AN ABSTRACT OF THE THESIS OF

Trygve Loken for the degree of Master of Science in Geology presented on December 6, 1982.

Title: HYDROTHERMAL ALTERATION AND OIL SHOW AT THE SUMMER COON INTRUSIVE CENTER, SAGUACHE COUNTY, COLORADO.

Abstract approved: Redacted for Privacy

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The Summer Coon intrusive center is located seven miles north of Del Norte, Colorado, on the eastern edge of the San Juan Mountains. The intrusive center is the core of a dissected calc-alkaline composite volcano of middle Oligocene age. The Summer Coon rocks belong to the Conejos Formation which is the oldest unit in the eastern part of the San Juan volcanic field.

The intrusive core is a composite stock of three fine- to medium-grained rock types. The oldest stock, a texturally inhomogeneous diorite, is cut by numerous radial dikes and is intruded in the center by a granodiorite porphyry and a rhyolitic vent breccia. The granodiorite porphyry and the vent breccia are part of a 2500-foot diameter central conduit, while the diorite occupies a two mile diameter stock of uncertain origin.

Hydrothermal alteration at the Summer Coon intrusive core grades concentrically inward from a propylitic zone to an intermediate argillic zone. The intermediate argillic zone has scattered pods of quartz-sericite and vuggy silica replacement of the host. The zone of intermediate argillic alteration centers on the 2500-foot diameter central conduit and radial dikes of silicic composition.

Alteration at the study area was caused by hot spring activity beneath the water table during the fumarolic stage of the volcano. The chemical process of alteration was hydrogen metasomatism, which caused variable hydrolytic decomposition of plagioclase feldspar and mafic minerals leading to the depletion of calcium, magnesium, manganese, nickel, and cobalt in the rocks. Metallization is related to the abundance of pyrite in veinlets and fractures. Centrally located molybdenum and lead anomalies, and weak peripheral zinc anomalies characterize surface geochemistry at the study area. A supergene oxidized cap zone 35 feet thick has created a superimposed effect upon hypogene alteration, and the more mobile elements have been leached from it.

The favorable aspects of the Summer Coon intrusive area as a porphyry copper-molybdenum exploration target include the existence of a composite stock with concentric zonation of hydrothermal alteration assemblages, and centrally located molybdenum, lead, and IP anomalies, low resistivity, and low magnetic value zones. Unfavorable aspects include the lack of structures, the lack of peripheral lead, zinc, silver, and gold mineralization, and the great depth at which hypothetical zones of intense hydrothermal alteration and mineralization may be located.

Tarry brownish-black petroleum was present in pyrite-coated fractures in cores from three diamond-drill holes. The petroleum was dated and is interpreted to have been locally generated from Cretaceous source rocks and to have migrated into the intrusive core after the cessation of hydrothermal activity.

HYDROTHERMAL ALTERATION AND OIL SHOW AT THE SUMMER COON INTRUSIVE CENTER, SAGUACHE COUNTY, COLORADO

by

Trygve Loken

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

Completed December 6, 1982

Commencement June 1983

APPROVED:

Redacted for Privacy

Professor of Geology in charge of major

Redacted for Privacy

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Redacted for Privacy

Dean of Graduate School

Date thesis is presented ___December 6, 1982___

Typed by Debra Meager for ___Trygve Loken___

ACKNOWLEDGEMENTS

Thanks go to Bill Bowes for funding this study and making data available; the staff at W. A. Bowes, Inc.; Bob Casaceli for making me aware of the existence of the study area; Dr. E. M. Taylor, my thesis advisor, and Dr. C. W. Field for their critical reading of preliminary drafts; Dr. K. F. Oles, my third committee member; L. P. James, consultant for W. R. Grace and Company, for making his garage available for core logging and his interest and discussions on the study area; Ed Howes and Micky Edell for drafting; Debbie Meager for typing; and last, but not least, my parents, whose support through the entire process of higher education is cherished.

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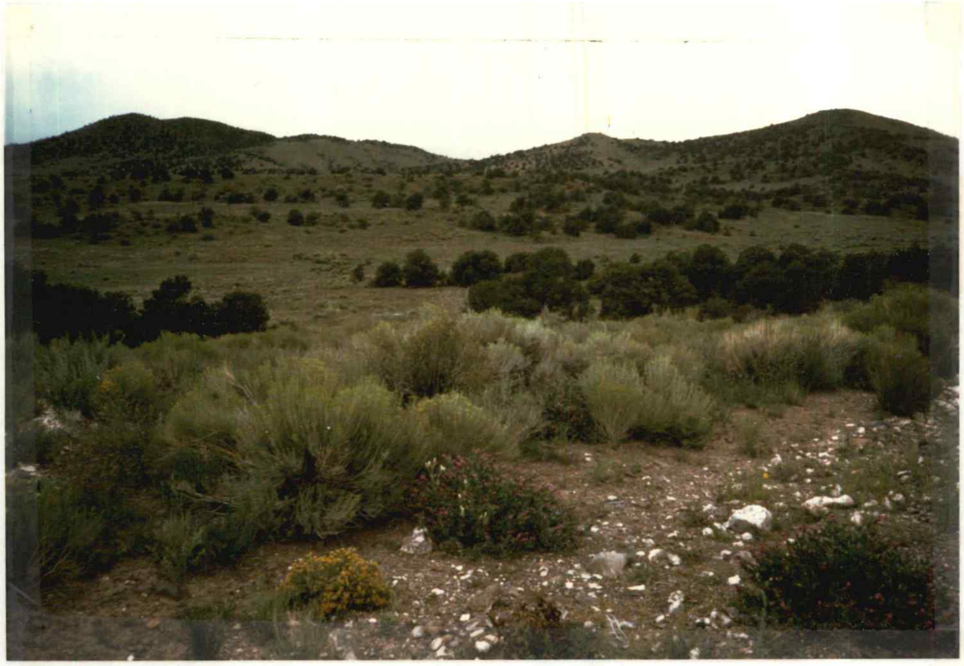


The Summer Coon intrusive center, looking southwest.

HYDROTHERMAL ALTERATION AND OIL SHOW AT THE SUMMER COON INTRUSIVE CENTER, SAGUACHE COUNTY, COLORADO

INTRODUCTION

Location and Access

The Summer Coon intrusive center is located seven miles north of Del Norte, Colorado, on the eastern edge of the San Juan Mountains (Fig. 1). Access is provided by light duty and unimproved dirt roads, and jeep trails on Rio Grande National Forest land. The study area covers about two and a half square miles, and access is assured by two-wheel drive vehicles from late spring to late fall. The topographic base map for the study is from the Twin Mountains and Twin Mountains S. E. 7.5-minute quadrangle sheets.

Topography, Vegetation, and Extent of Rock Exposures

Relief is mild. A volcanic neck forms a hill approximately four hundred feet high, one and a half miles long, and one mile wide. The highest point is 8856 feet above sea level. Exposure of surface rubble is good due to sparse sage, juniper, and pinyon cover. Outcrops of bedrock are rare and largely confined to the ridge tops and prospect pits.

