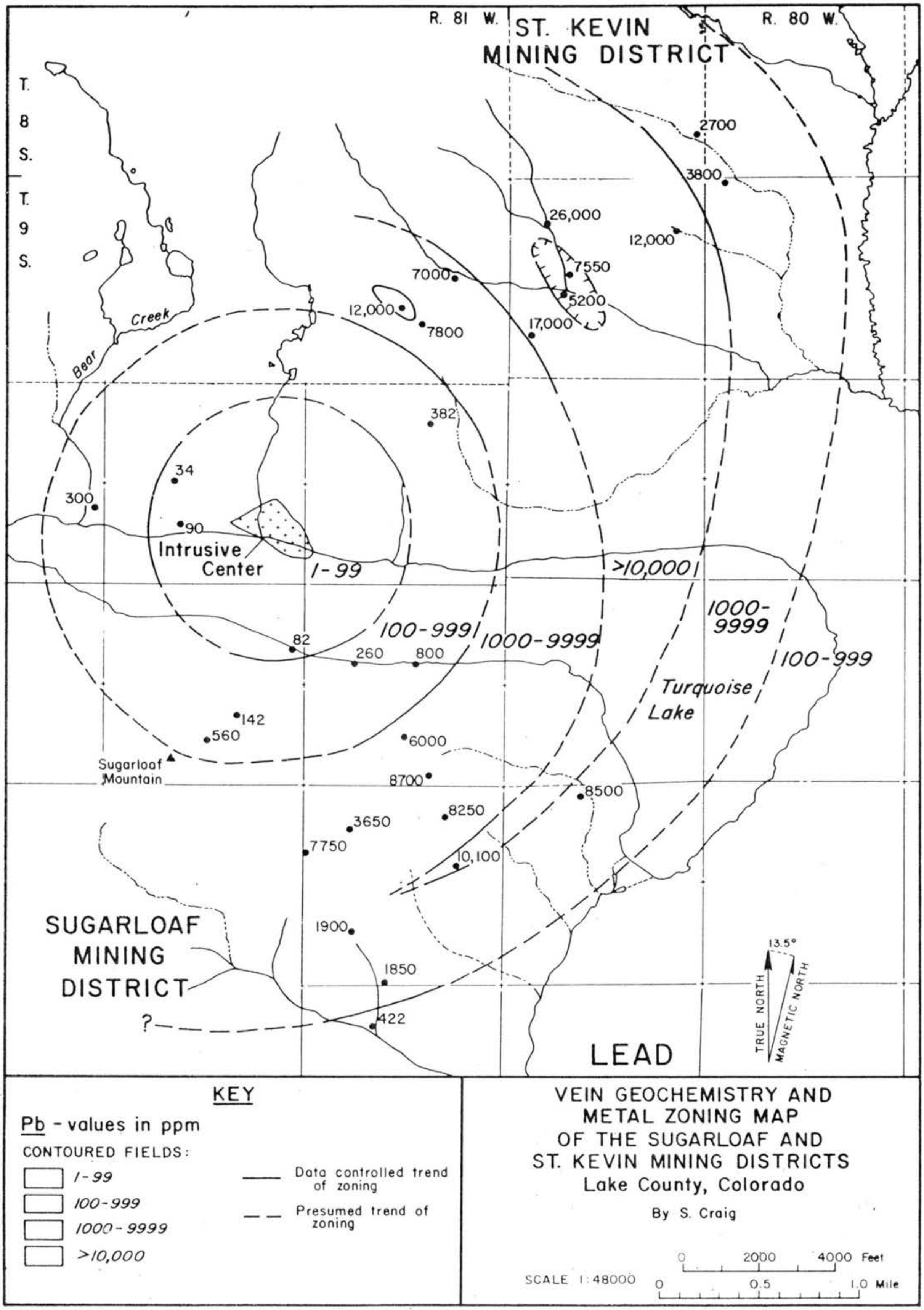

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
2700
3800
26,000
12,000
7550
7000
5200
12,000
7800
17,000
382
34
300
90
Intrusive Center
1-99
>10,000
100-999
1000-9999
1000-9999
100-999
82
260
800
Turquoise Lake
142
560
6000
Sugarloaf Mountain
8700
8500
3650
8250
7750
10,100
SUGARLOAF MINING DISTRICT
1900
1850
422
?
13.5°
TRUE NORTH
MAGNETIC NORTH
LEAD
KEY
Pb - values in ppm
CONTOURED FIELDS:
1-99
100-999
1000-9999
>10,000
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 43

of ore fluids was not restricted as much in the St. Kevin District, and therefore was able to deposit greater quantities of metals there.

Lead correlates with zinc and copper. Negative correlations exist with molybdenum, tungsten, and bismuth.

Zinc

Geochemical values of zinc in vein ranged from a low of 20 ppm up to 120,000 ppm (Figure 44). The dispersion pattern follows lead closely. Therefore, the discussion for lead holds true for zinc.

Zinc strongly correlates with copper and lead while a weaker but positive correlation exists with silver.

Silver

The metal that attracted all the mining activity in the two districts was silver (Figure 45). Singewald (1955) presented average silver grades from old records of a number of mines in the two districts. After conversion from ounce/ton to ppm, it was found that little difference exists between the writer's geochemical values and early mine records. For this reason, the values presented along with known concentration zones could be a guide in an exploration effort for silver.

The study of polished sections found silver minerals in less abundance than copper minerals. However, geochemical values between the two metals indicate silver is more abundant. Therefore,

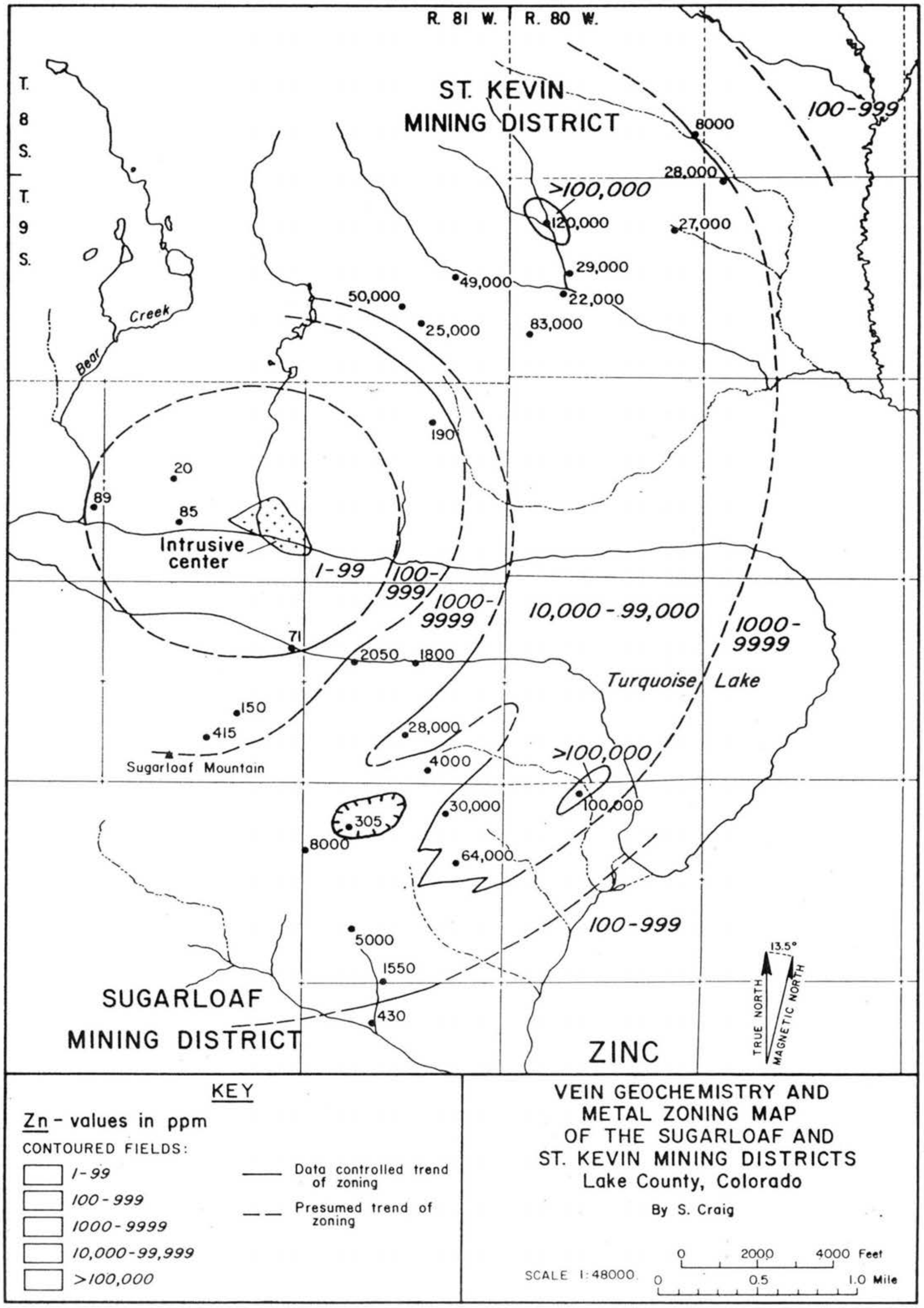

R. 81 W.
R. 80 W.
T. 8 S.
T. 9 S.
ST. KEVIN MINING DISTRICT
SUGARLOAF MINING DISTRICT
Bear Creek
Intrusive center
Turquoise Lake
Sugarloaf Mountain
>100,000
100-999
1-99
100-999
1000-9999
10,000-99,000
1000-9999
100-999
8000
28,000
120,000
27,000
29,000
49,000
22,000
50,000
25,000
83,000
190
20
89
85
71
2050
1800
150
415
28,000
4000
>100,000
100,000
30,000
305
8000
64,000
5000
1550
430
ZINC
13.5°
TRUE NORTH
MAGNETIC NORTH
KEY
Zn - values in ppm
CONTOURED FIELDS:
1-99
100-999
1000-9999
10,000-99,999
>100,000
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 44

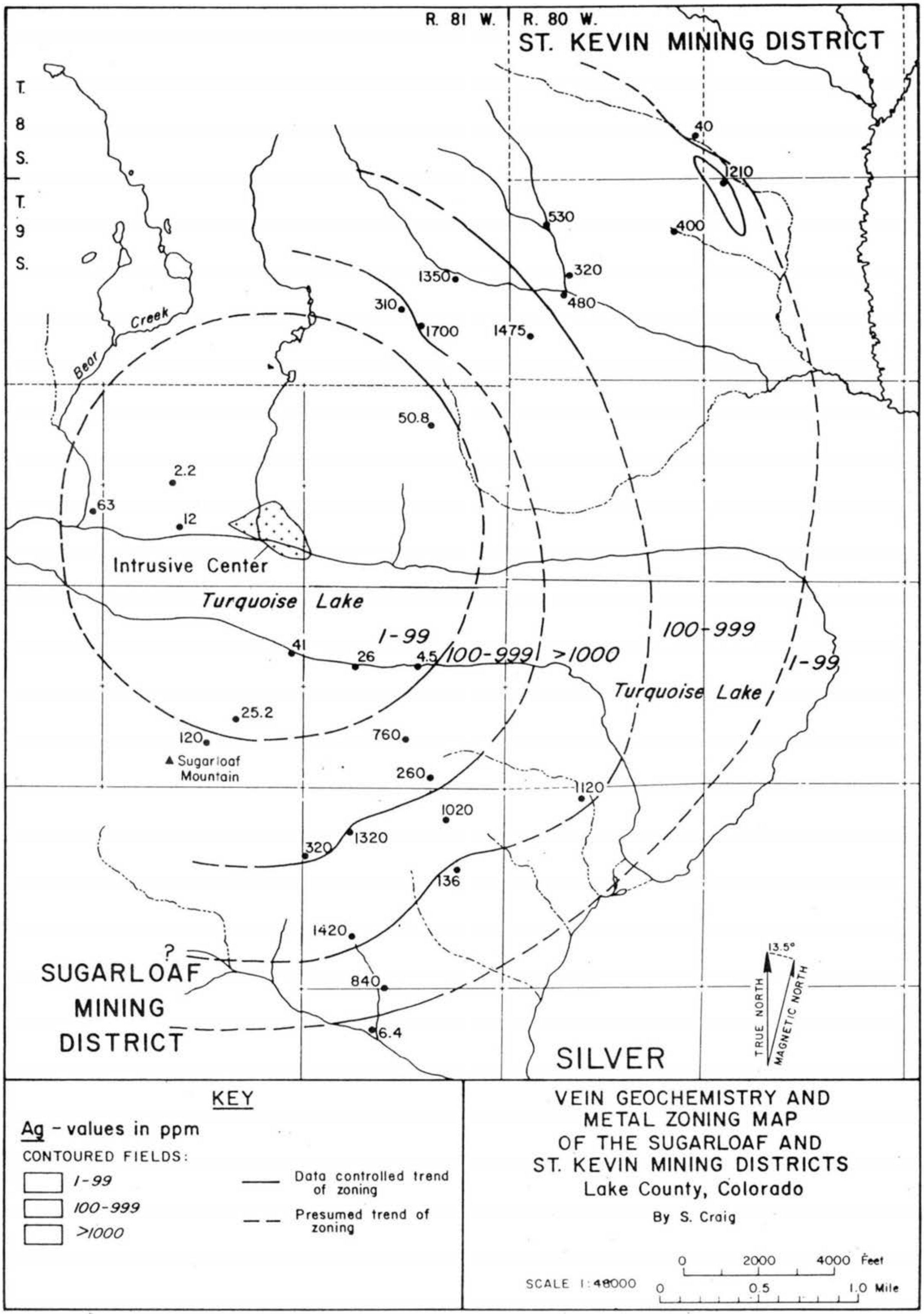

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
Intrusive Center
Turquoise Lake
1-99
100-999
>1000
100-999
1-99
Turquoise Lake
Sugarloaf Mountain
SUGARLOAF MINING DISTRICT
SILVER
TRUE NORTH
MAGNETIC NORTH
13.5°
40
1210
400
530
320
480
1350
310
1700
1475
50.8
2.2
63
12
41
26
4.5
25.2
120
760
260
1120
1020
1320
320
136
1420
840
6.4
?
KEY
Ag - values in ppm
CONTOURED FIELDS:
1-99
100-999
>1000
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 45

it is suggested that silver is tied up in the crystal latice of galena and possibly tetrahedrite giving higher geochemical values than expected.

Silver correlates very strongly with tin and copper. The strong correlation between silver and copper suggests the presence of tetrahedrite as reported by Sandburg (1935). A negative correlation exists with molybdenum and tungsten.

