# TRACE METAL GEOCHEMISTRY AND HYDROTHERMAL ALTERATION OF THREE MOLYBDENUM-BEARING STOCKS, GUNNISON AND PITKIN COUNTIES, COLORADO

By

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1968

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1973

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# PREFACE

Trace metal geochemistry and hydrothermal alteration patterns are two key tools used in exploration for stockwork molybdenum deposits. While hydrothermal alteration data is available from most of the major deposits, very little information has been published concerning trace metal patterns. This study attempts to define trends in trace metal distribution likely to develop in a molybdenum-bearing intrusive system by comparing three separate molybdenum-bearing systems which appear to be exposed at different levels by erosion. By "stacking" the surface trace metal patterns from these three systems vertical trends are suggested.

A study of this nature has several inherent problems, however. In order for the conclusions to be valid, it must be assumed that the metal content of each of the three systems is of the same order of magnitude. In most cases this cannot be proven, especially where only surface data is known. Individual peculiarities of each system must also be considered.

The writer wishes to express his gratitude and appreciation to Dr. Tommy B. Thompson, thesis adviser, for his suggestion of this unique study and for his guidance, assistance, and many enlightening discussions which led to its successful completion. Special thanks also are due to Dr. Zuhair Al-Shaieb for his helpful suggestions and for being so generous with his time in supervising the lab work for this thesis, and to Dr. John W. Shelton for his constructive criticism and help with the structural aspects of this study. The assistance of Mr. Terry Orin in the completion of the fieldwork necessary for this study is also gratefully acknowledged. The author was introduced to the study areas while employed by Bear Creek Mining Company.

Finally, and most importantly, the author would like to thank his wife, Mary Ann, for her patience and understanding during the past two years and for her excellent job of typing this thesis.

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# CHAPTER I

## ABSTRACT

Three mid-Tertiary molybdenum-bearing stocks located in central Colorado were mapped and sampled. On the basis of intensity of hydrothermal alteration it appears that the three stocks are exposed at different erosional levels in the intrusive systems: (1) the Tellurium Creek stock shows the least intense alteration and appears to be barely unroofed; (2) the Gold Creek stock has been altered more strongly and is exposed at an intermediate level; (3) the Pine Creek stock displays the most intense alteration of the three and is exposed at the lowest level.

Alteration products identified include: montmorillonite, 2M sericite, epidote and chlorite at Tellurium Creek; 2M sericite and montmorillonite at Gold Creek; and kaolinite, 2M sericite, montmorillonite, epidote, chlorite, and calcite at Pine Creek. Alteration products in the Pine Creek area show a definite zonal distribution reflecting less intense hydrogen metasomatism outward from the stock.

Comparison of threshold and mean values calculated from values of samples from within the three stocks shows that the Tellurium Creek "level" is highest in copper, lowest in molybdenum and intermediate in lead and zinc. All anomalies are confined to areas permeable enough to permit leakage of rising hydrothermal fluids such as contacts, fractures, pebble dikes, and brecciated areas. The Gold Creek "level" is highest in lead and zinc and intermediate in copper and molybdenum. Mineralization is basically restricted to the stock by relatively impermeable Precambrian country rock. The Pine Creek "level" is highest in molybdenum and lowest in lead, zinc and copper. This data suggests that in a single molybdenum-bearing system a zone high in lead and zinc would be likely to occur above and possibly peripheral to a zone high in molybdenum. Copper values appear to

decrease with depth. Correlation coefficients calculated using samples from all three stocks show negative correlation between copper and molybdenum, zinc and molybdenum, and a slight (statistically insignificant) negative correlation between lead and molybdenum.

Data from this study along with data from major stockwork molybdenum deposits are presented diagrammatically in an attempt to show vertical and lateral changes in alteration and approximate zonal distribution of mineralization associated with a molybdenum-bearing intrusive system.

# CHAPTER II

# INTRODUCTION

Approximately two-third of the Free World's molybdenum comes from large tonnage, low grade stockwork molybdenum deposits similar to the Climax and Henderson deposits of central Colorado (Clark, 1972). Hydrothermal alteration and trace metal geochemistry are two key tools used in exploration for this type of deposit. In the following investigation three molybdenum-bearing stocks located in the Sawatch Range of central Colorado were studied in an effort to describe and define factors which could be used in recognizing a molybdenum prospect. The three stocks, which are similar in many respects, are thought to be exposed at different levels by erosion, thus possibly affording the opportunity to observe and compare the alteration and trace metal patterns developed at each surface.

## Location and Accessibility

The Pine Creek, Tellurium Creek, and Gold Creek stocks are located in the Sawatch Range of central Colorado in Gunnison and Pitkin Counties (Figure 1).

The Pine Creek and Tellurium Creek stocks are in close proximity to each other at the northwest end of Taylor Park. Taylor Park is generally accessible from May through October from either Buena Vista via Colorado highway 306 west over Cottonwood Pass or from Gunnison via Colorado highway 135 north to Almont, then Colorado highway 306 northeast along the Taylor River. An improved dirt road known as the Taylor River road runs northwest across Taylor Park. The area of the Pine Creek and Tellurium Creek stocks is reached by a good four-wheel drive road which leaves the Taylor River road about 14 miles northwest of the Taylor Park Trading Post and follows Tellurium Creek north

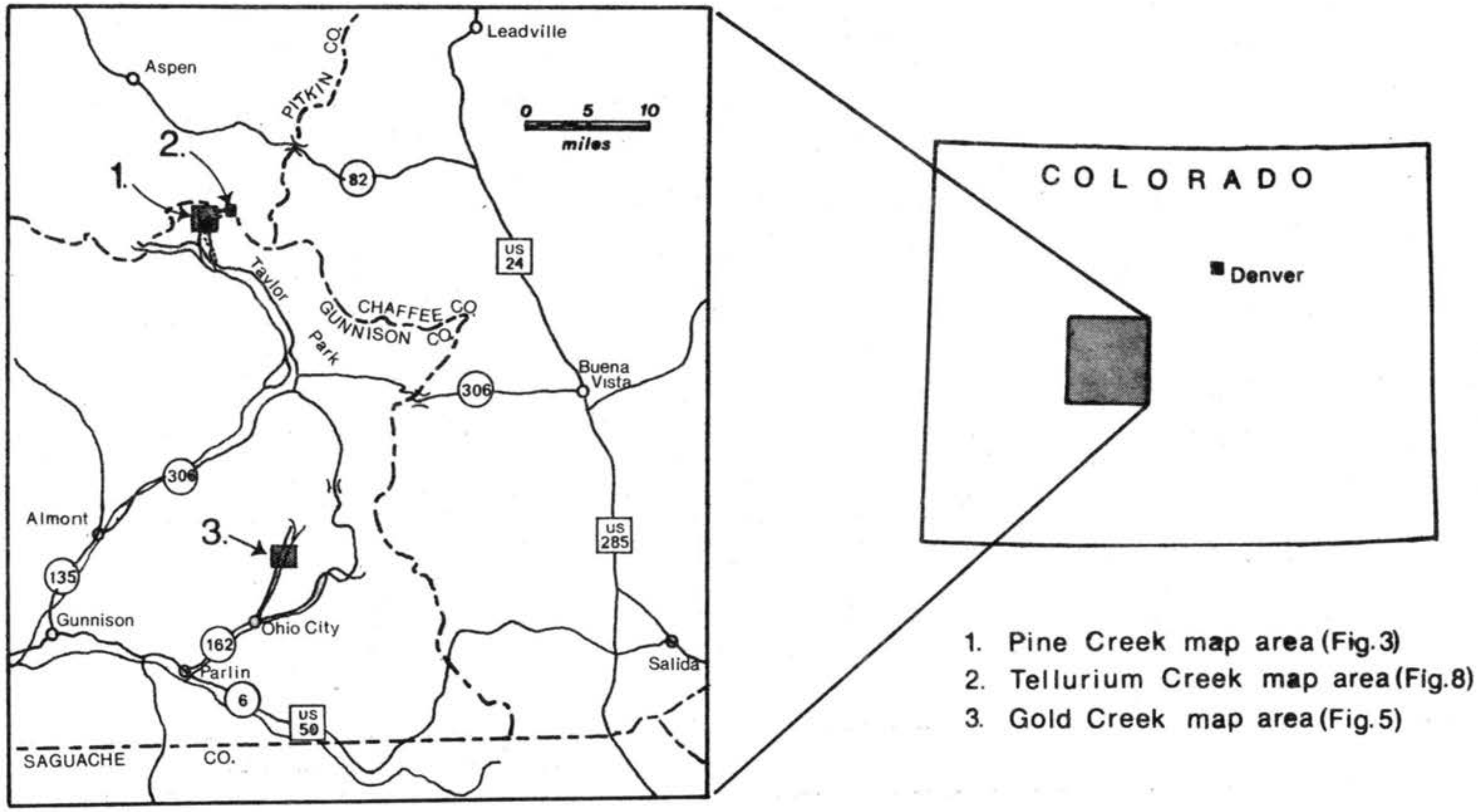


Figure 1. Location map.

approximately 5.5 miles to the area of Figure 3. Access to the area is generally limited to mid-June through early September by heavy snowfall.

The Gold Creek stock is located in southeastern Gunnison county. It can be reached from Gunnison by taking U. S. Highway 50 12 miles east to Parlin, then Colorado highway 162 northeast 9 miles to Ohio City. From Ohio City a gravel road follows Gold Creek north approximately 5 miles to the area of Figure 5. The area is usually accessible from April until late fall.

## Topography

The Pine Creek and Tellurium Creek areas are in glaciated mountainous terrain just west of the continental divide. Elevations range from 11,400 ft. to 13,230 ft. The valleys of Pine Creek and Tellurium Creek are typical U-shaped valleys which are partially filled by alluvium and morainal material. Since most of the Pine Creek and all of the Tellurium Creek map areas are above timberline (approximately 11,700 ft.), most of the slopes are talus-covered and there are several rock glaciers in the area. The area is drained by Pine and Tellurium Creeks which empty into the Taylor River.

Taylor Park, a northwest-trending intermontane basin approximately 25 miles long and 5 to 10 miles wide lies southeast of the Pine Creek-Tellurium Creek area. Its average elevation is 9,500 ft. and it is drained by the Taylor River which begins in the northwest end of Taylor Park and flows southeast into Taylor Reservoir. From the reservoir it flows southwest to Almont where it joins the East River to form the Gunnison River.

The Gold Creek map area ranges in elevation from 10,400 ft. to 9,550 ft. Gold Creek flows through the middle of the map area bisecting the Gold Creek stock. The Gold Creek valley is a steep-sided U-shaped valley partially filled by moraine and glacial debris. The map area is entirely below timberline (about 11,700 ft.) and is covered by dense second growth pine and spruce which makes mapping difficult.

## Mining and Development History

The Pine and Tellurium Creek stocks lie in the Taylor Park-Tincup mining district. Although the immediate map areas have been prospected, as evidenced by numerous prospect pits, there has been no production from it. The Enterprise Mine, about three miles to the south, produced lead-silver-gold-zinc ore in the early 1900's and later sporadically from 1928 into the early 1950's. The mineralization is fracture controlled in Precambrian schists and gneisses.

The Gold Creek stock lies in the Gold Brick Mining district which is located entirely within the Gold Creek drainage. Colorado Geological Survey Bulletin 10 by Crawford and Worcester (1916) describes the district and much of the following data is taken from it and records available in Mineral Resources of the United States (1882-1931) and Minerals Yearbook (1932-1960).

The Gold Brick district was the leading gold producer in Gunnison County in the early 1900's and again from 1934 to 1942, when most real production ceased. A considerable quantity of silver was mined in the late 1800's. Some of the major mines in terms of production were the Carter, Raymond, Gold Links, Sandy Hook, and Belzora Bassick (Figure 5).

The Carter and Raymond mines are located south of the map area on the east side of Gold Creek. The Carter was probably the largest and most consistent producer in the district, and for a number of years was the largest in Gunnison County. Gold, silver, and lead mineralization was mined from north-south trending fractures in the Precambrian schist and gneiss country rock. The Raymond Mine, located north of the Carter, is similar geologically but was a smaller producer. Both properties were equipped with amalgamating and concentration mills.

The Gold Links Mine, south of Hills Gulch on the east side of Gold Creek (Figure 5), produced sporadically from the turn of the century until 1960, although after 1942 there was little significant activity. The most important production occurred from 1908 to 1912. Gold, silver, lead, and copper mineralization was found in north-south trending fractures in Precambrian schist and gneiss. A map of the mine workings as they appeared in 1912 (Crawford and Worcester, 1916) shows a 3,900 ft. tunnel trending S 65° E and 2,500 ft. of cross-cuts along a vein running roughly N 30° E and intersecting the main tunnel 2,150 ft. from the portal. An amalgamating and concentration mill was located on the property. Many of the buildings are still standing, and the adit is open, although when the writer visited it a stream of water a foot or more deep was flowing out of it.

The Sandy Hook Mine is located on the west side of Gold Creek north of the Gold Creek stock. The main adit is open and extends approximately 900 ft. N 56° W through Precambrian gneiss and schist. As in most mines of the district gold, silver and lead mineralization occurred in north-south trending fractures. One of the smaller Sandy Hook adits is located within the stock and although open it is in poor condition. It is said to have contained both gold and silver mineralization. Only the foundation remains of the mill which was located across the road from the lower Sandy Hook tunnel.

The Belzora Bassick Mine, located north of Hills Gulch on the east side of Gold Creek, was not a large producer compared to some of the previously described mines but is of particular interest to this study since it explored mineralization along the contact of the Gold Creek stock with the surrounding Precambrian country rock. There were three main tunnels, all on the east side of Gold Creek (Figure 5): the Monte Vista, near the top of the hill, the Bassick, to the north of the Monte Vista, and the Mutual, to the west and down the hill from the Monte Vista. All three are now caved, but a smaller adit, the Mutual #5, to the south of the Mutual tunnel, is open and exposes the stock contact nicely (Figure 6). Mineralization was mainly in the form of silver-bearing galena found along the contacts, although some gold values were reported.

The Denver City, a small mine located across from the mouth of Hills Gulch on the west side of Gold Creek, is driven westward in Precambrian schists and gneisses. It is presumed any mineralization was similar to the fissure types found in most of the previously described mines.

## Field Methods

The field work for this investigation began May 17, 1972 and was completed in early July of the same year. Two weeks were spent in the Gold Creek area, three weeks in the Pine Creek area, and one week in the Tellurium Creek area. A geologic map of each area (Figures 3, 5, and 8) was prepared using U. S. Forest Service aerial photographs and U. S. Geological Survey 15 minute and 7.5 minute topographic maps. 293 rock chip samples were collected from available outcrop to be analyzed for trace metal content and for determination of alteration products present. In addition, a number of hand specimens were collected for petrologic and petrographic study.

## CHAPTER III

## GEOLOGY OF THE PINE CREEK STOCK, GOLD CREEK STOCK, AND TELLURIUM CREEK STOCK AREAS

The three study areas are located in the Sawatch Range, a large north-northwest trending uplift approximately 90 miles in length and 40 miles wide (Figure 2). It consists basically of a Precambrian core flanked on the east and west by faulting and Paleozoic sediments. Tweto (1968) suggests that the structure could best be characterized as a pair of opposite-facing monoclines that are essentially the result of an uplifted block of basement rock. To the west, Paleozoic sediments dip westward from the uplift into a broad syncline which, near Aspen, is cut along its axis by a large steeply dipping reverse fault. The eastern boundary is formed by the San Luis-Arkansas fault graben. Taylor Park, a small intermontane basin probably due to faulting, is located just southeast of the Pine Creek and Tellurium Creek map areas on the western edge of the Sawatch Range.

The Colorado mineral belt swells to its greatest width around the study areas to include nearly all of the Sawatch Range. The mineral belt, which is characterized by widespread intrusion and mineralization of Late Cretaceous and Tertiary age, is thought to represent a zone of crustal weakness caused by Precambrian shear zones which trend northeast across the state (Tweto and Sims, 1963). Negative gravity anomalies along the belt suggest that magma has intruded along the shear zones to form a batholith or series of batholiths (Tweto, 1968).

Two major periods of deformation have been recognized by Crawford and Worcester (1916) in the Gold Brick District, which includes the Gold Creek area. The first period occurred in Precambrian time. During this period existing sediments were regionally metamorphosed into gneisses, schists and quartzites. This was followed by igneous

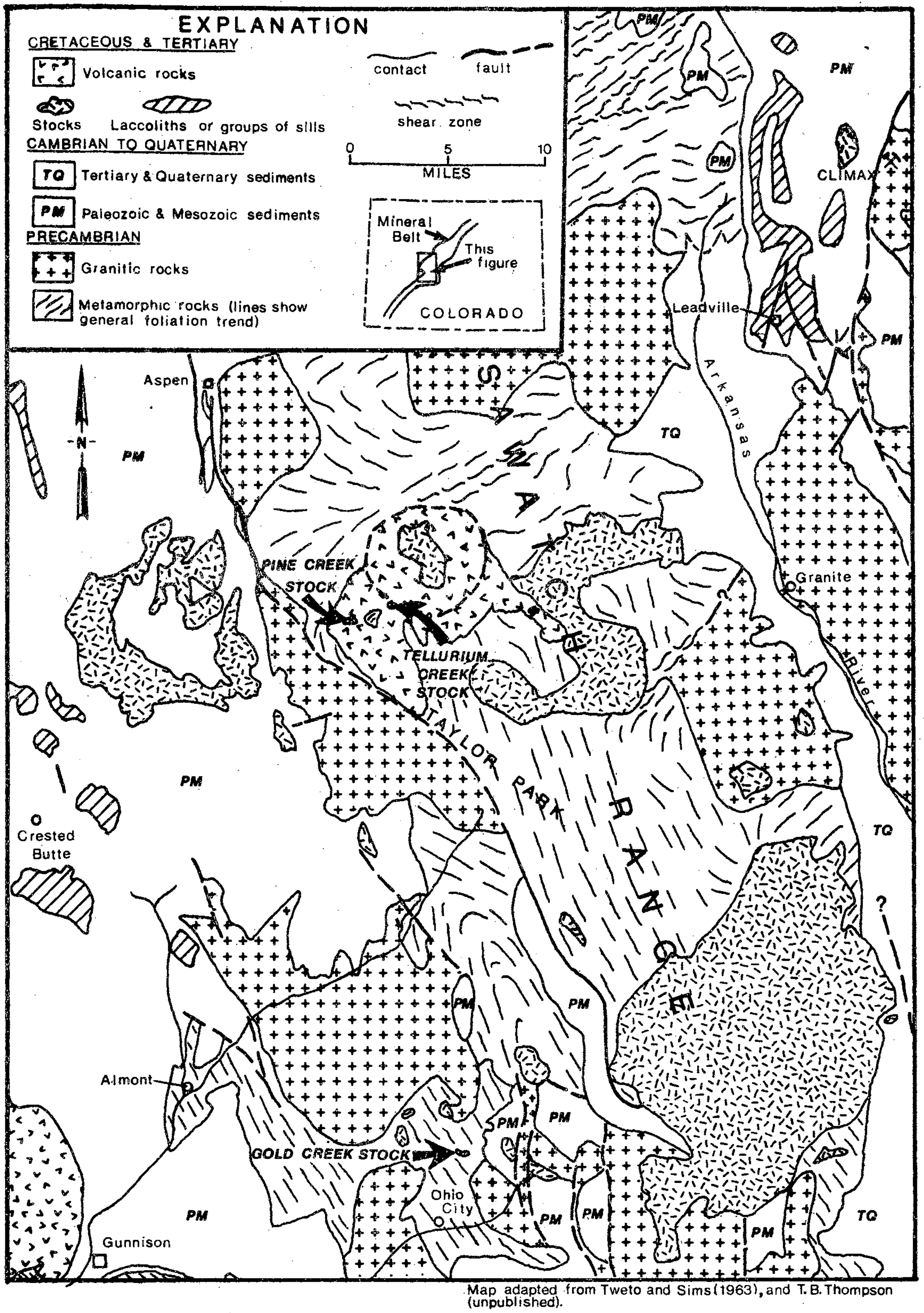


Figure 2. Generalized geologic map of central Colorado.

intrusion, erosion, and subsequent deposition of Paleozoic sediments. A second period of deformation, coinciding with the Laramide orogeny, caused folding and faulting of both Precambrian and Paleozoic rocks.

The Grizzly Peak cauldron complex is located immediately northeast of the Pine Creek and Tellurium Creek map areas (Figure 2). The Grizzly Peak Volcanics, a dacitic to rhyolitic sequence of welded ash-flows, occupy most of the complex. Cruson (1972) recognized nine welded ash-flow cooling units, interbedded with breccias of various origins. Resurgence resulted in the emplacement of a granodiorite stock, the Lincoln Gulch stock, near the center of the cauldron (Candee, 1971). The Grizzly Peak Volcanics are Oligocene in age (Obradovich et al, 1969). Structural features which may be related to the cauldron complex were noted in the Pine Creek and Tellurium Creek areas.

The following sections of this chapter contain descriptions of the structure and rocks exposed in each study area. Igneous rocks are classified using the system and nomenclature proposed by Streckeisen (1967). It should be noted that exact classification of the rock type of the three stocks was made difficult or impossible by the effects of hydrothermal alteration. Tentative classifications are made on the basis of the evidence available. Twenty thinsections were examined: two from the Tellurium Creek area, three from the Gold Creek area, and fifteen from the Pine Creek area.

## Pine Creek Stock Area

The Pine Creek area is the largest of the three study areas. Hydrothermal alteration, described in detail in a later chapter, is more intense and widespread than in the other two study areas. The Pine Creek stock is the only one of the three stocks to exhibit more than one intrusive phase. The reader should refer to the geologic map of the Pine Creek stock area (Figure 3) while reading this section.

### Petrology

Precambrian Rocks. Precambrian rocks are exposed in the Tellurium

Creek valley, east of Red Hill, and around and southeast of Ptarmigan Lake. They consist mainly of metasedimentary rocks, granite porphyry, biotite granodiorite, and granitic pegmatite. These units were not mapped in detail and are shown on the geologic map (Figure 3) as undifferentiated Precambrian material.

The metasediments consist mainly of quartz, biotite and muscovite in varying proportions. Texturally they range from very fine to moderately coarse-grained and the degree of foliation also varies from place to place.

The granite porphyry contains potassium feldspar phenocrysts 1 to 10 mm in length with interstitial quartz, biotite, muscovite and minor amounts of plagioclase. It is slightly to moderately foliated.

The biotite granodiorite is very slightly porphyritic with zoned subhedral to euhedral plagioclase phenocrysts 0.4 to 5 mm in size. They consist of an andesine core with an oligoclase rim and constitute about 52 percent of the rock. Biotite, quartz, and orthoclase are interstitial to the plagioclase and occur in lesser amounts (about 24, 15 and 6 percent, respectively). Apatite is a very common accessory mineral, comprising 2 to 3 percent of the rock.

Veins, veinlets, and lenses of granitic pegmatite consisting of large crystals of microcline, quartz and, locally, muscovite intrude the metasediments.

Grizzly Peak Volcanics. The Grizzly Peak Volcanics cover most of the Pine Creek map area (Figure 3), and the Tellurium Creek area as well (Figure 8). In outcrop the volcanics generally appear to be densely welded and are medium to dark gray in color. They usually display eutaxitic texture (Figure 4) and frequently contain xenoliths of Precambrian rock. The best exposures are found along the crest and flanks of Red Hill, particularly the east side. Interstratified breccia units, as found in the Tellurium Creek area and elsewhere in the volcanic field (Candee, 1971; Cruson, 1972; Holtzclaw, 1973), are less common in the Pine Creek area.

Analysis of thinsections of the volcanics in the Pine Creek area shows that they contain phenocrysts of andesine ($An_{31}$ to $An_{50}$),

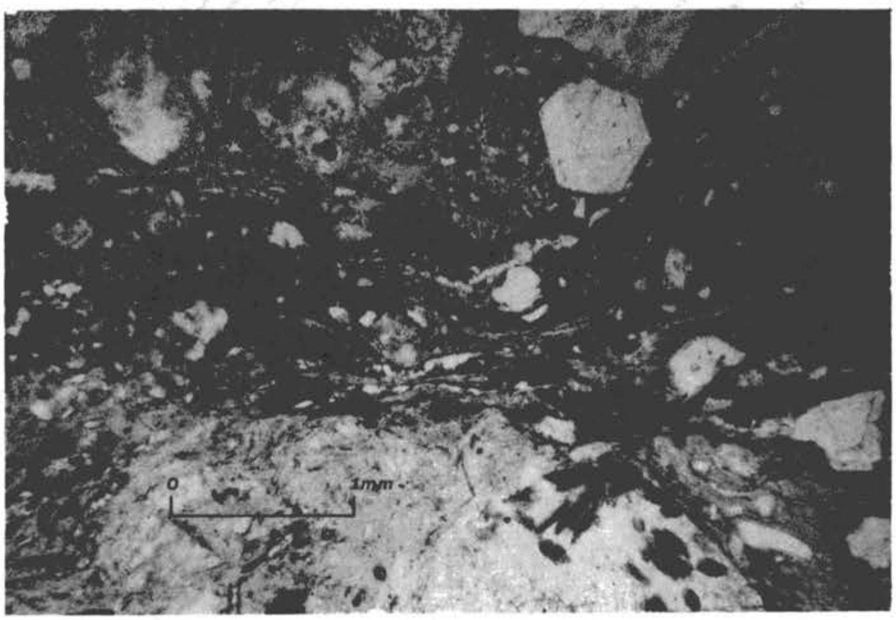


Figure 4. Photomicrograph of Grizzly Peak Volcanics showing typical eutaxitic texture due to compactional layering (plane light).

sanidine and quartz. Biotite is present in all sections studied, generally in amounts ranging from 1 to 3 percent. Occasional traces of apatite, sphene, and zircon were also noted and xenocrysts of quartz and microcline are commonly present. Crushed pumice fragments and glass generally make up 20 to 40 percent of the rock. Some of the glass is devitrified and spherulites are common in sections which have not been strongly affected by hydrothermal alteration. Where alteration has occurred the glass and pumice fragments appear to be the most susceptible portions of the rock and are nearly always completely altered.