Previous Geologic Work

The first formal geological mapping of the area was carried

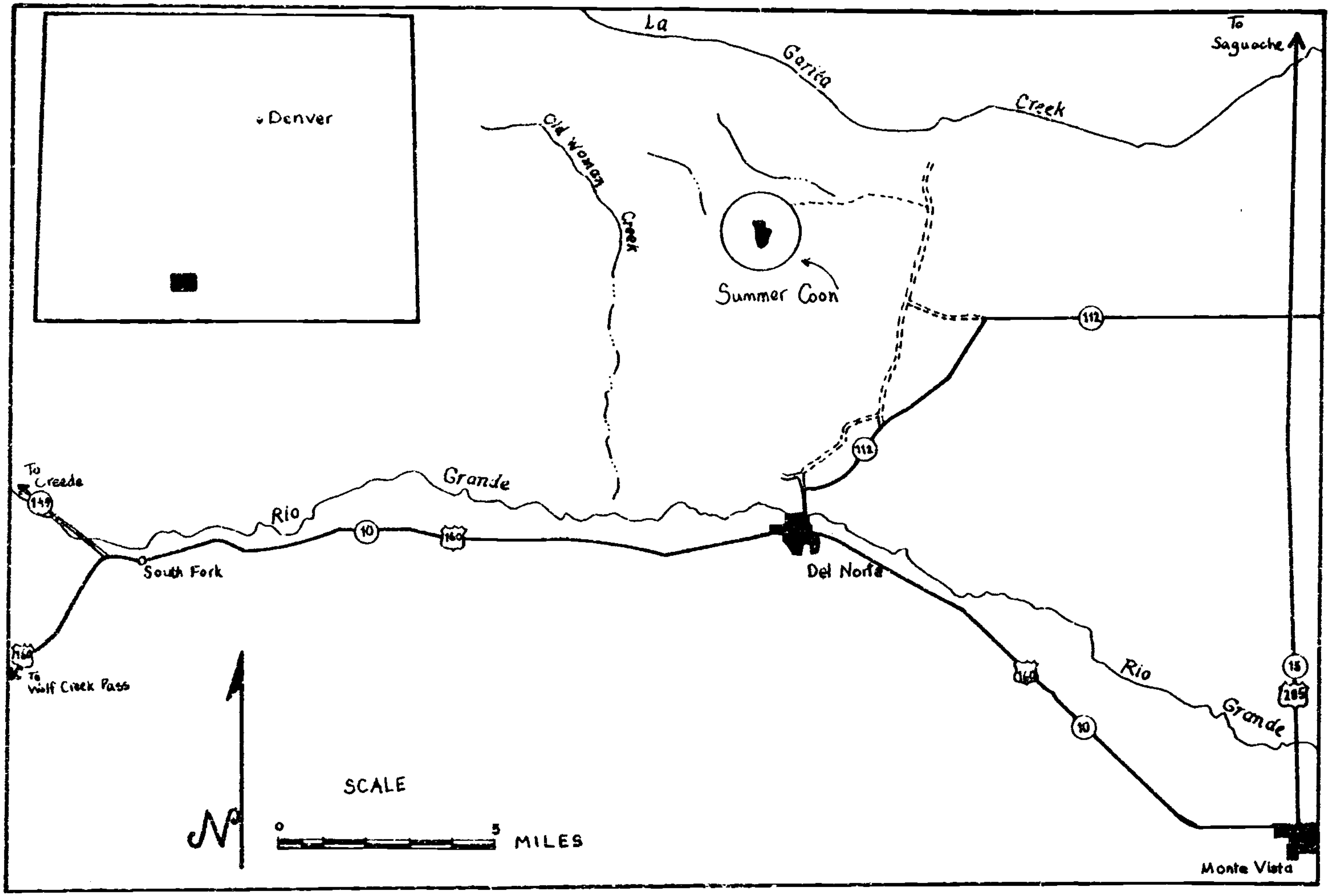


Figure 1. Index map showing the location of the Summer Coon intrusive center.

out by Burbank, Lovering, Goddard, and Eckel (1935) for the U. S. G. S. geologic map of Colorado. Larsen and Cross (1956) published the results of nearly forty years of work in a summary of the geology and petrology of the entire San Juan region. Included in this work is a short description of the study area. Larsen and Cross (1956) referred to the area as the Summer Coon stock, but the origin of the name is uncertain. Lipman and Mehnert (1968) collaborated on a study of the structural history of the eastern San Juan Mountains and the San Luis Valley.

Studies of the Summer Coon volcanic center were conducted by Lipman (1968) and Mertzman (1971, 1972). Lipman mapped the area at a scale of 1:40,000 and studied about 50 thin-sections for the purpose of defining the geological setting, lithologies, and petrology of this magmatic center. Mertzman, while a Ph. D. candidate at Case Western Reserve University, did a more detailed petrologic study of the center by utilizing isotope geochemistry and microprobe data. Mertzman (1971) contributed most of his data to the New Mexico Geological Society 22nd Field Conference Guidebook.

William A. Bowes, Inc. and W. R. Grace and Company have carried out a substantial amount of exploration work. Three shallow diamond-drill holes (100, 109, and 131 feet), two deep diamond-drill holes (407 and 1084 feet), and several air-drill holes 50 feet in depth have been completed. The deeper diamond-drill holes had oil shows. Other data available from W. A. Bowes include emission spectrographic analyses, geochemical contour maps and perspective diagrams, the results from magnetic, induced polarization, and resistivity surveys, and various supplemental and progress reports by L. P. James, G. Cress, and R. Lisle.

There has been much small-scale prospecting in the area through the years, including one patented claim with galena and sphalerite proof. It is a 10.33 acre claim straddled by the current Bowes claims 97, 98, and 99 (Fig. 2).

Purpose of Study

The nature of the problem is twofold. Hydrothermal alteration of the intrusive core of this volcanic center has been noted, but it has not been studied. And the two deepest drill holes showed oil instead of encountering mineralization. The purpose of the study is to assess the potential for finding a porphyry copper-molybdenum system at depth and to determine the nature of the petroleum occurrence.

Method of Study

Field work was conducted at the end of September into October in the fall of 1980 and sporadically through the summer of 1981. The intrusive core was remapped at 1"=500' scale, with particular attention being paid to variations in hydrothermal alteration and the location of breccia zones. Sampling was conducted on ridges and spurs for thin-section examination of alteration effects. Certain specimens were submitted for

