INVESTIGATION OF THE POTENTIAL USEFULNESS OF QUARTZ IN

GEOCHEMICAL EXPLORATION FOR PORPHYRY COPPER DEPOSITS

Research Report

by

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## INTRODUCTION

The following report deals with a research project conducted to determine the trace impurity content of quartz from porphyry copper deposits. Furthermore, the study was to determine whether the trace impurity content of porphyry copper related quartz might be useful as an exploration guide in the search for porphyry copper deposits such as those found in the southwestern United States and northern Mexico. Classical geochemical methods of soil, rock and mineral analysis for various elements as well as various geophysical techniques have been quite "hit or miss" in their ability to delineate such deposits.

## SUMMARY OF PAST RESEARCH

A considerable volume of literature pertaining to fluid inclusions in various minerals from a variety of geologic environments is available (Nash & Theodore, 1971; Roedder, 1971, 1972; and Roedder et al., 1968). Fluid inclusion studies generally tend to address themselves to questions of temperature and pressure of the environment of crystallization of the host mineral. Data on the composition of the fluids is sparse and where available (e.g. Roedder, 1972; Pinckney & Haffty, 1970) covers few elements.

Numerous workers, typically limiting themselves to one or a few elements, have investigated the trace impurity content of quartz from various environments. Table I presents a summary of the impurities that have been reported. In addition to the

## TABLE 1

### ELEMENTAL INPURITIES FOUND IN QUARTZ

| Element | Average/Range Concentration (ppm) | Association | Reference |
|---|---|---|---|
| Aluminum | 40-110 | Quartz kyanite schist | 4 |
| | 0-500 | Granite | 3 |
| | 1-8 | Various | 6 |
| Barium | trace | Not Reported | 6 |
| Beryllium | 3-7.2 | Zoned granite pegmatite | 12 |
| Boron | 0.25 | Biotite granodiorite | 14 |
| | 25 | Chalcopyrite deposit | 5 |
| | 1 | Veins in granite | 14 |
| | 1-4 | Pegmatite with tourmaline mineralization | 14 |
| | 70 | Quartzite | 5 |
| Calcium | 3-100 | Various | 6 |
| | 1000 | Rhyolite | 3 |
| Cesium | trace | Various | 6, 12 |
| Chromium | 0-30 | Various | 6 |
| Cobalt | 0-0.8 | Various | 6 |
| Copper | 0-100 | Various | 6 |
| | 1-15 | Mineralizing quartz monzonite | 11 |
| | 2.7-138 | Various | 9 |
| Gallium | 2 | Granite | 2 |
| | 5 | Granodiorite | 2 |
| Germanium | 1.8 | Granite | 1 |
| | 2.5-7.1 | Pegmatite | 1 |
| | 2.8 | Hydrothermal vein | 1 |
| Gold | <1.7-12.6 | Various | 9 |
| Hydrogen | 35-1200 | Zoned quartz | 6 |
| Iron | 32-2620 | Various | 9 |
| | 0-216 | Various | 6 |
| | 550 | Rhyolite | 3 |
| | 0-256 | Granite | 3 |

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TABLE 1 (Continued)

| Element | Average/Range Concentration (ppm) | Association | Reference |
|---|---|---|---|
| Lead | trace | Not reported | 6 |
| | 3 | Quartz diorite | 10 |
| | 4 | Granodiorite & biotite granite | 10 |
| Lithium | 0-38 | Various | 6 |
| | 0.3-1.9 | Granite | 13 |
| | 0.5-3.3 | Barren pegmatite | 13 |
| | 19-220 | Lithium-bearing pegmatite | 13 |
| | 110 | Zoned pegmatite | 12 |
| | <0.08-2.16 | Various | 9 |
| Magnesium | 5-100 | Various | 6 |
| | 0-8 | Granite | 3 |
| Manganese | 0-0.5 | Various | 6 |
| Molybdenum | 0.01 | Biotite granite | 15 |
| | 0.5-5.5 | Granite | 15 |
| | 0.1 | Vein in granite | 7 |
| Potassium | 1100 | Optically clear quartz from zoned pegmatite | 12 |
| Rubidium | trace | Not reported | 6 |
| Silver | 1 | Smoky quartz & Amethyst | 6 |
| | <0.75-9.7 | Various | 9 |
| Sodium | 0-104 | Various | 6 |
| | <1000 | Zoned pegmatite | 13 |
| Tin | Qual* | Granite & granite pegmatite | 16 |
| Titanium | 0-26 | Various | 6 |
| | 8-128 | Granite | 3 |
| | 200 | Granodiorite | 3 |
| Uranium | 0.9 | Quartz seyenite | 8 |
| | 1.0 | Leucocratic granite | 8 |
| | trace | Not reported | 6 |
| Vanadium | trace | Not reported | 6 |

TABLE 1 (Continued)

| Element | Average/Range Concentration (ppm) | Association | Reference |
|---------|-----------------------------------|-------------|-----------|
| Zinc | trace | Not reported | 6 |
| | 0.6-18 | Various | 9 |
| Zirconium | trace | Not reported | 6 |

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*Qual = Qualitative analysis only.

References:
1. Balitskiy et al. (1969)
2. Borisenko and Tauson (1959)
3. Dennen (1964)
4. Dennen (1966)
5. Dunaev (1959)
6. Frondel (1962)
7. Kuroda and Sandell (1954)
8. Leonova and Pogiblova (1961)
9. Price and Ragland (1966)
10. Rabinovich and Baskova (1959)
11. Shrivastava and Proctor (1962)
12. Solodov (1960)
13. Stavrov (1961)
14. Stavrov and Khitrov (1960)
15. Studennikova et al. (1957)
16. Tatekawa (1954)

cations listed, such anions and complexes as $Cl^-$, $F^-$, $SO_4^=$, $HCO_3^-$, $CO_3^=$, and $OH^-$ have been reported to be present in some quartz samples (Frondel, 1962; Roedder, 1972). The data in Table II, taken from various authors, presents the average abundances in igneous rocks of the elements reported to be present in some quartz samples. It is interesting to note that in some cases, notably beryllium, boron, chromium, copper, germanium, gold, lithium, molybdenum and silver, the impurity content of quartz can exceed the average crustal or igneous rock abundance.

Most authors concerned with the non-fluid inclusion impurities in quartz (Balitskiy et al., 1969; Cohen & Sumner, 1958; Deer et al., 1963; Dennen, 1964, 1966, 1967; Dennen et al., 1970; Dennen and Puckett, 1972; Frondel, 1962; and Ritter & Dennen, 1964) generally agree that some solid solution substitution occurs. $Ti^{+4}$ and $Ge^{+4}$ can substitute for $Si^{+4}$ in the tetrahedral site. $Al^{+3}$ can also substitute for $Si^{+4}$. Small alkali ions such as $Li^+$, $Na^+$, or $H^+$ then must enter the interstitial site to maintain charge balance. Alternately, one interstitial $Al^{+3}$ ion can balance three substitutional $Al^{+3}$ ions provided balance is not achieved through oxygen vacancies. Dennen and Puckett (1972) also make a case for substitutional $Fe^{+3}$.

Another mode of occurrence of impurities in quartz is microscopic and sub-microcopic inclusions. According to Dennen (1966), such inclusions are properly included in an analysis of

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## TABLE 2

### AVERAGE ABUNDANCE OF THE ELEMENTS

(all data in ppm unless otherwise stated)

| ELEMENT | REFERENCE 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Aluminium | | | 8.13% | 8.9% | 7.7% | 8.13% |
| Barium | 640 | 830 | 425 | 650 | 830 | 250 |
| Beryllium | 4.2 | 5.5 | 2.8 | | | 2-6 |
| Boron | 13 | 15 | 10 | | | 3-30 |
| Calcium | | | 3.63% | 4.7% | 1.6% | 3.63% |
| Cesium | | | 3 | | | 7 |
| Chromium | 117 | 25 | 100 | 50 | 25 | 35-530 |
| Cobalt | 18 | 5 | 25 | 10 | 5 | 8-80 |
| Copper | 70 | 30 | 55 | 35 | 20 | 60-70 |
| Gallium | | | 15 | 20 | 20 | 15 |
| Germanium | | | 1.5 | | | 4 |
| Gold | | 0.01 | 0.004 | | | 0.005 |
| Hydrogen | | | 1400 | | | |
| Iron | 4.65% | 2.7% | 5% | 5.9% | 2.7% | 5.0% |
| Lead | 16 | 18 | 13 | 15 | 20 | 16 |
| Lithium | 50 | 70 | 20 | 20 | 40 | 65 |
| Magnesium | | | 2.09% | 2.2% | 0.6% | 1.26% |
| Manganese | 1000 | 600 | 950 | 1200 | 600 | 1000-2200 |
| Molybdenum | 1.7 | 1.9 | 1.5 | | | 2.5 |
| Potassium | | | 2.59% | 2.3% | 3.3% | 2.59% |
| Rubidium | | | 90 | 100 | 200 | 310 |
| Silver | 0.2 | 0.15 | 0.07 | | | 0.10 |
| Sodium | | | 2.83% | 3.0% | 2.8% | 2.83% |

TABLE 2 (Continued)

| ELEMENT | 1 | 2 | REFERENCE 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Tin | 32 | 45 | 2 | | | 40 |
| Titanium | 4400 | 2300 | 4400 | 8000 | 2300 | 4400 |
| Uranium | 2.6 | 3.5 | 1.8 | | | 4 |
| Vanadium | 90 | 40 | 135 | 100 | 40 | 150-310 |
| Zinc | 80 | 60 | 70 | | | 132 |
| Zirconium | | | 165 | 260 | 200 | 220 |

References:
1. Hawkes and Webb (1962), Average Igneous Rocks
2. Hawkes and Webb (1962), Average Felsic Igneous Rocks
3. Mason (1966), Average Crustal Abundance
4. Krauskopf (1967), Average Intermediate Igneous Rocks
5. Krauskopf (1967), Average Felsic Igneous Rocks
6. Rankama and Sahama (1950), Average Igneous Rocks

high temperature quartz. He maintains that "the large change in volume of the interstitial site in the high-low inversion implies that larger ions dissolved at high temperatures must be exsolved when quartz inverts to the low form."

According to Stavrov (1961), Dennen (1966), and Balitskiy et al. (1969), the dominant contaminants of quartz are those ions which are most abundant in the environment in which the quartz was formed and not necessarily those of best structural fit.

Some practical applications of quartz elemental impurity data have been suggested by Dennen (1966, 1967), Dennen et al., (1970), Kamentsev (1963), Price and Ragland (1966), Stavrov and Khitrov (1960), and Stavrov (1961). Preliminary work by these investigators indicates that grossly different rock types exhibit reasonably systematic differences in the impurity element content of their associated quartz.

Dennen (1964) has attempted to show that at least the major element impurities (Mg, Fe, Ti, Al) in quartz are unique for individual intrusives. He has used the impurity content of quartz as an additional bit of evidence to prove or disprove the genetic relationship between spatially related stocks.

Dennen (1967) has also suggested using the impurity element "fingerprint" of quartz in quartz-bearing sedimentary rocks as a means of determining provenance.

Price and Ragland (1966) proposed that the iron content of the vein quartz that they studied may reflect the total

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amount of metallic mineralization in the vein.

Stavrov and Khitrov (1960) suggest the possibility of using the boron content of quartz to distinguish tourmaline-bearing from barren pegmatites.

Stavrov (1961) also proposes the use of the lithium content of quartz to distinguish between lithium-bearing and barren pegmatites. He found that quartz samples from lithium-bearing pegmatites contain at least an order of magnitude more lithium than quartz from barren pegmatites.

Kamentsev (1963), Komov & Novozhilov (1968) and Dennen, et al. (1970) propose the use of the impurity content of quartz, particularly the element aluminum, as a geothermometer.

Apparently no one has attempted to determine the applicability of quartz elemental impurity data to distinguish porphyry copper mineralized from barren intrusives. The presumed similar mode of origin and the close tectonic relationships among the various porphyry copper deposits are pointed out by Guilbert and Sumner (1961). Stringham (1966) points out the compositional and textural similarities of intrusives associated with porphyry copper deposits. It is reasonable to hope that if the fluids which formed porphyry copper deposits were grossly similar, then that fact should be reflected in the elemental impurity content of associated quartz.

SAMPLE DESCRIPTION

Hand speciman size samples were collected at operating porphyry copper deposits in Arizona and New Mexico. The

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deposits sampled include Ray, Inspiration, Christmas, Twin
Buttes, San Manuel, San Juan, Arizona and Tyrone and Santa
Rita, New Mexico. Samples from Kennecott's Safford, Arizona
property were also obtained. The personnel at Ray, Arizona
were kind enough to provide several diamond drill core samples
in addition to outcrop samples. Samples of Sandia Granite,
Embudo Granite and an unnamed Precambrian granite south of
Tyrone were also collected for comparison.

Several miscellaneous samples collected from areas of
non-porphyry copper mineralization were available and were
analyzed. These include samples from the fault fissure vein
lead/copper deposit at Bingham, New Mexico, the fault fissure
vein zinc/lead/silver deposit at Silverton, Colorado, the fault
fissure vein gold deposit at Goldfield, Nevada, the volcanogenic
massive sulfide copper deposit at Elizabeth, Vermont, and igneous
iron ore deposit at Durango, Mexico. Appendix A contains a
brief description of each sample.

SAMPLE PRE-PREPARATION

Samples were disaggregated with a jaw crusher. Thin
quartz veins were isolated by slabbing the samples with a diamond
saw prior to crushing. The disaggregated samples were then
sieved and the -20 +60 standard mesh size fraction retained
for subsequent separation of the quartz. This size fraction
provided physical isolation of most of the quartz grains from
other minerals in the samples. In addition, this size fraction
provided individual grains of sufficient size to be easily

manipulated under a binocular microscope. Whatever subsequent quartz concentration procedure was to be tried, the final procedure was to be that of separating contaminated and inclusion-bearing quartz from pure quartz by hand picking under a microscope. In addition, it was determined that a sample much larger than the 2 to 5 milligrams typically used by Dennen (1964, 1966) would be required. A larger sample size reduces the problem of obtaining a representative sample as well as improving the limits of detection within the sample.