Generally the volcanics in the Pine Creek area can be classified in the quartz-latite range. However, there are local variations in the proportions of plagioclase and sanidine. Within the Pine Creek map area the volcanics, particularly along Red Hill, have undergone various degrees of hydrothermal alteration ranging from complete argillization to weak propylitization (Figure 10 and Chapter IV).

Dikes. Along the crest of Red Hill and throughout the map area a number of dikes cut the volcanics (Figure 3). A brief study of hand specimens and two thinsections indicates that they can generally be divided into two types: latite porphyry dikes and light-colored, very fine grained dikes termed felsite dikes.

The latite porphyry dikes are the most common. They contain euhedral phenocrysts of andesine, minor amounts of quartz, and a generally high percentage (5 to 10 percent) of biotite. Some of these dikes are pyrite-rich and most contain some magnetite.

The felsite dikes are white to light gray in color, and have a very fine-grained, sugary texture with a few small quartz phenocrysts. No thinsections were prepared of these dikes, which occur in only a few places, and as a result their composition is unknown. Two small (1 to 2 feet wide) randomly oriented felsite dikes occur just east of the Pine Creek stock on the east side of Red Hill and a larger (10 to 15 feet wide) one cuts the volcanics and Precambrian rocks southeast of Ptarmigan Lake. The larger dike can be seen extending for some distance to the east out of the map area. It is conspicuously banded parallel to its contacts and is stained by green copper oxide in places.

The age of these dikes in relation to each other and to the Pine Creek stock is unknown since nowhere do they cross-cut or come in contact with each other. However, where the latite porphyry and felsite dikes are located close enough to the Pine Creek stock they appear to have been affected by hydrothermal alteration associated with the stock, suggesting that they were emplaced prior to the release of hydrothermal solutions from the stock.

Pine Creek Stock. The Pine Creek stock is exposed in the Pine Creek valley on the west side of Red Hill, where it forms a large talus slope with a few small low outcrops, and in a low saddle on the west side of Pine Creek (Figure 3). On the valley floor the stock is covered by a thin veneer of talus and glacial debris. A road which switchbacks up the west side of Red Hill provides fairly good exposures of the stock, as do two trenches cut across its western margin. On Red Hill the stock and surrounding volcanics are stained a bright red-yellow by jarosite and goethite and have been strongly affected by hydrothermal alteration as well, making rock classification very difficult.

Megascopically, the rock has a powdery, bleached appearance. Quartz phenocrysts and occasional small bleached biotite crystals are generally the only minerals identifiable. Most specimens contain fresh pyrite. Locally there are patches of rock which have apparently undergone less hydrothermal alteration and contain numerous fresh euhedral biotite crystals.

Near the western margin a second intrusive phase of the stock is exposed in a few small outcrops and in the two trenches. It is easily distinguished in hand specimen by its numerous doubly-terminated quartz phenocrysts and markedly lower amount of biotite.

Thinsections from the west side of the stock are the least altered and allow identification of some of the feldspars. Information from them indicates that the main body of the stock is porphyritic, with phenocrysts of plagioclase and quartz 1 to 2 mm in size set in a fine-grained groundmass of interlocking anhedral quartz, orthoclase, and plagioclase crystals. The groundmass also contains a considerable amount of clay and secondary quartz. The plagioclase phenocrysts are

TABLE I

MODAL ANALYSES OF SELECTED SAMPLES FROM THE PINE CREEK AREA

| Constituents | Pine Creek Stock: Granodiorite Porphyry[1] | Pine Creek Stock: Quartz Latite Porphyry[2] | Grizzly Peak Volcanics[3] |
|---|---|---|---|
| Quartz | 17.4 | 15.2 | 9.8 |
| Potassium feldspar | 7.3 | 4.2 | 6.7 |
| Plagioclase | 31.6 | 7.0 | 11.4 |
| Biotite | 4.4 | 0.4 | 3.1 |
| Opaque minerals | 2.1 | 1.8 | 1.3 |
| Rock fragments | -- | -- | 3.2 |
| Groundmass | 36.8 | 71.1 | 64.1 |
| Total percent | 99.6 | 99.7 | 99.6 |

[1] Average of samples PC - 140, PC - 142

[2] Sample PC - 137

[3] Average of samples PC - 2, PC - 17, PC - 44, PC - 47

usually subhedral and zoned, with the core often entirely altered to sericite. Crystals unaltered enough to permit measurement of albite and Carlsbad-albite twin extinction angles were found to be sodic andesine ($An_{30-35}$). Quartz phenocrysts are generally anhedral to subhedral and frequently have been fractured and strongly corroded and embayed. Subhedral biotite crystals with inclusions of apatite and occasionally sphene account for 4 to 5 percent of the rock. An approximate modal analysis is given in Table I. The rock is tentatively classified as a granodiorite porphyry.

The second phase of the stock is also porphyritic, containing phenocrysts of quartz, plagioclase, and sanidine in a very fine-grained matrix that has been almost totally replaced by sericite and other clay minerals. About 70 percent of the rock is groundmass. Of the remaining 30 percent bipyramidal quartz phenocrysts 1 to 3 mm in size account for approximately 15 percent. They are frequently strongly corroded and embayed. Numerous smaller angular fragments of quartz are also present. Plagioclase phenocrysts make up about 7 percent of the rock and are somewhat more sodic than the plagioclase found in the granodiorite porphyry, generally having a composition ranging from $An_{22}$ to $An_{28}$ (oligoclase). The phenocrysts are usually zoned and have been sericitized to varying degrees. Approximately 5 percent of the rock is sanidine which occurs as subhedral phenocrysts 1 mm and less in size. Biotite is conspicuous by its scarcity, accounting for less than 0.5 percent of the rock. On the basis of the approximate percentages given above the second phase is tentatively classified as a quartz latite porphyry and may represent a differentiation product of the same parent magma which earlier produced the granodiorite porphyry. Both rock types are low in quartz (Table I).

## Structural Geology

Precambrian Structure. Precambrian rocks are exposed in a "window" cut by erosion through the Grizzly Peak Volcanics in the Tellurium Creek valley. Foliation trends in these rocks range from N 35° E to N 75° E with an average of about N 50° E. Dips of the foliation are all nearly vertical. These trends generally match those reported by Tweto and Sims (1963) for the Independence Pass region to the northeast and are thought to represent a major period of Precambrian deformation.

Tertiary Structure. Due to the close proximity of the Pine Creek and Tellurium Creek areas to the Grizzly Peak cauldron complex it appears that many of the structural features observed in these two areas may be related to the development of the cauldron complex.

Numerous fractures and dikes which cut the volcanics within the Pine Creek area trend in an east-northeast direction and may reflect a radial pattern of fracturing related to the cauldron complex. Foliation in the Precambrian rocks also trends in this direction, however, and may have had some influence on the direction of fracturing.

On either side of Red Hill, and in the Tellurium Creek area, compactional layering in the Grizzly Peak Volcanics shows only a slight dip, usually in the vicinity of 5 to 15°. East of Red Hill the dips are generally in an easterly or northeasterly direction and west of Red Hill they dip to the west. Along Red Hill, however, the compactional layering strikes about N 20° W and dips 40° to 60° to the west. Fracture zones, which have apparently been truncated by the stock, are exposed along the west side of Red Hill gradually curving to the east near both ends of Red Hill. The abrupt change in the dip of the compactional layering and the fracture pattern on the west side of Red Hill suggest the possibility of an eastward-dipping, arcuate, normal fault developed there. The fault may be related to subsidence within the cauldron complex.

Intrusion of the Pine Creek stock has caused some minor fracturing and brecciation in the surrounding volcanics mainly to the east of the stock. The stock contact appears to dip steeply, although due to intense hydrothermal alteration the exact relationship could not be determined. Several pebble dikes east of the stock on Red Hill are probably the result of late stage hydrothermal activity associated with the stock.

## Gold Creek Stock Area

The Gold Creek study area is located approximately 25 miles south of the Pine Creek and Tellurium Creek areas and includes the Gold Creek stock and the area immediately surrounding it. It is in a somewhat different geologic setting in that the stock intrudes regionally metamorphosed Precambrian rocks rather than Tertiary volcanics and it has no apparent relation to a cauldron complex. The reader should consult the geologic map of the area (Figure 5) while reading this section.

### Petrology

Precambrian Rocks. Precambrian rocks completely surround the Gold Creek stock. Only those in the immediate vicinity of the stock are described and, since no thinsections of Precambrian rock were prepared, the descriptions are brief. For more detailed and complete description of these rocks the reader may wish to refer to the work of Crawford and Worcester (1916). Individual Precambrian rock units are not shown on Figure 5.

Quartz-mica schist makes up the bulk of the country rock which the Gold Creek stock has intruded. It is usually fine-grained and consists almost entirely of quartz, muscovite and biotite in varying proportions. The color varies with the relative amounts of biotite and muscovite present. Chlorite frequently accompanies the biotite. The quartz-mica schist is usually thinly laminated and, although there are local contortions, the strike of the foliation is generally north to slightly west of north.

Interlayered with the quartz-mica schist are bands of amphibole schist and granitic gneiss. The amphibole schist appears to consist predominately of hornblende with some quartz and biotite. Locally it contains epidote-filled fractures. The granitic gneiss consists of finely-laminated bands of pink feldspar, quartz, biotite and muscovite.

Locally, thin veins of granitic pegmatite intrude the abovementioned rocks. These veins range in width from a few inches or less to several feet, and although they are usually concordant with the foliation of the rocks they intrude, in places they cut across it. The pegmatite is composed primarily of microcline, quartz, and muscovite. It varies texturally from that of a medium-grained granite to one in which individual crystals may be an inch or so in size.

With the obvious exception of the granitic pegmatite, all of the Precambrian rocks in the immediate vicinity of the Gold Creek stock are thought to be metasedimentary. Precambrian igneous rocks are present approximately one half mile south of the map area and also to the north and west and are the suggested source for the granitic pegmatites (Crawford and Worcester, 1916).

Sawatch Quartzite. Near the eastern edge of the map area there are several outcrops of massive, pure, white, fine-grained quartzite which is identified as the Sawatch Quartzite. It is thought to be Cambrian in age and unconformably overlies the Precambrian rocks (Crawford and Worcester, 1916; Whitebread, 1951).

Dikes. Two dikes were noted within the map area: (1) a fairly large northeast-trending quartz latite porphyry dike located southeast of the stock, and (2) a smaller felsite dike north of the stock trending east-southeast. The age of these dikes in relation to each other or to the stock could not be determined since no cross-cutting relationships or contacts between them were found.

The quartz latite porphyry dike is found primarily as talus and in small outcrops southeast of the stock. Talus of it extends for some distance to the south and northeast. The rock consists of quartz, plagioclase, sanidine, biotite, and hornblende phenocrysts set in an aphanitic gray groundmass. Quartz occurs as subhedral crystals ranging in size from 0.5 to 3 mm. Plagioclase, which was found to be andesine ($An_{40-47}$), forms large (3 to 5 mm) phenocrysts which are strongly zoned and display well-developed Carlsbad-albite twinning. Sanidine phenocrysts are smaller, subhedral, and less abundant than plagioclase. Biotite accounts for about 3 percent of the rock and contains inclusions of apatite. Hornblende, which occurs in amounts of less than 1 percent, is subhedral, green in plane light, and appears to have been altered to iron oxide in places. Small euhedral crystals of sphene and magnetite are present in trace amounts.

The smaller felsite dike is found in outcrop cutting Precambrian rocks north of the stock. It is about 5 to 7 feet wide and extends as float for several hundred feet to the east. The rock is fine-grained, sugary-textured and light colored, containing subhedral quartz phenocrysts 1 to 3 mm in size.

Gold Creek Stock. The Gold Creek stock is exposed in a few small outcrops, in roadcuts, and in old mine workings on the east and west sides of Gold Creek north of Hills Gulch (Figure 5). It is covered by morainal material and alluvium on the valley floor. Since the stock has undergone hydrothermal alteration it is not a resistant unit and only a few natural outcrops of it are exposed. On the east side of the creek there are four adits, the Mutual, Mutual #5, Monte Vista, and Bassick (Figure 5), which expose the stock and stock-Precambrian rock contact. Three of them are caved, but the Mutual #5 is open and exposes the contact nicely (Figure 6). In all of the adits material was mined from the stock-Precambrian rock contact (Crawford and Worcester, 1916) and this material was available for examination on the mine dumps. On the west side of the valley the main Sandy Hook tunnel, about 250 feet north of the stock, exposes only Precambrian material, but a smaller adit is driven into the center of the stock about 800 feet southwest of the Sandy Hook portal providing good exposure.

In hand specimen, the rock contains numerous euhedral, bi-pyramidal quartz phenocrysts 1 to 4 mm in length set in a powdery white matrix which is for the most part unidentifiable. Small patches of lighter colored material appear to represent altered feldspar crystals, and in some specimens occasional square limonite-coated casts indicate the former presence of pyrite. Limonite staining of the stock overall is much weaker than that observed at either the Pine Creek or Tellurium Creek stocks and is mainly confined to material from along or near the contact.

In thinsection, the rock is porphyritic, containing euhedral quartz phenocrysts, some of which have been strongly embayed (Figure 7), and feldspar pseudomorphs wnich are composed mainly of sericite.

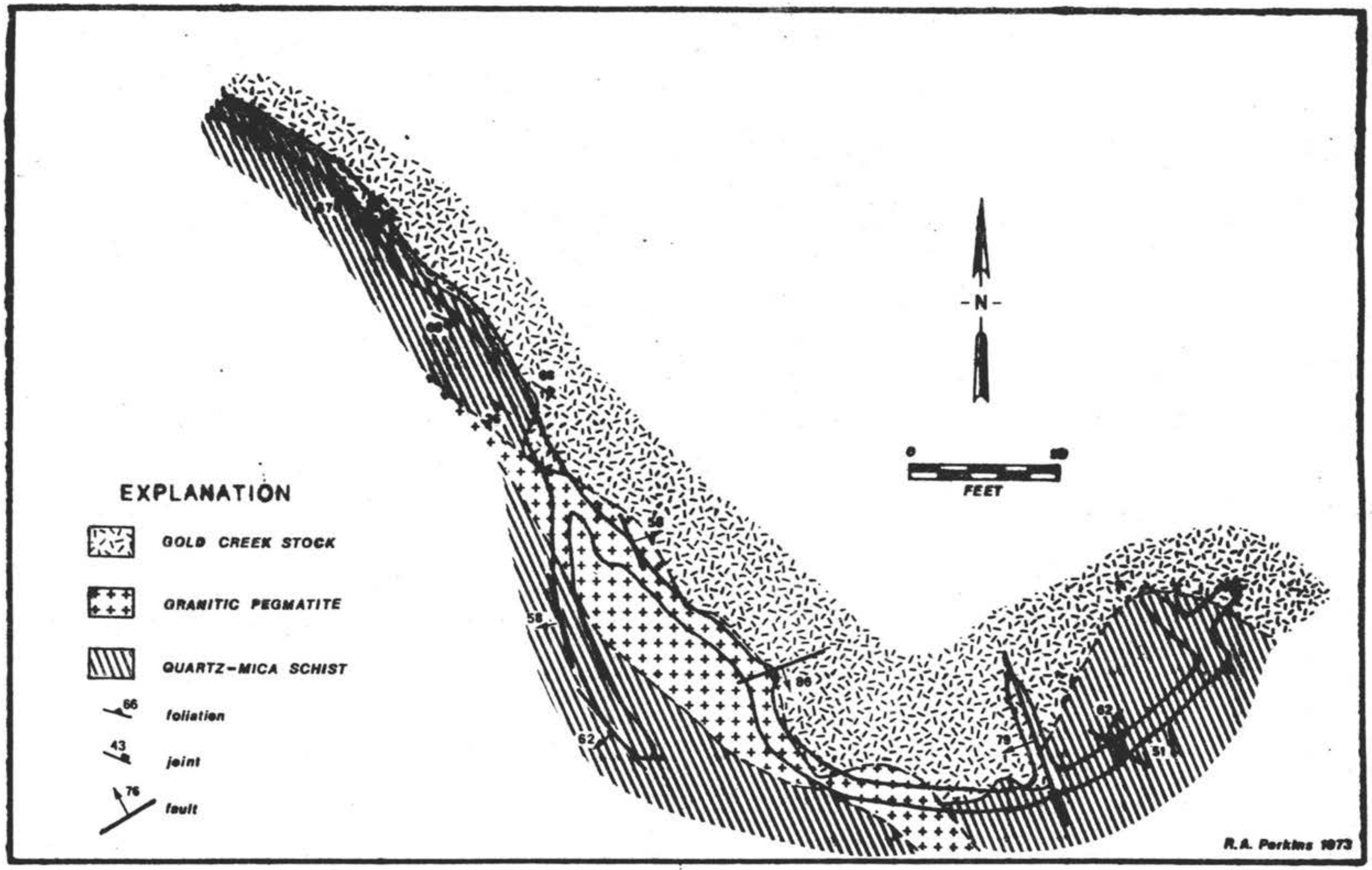


Figure 6. Geologic map of the Mutual #5 adit.

Figure 7. Photomicrograph of embayed quartz pheno-
cryst; Gold Creek stock (crossed nicols).

Biotite occurs as subhedral to euhedral crystals present in amounts up to 1.5 percent. Near the stock contact there are numerous angular fragments of quartz and microcline (probably xenocrysts), and xenoliths of Precambrian quartz-mica schist. Quartz generally accounts for 20 to 30 percent of the rock while feldspar pseudomorphs constitute about 20 percent. Feldspar could not be positively identified in enough cases to permit a definite classification of the rock, but it is suspected it lies in the rhyolite to quartz-latite range, although from the available data the possibility of dacite cannot be completely ruled out.

## Structural Geology

Precambrian Structure. Precambrian rocks in the Gold Creek area have been moderately to strongly metamorphosed, reflecting a major period of deformation which occurred in Precambrian time. Foliation in these rocks generally strikes north-northwest and dips steeply to the west. Folding and faulting of Precambrian age has also been recognized (Crawford and Worcester, 1916). Many of these faults tend to parallel the foliation. Later intrusion of dioritic and granitic igneous rocks was followed by mineralization of pre-existing fractures and faults, and intrusion of granitic pegmatite (Crawford and Worcester, 1916).

Laramide Structure. A second period of deformation probably coinciding with the Laramide orogeny (Crawford and Worcester, 1916) caused additional folding and faulting. Faults of this deformational period cut and offset Precambrian faults and were a major source of annoyance to early miners attempting to follow mineralized Precambrian fractures. In the Gold Creek map area a roughly north-south trending fault known as the Gold Links fault was mapped by Crawford and Worcester (1916) approximately 650 feet east of the Gold Creek stock. It is primarily exposed in the Gold Links Mine where it cuts mineralized Precambrian fractures. No direct evidence of this fault could be found at the surface, but topography and material found on several prospect pits in the vicinity suggest that a fault zone does exist.

Crawford and Worcester (1916) were unable to determine exact dip, strike, and displacement of the fault.

Above the Monte Vista adit (Figure 5) a 5 to 7 feet wide fracture is exposed trending N 30° W and dipping 52° to the west. It is filled with rounded Precambrian rock fragments and gouge, and contains visible lead-zinc mineralization. The age of this fault is uncertain.

Tertiary Structure. During Tertiary time several small intrusives, including the Gold Creek stock, were emplaced in the Gold Brick District. The Gold Creek stock has intruded the Precambrian metasediments causing only minor deformation. In the Mutual #5 adit (Figure 6), and in several places at the surface, small, steeply-dipping fractures with displacement of a few feet or less can be seen radiating outward from the stock. Data reported by Crawford and Worcester (1916) from the now-caved Monte Vista and Mutual tunnels indicates that the eastern contact dips steeply to the west suggesting that the intrusion of the stock may have been influenced by the westward-dipping foliation of the Precambrian rocks. The western contact, exposed in the adit near the center of the western part of the stock, is nearly vertical.

## Tellurium Creek Stock Area

The Tellurium Creek area is the smallest of the three study areas. It is located on the edge of the Grizzly Peak cauldron complex about 1.5 miles northeast of the Pine Creek stock. In elevation the Tellurium Creek area is higher than the other two areas and it appears that the stock is exposed at a high level in the intrusive system. Reference should be made to the geologic map (Figure 8) while reading this section.

### Petrology

Grizzly Peak Volcanics. The Grizzly Peak Volcanics cover nearly all of the Tellurium Creek map area, forming prominent outcrops on all of the ridges. They are similar to the volcanics found in the Pine Creek area (see description on page 12), with the exception of the increased presence of breccia units interstratified with the welded ash-flows. The breccias are composed for the most part of poorly sorted angular fragments of Precambrian rock with rare fragments of ash-flow material. They are thought to be fanglomerate or slump breccias formed by erosion of material from the walls of the caldera (Candee, 1971; Cruson, 1972). Although no attempt was made to measure thicknesses of the volcanic rocks, it appears there is a somewhat thicker sequence present in the Tellurium Creek area than in the Pine Creek area.

Felsite Porphyry Dike. A large, very continuous felsite porphyry dike trending approximately N 50° W cuts the volcanic rocks immediately north of the Tellurium Creek stock. It is light gray in color, with a very fine-grained sugary texture and numerous small quartz phenocrysts. The dike is 10 to 15 feet in width and can be seen extending beyond the map area for a considerable distance both to the northwest and southeast.

Tellurium Creek Stock. The Tellurium Creek stock is exposed in a few outcrops and as talus on the crest and flanks of a steep ridge above the eastern headwaters of Tellurium Creek. It is strongly stained bright yellow as a result of supergene alteration of pyrite. Megascopically the rock is light gray to white on unstained surfaces due to hydrothermal alteration. Phenocrysts of quartz, partially argillized feldspar, and bleached biotite are the only recognizable minerals.

Petrographic and x-ray analyses show that most of the feldspar is sanidine, which occurs as subhedral to euhedral phenocrysts 1 to 2 mm in length accounting for about 20 percent of the rock. The sanidine phenocrysts show incipient alteration to sericite (Figure 15). Plagioclase, found to be oligoclase, is present as smaller partially argillized subhedral phenocrysts. It constitutes approximately 6 percent of the rock. Quartz occurs in amounts of about 10 percent as corroded and embayed phenocrysts up to 3 mm in size (Figure 9). Subhedral, weakly sericitized biotite crystals up to 2 mm in length are present making up about 2 percent of the rock and containing inclusions

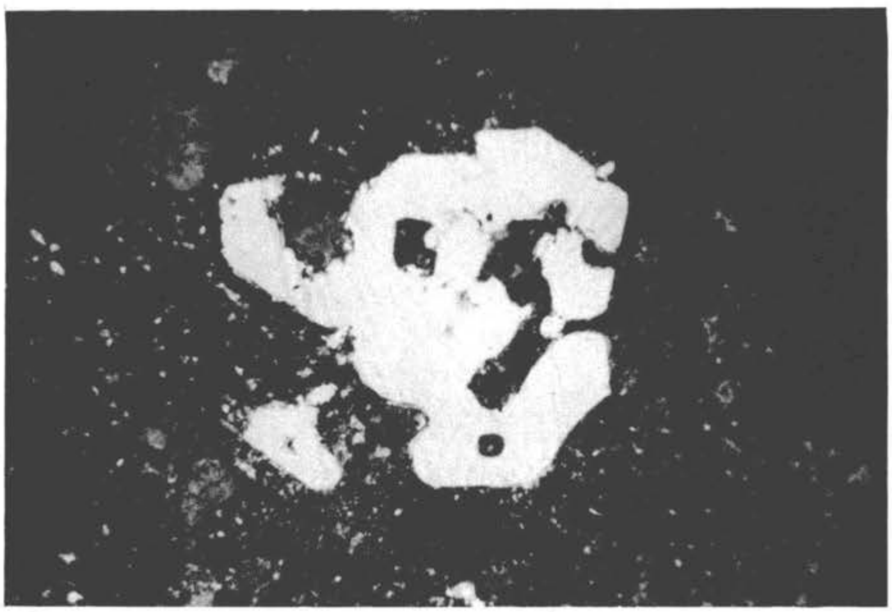

Figure 9. Photomicrograph of embayed quartz phenocryst; Tellurium Creek stock (crossed nicols).

0 1 mm

of apatite and sphene. The remainder of the rock (approximately 62 percent) consists of a very fine-grained groundmass of what appears to be quartz, argillized feldspar crystals, and clay. Fresh pyrite is present in most specimens, usually in amounts of 0.5 percent or less. The rock might be best classified as a quartz-poor rhyolite porphyry.

## Structural Geology

Precambrian Structure. Although there are no exposures of Precambrian rocks within the Tellurium Creek map area, they do crop out just west of the map area and extend westward into the Pine Creek area. The rock units are the same as those found in the Pine Creek area and northeasterly foliation trends predominate.

Tertiary Structure. Structurally the Tellurium Creek stock appears to be located on or near what is probably a ring fault associated with the Grizzly Peak cauldron complex. As mentioned, Precambrian rocks are exposed west of the Tellurium Creek area. They generally occur at elevations of about 12,200 feet and below. North and east of the Tellurium Creek area, however, no Precambrian rocks are exposed at similar elevations. It appears that the Grizzly Peak Volcanics tend to thicken in the Tellurium Creek area and to the north and east, suggesting that, probably due to cauldron subsidence, the area east of the Tellurium Creek stock has been faulted downward. The felsite dike immediately north of the stock may be a manifestation of this faulting. The fault also may have influenced the emplacement of the Tellurium Creek stock.