Tin

The dispersion halos of tin (Figure 46) suggest that at least two mineralization pulses with evidence that perhaps a third event took place at Turquoise Lake. An inner halo covers the stock which is surrounded by a band of less than 1 ppm mineralization. This, in turn, is surrounded by a broad outer halo that falls in the center of the two mining districts. It is possible that the inner halo may only reflect the geochemistry associated with the main ore stage while the outer halo is the primary dispersion pattern of the early ore preparation stage.

The strongest correlations reported in Table 2 exist between tin, silver, bismuth and copper. Negative or neutral correlations exist with the other metals.

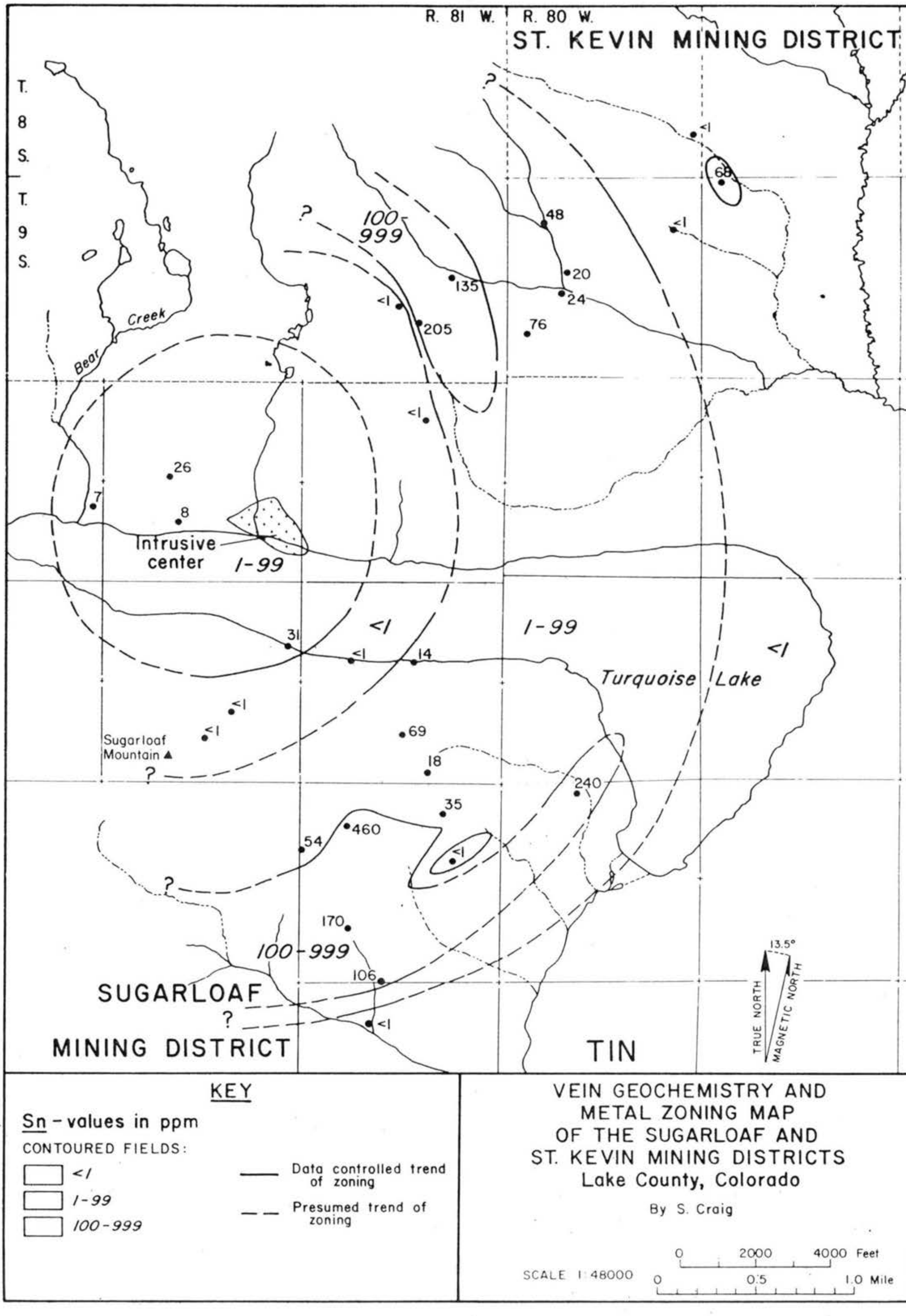

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
Intrusive center
1-99
100-999
<1
1-99
<1
Turquoise Lake
Sugarloaf Mountain
100-999
SUGARLOAF MINING DISTRICT
TIN
TRUE NORTH
MAGNETIC NORTH
13.5°
KEY
Sn - values in ppm
CONTOURED FIELDS:
<1
1-99
100-999
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND
METAL ZONING MAP
OF THE SUGARLOAF AND
ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 46

Tungsten

The geochemical values of tungsten in vein (Figure 47) are considered to be very low. The dispersion pattern is practically identical to molybdenum. For further discussion, see the section under molybdenum.

As expected from the similar dispersion patterns between molybdenum and tungsten, correlation exists between the two at $r = 0.41$. All other elements correlate negatively with tungsten.

Bismuth

Bismuth (Figure 48) forms a wide dispersion zone in veins beginning at about the outer boundary of the pervasive alteration zone surrounding the stock. Several very high zones are noted in both districts. One sample in the St. Kevin District yielded a value of 4900 ppm bismuth. The only explanation to be offered is that the mineral bismuthinite is present in the sample even though ore petrography failed to uncover this mineral.

Bismuth correlates with tin and copper. Negative correlations exist with molybdenum, lead, zinc, and tungsten.

Metal Ratios

Four ratios between selected metals were calculated to check the truthfulness of the vein geochemistry figures based on face-value geochemical results. Generally, the ratios reinforce the concept of

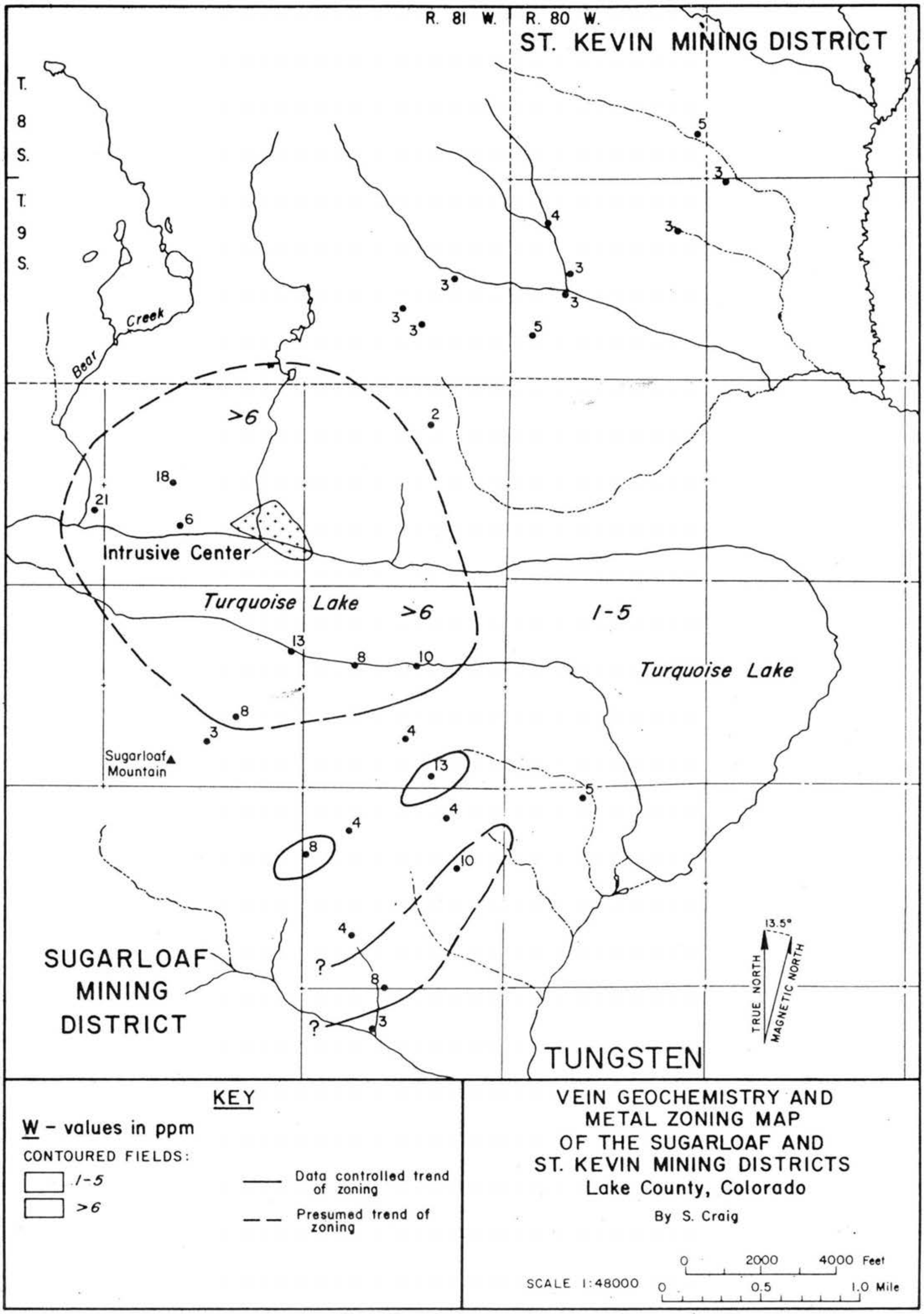

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
>6
Intrusive Center
Turquoise Lake
>6
1-5
Turquoise Lake
Sugarloaf Mountain
SUGARLOAF MINING DISTRICT
TUNGSTEN
13.5°
TRUE NORTH
MAGNETIC NORTH
KEY
W - values in ppm
CONTOURED FIELDS:
1-5
>6
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 47

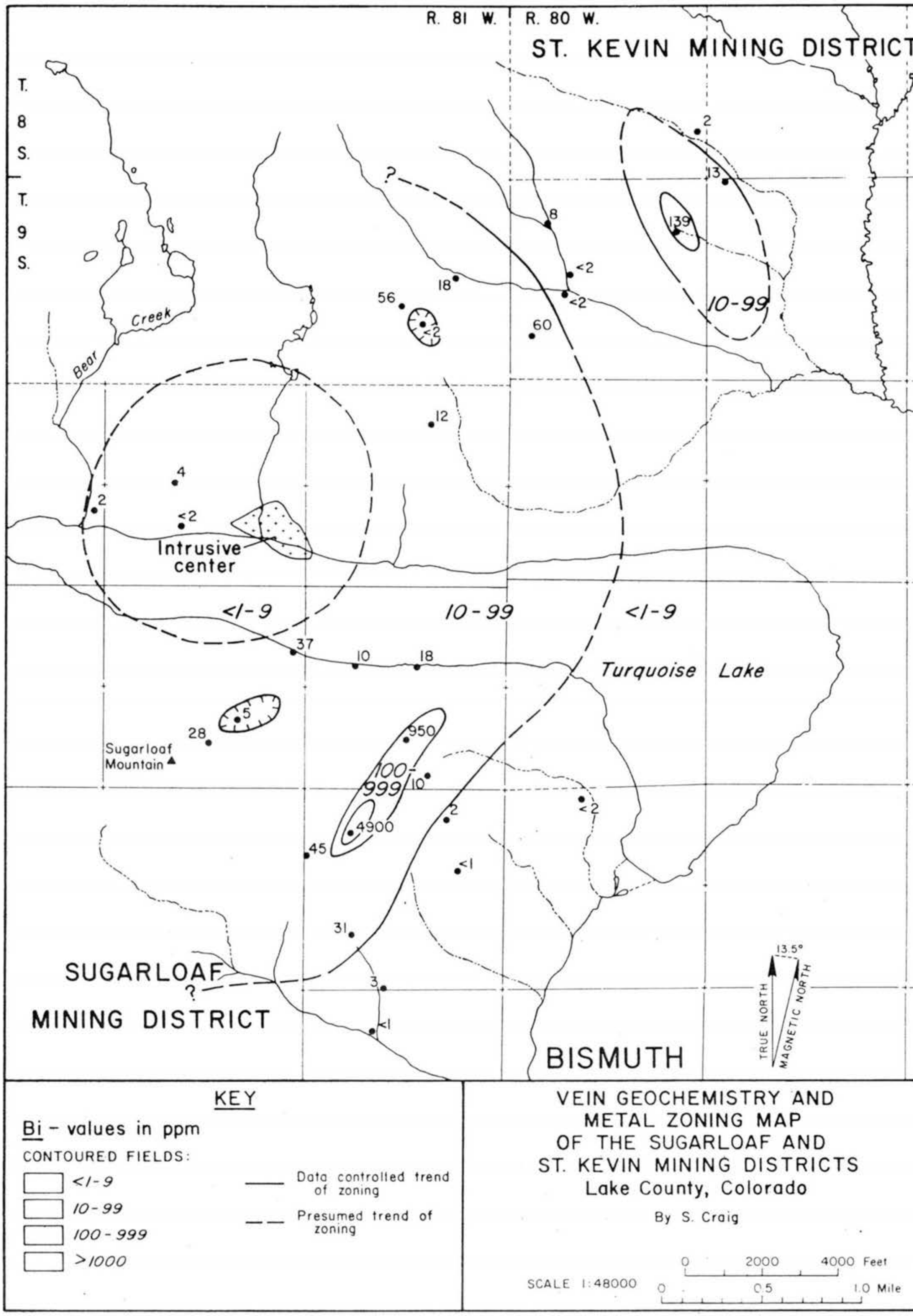

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
Intrusive center
<1-9
10-99
<1-9
10-99
100-999
Turquoise Lake
Sugarloaf Mountain
SUGARLOAF MINING DISTRICT
BISMUTH
TRUE NORTH
MAGNETIC NORTH
13.5°
KEY
Bi - values in ppm
CONTOURED FIELDS:
<1-9
10-99
100-999
>1000
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY AND METAL ZONING MAP OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 48

point source dispersion of metals into the adjacent vein systems from the Turquoise Lake stock.

The silver/molybdenum ratio (Figure 49) points out a logarithmically increasing concentration of silver over molybdenum away from the stock. This type of ratio compares the inner halo character of molybdenum against the outer halo character of silver.

The zinc/lead ratio (Figure 50) yields only two broad zones where lead is more common than zinc in the stock area, and zinc is more common than lead in the adjacent mining districts.

The zinc/copper ratio (Figure 51) indicates copper is more common in the stock area while zinc overwhelmingly dominates in the adjacent mining districts. This can probably be expected due to the very high geochemical values of zinc over copper in the districts.