QUARTZ ISOLATION

A research project, tributary to the main question of interest, was embarked upon in an effort to devise a rapid method of quartz isolation. The ideal method hoped for was one that would be amenable to batch processing wherein unique sample characteristics, such as degree of alteration, would not require a unique procedure for each individual sample.

I was as disturbed as Clocchiatti and Touray (1971) apparently were to discover that isolation of pure quartz is neither as simple or as rapid as implied by Dennen in his numerous publications. It soon became apparent why many publications on the subject of the contaminating elements in quartz include a bare minimum number of samples (e.g. Shrivastava and Proctor (1962), 7 samples; and Price and Ragland (1966), 14 samples).

Quartz isolation procedures such as those described by Sheppard et al. (1971) require grinding to silt size particles

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which are difficult to manipulate at the final purification stage. In addition, the methods typically result in a sample of only about 95% purity. When attempting to determine the concentrations of a large number of elements in a mineral normally as pure as quartz, 95% sample purity is obviously not acceptable.

Several physical and chemical methods were investigated, with varying degrees of success, that promised a high degree of quartz concentration. The concentration methods investigated include magnetic separation, heavy liquid separation, cationic froth floatation, differential comminution, selective digestion with fluxes and selective digestion with acids.

Magnetic Separation. Separation of quartz from most other minerals, though difficult, is possible with a well tuned Frantz isodynamic magnetic separator. Published separation procedures typically require fine grinding of the sample (Rosenblum, 1958; Dean & Davis, 1941). As previously mentioned, this was deemed undesirable for the present study. At any rate, a commercial Frantz separator was not available for separating the samples used in this study. The possibility of using the magnetic properties of the minerals to effect separation was nevertheless investigated. A project was undertaken to build a magnetic separator. A large electromagnet with moveable ten centimeter diameter pole pieces and a power supply were available. An adjustable vibrating table similar in principal to those described by Allman and Lawrence (1972) and Dean & Davis (1941) was

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constructed.

Tests were conducted to determine the optimum configuration and the separation efficiency of the equipment at hand. The configurations investigated included the uniform magnetic field and variable table orientation used in the Frantz separator as well as nonuniform field configurations suggested by Taggert (1954) and Gaudin (1939).

A nonuniform magnetic field employing tractive force was found to be the most effective for the coarse samples used. In the optimum configuration of the separator used in this study, the flux density across the 2.5 cm vibrating table varied from 5000 Gauss at one pole piece to 2000 Gauss at the other.

Separation of quartz from biotite, muscovite, chlorite and minerals with heavy iron oxide coatings was obtained. The separation of quartz from feldspar, both having very low and almost identical magnetic susceptibilities, was not obtained. Refinement of the magnetic separator in order to obtain this separation was not attempted because of the prohibitive cost in terms of design time, shop time and material. However, many of the samples were pre-concentrated with the magnetic separator.

Heavy Liquid Separation. An attempt was made to use bromoform and bromoform-acetone mixtures to effect separation of quartz. It soon became apparent that heavy liquid separations would be a messy and tedious procedure with only limited success.

Table 3, taken from Lange (1946) and Allman and Lawrence

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## TABLE 3

### SPECIFIC GRAVITY OF MINERALS

| Mineral | Average Range Specific Gravity |
|---|---|
| Quartz | 2.65 |
| Chlorite | 2.65-2.94 |
| Serecite | 2.76-3.00 |
| Orthoclase | 2.56-2.58 |
| Albite | 2.60-2.62 |
| Andesine | 2.68 |

(1972) gives the specific gravities of the minerals most commonly found in the samples used in this report and whose separation is the most difficult.

The specific gravity range of feldspar overlaps that of quartz. The success, or lack thereof, of separating quartz from feldspar at the particle size range used in this study is intimately related to the initial composition of the feldspar as well as the degree of feldspar alteration. Sample separations proved to be unique for each individual sample and thereby were not amenable to routine processing of large numbers of samples. Because of the limited success, potential for contamination, and time consuming nature of the procedure, heavy liquid separation was abandoned as a practical routine sample concentration technique.

Cationic Froth Flotation. The separation of quartz from feldspar, micas, iron oxides, and clays is technically feasible as indicated by technical publications from Armour Hess (1974)

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and other flotation reagent manufacturers. Cationic froth flotation is used in the purification of silica sand for the glass industry. However, flotation was not attempted in connection with concentration and purification of quartz for this study. Because of the diversity of physical properties, including mineralogic composition and degree of alteration of samples, each sample would have presented its own unique flotation problems, much as in heavy liquid separation.

Differential Comminution. Some concentration of quartz was possible for samples whose feldspar was appreciably altered. A portion of the +20 mesh fraction of the sample was placed in an iron mortar and ground with an iron pestle by applying no more pressure than that provided by the weight of the pestle. The size of the altered feldspar was more rapidly reduced than the size of the quartz grains. A fair degree of concentration of quartz was achieved by alternate light grinding and sieving. However, the samples were differentially contaminated with traces of iron from the mortar, and the resulting concentrate still had to be laborously hand picked. Differential comminution was also abandoned as a routine sample processing procedure.

Fusions. The potential for effecting quartz separation using several fluxing reagents in combination with various acid attacks was investigated.

Maxwell (1968) suggests the use of a potassium pyrosulfate fusion to obtain separation of quartz and opal from other silicates in a rock. Potassium pyrosulfate fusions in borosilicate

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glass were tried on several of the samples. The resulting
fusion cakes were leached with hydrochloric, nitric and sulfuric
acids. Quartz in the samples was apparently not attacked.
Micaceous minerals and sulfides were digested, but feldspars
were not digested or sufficiently attacked to permit their
removal by sieving the samples again.

Selective decomposition of several samples was attempted
with a fusion mixture of sodium and potassium carbonate in
platinum crucibles at $1000^{\circ}C$. Quartz and feldspar were both
etched by the fusion to about the same degree. Fresh unaltered
feldspars were considerably bleached but proved to be no more
amenable to acid attack than untreated feldspars.

Low ($150^{\circ}C$) and high ($600^{\circ}C$) temperature fusions with
variable fusion times were attempted with sodium and potassium
hydroxides in iron and nickel crucibles. Both quartz and
feldspar were attacked by these fluxes. Sodium hydroxide was
slightly more effective and appeared to attack feldspar more
rapidly than quartz. From sample to sample the predictability
of the degree of preferential decomposition of feldspar over
quartz was not sufficient to warrant routine use of the basic
fluxes.

Lithium metaborate fusions in graphite crucibles at $950^{\circ}C$
proved to have the same short-comings of predictability as the
alkaline hydroxide fusions.

Selective Acid Digestion. It is not possible to obtain the
separation of quartz from feldspar by digestion of the sample

with the more common mineral acids. Syers et al., (1968) suggest a method of obtaining a high purity quartz concentrate with hydrofluosilicic acid. Their method involves fine grinding of the sample and fusion with sodium pyrosulfate which removes most minerals except quartz and feldspar. They treat the fusion residue with hydrofluosilicic acid ($H_2SiF_6$, "Fluosilicic Acid" of Fisher Scientific), which they claim completely removes the feldspar. The method was tried and found to work remarkably well, even on the large size fraction employed in this study. It was discovered that the sodium pyrosulfate fusion was not necessary in order to obtain quartz isolation.

Summary Of Quartz Isolation Procedure Used. A standard procedure was finally settled upon for isolation of quartz for the purpose of this study. The -20 +60 standard mesh size fraction of the samples were pre-concentrated with the magnetic separator that had been manufactured. That served to remove a substantial amount of the more magnetically susceptible minerals in the samples. The samples were then placed in polypropylene beakers and leached with fluosilicic acid for approximately 24 hours. The fluosilicic acid was then decanted and the samples rinsed two times with deionized water. The samples were next leached with aqua regia for approximately 24 hours. The aqua regia served to remove sulfides not attacked by the fluosilicic acid and to further alter the feldspars. The aqua regia was then decanted and the samples rinsed two more times with deionized water.

At that stage of digestion the feldspars in the samples were not completely digested but were highly altered to an opaque white material resembling kaolinite. The original volume of the feldspar grains was still retained but their structure consisted of a delicate and friable open boxwork-like lattice of aluminum oxide. That delicate structure of the feldspar was taken advantage of in subsequent treatment.

A third portion of deionized water was then placed in the sample container. The delicate feldspar residue was disaggregated by insertion of a ultrasonic probe into the sample container. The instrument used for this purpose was a Lab-Line Ultratip Labsonic System fitted with a half wave titanium step horn. The probe was operated at 80 watts power output for one minute for each successive treatment. The 80 watts of power was dissipated by the one half square inch surface area of the probe tip. The ultrasonic probe effectively disrupted the delicate altered feldspar framework and produced a milky white slurry. The slurry was carefully decanted and the procedure repeated until the ultrasonically treated sample rinse solution remained clear. This was typically accomplished in four or five applications of the probe.

A few grains of altered feldspar remained in the samples after this treatment. Most of these were easily removed by sieving the sample again through a 60 standard mesh nylon screen.

The next step in the procedure was to purify the quartz by removal of grains that contained inclusions. This was accomplished

in a manner similar to that described by Dennen (1964).

The samples were placed on a glass plate and viewed first against a black background and then against a white background with a 10X binocular microscope. The black background facilitated identification and removal of any remaining feldspar contaminants. The white background served to identify inclusions and surface coatings on the quartz grains. Unwanted minerals and inclusion-bearing quartz grains were pushed off the glass plate with a 17 gauge stainless steel hypodermic needle.

In order to check the purity of quartz at this stage, the samples were immersed in acetone and viewed against a white background. The refractive index of acetone is close to that of quartz. Any inclusions missed in the first examinations became obvious under the acetone, and the remaining inclusion-bearing grains were removed.

The purified samples were than transferred to 9 dram polystyrene snap cap vials for subsequent weighing, digestion and analysis.

ANALYTICAL METHOD

The analytical method employed consisted of digestion of the samples and qualitative emission spectrographic analysis.

Quartz Digestion. The particular emission spectrographic analytical method used for analysis required that the sample be in solution form. 0.3000 to 0.5000 grams of the purified quartz samples were weighed on a Ainsworth chainomatic balance and transferred to a 50 milliliter polypropylene tri-pour beaker.

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Ten milliliter portions of reagent grade hydrofluoric acid were then measured with a ten milliliter capacity Nalgene graduate cylinder and added to each sample beaker. The samples plus acid were then allowed to stand overnight in a fume hood. The following morning, 25 milliliters of concentrated reagent grade nitric acid was measured into a 50 milliliter Nalgene graduate cylinder and added to each sample. The samples had been placed on a sand bath on a variable temperature hot plate. After addition of the nitric acid, the hydrofluoric/nitric acid solution of each sample was evaporated to dryness at $100^{\circ}C$. The resulting residue was digested in ten milliliters of one Molar hydrochloric acid. Lids were placed on the tri-pour beakers while the samples awaited analysis.

Instrument Description. A Spectrametrix Inc., Model 101, SpectraSpan Atomic Analysis System was used for all determinations. The instrument is a direct reading, high resolution, high dispersion, high energy throughput spectrometer coupled with a high temperature argon plasma excitation source. The instrument has been updated by the addition of SpectraSpan III System echelle grating, SpectraJet, and signal handling electronics package.

The plasma jet utilizes argon ions to dissociate the sample molecules into atomic vapor and "excite" the resulting atoms to high emissive levels at approximately $10,000^{\circ}K$. Samples are introduced into the plasma by nebulizing a solution and pre-mixing the resulting mist with argon. The sample

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solution is delivered to the nebulizer mixing chamber through
a memory free 0.030 inch I.D. silicone tubing with a six rotor
peristaltic pump.

The spectrometer of the instrument consists of a echelle
grating and quartz prism in a modified Czerny-Turner configuration.
The prism is oriented to disperse normal to the optical plane
of the Czerny-Turner resulting in a two dimensional or stacked
spectral display. The instrument has a 0.75 meter focal length,
f/10 speed, reciprocal linear dispersion of 0.65 Angstroms per
millimeter and a resolution of 0.006 Angstroms at 2000 Angstroms.
The position of the spectrum may be shifted by rotating the
grating and thereby allow positioning of a desired wavelength
on the exit slit.

The readout section of the instrument provides automatic
background correction by means of a triple exit slit and
tuning fork chopper that alternates the signal received by a
photomultiplier tube between the two side slits and the exit
slit. The chopped output signal of the photomultiplier tube
is demodulated by an lock-in amplifier. The readout signal is
presented as the voltage output of an operational amplifier
with a variable time constant. A Hewlett-Packard strip chart
recorder was used to record the output signal.

Instrumental operating parameters are given in Table 4.
Table 5 gives the analytical wavelengths used and the order
of magnitude of the sensitivities obtained for the various
elements investigated.

TABLE 4

TYPICAL INSTRUMENTAL OPERATING PARAMETERS

| | |
|---|---|
| Operating Mode | Emission |
| Argon Flow Rates (at 42 P.S.I.) | |
| Aspirator/Nebulizer | 5.5 c.f.h. |
| Anode/Cathode | 3.5 c.f.h. |
| Plasma Current | 6.0 amps |
| Time Constant | 1 |
| Entrance Slit | 200 X 200 microns |
| Exit Slit | 200 X 400 microns with two 100 X 400 side slits |
| Sample Aspiration Rate | 0.5 milliliters per minute |

Analytical working curves were constructed on three by five cycle full logarithmic paper. Data for constructing the curves were obtained by aspirating prepared standards of suitable concentrations so as to bracket sample concentrations for the various elements. The working curves were all linear over the concentration ranges encountered in the samples.