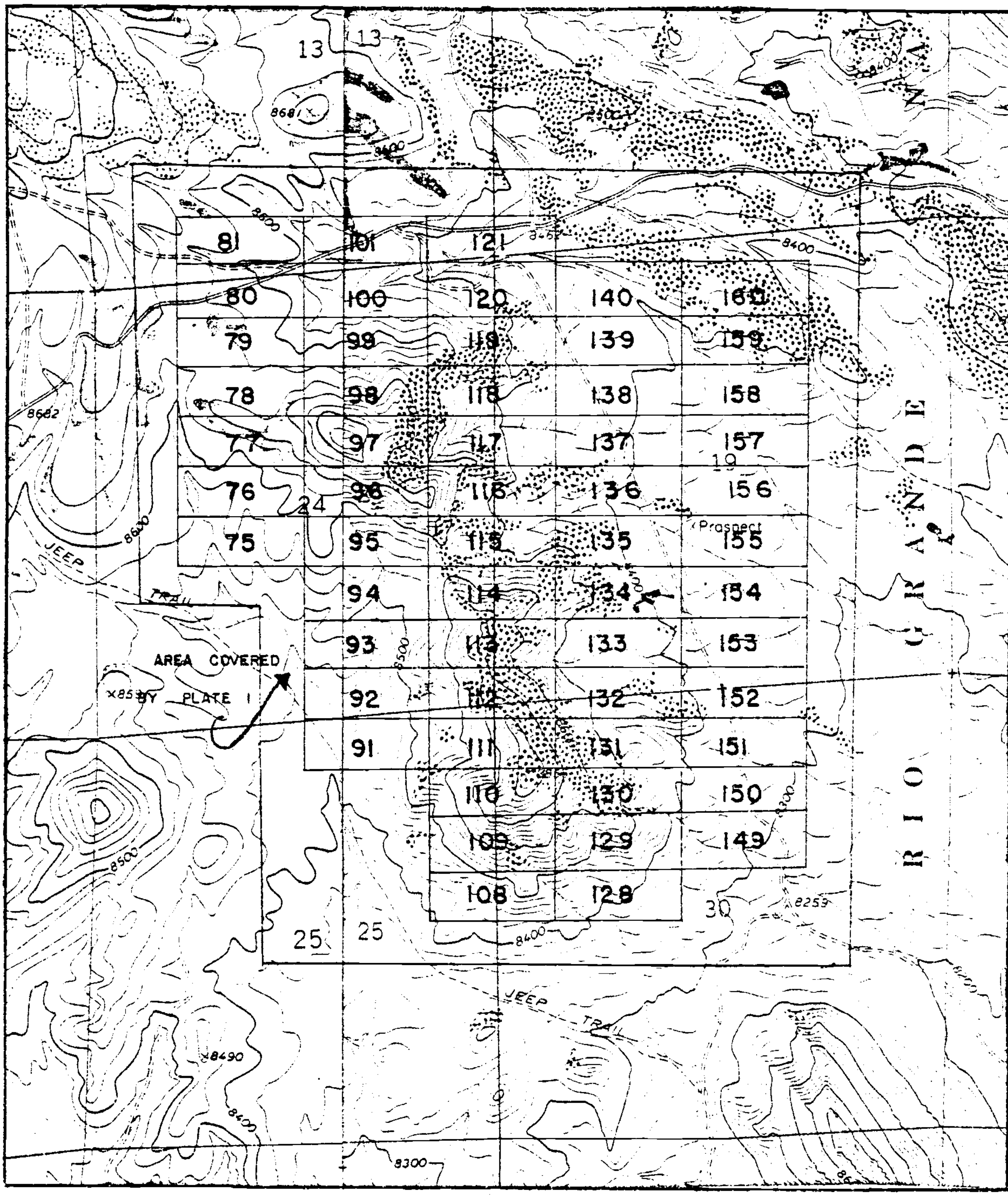


Figure 2. Index map showing W. A. Bowes, Inc. claim block, sparse vegetation (stippled), and the area mapped during this study. The scale is 1"=2,000'. North is toward the top of the page.

chemical analysis to test for mineralization and to complement existing geochemical data. Cores from diamond-drill holes were examined and compared with the logs. One existing hole was deepened 200 feet to a depth of 407 feet in September 1981. This core was logged and sampled at the end of October 1981. All additional available data in the form of geochemical and geophysical results were compiled.

W. A. Bowes, Inc. provided Robbie Gries, a consultant for Amerex, Inc., with a suitable quantity of petroleum-stained core for analysis. The core was shipped to Amoco Production Company for analysis and dating. The results of the analysis and comparison to other unusual oil shows made it possible to speculate on the source and mode of migration of the petroleum.

REGIONAL GEOLOGICAL SETTING

The San Juan volcanic field covers about 5,000 square miles of southwestern Colorado, bounded on the north by the Gunnison River valley, on the east by the San Luis Valley, and on the south and west by an area of eroded Mesozoic and Tertiary rocks. The volcanic rocks of the field are mid-Tertiary and can be grouped into four major units from oldest to youngest (Lipman, 1968):

1) lavas of intermediate composition and breccias of the San Juan, Lake Fork, and West Elk Formations in the western San Juan Mountains, and of the Conejos Formation in the east.

2) silicic ash-flow tuffs erupted from calderas in the western and central San Juan Mountains.

3) intermediate to silicic lavas and penecontemporaneous volcanic sediments of the Fisher and Los Pinos Formations.

4) basaltic lavas of the Hinsdale Formation (Fig. 3).

Initial volumes of the first two units were on the order of several thousand cubic miles of magma. The later two units had smaller initial volumes, but still were widespread.

Older rocks are exposed locally and in the western and northern parts of the volcanic field. This complex of pre-Cambrian, Paleozoic, Mesozoic, and Tertiary strata dip southwestward toward the San Juan Basin, and is overlain unconformably by the volcanic units of the San Juan field (Larsen and Cross, 1956). The San Juan volcanic field generally overlies pre-Cambrian rocks as a result of the uplift and erosion of the former Uncompahgre-Needle Mountains highlands during the Laramide