The lead/silver ratio (Figure 52) indicates that lead is far more common than silver in the St. Kevin District and portions of the Sugarloaf District.

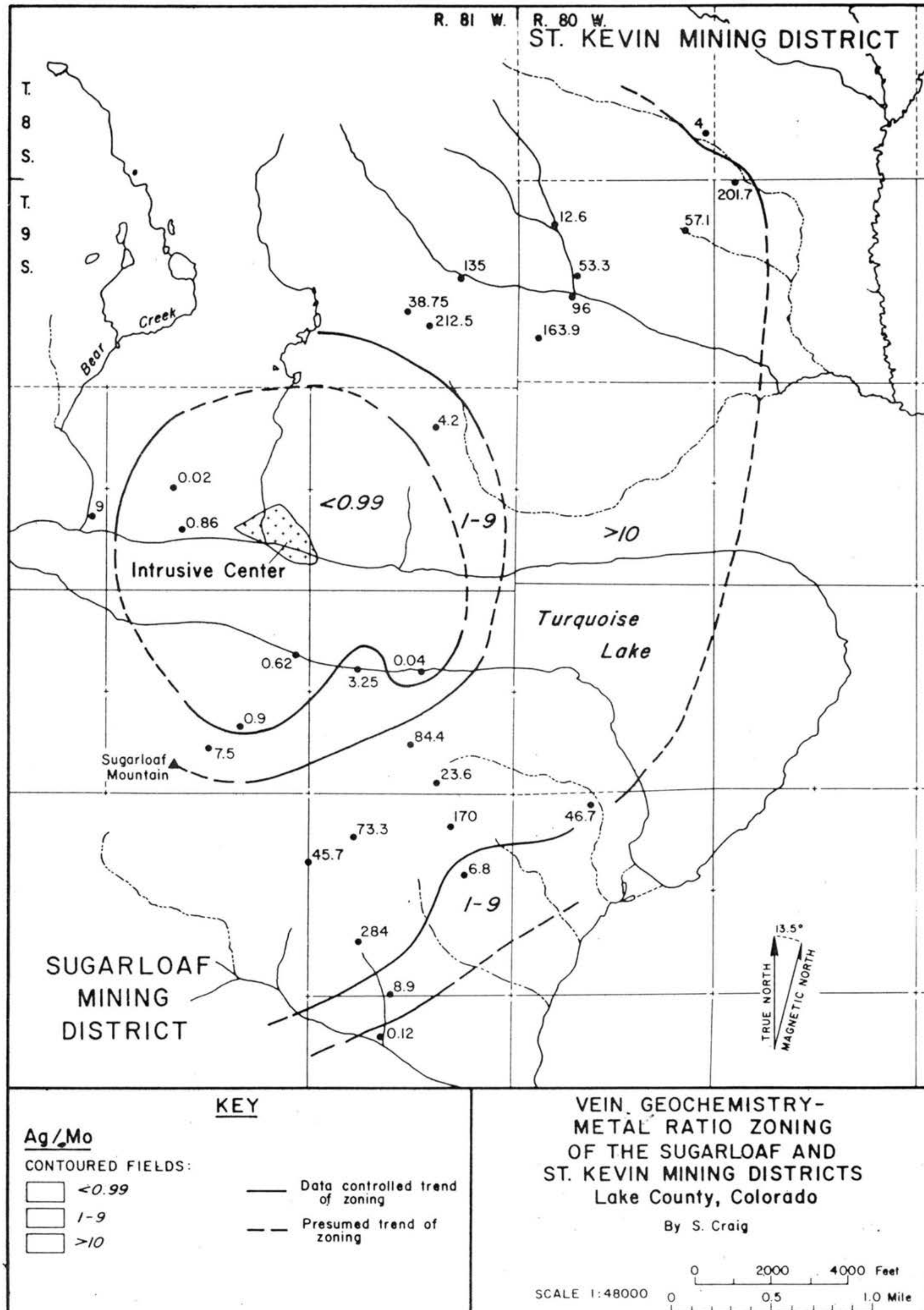

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
4
201.7
12.6
57.1
135
53.3
96
38.75
212.5
163.9
4.2
0.02
9
0.86
<0.99
1-9
>10
Intrusive Center
Turquoise Lake
0.62
0.04
3.25
0.9
7.5
84.4
Sugarloaf Mountain
23.6
46.7
170
73.3
45.7
6.8
1-9
284
8.9
0.12
SUGARLOAF MINING DISTRICT
13.5°
TRUE NORTH
MAGNETIC NORTH
KEY
Ag/Mo
CONTOURED FIELDS:
<0.99
1-9
>10
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY-
METAL RATIO ZONING
OF THE SUGARLOAF AND
ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
0 2000 4000 Feet
SCALE 1:48000
0 0.5 1.0 Mile

Figure 49

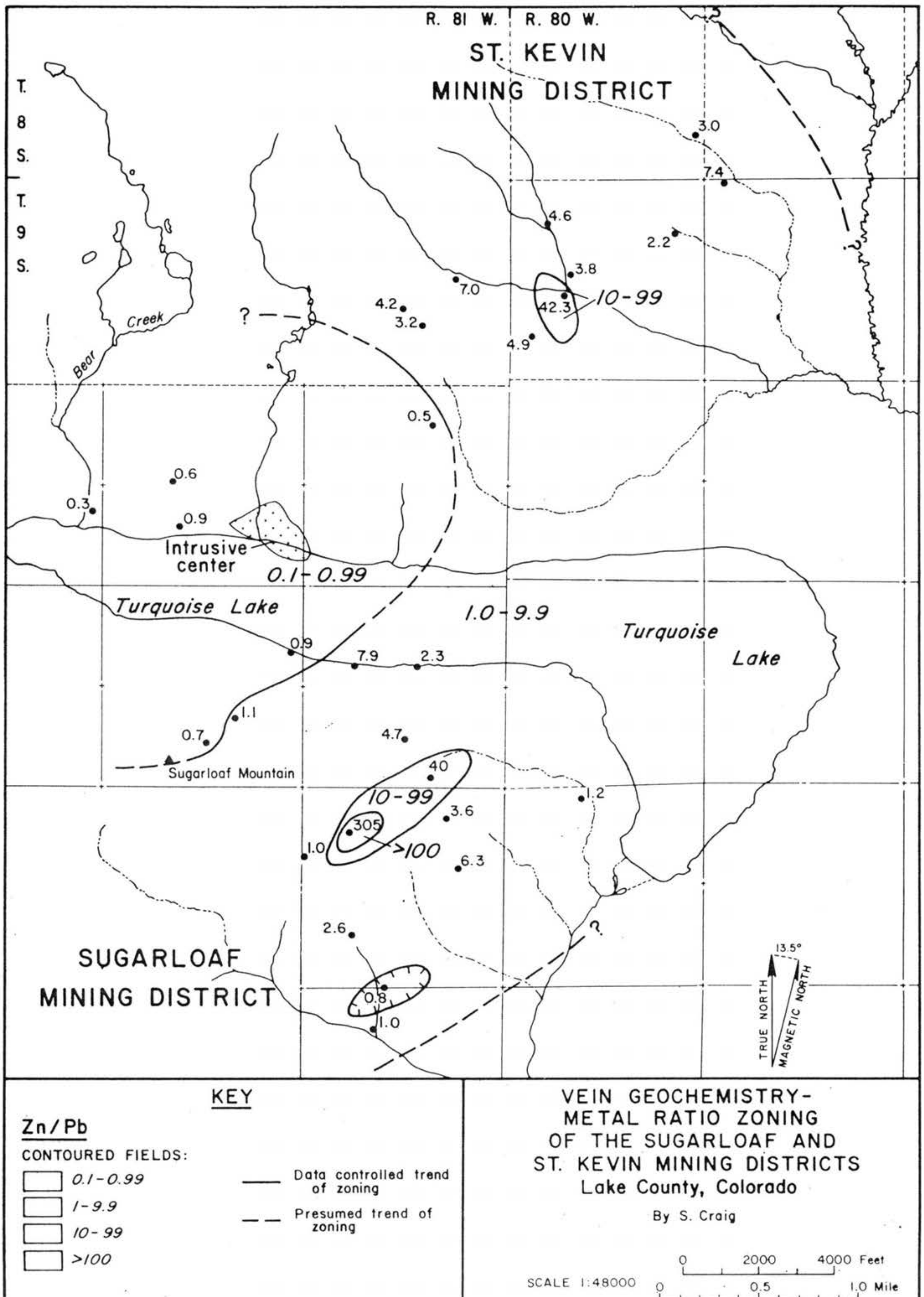

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
Intrusive center
0.1-0.99
1.0-9.9
10-99
>100
Turquoise Lake
Sugarloaf Mountain
SUGARLOAF MINING DISTRICT
TRUE NORTH
MAGNETIC NORTH
13.5°
KEY
Zn / Pb
CONTOURED FIELDS:
0.1-0.99
1-9.9
10-99
>100
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY-METAL RATIO ZONING OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 50

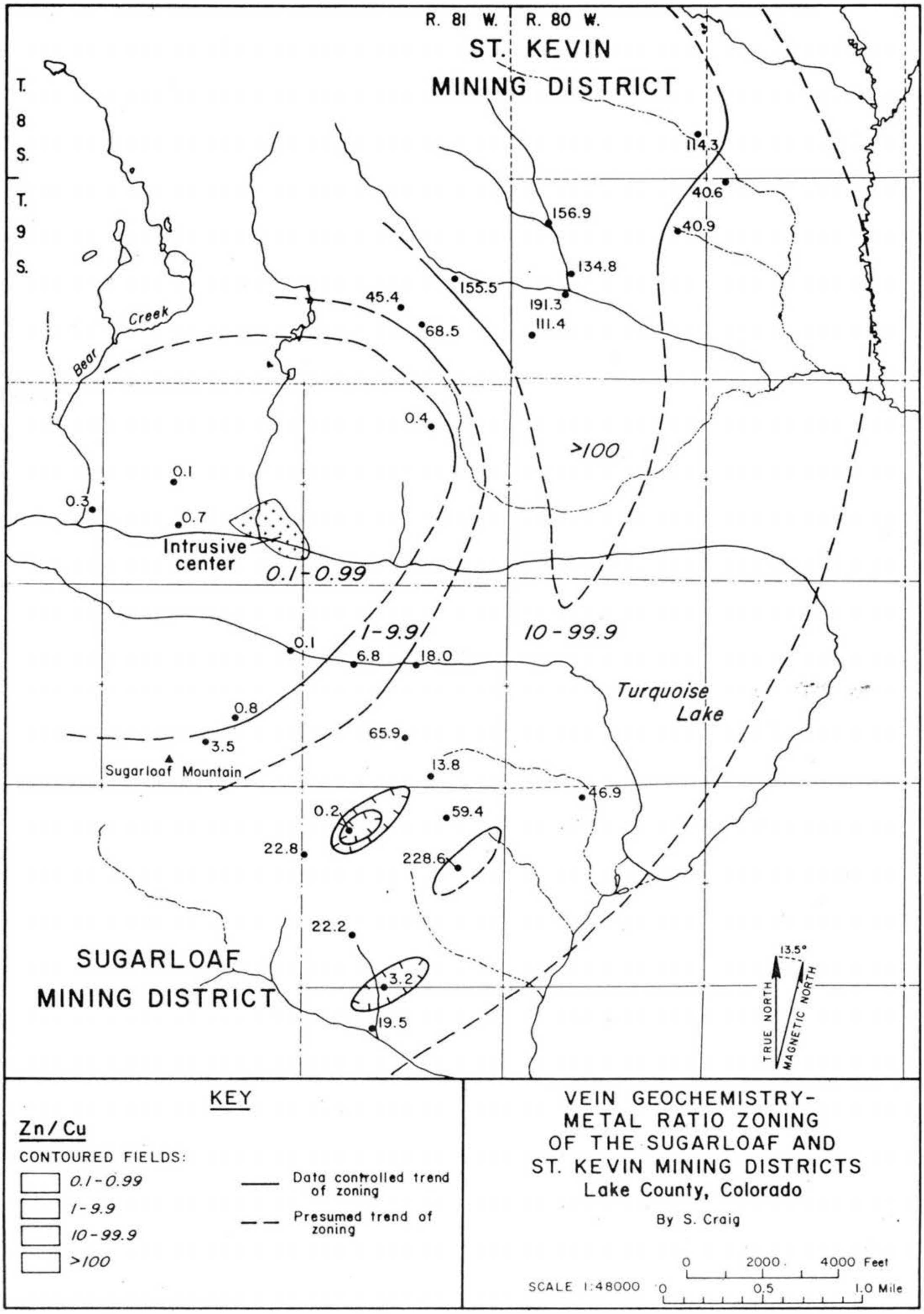
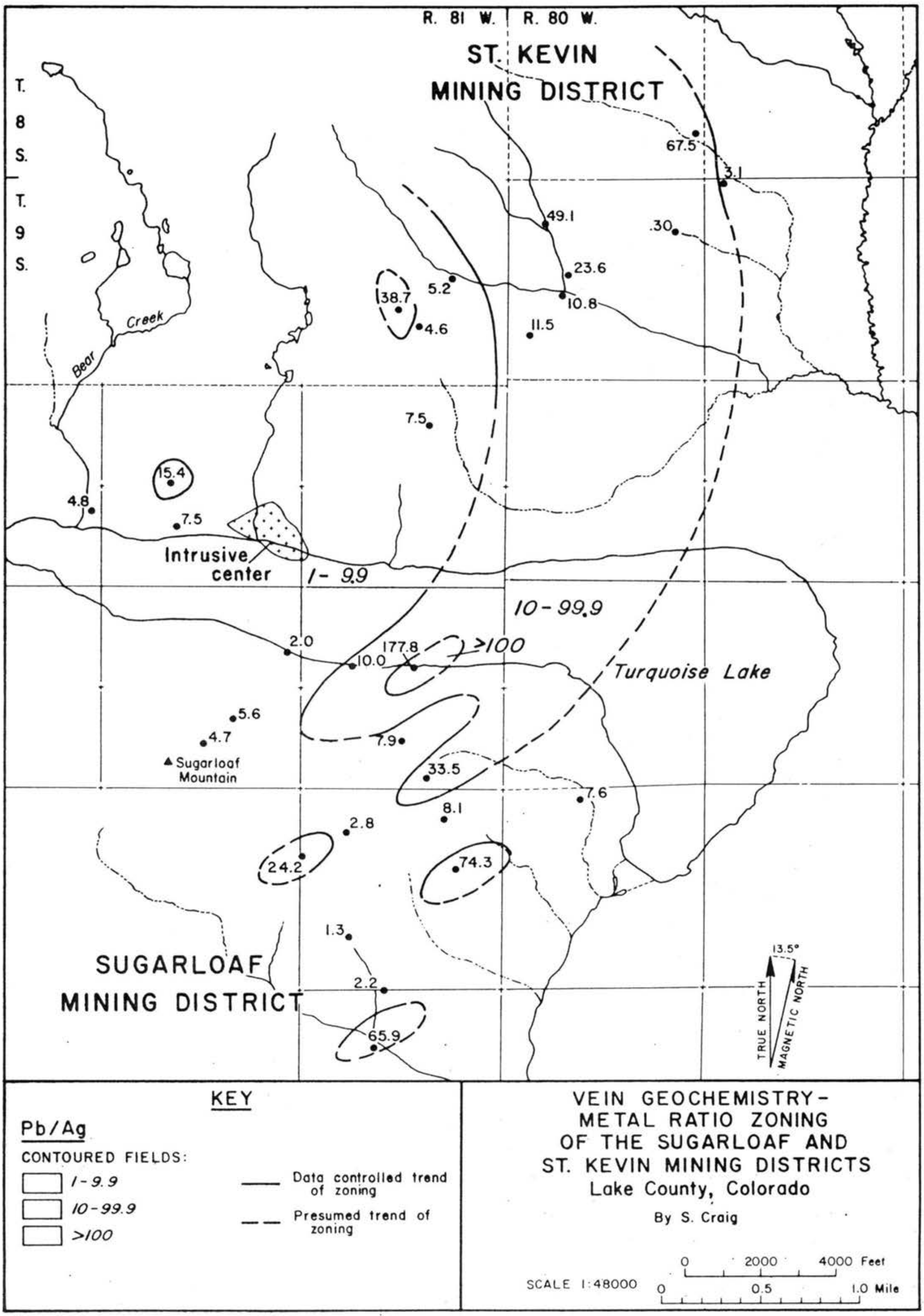