Reagent blanks were generally quite low or below the detection limit for the various elements. Where positive blanks were encountered, the values were subtracted from the values obtained for the samples. Table 6 provides a list of the mean and standard deviation of blank levels encountered for 22 blanks analyzed through the course of the study. Absense of an element from Table 6 indicates a consistent blank level below the detection limit.

Precision And Accuracy. Precision of the analytical method was determined by six to ten replicate determinations

TABLE 5

ANALYTICAL WAVELENGTHS

| Element | Line Used | Order of Magnitude of Detection limit (ppm) |
|---------|-----------|---------------------------------------------|
| Aluminum | 3961.5 | 0.1 |
| Barium | 4554.0 | 0.001 |
| Beryllium | 2348.6 | 0.01 |
| Boron | 2497.7 | 0.1 |
| Cadmium | 2288.0 | 0.1 |
| Calcium | 4226.7 | 0.001 |
| Cobalt | 3453.5 | 0.1 |
| Copper | 3247.5 | 0.01 |
| Iron | 3737.1 | 0.1 |
| Lead | 4057.8 | 0.1 |
| Lithium | 6707.8 | 0.01 |
| Magnesium | 2852.1 | 0.01 |
| Manganese | 4030.8 | 0.1 |
| Molybdenum | 3864.1 | 0.1 |
| Nickel | 3524.5 | 0.1 |
| Potassium | 7664.9 | 0.1 |
| Rubidium | 7800.2 | 0.1 |
| Sodium | 5890.0 | 0.01 |
| Strontium | 4077.7 | 0.01 |
| Titanium | 3653.5 | 0.1 |
| Vanadium | 3093.1 | 0.1 |
| Zinc | 2138.6 | 0.1 |
| Zirconium | 3438.2 | 1.0 |

on five different samples. In addition, 20% of all the samples were analyzed in duplicate. The average range in concentration for all elements was found to vary by less than ± 15%. Dennen (1964) reports a considerably greater variation within a given hand speciman size sample. His data indicate a lognormal

distribution of analytical values within a given hand speciman size sample. The fact that the sample size used in this study was approximately 100 times greater than that used by Dennen probably obscures this lognormal pattern. In fact, the lognormal distribution obtained by Dennen may be an affectation induced by the very small sample size that he used.

TABLE 6

REAGENT BLANK LEVELS

| Element | Mean Content (ppm) | One Standard Deviation |
|---|---|---|
| Aluminum | 0.23 | 0.07 |
| Boron | 0.10 | 0.06 |
| Calcium | 1.4 | 0.36 |
| Copper | 0.02 | 0.0015 |
| Iron | 1.0 | 0.23 |
| Potassium | 0.41 | 0.31 |
| Magnesium | 0.13 | 0.06 |
| Sodium | 1.05 | 0.13 |
| Titanium | 2.0 | 0.30 |

It is not the purpose of this paper to review the myrid problems associated with insuring a representative sampling because they are generally well known.

An effort was made to obtain at least a qualitative estimate of the Overall accuracy or the analytical method. Aliquots of the U.S.G.S. and Canadian Department of Energy, Mines and Resources silicate rock standards were digested by the procedures outlined above and analyzed. The standards used were U.S.G.S. W-1, G-2, AGV-1 and GSP-1 and Canadian SY-2 and SY-3. Appendix III, compiled from data by Blackburn et al. (1971),

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Fleischer (1969), Faye (1969), and Flanagan (1969) gives the recommended values for the standards and the values found in this study for the various elements. Agreement is generally within one standard deviation for those elements reported by Blackburn, et al. (1971). Agreement between recommended values and values found in this study is better for the U.S.G.S. standard rocks than for the Canadian rock standards. It must be kept in mind, however, that the values for the relatively new Canadian standards are only provisional. One has only to recall the analytical history of the U.S.G.S. standards to appreciate the inherent implications of a provisional value. The notable exceptions to the analytical precision claimed herein are the cases of boron and molybdenum. This author has joined the rest of the world in the apparent confusion over best boron values (see previous references) for the various rock standards. Molybdenum values reported herein are high by approximately one order of magnitude for half of the standards. Because molybdenum did not appear to be present in significantly large numbers of samples, the cause for the analytical difficulty was not pursued in connection with this investigation.

ANALYTICAL RESULTS

All samples were routinely analyzed for aluminum, boron, barium, beryllium, calcium, copper, iron, lithium, magnesium, manganese, molybdenum, potassium, sodium, strontium, titanium,

25

and zinc. After these analyses were completed, the remaining
sample solutions were used to randomly check for the presence
of cadmium, cobalt, lead, nickel, rubidium, vanadium, and
zirconium.

In addition, twelve samples from Ray, Twin Buttes, and
Santa Rita were analyzed for these last elements and found
to contain less than the detectable limit. Those particular
samples had been prepared prior to the development of the
final quartz separation technique and were known to be
contaminated. I think that it is reasonable to assume that
cadmium, cobalt, nickel, lead, rubidium, vanadium and
zirconium are absent from the samples.

Appendix B contains a summary of the analytical results
obtained for all samples.

QUALITATIVE INTERPRETATION OF DATA

Major elements (Al, Ca, Fe, K, Mg, Mn, Na, & Ti). Table
7 provides a qualitative summary of the major element
impurity content of quartz from various environments. The
data are taken from Dennen (1964) and this report. The table
provides a comparison of the percentages of samples in which
the major elements have been found as a function of gross
rock type or association.

With the exception of manganese, all porphyry copper
associated quartz samples are qualitatively similar to
quartz from granitic rocks in their major element content.

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TABLE 7

## PRESENCE OF MAJOR ELEMENTS IN QUARTZ
## FROM VARIOUS ROCK TYPES

| ROCK TYPE | PER CENT OF SAMPLES IN WHICH FOUND | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Al | Ca | Fe | K | Mg | Mn | Na | Ti |
| **Data from Dennen (1964):** | | | | | | | | |
| Granitic rocks | 100 | 94 | 94 | | 98 | 8 | | 96 |
| Rhyolites | 100 | 100 | 56 | | 89 | 0 | | 78 |
| Pegmatites | 94 | 48 | 48 | | 64 | 3 | | 39 |
| High-grade meta-morphic rocks | 100 | 54 | 57 | | 100 | 0 | | 16 |
| Crystal quartz | 92 | 15 | 46 | | 85 | 0 | | 8 |
| Veins | 10 | 55 | 35 | | 70 | 5 | | 30 |
| **Data from this report:** | | | | | | | | |
| All porphyry copper related quartz | 100 | 86 | 93 | 100 | 99 | 100 | 99 | 86 |
| All porphyry copper related veins | 100 | 89 | 94 | 100 | 98 | 100 | 98 | 87 |
| All porphyry copper related sulfide bearing veins | 100 | 86 | 96 | 100 | 100 | 100 | 98 | 84 |
| All porphyry copper related molybdenite bearing veins | 100 | 94 | 94 | 100 | 100 | 100 | 100 | 100 |
| Porphyry copper related phenocrysts | 100 | 88 | 88 | 100 | 100 | 100 | 100 | 75 |
| Non-porphyry related intrusives | 100 | 93 | 73 | 100 | 100 | 100 | 100 | 93 |
| Non-porphyry related metamorphics | 100 | 100 | 100 | 100 | 100 | 100 | 80 | 80 |
| All miscellaneous base and precious metal related veins | 100 | 83 | 83 | 100 | 100 | 100 | 71 | 33 |

The two data sets are not strictly comparable because the detection limits of the two analytical methods used to generate the data are not the same. Detection limits for the method employed in this study are lower than Dennen obtained.

The mean value for manganese for non-porphyry related granitic rock quartz in this study is 6.7 ppm. This value is lower than the 10 ppm detection limit claimed by Dennen. Only 27% of the granitic rock samples from this study had manganese values greater than 10 ppm. Of all porphyry copper related samples, 26% had values greater than 10 ppm.

Dennen (1964) does not report potassium and sodium data because of the poor analytical precision that he obtained for these elements. A qualitative evaluation of potassium and sodium data from this study does not reveal any significant differences between the porphyry copper related and granitic rock samples.

Comparison of the major element data from vein quartz provides some striking contrasts. Dennen reports that only 10% of the vein quartz that he analyzed contained detectable aluminum. 100% of the vein quartz from porphyry copper deposits in this study were found to contain aluminum, and these with a mean concentration of 350 ppm.

86% of porphyry copper related quartz samples were found to contain detectable amounts of titanium as opposed 30% of the vein quartz analyzed by Dennen. Differences in

detection limit for titanium between the two analytical
methods do not account for this disparity. The titanium
values in the porphyry copper related samples are generally
at least an order of magnitude greater than the 5 ppm
detection limit claimed by Dennen.

A higher percentage of vein samples from porphyry
copper environments were found to contain calcium, iron,
and magnesium than non-porphyry related vein samples.

The disparity in manganese data previously mentioned
also applies to comparison of the vein data. The difference
of 100% of the porphyry samples containing manganese and
none of the unrelated veins containing manganese is
probably a function of differences in detection limits.

Table 8 provides a summary of the percentages of the
samples that were found to contain detectable quantities
of boron, barium, beryllium, copper, lithium, molybdenum,
strontium and zinc. Comparable data by other are not
available. Comparison of these data for porphyry copper
related samples and samples from barren intrusives reveals
no significant qualitative differences for boron, barium,
copper, lithium and strontium. Almost half of the porphyry
copper related samples show detectable beryllium. The
intrusive and metamorphic samples show no detectable
beryllium. 11% of the sulfide bearing quartz veins from
porphyry copper deposits contain detectable molybdenum while

## TABLE 8

### PRESENCE OF MINOR ELEMENTS IN QUARTZ

### FROM VARIOUS ROCK TYPES

| ROCK TYPE | PER CENT OF SAMPLES IN WHICH FOUND | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | B | Ba | Be | Cu | Li | Mo | Sr | Zn |
| All porphyry copper related quartz | 62 | 95 | 42 | 99 | 99 | 7 | 99 | 56 |
| All porphyry copper related veins | 62 | 96 | 40 | 98 | 98 | 9 | 98 | 56 |
| All porphyry copper related sulfide-bearing veins | 61 | 96 | 41 | 100 | 98 | 11 | 98 | 59 |
| All porphyry copper related molybdenite-bearing veins | 39 | 94 | 44 | 100 | 94 | 11 | 100 | 44 |
| All porphyry copper related barren veins | 45 | 100 | 55 | 91 | 100 | 0 | 100 | 55 |
| All porphyry copper related phenocrysts | 33 | 83 | 33 | 100 | 100 | 0 | 100 | 50 |
| Non-porphyry related intrusives | 73 | 93 | 0 | 100 | 93 | 0 | 86 | 20 |
| Non-porphyry related metamorphics | 20 | 100 | 0 | 100 | 20 | 0 | 100 | 80 |
| All miscellaneous base and precious metal related veins | 29 | 83 | 33 | 100 | 100 | 0 | 100 | 50 |

non-porphyry related samples show none. Zinc is present in a greater number of porphyry copper related samples than in unrelated granitic rock quartz.

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QUANTITATIVE INTERPRETATION OF DATA

Statistical evaluation of the great quantity of data presented in this report is difficult without the aid of a computer. Unfortunately, one was not available this study. The statistical calculations that were made were performed with the aid of a Hewlett Packard Model 65 programmable hand calculator and by graphical means such as those suggested by Lepeltier (1969). Appendix D presents a statistical summary of mean values and standard deviations for all elements found to be present in samples included in this study.

Major elements (Al, Fe, Mg, Ti). Figure 1 presents the major element "fingerprint" for quartz from various granitic rocks presented by Dennen (1964) as well as the fingerprints for all of the sulfide bearing veins and intrusives analyzed in this study. No significant discriminating characteristics for porphyry copper related samples are obvious from the figure. Modal values for the porphyry copper related samples do follow the general concentration relationship Al > Ti > Fe. Only half of the granitic rock quartz samples studied by Dennen and non-porphyry related samples studied in this report follow this relationship.