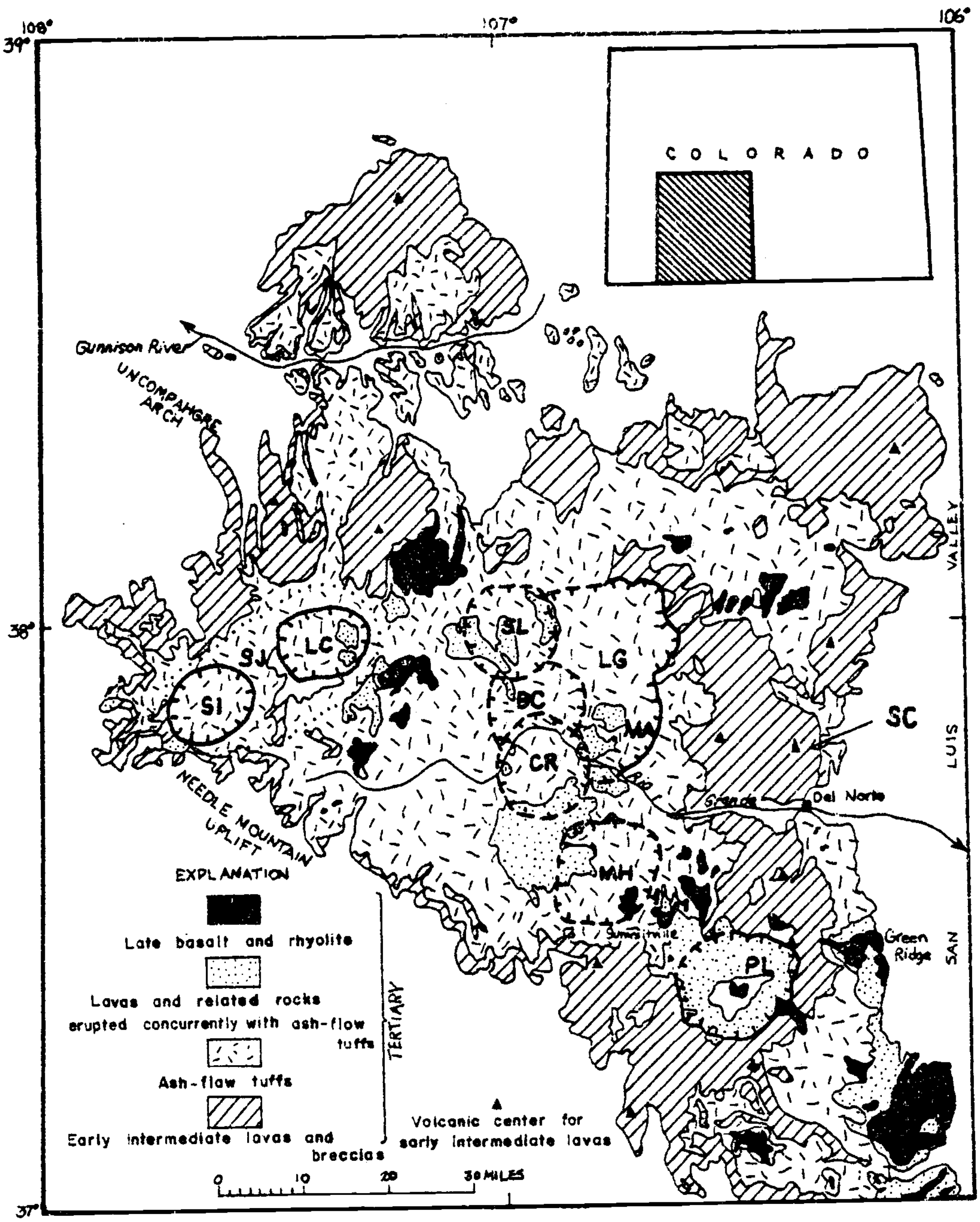


Figure 3. Generalized geologic map of the San Juan volcanic field showing the location of volcanic centers and calderas. SC is the study area. (PL-Platoro caldera; MH-Mt. Hope caldera; CR-Creede caldera; BC-Bachelor caldera; SL-San Luis caldera; LG-La Garita caldera; MA-Mammoth caldera fragment; LC-Lake City cauldron; SI-Silverton cauldron; SJ-San Juan volcanic depression.) Modified from Lipman et al.(1970).

orogeny (Butler, 1971).

The evolution of the San Juan volcanic field is well documented by Lipman and others (1970) in their regional study of potassium-argon ages. Volcanism began in earliest Oligocene time from numerous scattered volcanoes. Among these is the still preserved Summer Coon center (Fig. 3). Ages of these early eruptions of andesitic to rhyodacitic lavas and breccias range from 30 to 35 m. y. b. p. It is possible that eruptions began as early as 40 m. y. ago. About 30 m. y. ago the eruption of intermediate composition lavas ebbed and the activity shifted to explosive ash-flow tuffs of quartz latite and low silica rhyolite, erupting from calderas. This activity continued for about 5 m. y. These more silicic rocks were derived by differentiation in the upper part of the magma chambers (Lipman, 1968).

The beginning of eruptions of the younger basalts and rhyolites of the early Miocene Hinsdale Formation coincides with the development of the San Luis Valley segment of the Rio Grande Rift. Basalt began erupting about 23 m. y. ago and is interbedded with much less voluminous rhyolite. This episodic activity continued into the Pleistocene. The significant change to bimodal volcanism indicates either different conditions of magma generation, or differentiation. This change appears to be characteristic of that part of the western interior of the United States affected by crustal extension (Lipman and others, 1970).

According to Steven and Epis (1968), the San Juan volcanic field is but a fragment of a more extensive mid-Tertiary field which once covered most of south-central Colorado.

LOCAL GEOLOGIC SETTING

General Geology

The Summer Coon center has been interpreted by Lipman (1968) to be a dissected stratovolcano. The volcano has been eroded such that the intrusive core is exposed as a nearly circular composite intrusive feature in the center of the area, and the extrusive rocks are well exposed on the flanks. Radial dikes of varying compositions radiate in a nearly evenly distributed pattern from the intrusive core (Fig. 4). Rocks of the Summer Coon volcano are exposed over approximately 50 square miles. The composition of the eruptive rocks ranges from basalt to rhyolite. All rocks related to the Summer Coon volcano are part of the middle Oligocene Conejos Formation (Lipman, 1968). Lipman and others (1970) obtained three potassium-argon ages for rocks from the Summer Coon area. Rhyodacite upon which the volcano developed yielded an age of 34.4 $\pm$ 1.4 m. y. b. p. based on biotite. Rhyolite from a dike at Summer Coon volcano yielded an age of 32.4 $\pm$ 1.3 m. y. b. p. from biotite. The age of the rhyodacite places the maximum age for the complex at about 33 to 35 million years.

Field relations of the various units of the Summer Coon volcano are summarized from Lipman (1978) and Mertzman (1972). The extrusive rocks of the cone are divided into three units (Mertzman, 1972). The stratigraphic sequence begins with a mafic unit overlain by a silicic unit, followed by an intermediate