Intrusion of the stock has caused a minor amount of brecciation in the volcanic rocks on the east side of the stock, but otherwise very little deformation has resulted. Late stage hydrothermal activity has caused the formation of several pebble dikes south and east of the stock. Near the contact, particularly to the northwest, the stock exhibits a thin platy cleavage parallel to the contact. The contact is fairly sharp and dips steeply (average 68$^{o}$) outward from the stock.

As in the Pine Creek area, several east-northeast trending fractures and small dikes were noted cutting the volcanic rocks. Several larger fractures following this same trend were noted south of the map area.

# CHAPTER IV

# ALTERATION

All three study areas have been affected by hydrothermal alteration and to a lesser extent by supergene alteration. From field observation, samples thought to be representative of the various types and zones of alteration were collected. Thinsections were prepared of some of these specimens for optical study. All of the samples were crushed, pulverized, and prepared, following a procedure modified from Kittrick and Hope (1963), for identification by x-ray diffraction. Maps showing the distribution of alteration products in each area are presented as Figures 10A, 10B, and 10C inside the back cover.

## Pine Creek Stock Area

A well-developed alteration halo surrounds the Pine Creek stock (Figure 10C). Alteration products identified include kaolinite, montmorillonite, sericite, chlorite, epidote, jarosite and goethite.

### Hydrothermal Alteration

Zones of hydrothermal alteration products corresponding to the intermediate argillic and propylitic assemblages of Meyer and Hemley (1967) were identified covering and surrounding the Pine Creek stock (Figure 10C). In general the sequence observed from the center of the stock outward includes a central subzone of kaolinite, an overlapping area of abundant 2M sericite, and a fairly wide subzone of montmorillonite, all of which belong to the intermediate argillic assemblage. These are surrounded by an extensive zone of propylitic alteration characterized by epidote and chlorite. All of the zones and subzones of alteration overlap to some extent and some products, such as sericite, are present in all zones in varying amounts.

The kaolinite subzone corresponds roughly to the central part of the stock and is generally overlapped by an area of abundant sericite. Plagioclase and biotite are completely altered to sericite and kaolinite, while potassium feldspar is partially to completely sericitized. Quartz is not usually affected. The original rock texture is still recognizable in thinsection, but megascopically the rock takes on a powdery white appearance with quartz phenocrysts the only easily identifiable mineral.

The montmorillonite subzone extends outward from the kaolinite subzone and its inner margin is overlapped by the area of abundant sericite. It grades outward into the propylitic zone. Even in thin-section it is difficult to distinguish between specimens from the kaolinite subzone and the inner part of the montmorillonite subzone and the boundary is drawn on the basis of x-ray analyses. Moving outward within the montmorillonite subzone the rock becomes less altered. Plagioclase is only partially replaced by montmorillonite and sericite, and potassium feldspar is usually unaltered or shows only incipient alteration. Since this subzone lies mainly within the volcanic rocks which surround the stock, areas of glass and crushed pumice fragments are the most noticeably altered portions of the rock and in hand specimen this accentuates the eutaxitic texture of the volcanics.

The montmorillonite subzone gradually gives way to the propylitic zone, which is characterized by complete replacement of glass and pumice fragments and generally partial but occasionally complete alteration of plagioclase and biotite to epidote and chlorite. This zone is very wide in places, extending well out of the map area to the south. Montmorillonite and sericite, in generally minor amounts, were noted throughout the propylitic zone. The extensive distribution of propylitized rock suggests that hydrothermal fluid leakage occurred not only from the stock center, but also along the southeast-trending fracture zone mentioned in the previous chapter.

On the western side of the stock alteration is, in general, less intense and the zonal arrangement less well developed than it is on Red Hill. In and around the quartz latite porphyry (Figure 3) are

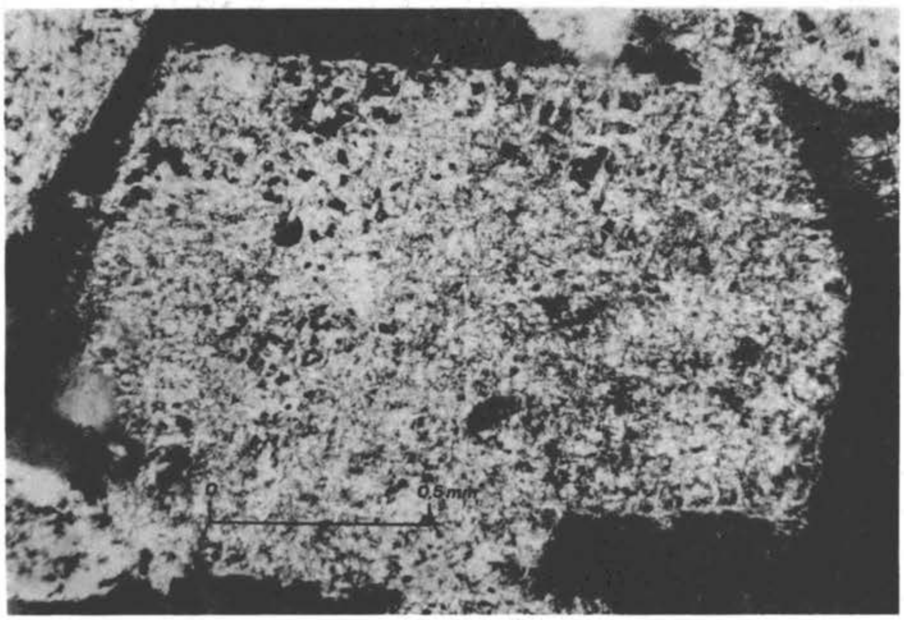


Figure 11. Photomicrograph showing feldspar completely altered to sericite; Grizzly Peak Volcanics near contact with Pine Creek stock (crossed nicols).

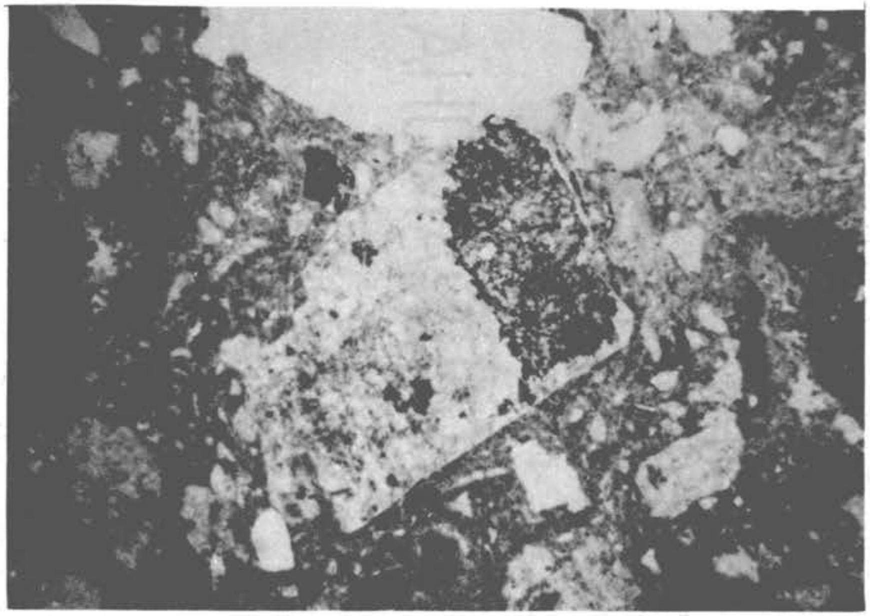

Figure 12. Photomicrograph showing plagioclase altering to epidote in Grizzly Peak Volcanics; Pine Creek area, propylitic zone (crossed nicols).

0 1 mm

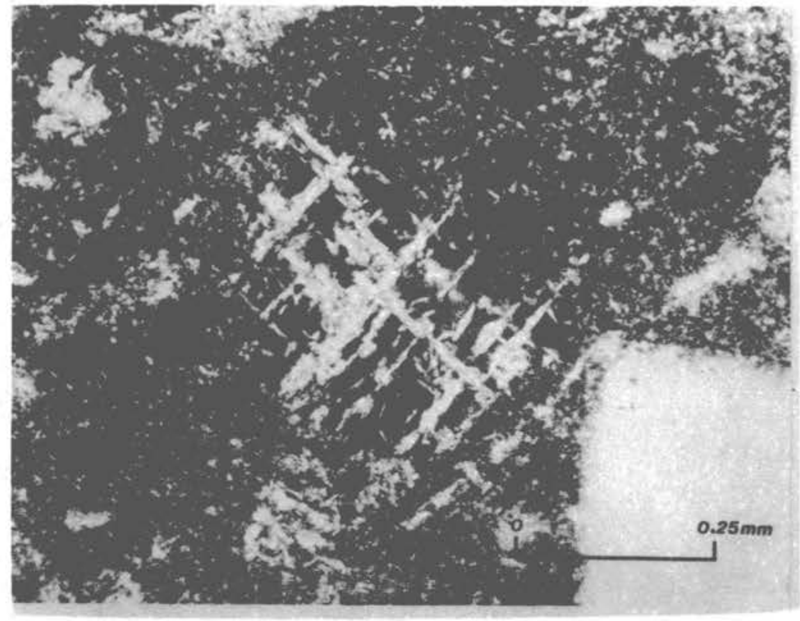


Figure 13. Photomicrograph showing plagioclase altering to sericite along cleavages; Grizzly Peak Volcanics, montmorillonite subzone (crossed nicols).

quartz stockworks which have accompanying envelopes of sericitic alteration. Commonly plagioclase phenocrysts have a sericitized or argillized core, but an unaltered rim. Sanidine crystals are largely unaffected. The reasons for the less intense alteration in this portion of the stock are difficult to ascertain from surface indications. Evidence available suggests two possibilities: (1) As mentioned, compactional layering in the Grizzly Peak Volcanics on Red Hill dips steeply (40 to $60^{o}$) to the west, possibly making them more permeable in an easterly direction to rising hydrothermal fluids. Thus a pressure-temperature gradient could develop which would draw the fluids to the eastern portion of the stock altering these rocks to a greater degree than those to the west. Fracturing noted on Red Hill would also have allowed easier escape of fluids. (2) Since the western part of the stock is at a lower elevation than the eastern part it is possible that alteration decreases with depth. Whether one or a combination of these interpretations is correct or if other factors are involved cannot be proven from evidence at hand.

Although no whole-rock or major element analyses were done, changes in mineralogy and comparison to previously published studies of hydrothermal alteration allow some general observations to be made. It is presumed that the alteration is due to the introduction of hydrothermal fluids derived from depth, and probably from the same source as the stock. As the fluid rose, changing temperatures and pressures allowed dissociation to occur and as the activity of $H^+$ increased intense hydrogen metasomatism and leaching of cations such as $Ca^{2+}$, $Na^+$, $Fe^{2+}$ and $Mg^{2+}$ took place. In the inner part of the intermediate argillic zone potassium feldspar and plagioclase were attacked and altered as shown by the following equations from Meyer and Hemley (1967) and Hemley and Jones (1964):

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

(alteration of potassium feldspar to sericite and quartz with release of $K^+$)

$$KAl_3Si_3O_{10}(OH)_2 + H^+ + 1.5H_2O \longrightarrow 1.5Al_2Si_2O_5(OH)_4 + K^+ \quad (2)$$

(further leaching of $K^+$ to form kaolinite from sericite)

$$0.75\ Na_2CaAl_4Si_8O_{24} + 2H^+ + K^+ \longrightarrow KAl_3Si_3O_{10}(OH)_2 + 1.5Na^+ + 0.75Ca^{2+} + 3SiO_2 \quad (3)$$

(alteration of andesine in the presence of $K^+$ to form sericite and quartz releasing $Na^+$ and $Ca^{2+}$)

$$Na_2CaAl_4Si_8O_{24} + 4H^+ + 2H_2O \longrightarrow 2Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2Na^+ + Ca^{2+} \quad (4)$$

(alteration of andesine to kaolinite and quartz releasing $Na^+$ and $Ca^{2+}$)

Chlorite was formed from biotite by exchange of $H^+$ for $K^+$ as shown by equation 5:

$$2K(Mg,Fe)_3AlSi_3O_{10}(OH)_2 + 4H^+ \longrightarrow Al(Mg,Fe)_5\ AlSi_3O_{10}(OH)_8 + (Mg,Fe)^{2+} + 2K^+ \quad (5)$$

The chlorite was in turn sericitized releasing $Fe^{2+}$ and $Mg^{2+}$ as in equation 6:

$$2Al(Mg,Fe)_5\ AlSi_3O_{10}(OH)_8 + 5Al^{3+} + 3Si(OH)_4 + 3K^+ + 2H^+ \longrightarrow 3KAl_2AlSi_3O_{10}(OH)_2 + 10\ (Fe,Mg)^{2+} + 12H_2 \quad (6)$$

Outward from the kaolinite subzone the concentration of cations increased, the activity of $H^+$ decreased in the fluids and hydrolytic displacement of cations decreased. Montmorillonite and sericite replaced plagioclase, and potassium feldspar was only partially altered. This change in the chemical composition of the hydrothermal fluids is represented by the montmorillonite subzone.

In the propylitic zone due to very low $H^+$ activity only plagioclase, mafic minerals, glass and pumice fragments were vulnerable to weak exchange of $H^+$ for cations. Calcium-, sodium-, iron-, and magnesium-bearing minerals such as epidote, chlorite, and montmorillonite replaced biotite and plagioclase. Minor quantities of sericite developed also. Small amounts of calcite and pyrite found in vugs in the volcanic rocks indicate the presence of $CO_2$ and $S^{2+}$ in the solutions.

Temperatures in the central part of the intermediate argillic zone are estimated to have been between 250° and 400° C since Hemley and Jones (1964) impose an upper limit of 400° C on kaolinite-bearing assemblages and data from Yoder and Eugster (1955) indicates that formation of 2M sericite requires temperatures of at least 200° C at 15,000 psi.

### Supergene Alteration

The Pine Creek stock and the volcanic rocks surrounding it, especially on Red Hill, are stained a bright orange-yellow grading into red outward from the stock. This suggests a gradation from jarosite-rich material over the stock to goethite-rich material near the stock margins and into the volcanics, reflecting the higher pyrite content of the stock (Blanchard, 1968). It is doubtful that supergene alteration has been effective much below the surface, however, since fresh pyrite is found disseminated throughout the rock, and in some specimens only a few centimeters below the oxidized surface.

Black manganese oxide is found coating the contacts of many of the dikes and along some fractures in the volcanics. It is also present as a discontinuous halo partially ringing the stock about 100 to 200 feet outward from the stock contact. This halo is especially noticeable southeast of the stock on the crest of Red Hill and in the volcanic rocks west of the stock. No hypogene manganese-bearing mineral has been identified.

## Gold Creek Stock Area

Alteration in the Gold Creek area is primarily confined to the Gold Creek stock, and does not show the well defined zonal pattern developed in the Pine Creek area. Due to a lack of outcrop, samples were widely spaced in some areas. Most samples are of rocks exposed in roadcuts. Alteration products identified include montmorillonite, sericite, goethite, and jarosite (Figure 10B).

### Hydrothermal Alteration

Sericite and montmorillonite, clay minerals belonging to the intermediate argillic assemblage, are the main hydrothermal products identified in the Gold Creek stock. As mentioned, no regular pattern of distribution could be determined from the samples analyzed, although there is some indication that sericite is more abundant near the stock contact.

The sericite identified is 2M polytype. Generally, all plagioclase and biotite has been completely altered to sericite, but potassium feldspar is usually only partially altered and in some cases unaltered microcline fragments are present. Locally, near the stock contact, everything except quartz has been altered to sericite. In thinsection coarsely crystalline sericite pseudomorphs after feldspar are especially striking (Figure 14).

Montmorillonite was found in most samples, generally replacing plagioclase or part of the groundmass. Sericite was always present with it, and nearly always in greater amounts.

No propylitic assemblage could be found in the Gold Creek area. Precambrian rocks, even at the stock contact, do not appear to have been appreciably altered hydrothermally. Locally, there are epidote-rich areas within the Precambrian rocks, but this is more likely due to regional metamorphism than hydrothermal alteration. It seems probable that the Precambrian material was less permeable than the stock to hydrothermal solutions and thus was not noticeably altered.

Although the number and location of samples from the Gold Creek stock limit the conclusions which can be drawn, some general statements can be made. The alteration assemblage present at the surface corresponds roughly to the sericite-montmorillonite area found along the contact of the Pine Creek stock and probably represents a similar chemical environment. It seems likely that the hydrothermal fluids were able to penetrate upward along the stock contact more easily, causing the apparently more intense alteration observed there. These fluids were able to move vertically, but were restricted laterally by the less permeable Precambrian schists and gneisses. Any propylitic assemblage developed would have been at a higher level in the intrusive system than the present surface and would have been removed by erosion.

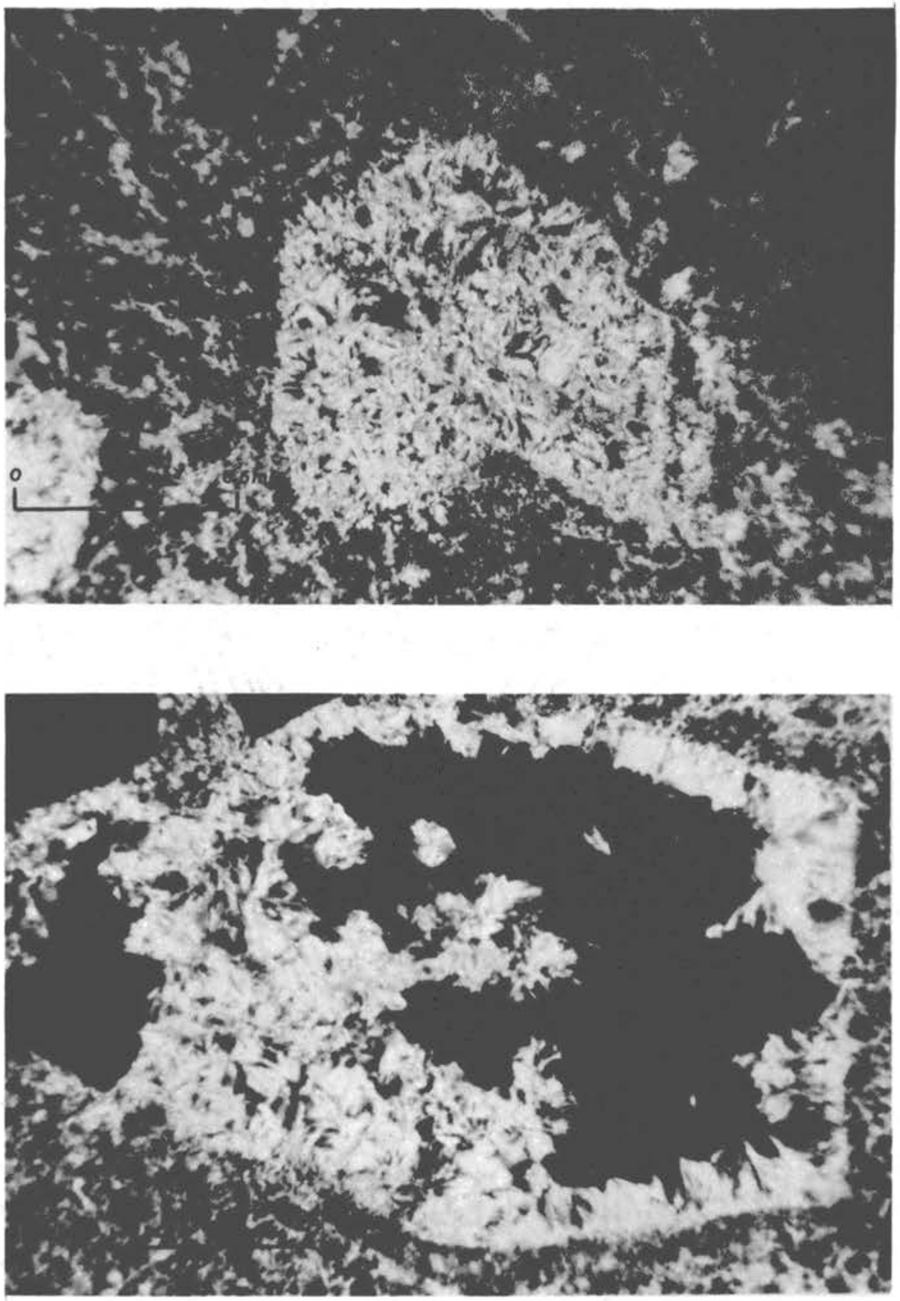

Figure 14. Photomicrographs showing feldspar completely altered to sericite; Gold Creek stock (crossed nicols).

Supergene Alteration

It is difficult to judge the extent to which supergene alteration has been responsible for the alteration found in the Gold Creek stock. In places the stock is stained by goethite and jarosite, mainly along or near the contacts, but this staining is not nearly as strong or widespread as at the Pine Creek or Tellurium Creek stocks. Fresh disseminated pyrite is found in many samples. Whether the montmoillonite is due in part to supergene processes is unknown, but it is treated herein as a hydrothermal product.

Black manganese oxide is frequently present along the stock contacts. No hypogene manganese-bearing mineral was identified.

## Tellurium Creek Stock Area

The Tellurium Creek stock and the area surrounding it are exposed at a level of less intense hydrothermal alteration than that found at either the Gold Creek or Pine Creek areas. Alteration does not extend far into the surrounding Grizzly Peak Volcanics. Alteration products identified include sericite, montmorillonite, jarosite, and goethite (Figure 10A). Locally small amounts of chlorite and epidote were also noted. As at Gold Creek, lack of sufficient outcrop prevented thorough sampling of the stock.

Hydrothermal Alteration

Montmorillonite and 2M sericite are the two major hydrothermal products identified in the Tellurium Creek area. Montmorillonite is more widespread and abundant than sericite. Toward the stock contact the amount of sericite seems to increase, although due to the small number of samples analyzed this trend could not be fully substantiated.

In thinsection both sericite and montmorillonite can be seen as incipient alteration products of sanidine phenocrysts and replacing some of the groundmass of the stock (Figure 15).

Moving outward from the stock into the volcanics small amounts of epidote and chlorite, usually replacing plagioclase and biotite,

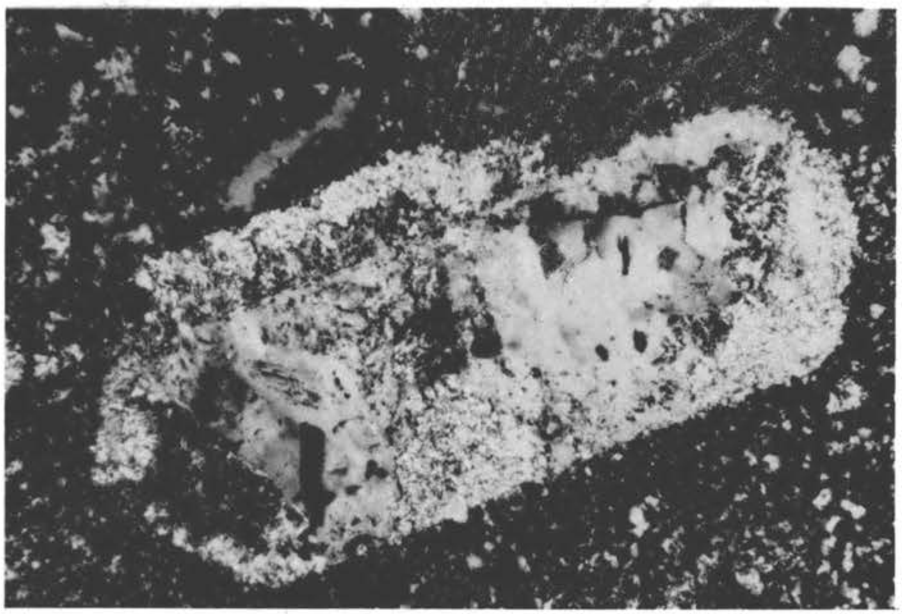

Figure 15. Photomicrograph showing incipient argillization of sanidine crystal; Tellurium Creek stock (crossed nicols).

0 0.25 mm

respectively, are found locally and apparently represent a very weak and discontinuous zone of propylitic alteration.

Chemically the alteration products at Tellurium Creek represent an environment of weak to very weak hydrogen metasomatism comparable to the outer montmorillonite and inner propylitic zones found in the Pine Creek area. The Tellurium Creek stock is apparently exposed at a level high in the intrusive system, and hydrothermal solutions were sufficiently depleted in $H^+$ at this level that intense cation leaching did not take place. The solutions were apparently more easily dispersed upward and consequently a widespread alteration halo did not develop laterally, as at Pine Creek.

## Supergene Alteration

The Tellurium Creek stock is strongly stained a bright yellow-orange color due to abundant jarosite and goethite derived from supergene alteration of pyrite. As at the Pine Creek stock, however, unoxidized pyrite is commonly found just below the surface and thus it appears supergene processes have been active only at or very near the surface.

Black manganese oxide is present adjacent to the stock, along dike contacts and on fractures within the volcanics. No hypogene manganese-bearing mineral was identified.