Alkali metals (Li, Na, K). Figure 2 gives the alkali metal distributions in the form of mean values for the individual porphyry copper deposits, non-porphyry related
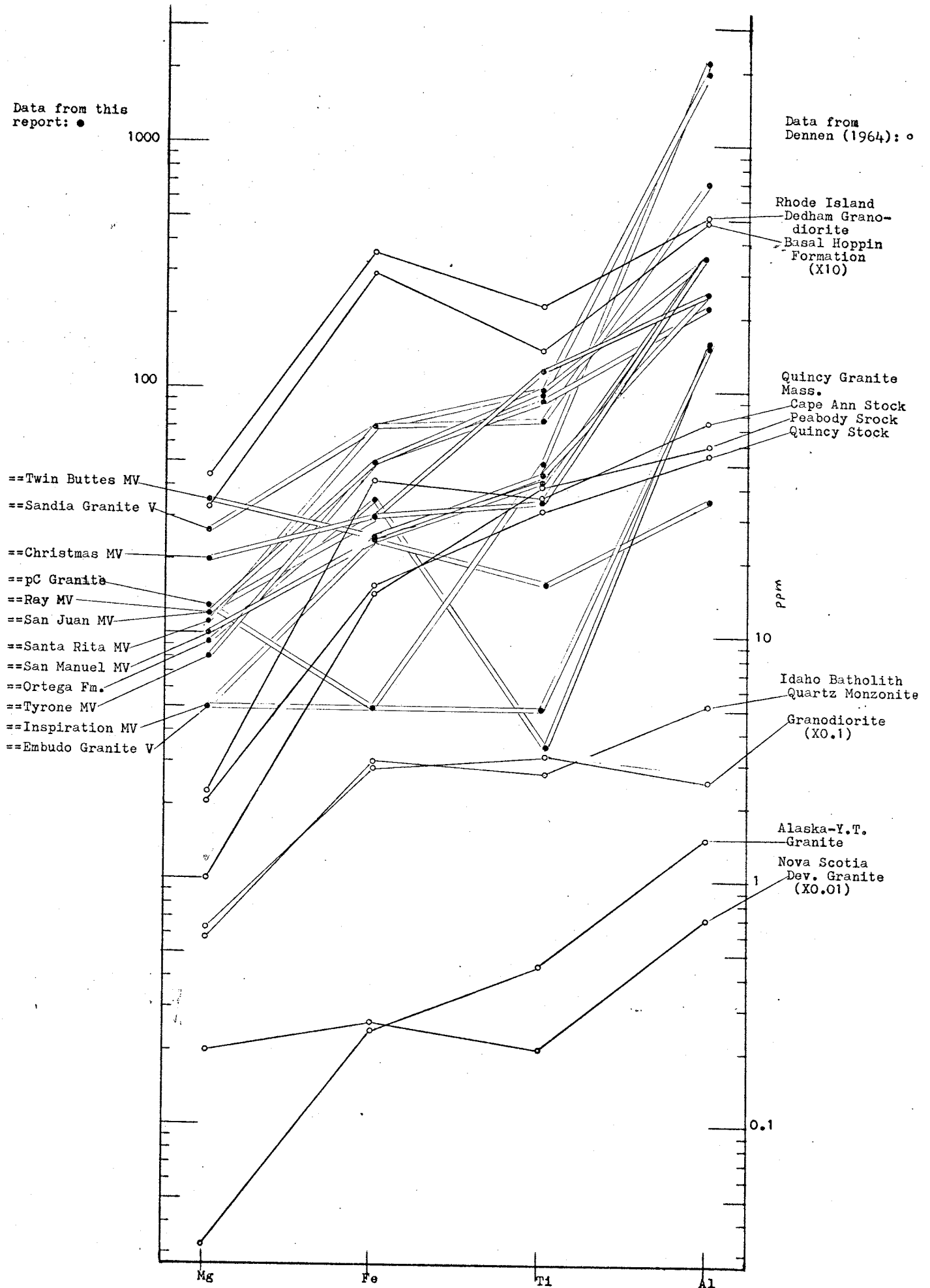
Figure 1. Comparison of major element impurities in quartz from various environments.
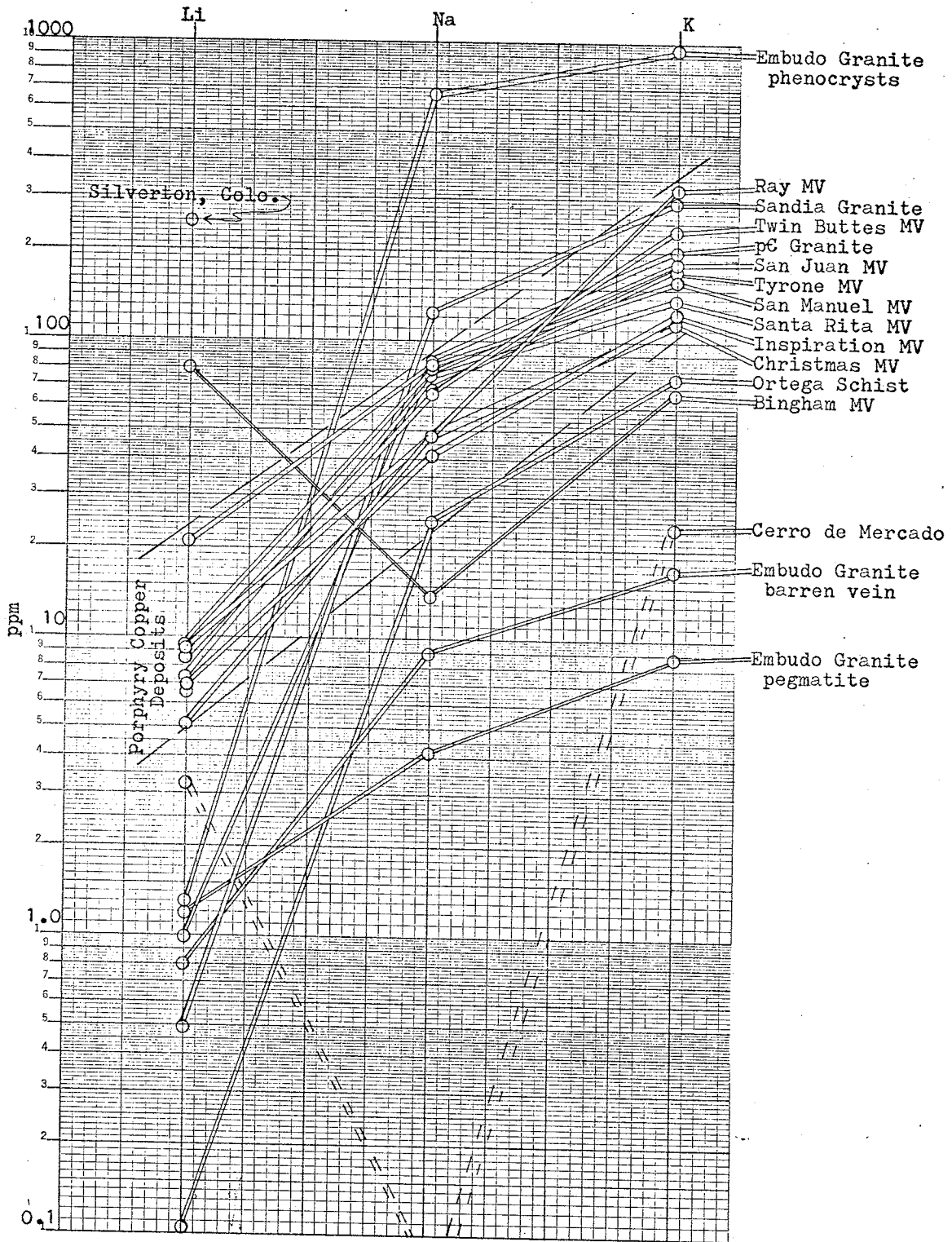
Figure 2. Distribution of alkali metals in
quartz from various environments.

intrusives, veins, pegmatites, metamorphic rocks, and base metal veins. With some remarkable exceptions, the alkali metal profiles follow the general felsic rock abundance distribution of K > Na >> Li.

The alkali metal profiles for all porphyry copper related mineralized vein samples all fall within discreet value limits. The limits may be seen to be Li,5 to 25 ppm, Na, 35 to 90 ppm, and K, 110-to 350 ppm. With the exception of lithium, non-porphyry related samples may fall above, below, or within these limits. The lithium range contains no non-porphyry copper related samples.

An interesting anomaly in alkali metal distribution occurs in the base metal vein samples. The alkali distribution for these samples is Li > K > Na, which is unlike any general abundance relationship.

The sodium and potassium content of quartz does not appear to provide a discriminating factor in identifying porphyry copper mineralization. The lithium content, on the other hand,may be of some use. There is, in fact, some hint from the data that the lithium content of quartz may be useful as a general indicator of mineralization.

Alkaline earth metals (Be, Mg, Ca, Sr, Ba). Figure 3 shows the various distributions of mean values for the alkaline earth metals. The distributions are generally of the same form, Ca > Mg > Sr > Ba > Be, as general elemental
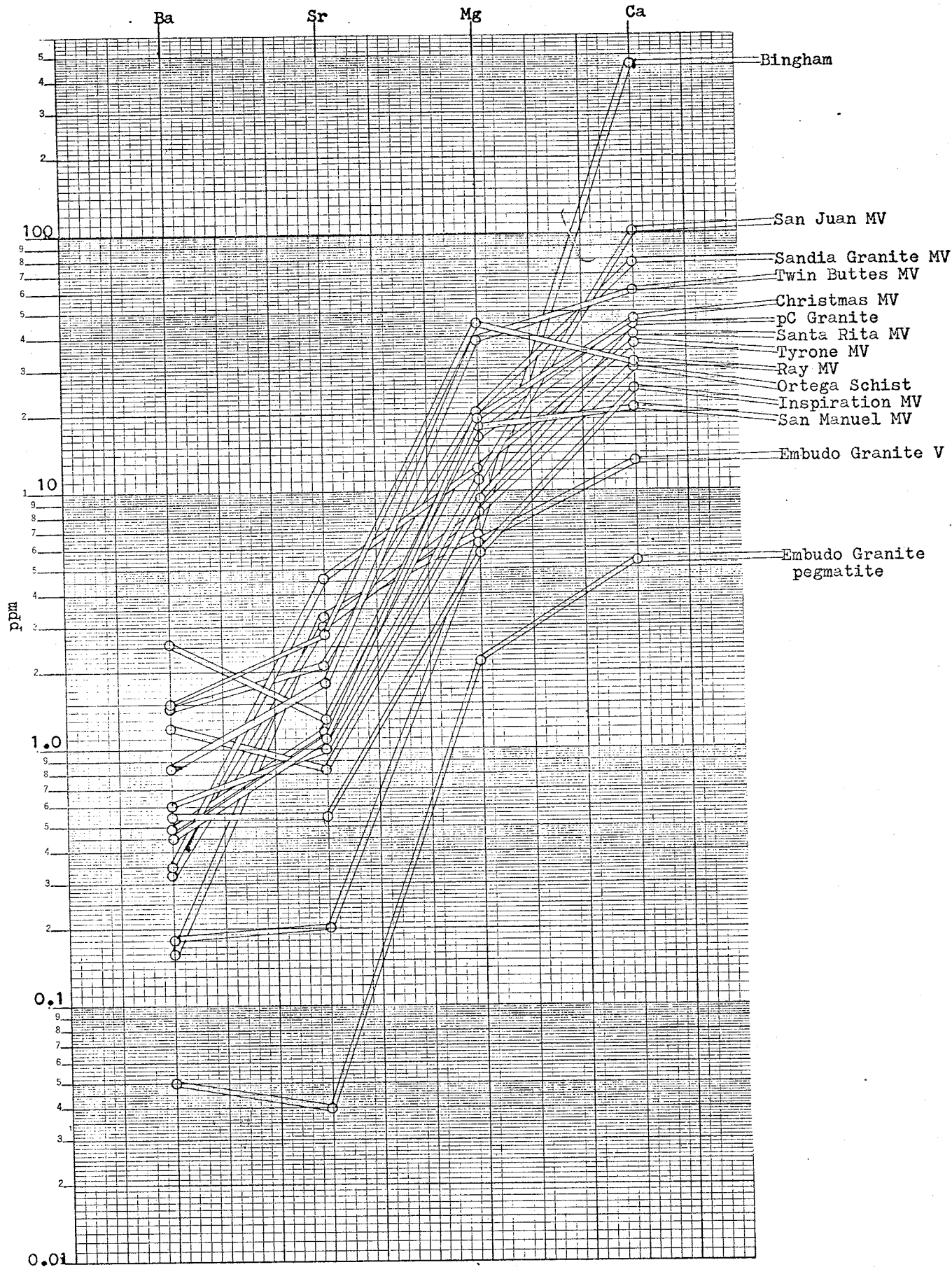
Figure 3. Distribution of alkaline earth metals in quartz from various environments.

abundances. Beryllium mean values were not plotted because only about half of the samples contained measurable beryllium. The presence of this element, as previously mentioned, does correlate with mineralization.

The alkaline earth distributions shown in figure 3 do not appear to provide any unique features that would allow a distinction to be made between porphyry copper and un-mineralized intrusives.

Other elements found in quartz (B, Cu, Fe, Mn, Zn). Figure 4 gives the distributions of these elements in the quartz samples from the various environments. Iron and manganese do not appear to be particularly diagnostic.

The conclusion of Price and Ragland (1966) that the iron content of quartz vein material reflects the total metallic mineralization in a vein is apparently refuted by the present data. Their contention that the copper and zinc content of quartz correlates with the presence of gold and silver cannot be adequately evaluated because of the limited number of samples from precious metal deposits. Copper and Zinc do tend to be higher in samples from porphyry copper deposits than in samples from barren intrusives. Boron tends to be relatively low in porphyry copper related samples.