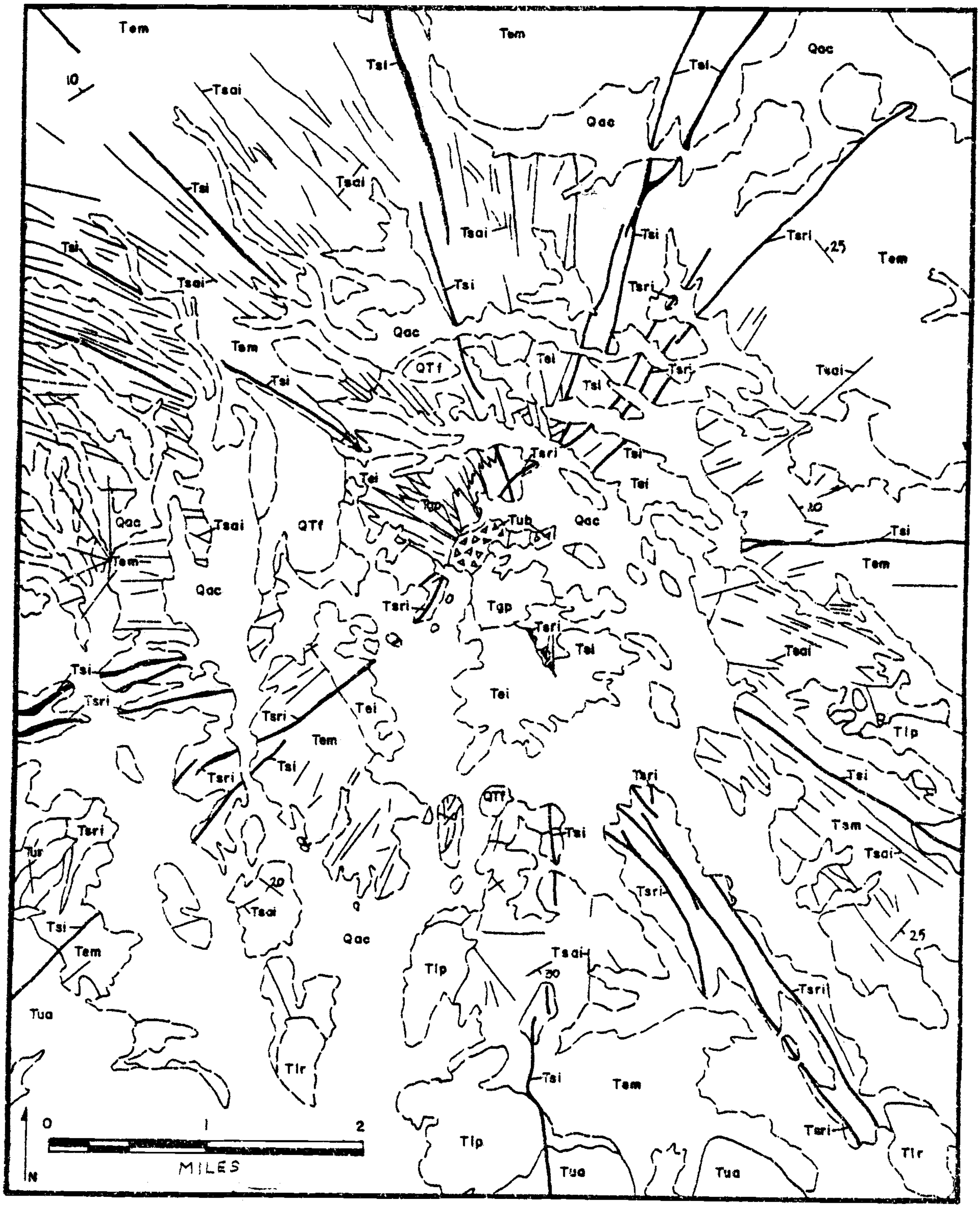


Figure 4. Geology of the Summer Coon Volcano. Modified from Lipman (1976) with data from Mertzman (1972). For full explanation refer to text. QTf-Pleistocene and Pliocene fan deposits; Qac-Quaternary alluvium and colluvium.

unit (Table 1). Mertzman grouped the dikes, as well as the flows and breccias, into this sequence.

The Early Mafic Unit (Fig. 4, map unit Tem) consists mainly of weakly stratified breccia. It contains four distinct rock types: olivine-augite basalt, olivine-bearing two-pyroxene andesite, pyroxene andesite, and two-pyroxene hornblende andesite. Of these, the olivine-augite basalt and pyroxene andesite make up nearly 95 percent of the Early Mafic Unit, which is 2800 to 3100 feet thick.

The Middle Silicic Unit (Fig. 4, map units Tlr and Tur) is divided into two parts, the Lower Rhyodacite Member and the Upper Rhyolite Member (Table 1). The Lower Rhyodacite Member is exposed only on the south end of the eroded cone. Thickness for this unit (not recognized by Lipman) is 50 feet. The Upper Rhyolite Member is restricted to one small exposure at the southwest end in association with a rhyolite dike. The flow has a maximum thickness of 330 feet. Both members of the Middle Silicic Unit are characterized by sparse feldspar and biotite phenocrysts.

The Late Intermediate Unit is also subdivided into two members. The Lower Pyroclastic Member (Fig. 4, map unit Tlp) is predominantly breccia of quartz latitic composition. Thickness is 600 feet, but neither the top nor the bottom are exposed. The Upper Andesite Member (Fig. 4, map unit Tua) is labeled a rhyodacite by Lipman (1968 and 1976). The aggregate thickness of the numerous flows comprising the unit is on the order of

<table>
<tr><td rowspan="5">Conejos Formation</td><td rowspan="2">Late Intermediate Unit</td><td>Upper Andesite Member (Tua)</td></tr>
<tr><td>Lower Pyroclastic Member (Tlp)</td></tr>
<tr><td rowspan="2">Middle Silicic Unit</td><td>Upper Rhyolite Member (Tur)</td></tr>
<tr><td>Lower Rhyodacite Member (Tlr)</td></tr>
<tr><td colspan="2">Early Mafic Unit (Tem)</td></tr>
</table>

Table 1. Volcanic stratigraphy of the Summer Coon Shield Sequence, Colorado. (Modified from Mertzman, 1972)

4000 to 5000 feet. Individual flows of varying compositions range between 50 and 300 feet in thickness. It is likely that the flows erupted from a variety of parasitic fissure vents. The eruptive rocks of the Summer Coon volcano are overlain unconformably by tuffs erupted from the Mt. Hope and La Garita calderas (Fig. 3).

Field relations and compositions of the radial dikes make it possible to correlate them stratigraphically with the eruptive rocks. Early Mafic Unit dikes are designated Tsai, Middle Silicic Unit dikes are designated Tsri, and Late Intermediate Unit dikes are designated Tsi (Fig. 4).

Intrusive rocks of the core area are likewise divided into three stratigraphic units by Mertzman (1972). Table 2 outlines the similar terminology used; Early Intrusive Unit, Middle Intrusive Unit, and Late Intrusive Unit. Only the Middle Intrusive Unit is subdivided into two members. The designation of the intrusive units is by analogy with the extrusive units.

The Early Intrusive Unit (Fig. 4, map unit Tei) consists of a variety of lithologic types. Chemically and mineralogically they are all quite similar. The unit varies texturally from fine-grained to medium-grained, and from porphyritic to holocrystalline. This texturally inhomogeneous unit appears to be several cupolas of different sizes and geometries which gave them different rates of cooling. Mertzman (1972) identified them all as either augite andesites or two-pyroxene andesites. A more plutonic-looking

<table>
<tr><td rowspan="4">Conejos Formation</td><td colspan="2">Late Intrusive Unit</td></tr>
<tr><td rowspan="2">Middle Intrusive Unit</td><td>Upper Breccia Member (Tub)</td></tr>
<tr><td>Granodiorite Porphyry Member (Tgp)</td></tr>
<tr><td colspan="2">Early Intrusive Unit (Tei)</td></tr>
</table>

Table 2. Volcanic stratigraphy of the Summer Coon intrusive rocks, Colorado. (Modified from Mertzman, 1972)

exposure was identified as a two-pyroxene diorite.

The Middle Intrusive Unit (Fig. 4, map units Tsp and Tst) is divided into two silicic members (Table 2). The lower (older) member is identified as a granodiorite porphyry by Mertzman (1972) and as a quartz monzonite porphyry by Lipman (1968). Total phenocryst percentage is about 25 percent. Plagioclase is the principal phenocryst-forming mineral and ranges up to 3 mm in size. The rock becomes finer grained toward the contact with the Early Intrusive Unit. The Upper (younger) Breccia Member is called a tuff breccia by Lipman (1968). It consists of granodiorite porphyry fragments in a matrix of cryptocrystalline quartz with isolated lumps of devitrified pumice (Mertzman, 1972). Little work was done on this member by earlier workers, due to the lack of identifiable original mineralogy as a result of hydrothermal alteration.