# CHAPTER V

# MINERALIZATION AND TRACE METAL GEOCHEMISTRY

In the following sections mineralization and the results of trace metal analyses from each of the study areas are discussed. A total of 293 rock chip samples was collected on a random basis from available outcrop (Figure 16) and analyzed by atomic absorption spectrophotometry for copper, molybdenum, lead and zinc. Methods of preparation and analysis are given in the Appendix along with the results of the analyses. Contoured trace element distribution maps are included as Figures 17, 18, 19, and 20. These maps are necessarily interpretative in places due to wide sample spacing in areas of sparse outcrop. Approximate background values, threshold values, and correlation coefficients were calculated using values from samples from each of the three stocks and for the Pine Creek and Tellurium Creek map areas. These are intended only as relative values to provide a means for comparison of the three study areas.

## Pine Creek Stock Area

In the absence of evidence to the contrary, it is assumed that in the Pine Creek area one general hydrothermal event was responsible for the majority of the mineralization and trace metal dispersion observed there. A small amount of mineralization is obviously related to some of the dikes in the area.

The main hydrothermal episode postdates the intrusion of both the granodiorite porphyry and quartz latite porphyry phases of the stock as evidenced by the molybdenite-bearing quartz stockworks found cutting both phases and the fact that both phases have been altered hydrothermally. As mentioned in the preceding section, apparently conditions were such that the altering and mineralizing solutions were allowed to disperse laterally a considerable distance into the surrounding Grizzly Peak Volcanics. This is especially true on Red Hill, but in the western portion of the stock, which is 200 to 400 feet lower in elevation, alteration was found to be less intense and less widespread, possibly indicating that the movement of the rising fluids was influenced toward the east.

Stockwork mineralization exposed in the western portion of the stock is of three types: (1) quartz-pyrite-molybdenite veinlets ranging from hairline size up to 1½ cm in width; (2) quartz-pyrite veinlets 0.1 mm to 1 mm in width; and (3) barren quartz veinlets 0.2 mm to 5 mm in width. Definite age relationships between these three types of veinlets were not established. The molybdenite found in the first type of veinlets occurs as extremely fine flakes either disseminated or in thin bands in a fine-grained interlocking mosaic of anhedral quartz crystals. Pyrite is the most abundant metallic mineral in the first two types of veinlets. It usually occurs as small isolated cubes or clusters of cubes and occasional granular masses within the veinlets.

In the eastern portion of the stock stockwork quartz veinlets were also noted. They are similar to the third type of veinlets found in the western portion, generally containing only quartz.

Figures 17C, 18C, 19C, and 20C show the distribution of Cu, Mo, Pb, and Zn, respectively. Since the object of these maps is to show trends, the contour interval used varies.

## Molybdenum

As might be expected, anomalous molybdenum values are nearly all confined to within the stock, reflecting the relatively lower mobility of molybdenum in a hydrothermal system. Comparison of mean and threshold values (Table II) calculated using only samples from the stock with those calculated using all samples bears this out. The anomaly shown in the western part of the stock coincides with the stockworks observed there. A few higher than average values occur just east of the stock in fractures on the east side of Red Hill, but generally all molybdenum values outside of the stock are 5 ppm or less. Higher

TABLE II

ARITHMETIC MEAN, STANDARD DEVIATION, AND THRESHOLD VALUES FOR THE PINE CREEK AREA

| | n[1] | Restrictive Range[2] | Arithmetic Mean[2] | Std. Dev.[2] | Threshold Value[2,3] |
|---|---|---|---|---|---|
| All Rock Types | | | | | |
| Copper | 145 | 200 | 17.21 | 22.20 | 61.61 |
| Molybdenum | 146 | 51 | 2.62 | 6.72 | 16.05 |
| Lead | 139 | 200 | 34.72 | 32.19 | 99.10 |
| Zinc | 128 | 150 | 50.72 | 35.77 | 122.27 |
| Pine Creek Stock[4] | | | | | |
| Copper | 22 | 200 | 13.91 | 10.65 | 35.22 |
| Molybdenum | 22 | 51 | 7.83 | 12.95 | 33.73 |
| Lead | 22 | 200 | 18.04 | 13.55 | 45.13 |
| Zinc | 22 | 150 | 20.65 | 11.21 | 43.07 |

[1] n varies due to restrictive range limitation.

[2] All values in parts per million.

[3] Calculated using the formula: Threshold = mean + 2 (std. dev.); from Hawkes and Webb (1962).

[4] Samples PC - 54, 56, 57, 58, 59, 61, 62, 63, 67, 68, 72, 73, 74, 137, 138, 139, 140, 141, 142, 144, 145, 146.

molybdenum values appear to correlate fairly well with areas containing higher amounts of sericite (compare with Figure 10).

## Lead

The Pine Creek stock is expressed as a negative lead anomaly, while positive anomalies occur outside of and partially encircle the stock (as shown on Table II by higher mean and threshold values calculated using all samples). Smaller anomalies are found associated with dikes and fractures along Red Hill. It is interesting to note that the western portion of the stock, which contains the highest molybdenum values, shows low lead values and only a weak anomaly outside the stock.

## Zinc

The distribution of zinc closely parallels that of lead, as shown on Table III by the high positive correlation between the two. The stock is conspicuously low, while significant anomalies exist just outside of it and along Red Hill. The zinc anomalies are generally somewhat more widespread than lead anomalies. Whether this due to its greater susceptibility to migrate under supergene conditions or to a slightly greater mobility under hydrothermal conditions is open to question.

## Copper

With only a few small exceptions the entire Pine Creek area, and particularly the stock, shows no significant enrichment of copper. Most of the values are about equal to or below the average copper content for granitic rocks (Vinogradov, 1962; Turekian and Wedepohl, 1961). The largest values occur in association with a felsite dike near the eastern edge of the map area which contained green copper oxide staining. Other anomalous values occur in or near fractures on Red Hill. It seems probable that the apparent lack of anomalous copper values in the Pine Creek area reflects initially low amounts of copper in the hydrothermal fluids which caused the lead, zinc, and molybdenum mineralization.

TABLE III

CORRELATION COEFFICIENTS CALCULATED USING
PINE CREEK AREA SAMPLES

| | Cu | Pb | Mo |
|---|---|---|---|
| Zn | -0.01 | 0.66 | 0.21 |
| Cu | -- | 0.01 | -0.03 |
| Pb | -- | -- | 0.17 |

Note: n = 146, therefore significant r at $P_{.05}$ = 0.225 (Neville and Kennedy, 1968).

## Gold Creek Stock Area

There have been at least two periods of mineralization in the Gold Creek area: one in Precambrian time that formed the vein-type deposits which were exploited by most of the major producing mines in the district; and a second period related to Tertiary intrusives in the area (Crawford and Worcester, 1916). The first period is related to Precambrian granitic intrusions. Pegmatite dikes and veinlets intruding the Precambrian metasediments also contain small amounts of mineralization, particularly molybdenite, which occurs in aggregates up to 2 inches in diameter near Lamphier Lakes about 2 miles north of the Gold Creek map area. This study is concerned with the mineralization associated with the intrusion of the Gold Creek stock, which is part of the second period of mineralization.

Visible mineralization attributable to hydrothermal events related to the Gold Creek stock includes mainly sphalerite, galena and pyrite which are found abundantly on the dumps of the Mutual #5 dump. Crawford and Worcester (1916) state that ore taken from these adits was "mostly silver-bearing galena and iron oxide with a little lead carbonate." Pyrite was also very common. This material reportedly came from near the contact of the stock with Precambrian gneiss and schist, where in Crawford's words "the porphyry is mineralized with crystals of pyrite and veinlets of galena for two to six feet from the contact." The ore averaged 3.5 oz. gold and 10 oz. silver per ton and 15 percent lead (Crawford and Worcester, 1916). A small amount of calcite was also reported. On the west side of Gold Creek an adit, which was part of the Sandy Hook Mine, was driven west into the center of the stock. According to Crawford and Worcester (1916) no well-defined vein was exposed and the ore, which was taken from "iron-stained streaks in the porphyry", assayed 2.54 oz. gold and 11.2 oz. silver per ton. In addition to the galena, pyrite and sphalerite observed on the mine dumps, occasional small isolated cubes and clusters of crystals of galena and also sphalerite, along with pyrite and pyrite casts are found disseminated throughout the stock.

The distribution of Cu, Mo, Pb, and Zn is shown on Figures 17B, 18B, 19B, and 20B, respectively. Major anomalies are generally confined to the stock, reflecting the relative impermeability of the Precambrian rocks surrounding the stock. Anomalies outside the stock are generally related to fracture-controlled Precambrian mineralization or to the thin pegmatite bands intruding the schists and gneisses. Near the stock, however, it is impossible to tell whether the values represent pre-existing mineralization or leakage outward from the stock. This uncertainty also causes difficulties when attempting to statistically treat the data. Tables IV and V include only samples from the stock since mixing samples which contain Precambrian mineralization with those containing mineralization related to the stock would only create confusion. The trace metal maps include samples from the stock and surrounding Precambrian rocks and the reader should be aware that at least two periods of mineralization are represented in these values. The following is a summary of trends shown by these trace metal maps.

Molybdenum

A low (10 - 15 ppm) widespread anomaly covers most of the western portion of the stock, while the eastern portion contains no significant amounts of molybdenum with the exception of one anomalous sample (50 ppm) taken near the contact in the Mutual #5 tunnel. Other anomalies outside the stock are generally related to the numerous thin veins of granitic pegmatite previously mentioned, or to fractures. As observed at Pine Creek, molybdenum within the stock seems to coincide with sericitized areas and lower lead-zinc values.

Lead-Zinc

A large lead-zinc anomaly occurs covering the eastern part of the stock, particularly along the contact and around a fault just east of the contact. A smaller anomaly occurs in the western part of the stock and along a large fracture to the north. Whether the mineralization found in this fracture is associated with the stock or is Precambrian is open to question. Specimens of sphalerite found in it are a resinous pale yellow, in contrast to the darker varieties reported in other areas in the Gold Brick district by Crawford and Worcester (1916). Overall,

TABLE IV

ARITHMETIC MEAN, STANDARD DEVIATION, AND THRESHOLD VALUES FOR THE GOLD CREEK STOCK[1]

| | n[2] | Restrictive Range[3] | Arithmetic Mean[3] | Std. Dev.[3] | Threshold Value[3,4] |
|---|---|---|---|---|---|
| Copper | 37 | 200 | 44.85 | 42.31 | 129.46 |
| Molybdenum | 37 | 51 | 3.97 | 4.73 | 13.43 |
| Lead | 31 | 400 | 122.17 | 87.20 | 296.57 |
| Zinc | 31 | 400 | 146.83 | 109.99 | 366.81 |

[1]Samples GC - 1, 2, 3, 5, 6, 8, 9, 13, 14, 15, 27, 31, 32, 33, 35, 36, 38, 39, 40, 41, 42, 52, 53, 59, 60, 65, 66, 67, 68, 69, 70, 71, 72, 73, 75, 99, 100, 101, 102.

[2]n varies due to restrictive range limitation.

[3]All values in parts per million.

[4]Calculated using the formula: Threshold = mean + 2 (std. dev.); from Hawkes and Webb (1962).

TABLE V

CORRELATION COEFFICIENTS CALCULATED USING SAMPLES FROM THE GOLD CREEK STOCK

| | Cu | Pb | Mo |
|---|---|---|---|
| Zn | 0.39 | 0.89 | -0.09 |
| Cu | -- | 0.62 | -0.06 |
| Pb | -- | -- | -0.08 |

Note: n = 39, therefore significant r at $P_{.05}$ = 0.419 (Neville and Kennedy, 1968).

however, the lead-zinc distribution is confined to the stock, again reflecting the relative impermeability of the Precambrian country rock.

### Copper

Copper shows a distribution similar to that of lead and zinc (Table V), but the anomalies are more restricted--almost completely confined to a narrow band along the western contact--and of lower intensity.

## Tellurium Creek Stock Area

Since the Tellurium Creek stock is exposed at such a high level in the intrusive system only minor amounts of visible mineralization are present and the trace metal anomalies occur mainly in areas which allowed upward leakage of hydrothermal fluids, such as pebble dikes, fractures, brecciated areas, and along stock contacts. Thus the trace metals do not show a well-defined zonal distribution, but instead the anomalies are all found in basically the same areas (as shown by the generally high correlation coefficients on Table VII) although some are more restricted than others.

Visible mineralization includes abundant pyrite disseminated throughout the stock and in veinlets formed in small fractures, and small amounts of galena, sphalerite, barite, and copper oxide staining found mainly in fractures in the volcanics south of the stock and near the large felsite porphyry dike north of the stock. Barite occurrences were also noted in fractures within the stock.

Figures 17A, 18A, 19A, and 20A show the trace metal distributions observed for copper, molybdenum, lead and zinc respectively. Although, as mentioned, the patterns are all basically similar, some discussion is warranted.

### Molybdenum

Molybdenum anomalies all occur outside the stock (as shown on Table VI by the low mean and threshold values for samples within the

TABLE VI

ARITHMETIC MEAN, STANDARD DEVIATION, AND THRESHOLD VALUES FOR THE TELLURIUM CREEK AREA

| | n[1] | Restrictive Range[2] | Arithmetic Mean[2] | Std. Dev.[2] | Threshold Value[2,3] |
|---|---|---|---|---|---|
| <u>All Rock Types</u> | | | | | |
| Copper | 42 | 175 | 46.82 | 44.66 | 136.14 |
| Molybdenum | 42 | 51 | 4.66 | 9.79 | 24.24 |
| Lead | 39 | 150 | 43.29 | 26.61 | 96.52 |
| Zinc | 39 | 400 | 131.51 | 104.16 | 339.83 |
| <u>Tellurium Creek Stock</u>[4] | | | | | |
| Copper | 10 | 175 | 60.90 | 42.92 | 146.75 |
| Molybdenum | 10 | 51 | 0.50 | 1.58 | 3.66 |
| Lead | 9 | 150 | 55.00 | 42.42 | 139.85 |
| Zinc | 10 | 400 | 121.50 | 108.65 | 338.81 |

[1] n varies due to restrictive range limitation.

[2] All values in parts per million.

[3] Calculated using the formula: Threshold = mean + 2 (std. dev.); from Hawkes and Webb (1962).

[4] Samples TC - 9, 11, 14, 30, 31, 32, 33, 34, 35, 43.

TABLE VII

CORRELATION COEFFICIENTS CALCULATED USING TELLURIUM CREEK AREA SAMPLES

| | Cu | Pb | Mo |
|---|---|---|---|
| Zn | 0.77 | 0.95 | 0.17 |
| Cu | -- | 0.76 | 0.31 |
| Pb | -- | -- | 0.22 |

Note: n = 43, therefore significant r at $P_{.05}$ = 0.397 (Neville and Kennedy, 1968).

stock), mainly in fractures and pebble dikes, which allowed easier passage of hydrothermal solutions. The anomalies are very limited in extent. It is interesting to note that molybdenum values (Table VII) do not correlate with lead, zinc, or copper values. The reasons for this cannot be completely explained from the evidence available, however it may reflect the different conditions under which these elements are precipitated or possibly indicate two pulses of mineralization.

## Lead-Zinc

Lead and zinc anomalies are found mainly in or near fractures, pebble dikes, or brecciated areas. The highest values occur in a small prospect pit near the felsite dike-volcanics contact north of the stock. At this location a considerable amount of fracturing has taken place in the volcanics, and since the dike shows lower trace metal values elsewhere along its length, it appears that the mineralization represents leakage from the stock along the fractures rather than mineralization related to the dike itself. Anomalous lead and zinc values also occur to a limited extent within the stock (zinc more so than lead) while molybdenum generally does not. (Mean and threshold values for lead and zinc are somewhat misleading in this case due to the small number of samples from within the stock.) Zinc anomalies are somewhat greater in extent than lead, and lead anomalies greater in extent than those of molybdenum. This probably reflects the relatively lower mobility of molybdenum under hydrothermal conditions and either the relatively higher susceptibility of zinc to supergene transport or a higher mobility under hydrothermal conditions.

## Copper

Copper is found in basically the same places as lead and zinc as shown by the relatively high correlation between copper and lead, and copper and zinc on Table VII.

# CHAPTER VI

# COMPARISON AND CONCLUSIONS

One of the major purposes of this thesis is to attempt a comparison of the trace metal geochemistry and hydrothermal alteration of the three study areas on the assumption that they might represent different levels of exposure in intrusive systems which are similar enough that changes observed in trace metal distribution and alteration patterns might bring to light trends likely to develop in a single molybdenum-bearing system. Obviously, one major difficulty inherent to a comparison of this type lies in the fact that each study area represents a single, separate intrusive system with some characteristics not shared by the other two. Differentiating between those characteristics which are unique to an individual system and those which represent differences due to exposure level is difficult and in some cases impossible. The study is further limited in that only surface data were available for examination. Any changes with depth in each of the study areas remain unknown, and the existence of higher concentrations of molybdenum at depth is unproven. Nevertheless, comparison of the three study areas to each other and to published data from major stockwork molybdenum deposits leads to some interesting speculations.

## Comparison of the Pine Creek, Gold Creek, and Tellurium Creek Stocks and Major Stockwork Molybdenum Deposits

The Pine Creek, Gold Creek, and Tellurium Creek stocks are similar in that they are all thought to be mid-Tertiary in age and occur in the central part of the Colorado mineral belt. They have all undergone hydrothermal alteration and have anomalous amounts of molybdenum associated with them.

The Pine Creek and Tellurium Creek stocks occur in very similar geologic environments: both intrude the Grizzly Peak Volcanics and may be related to the Grizzly Peak cauldron complex. The Gold Creek stock, however, intrudes regionally metamorphosed Precambrian rocks and has no apparent relation to a caldera.

Compositionally the three stocks are different. The Tellurium Creek stock appears to be rhyolitic, the Gold Creek stock is probably in the rhyolite to quartz latite range, and the Pine Creek stock is primarily granodiorite with a later quartz-latite phase. All of these rocks are porphyritic and quartz phenocrysts in them are corroded and embayed. A review of host intrusives of major stockwork molybdenum deposits reveals that they are generally oversaturated in silica, ranging from granodiorite to granite in composition (Clark, 1972). They are nearly always porphyritic, and embayed or resorbed quartz phenocrysts are reported at Questa, New Mexico (Carpenter, 1968) and Urad-Henderson (MacKenzie, 1970). The Climax and Urad-Henderson deposits, which are located in the Colorado mineral belt northeast of the study areas, and the Questa deposit are associated with rocks of granite composition. Overall, there seems to be a positive correlation between stockwork molybdenum deposits and rocks high in silica and potassium (Clark, 1972), and many deposits occur in stocks of a multiple intrusive nature.

## Hydrothermal Alteration

A comparison of the hydrothermal alteration of the Pine Creek, Gold Creek, and Tellurium Creek stocks show that in terms of hydrogen metasomatism the intensity of alteration decreases from the Pine Creek stock to the Gold Creek stock to the Tellurium Creek stock. This suggests that the stocks are exposed at different levels in the intrusive systems: the Tellurium Creek stock at a high level; the Gold Creek stock at an intermediate level; and the Pine Creek stock at the lowest level of the three. The most complete sequence known of hydrothermal alteration associated with stockwork molybdenum deposits is exhibited by the Henderson deposit. Characteristic mineral assemblages recognized by MacKenzie (1970) include, in order of increasing depth: (1) a widespread propylitic zone, (2) an intermediate argillic zone of kaolinite and montmorillonite, (3) a quartz-sericite-pyrite zone, (4) a quartz-topaz and high silica zone, (5) a zone of potassic alteration characterized by secondary potassium feldspar and biotite, which roughly coincides with the ore zone, and (6) a lower greisen zone. Alteration reported at other major deposits is similar, although rarely as well developed. At Climax multiple intrusion has caused overlapping and repetition of alteration zones. Potassic alteration is generally coincident with the ore zones and quartz-topaz-sericite, high silica, and argillic zones are recognized, but propylitic alteration is for the most part lacking due to the removal of the upper portion of the intrusive complex (Wallace et al, 1968). Potassic alteration, mainly in the form of secondary biotite, and widespread propylitic alteration are displayed at Questa, with quartz-sericite and kaolinite halos developed near veins (Carpenter, 1968). At the Endako deposit, British Columbia, potassic and quartz-sericite-pyrite envelopes are developed around veins, with argillic alteration present as pervasive kaolinization (Drummond and Kimura, 1969). The deposit at Alice Arm, British Columbia, is accompanied by quartz-orthoclase and quartz-sericite alteration assemblages with lesser amounts of kaolinite (Woodcock et al, 1966). Similar types of alteration are reported for Russian stockwork molybdenum deposits (Kruglova et al, 1965).

The Pine Creek, Gold Creek, and Tellurium Creek stocks exhibit alteration equivalent to the argillic and propylitic assemblages and thus all three would be exposed at levels above any possible molybdenum mineralization. The alteration pattern developed in the Pine Creek area departs somewhat from the general pattern displayed at Henderson since it appears to be developed laterally and possibly not as well developed vertically, probably due to local structure. At Gold Creek alteration is confined to the stock, probably because of the relatively impermeable country rock, and so a vertically-developed pattern would be expected. The Tellurium Creek system also appears to have developed vertically with only relatively minor alteration occurring outside the stock.

Mineralization and Trace-Metal Geochemistry

Molybdenite is charcteristically the only ore mineral recovered from most stockwork molybdenum deposits, with the exception of cassiterite and huebnerite which are by-products at Climax (Clark, 1972). Pyrite is the most common and abundant sulfide mineral in most of the deposits, with chalcopyrite, sphalerite, galena and pyrrhotite occurring in lesser amounts (Clark, 1972). Magnetite is also frequently reported.

Zonal distribution of these associated minerals is somewhat variable from deposit to deposit. At both the Henderson and Climax deposits (and others) a zone high in pyrite is found above and peripheral to the ore zone (MacKenzie, 1970; Wallace et al, 1968). At Henderson and also at the Rialto stock, New Mexico, a magnetite zone occurs immediately above and peripheral to the molybdenite zone (MacKenzie, 1970; Thompson, 1968). At Climax overlying zones of tungsten accompany each ore body (Wallace et al, 1968). A peripheral zone of lead-zinc mineralization has been reported at the Rialto stock by Thompson (1968) and a similar crude Base Metal Zone reported at Hudson Bay Mountain by Jonson et al (1968). Kruglova (1965) reports vertical and horizontal zoning ascribed to different stages of mineralization in a stockwork molybdenum deposit in the USSR. A tendency for molybdenum to occupy the central core and for pyrite to form a fringing halo has been reported for porphyry deposits of the Pacific northwest (Field et al, 1973).

Complete trace metal data from most stockwork molybdenum deposits has generally not been published. Tauson and Petrovskaya (1970) studied the distribution of molybdenum, lead, zinc, copper and mercury associated with hydrothermal molybdenum deposits in Eastern Transbaykalia, USSR, and observed that upward and outward from the ore veins the concentrations of these elements decrease in the following order: Mo-Pb-Zn-Cu-Hg. Data from the Pine Creek, Gold Creek, and Tellurium Creek stocks suggest a similar trend.

At the Tellurium Creek "level" copper, lead, zinc, and molybdenum anomalies are generally limited to permeable areas such as fractures, brecciated areas, pebble dikes, and dike and stock contacts which allowed upward leakage of metal-bearing fluids. Molybdenum anomalies especially tend to be restricted in extent.

At the Gold Creek "level" higher and more widespread anomalies are present. Anomalies are for the most part restricted to the stock probably due to the relatively impermeable country rock. The stock contacts apparently provided the least resistance to upward movement of fluids and thus lead, zinc, and copper anomalies are highest there. It is interesting to note that molybdenum anomalies seem to show a tendency to occur in areas somewhat lower in lead and zinc (Figures 18, 19, and 20).

At the Pine Creek "level" molybdenum anomalies are generally confined to the stock, while lead and zinc anomalies occur just beyond the stock contacts. Again there seems to be a tendency for molybdenum to occur in areas lower in lead and zinc. Copper values at Pine Creek are low and eratically distributed.

If the assumption is made that the total metal content of the three intrusive systems is of a similar magnitude, comparison of the threshold values and arithmetic means calculated for the three areas (Table VIII) leads to some interesting speculations. Within the stock, the Tellurium Creek "level" is lowest in molybdenum, intermediate in lead and zinc, and highest in copper. The Gold Creek "level" is intermediate in molybdenum and copper and highest in lead and zinc. The Pine Creek "level" is highest in molybdenum and lowest in lead, zinc, and copper. This gives rise to the speculation that in a single molybdenum-bearing system the amount of molybdenum would tend to increase with depth and that it would be likely to find a zone high in lead and zinc above (as at Gold Creek?) and peripheral (as at Pine Creek) to a zone high in molybdenum. Correlation coefficients (Table IX) calculated using values from all three stocks together somewhat substantiate this trend, showing low negative correlations between molybdenum and zinc, and molybdenum and lead. Copper values show a decrease from the Tellurium Creek "level" to the Pine Creek "level" possibly suggesting a decrease in copper with depth. Copper correlates negatively with molybdenum (Table IX).

TABLE VIII

COMPARISON OF MEAN AND THRESHOLD VALUES FROM THE TELLURIUM CREEK, GOLD CREEK, AND PINE CREEK STOCKS[1]

| | Cu | | Mo | | Pb | | Zn | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Threshold | Mean | Threshold | Mean | Threshold | Mean | Threshold |
| Tellurium Creek Stock | 60.90 | 146.75 | 0.50 | 3.66 | 55.00 | 139.85 | 121.50 | 338.81 |
| Gold Creek Stock | 44.85 | 129.46 | 3.97 | 13.43 | 122.17 | 296.57 | 146.83 | 366.81 |
| Pine Creek Stock | 13.91 | 35.22 | 7.83 | 33.73 | 18.04 | 45.13 | 20.65 | 43.07 |

[1]All values in parts per million.