Unique features of quartz from porphyry copper deposits (B, Be, Cu, Li, Zn). Figure 5 shows the distributions of
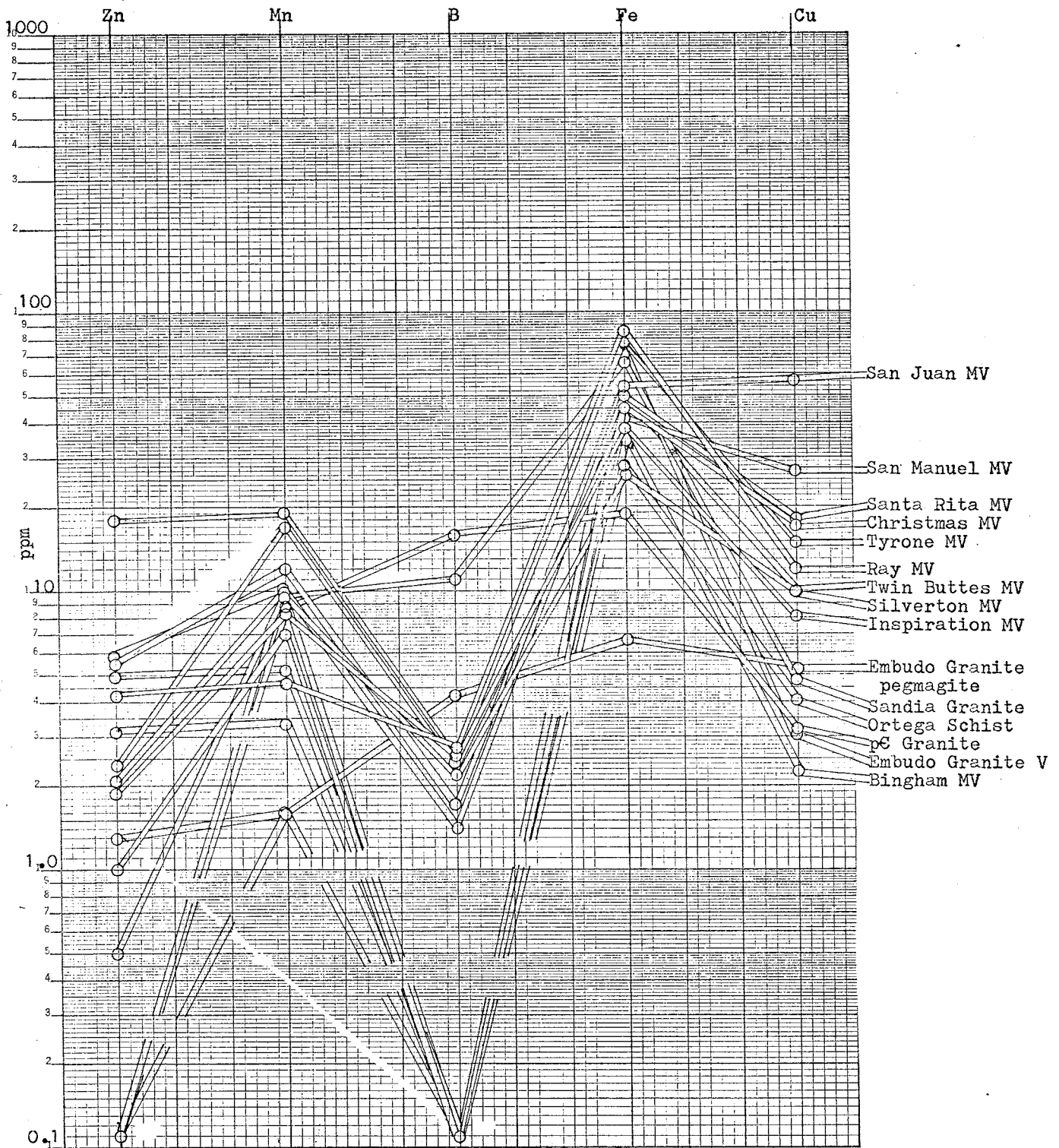
Figure 4. Distribution of Zinc, Manganese, Boron, Iron, and Copper in quartz from various environments.
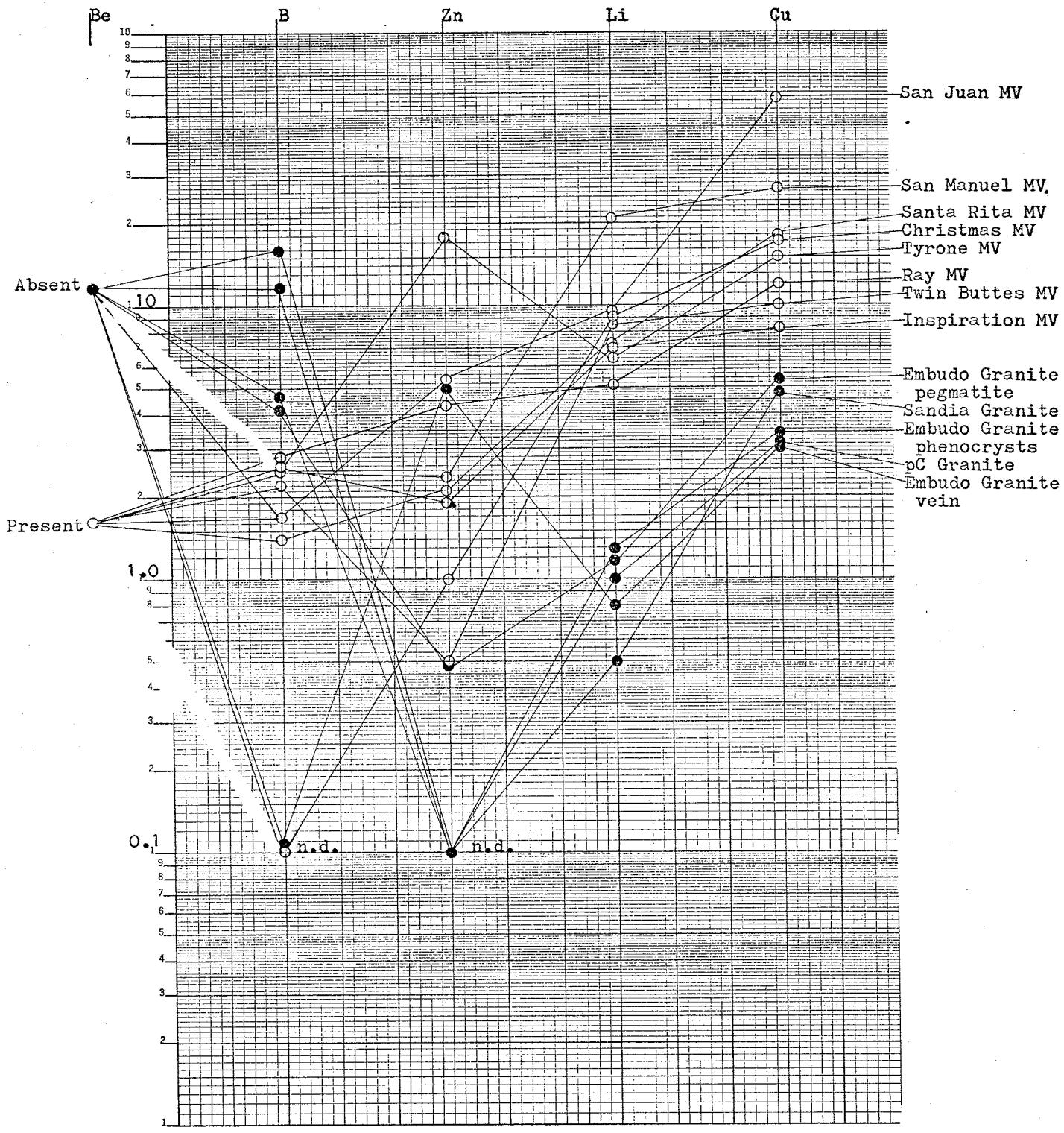
Figure 5. Distribution of Beryllium, Boron, Zinc, Lithium, and Copper in quartz from various environments.

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these five elements in quartz from the various areas
studied. Samples from porphyry copper deposits are
characterized by high beryllium, copper, lithium and
zinc and low boron relative to quartz from unmineralized
areas.

## CONCLUSIONS

A surprisingly large number of elements were found
to be present in the quartz samples that were studied.
Of the elements found, strontium has not been previously
reported as a contaminant in quartz. In addition, the
concentration of barium has only been previously reported
as "trace."

Quartz from porphyry copper deposits does appear to
have a unique impurity element distribution. It is
characterized by high lithium, copper, zinc and beryllium,
and low boron, relative to quartz from unmineralized areas.

Based upon the conclusions of other authors and the
data obtained during this study, the lithium content of
quartz appears to be a general indicator of mineralization.

# APPENDIX A

## SAMPLE DESCRIPTIONS

## SAMPLE DESCRIPTIONS

RAY MINE
KENNECOTT COPPER CORP.
HAYDEN, ARIZONA

| | |
|---|---|
| RAY 1MV | 15-20 mm chalchocite, quartz vein in silicified pⒸ Pinal Schist. (1660 level in zone of secondary enrichment) |
| RAY 2MV | 30-35 mm quartz, pyrite, molybdenite vein in diabase. (1700 level) |
| RAY 3MV | 15-20 mm quartz, pyrite, molybdenite vein in diabase. (1700 level) |
| RAY 4MV | 8-10 mm quartz, pyrite, molybdenite vein in Granite Mountain Porphyry. (1740 level) |
| RAY 5MV | 10-15 mm quartz, pyrite, molybdenite vein in Granite Mountain Porphyry. (1740 level) |
| RAY 6MV | 5-8 mm quartz, pyrite, chalcopyrite vein in Pinal Schist. (DDH 962) |
| RAY 7MV | 10-12 mm quartz, pyrite, chalcopyrite vein in Pinal Schist. (DDH 962) |
| RAY 8MV | 5-10 mm quartz, pyrite, chalcopyrite vein in Pinal Schist. (DDH 962) |
| RAY 9MV | 2-5 mm quartz, pyrite, chalcopyrite vein in pⒸ Oracle granite. (DDH 963) |
| RAY 10V | 15-20 mm barren quartz vein in diorite porphyry. (DDH 680) |
| RAY 11V | 5-8 mm barren quartz vein in diorite porphyry. (probably later vein than RAY 10V) (DDH 680) |
| RAY 12V | 6-10 mm barren quartz vein in diorite porphyry. (DDH 680) |
| RAY 13V | 15-20 mm barren quartz vein in Granite Mountain Porphyry. (DDH 966) |

SAMPLE DESCRIPTION (Continued)

RAY 14V        5-8 mm barren quartz vein in p€ Pioneer Formation (quartzite). Pyrite disseminated in host rock, but none in vein. (DDH 966)

RAY 15         2-5 mm quartz phenocrysts in Teapot Mountain Porphyry. Rock is silicified and sericitized and contains minor pyrite and chalcopyrite. (DDH 964)

RAY 16         3-6 mm quartz phenocrysts in sericitized Granite Mountain Porphyry. (1740 level - same sample site as RAY 4MV)


THORTON PIT
INSPIRATION CONSOLIDATED COPPER CO.
INSPIRATION, ARIZONA

ICC 1MV       35-40 mm quartz, pyrite, chalcopyrite vein in Pinal Schist, chrysocolla on fracture surfaces.

ICC 2MV       25-30 mm quartz, pyrite, chalcopyrite vein in Pinal Schist, chrysocolla on fracture sufaces.

ICC 3MV       10-20 mm quartz, pyrite, chalcopyrite vein in Pinal Schist.

ICC 4MV       10-15 mm quartz, pyrite, chalcopyrite vein in Pinal Schist.

ICC 5MV       20-25 mm quartz, pyrite, chalcopyrite vein in Pinal Schist.

ICC 6MV       20-25 mm quartz, pyrite, chalcopyrite vein in Pinal Schist.

ICC 7MV       40-45 mm quartz, pyrite, chalcopyrite yein in Pinal Schist.

ICC 8MV       35-40 mm quartz, pyrite, chalcopyrite vein in Pinal Schist.

SAMPLE DESCRIPTION (Continued)

ICC  9MV     10-15 mm quartz, pyrite, molybdenite vein
             in Granite Porphyry.

ICC 10MV     3-4 mm quartz, molybdenite vein in Granite
             Porphyry.

ICC 11MV     15-20 mm quartz, molybdenite vein in Granite
             Porphyry.

ICC 12MV     40-50 mm highly fractured quartz vein in
             Pinal Schist with chrysocolla on fracture
             planes and as cavity fillings.

ICC 13MV     35-40 mm highly fractured quartz vein in
             Pinal Schist with chrysocolla on fracture
             planes and as cavity fillings.

ICC 14       1-5 mm euhedral quartz phenocrysts in "quartz
             porphyry sill."

ICC 15       1-5 mm euhedral quartz phenocrysts in "quartz
             porphyry sill."

ICC 16       1-5 mm quartz phenocrysts in Granite Porphyry.

ICC 17       1-5 quartz phenocrysts in Granite Porphyry.


CHRISTMAS MINE
INSPIRATION  CONSOLIDATED COPPER CO.
CHRISTMAS, ARIZONA


ICR  1MV     10-15 mm quartz, pyrite, chalcopyrite vein with
             chrysocolla on fracture surfaces in diorite
             porphyry.

ICR  2MV     10-20 mm quartz, pyrite, chalcopyrite vein
             with chrysocolla on fracture surfaces in
             diorite porphyry.

ICR  3MV     10-15 mm quartz, pyrite, molybdenite vein with
             heavy iron oxide staining in diorite porphyry.

## SAMPLE DESCRIPTION (Continued)


ICR 4MV    12-20 mm quartz, molybdenite vein with
           minor iron oxide staining in diorite porphyry.

ICR 5MV    10-15 mm quartz, molybdenite vein with
           minor iron oxide staining in diorite porphyry.

ICR 6MV    10-18 mm quartz, pyrite, molybdenite vein
           in fine grained diorite.

ICR 7MV    20-25 mm quartz, pyrite, calcite vein in
           diorite porphyry.

ICR 8V     15-20 mm barren quartz vein in diorite porphyry.


TWIN BUTTES MINE
THE ANACONDA COMPANY
SAHUARITA, ARIZONA


TB  1MV    20-25 mm quartz pyrite vein in skarn, chryso-
           colla on fracture surfaces.

TB  2MV    8-10 mm quartz, calcite, molybdenite, pyrite
           vein in quartz monzonite porphyry.

TB  3MV    8-10 mm quartz, calcite, molybdenite, pyrite
           vein in quartz monzonite porphyry.

TB  4MV    10-12 mm quartz, calcite, molybdenite, pyrite,
           chalcopyrite vein quartzite.

TB  5MV    25-30 mm quartz, pyrite vein in skarn.

TB  6V     15-20 mm barren quartz vein in breccia pipe.

TB  7V     10-15 mm barren quartz vein in breccia pipe.

TB  8V     5-8 mm barren quartz vein in quartz monzonite
           porphyry.

## SAMPLE DESCRIPTION (Continued)


SAN MANUEL MINE
MAGMA COPPER CO.
SAN MANUEL, ARIZONA


| | |
|---|---|
| SM 1MV | 7-9 mm quartz, pyrite, chalcopyrite vein in K-T monzonite porphyry. |
| SM 2MV | 20-25 mm quartz, molybdenite, pyrite vein in K-T monzonite porphyry. |
| SM 3MV | 15-20 mm quartz, molybdenite, pyrite vein in K-T monzonite porphyry. |
| SM 4MV | 10-15 mm quartz, pyrite vein in p€ quartz monzonite. |
| SM 5V | 2-3 mm barren quartz vein in p€ oracle granite. |


SAFFORD PROPERTY
KENNECOTT COPPER CORP.
SAFFORD, ARIZONA


| | |
|---|---|
| SF 1MV | 8-10 mm quartz vein with abundant iron oxide staining, in dacite dike (gossan). |
| SF 2MV | 10-12 mm quartz vein with abundant iron oxide staining, in dacite dike (gossan). |
| SF 3MV | 9-11 mm quartz vein with abundant iron oxide staining, in mineralized rhyolite tuff (gossan). |
| SF 4MV | 10-15 mm quartz vein with abundant iron oxide staining and pyrite molds (gossan). Quartz is milky white, almost opaque in small grains. Sample is probably contaminated. |
| SF 5V | 25-30 mm quartz vein, in dacite dike. Very clear quartz. |

SF 6       1-3 mm quartz phenocrysts in mineralized rhyolite tuff.