R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
114.3
40.6
40.9
156.9
134.8
155.5
191.3
111.4
45.4
68.5
0.4
>100
0.1
0.3
0.7
Intrusive center
0.1-0.99
1-9.9
10-99.9
0.1
6.8
18.0
Turquoise Lake
0.8
3.5
65.9
Sugarloaf Mountain
13.8
46.9
0.2
59.4
22.8
228.6
22.2
SUGARLOAF MINING DISTRICT
3.2
19.5
13.5°
TRUE NORTH
MAGNETIC NORTH
KEY
Zn/Cu
CONTOURED FIELDS:
0.1-0.99
1-9.9
10-99.9
>100
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY-METAL RATIO ZONING OF THE SUGARLOAF AND ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 51



R. 81 W.
R. 80 W.
ST. KEVIN MINING DISTRICT
T. 8 S.
T. 9 S.
Bear Creek
67.5
3.1
49.1
.30
23.6
5.2
38.7
10.8
4.6
11.5
7.5
15.4
4.8
7.5
Intrusive center
1- 9.9
10- 99.9
2.0
177.8
>100
10.0
Turquoise Lake
5.6
4.7
Sugarloaf Mountain
7.9
33.5
7.6
8.1
2.8
24.2
74.3
1.3
SUGARLOAF MINING DISTRICT
2.2
65.9
13.5°
TRUE NORTH
MAGNETIC NORTH
KEY
Pb/Ag
CONTOURED FIELDS:
1-9.9
10-99.9
>100
Data controlled trend of zoning
Presumed trend of zoning
VEIN GEOCHEMISTRY-
METAL RATIO ZONING
OF THE SUGARLOAF AND
ST. KEVIN MINING DISTRICTS
Lake County, Colorado
By S. Craig
SCALE 1:48000
0 2000 4000 Feet
0 0.5 1.0 Mile

Figure 52

COMPARISON TO GENERAL MOLYBDENUM MODEL

The work at Climax, Henderson, Questa, and other molybdenum mines and prospects have allowed the creation of a general model for field recognition of molybdenum systems during exploration. Papers by Carpenter (1968), Hollister (1978), Mackenzie (1970), Perkins (1973), Ranta (1974), Ranta et al. (1976), Sharp (1978, 1979), Sutulov (1978), Wallace et al. (1968) and Wallace et al. (1978) describe the salient features of this model.

The following listing describes the most important characteristics of the stockwork molybdenum model. A comparison of each feature is then applied to the Turquoise Lake system to point out similarities and dissimilarities.

1. Molybdenum systems are small rhyolitic-granitic multiple intrusive complexes with related radial and/or concentric dike systems.

The Turquoise Lake stock is a small single phase intrusive of latitic composition with a related dike system of similar composition. The lack of rhyolitic rocks associated with the main intrusive activity at Turquoise Lake suggests that the development of a molybdenite ore body may not have taken place. As known from major molybdenum mines, a granite body with associated rhyolitic rocks are spatially related to the ore body. Due to the geochemical behavior of molybdenum, these rock types are essential for the formation of large tonnage, high grade ore bodies.

2. The age of major molybdenum mineralization is from middle to late Oligocene in central Colorado.

The age of 35.6 million years at Turquoise Lake is not considered to be a favorable time for the development of a major molybdenum ore body. For comparison, the time of mineralization at Climax and Henderson is 30 and 26 million years, respectively (Hollister, 1978). It is thought that differentiation of a common magma underlying this section of the Colorado Mineral Belt had not evolved into rocks of granitic composition during early Oligocene. It was not until middle or late Oligocene that favorable conditions existed for creation of major ore bodies such as at Henderson and Climax. One exception, however, occurs at Middle Mountain where a weak molybdenite ore body associated with granitic rocks formed about 36 million years ago (Ranta, 1974).

3. Molybdenum systems contain a distinct sequence of hydrothermal alteration halos grading down into and including ore. These zones include (1) propylitic, (2) argillic, (3) phyllic, (4) topaz subzone, (5) silica subzone, (6) potassic, (7) greisen, (8) and a lower argillic zone that often overprints the lower halos.

The alteration sequence exposed at the surface of Turquoise Lake clearly follows the sequence found in a deeply eroded molybdenum system. The weak character of the propylitic zone, lack of argillic zone, and the presence of the phyllic zone and quartz-topaz subzone places the surface near a molybdenum ore body if the typical model holds true. The lower argillic zone may be represented by the kaolinite-sericite zone found deep in the Turquoise Lake stock. However, it is felt that this zone could be an alteration halo from a deeper undiscovered intrusive body, rather than the collapse of the convection system that was driven by the intrusive "heat engine." This type of collapse usually overprints an argillic alteration assemblage on to an earlier suite of alteration minerals.

4. The presence of anomalous geochemistry, especially Mo, W, Sn, and F which form discrete halos. These elements are typically derived from a silicic magma of felsic composition in molybdenum systems.

The geochemistry associated with the Turquoise Lake stock exhibits strongly anomalous halos of Mo, W, Sn, and F. Other elements found in anomalous dispersion halos include Cu, Pb, and Zn. However, the style and distribution of the trace element mineralization and the alteration does not follow that of a typical molybdenum system. According to Bright and White (1974) and Wallace et al. (1968), the halos over and including ore form zones circular to ring shaped in plan and arcuate in section. Generally, the geochemical and alteration halos at Turquoise Lake appear to be ring shaped around the stock. However, examination of key cross sections, particularly the alteration cross section (Figure 8) and Mo, Pb, and Cu geochemistry (Figure 26), find the halos distorted upward along the quartz-topaz subzone. This distribution style can be attributed to the upward channeling of vast quantities of trace element rich, hydrothermal fluids along the margins of the stock.

5. The presence of widespread pyrite with a high concentration in the phyllic zone above the ore body.

Pyrite is widely dispersed throughout the alteration system at Turquoise Lake. Its distribution pattern forms a continuous halo increasing up to 10 volume percent centered in a "bullseye" on the northwest side of the stock.

6. The presence of brecciation features, such as pebble dikes, and intrusive breccias, that pinch out at depth.

The Turquoise Lake stock gave rise to many brecciation features. These include the breccia border phase of the Turquoise Lake stock (Ttlpbx) and many isolated occurrences of intrusive breccias (Tibx). These breccias indicate that forceful emplacement of the stock took place with associated degassing above the magma chamber.

7. The presence of quartz-molybdenite veining at the outer margin of the stock.

Molybdenite values up to 0.04 percent are found concentrated in the quartz-topaz subzone adjacent to the stock. Quartz-molybdenite occurrences are found decreasing away from the stock margins.

RECOMMENDATIONS FOR FUTURE EXPLORATION

The following listing describes recommendations and ideas for future exploration in the Turquoise Lake areas.

1. The deep erosion level found at Turquoise Lake suggests the target depth is shallow and BL-1 and BL-2 adequately tested this target. However, the fact that the phyllic alteration continues to at least 1,500 feet in BL-1 and the intersection of kaolinite alteration in BL-2 (Figure 8) is encouraging in that it allows room for a target deeper than anticipated. If a Henderson type molybdenite ore body exists at Turquoise Lake, then its width can be expected to range from 2,000 to 3,000 feet in diameter. If there is no offset from the surface geology due to tilting as at Henderson (Wallace et al., 1978), then deepening either BL-1 or particularly BL-2 might intercept such an ore body if it exists. Drilling should not be terminated until the ore target, a barren potassically altered core, or fresh rock is intercepted. Discovery of favorable rock types, deeper geochemical halos, or a change in alteration should lend encouragement in evaluating the drill results.

2. Instead of being vertical, the stock may be plunging to the west or northwest. Evidence comes from the fault pattern and orientation in the adjacent vein systems (Figure 40) which suggests that the

stock may have been emplaced at an angle, or tilting of the Sawatch Range forced the stock into an inclined position. If this situation holds true, then deepening BL-1 or starting a new hole about 500 feet north of BL-1 would adequately test a target which is offset from the surface outline of the stock.

3. The magnetic low centered to the southwest of the stock (Figure 29) may indicate the stock is plunging in that direction rather than to the west or northwest as described in (2) above. Unfortunately, a target in this area may never be tested due to the position of Turquoise Lake.

4. A good site for an additional drill hole should be located approximately 1,500 feet north to northwest of BL-2. Since there is a possibility that the stock extends in that direction, a drill hole is needed to test a target under glacial cover.

5. Since published reports indicate many veins were never exhausted, the adjacent vein systems hold exploration promise for silver. Prospect evaluation and exploration should be directed in the areas demonstrated to contain the highest silver concentration in the veins of the Sugarloaf and St. Kevin Mining Districts (Figure 45).

6. The author did not study the gold geochemistry and distribution in the vein systems. However, in light of the present high interest in the metal, two areas could be considered for future evaluation. Walker (pers. comm.) found that gold occurs at the Hap Hazard Mine

west of the stock in some veins of pyrite, but not in others. (Recall the author found two stages of pyrite mineralization.) This same mode of occurrence may have been responsible for the accumulation of placer gold deposits in Colorado Gulch where quartz-pyrite veins are found in the vicinity of the Tiger Shaft in the Sugarloaf District.

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APPENDICES

APPENDIX A

Results of Geochemical Analyses of Rock, Vein, and Composite Drill Hole Samples

Table 1. Rock Geochemistry Results of the Turquoise Lake Stock Area. Values are in parts per million except K_2O which is in percentage units.

Sample	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
17251	36	18	140	38		26	8	2.5	18600
52	20	12	51	26		35	10	4.2	6800
53	12	12	33	22		18	8	5.1	4400
54	40	8	160	105		< 1	5	4.7	1650
55	32	46	52	36		19	5	3.9	2050
56	17	30	97	73		10	4	2.4	1750
57	15	8	240	65		12	4	4.8	2600
58	84	225	65	39		12	20	2.3	1650
59	12	13	35	18		45	40	3.7	2600
60	15	48	43	34		22	15	4.8	3000
61	10	12	28	29		11	10	5.5	4200
62	17	8	120	70		14	8	5.9	4900
63	7	6	74	49		5	8	4.7	1350
64	14	14	140	185		1	8	5.7	570
65	11	10	87	240		6	8	4.0	630
66	4	4	255	245		1	10	5.1	1050
67	16	10	41	155		< 1	8	3.4	830
68	12	8	69	100		7	8	5.7	1400
70	11	5	61	260		5	3	3.4	2600
71	8	10	51	28		5	5	4.3	1950
72	11	10	95	51		6	10	4.8	3100
73	15	5	66	35		14	15	4.6	1850
74	13	9	46	69		4	15	4.3	2400
75	9	10	78	27		10	15	3.5	4500
76	11	7	34	28		10	10	4.5	3250

Table 1 (Continued).

Sample	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
17277	17	9	125	35		13	10	4.8	3000
78	26	14	115	77		11	15	5.3	2500
79	14	9	42	69		6	10	3.0	1050
80	37	12	55	50		10	15	5.7	2900
81	25	16	425	16		25	25	1.3	5100
82	16	10	400	18		54	30	4.5	7400
83	16	12	89	15		43	10	3.7	4900
84	31	5	57	23		50	15	4.0	8600
85	28	255	66	28		36	30	3.0	9400
86	14	76	37	21		97	10	2.4	12000
87	25	12	68	15		55	10	2.2	21000
88	17	16	115	13		35	8	1.4	20000
89	16	18	120	28		9	10	2.6	2600
90	37	13	130	49		12	10	4.2	2800
91	16	10	45	51		11	10	4.6	1800
92	10	9	28	31		1	3	4.4	2800
93	43	36	86	26		21	10	2.6	1200
94	76	42	77	26		11	10	1.9	2100
95	11	10	98	20		11	10	4.3	2100
96	80	155	90	35		11	10	3.4	2000
97	29	70	61	25		20	18	1.0	4400
98	14	10	300	33		23	15	3.9	9000
99	28	50	245	35		28	15	3.7	3100
17300	31	18	440	34		28	10	3.0	5300
1	100	10	545	295		17	10	4.4	3000
2	10	6	800	28		22	15	5.5	4500

Table 1 (Continued).

Sample	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
17303	7	8	95	19		18	13	4.6	5100
4	56	5	240	37		13	6	5.6	5400
5	22	10	62	310		5	6	6.3	1600
6	22	10	66	385		12	2	1.5	1500
7	9	7	250	100		< 1	2	5.9	1050
8	28	10	315	345		< 1	3	3.1	1850
9	20	13	13	12	395	27	5	1.2	23500
10	14	11	185	19	370	53	5	4.0	6400
11	8	8	86	15	175	40	6	4.3	4000
12	13	12	150	17	405	34	8	4.8	4100
13	26	9	180	16	225	45	8	2.5	8200
14	17	6	69	95	190	5	8	6.5	1275
15	6	6	150	28	135	29	10	4.5	1450
16	15	6	105	155	345	< 1	10	3.8	1550
17	9	7	230	18	91	6	5	.21	1400
18	7	6	165	13	205	8	6	.72	1750
19	13	8	185	90	260	8	5	6.3	1450
20	8	7	310	25	190	2	8	4.5	3300
21	18	8	89	25	245	18	10	5.0	3100
22	23	5	62	170	385	< 1	5	6.1	815
23	48	9	100	290	1200	4	3	4.0	2750
24	18	6	54	235	895	5	6	3.9	2250
25	11	5	155	90	155	9	10	4.7	1550
26	15	7	40	57	315	11	5	4.5	960
27	9	8	625	59	180	7	8	5.4	1700
28	25	8	250	77	355	1	3	1.8	320

Table 1 (Continued).