TABLE IX

CORRELATION COEFFICIENTS CALCULATED USING SAMPLES FROM ALL THREE STOCKS

| | Cu | Pb | Mo |
|---|---|---|---|
| Zn | 0.30 | 0.23 | -0.35 |
| Cu | -- | -0.05 | -0.32 |
| Pb | -- | -- | -0.10 |

Note: $n = 70$, therefore significant $r$ at $P_{.05} = 0.324$ (Neville and Kennedy, 1968).

## Conclusions

Figure 21 diagrammatically summarizes some of the important characteristics reported from major stockwork molybdenum deposits along with the data generated by this study. The position of mineralized zones and trace metal patterns likely to occur are shown in order of increasing depth and/or temperature and in relation to zones of hydrothermal alteration. Scales used on this diagram are generalized and are intended to show maximum probable amounts of the indicated mineralization and trace elements.

In a typical stockwork molybdenum deposit the intensity of hydrothermal alteration increases downward toward the ore zone (as at Henderson and Climax). In the propylitic zone low lead, zinc, molybdenum, and possibly copper anomalies are found in the related intrusive. Higher anomalies are likely near contacts, and in pebble dikes, fractures, and brecciated areas. Small veinlets weakly mineralized with galena, sphalerite, calcite and barite are common. Moderate amounts of pyrite would also be expected.

Lead and zinc anomalies increase markedly within the intermediate argillic zone, along with a slight increase in molybdenum values, particularly along contacts, in pebble dikes, or in stockwork veinlets. Molybdenum values gradually increase with depth, while lead and zinc values gradually decrease.

In the sericitc zone molybdenum values continue increasing, while lead and zinc values are greatly decreased. In the lower part of this zone fringing halos of pyrite, tungsten and possibly tin may occur. A magnetite zone has also been noted at several major deposits coinciding with the outer part of the ore zone and extending above it.

The $MoS_2$ ore zone coincides with the potassic alteration zone. Below this, greisen-type alteration occurs at Henderson and Climax (MacKenzie, 1970; Wallace et al, 1968). Some weak lead and zinc mineralization is reported from this zone. Fluorite is ubiquitous at Questa, Climax and Henderson.

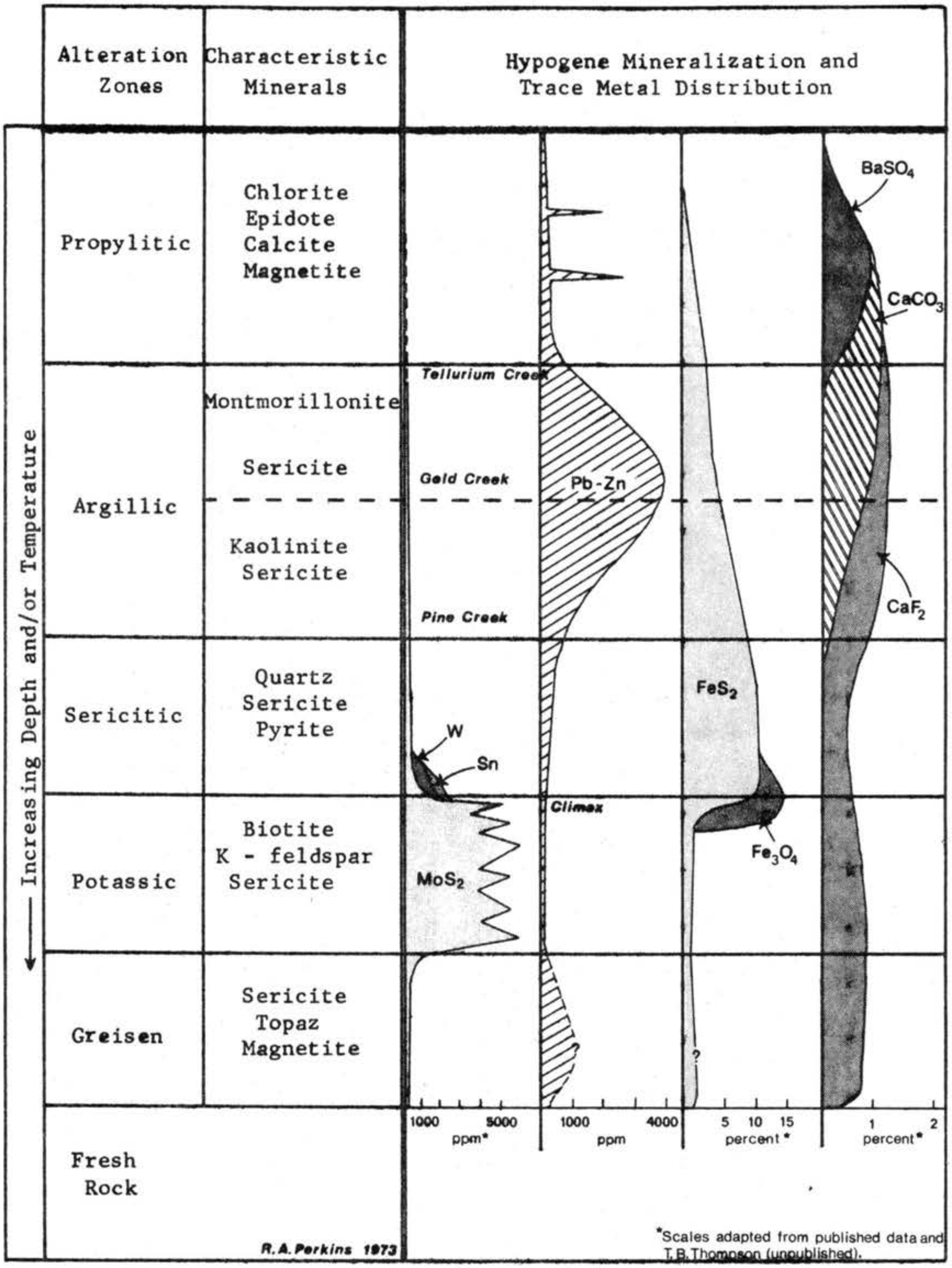


Figure 21. Diagrammatic summary of hydrothermal alteration, trace metal distribution and mineralization of stockwork molybdenum deposits.

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# APPENDIX

# SAMPLE PREPARATION, ANALYTICAL PROCEDURES AND TRACE ELEMENT ANALYSES

## Sample Preparation

The rock chip samples were crushed in a jaw crusher and then pulverized using a Spex ball mill to a grain size of approximately 80 mesh or less.

## Analytical Procedures

A 1.0 gram portion of each sample was placed in a 100 ml teflon beaker and approximately 30 ml of concentrated hydrofluoric acid and 10 ml of concentrated nitric acid were added. The solution was allowed to stand overnight. Next, 2 ml of 70 percent perchloric acid were added and the samples were heated until fuming ceased. The samples were then dissolved in appxoximately 1 ml of distilled water and 10 ml of concentrated hydrochloric acid. This solution was brought to boil and when all solids were dissolved approximately 25 ml of distilled water was added slowly. The solution was allowed to continue boiling until clear. The samples were allowed to cool and then were transferred to a 50 ml volumetric flask and diluted to 50 ml with distilled water. The solutions were next transferred to polyethelene bottles.

The samples were analyzed using a Perkin-Elmer 403 double-beam atomic absorption spectrophotometer with digital readout. Copper, lead and zinc contents were analyzed using an air-acetylene flame. A nitrous oxide-acetylene flame was used for molybdenum analysis. The samples were analyzed at the instrument settings recommended for standard analysis by the instrument manufacturer as shown in Table X.

TABLE X

RECOMMENDED INSTRUMENT SETTINGS FOR
STANDARD ELEMENT ANALYSIS

| Element | Range | Wavelength in Å | Slit | Current Lamp (MA) | Oxidant-fuel flow |
|---|---|---|---|---|---|
| Cu | UV | 3247 | 4 | 30 | oxidizing |
| Mo* | UV | 3133 | 4 | 40 | reducing |
| Pb | UV | 2833 | 4 | 10 | oxidizing |
| Zn | UV | 2139 | 4 | 20 | oxidizing |

*nitrous oxide-acetylene flame used

TABLE XI

TRACE ELEMENT ANALYSES

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| PC - 1 | 10 | -5 | 50 | 145 |
| PC - 2 | 10 | -5 | 75 | 225 |
| PC - 3 | 20 | -5 | 25 | 50 |
| PC - 4 | 5 | -5 | 25 | 50 |
| PC - 5 | 5 | -5 | 50 | 75 |
| PC - 6 | 10 | -5 | 60 | 220 |
| PC - 7 | 5 | -5 | 35 | 45 |
| PC - 8 | 10 | -5 | 80 | 70 |
| PC - 9 | 5 | -5 | 50 | 80 |
| PC - 10 | 5 | -5 | 10 | 15 |
| PC - 11 | 10 | 5 | 55 | 265 |
| PC - 12 | 5 | -5 | 20 | 55 |
| PC - 13 | 5 | -5 | 25 | 90 |
| PC - 14 | 5 | -5 | 25 | 105 |
| PC - 15 | 5 | -5 | 30 | 80 |
| PC - 16 | 10 | -5 | 35 | 70 |
| PC - 17 | 5 | -5 | 30 | 50 |
| PC - 18 | 5 | -5 | 85 | 190 |
| PC - 19 | 30 | -5 | 5 | 80 |
| PC - 20 | 5 | 5 | 40 | 70 |
| PC - 21 | 10 | 5 | 25 | 30 |
| PC - 22 | 5 | -5 | 180 | 165 |
| PC - 23 | 10 | -5 | 35 | 55 |
| PC - 24 | 30 | 5 | 250 | 380 |
| PC - 25 | 10 | -5 | 40 | 120 |
| PC - 26 | 10 | -5 | 55 | 670 |
| PC - 27 | 10 | 5 | 40 | 80 |
| PC - 28 | 5 | -5 | 80 | 30 |
| PC - 29 | 5 | 5 | 30 | 125 |
| PC - 30 | 5 | -5 | 35 | 50 |
| PC - 31[3] | 5 | -5 | 205 | 365 |
| PC - 31 I[3] | 5 | -5 | 195 | 350 |
| PC - 31 II[3] | 5 | -5 | 215 | 355 |
| PC - 32 | 5 | -5 | 40 | 45 |
| PC - 33 | 20 | -5 | 130 | 305 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| PC - 34 | 10 | 5 | 30 | 80 |
| PC - 35 | 10 | -5 | 25 | 35 |
| PC - 36 | 20 | -5 | 15 | 50 |
| PC - 37 | 55 | -5 | 100 | 80 |
| PC - 38 | 50 | 5 | 25 | 55 |
| PC - 39 | 10 | -5 | 10 | 10 |
| PC - 40 | 15 | -5 | 85 | 180 |
| PC - 41 | 5 | -5 | 25 | 155 |
| PC - 42 | 10 | -5 | 25 | 145 |
| PC - 43 | 5 | -5 | 35 | 60 |
| PC - 44 | 10 | -5 | 25 | 105 |
| PC - 45 | 5 | -5 | 20 | 45 |
| PC - 46 | 10 | 5 | 35 | 145 |
| PC - 47 | 5 | -5 | 25 | 51 |
| PC - 48 | 5 | -5 | 15 | 40 |
| PC - 49 | 15 | -5 | 10 | 25 |
| PC - 50 | 5 | -5 | 15 | 40 |
| PC - 51 | 10 | -5 | 10 | 15 |
| PC - 52 | 25 | -5 | 5 | 25 |
| PC - 53 | 30 | 5 | 20 | 45 |
| PC - 54 | 15 | 15 | 25 | 25 |
| PC - 55 | 10 | -5 | 10 | 20 |
| PC - 56 | 5 | -5 | 5 | 15 |
| PC - 57 | 10 | 15 | 15 | 20 |
| PC - 58 | 55 | 10 | 45 | 40 |
| PC - 59 | 5 | -5 | -5 | 15 |
| PC - 60 | 5 | -5 | 15 | 15 |
| PC - 61 | 30 | -5 | 30 | 25 |
| PC - 62 | 15 | -5 | 50 | 60 |
| PC - 63 | 5 | -5 | 5 | 25 |
| PC - 64 | 25 | 5 | 1,025 | 60 |
| PC - 65 | 145 | 25 | 1,074 | 2,199 |
| PC - 66 | 30 | -5 | 190 | 255 |
| PC - 67 | 15 | 40 | 10 | 10 |
| PC - 68 | 10 | 10 | 20 | 15 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| PC - 69 | 10 | -5 | 60 | 115 |
| PC - 70 | 5 | -5 | 45 | 210 |
| PC - 71 | 5 | -5 | 40 | 60 |
| PC - 72 | 10 | 10 | 5 | 15 |
| PC - 73 | 10 | -5 | 5 | 15 |
| PC - 74 | 10 | -5 | 20 | 20 |
| PC - 75 | 5 | -5 | 40 | 20 |
| PC - 76 | 10 | -5 | 35 | 30 |
| PC - 77 | 15 | -5 | 30 | 25 |
| PC - 78 | 20 | -5 | 50 | 40 |
| PC - 79 | 15 | 5 | 50 | 40 |
| PC - 80 | 5 | -5 | 50 | 105 |
| PC - 81 | 10 | -5 | 50 | 50 |
| PC - 82 | 10 | -5 | 30 | 320 |
| PC - 83 | 15 | -5 | 25 | 15 |
| PC - 84 | 10 | -5 | 30 | 35 |
| PC - 85 | 15 | 5 | 35 | 125 |
| PC - 86 | 5 | -5 | 40 | 40 |
| PC - 87 | 20 | 5 | 30 | 60 |
| PC - 88 | 5 | -5 | 40 | 45 |
| PC - 89 | 20 | -5 | 50 | 50 |
| PC - 90 | 20 | -5 | 75 | 40 |
| PC - 91 | 5 | -5 | 30 | 35 |
| PC - 92 | 5 | 5 | 15 | 40 |
| PC - 93 | 10 | -5 | 30 | 25 |
| PC - 94 | 20 | -5 | 15 | 45 |
| PC - 95 | 20 | 5 | 15 | 405 |
| PC - 96 | 20 | 10 | 20 | 145 |
| PC - 97[3] | 10 | -5 | 15 | 90 |
| PC - 97 I[3] | 10 | -5 | 25 | 95 |
| PC - 97 II[3] | 10 | -5 | 25 | 95 |
| PC - 98 | 5 | -5 | 30 | 15 |
| PC - 99 | 5 | -5 | 30 | 90 |
| PC - 100 | 60 | 5 | 75 | 70 |
| PC - 101 | 15 | 5 | 25 | 90 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| PC - 102 | 20 | -5 | 25 | 45 |
| PC - 103 | 45 | -5 | 25 | 210 |
| PC - 104 | 15 | 5 | 20 | 30 |
| PC - 105 | 155 | 5 | 165 | 125 |
| PC - 106 | 30 | -5 | 35 | 45 |
| PC - 107 | 20 | -5 | 25 | 45 |
| PC - 108 | 10 | -5 | 15 | 15 |
| PC - 109 | 25 | 10 | 30 | 45 |
| PC - 110 | 95 | -5 | 25 | 75 |
| PC - 111 | 5 | 10 | 10 | 60 |
| PC - 112 | 5 | -5 | 35 | 10 |
| PC - 113 | 5 | -5 | 20 | 50 |
| PC - 114 | 805 | -5 | 20 | 35 |
| PC - 115 | 70 | 15 | 15 | 130 |
| PC - 116 | 35 | -5 | 15 | 90 |
| PC - 117 | 10 | -5 | 15 | 60 |
| PC - 118 | 10 | 5 | 25 | 95 |
| PC - 119 | 5 | -5 | 35 | 95 |
| PC - 120 | 15 | 5 | 25 | 60 |
| PC - 121 | 20 | -5 | 35 | 20 |
| PC - 122 | 10 | -5 | 15 | 20 |
| PC - 123 | 15 | -5 | 15 | 20 |
| PC - 124 | 10 | -5 | 5 | 15 |
| PC - 125 | 15 | -5 | 25 | 20 |
| PC - 126 | 20 | -5 | 50 | 15 |
| PC - 127 | 30 | -5 | 50 | 80 |
| PC - 128[4] | | | | |
| PC - 129 | 5 | -5 | 35 | 35 |
| PC - 130 | 70 | -5 | 40 | 55 |
| PC - 131 | 5 | -5 | 20 | 15 |
| PC - 132 | 100 | -5 | 280 | 15 |
| PC - 133[4] | | | | |
| PC - 134 | 15 | -5 | 15 | 15 |
| PC - 135 | 45 | -5 | 20 | 25 |
| PC - 136 | 10 | -5 | 10 | 5 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| PC - 137 | 10 | -5 | 30 | 15 |
| PC - 138 | 10 | -5 | 15 | 10 |
| PC - 139 | 10 | 5 | 40 | 30 |
| PC - 140 | 20 | 10 | 15 | 20 |
| PC - 141 | 10 | 30 | 40 | 35 |
| PC - 142 | 20 | 50 | 25 | 15 |
| PC - 143 | 10 | 5 | 10 | 30 |
| PC - 144[3] | 10 | -5 | 15 | 20 |
| PC - 144 I[3] | 10 | -5 | 10 | 25 |
| PC - 144 II[3] | 10 | 5 | 15 | 20 |
| PC - 145 | 15 | -5 | 5 | 10 |
| PC - 146 | 15 | 10 | 10 | 10 |
| PC - 147 | 20 | -5 | 330 | 150 |
| GC - 1 | 15 | 10 | 90 | 135 |
| GC - 2 | 75 | 10 | 740 | 1,200 |
| GC - 3 | 10 | 15 | 60 | 50 |
| GC - 4 | 10 | 10 | 20 | 70 |
| GC - 5 | 10 | 5 | 345 | 300 |
| GC - 6 | 20 | 5 | 150 | 260 |
| GC - 7 | 30 | 5 | 20 | 235 |
| GC - 8 | 75 | 10 | 50 | 30 |
| GC - 9[3] | 65 | 5 | 50 | 35 |
| GC - 9 I[3] | 65 | -5 | 50 | 35 |
| GC - 9 II[3] | 65 | 5 | 55 | 35 |
| GC - 10 | 130 | 15 | 35 | 135 |
| GC - 11 | 95 | 10 | 30 | 125 |
| GC - 12 | 150 | 15 | 25 | 170 |
| GC - 13 | 95 | 10 | 120 | 105 |
| GC - 14 | 10 | 10 | 50 | 70 |
| GC - 15 | 10 | 15 | 120 | 115 |
| GC - 16 | 10 | 15 | 40 | 85 |
| GC - 17 | 40 | 15 | 20 | 55 |
| GC - 18 | 10 | -5 | 20 | 115 |
| GC - 19 | 10 | 10 | 15 | 110 |
| GC - 20 | 10 | 15 | 170 | 45 |
| GC - 21 | 150 | -5 | 350 | 210 |
| GC - 22 | 30 | -5 | 10,741 | 80 |
| GC - 23 | 40 | -5 | 30 | 105 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| GC - 24 | 70 | 5 | 210 | 375 |
| GC - 25 | 5 | -5 | 35 | 90 |
| GC - 26 | 45 | -5 | 15 | 30 |
| GC - 27 | 10 | 5 | 135 | 290 |
| GC - 28 | 10 | 10 | 25 | 85 |
| GC - 29 | 40 | 10 | 315 | 210 |
| GC - 30 | 40 | -5 | 50 | 125 |
| GC - 31 | 165 | -5 | 160 | 240 |
| GC - 32 | 10 | 5 | 105 | 80 |
| GC - 33 | 30 | -5 | 1,725 | 845 |
| GC - 34 | 100 | -5 | 50 | 135 |
| GC - 35 | 20 | -5 | 645 | 1,700 |
| GC - 36 | 420 | 5 | 1,700 | 1,700 |
| GC - 37 a[5] | 140 | -5 | 5,101 | 200 |
| GC - 37 b[5] | 1,975 | 15 | 21,254 | 640 |
| GC - 38 | 30 | 10 | 40 | 300 |
| GC - 39 | 145 | -5 | 170 | 285 |
| GC - 40 | 60 | -5 | 340 | 105 |
| GC - 41 | 35 | -5 | 130 | 155 |
| GC - 42 | 135 | -5 | 65 | 40 |
| GC - 43 | 40 | 5 | 35 | 120 |
| GC - 44 | 40 | 10 | 10 | 65 |
| GC - 45 | 35 | -5 | 20 | 40 |
| GC - 46 | 65 | -5 | 35 | 120 |
| GC - 47 | 30 | -5 | 50 | 135 |
| GC - 48 | 70 | -5 | 35 | 120 |
| GC - 49 | 70 | -5 | 40 | 165 |
| GC - 50 | 25 | 10 | 20 | 45 |
| GC - 51 | 15 | -5 | 15 | 70 |
| GC - 52 | 120 | 5 | 3,075 | 3,400 |
| GC - 53 | 15 | -5 | 120 | 180 |
| GC - 54 | 115 | -5 | 480 | 170 |
| GC - 55 | 10 | -5 | 35 | 175 |
| GC - 56 | 5 | -5 | 15 | 120 |
| GC - 57 | 20 | -5 | 25 | 360 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| GC - 58 | 5 | -5 | 25 | 145 |
| GC - 59 | 25 | -5 | 395 | 150 |
| GC - 60 | 220 | -5 | 2,175 | 7,000 |
| GC - 61 | 5 | -5 | 5 | 20 |
| GC - 62 | 5 | -5 | 5 | 10 |
| GC - 63 | 5 | -5 | 25 | 40 |
| GC - 64 | 115 | -5 | 20 | 220 |
| GC - 65[3] | 45 | -5 | 85 | 75 |
| GC - 65 I[3] | 40 | -5 | 95 | 70 |
| GC - 65 II[3] | 40 | -5 | 90 | 75 |
| GC - 66 | 10 | -5 | 245 | 130 |
| GC - 67 | 10 | -5 | 175 | 315 |
| GC - 68 | 10 | -5 | 50 | 165 |
| GC - 69 | 30 | -5 | 1,126 | 1,801 |
| GC - 70 | 20 | -5 | 70 | 385 |
| GC - 71 | 25 | -5 | 195 | 140 |
| GC - 72 | 40 | -5 | 20 | 25 |
| GC - 73 | 45 | -5 | 290 | 25 |
| GC - 74 | 445 | -5 | 5 | 160 |
| GC - 75 | 10 | 1,025 | 80 | 35 |
| GC - 76 | 30 | 15 | 25 | 150 |
| GC - 77 | 5 | -5 | 25 | 75 |
| GC - 78 | 10 | 10 | 15 | 100 |
| GC - 79 | 30 | 15 | 15 | 50 |
| GC - 80 | 80 | 5 | 20 | 160 |
| GC - 81 | 195 | -5 | 25 | 140 |
| GC - 82 | 70 | 15 | 15 | 135 |
| GC - 83 | 70 | 5 | 30 | 160 |
| GC - 84 | 3,301 | 10 | 85 | 150 |
| GC - 85 | 45 | -5 | 20 | 70 |
| GC - 86 | 45 | -5 | 485 | 385 |
| GC - 87 | 155 | -5 | 110 | 315 |
| GC - 88 | 105 | 10 | 280 | 205 |
| GC - 89 | 10 | -5 | 15 | 20 |
| GC - 90 | 85 | -5 | 25 | 85 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| GC - 91 | 75 | -5 | -5 | 65 |
| GC - 92 | 115 | 5 | 60 | 150 |
| GC - 93 | 15 | -5 | -5 | 95 |
| GC - 94 | 5 | 10 | 10 | 50 |
| GC - 95 | 35 | -5 | 75 | 250 |
| GC - 96 | 30 | -5 | 90 | 355 |
| GC - 97 | 5 | 10 | 15 | 60 |
| GC - 98 | 105 | 75 | 1,275 | 25,503 |
| GC - 99 | 5 | 5 | 25 | 55 |
| GC - 100 | 100 | 5 | 90 | 315 |
| GC - 101 | 10 | -5 | 35 | 20 |
| GC - 102 | 55 | 50 | 825 | 1,401 |
| TC - 1 | 40 | 5 | 35 | 110 |
| TC - 2 | 85 | -5 | 20 | 175 |
| TC - 3 | 20 | -5 | 40 | 75 |
| TC - 4 | 135 | 10 | 45 | 70 |
| TC - 5 | 51 | 5 | 35 | 294 |
| TC - 6 | 25 | 40 | 50 | 45 |
| TC - 7 | 75 | -5 | 30 | 50 |
| TC - 8 | 25 | -5 | 40 | 80 |
| TC - 9 | 140 | -5 | 20 | 65 |
| TC - 10[3] | 10 | -5 | 25 | 190 |
| TC - 10 I[3] | 10 | -5 | 25 | 195 |
| TC - 10 II[3] | 10 | -5 | 30 | 195 |
| TC - 11 | 65 | -5 | 160 | 195 |
| TC - 12 | 390 | 30 | 6,944 | 3,497 |
| TC - 13 | 10 | -5 | 40 | 520 |
| TC - 14 | 55 | -5 | 150 | 225 |
| TC - 15 | 165 | -5 | 100 | 345 |
| TC - 16 | 10 | -5 | 50 | 15 |
| TC - 17 | 25 | -5 | 50 | 70 |
| TC - 18 | 5 | -5 | 35 | 45 |
| TC - 19 | 20 | -5 | 100 | 340 |
| TC - 20 | 25 | 10 | 50 | 325 |
| TC - 21 | 165 | 15 | 35 | 900 |
| TC - 22 | 10 | 30 | 405 | 280 |
| TC - 23 | 65 | 30 | 50 | 20 |

TABLE XI (Continued)

| Sample[1] No. | Cu (ppm) | Mo[2] (ppm) | Pb[2] (ppm) | Zn (ppm) |
|---|---|---|---|---|
| TC - 24 | 105 | 15 | 55 | 15 |
| TC - 25 | 110 | 95 | 25 | 15 |
| TC - 26 | 20 | -5 | 35 | 480 |
| TC - 27 | 10 | -5 | 5 | 15 |
| TC - 28 | 15 | -5 | 30 | 55 |
| TC - 29 | 20 | -5 | 40 | 245 |
| TC - 30 | 15 | -5 | 35 | 10 |
| TC - 31 | 10 | -5 | 5 | 15 |
| TC - 32 | 60 | -5 | 45 | 115 |
| TC - 33 | 105 | -5 | 55 | 35 |
| TC - 34 | 95 | -5 | 85 | 330 |
| TC - 35 | 55 | -5 | 60 | 190 |
| TC - 36 | 45 | -5 | 40 | 175 |
| TC - 37 | 25 | -5 | 20 | 79 |
| TC - 38 | 5 | -5 | 15 | 204 |
| TC - 39 | 35 | 5 | 60 | 140 |
| TC - 40 | 45 | -5 | 292 | 104 |
| TC - 41 | 20 | -5 | 45 | 155 |
| TC - 42 | 10 | -5 | 25 | 55 |
| TC - 43 | 10 | 5 | 40 | 35 |

[1]PC indicates Pine Creek, GC indicates Gold Creek, TC indicates Tellurium Creek.