SF 7       2-5 mm quartz phenocrysts in mineralized rhyolite tuff.


SAN JUAN STOCK (MINE)
PEACOCK MINERALS CORP.
SAFFORD, ARIZONA

SJ 1MV     8-10 mm quartz, pyrite vein, in quartz monzonite porphyry.

SJ 2MV     10-20 mm quartz, pyrite, chalcopyrite vein, in quartz monzonite porphyry.

SJ 3MV     Composite sample of 5 quartz, pyrite, chalcopyrite veins, 1-2 mm wide in brecciated shear zone, in quartz monzonite porphyry.


TYRONE MINE
PHELPS DODGE CORP.
SILVER CITY, NEW MEXICO

T 1MV      6-9 mm quartz, pyrite vein, in silicified intrusive breccia. Dike adjacent to fault.

T 2MV      10-15 mm quartz, pyrite vein in area of secondary enrichment in p€ granite.

T 3MV      10-20 mm quartz, pyrite vein in area of secondary enrichment in p€ granite.

T 4V       4-5 mm quartz, pyrite vein, in quartz monzonite porphyry.

SANTA RITA MINE
KENNECOTT COPPER CORP.
HURLEY, NEW MEXICO

SR 1MV       10-15 mm quartz, native copper, molybdenite
             vein in monzonite.

SR 2MV       20-25 mm quartz, native copper, molybdenite
             vein in monzonite.

SR 3         3mm X 6mm to 1mm X 2mm euhedral quartz crystals
             in pods associated with euhedral pyrite pyrito-
             hedrons and serecite in K Beartooth Quartzite.

SR 3A        Single 3mm X 6mm euhedral quartz crystal from
             SR 3.

SR 4MV       5-8mm quartz, pyrite vein in monzonite.


                   -BARREN GRANITIC ROCKS-


SANDIA GRANITE
SANDIA MOUNTAINS
BERNALILLO COUNTY, NEW MEXICO

SG 1         3-4 mm quartz phenocrysts in intermediate
             grained biotite granite.

SG 2         4-5 mm quartz phenocrysts in coarse grained
             biotite granite.

SG 3         3-4 mm quartz phenocrysts in intermediate
             grained biotite granite.

SG 4         3-4 mm quartz phenocrysts in intermediate
             ground biotite granite.

# SAMPLE DESCRIPTION (Continued)

PRECAMBRIAN GRANITE
BIG BURRO MOUNTAINS
GRANT COUNTY, NEW MEXICO

OG 1     1-2 mm quartz phenocrysts in intermediate grained quartz monzonite.

OG 2     0.5-2 mm quartz phenocrysts in intermediate grained quartz monzonite.

OG 3     1-4 mm quartz phenocrysts in intermediate grained quartz monzonite.

OG 4     1-4 mm quartz phenocrysts in intermediate grained quartz monzonite.

EMBUDO GRANITE (p€)
SANTA FE RANGE
RIO ARRIBA COUNTY, NEW MEXICO

EG 1V     15-20 mm quartz vein in intermediate grained granite.

EG 2V     50-60 mm quartz vein in intermediate grained granite.

EG 3V     30-40 mm quartz vein in intermediate grained granite.

EG 4P     0.3 meter wide quartz, biotite, microcline pegmatite in intermediate grained granite.

EG 5P     Same pegmatite as sample EG 4P, sample site 5 meters vertically above EG 4P.

EG 6P     Same pegmatite as sample EG 4P, EG 5P, sample site 40 meters north of EG 4P, EG 5P.

EG 7     2-6 mm euhedral quartz phenocrysts in intermediate grained granite.

-BARREN METAMORPHIC ROCKS-

ORTEGA FORMATION (p$\in$)
PICURIS RANGE
TAOS COUNTY, NEW MEXICO

        TA 1     Coarse grained quartz muscovite schist.

        TA 2     Coarse grained quartz muscovite schist.

        TA 3     Coarse grained quartz muscovite schist.

        TA 4     Coarse grained quartz muscovite schist.

ALBA QUARTZITE ($\in$-O)
ALBION RANGE, IDAHO

        AQ 1     Clean suggary textured quartzite.

SAMPLE DESCRIPTION (Continued)


-MISCELLANEOUS SAMPLES-


BLANCHARD CLAIM GROUP (Fault, fissure vein Pb-Cu deposit)
BINGHAM, NEW MEXICO

    BNM 1    3mm X 3mm euhedral quartz crystals lining
                 cavity with intergrown galena and barite.

    BNM 2    10mm X 50mm euhedral quartz crystals lining
                 cavity with intergrown galena and pyrite.

    BNM 3    3mm X 5mm euhedral quartz crystals lining
                 cavity with brochantite overgrown on quartz.


SILVERTON, COLORADO (Fault fissure vein Zn-Pb-Ag deposit)

    SC 1    10mm X 70mm euhedral quartz crystals with
                 intergrown sphalerite and pyrite from 1/2
                 meter wide vein.


GOLDFIELD, NEVADA (Fault, fissure vein Au deposit)

    GFN 1    10mm X 20mm to 3mm X 5mm euhedral quartz
                 crystals lining cavity on Columbia Mountain
                 Fault in Tertiary Volcanics.

    GFN 2    5mm X 10mm euhedral quartz crystals lining
                 cavity, from dump in vicinity of Kendall Shaft
                 in Tertiary Volcanics.

SAMPLE DESCRIPTION (Continued)


-MISCELLANEOUS SAMPLES-


ELIZABETH MINE (Metamorphosed volcanogenic massive sulfide)
ORANGE COUNTY, VERMONT


    EM  1     1-2mm quartz grains in massive pyrrhotite
               chalchopyrite.(Incomplete analysis--sample lost)



CERRO de MERCADO (Massive iron deposit)
DURANGO, MEXICO


   · CdM 1    Milky quartz in 25 cm cavity with associated
             euhedral apatite crystals.

APPENDIX B

ANALYSIS SUMMARY

## APPENDIX B

### ANALYSIS SUMMARY

### (ALL VALUES IN PPM)

PORPHYRY COPPER DEPOSITS

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RAY, ARIZONA | | | | | | | | | | | | | | | | |
| Ray 1 MV | 890 | 8.3 | 2.2 | 0.26 | n.d | 28. | 175. | 1190. | 10. | 90. | 3.6 | n.d | 95. | 13.4 | 78. | n.d |
| Ray 2 MV | 160 | n.d | 0.21 | 0.12 | 46. | 7.1 | 18.5 | 20. | 0.4 | 39. | 0.8 | n.d | 8.8 | 0.18 | 36. | n.d |
| Ray 3 MV | 290 | n.d | 0.39 | n.d | 130. | 20. | 39. | 115. | 4.3 | 59. | 9.0 | 4.6 | 32. | 0.6 | 5.1 | 100 |
| Ray 4 MV | 200 | n.d | 0.29 | 0.24 | 8.3 | 1.9 | 21. | 77. | 1.4 | 15. | 0.9 | n.d | 21. | 0.18 | 30. | 0.7 |
| Ray 5 MV | 350 | n.d | 1.0 | 0.26 | 33. | 27. | 88. | 280. | 5.5 | 46. | 4.7 | n.d | 50. | 1.1 | 39. | 6.4 |
| Ray 6 MV | 400 | 8.3 | 0.58 | n.d | 23. | 0.8 | 77. | 190. | 5.2 | 17. | 8.6 | 0.09 | 68. | 0.45 | 45. | 2.0 |
| Ray 7 MV | 1200 | 4.5 | 1.5 | n.d | 19. | 4.0 | 137. | 148. | 0.76 | 21. | 8.0 | n.d | 67. | 2.1 | 50. | 4.3 |
| Ray 8 MV | 600 | n.d | 4.0 | n.d | 25. | 12. | 43 | 56. | 7.8 | 18. | 4.1 | 1.1 | 47. | 5.9 | 52 | 15. |
| Ray 9 MV | 750 | 4.1 | 3.0 | 0.24 | n.d | 4.4 | 190 | 903. | 10.3 | 97. | 2.8 | n.d | 56 | 1.2 | 45 | n.d |
| Ray 10 V | 160 | 2.5 | 0.09 | 0.15 | 6.0 | 2.6 | n.d | 42. | 0.63 | 2.5 | 5.3 | n.d | 7.2 | 0.16 | 24 | n.d |
| Ray 11 V | 110 | 0.4 | 0.07 | 0.12 | 12. | 1.9 | 20. | 33. | 0.57 | 5.2 | 0.6 | n.d | 31. | 0.22 | 37. | 1.3 |
| Ray 12 V | 170 | 4.1 | 0.09 | 0.16 | 7.7 | n.d | n.d | 40. | 0.56 | 2.6 | 3.7 | n.d | 8.2 | 0.17 | 30. | n.d |
| Ray 13 V | 115 | 1.4 | 0.38 | 0.18 | 23. | 18. | 54. | 29. | 4.2 | 12. | 0.6 | n.d | 38. | 0.18 | 51. | 3.1 |
| Ray 14 V | 336 | 7.1 | 0.26 | n.d | 22. | 1.6 | 28. | 130. | 4.4 | 16. | 8.2 | n.d | 11. | 0.18 | 90. | n.d |
| Ray 15 | 825 | n.d | 30. | n.d | n.d | 4.1 | n.d | 1400 | 5.0 | 13.0 | 6.2 | n.d | 320 | 3.2 | 165 | 9.6 |
| Ray 16 | 870 | 5.6 | 57. | 0.21 | 44. | 6.2 | 300. | 1500 | 10.2 | 430. | 7.3 | n.d | 490 | 5.2 | 115 | 5.5 |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **INSPIRATION, ARIZONA** | | | | | | | | | | | | | | | | |
| ICC 1 MV | 70. | 2.0 | 0.34 | 0.16 | 30. | 30. | 140. | 110. | 4.6 | 4.0 | 7.5 | n.d | 68. | 0.2 | 11. | 1.1 |
| ICC 2 MV | 65. | n.d | 0.23 | 0.18 | 12. | 1.4 | 15. | 20. | 2.6 | 4.8 | 2.2 | n.d | 31. | 0.14 | 8.1 | 0.8 |
| ICC 3 MV | 1100. | 3.9 | 1.0 | 0.28 | 20. | 3.2 | 17. | 250. | 8.1 | 5.0 | 2.3 | n.d | 61. | 0.38 | 12. | 1.0 |
| ICC 4 MV | 130. | 1.8 | 0.09 | 0.32 | 10. | 1.4 | 14. | 47. | 5.8 | 7.8 | 6.3 | n.d | 11. | 0.21 | n.d | 1.9 |
| ICC 5 MV | 200. | 4.6 | 1.5 | 0.34 | 27. | 5.8 | 10.6 | 590 | 11.0 | 6.2 | 18.5 | n.d | 82. | .56 | 27. | 1.9 |
| ICC 6 MV | 310. | 2.7 | 0.21 | 0.35 | 7.2 | 2.1 | 6.7 | 140. | 7.2 | 16. | 5.9 | n.d | 12. | .15 | n.d | n.d |
| ICC 7 MV | 100. | n.d | n.d | 0.17 | n.d | 1.0 | n.d | 19. | 7.2 | 1.5 | 2.1 | n.d | 10. | n.d | 45. | n.d |
| ICC 8 MV | 130. | 1.1 | 0.04 | 0.19 | n.d | 1.0 | 8.1 | 25. | 6.0 | 3.1 | 2.5 | n.d | 22. | 0.12 | 40. | n.d |
| ICC 9 MV | 140. | 0.7 | 0.5 | 0.34 | n.d | 1.1 | 3.5 | 16. | 7.1 | 1.7 | 1.4 | n.d | 15. | 0.24 | 38. | n.d |
| ICC 10 MV | 230. | 4.3 | 2.8 | 0.45 | 90. | 50. | 108. | 210. | 15. | 7.4 | 16. | n.d | 89. | 3.7 | 100. | 7.2 |
| ICC 11 MV | 90 | 4.0 | 0.03 | 0.03 | 4.1 | 1.1 | n.d | 16. | 6.0 | 4.8 | 3.0 | n.d | 4.0 | 0.10 | 8.8 | n.d |
| ICC 12 MV | 120 | 2.5 | 0.13 | n.d | 100. | 2.5 | 36. | 38. | 4.7 | 8.5 | 9.2 | n.d | 26. | 0.54 | n.d | 2.3 |
| ICC 13 MV | 140 | 5.8 | 0.23 | n.d | 26 | 4.2 | 140. | 160. | 5.1 | 4.5 | 28. | n.d | 100. | 0.84 | n.d | 8.7 |
| ICC 14 | 600 | n.d | 0.89 | n.d | 11. | 5.8 | 34. | 315. | 3.2 | 29. | 6.7 | n.d | 16. | 1.8 | 110. | n.d |
| ICC 15 | 900 | n.d | n.d | n.d | 95. | 4.6 | 32. | 510 | 6.8 | 44. | 8.5 | n.d | 7.3 | 2.2 | 150 | n.d |
| ICC 16 | 210 | 6.1 | 0.21 | 0.23 | 62. | 1.3 | 52 | 95. | 7.4 | 17.3 | 14.7 | n.d | 68. | 0.26 | n.d | 4.5 |
| ICC 17 | 1080 | n.d | 3.4 | n.d | 28. | 7.1 | 14. | 410 | 3.7 | 17.6 | 10. | n.d | 75. | 0.62 | n.d | n.d |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CHRISTMAS MINE, ARIZONA | | | | | | | | | | | | | | | | |
| ICR 1 MV | 210 | n.d | 0.56 | n.d | 62. | 13. | 62. | 62. | 3.8 | 15. | 5.6 | n.d | 53. | 1.3 | 121. | 3.2 |
| ICR 2 MV | 248 | n.d | 0.16 | n.d | 45. | 20. | 110 | 87. | 10.4 | 14. | 12. | n.d | 55. | 0.5 | 137 | n.d |
| ICR 3 MV | 327 | n.d | 0.77 | n.d | 26. | 19. | 50. | 250. | 10.1 | 13.5 | 8.7 | n.d | 79. | 1.3 | 115 | n.d |
| ICR 4 MV | 230 | n.d | n.d | n.d | 67. | 17.6 | 4.0 | 31. | 12. | 15.6 | 5.5 | n.d | 19. | 0.9 | 170 | n.d |
| ICR 5 MV | 200 | n.d | 0.41 | n.d | 59. | 13.9 | 25. | 82. | 13.5 | 24. | 8.6 | n.d | 23. | 1.7 | 9.0 | n.d |
| ICR 6 MV | 232 | n.d | 0.32 | n.d | 21. | 8.7 | 24. | 57. | n.d | 29. | 3.7 | n.d | 9.4 | 1.0 | 109. | n.d |
| ICR 7 MV | 244 | n.d | 0.89 | n.d | 50. | 25. | 35. | 280. | 9.6 | 20. | 9.2 | n.d | 105 | 1.3 | 100. | n.d |
| ICR 8 MV | 1200 | n.d | 0.49 | n.d | 44. | 21. | 54. | 110. | 13. | 25. | 3.0 | n.d | 45. | 0.75 | 125 | 4.5 |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TWIN BUTTES, ARIZONA | | | | | | | | | | | | | | | | |
| TB - 1 MV | 131 | 1.3 | 0.24 | n.d | 47. | 26.5 | 25. | 25. | 6.4 | 35. | 6.1 | n.d | n.d | 0.6 | n.d | n.d |
| TB - 2 MV | 375 | n.d | 0.24 | n.d | 27. | 7.4 | 7.3 | 79. | 10.4 | 46. | 6.0 | n.d | 32. | 0.9 | 3.0 | n.d |
| TB - 3 MV | 1000 | 2.6 | 1.8 | 0.29 | 98. | 7.0 | 11.0 | 570 | 13.2 | 32. | 7.0 | n.d | 170 | 4.5 | 43. | n.d |
| TB - 4 MV | 290 | n.d | 0.17 | n.d | 54. | 4.6 | 28. | 70 | 8.1 | 11. | 11.5 | n.d | 28. | 1.0 | 46. | n.d |
| TB - 5 MV | 210 | 7.0 | 1.7 | n.d | 75. | 6.4 | 57. | 465. | 5.5 | 70. | 18. | n.d | 105 | 1.9 | 75. | 2.7 |
| TB - 6 V | 143 | n.d | 0.3 | n.d | 18. | 5.3 | 23. | 77. | 7.6 | 4.0 | 3.9 | n.d | 21. | 0.4 | 28. | 1.8 |
| TB - 7 V | 210 | n.d | 0.9 | 0.12 | 21. | 4.1 | 63. | 107. | 8.1 | 21. | 1.7 | n.d | 95. | 1.1 | 45. | 4.3 |
| TB - 8 V | 330 | n.d | 2.2 | n.d | 46. | 5.1 | 45. | 320. | 5.4 | n.d | 10. | n.d | 55. | 2.7 | 86. | n.d |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAN MANUEL MINE, ARIZONA | | | | | | | | | | | | | | | | |
| SM - 1 MV | 540 | 2.1 | 3.1 | n.d | 32. | 29. | 58. | 335. | 29. | 35. | 37. | n.d | 52. | 1.8 | 43. | 2.0 |
| SM - 2 MV | 376 | 2.4 | 0.25 | 0.096 | 8.9 | 6.7 | 63. | 47. | 18. | 7.8 | 5.6 | n.d | 82. | 0.78 | 50. | 3.1 |
| SM - 3 MV | 420 | 5.5 | 1.8 | n.d | 31. | 45. | 27. | 136. | 20. | 25. | 22. | n.d | 40. | 2.0 | 35. | 1.0 |
| SM - 4 MV | 320 | n.d | 5.1 | n.d | 13. | 27. | 25. | 130. | 15. | 10. | 3.6. | n.d | 160. | 0.5 | 130. | 3.5 |
| SM - 5 V | 400 | n.d | 1.9 | n.d | 94. | 30. | 110. | 275. | 15. | 29. | 10. | n.d | 113. | 3.2 | 94. | 6.1 |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAFFORD PROPERTY, ARIZONA | | | | | | | | | | | | | | | | |
| SF - 1 MV | 490 | 4.3 | 0.15 | n.d | n.d | 36. | 33. | 85. | 11.7 | 2.2 | 3.6 | n.d | 110. | 0.66 | 67 | 5.1 |
| SF - 2 MV | 1200 | 3.6 | 0.71 | n.d | 100. | 4.1 | 16. | 59. | 8.7 | 3.2 | 35. | n.d | 77. | 1.6 | n.d | n.d |
| SF - 3 MV | 1290 | 1.6 | 0.89 | 0.45 | 20. | 6.0 | 84. | 480. | 18. | 12.7 | 27. | n.d | 90. | 2.6 | n.d | 5.4 |
| SF - 4 MV* | 3660 | 6.8 | 0.55 | n.d | 37. | 8.0 | 16.0 | 350. | 230. | 5.6 | 52. | n.d | 138 | 4.4 | n.d | n.d |
| SF - 5 V | 321 | 1.2 | 1.54 | 0.19 | 36. | 4.8 | 89. | 60. | 15.5 | 23. | 10. | n.d | 28. | 1.5 | 19. | 2.6 |
| SF - 6 * | 1100 | 11.4 | 4.2 | n.d | 66. | 8.0 | 27. | 235. | 9.4 | 97. | 58. | n.d | 120. | 4.4 | 105. | 8.7 |
| SF - 7 * | 1700 | 27. | 6.9 | n.d | 55. | 5.9 | 140 | 128. | 8.6 | 13. | 42. | n.d | 320. | 3.8 | 21. | n.d |