On the basis of bulk chemical analyses and mineralogy, the Lower Granodiorite Member is correlated with the Lower Rhyodacite Member of the Middle Silicic Unit of the extrusive sequence. Based on field evidence, the Upper Breccia Member is correlated with the Upper Rhyolite Member of the Middle Silicic Unit (Mertzman, 1972).

The Late Intrusive Unit (Table 2) is a pipe 20 feet in diameter intruding the Early Intrusive Unit (map unit Tei). The Late Intrusive Unit is not mappable at the scale of either Mertzman's (1972) or Lipman's (1976) maps, so no map unit was designated for it. It was called an augite monzonite porphyry by Mertzman (1972). On the basis of mineralogy and bulk chemistry, the Late Intrusive Unit is correlated to the Late Intermediate Unit of the extrusive sequence.

Structure

The most conspicuous structural feature of the Summer Coon volcano is the well-developed system of radial dikes. Lipman (1968) interpreted them as forming from the intrusion of radial fractures caused by minor doming around and over the intrusive core. Cited were the model studies simulating salt domes by Parker and McDowell (1955), which suggest that the first fractures to form during doming are radial fractures around the base of the incipient dome. As the dome enlarged, horst and graben structures developed in the central region of the dome, causing more complex fracture patterns. At Summer Coon there is no evidence, such as horst and graben structures, for large scale doming during the volcanic activities. The nearly perfect radial pattern of the dikes indicates that the fractures were formed in an isotropic or very weakly anisotropic stress condition. An anisotropic regional stress condition would have given a greater density of fractures in some preferred orientation. Such a condition would have been present during the subsidence of the San Luis Valley part of the Rio Grande Rift. But this event has been demonstrated to have been initiated in early Miocene time (Lipman and Mehnert, 1968). Further indication that the San Luis Valley did not begin subsiding until after the extinction of the Summer Coon volcano is demonstrated by the tilt of the Summer Coon area to the east-southeast. Volcanic flows to the east and southeast dip 25 to 35 degrees while to the west of the core area, flows dip 5 to 15 degrees. If the effect of regional tilting were removed, the flows would dip nearly symmetrically at primary depositional attitudes of 15 to 20 degrees away from the core area.

Actual faults have not been noted in the Summer Coon area except for some minor high angle normal faults at the southern extremity of exposed Summer Coon rocks. The lack of structural disruption of the Summer Coon area is noteworthy, and will be discussed in the conclusion.

Summary of Petrology

Mertzman (1972) did a substantial amount of petrographic and analytical work which provides significant insight on the genesis of the volcano. The following is a summary of his conclusions based upon bulk and trace element chemistry, isotope geochemistry, electron microprobe analyses, and petrographic study.

The Summer Coon calc-alkaline complex formed by the process of magmatic differentiation as indicated by silica variation and normative mineral diagrams. The combination of petrography, K/Rb data, and Ni Differentiation Index trend suggests a period of olivine and pyroxene crystallization prior to the precipitation of large amounts of plagioclase together with amphibole or pyroxene. Microprobe data of clinopyroxene compositions demonstrate that most crystallized before plagioclase was a major liquidous phase. Sub-silicic and nepheline normative amphibole crystallization enriched the liquid phase in SiO_2. Zonation patterns of plagioclase indicate that the parent magma was water-saturated which could have contributed to the early precipitation of olivine and pyroxene before plagioclase. The conclusion is that the Summer Coon rocks were generated under conditions of P_{H2O} less than P_{load}; P_{H2O} was in the range of 1.6 to 2.6 kilobars at a depth not greater than 50 kilometers. The mineralogy and chemistry of Summer Coon lavas could have been produced by the crystallization of a hydrous basalt or a hydrous basaltic-andesite at lower crustal depths. Further support for the Summer Coon rocks being products of the same magma is provided by strontium isotope geochemistry. The range of Sr^{87}/Sr^{86} is very small (0.752-0.757) while the whole-rock Sr content varies between 1050 and 300 ppm.

FIELD GEOLOGY AND PETROGRAPHY

Introduction

The intrusive center was remapped at a scale of 1"=500'. Attention was focused on the hydrothermally altered area covered by the claim block controlled by William A. Bowes, Inc. (Fig. 2). The area covered by Plate I does not cover the entire intrusive core of the volcano, as field mapping stopped short of the periphery of the core. The intent of this study was to refine lithologic contacts and to establish the spatial distribution of the hydrothermal alteration pattern. Lithologic units were assigned on the basis of mineralogy and textures recognizable in the field and Mertzman's (1972) study. Forty-four surface locations and ten pieces of diamond-drill core were sampled for thin-section examination. Emphasis was placed on the sampling of large intrusive bodies; only five surface exposures of dikes were sampled. All rocks at the study area are part of the middle Oligocene Conejos Formation.

Early Diorite Unit

The most heterogeneous unit of the intrusive core has been defined as the Early Diorite Unit. The exposure of the unit describes a discontinuous annular feature that is two miles in diameter. The Early Diorite Unit represents the oldest intrusive phase preserved at the Summer Coon volcano. In view of the intrusive character of the unit, rocks called andesite by previous workers are designated as diorite in this study.

The texture in hand specimens ranges from porphyritic to equigranular (Fig. 5). The porphyritic varieties have nearly white plagioclase phenocrysts floating in a greenish-gray groundmass. Phenocrysts of pyroxene and hornblende are more visible on a weathered surface. Phenocrysts of plagioclase feldspar average 1 mm across in the fine-grained rocks, and range up to 5 mm across in the medium-grained rocks. Phenocrysts of mafic minerals have about the same size distribution as plagioclase. The equigranular specimens vary from fine- to medium-grained and have a spotted off-white and greenish gray appearance. Maximum grain size is 4 mm for plagioclase and mafic minerals alike.

The fine-grained porphyritic variety is found at locations 35 and 40 (Plate I), and the medium-grained porphyritic variety at locations 36, 38, and 43. The medium-grained equigranular variety is found at location 2, and the fine-grained equigranular variety is found at locations 4-A, 34 and 42. No contact between the textural varieties were found, and preliminary mapping of float yielded no satisfactory geometric pattern to attempt to unravel the chaos.

In thin section, all specimens showed alteration effects, but primary textures and mineralogy are not obliterated. The porphyritic varieties have a cryptocrystalline to microcrystalline hypidiomorphic granular groundmass. The holocrystalline varieties have a nearly equigranular diabasic texture. Modal percentages

Figure 5. Textural variations of the Early Diorite Unit. Sampling locations, clockwise and beginning with penny for scale: 34, 35, 38, 43, and 2.