[2](-) denotes less than 5 ppm.

[3]sample analyzed in triplicate.

[4]not analyzed.

[5]GC - 37 a and GC - 37 b are two separate samples from the same location: GC 37 a from outcrop, GC - 37 b from prospect dump.

VITA

Robert Allen Perkins

Candidate for the Degree of

Master of Science

Thesis: TRACE METAL GEOCHEMISTRY AND HYDROTHERMAL ALTERATION OF THREE MOLYBDENUM-BEARING STOCKS, GUNNISON AND PITKIN COUNTIES, COLORADO

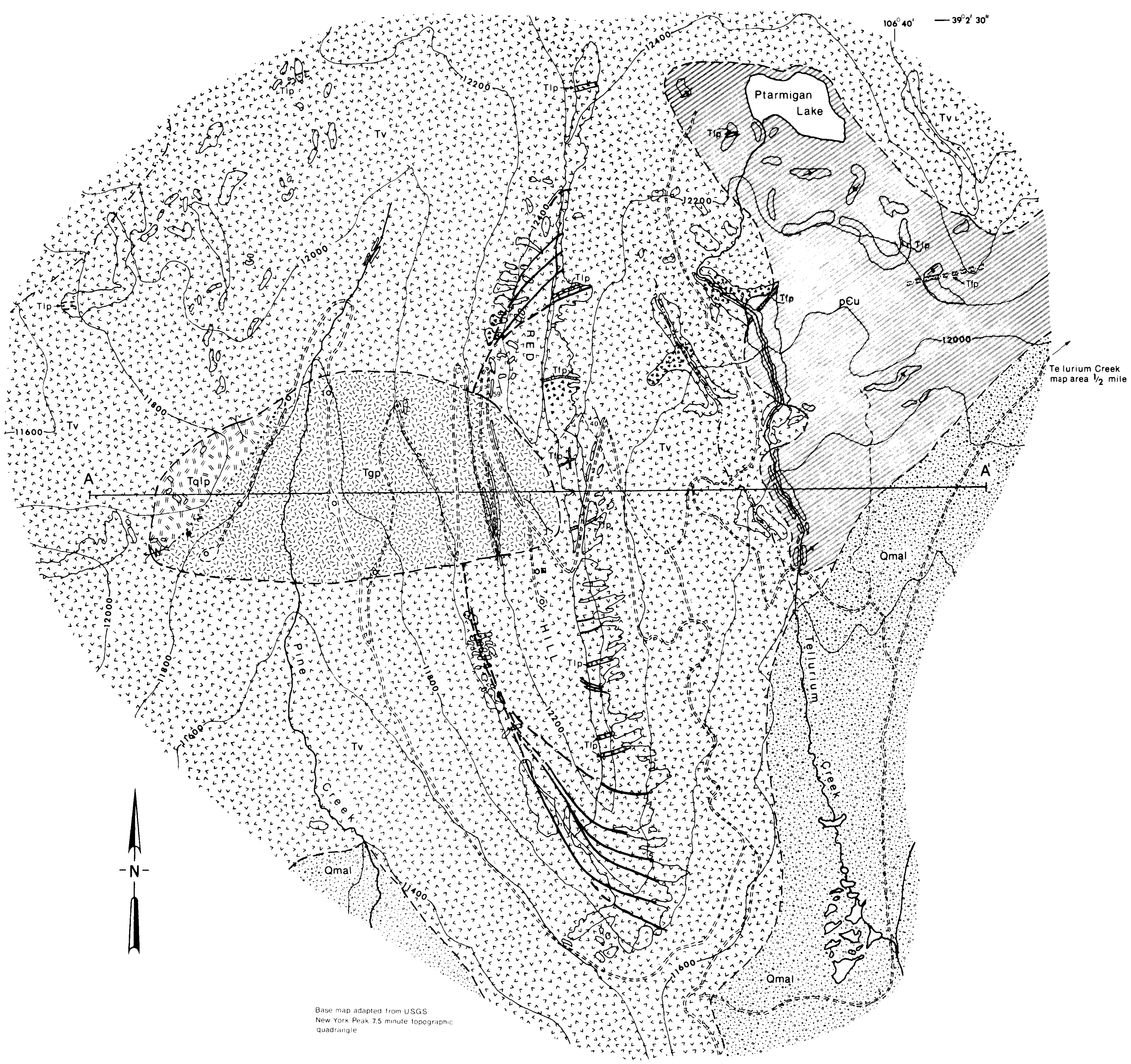
Major Field: Geology

Biographical:

Personal Data: Born in Canton, Ohio, May 21, 1946, the son of Mr. and Mrs. George Lewis Perkins.

Education: Graduated from Jackson Memorial High School, Massillon, Ohio in June, 1964; received the Bachelor of Arts degree from Bowling Green State University, Bowling Green, Ohio in June, 1968, with a major in Geology; enrolled in Master of Education program at Bowling Green State University, 1968 - 1971; completed requirements for Master of Science degree at Oklahoma State University in July, 1973, with a major in Geology.

Professional Experience: Assistant geologist, Bear Creek Mining Company, Marquette, Michigan, summer, 1968; teacher, Woodmore Local School District, Woodville, Ohio, 1968 - 1971; assistant geologist, Bear Creek Mining Company, Ladysmith, Wisconsin, summer, 1969, Englewood, Colorado, summers 1970 and 1971; Graduate teaching assistant, Department of Geology, Oklahoma State University, 1971 - 1973; Graduate field assistant, Oklahoma Geology Camp, Canon City, Colorado, summer, 1972. Student member of the American Institute of Mining, Metallurgical, and Petroleum Engineers; Student Associate of the Geological Society of America; Student member of the Mineralogical Society of America.




SCALE 1:7200

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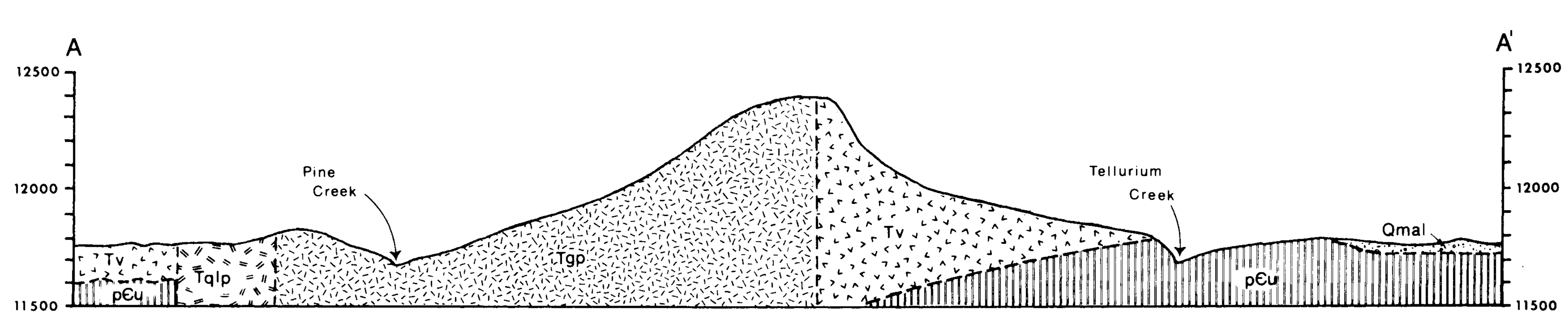
SCALE FEET

Contour Interval 200 feet




# EXPLANATION

**QUATERNARY**

- Qmal — Quaternary moraine and alluvium, undivided

**TERTIARY**

- Tqlp — Quartz latite porphyry
- Tgp — Granodiorite porphyry
- Tlp — Latite porphyry
- Tfp — Felsite porphyry
- Tv — Grizzly Peak Volcanics

**PRECAMBRIAN**

- pЄu — Precambrian rocks, undivided

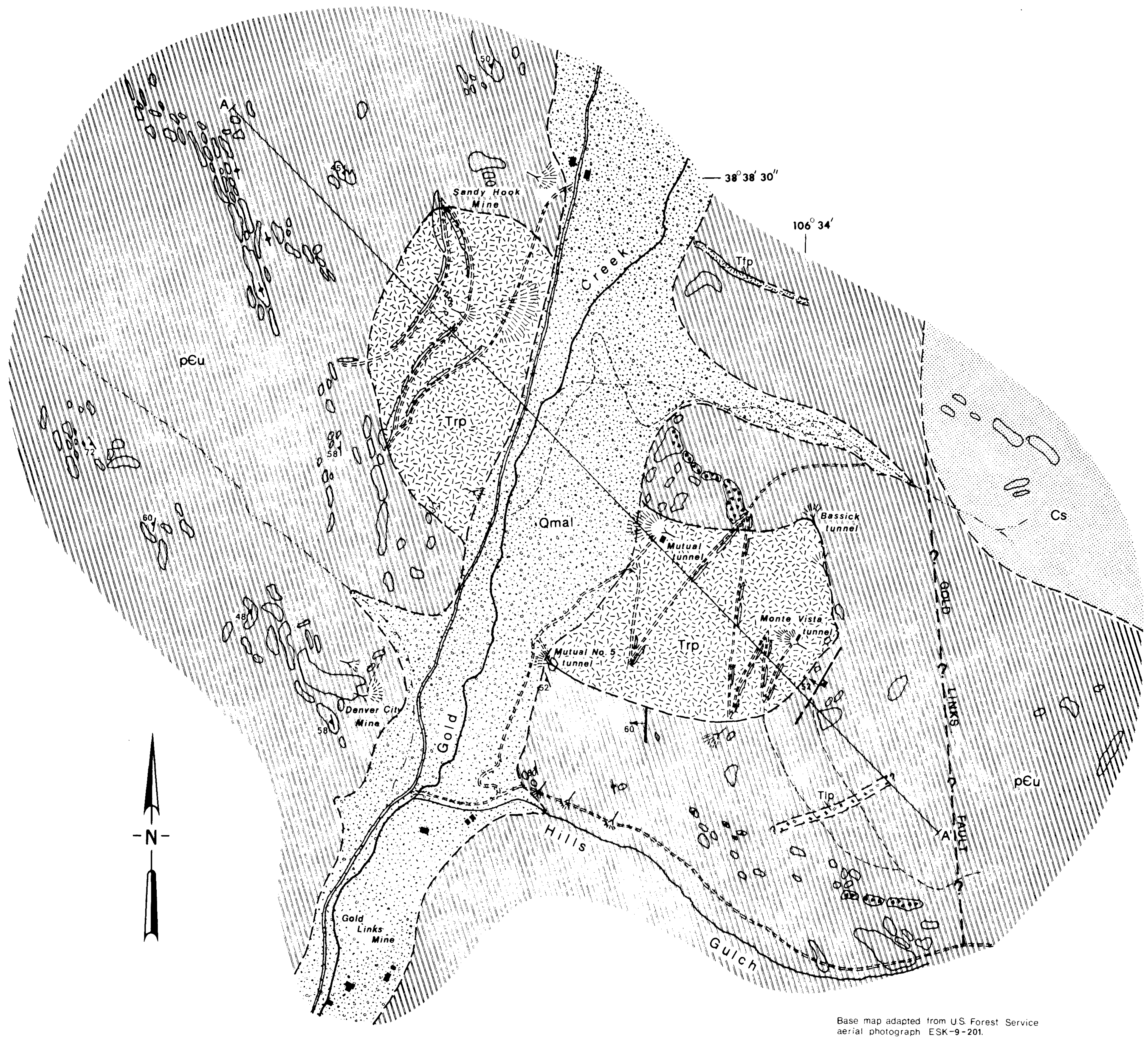
- adit
- trench
- shaft
- drill hole
- foliation, showing dip
- foliation, vertical
- fault, dashed where inferred
- dip and strike of compactional layering
- contact: solid where exposed, dashed where inferred, dotted where concealed
- four-wheel drive road
- foot trail
- outcrop
- breccia
- stream
- intermittent stream

## FIGURE 3

# GEOLOGIC MAP OF THE PINE CREEK STOCK AREA

Robert A. Perkins

1973

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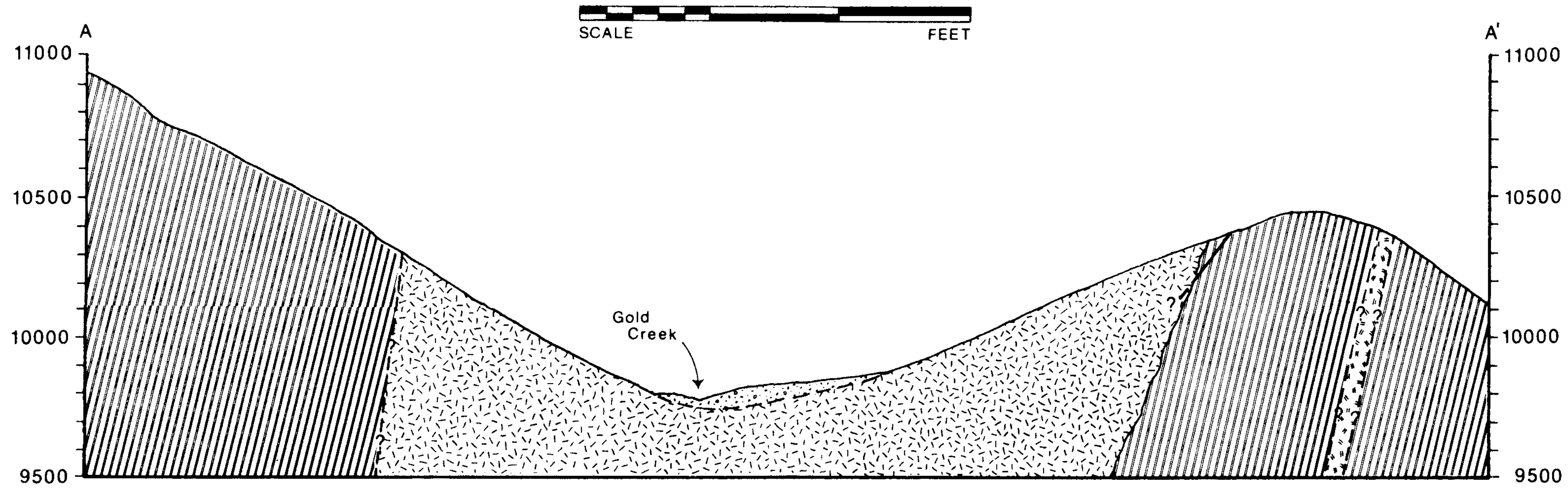
SCALE FEET




## EXPLANATION

**QUATERNARY**

Qmal — Quaternary moraine and alluvium, undivided

**TERTIARY**

Trp — Rhyolite(?) porphyry

Tfp — Felsite porphyry

Tlp — Latite porphyry

**CAMBRIAN**

Cs — Sawatch Quartzite

**PRECAMBRIAN**

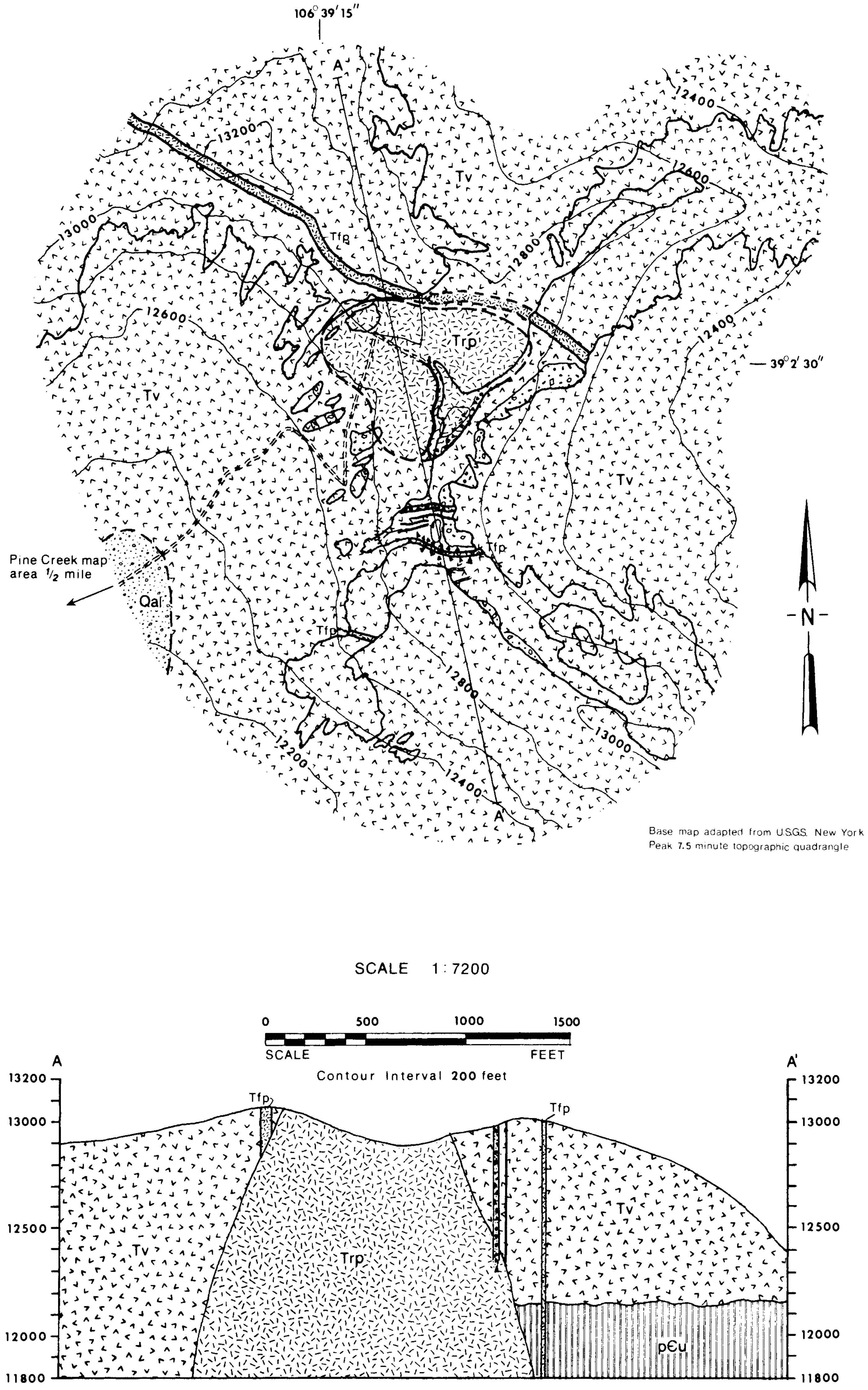
pЄu — Precambrian rocks, undivided (lines approximate foliation trend)

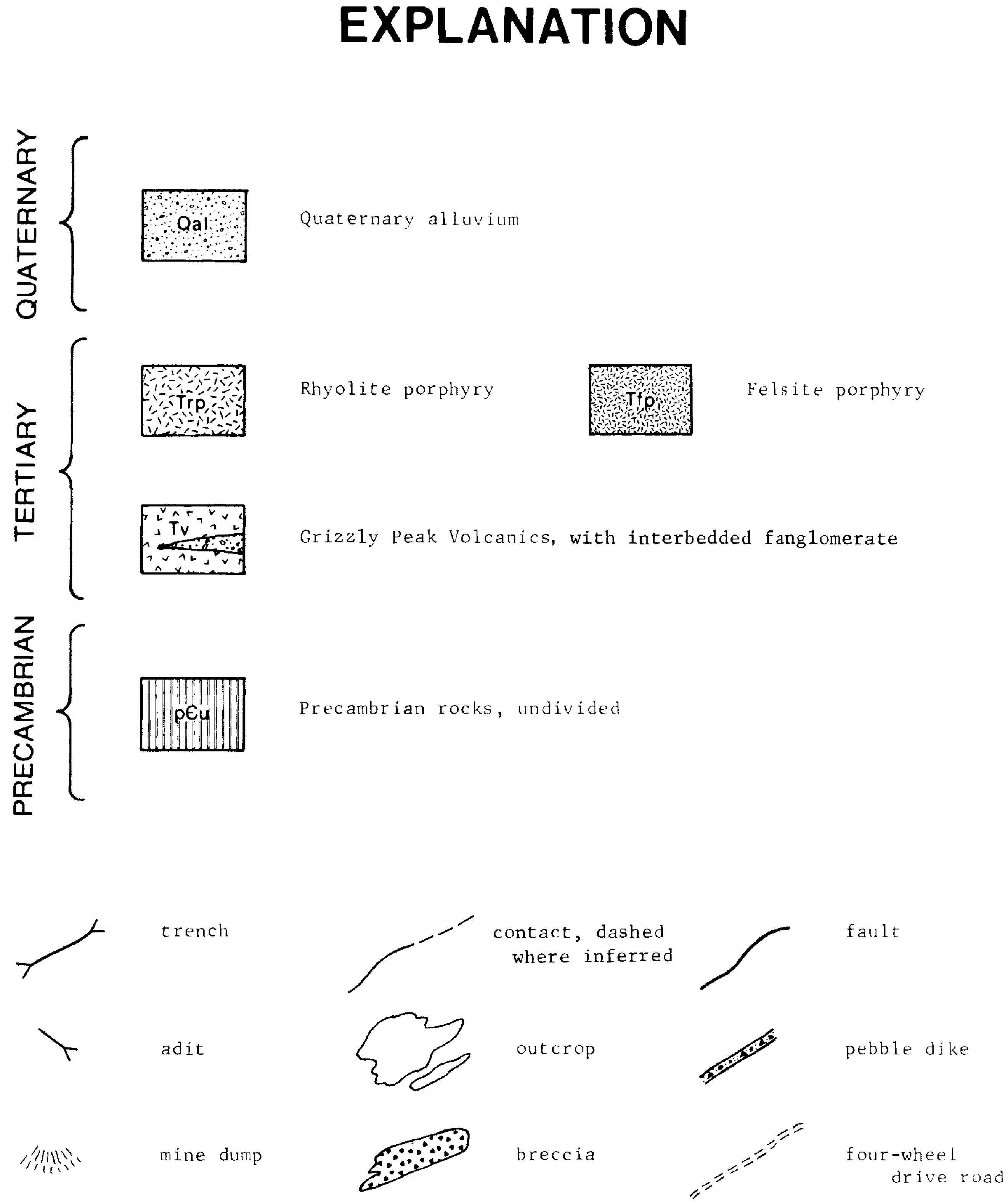
- road
- outcrop
- contact, dashed where inferred
- four-wheel drive trail
- breccia
- 78 foliation, showing dip
- foot trail
- adit
- foliation, vertical
- stream
- mine dump
- 67 fault, dashed where inferred
- intermittent stream
- shaft
- building