*Samples probably contaminated

**SAN JUAN STOCK, SAFFORD, ARIZONA**

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SJ - 1 MV | 433 | 0.7 | 0.54 | n.d | 109 | 100. | 87. | 230. | 6.4 | 14.3 | 12. | n.d | 73. | 1.2 | 52. | 7.2 |
| SJ - 2 MV | 320 | 3.0 | 0.75 | n.d | 90 | 30. | 50. | 150. | 10.0 | 12.0 | 8.7 | n.d | 80. | 0.87 | 110. | 3.8 |
| SJ - 3 MV | 570 | 1.4 | 0.46 | n.d | 112 | 48. | 23. | 180 | 12.3 | 5.5 | 14. | n.d | 100 | 0.96 | 90. | 5.6 |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TYRONE MINE, NEW MEXICO** | | | | | | | | | | | | | | | | |
| T - 1 MV | 220 | 3.4 | 0.28 | 0.44 | 24. | 14.1 | 134. | 74. | 8.9 | 7.9 | 10.7 | n.d | 55. | 5.4 | 87. | 7.4 |
| T - 2 MV | 231 | 2.3 | 0.21 | n.d | n.d | 12.6 | 76. | 280. | 1.5 | 8.3 | 14.8 | n.d | 43. | 1.7 | 89. | 22. |
| T - 3 MV | 310 | 1.7 | 0.57 | n.d | 90. | 19.6 | 36. | 175. | 9.8 | 17.1 | 32. | n.d | 110. | 6.6 | 120 | 26. |
| T - 4 V | 250 | n.d | 0.33 | 0.25 | 35. | 10.5 | 100. | 95. | 11.3 | 15.0 | 9.5 | n.d | 74. | 2.1 | 95. | n.d |

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SANTA RITA MINE, NEW MEXICO** | | | | | | | | | | | | | | | | |
| SR - 1 MV | 375 | n.d | 0.29 | n.d | 16. | 12. | 50. | 180 | 2.3 | 11.3 | 14. | 9.8 | 60. | 1.2 | 85. | 3.5 |
| SR - 2 MV | 660 | 2.0 | 1.4 | n.d | 54. | 31. | 82. | 130. | 2.2 | 12.4 | 9.8 | n.d | 75. | 0.89 | 70. | 2.9 |
| SR - 3 MV | 1000 | 2.2 | 0.4 | .98 | n.d | 8.9 | 42. | 36. | 13.9 | 8.3 | 3.0 | n.d | 25. | 0.80 | 24. | n.d |
| SR - 4 MV | 780 | 1.0 | n.d | n.d | n.d | 6.3 | 25. | 16. | 14. | 13.7 | 7.1 | n.d | 23. | 0.60 | 140. | n.d |
| SR - 5 MV | 770 | 2.1 | 1.9 | 0.83 | 51. | 11.5 | 19. | 94. | 16.8 | 5.1 | 3.9 | 1.2 | 110. | 0.34 | 54. | n.d |

BARREN IGNEOUS ROCKS

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SANDIA GRANITE, NEW MEXICO | | | | | | | | | | | | | | | | |
| SG - 1 | 1600 | 4.7 | 0.66 | n.d | 54. | 5.0 | 49. | 140. | 0.9 | 16.0 | 3.8 | n.d | 52. | 1.1 | 100. | n.d |
| SG - 2 | 2200 | 16.8 | 1.8 | n.d | 43. | 5.8 | 73. | 410. | n.d | 26. | 7.4 | n.d | 184. | 2.2 | 92. | n.d |
| SG - 3 | 1800 | 8.6 | 1.5 | n.d | 123. | 7.3 | 84. | 240. | 0.7 | 26. | 17.1 | n.d | 143. | 3.0 | 150. | n.d |
| SG - 4 | 2800 | 12.5 | 2.0 | n.d | 95. | 1.4 | 64. | 400. | 0.4 | 13.7 | 10.5 | n.d | 114. | 2.0 | 77. | n.d |
| BIG BURRO MOUNTAINS, NEW MEXICO | | | | | | | | | | | | | | | | |
| OG - 1 | 2050 | 14.3 | 0.29 | n.d | 38. | 2.2 | 11. | 170. | 0.43 | 13.9 | 13. | n.d | 100. | 0.91 | n.d | n.d |
| OG - 2 | 860 | 16.4 | 0.36 | n.d | 49. | 1.2 | n.d | 137. | 1.1 | 11.7 | 4.4 | n.d | 71. | 0.61 | 36. | n.d |
| OG - 3 | 2400 | 18.5 | 0.62 | n.d | 56. | 6.7 | n.d | 182. | 1.7 | 16.6 | 5.4 | n.d | 50. | 1.7 | 51. | n.d |
| OG - 4 | 2200 | 16.1 | 0.63 | n.d | 36. | 2.5 | 66. | 290. | 0.6 | 24. | 12.6 | n.d | 105. | 1.1 | 66. | n.d |
| EMBUDO GRANITE, NEW MEXICO | | | | | | | | | | | | | | | | |
| EG - 1 V | 35 | n.d | 0.16 | n.d | 24. | 1.7 | 170. | 19. | 0.38 | 9.0 | 1.8 | n.d | 10.0 | 0.25 | 11.5 | 15.0 |
| EG - 2 V | 59 | n.d | 0.16 | n.d | 15. | 5.0 | 29 | 15.8 | 1.1 | 6.5 | 5.7 | n.d | 8.0 | 0.20 | 17.2 | n.d |
| EG - 3 V | 64 | n.d | 0.23 | n.d | 0.8 | 2.7 | 24. | 18. | 0.92 | 3.3 | 7.7 | n.d | 8.9 | 0.14 | 16.0 | n.d |
| EG - 4 V | 38 | n.d | 0.11 | n.d | 10.0 | 3.1 | 20. | 6.0 | 1.1 | 4.1 | 0.4 | n.d | 7.0 | 0.11 | 21.3 | 0.7 |
| EG - 5 P | 57 | 8.9 | 0.05 | n.d | 6.0 | 6.4 | n.d | 9.4 | 1.3 | 1.4 | 4.2 | n.d | 3.6 | n.d | 17. | 0.9 |
| EG - 6 P | 55. | 3.8 | n.d | n.d | n.d | 6.8 | n.d | 11.4 | 1.3 | 1.0 | 0.3 | n.d | 1.7 | n.d | 45. | n.d |
| EG - 7 | 2800 | 4.7 | 2.6 | n.d | 108. | 3.4 | 51. | 980. | 1.3 | 27. | 6.0 | n.d | 690. | 2.5 | 59. | n.d |

## BARREN METAMORPHIC ROCKS

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ORTEGA FORMATION, NEW MEXICO | | | | | | | | | | | | | | | | |
| TA - 1 | 540 | n.d | 0.30 | n.d | 56. | 1.9 | 35. | 92. | n.d | 8.0 | 1.6 | n.d | 37. | 6.8 | 4.8 | 1.2 |
| TA - 2 | 150 | n.d | 0.43 | n.d | 35. | 4.1 | 36. | 58. | n.d | 10.0 | 1.0 | n.d | 27. | 0.72 | 21. | 1.9 |
| TA - 3 | 165 | n.d | 0.29 | n.d | 6.2 | 4.5 | 22. | 61. | 0.1 | 5.6 | 1.1 | n.d | 10. | 0.67 | 17. | 0.9 |
| TA - 4 | 270 | n.d | 0.32 | n.d | 28. | 6.2 | 14. | 95. | n.d | 10.0 | 2.8 | n.d | 24. | 4.0 | n.d | 1.1 |
| ALBA QUARTZITE, IDAHO | | | | | | | | | | | | | | | | |
| AQ - 1 | 1200 | 2.2 | 1.4 | n.d | 24. | 2.7 | 20. | 105. | n.d | 10.3 | 1.4 | n.d | n.d | 3.0 | 62. | n.d |