Sample	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
17329	12	8	42	23	368	29	23	2.8	3300
30	11	8	330	21	335	48	20	1.6	5500
31	18	8	132	26	406	74	10	2.4	5500
32	17	7	60	26	343	59	25	2.7	4900
33	13	10	80	29	561	30	18	2.8	2900
34	11	5	116	33	381	28	3	2.4	4800
35	13	30	140	24	297	26	23	4.0	2100
36	24	74	42	25	464	20	25	1.7	1100
37	26	24	112	33	658	25	18	1.7	4000
38	7	25	120	320	1051	< 1	6	2.5	460
39	20	12	80	230	1613	2	5	1.6	370
40	19	8	325	290	1045	< 1	6	3.5	320
41	9	8	40	40	510	3	3	2.1	590
42	7	5	90	61		8	3	4.2	250
59	6	5	240	28		12	13	1.5	5300
60	7	7	108	35		8	4	3.0	4500
61	13	5	620	17		74	13	3.0	5100
62	18	6	60	430		< 1	4	2.5	1800
63	15	10	240	16		63	11	1.1	7400
64	32	15	230	70		< 1	10	3.3	1550
65	135	38	1000	320		10	8	2.7	330
66	8	8	120	175		6	3	1.8	1600
67	6	9	46	48		< 1	3	1.2	330
75	24	168	30	50		24	23	3.4	2200
76	62	16	134	140		4	10	3.7	2000
77	14	14	164	20		45	8	4.8	9000

Table 1 (Continued).

Sample	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
17378	18	10	42	20		< 4	28	4.2	1400
79	58	12	1000	430		< 1	2	4.2	400
80	36	6	600	100		< 1	2	6.5	1050
81	16	10	72	150		6	3	5.7	600
82	22	8	86	60		2	8	3.0	1750
83	38	50	34	20		30	25	4.0	3200

Table 2. Vein Geochemistry Results of the Sugarloaf and St. Kevin Mining District. Values are in parts per million.

Sample	Cu	Mo	Pb	Zn	Ag	Sn	W	Bi
17269	100	115	800	1800	4.5	14	10	18
17343	690	6	3800	28000	1210	68	3	13
44	660	7	12000	27000	400	< 1	3	139
45	70	10	2700	8000	40	< 1	5	2
46	490	94	1850	1550	840	106	8	3
47	225	5	1900	5000	1420	170	4	31
48	350	7	7750	8000	320	54	8	45
49	1400	18	3650	305	1320	460	4	4900
50	290	11	8700	4000	260	18	13	10
51	505	6	8250	30000	1020	35	4	2
52	365	8	7800	25000	1700	205	3	< 2
53	1100	8	12000	50000	310	< 1	3	56
54	2130	24	8500	100000	1120	240	5	< 2
55	425	9	6000	28000	760	69	4	950
56	1150	5	5200	220000	480	24	3	< 2
57	215	6	7550	29000	320	20	3	< 2
58	765	42	26000	120000	530	48	4	8
68	120	16	560	415	120	< 1	3	28
69	690	66	82	71	41	31	13	37
70	300	8	260	2050	26	< 1	8	10
71	120	14	90	85	12	8	6	< 2
72	275	7	300	89	63	7	21	2
73	745	9	17000	83000	1475	76	5	60
74	315	10	7000	49000	1350	135	3	18

Table 2 (Continued).

Sample	Cu	Mo	Pb	Zn	Ag	Sn	W	Bi
17384	520	12	382	190	50.8	< 1	2	12
85	200	94	34	20	2.2	26	18	4
86	176	28	142	150	25.2	< 1	8	5
87	280	20	10100	64000	136	< 1	10	< 1
88	22	54	422	430	6.4	< 1	3	< 1

Table 3. Composited Drill Hole Geochemistry Results of DDH BL1. Values are in parts per million except K_2O which is in percentage units.

Footage Interval	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
15-50	20	4	21	19	26	10	10	3.6	3200
100-150	18	3	62	77	28	11	14	3.4	3300
200-250	32	56	31	81	32	23	20	3.1	3300
300-350	26	102	19	53	28	17	21	3.2	4300
400-450	42	104	25	38	40	6	15	2.2	2600
500-550	100	103	380	710	268	5	19	2.9	2500
600-650	50	74	12	110	34	30	25	3.7	3900
700-750	48	69	53	62	40	24	25	3.1	3900
800-850	30	75	17	192	30	27	21	3.9	6700
900-950	18	40	12	140	28	28	21	4.3	7000
1000-1050	28	79	10	340	32	28	22	3.8	5200
1100-1150	28	58	11	64	42	20	21	3.7	4500
1200-1250	16	130	12	51	28	27	25	3.0	5000
1300-1350	20	50	7	85	32	22	23	3.4	6100
1400-1450	46	38	20	215	36	19	24	3.6	4300
1500-1514	8	6	8	49	22	< 5	6	3.4	4100

Table 4. Composited Drill Hole Geochemistry Results of DDH BL2. Values are in parts per million except K_2O which is in percentage units.

Footage Interval	Cu	Mo	Pb	Zn	Mn	Sn	W	K_2O	F
18-50	128	6	110	220	92	14	8	3.7	3000
100-150	126	7	100	76	54	14	8	3.4	2200
200-250	3500	5	650	3200	130	< 5	8	3.8	4500
300-350	34	10	33	490	52	20	8	2.2	3300
400-450	19	11	42	66	16	9	13	2.4	3500
500-550	36	7	30	78	24	10	8	2.5	3300
600-650	15	6	30	77	20	7	15	3.9	3200
700-750	10	8	38	36	16	< 5	10	3.7	2700
800-850	25	6	55	270	30	8	10	4.0	2700
900-950	12	5	17	74	20	< 5	15	3.8	2700
1000-1050	16	6	52	480	40	10	15	4.0	3200
1100-1150	22	6	190	450	46	7	15	3.6	2900
1200-1250	26	13	27	82	26	8	16	3.6	2600
1300-1350	48	23	26	190	34	11	18	4.0	2700
1400-1450	38	20	29	390	30	7	18	3.2	2200
1500-1544	122	27	30	164	92	18	17	3.2	2500

APPENDIX B

Histograms and Cumulative Frequency Graphs

of Rock and Vein Geochemistry Analyses

Explanation

Cumulative frequency graphs:

- ● Cumulative data point
- ○ Approximate area of threshold values at inflection points
- / Visually fitted line through data points

Histograms:

- ↓ Selected contour intervals in rock geochemistry figures
- // Break in baseline interval or change of inclusive geochemical values

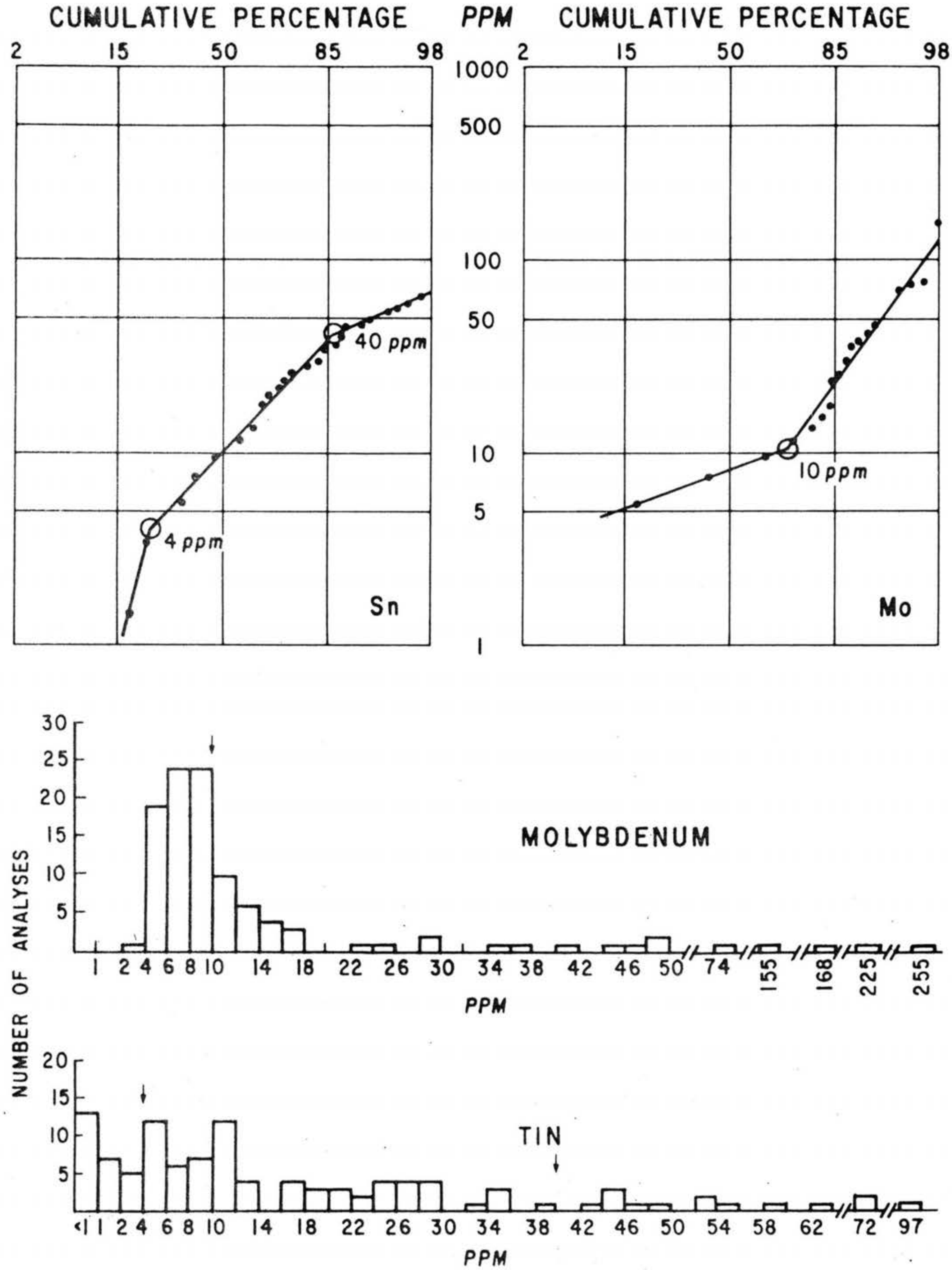


Figure 53. Rock Samples.

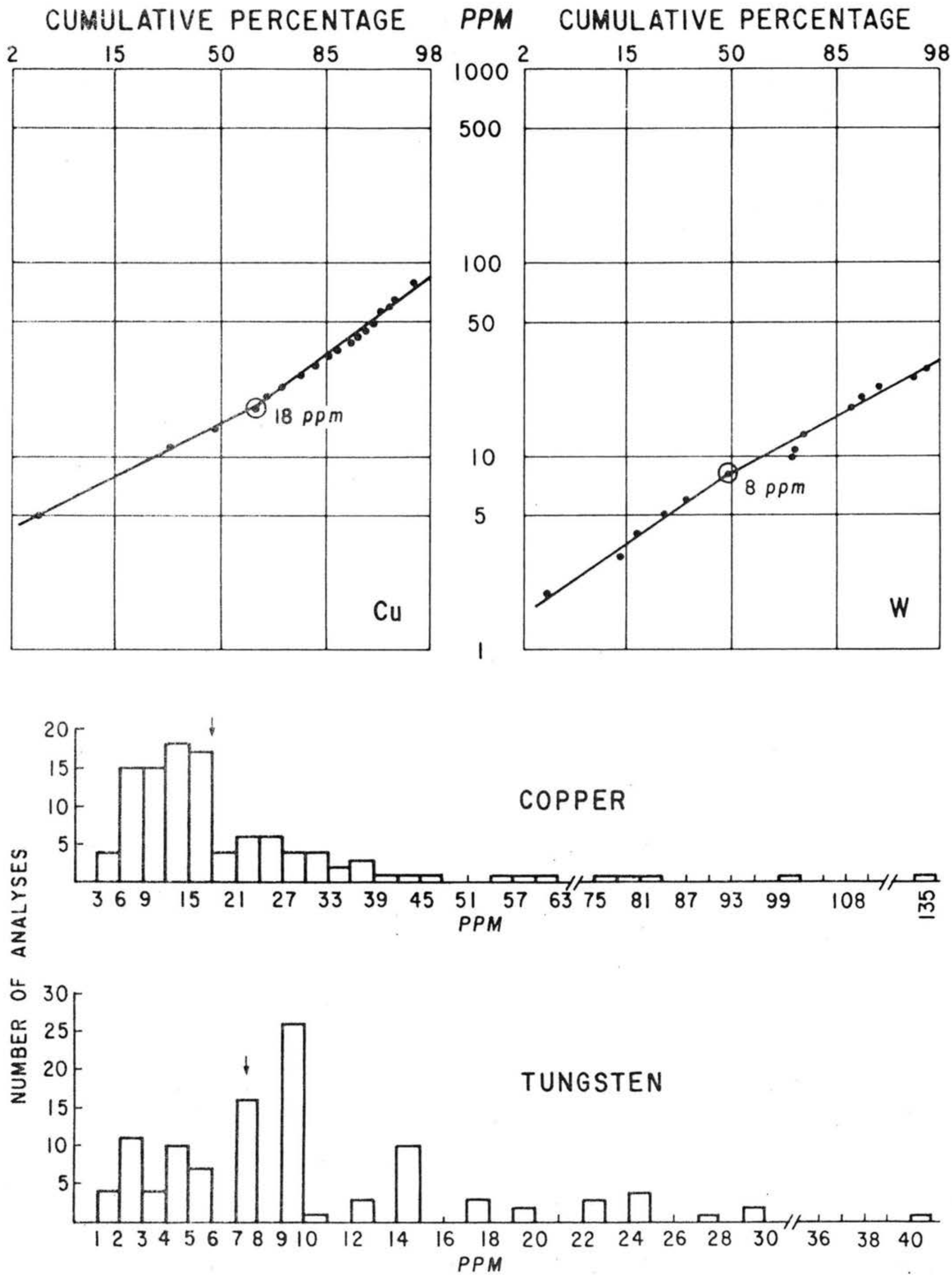


Figure 54. Rock Samples.