of the principal phenocryst minerals of the porphyritic variety are (Table 3): plagioclase, 12 to 27 percent; clinopyroxene, 2 to 23 percent; orthopyroxene, 0 to 3 percent; hornblende, 0 to 2.5 percent; quartz, 0 to 2 percent; biotite, 0 to 0.5 percent; and opaques, 0.5 to 3 percent. Total phenocryst percentage ranges from 21 to 37 percent. The groundmass contains predominantly plagioclase, with minor mafic and opaque minerals scattered throughout, and traces of quartz. Modal percentages of the principal mineralogy of the holocrystalline specimens are (Table 3): plagioclase, 60 to 67 percent; clinopyroxene, 11 to 23 percent; quartz, 0.5 to 5 percent; K-feldspar, 0 to 10 percent; hornblende, 0 to 4.5; orthopyroxene 0 to 3; and opaques, 2 to 8 percent. Crystals of plagioclase feldspar are generally normally zoned, but oscillatory zoned crystals are present in nearly all specimens as well. Compositions range from An_{34} to An_{58}, with the phenocrysts in the porphyritic varieties typically being more calcic than the grains in the holocrystalline specimens. The clinopyroxene is a calcic augite and the orthopyroxene is a magnesium-rich hypersthene as reported by Mertzman (1972). Augite is ubiquitous, whereas hypersthene is not. Potassium feldspar is only observed in a few specimens where it usually rims plagioclase feldspar. Hornblende is common in nearly all specimens and shows distinct brown pleochroism. Clearly primary biotite is present in only one porphyritic specimen as euhedral plates 1 mm in diameter. Secondary biotite is found as anhedral aggregates attached to augite and hornblende in specimens of

EARLY DIORITE UNIT

Porphyritic variety:' total phenocryst percentage - 21 to 37%.

MINERAL	plagioclase	clinopyroxene	orthopyroxene	hornblende	quartz	biotite	opaque
PERCENT	12 to 27	2 to 23	0 to 3	0 to 2.5	0 to 2	0 to 0.5	0.5 to 3

Holocrystalline variety

MINERAL	plagioclase	clinopyroxene	quartz	K-feldspar	hornblende	orthopyroxene	opaque
PERCENT	60 to 67	11 to 23	0.5 to 5	0 to 10	0 to 4.5	0 to 3	2 to 8

MIDDLE GRANODIORITE UNIT

Total phenocryst percentage - 25 to 45%.

MINERAL	plagioclase	hornblende	biotite	quartz	opaque
PERCENT	22 to 34	3 to 5	3 to 4	1 to 3	0.5 to 1

LATE VENT BRECCIA

MINERAL AND LITHIC FRAGS.	quartz	plagioclase	porphyritic lithic fragments	biotite	opaques	void spaces
APPROX. PERCENT	5 to 12	5 to 10	3 to 6	1 to 10	0.5 to 1	0 to 10

Table 3. Modal percentages of the primary constituent minerals of the three main intrusive units (surface and sub-surface) at the Summer Coon intrusive center.

both textural varieties. The biotite is always characterized by reddish-brown pleochroism. Quartz is present in trace amounts in the porphyritic rock, and in higher concentrations in the holocrystalline varieties as an interstitial space filler.

The origin of the Early Diorite Unit is open to debate. Lipman (1968) and Mertzman (1972) interpreted the emplacement of the rocks included in the unit being caused by lava pooling in a caldera or a crater, or from the formation of cupolas as offshoots of a central conduit. These interpretations are possible, but unlikely. It is unlikely that a summit crater would have had such a large diameter as two miles at the depth to which the volcano has been dissected by erosion. The lack of structures indicative of caldera collapse precludes the possibility of intracaldera lava pooling as a mode of emplacement. Lava pooling ought also to have formed a more texturally homogeneous mass with respect to the geometry described by the unit. Lipman (1975) has interpreted a similar rock unit, the Summitville Andesite, to have formed by intracaldera lava pooling within the Summitville-Platoro caldera complex. From personal observation, this fine-grained andesite varies only slightly laterally and with depth, and not in such a bewildering and chaotic manner as at the Summer Coon intrusive center. The last reservation concerns the cupola origin. It is difficult to envision cupolas formed by offshoots describing such a nearly circular feature in plan view. One would expect a more random and irregular distribution for a unit emplaced by a series of offshoots. An alternate hypothesis for the emplacement of the Early Diorite Unit is therefore presented in this study. The possibility exists that the unit is part of a composite sub-volcanic stock which intruded the lower levels of the volcanic edifice. Williams and McBirney (1979) note that some of these large stocks appear to have risen late in the history of a volcano. These composite stocks have chemical compositions that approximate those of the lavas which they intrude. Mertzman (1972) noted this compositional similarity and it led to his correlation of the rocks included in this unit to the early andesitic lavas and breccias of the cone sequence. Emplacement of the composite diorite stock was probably by magmatic stoping, which assimilated earlier conduits and lava beds to make room for itself. Piece-by-piece magmatic stoping could account for the textural variations within the unit by providing varied rates of cooling for different segments of this high level intrusion. The geometry of the stock is not known, but it could be a sill or a laccolith. The emplacement of a laccolith could account for the doming features (radial dikes) noted at the study area.

Middle Granodiorite Unit

A granodiorite porphyry is deduced from field evidence to be the next oldest intrusion of the intrusive core complex. This body intruded the central part of the Early Diorite Unit and was in turn intruded and disrupted by the last major central intrusive phase, a vent breccia (Plate I). Prior to being disrupted by the vent breccia, the granodiorite described a circular feature about 2500 feet in diameter. The unit was defined as a granodiorite by Mertzman (1972), and the name is preserved in this study.

The granodiorite porphyry is altered to some degree at all exposures. Groundmass color varies from light grayish brown to light gray. Total phenocryst percentage ranges from 25 to 45 percent. Phenocrysts of plagioclase feldspar are between 1 mm and 6 mm in size, and biotite and hornblende ghosts are up to 2 mm in diameter. The porphyry is coarsest near the contact with the vent breccia. Toward the contact with the diorite, the granodiorite becomes finer grained, and brecciated. Considerable movement of the fragments is not implied by the use of the term breccia by the author. The breccia is monolithic and the sub-angular fragments almost fit together (Fig. 6). The fragments range in size from 0.5 to 6 cm, spaced never more than 1 cm apart. The breccia is cemented by secondary silica, limonite, and goethite. Local heavy goethite stains are accompanied by a frothy encrustation of the fragments. A similar breccia is found at locality 23, but silica is lacking in the cement and the fragments are fitted more tightly together. This breccia appears to be only highly fractured rock, with clay and goethite filling the fractures.

In thin-section the groundmass has diffuse grain boundaries caused by alteration, but less altered samples have a microcrystalline

Figure 6. Monolithic granodiorite porphyry breccia from locations 33 (right) and 3 (left).

hypidiomorphic granular texture. Modal percentages of the original phenocryst minerals are (Table 3): plagioclase, 22 to 34 percent; hornblende, 3 to 5 percent; biotite, 3 to 4 percent; quartz, 1 to 3 percent; and opaques, 0.5 to 1 percent. The plagioclase feldspar is typically too altered for accurate determination of composition, but fresher phenocrysts have a composition in the range of An_{40} to An_{53}. Plagioclase phenocrysts are either reversely or oscillatory zoned. Biotite and hornblende are so altered that they can only be distinguished by alteration ghosts of the original crystal morphology. In the less altered surface samples and in drill core, biotite and hornblende can be firmly identified. Quartz is present in trace amounts as microphenocrysts, but is abundant in the groundmass. Much of the quartz may be secondary. Plagioclase feldspar is deduced to have been another major groundmass constituent. Opaque and altered mafic minerals are scattered throughout the groundmass in grains up to 0.3 mm in diameter.