## MISCELLANEOUS SAMPLES, MINERALIZED AREAS

| SAMPLE NUMBER | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BINGHAM, NEW MEXICO | | | | | | | | | | | | | | | | |
| BNM - 1 | 895 | 0.11 | 0.26 | n.d | 480 | 1.4 | 35. | 28 | 68. | 7.6 | 0.12 | n.d | 36. | 0.48 | 31. | 1.5 |
| BNM - 2 | 970 | n.d | n.d | n.d | 880. | 2.1 | 70. | 28. | 59. | 9.5 | 5.6 | n.d | n.d | 7.6 | n.d | n.d |
| BNM - 3 | 1400 | n.d | 0.21 | n.d | 30. | 3.5 | n.d | 150. | 114. | 3.2 | 4.4 | n.d | 4.7 | 1.0 | n.d | 7.9 |
| SILVERTON, COLORADO | | | | | | | | | | | | | | | | |
| SC - 1 | 2500 | n.d | 0.32 | 0.28 | 37. | 10. | 40. | 120. | 250. | 16. | 10. | n.d | | 2.2 | n.d | 5.9 |
| GOLDFIELD, NEVADA | | | | | | | | | | | | | | | | |
| GFN - 1 | 190 | 1.2 | 0.03 | n.d | n.d | 0.8 | 6.7 | 44. | 11.6 | 4.2 | 0.8 | n.d | 27. | 0.2 | 10.5 | n.d |
| GFN - 2 | 85 | n.d | 0.15 | 1.4 | 27. | 2.5 | 51. | 73. | 1.5 | 25. | 1.8 | n.d | 35 | 1.1 | n.d | n.d |
| ELIZABETH, VERMONT | | | | | | | | | | | | | | | | |
| EM - 1 | 2100 | n.d | - | Sample Lost | | | | | | | | | 100. | | | |
| CERRO DE MERCADO, MEXICO | | | | | | | | | | | | | | | | |
| CDM - 1 | 46. | 1.8 | 0.07 | n.d | n.d | 2.1 | 48. | 24. | 3.3 | 115 | n.d | n.d | n.d | n.d | 20. | n.d |

APPENDIX C

ANALYTICAL ACCURACY

## APPENDIX C

### ANALYTICAL ACCURACY

| Sample | Al % | B ppm | Ba ppm | Be ppm | Ca % | Cu ppm | Fe % | K % | Li ppm | Mg % | Mn ppm | Mo ppm | Na % | Sr ppm | Ti ppm | Zn ppm | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **W-1** | | | | | | | | | | | | | | | | | |
| Average Value | 7.86 | 15. | 180 | 0.8 | 7.83 | 110. | 7.76 | 0.53 | 12. | 3.98 | 1317 | 0.5 | 1.6 | 180. | 6415 | 82. | 1 |
| Value Found | 7.9 | 77. | 174 | n.d. | 7.36 | 115. | 7.5 | 0.67 | 11.8 | 2.45 | 1500 | 8.3 | 1.5 | 160. | 6440 | 110. | |
| **SEY-2** | | | | | | | | | | | | | | | | | |
| Provisional Value | 6.0 | 35. | 430 | 16. | 6.9 | <8 | 5.0 | 3.49 | n.r. | 1.21 | 2300 | 0.99 | 3.12 | 270. | n.r. | 200. | 2 |
| Value Found | 5.8 | 100. | 515 | 30. | 7.1 | 1.6 | 6.0 | 3.7 | 120. | 1.91 | 3100 | 6.4 | 3.0 | 270. | 846 | 320. | |
| **SEY-3** | | | | | | | | | | | | | | | | | |
| Provisional Value | 6.09 | 45. | 410 | 16. | 5.8 | 18. | 4.9 | 3.24 | n.r. | 1.57 | 2300 | 0.91 | 2.89 | 300. | n.r. | 180. | 2 |
| Value Found | 5.9 | 130. | 430 | 33. | 6.7 | 16. | 5.7 | 5.03 | 110. | 1.63 | 3200 | 8.6 | 3.0 | 290. | 870 | 350. | |
| **G-2** | | | | | | | | | | | | | | | | | |
| Average Value | 8.12 | 2.0 | 1950 | 2.4 | 1.42 | 10.7 | 1.9 | 3.45 | 42.7 | 0.47 | 265 | 1.2 | 3.08 | 463. | 3177 | 74.9 | 3 |
| Value Found | 8.2 | 5.2 | 1890 | 2.7 | 1.79 | 12.0 | 2.5 | 3.51 | 36.8 | 0.48 | 266 | 2.1 | 2.9 | 423. | 3480 | 106. | |
| Standard Deviation | n.r. | n.r. | 283 | 0.4 | n.r. | 1.7 | n.r. | n.r. | 6.5 | n.r. | n.r. | 0.9 | n.r. | 25. | n.r. | n.r. | 4 |
| **AGV-1** | | | | | | | | | | | | | | | | | |
| Average Value | 9.0 | - | 1410 | 1.8 | 3.56 | 63.7 | 4.74 | 2.4 | 12.1 | 0.90 | 728 | 3.7 | 3.21 | 657. | 6475 | 112. | 3 |
| Value Found | 8.6 | 30. | 1360 | 2.0 | 4.98 | 66.4 | 5.1 | 2.9 | 11.3 | 0.88 | 864 | 5.9 | 3.3 | 700. | 6510 | 103. | |
| Standard Deviation | n.r. | n.r. | 105 | 0.4 | n.r. | 2.2 | n.r. | n.r. | 1.2 | n.r. | n.r. | 0.6 | n.r. | 18. | n.r. | n.r. | 4 |
| **GSP-1** | | | | | | | | | | | | | | | | | |
| Average Value | 8.0 | <0.7 | 1360 | 0.80 | 1.45 | 35.2 | 3.03 | 4.55 | 36.2 | 0.57 | 326 | 1.6 | 2.14 | 247. | 4140 | 143. | 3 |
| Value Found | 7.9 | 12.5 | 1360 | 0.78 | 1.73 | 33.4 | 3.25 | 4.4 | 31.6 | 0.54 | 346 | 2.9 | 2.3 | 220. | 4120 | 120. | |
| Standard Deviation | n.r. | n.r. | 69 | 0.2 | n.r. | 4.0 | n.r. | n.r. | 4.4 | n.r. | n.r. | 0.3 | n.r. | 9.3 | n.r. | n.r. | 4 |

References: 1. Fleischer (1969)  2. Faye (1969)  3. Flanagan (1969)  4. Blackburn et al. (1971)

n.r. = not reported

# APPENDIX D

## STATISTICAL SUMMARY

## STATISTICAL SUMMARY

| SAMPLE | Al | B | Ba | Be | Ca | Cu | Fe | K | Li | Mg | Mn | Mo | Na | Sr | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **All Molybdenite Bearing Veins** | | | | | | | | | | | | | | | | |
| Mean | 335 | 1.1 | 0.70 | 0.12 | 43 | 15.6 | 36 | 131 | 8.3 | 22 | 7.7 | | 47 | 1.2 | 55 | 5.5 |
| Standard deviation | 210 | 1.8 | 0.77 | 0.15 | 35 | 14.4 | 31 | 135 | 6.1 | 16 | 5.6 | | 41 | 1.2 | 45 | 16.8 |
| **All Porphyry Copper Related Sulfide Bearing Veins** | | | | | | | | | | | | | | | | |
| Ray | | | | | | | | | | | | | | | | |
| Mean | 540 | 2.8 | 1.5 | 0.12 | 32 | 12. | 88 | 331 | 5.1 | 45 | 4.7 | 0.6 | 49 | 2.8 | 44 | 4.3 |
| Standard deviation | 350 | 3.6 | 1.3 | 0.13 | 40 | 11. | 65 | 419 | 3.8 | 32 | 3.1 | 1.5 | 26 | 4.4 | 19 | 5.3 |
| Inspiration | | | | | | | | | | | | | | | | |
| Mean | 217 | 2.6 | 0.55 | 0.22 | 25 | 8.1 | 39 | 126 | 7.0 | 5.8 | 8.1 | 0 | 41 | 0.55 | 22 | 1.9 |
| Standard deviation | 273 | 1.9 | 0.80 | 0.15 | 33 | 15.0 | 53 | 160 | 3.2 | 3.7 | 8.1 | | 34 | 0.99 | 28 | 2.8 |
| Christmas | | | | | | | | | | | | | | | | |
| Mean | 361 | 0 | 0.45 | 0 | 47 | 17.3 | 45 | 120 | 9.1 | 19.5 | 7.0 | | 49 | 1.1 | 110 | 1.0 |
| Standard deviation | 341 | | 0.30 | | 17 | 5.2 | 32 | 93 | 4.7 | 5.9 | 3.1 | | 32 | 0.4 | 47 | 1.8 |
| Twin Buttes | | | | | | | | | | | | | | | | |
| Mean | 400 | 2.2 | 0.83 | 0.06 | 60 | 10. | 26 | 240 | 8.7 | 39 | 9.7 | 0 | 67 | 1.8 | 33 | 0.5 |
| Standard deviation | 350 | 2.9 | 0.84 | 0.13 | 27 | 9.1 | 20 | 250 | 3.1 | 22 | 5.1 | | 69 | 1.6 | 32 | 1.2 |
| San Manuel | | | | | | | | | | | | | | | | |
| Mean | 414 | 2.5 | 2.6 | 0.02 | 21 | 27. | 43 | 160 | 21. | 19 | 17. | 0 | 84 | 1.3 | 65 | 2.4 |
| Standard deviation | 93 | 2.3 | 2.1 | 0.05 | 12 | 16. | 20 | 122 | 6. | 13 | 16. | | 54 | 0.7 | 44 | 1.1 |
| San Juan | | | | | | | | | | | | | | | | |
| Mean | 440 | 1.7 | 0.6 | 0 | 104 | 59. | 53 | 186 | 9.6 | 11 | 12. | 0 | 84 | 1.0 | 84 | 5.5 |
| Standard deviation | 125 | 1.2 | 0.2 | | 12 | 36. | 32 | 40 | 3.0 | 4.6 | 3. | | 14 | 0.2 | 29 | 1.7 |
| Tyrone | | | | | | | | | | | | | | | | |
| Mean | 253 | 2.5 | 0.35 | 0.15 | 38 | 15. | 82 | 176 | 6.7 | 11.1 | 19. | 0 | 69 | 4.6 | 99 | 18. |
| Standard deviation | 49 | 0.9 | 0.19 | 0.25 | 47 | 3.7 | 49 | 103 | 4.6 | 5.2 | 11. | | 36 | 2.6 | 19 | 10. |
| Santa Rita | | | | | | | | | | | | | | | | |
| Mean | 600 | 1.4 | 1.2 | 0.3 | 40 | 18. | 50 | 135 | 7.1 | 9.6 | 9.2 | 3.7 | 82 | 0.81 | 70 | 2.1 |
| Standard | 200 | 1.2 | 0.8 | 0.5 | 21 | 11. | 32 | 43 | 8.4 | 3.9 | 5.1 | 5.4 | 26 | 0.44 | 16 | 1.9 |
| **Sandia Granite Phenocrysts** | | | | | | | | | | | | | | | | |
| Mean | 2100 | 10.7 | 1.5 | 0 | 79 | 4.9 | 68 | 300 | 0.5 | 20. | 9.7 | 0 | 123 | 2.1 | 105 | 0 |
| Standard deviation | 530 | 5.1 | 0.6 | | 37 | 2.5 | 15 | 130 | 0.4 | 6.5 | 5.6 | | 55 | 0.8 | 32 | |
| **Precambrian granite phenocrysts** | | | | | | | | | | | | | | | | |
| Mean | 1880 | 16.3 | 0.48 | 0 | 45 | 3.2 | 19 | 200 | 1.0 | 16.6 | 8.9 | 0 | 82 | 1.1 | 39 | 0 |
| Standard deviation | 690 | 1.7 | 0.18 | | 9 | 2.4 | 31 | 66 | 0.6 | 5.4 | 4.6 | | 26 | 0.5 | 28 | |
| **Embudo Granite--Pegmatite** | | | | | | | | | | | | | | | | |
| Mean | 50 | 4.2 | 0.05 | 0 | 5.3 | 5.4 | 6.7 | 8.9 | 1.2 | 2.2 | 1.6 | 0 | 4.1 | 0.04 | 28 | 0.5 |
| Standard deviation | 10 | 4.5 | 0.06 | | 5.0 | 2.0 | 12. | 2.7 | 0.1 | 1.7 | 2.2 | | 2.7 | 0.06 | 15 | 0.5 |
| **Embudo Granite--Vein** | | | | | | | | | | | | | | | | |
| Mean | 53 | 00 | 0.18 | 0 | 13 | 3.1 | 74 | 17.6 | 0.8 | 6.3 | 5.1 | 0 | 9. | 0.2 | 15 | 5.0 |
| Standard Deviation | 16 | | 0.04 | | 12 | 1.7 | 82 | 1.6 | 0.4 | 2.9 | 3.0 | | 1. | 0.06 | 3 | 8.7 |
| **Ortega Schist** | | | | | | | | | | | | | | | | |
| Mean | 280 | 0 | 0.34 | 0 | 31 | 4.2 | 27 | 77 | 0.03 | 8.4 | 1.6 | 0 | 25 | 3.0 | 11. | 1.3 |
| Standard deviation | 180 | | 0.06 | | 21 | 1.8 | 11 | 20 | 0.05 | 2.1 | 0.8 | | 11 | 3.0 | 9.9 | 0.4 |
| **Bingham, New Mexico** | | | | | | | | | | | | | | | | |
| Mean | 1088 | 0.04 | 0.16 | 0 | 460 | 2.3 | 35 | 69 | 80. | 6.8 | 3.4 | 0 | 14 | 3.1 | 10 | 3.1 |
| Standard deviation | 272 | 0.06 | 0.14 | | 425 | 1.1 | 35 | 70 | 30. | 3.2 | 2.9 | | 20 | 4.1 | 18 | 4.2 |

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