# FIGURE 5
# GEOLOGIC MAP OF THE GOLD CREEK STOCK AREA

Robert A. Perkins

1973




# FIGURE 8
# GEOLOGIC MAP OF THE TELLURIUM CREEK STOCK AREA

Robert A. Perkins

1973

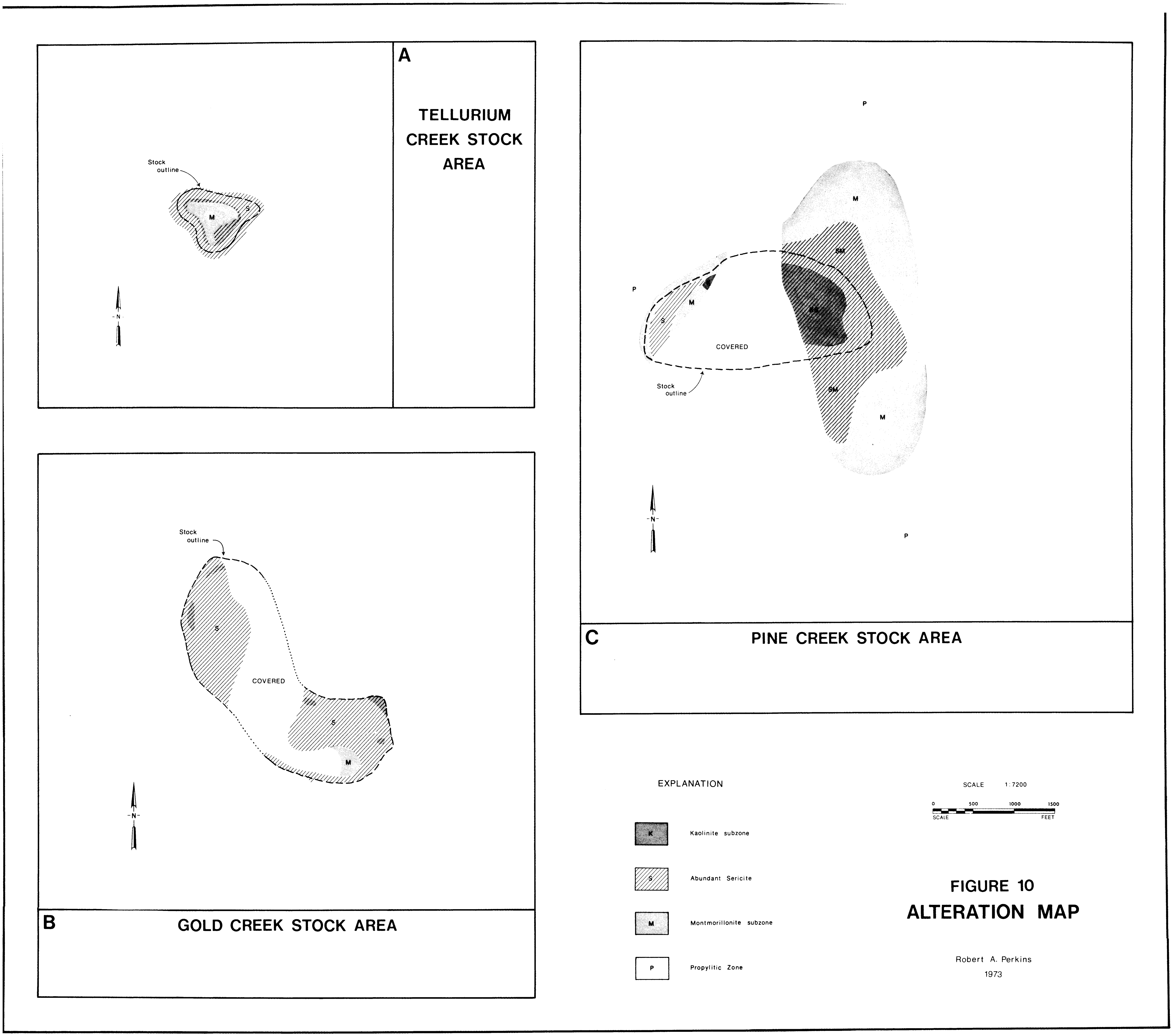
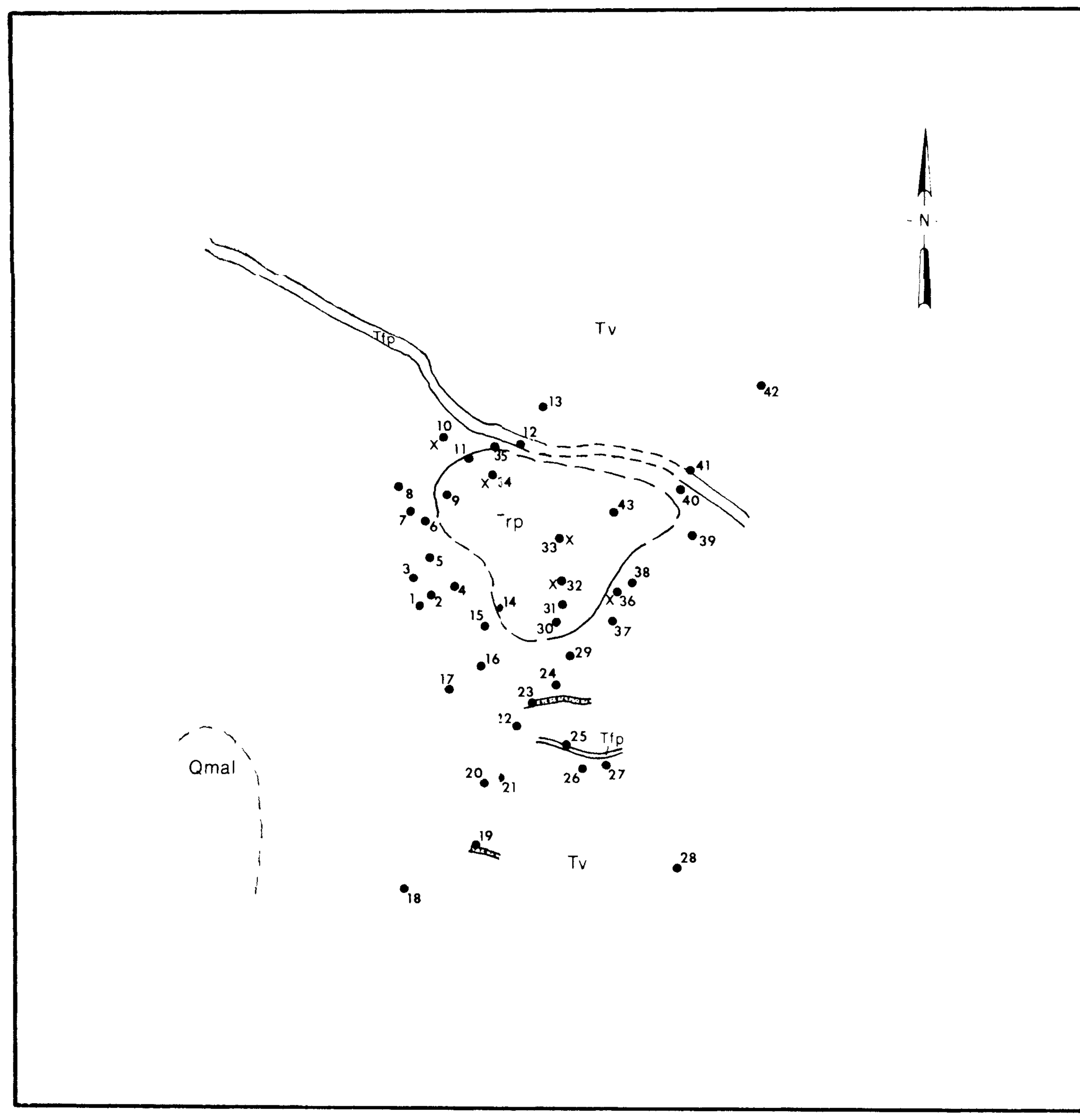



**FIGURE 10**
**ALTERATION MAP**

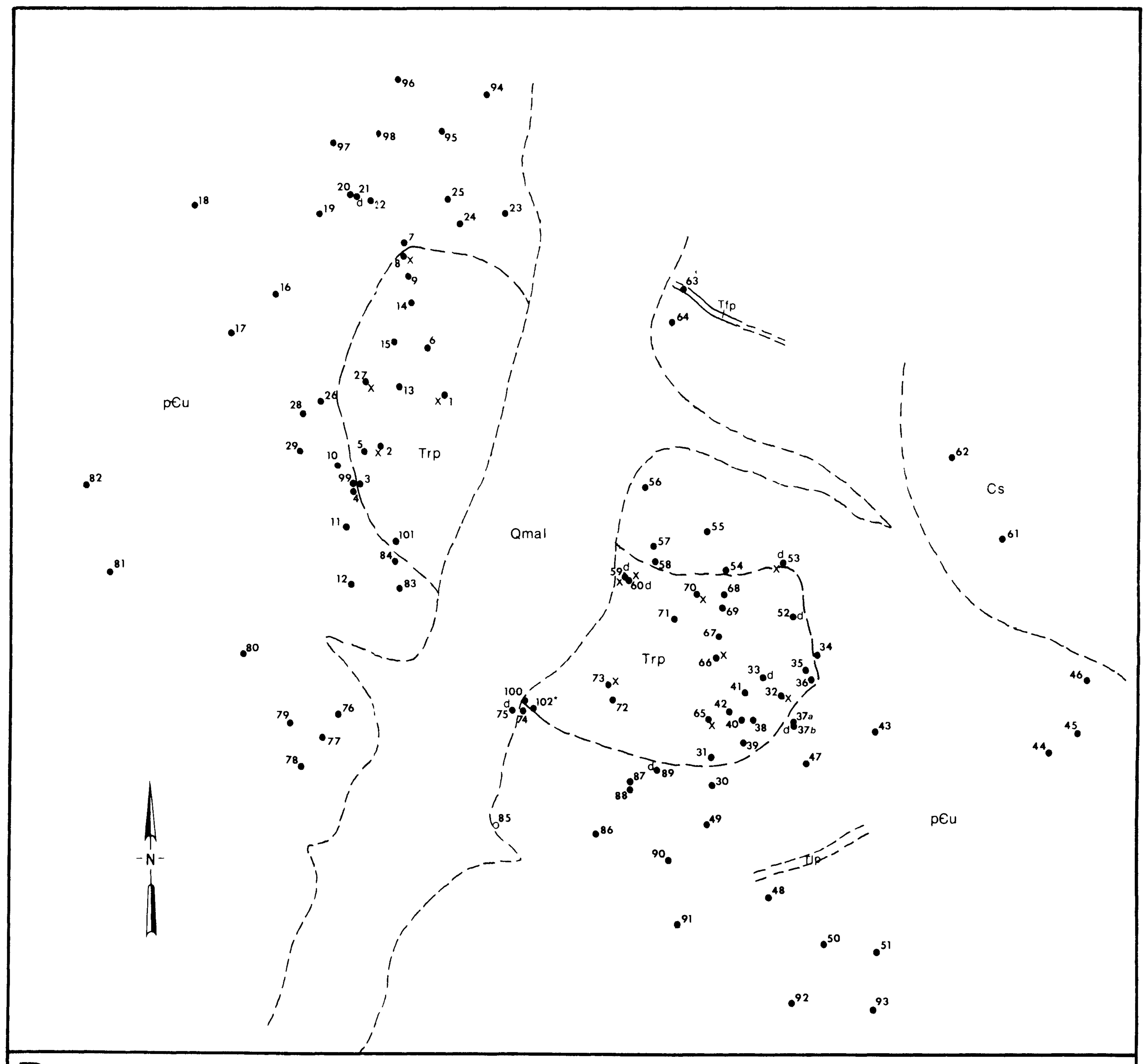
Robert A. Perkins
1973




**A**

## TELLURIUM CREEK STOCK AREA

ROCK UNIT SYMBOLS SAME AS FIGURE 8




**B**

## GOLD CREEK STOCK AREA

ROCK UNIT SYMBOLS SAME AS FIGURE 5

*Sample 102 taken in Mutual #5 adit


**C**

## PINE CREEK STOCK AREA

ROCK UNIT SYMBOLS SAME AS FIGURE 3

• SAMPLE LOCATION

x X-RAY ANALYSIS

d MINE OR PROSPECT PIT DUMP SAMPLE

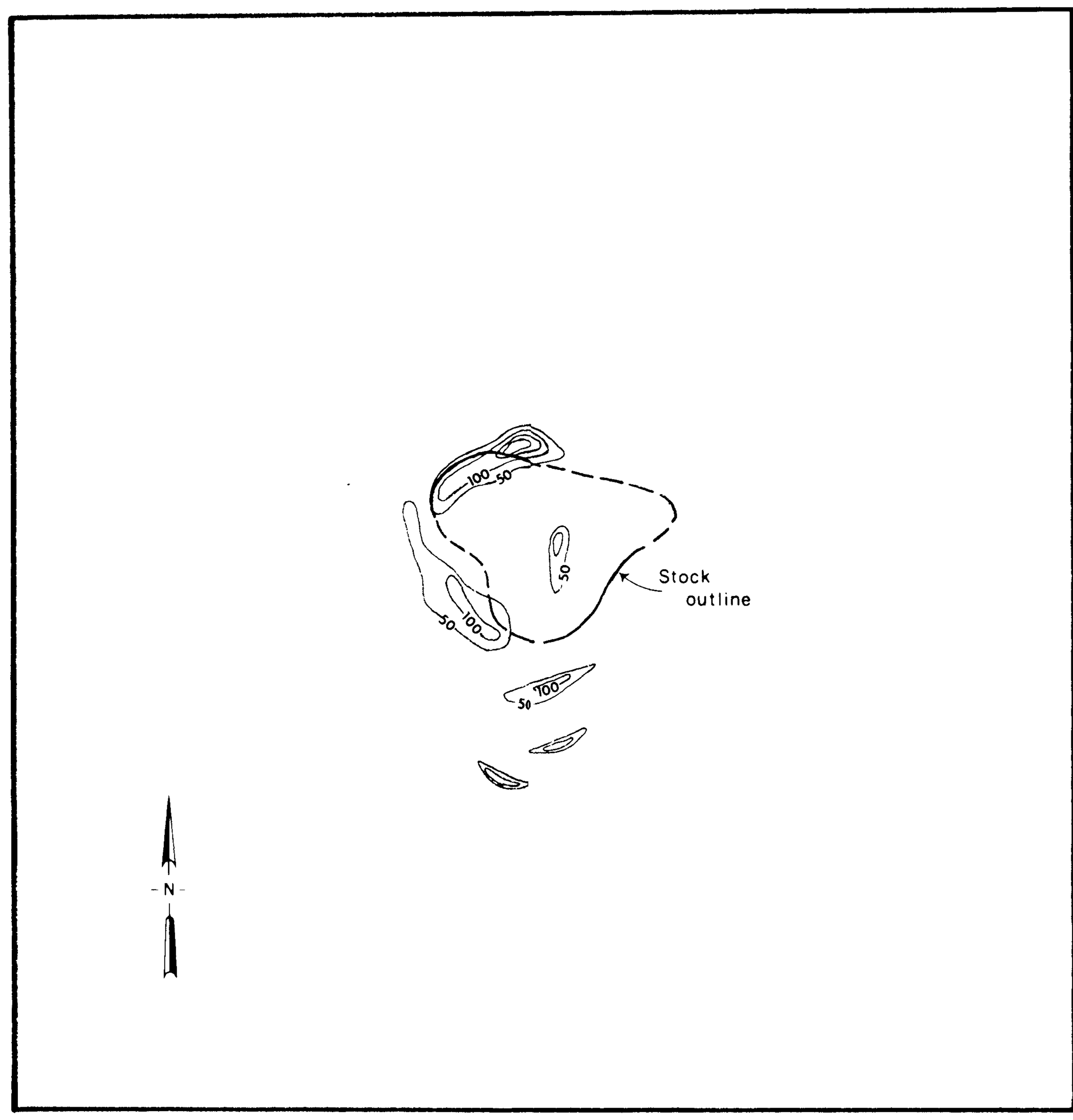
SCALE 1:7200

0 500 1000 1500
SCALE FEET

# FIGURE 16
# SAMPLE LOCATION MAP


Robert A. Perkins


1973



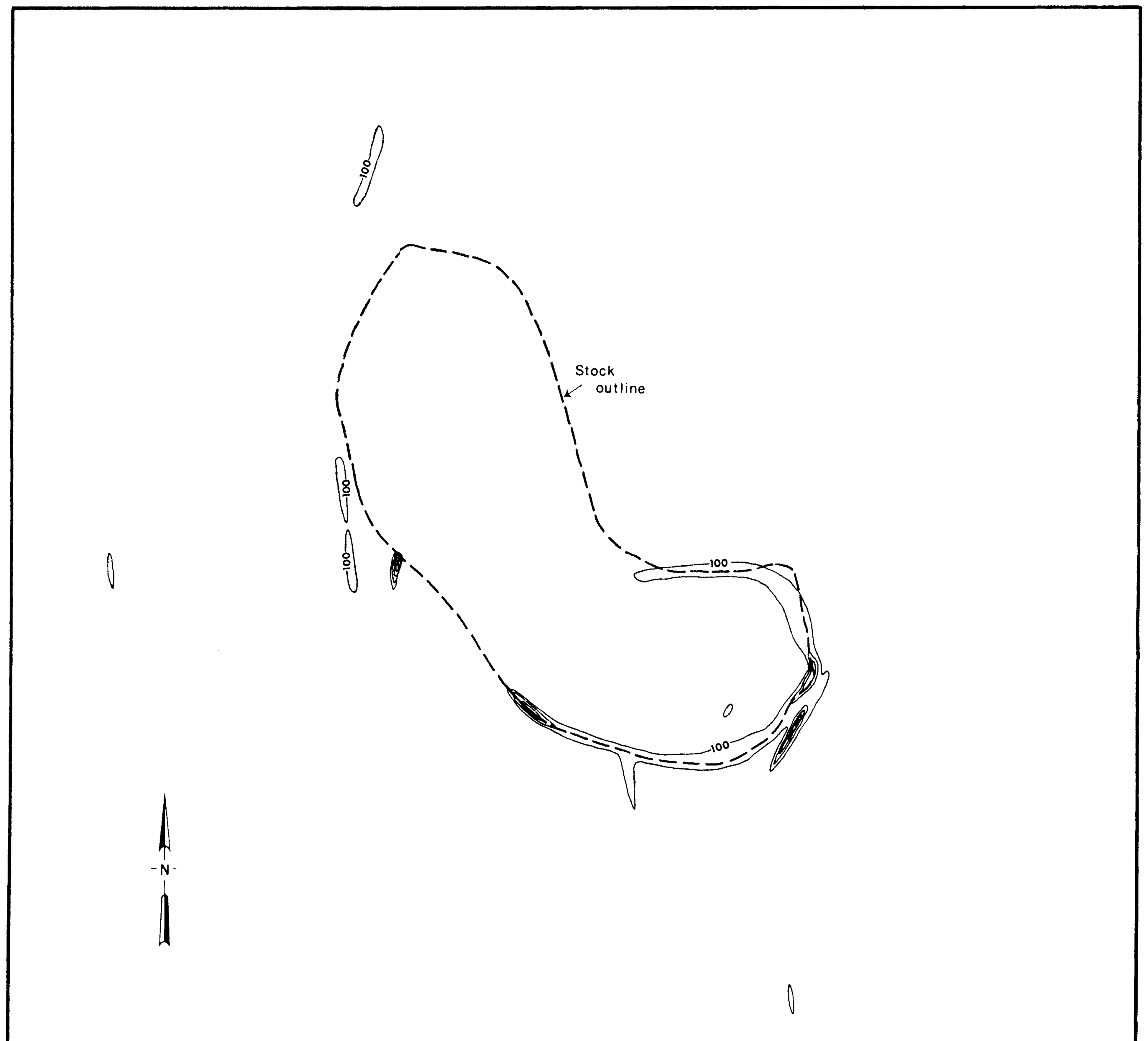

**A**

## TELLURIUM CREEK STOCK AREA

Contour Interval

50, 100, 200, 300 ppm

| | Mean | Threshold |
|---|---|---|
| Stock | 60.90 | 146.75 |
| All Rock Types | 46.82 | 135.14 |



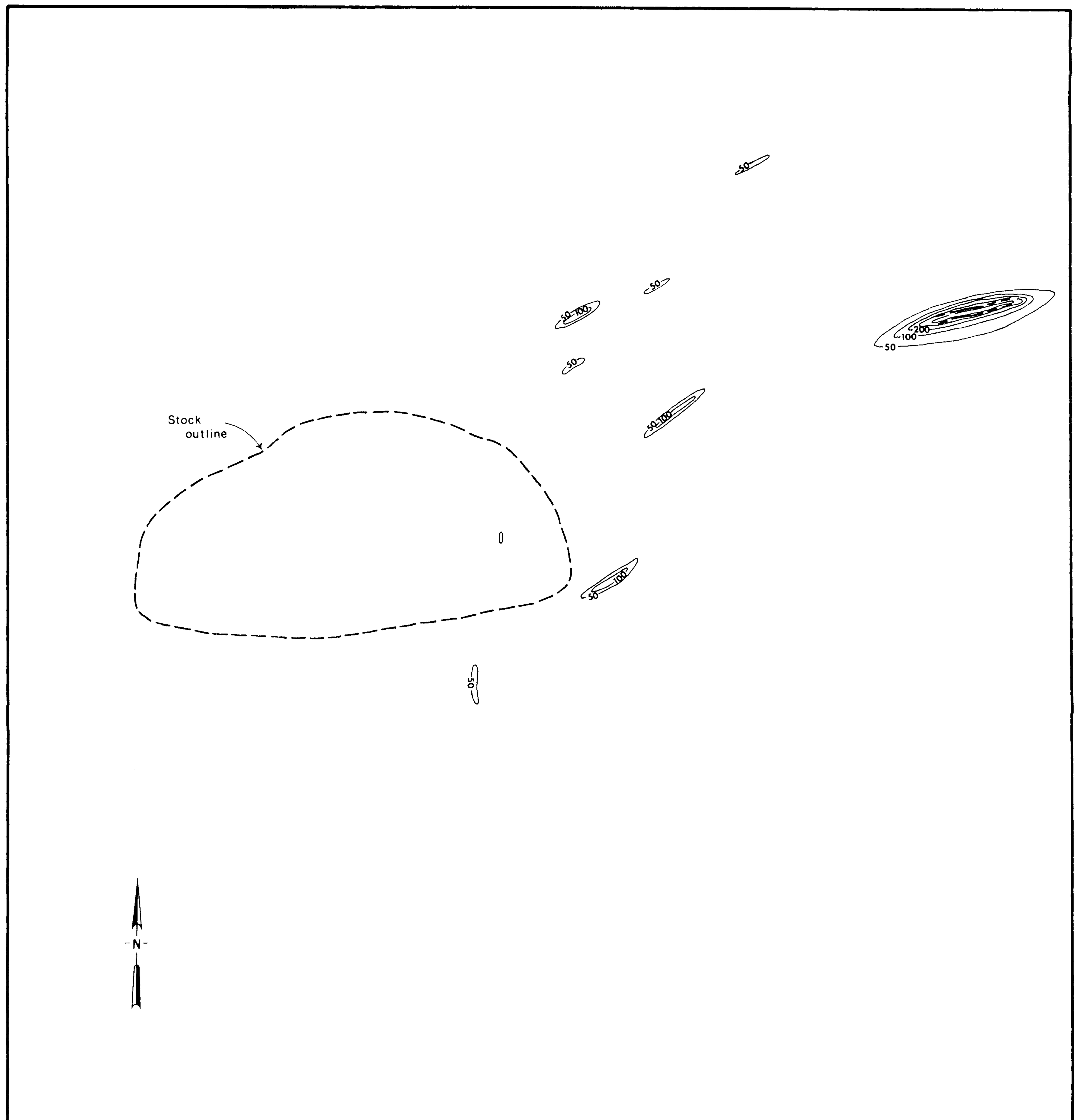

**B**

## GOLD CREEK STOCK AREA

| | Mean | Threshold |
|---|---|---|
| Stock | 44.85 | 129.46 |

Contour Interval

100, 200, 300, 500, 1000 ppm




**C**

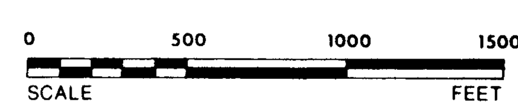
## PINE CREEK STOCK AREA

| | Mean | Threshold |
|---|---|---|
| Stock | 13.91 | 35.22 |
| All Rock Types | 17.21 | 61.61 |