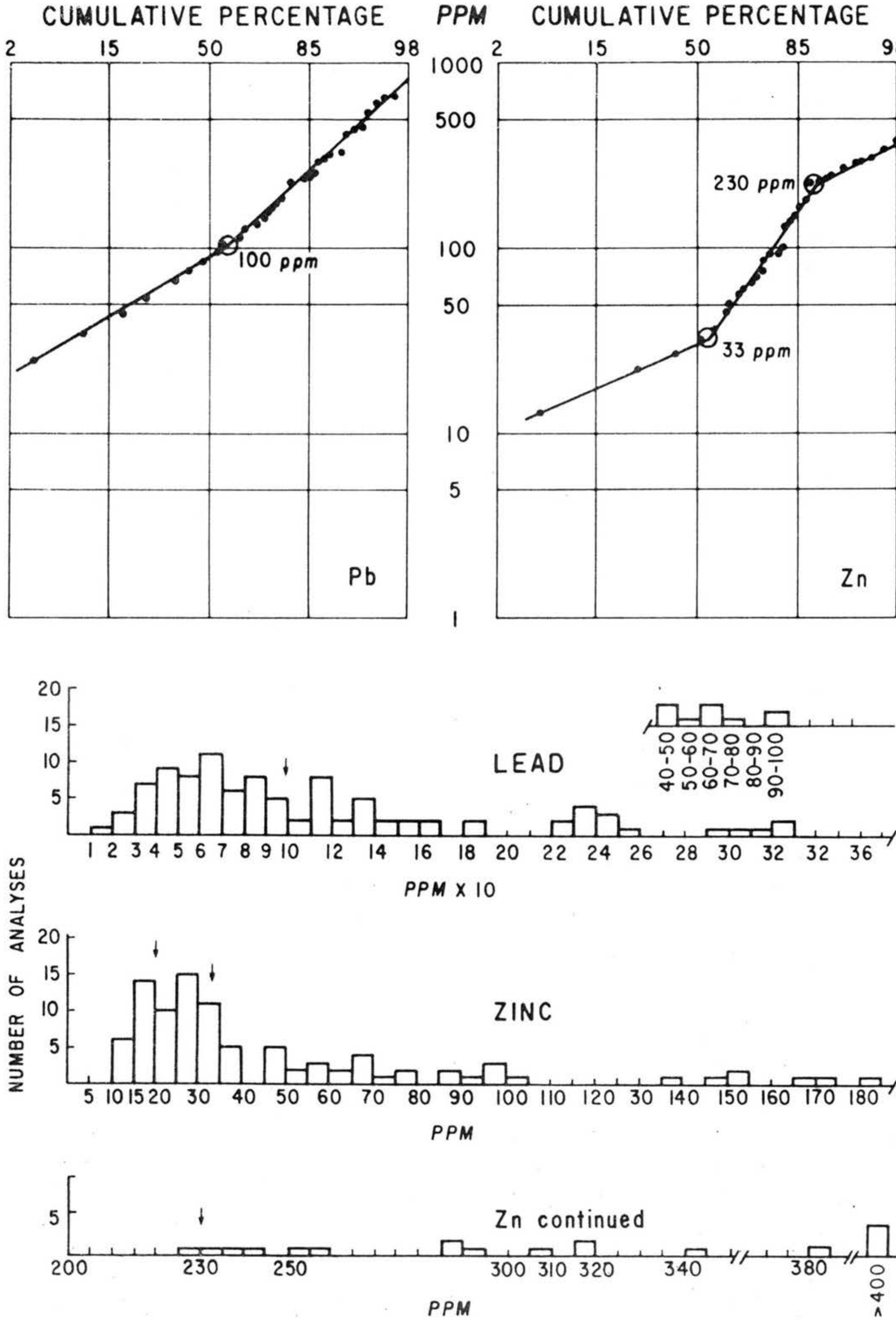


Figure 55. Rock Samples.

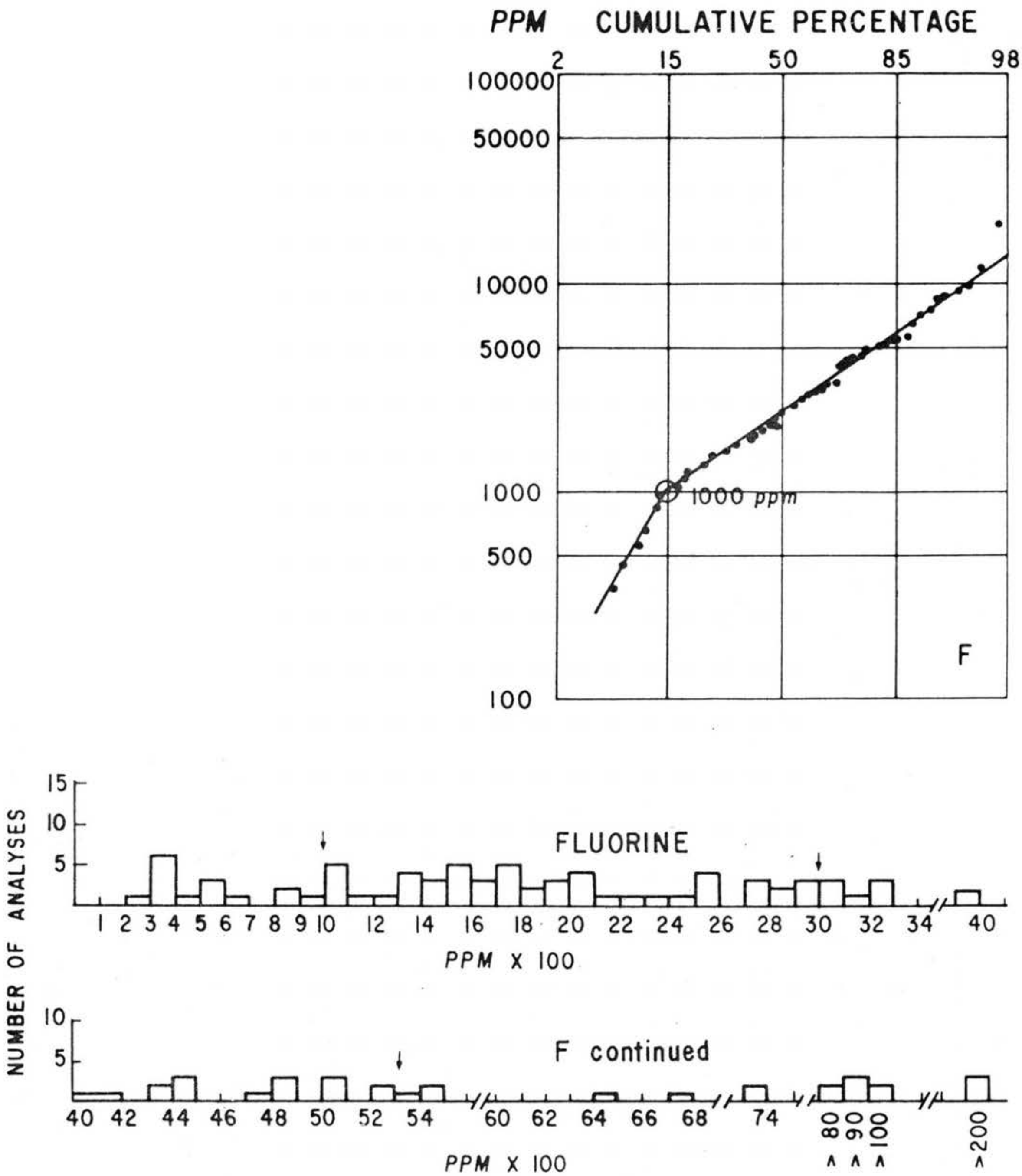


Figure 56. Rock Samples.

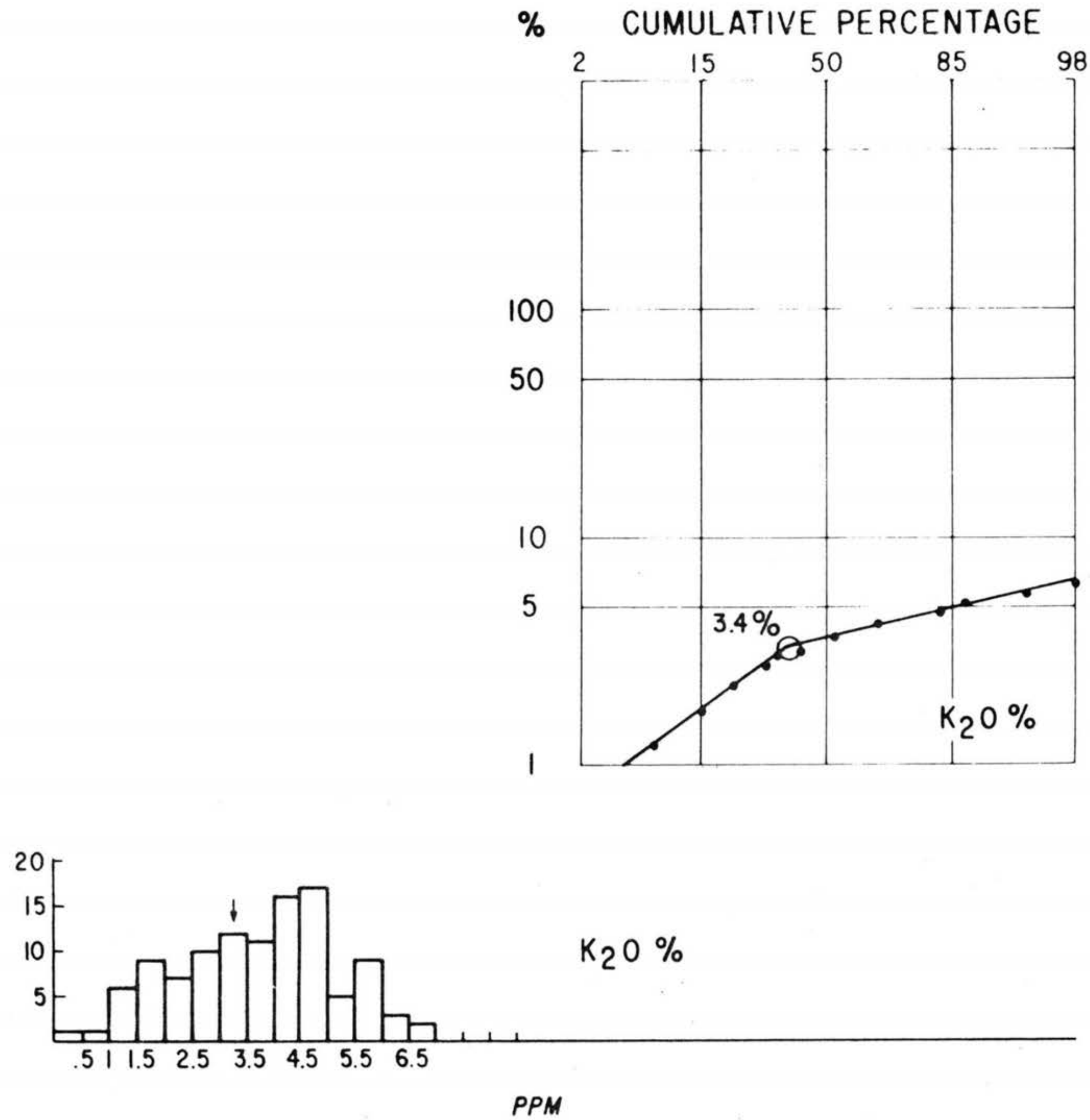


Figure 57. Rock Samples.

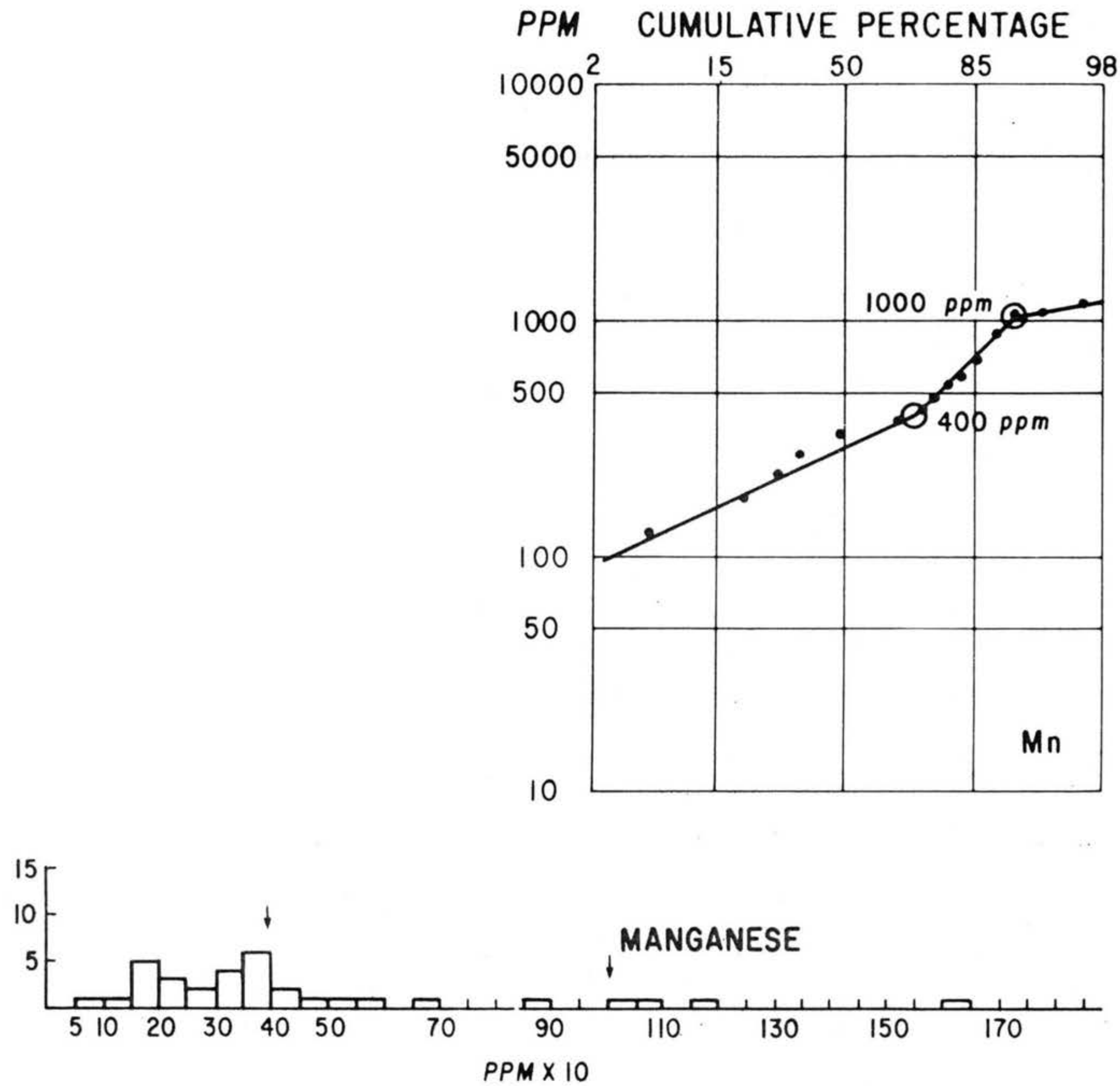


Figure 58. Rock Samples.

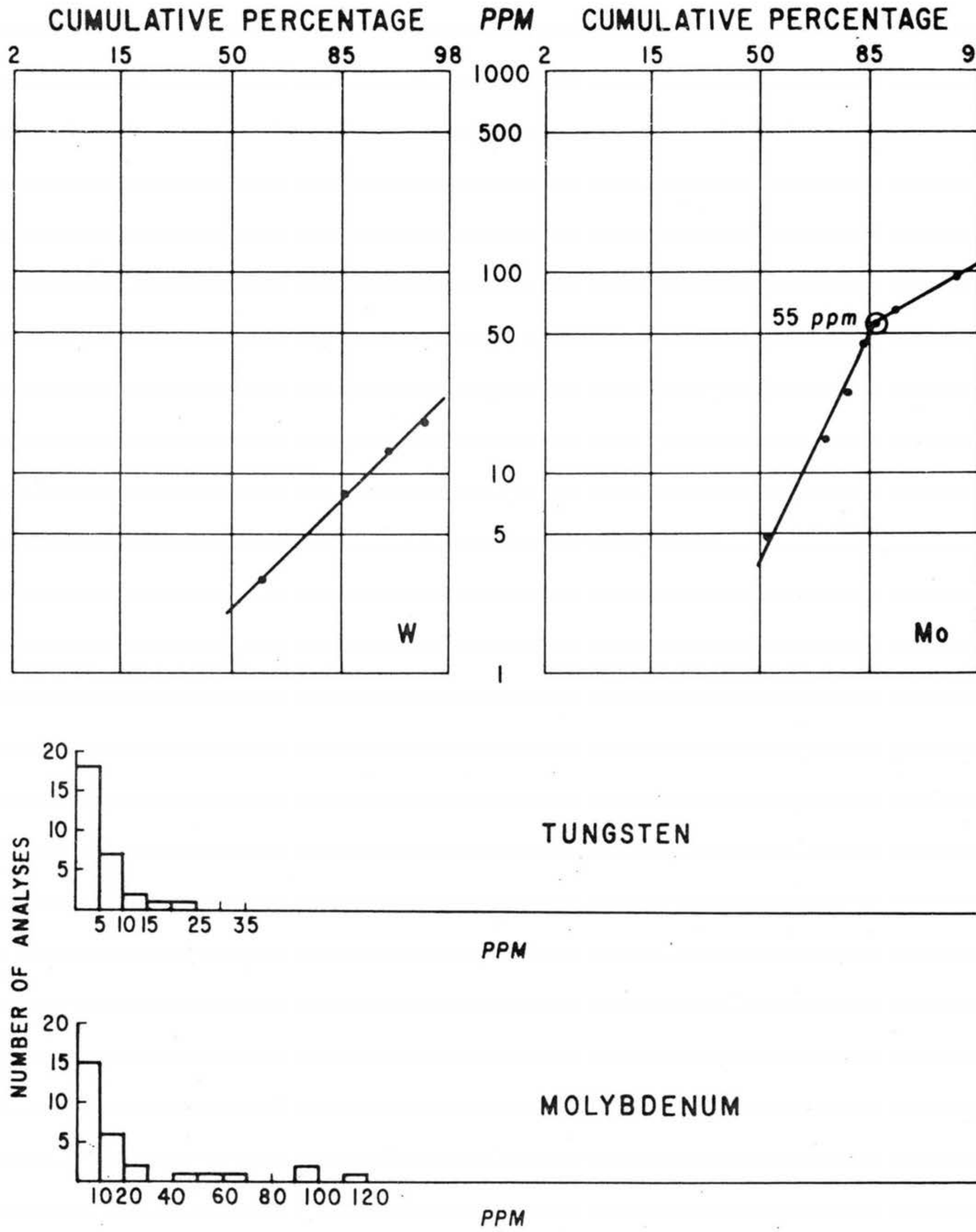


Figure 59. Vein Samples.

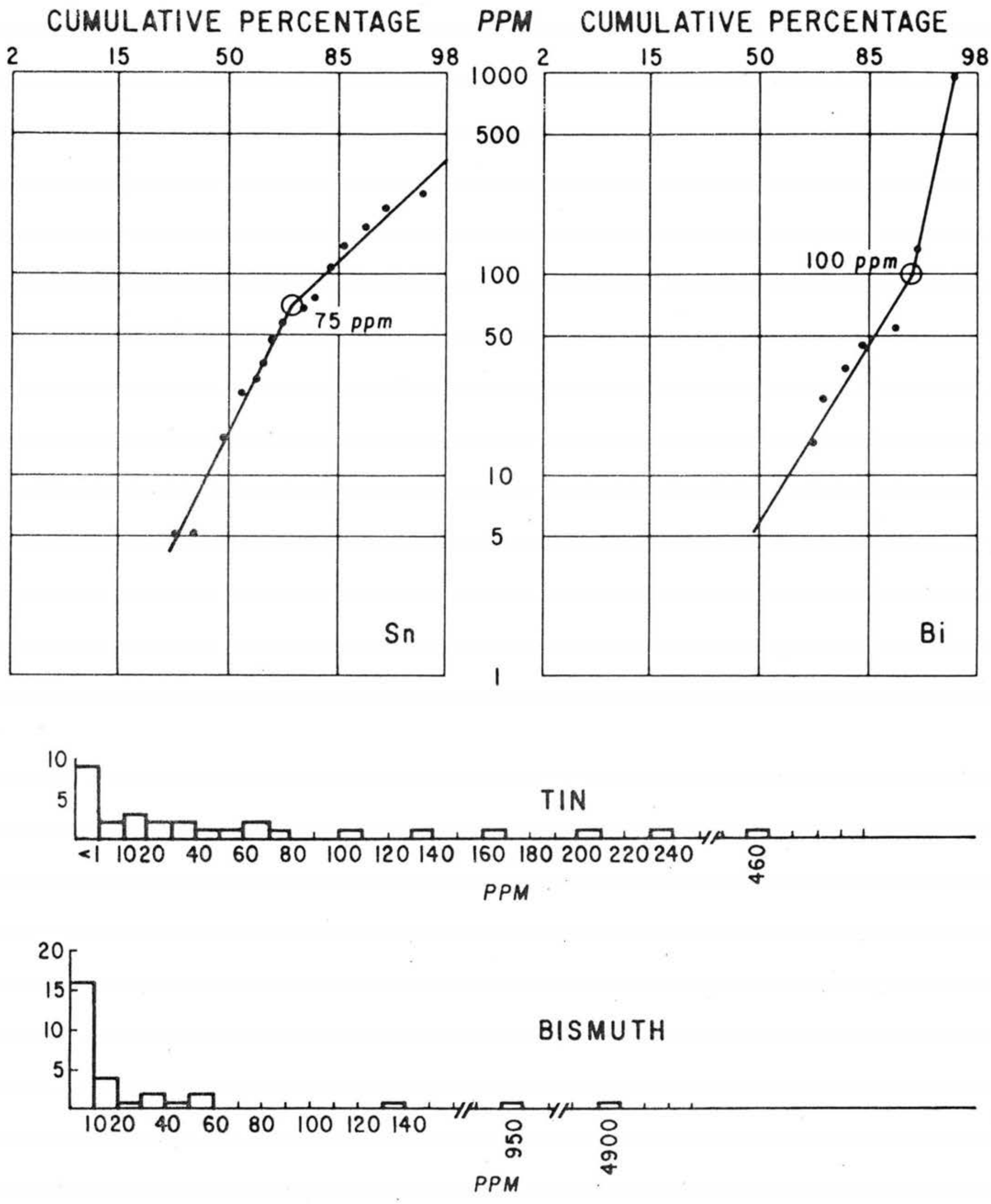


Figure 60. Vein Samples.

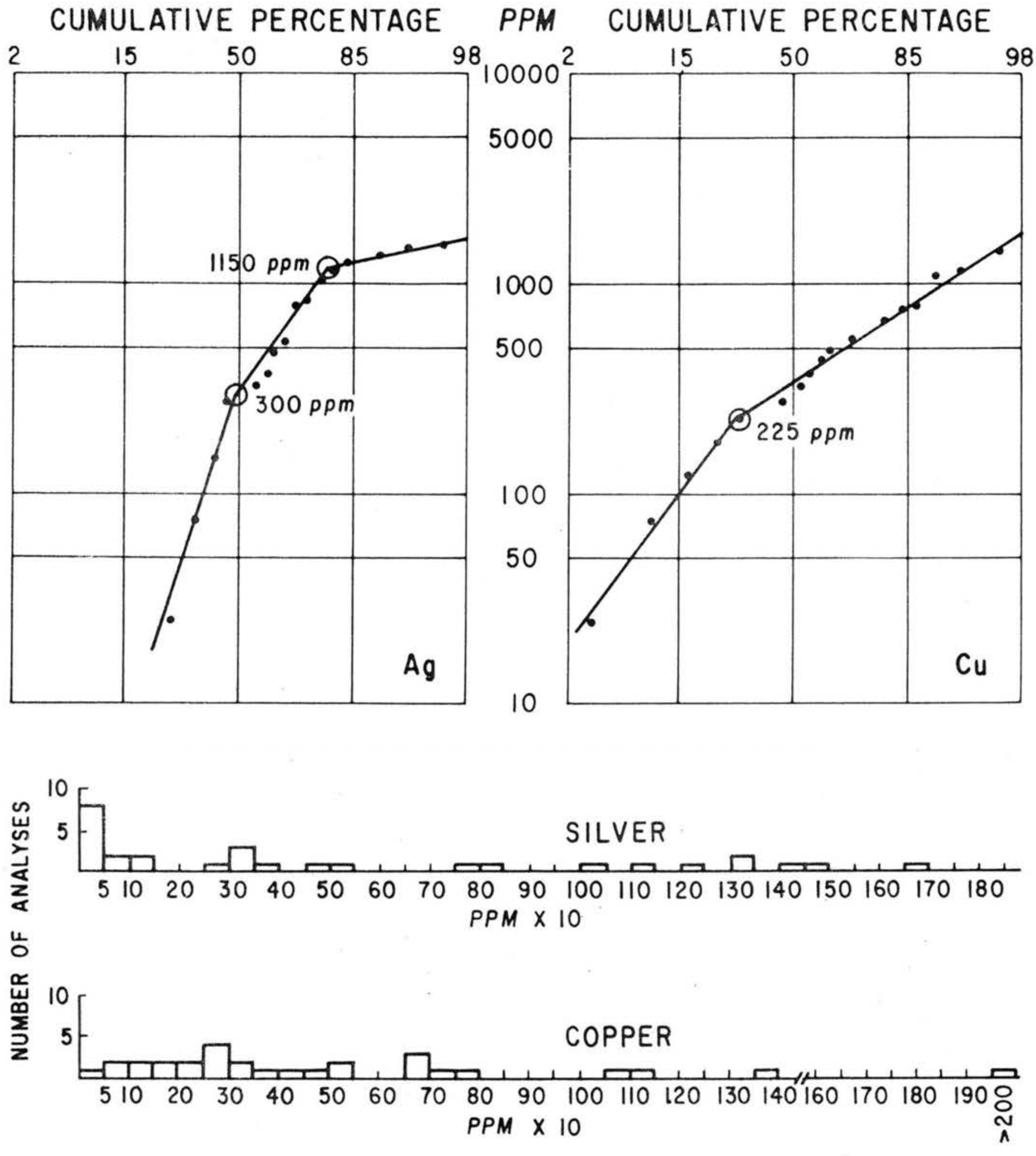


Figure 61. Vein Samples.

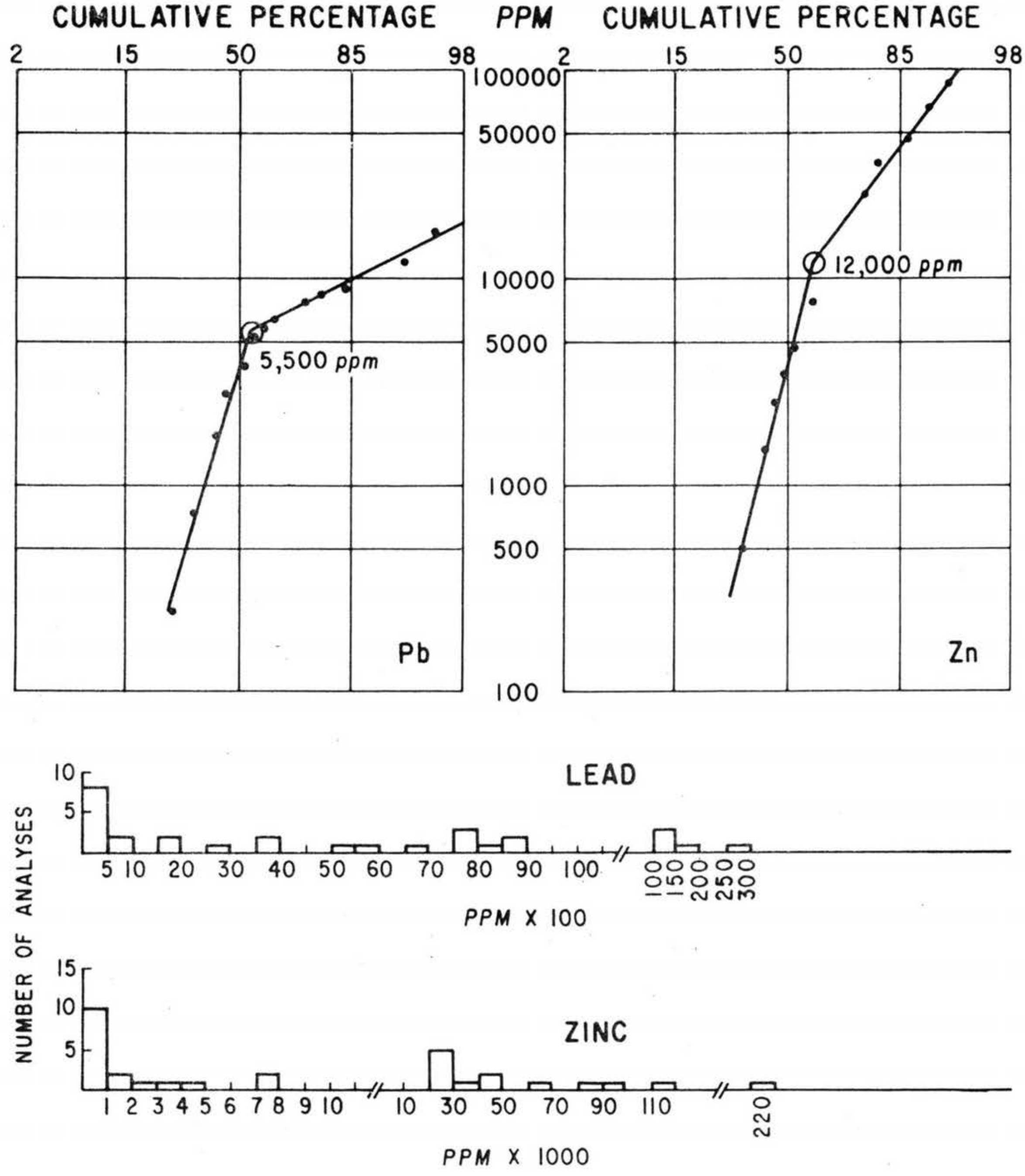


Figure 62. Vein Samples.