Contour Interval

50, 100, 200, 300, 500, 1000 ppm

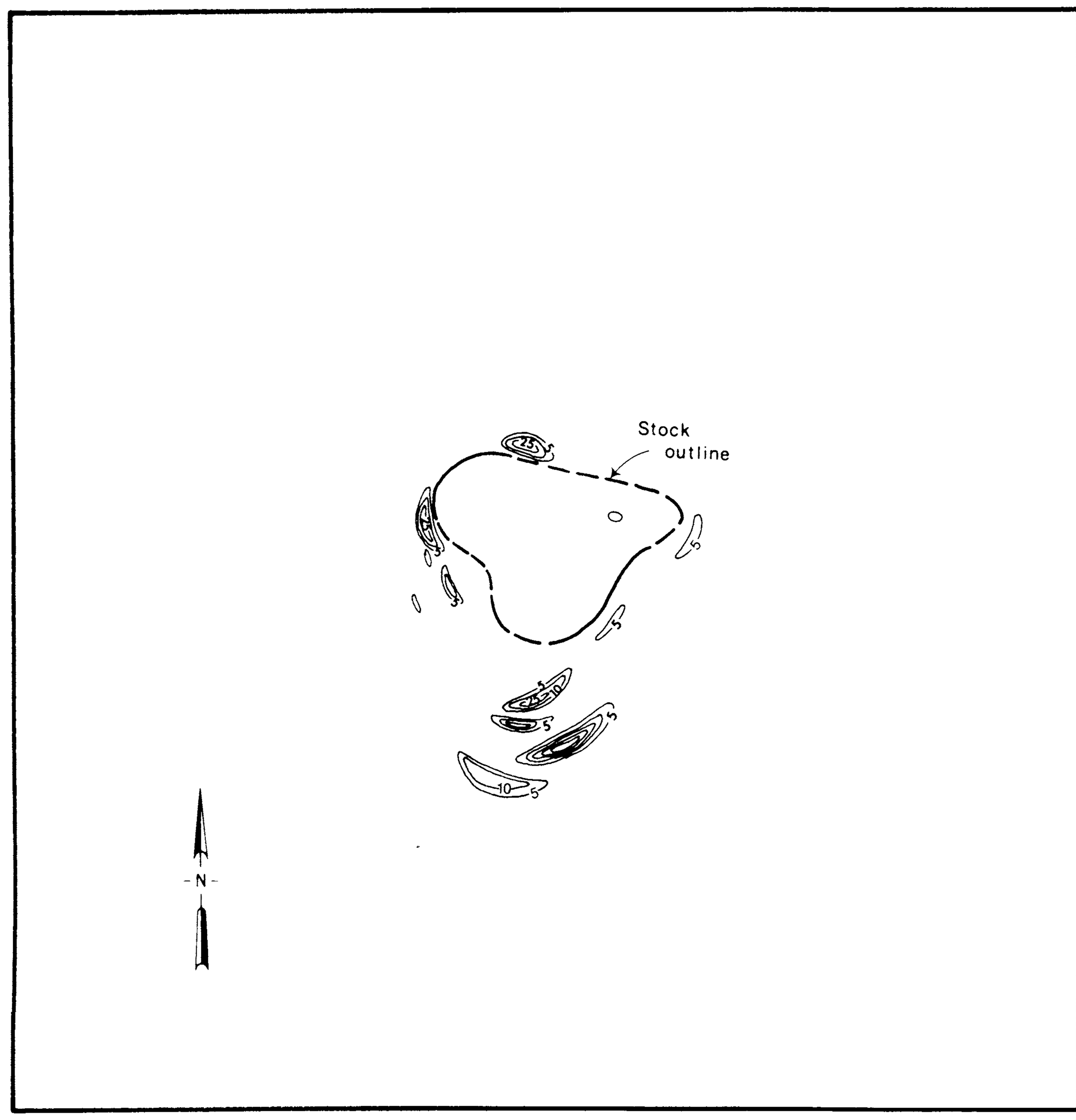
SCALE 1:7200




# FIGURE 17
# DISTRIBUTION OF COPPER IN ROCK

Robert A. Perkins

1973



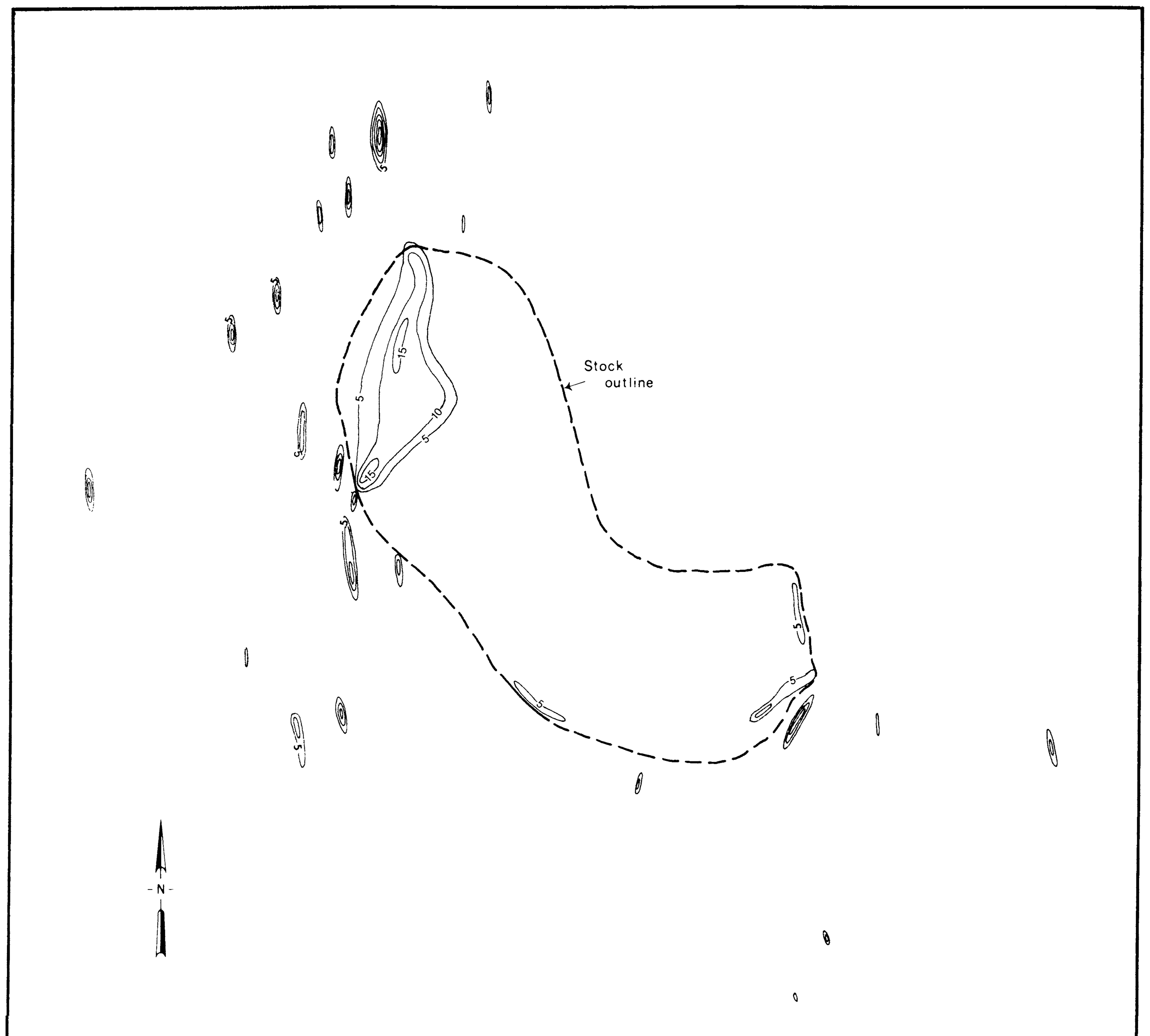

**A**

## TELLURIUM CREEK STOCK AREA

Contour Interval

5, 10, 25, 50, 75 ppm

| | Mean | Threshold |
|---|---|---|
| Stock | 0.50 | 3.66 |
| All Rock Types | 4.66 | 24.24 |



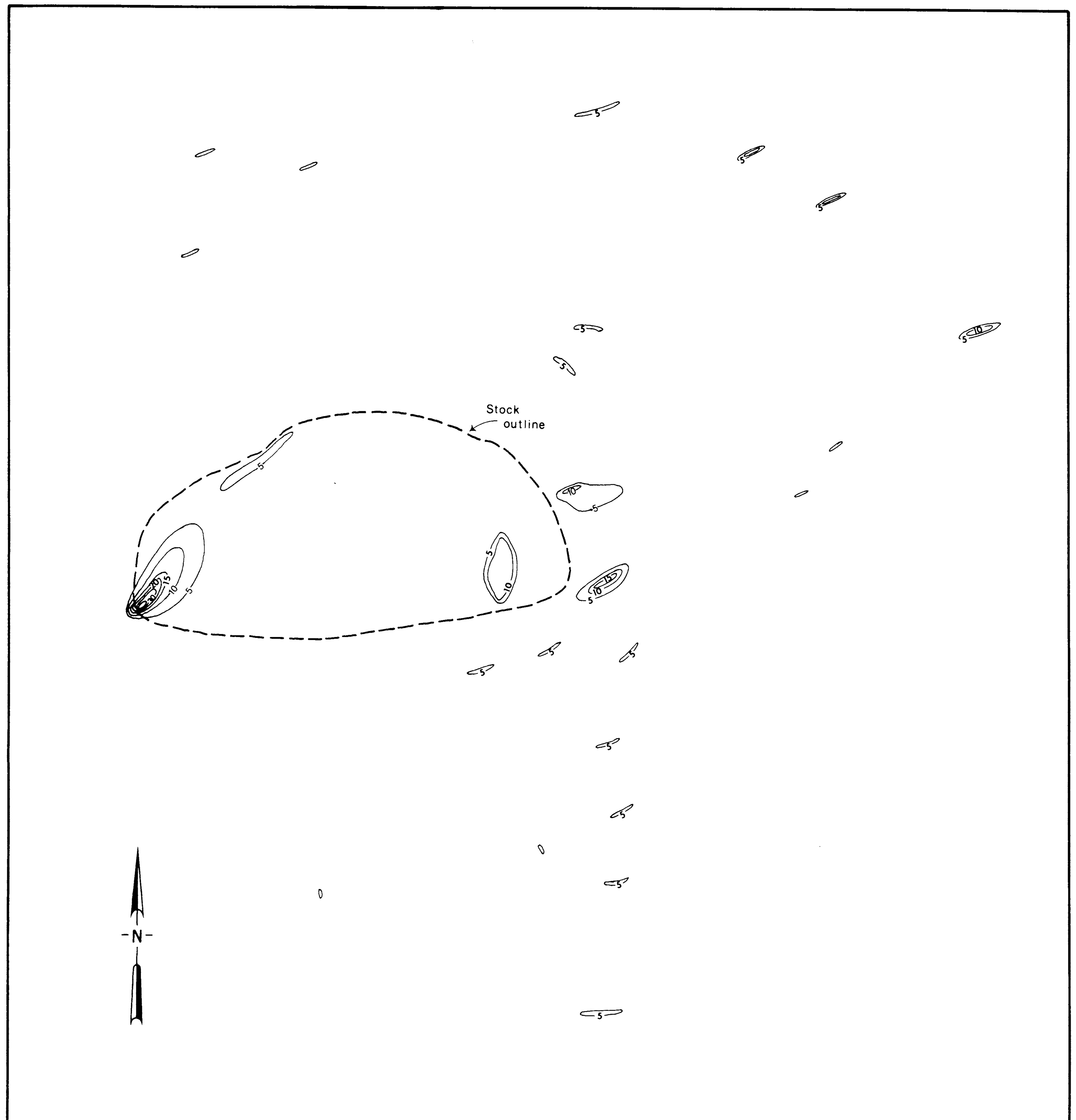

**B**

## GOLD CREEK STOCK AREA

| | Mean | Threshold |
|---|---|---|
| Stock | 3.97 | 13.43 |

Contour Interval

5, 10, 15, 25, 50 ppm




**C**

## PINE CREEK STOCK AREA

| | Mean | Threshold |
|---|---|---|
| Stock | 7.83 | 33.73 |
| All Rock Types | 2.62 | 16.05 |

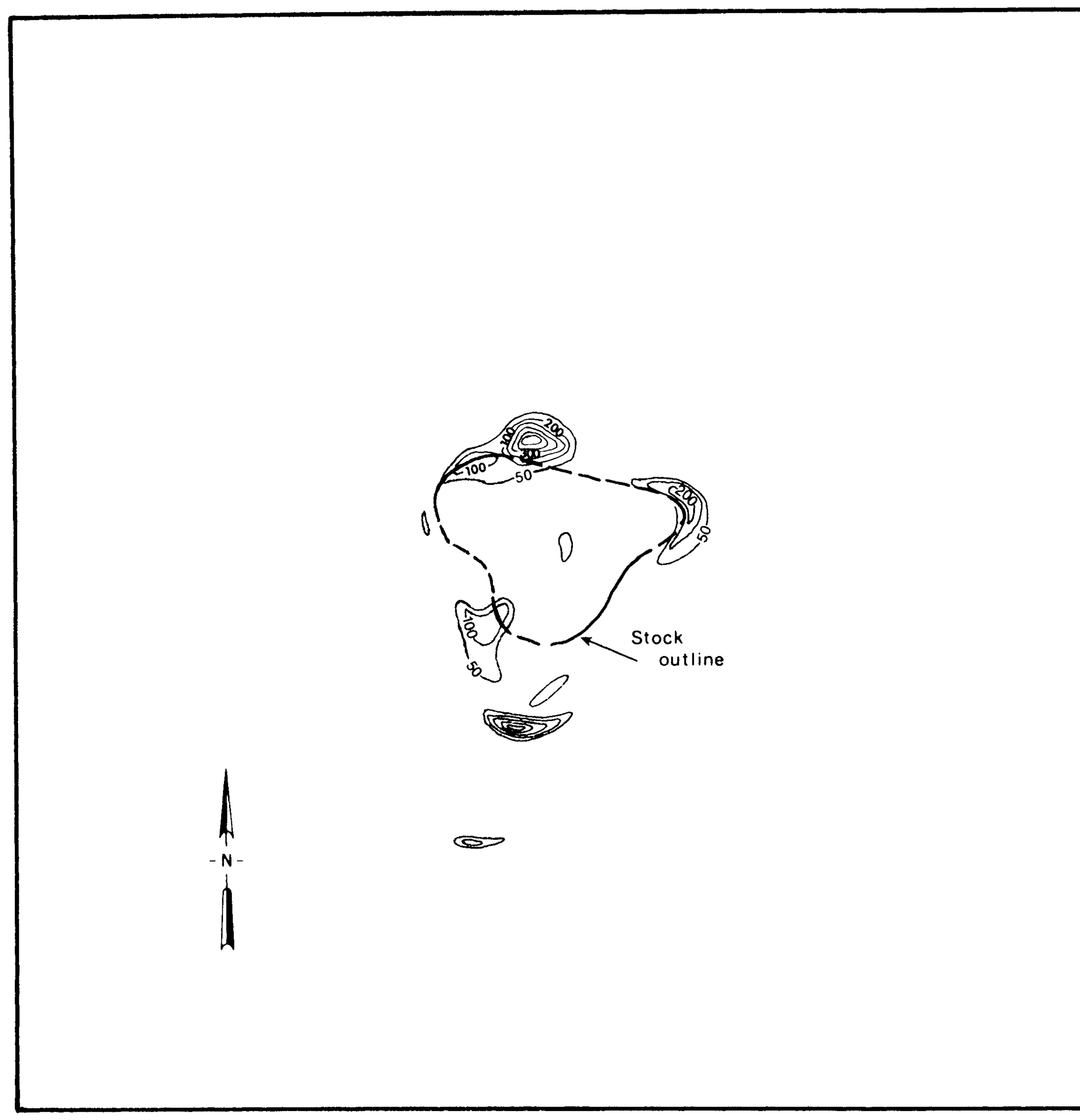
Contour Interval

5, 10, 15, 20, 30, 40, 50 ppm

SCALE 1:7200


# FIGURE 18
# DISTRIBUTION OF MOLYBDENUM IN ROCK

Robert A. Perkins
1973



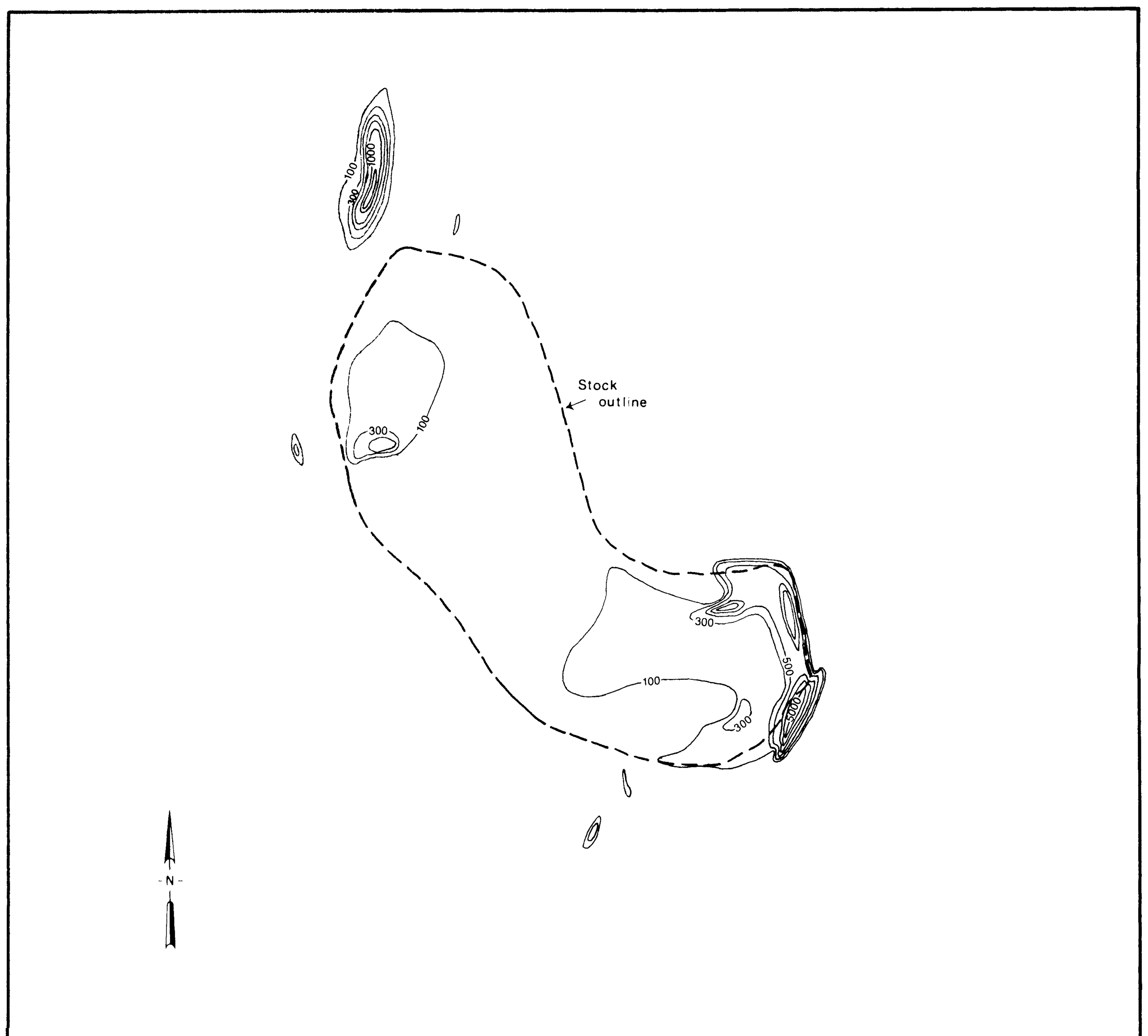

**A**

## TELLURIUM CREEK STOCK AREA

Contour Interval

50, 100, 200, 300, 500, 1000 ppm

| | Mean | Threshold |
|---|---|---|
| Stock | 55.00 | 139.85 |
| All Rock Types | 43.29 | 96.52 |



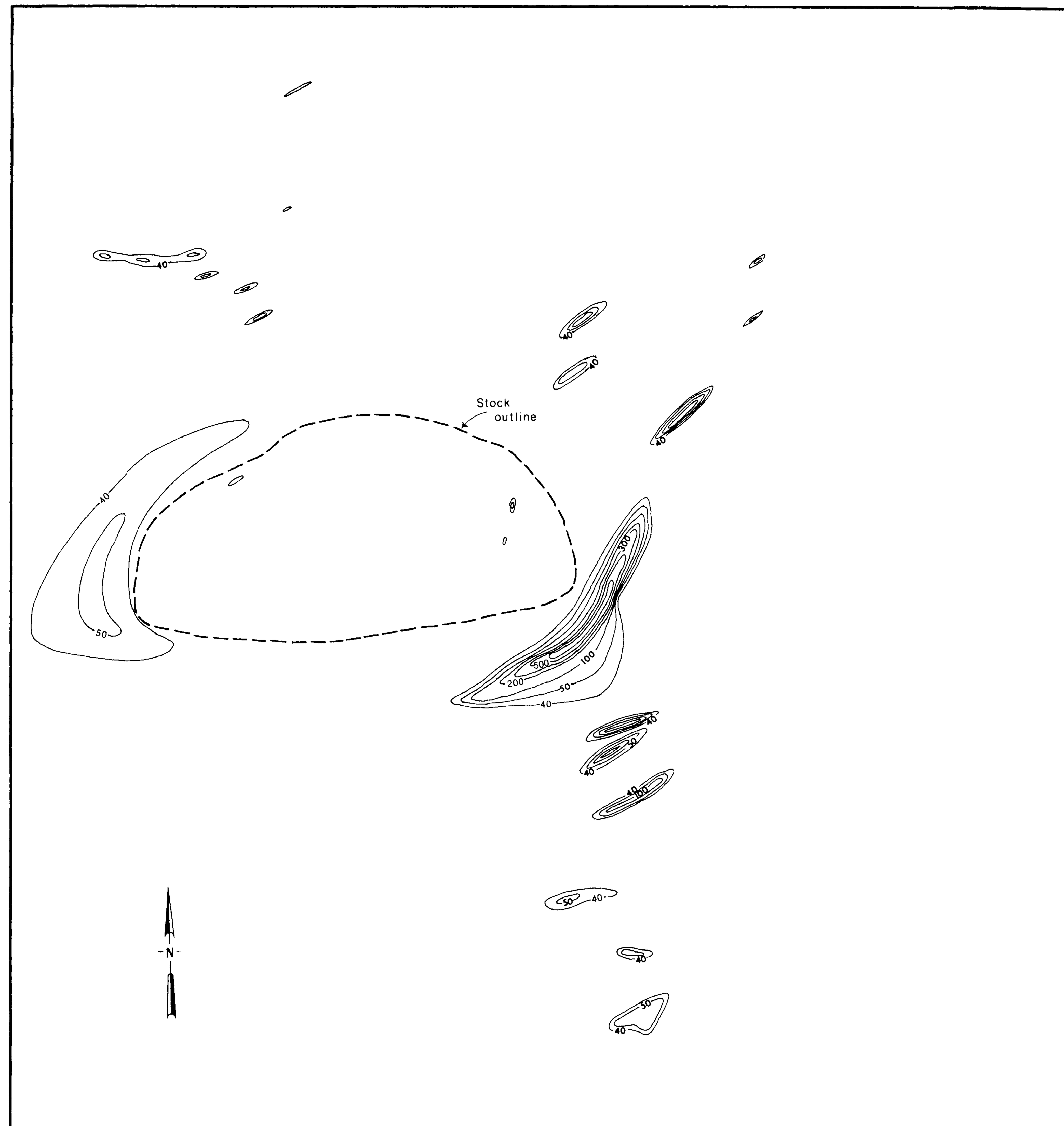

**B**

## GOLD CREEK STOCK AREA

| | Mean | Threshold |
|---|---|---|
| Stock | 122.17 | 296.57 |

Contour Interval

100, 300, 500, 750, 1000, 5000 ppm




**C**

## PINE CREEK STOCK AREA

| | Mean | Threshold |
|---|---|---|
| Stock | 18.04 | 45.13 |
| All Rock Types | 34.72 | 99.10 |

Contour Interval

40, 50, 100, 200, 300, 500, 1000 ppm

SCALE 1:7200

0 500 1000 1500

SCALE FEET

# FIGURE 19
# DISTRIBUTION OF LEAD IN ROCK

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1973

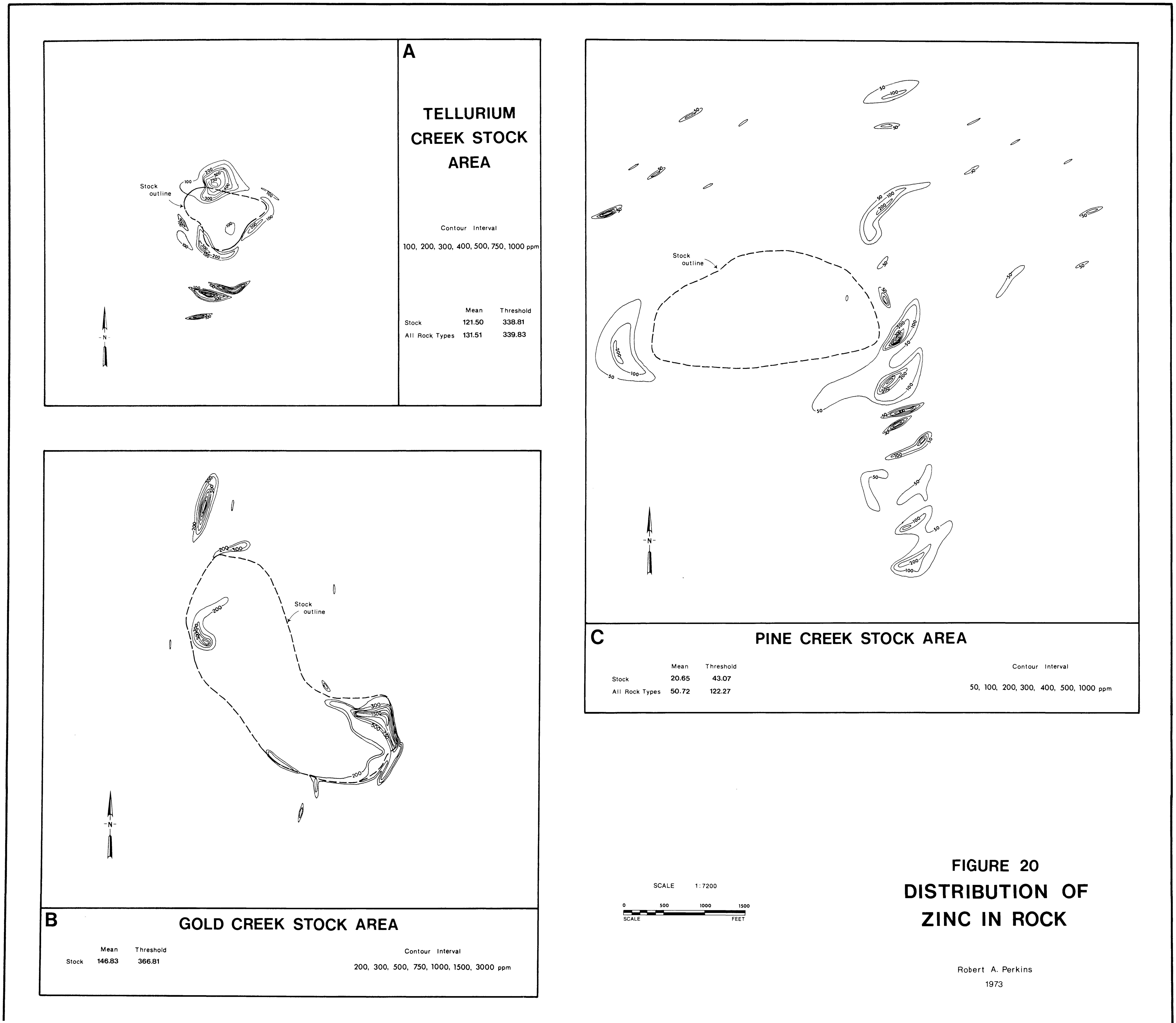


FIGURE 20
DISTRIBUTION OF ZINC IN ROCK

Robert A. Perkins
1973