APPENDIX C

Radiometric Age Determination Data

Sample Description: Turquoise Lake Porphyry - coarse phase

Location: Dump Rock Sample: SW 1/4, Sec 11, T. 9 S., R 81 W.; from large dump about 1500 feet and N. 65° W. from the common corner of sections 11, 12, 13, 14, T. 9 S., R. 81 W.

Material Analyzed: Sericite concentrate, -100/+200 mesh. Aggregates of very fine grained sericite.

Method: Potassium-Argon

Determined by: Geochron Laboratories, Inc., 1978 (No. M-4351)

Age: 35.6 ± 1.4 M.Y.

Argon Analyses:

Ar^{40*}, ppm	Ar^{40*}/Total Ar^{40}	Ave. Ar^{40*}, ppm
.01366	.528	.01377
.01387	.500	

Potassium Analyses:

% K	Ave. % K	K^{40}, ppm
5.395	5.359	6.538
5.324		

Ratio: Ar^{40*}/K^{40} = .002105

Constants Used:

$\lambda_\beta = 4.72 \times 10^{-10}$/year

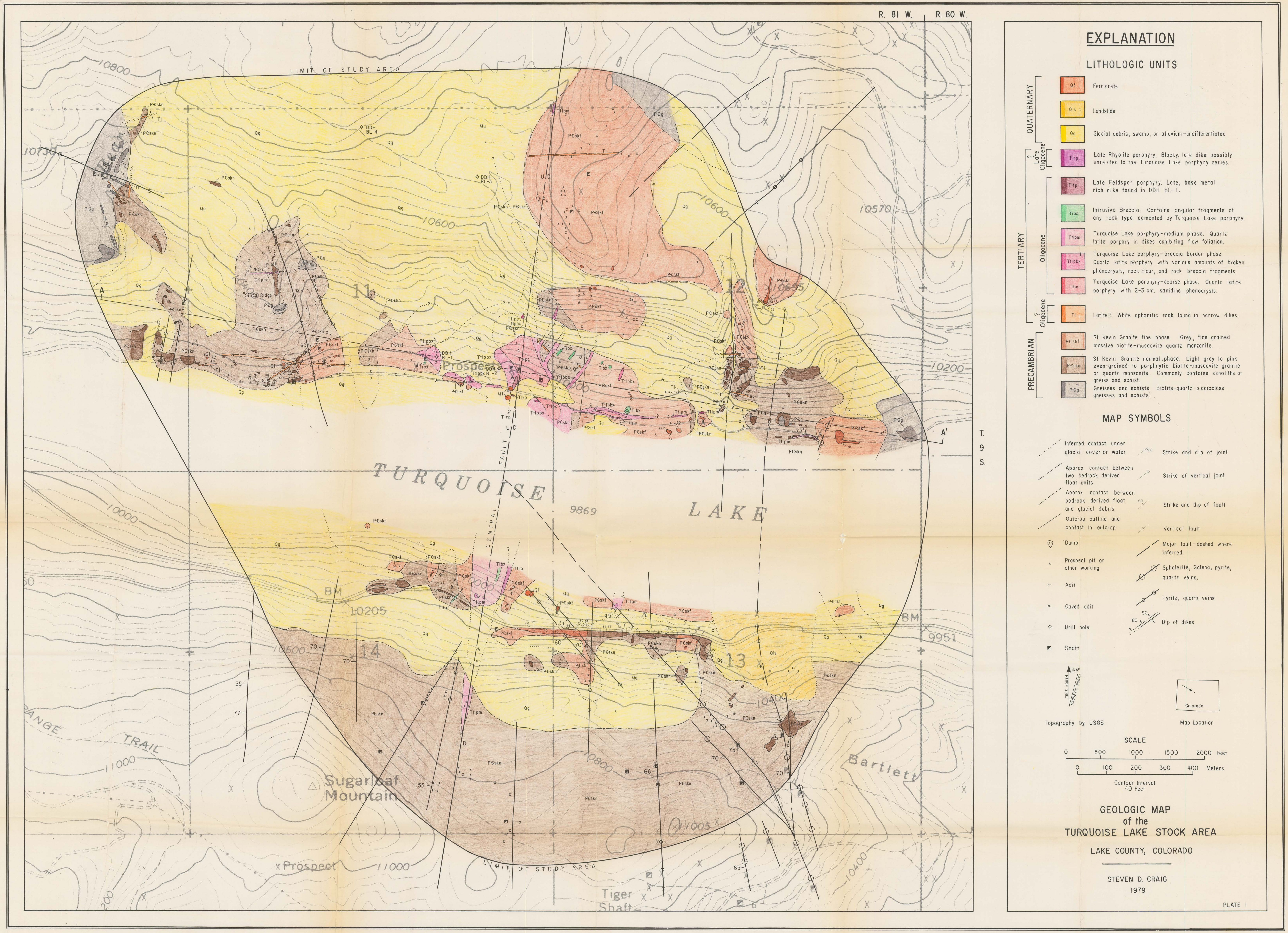
$\lambda_e = 0.585 \times 10^{-10}$/year

$K^{40}/K = 1.22 \times 10^{-4}$ g/g

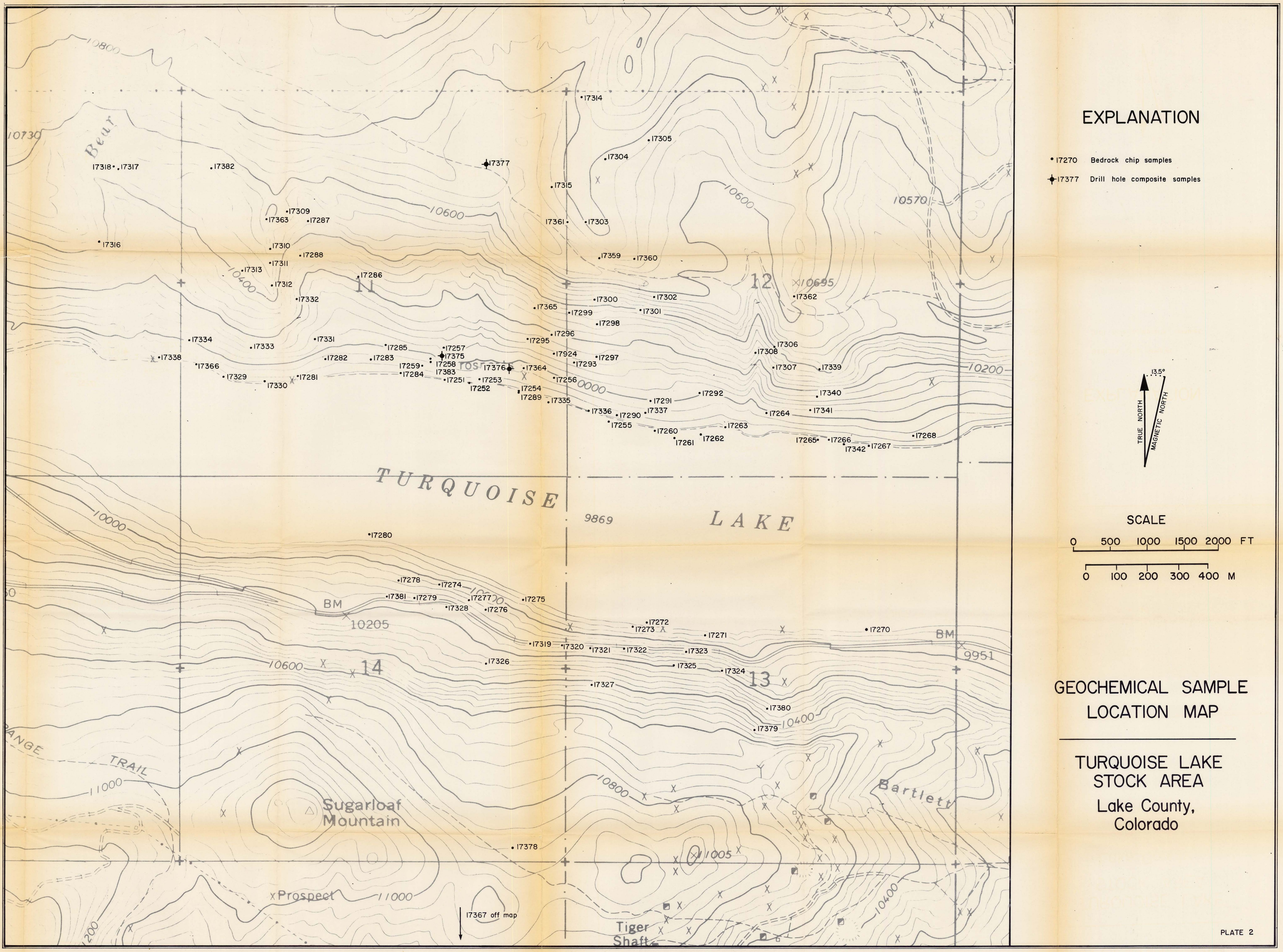
$$AGE = \frac{1}{\lambda_e + \lambda_\beta} \ln \left[\frac{\lambda_\beta + \lambda_e}{\lambda_e} \times \frac{Ar^{40*}}{K^{40}} + 1 \right]$$

Note: Ar^{40*} refers to radiogenic Ar^{40}.

M.Y. refers to millions of years.


R. 81 W.
R. 80 W.
LIMIT OF STUDY AREA
TURQUOISE LAKE
CENTRAL FAULT
Sugarloaf Mountain
Prospect
Tiger Shaft
Bartlett
TRAIL
Silica Ridge
T. 9 S.
A
A'
11
12
13
14
EXPLANATION
LITHOLOGIC UNITS
QUATERNARY
Qf Ferricrete
Qls Landslide
Qg Glacial debris, swamp, or alluvium–undifferentiated
TERTIARY
? Late Oligocene
Tlrp Late Rhyolite porphyry. Blocky, late dike possibly unrelated to the Turquoise Lake porphyry series.
Oligocene
Tlfp Late Feldspar porphyry. Late, base metal rich dike found in DDH BL-1.
Tibx Intrusive Breccia. Contains angular fragments of any rock type cemented by Turquoise Lake porphyry.
Ttlpm Turquoise Lake porphyry–medium phase. Quartz latite porphry in dikes exhibiting flow foliation.
Ttlpbx Turquoise Lake porphyry–breccia border phase. Quartz latite porphyry with various amounts of broken phenocrysts, rock flour, and rock breccia fragments.
Ttlpc Turquoise Lake porphyry–coarse phase. Quartz latite porphyry with 2-3 cm. sanidine phenocrysts.
? Oligocene
Tl Latite?. White aphanitic rock found in narrow dikes.
PRECAMBRIAN
P€skf St Kevin Granite fine phase. Grey, fine grained massive biotite-muscovite quartz monzonite.
P€skn St Kevin Granite normal phase. Light grey to pink even-grained to porphrytic biotite-muscovite granite or quartz monzonite. Commonly contains xenoliths of gneiss and schist.
P€g Gneisses and schists. Biotite-quartz-plagioclase gneisses and schists.
MAP SYMBOLS
Inferred contact under glacial cover or water
Approx. contact between two bedrock derived float units.
Approx. contact between bedrock derived float and glacial debris
Outcrop outline and contact in outcrop
Dump
Prospect pit or other working
Adit
Caved adit
Drill hole
Shaft
Strike and dip of joint
Strike of vertical joint
Strike and dip of fault
Vertical fault
Major fault–dashed where inferred.
Sphalerite, Galena, pyrite, quartz veins.
Pyrite, quartz veins
Dip of dikes
13.5°
TRUE NORTH
MAGNETIC NORTH
Topography by USGS
Colorado
Map Location
SCALE
0 500 1000 1500 2000 Feet
0 100 200 300 400 Meters
Contour Interval 40 Feet
GEOLOGIC MAP of the TURQUOISE LAKE STOCK AREA
LAKE COUNTY, COLORADO
STEVEN D. CRAIG
1979
PLATE I


A
A'
Bear Creek
"Silica Ridge"
DDH BL-1
DDH BL-2
CENTRAL FAULT
ELEVATION ABOVE SEA LEVEL IN FEET
400
200
10,000
800
600
400
200
9,000
800
600
400
200
8,000
800
600
400
200
7,000
Qg
p€g
p€skn
p€skf
Tl
Ttlpbx
Ttlpc
Tlfp
Tibx
Ttlpm
Tlrp
U
D
TD 1514'
TD 1544'
Quartz Monzonite Phase ?
Total displacement unknown
CROSS SECTION
OF THE
TURQUOISE LAKE STOCK AREA
Lake County, Colorado
0 200 400 600 800 1000
FEET
Data by S. Craig
PLATE IA


EXPLANATION
• 17270 Bedrock chip samples
✦ 17377 Drill hole composite samples
TRUE NORTH
MAGNETIC NORTH
13.5°
SCALE
0 500 1000 1500 2000 FT
0 100 200 300 400 M
GEOCHEMICAL SAMPLE LOCATION MAP
TURQUOISE LAKE STOCK AREA
Lake County, Colorado
PLATE 2
TURQUOISE LAKE
9869
Bear
11
12
13
14
BM
10205
BM
9951
10695
Sugarloaf Mountain
Prospect
Tiger Shaft
Bartlett
TRAIL
17367 off map
17314
17305
17304
17377
17318
17317
17382
17315
17309
17363
17287
17361
17303
17316
17310
17288
17311
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17313
17286
17312
17332
17302
17300
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17365
17299
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17375
17924
17297
17366
17259
17258
17293
17307
17339
17329
17284
17383
17376
17364
17330
17281
17251
17253
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17380
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