Late Vent Breccia Unit

The last major central intrusive phase is a vent breccia, which was called the Upper Tuff Breccia Member of the Middle Intrusive Unit by Mertzman (1972). The vent breccia disrupts the northern part of the granodiorite porphyry and intrudes it as two small discrete bodies aligned in a northeasterly direction (Plate I). The two small bodies are probably offshoots from the main body.

The vent breccia is distinctly fragmental and hydrothermally altered at all exposures. The overall characteristics of the rock are those of a poorly sorted and unstratified tuff breccia. The fragments and phenocrysts are susceptible to weathering out of the rock, giving it the appearance of a natural sponge (Fig. 7). The color of the rock is light yellowish brown. The matrix contains abundant clay and quartz and has numerous subangular to rounded fragments of porphyritic rock with suspended phenocrysts. The fragments range in size from 0.5 to 5 cm, with those fragments 2 to 3 cm in diameter being the most common. Xenoliths of diorite larger than a meter in diameter are observed in drill hole intercepts, but are not common.

In certain thin-sections the fragmental nature of the rock is not readily discernible, appearing similar to strongly altered specimens of the granodiorite porphyry. Closer examination reveals that the vent breccia has a much higher quartz content and is unique because of the presence of polycrystalline quartz phenocrysts. The matrix has diffuse grain boundries and is composed of cryptocrystalline to microcrystalline quartz, altered feldspar, and opaque minerals. Approximate percentages of fragments and altered phenocrysts are (Table 3): quartz, 5 to 12 percent; plagioclase, 5 to 10 percent; biotite, 3 to 6 percent; porphyritic lithic fragments, 1 to 10 percent; and opaques, 0.5 to 1 percent. Void spaces from vesiculation and removal of phenocrysts account for zero to 10 percent of the volume of the rock. The fragments are predominantly granodiorite

Figure 7. Hand specimen of the Late Vent Breccia Unit from location 30, illustrating the fragmental nature of the unit.

porphyry, but severely altered porphyritic fragments with a dark groundmass are observed. These are probably related to the Early Diorite Unit. In hand specimen, fragments of apparent devitrified pumice and tuff are observed.

The light color and pyroclastic texture of the vent breccia suggests a rhyolitic composition. The emplacement of the vent breccia was most likely by explosive force, clearing out about one third of the 2500 foot diameter central conduit and brecciating parts of the earlier granodiorite. Further fragmentation and rounding of fragments may have occurred during settling in the irregularly shaped conduit.

Dikes

Three distinct groups of dikes intrude the Early Diorite Unit. Andesitic dikes intrude the outer edge of the unit, and rhyodacitic and rhyolitic dikes extend from the center out to the edge. The andesitic dikes were not mapped in this study because of poor exposures, thinness (about 5 feet), and a striking similarity to the rocks they intrude. The rhyodacitic and rhyolitic dikes are much thicker and strongly altered. Maximum thickness of these dikes approach 50 feet, and exposures are enhanced by numerous prospect pits.

The rhyolitic dikes are light tan to light greenish gray and are deficient in phenocrysts (less than 10 percent) compared to other dikes. Not enough dikes were sampled for valid petrographic study. The sampled rhyolitic dikes (locations 39, 41, and 44; Plate I) have a devitrified groundmass. The principal minerals are plagioclase, biotite, and quartz. Maximum phenocryst dimensions are 6 mm for plagioclase, and 2 mm for biotite and quartz in the medium-grained dikes (41 and 44). The dike at location 41 also contains hornblende. It is grouped with the rhyolitic dikes on the basis of groundmass texture and being on strike with other rhyolitic dikes. The finer grained dike at location 39 has the highest phenocryst content, about 10 percent. Phenocrysts of plagioclase feldspar and biotite are up to 4 mm and 3 mm in diameter, respectively. They are crudely aligned in a nearly vertical flow texture along strike. Quartz phenocrysts are all embayed as a result of resorption.

The sampled rhyodacitic dikes (locations 37 and 4-B) are light brown. Plagioclase phenocryst sites are marked by voids that are partially filled by clay. Total phenocryst percentage is on the order of 20 percent. Mafic minerals originally present probably were biotite and hornblende. There is less than 1 percent quartz. The groundmass is hypidiomorphic granular and is composed of altered plagioclase feldspar and mafic minerals, and quartz.

Diamond-Drill Hole Summary

Cores from the two deep diamond-drill holes were made available by W. A. Bowes, Inc. for thin-section examination. Drill hole SC-1 was drilled to a depth of 758 feet in 1975 and deepened to 1084 feet in 1977. The drilling was commissioned by W. R. Grace and Company in accordance with an agreement with W. A. Bowes, Inc. Drill hole SC-5 was completed by W. R. Grace and Company in a similar manner. It was drilled to 208 feet in 1979, and deepened to 407 feet in 1981. Prior to W. R. Grace and Company involvement, W. A. Bowes, Inc. completed three diamond-drill holes to depths of 109, 131, and 100 feet. On Plate I, these are labeled SC-2, 3, and 4 respectively. These shallow drill holes were not sampled for thin-section study. Geologic logs by L. P. James of all drill holes are available from W. A. Bowes, Inc. The author compared cores with these existing logs and logged the last half of SC-5.

Drill holes SC-3, 4, and 5 intercepted mostly the Middle Granodiorite Unit. SC-5 intercepted eight feet of a diorite zenolith at 27 feet from the collar. A variety of the Vent Breccia Unit with isolated diorite fragments is present to a depth of 126 feet. This is probably the offshoot exposed south of the drill hole. The rest of SC-5 intercepted granodiorite porphyry as verified by thin-sections at 209, 282, and 407 feet. Drill holes SC-3 and 4 intercepted only granodiorite porphyry. Drill hole SC-2 had poor core recovery, but from overall appearance the rock type intercepted is the Vent Breccia Unit. A diorite xenolith was also intercepted in a one foot interval.

Drill hole SC-1 is the most geologically complex of the drill holes. It was collared in alluvium near the contact of the vent breccia with the diorite (Plate I). The rock is hydrothermally altered throughout the hole. The dominant lithology intercepted is fine grained greenish-gray holocrystalline diorite very similar to surface exposures of that variety of the Early Diorite Unit. Specimens of the unit were sampled for thin-section study at depths of 93, 202, 235.5, 929 and 1048 feet. In thin-section the rock has a diabasic texture as do its equivalents from surface exposures. The principal minerals are plagioclase, pyroxene, hornblende, secondary and primary biotite, and traces of quartz. The cores are only moderately fractured, but close to the several short intercepts of offshoots of the granodiorite porphyry and vent breccia units the rock becomes more intensely fractured. These intercepts are all five to 25 feet long. The granodiorite porphyry was sampled at 663.5 feet for thin-section examination. On the basis of texture, original mineralogy, and alteration, it can be correlated to surface exposures of granodiorite porphyry. Dike offshoot intercepts are also noted. At 828 feet a 5-foot intercept of phenocryst-poor rock was sampled for thin-section examination. It shows a striking resemblance to the medium-grained rhyolitic dikes in texture, mineralogy, abundance of the phenocryst minerals, and alteration.

Further complexity of the geology of drill hole SC-1 is demonstrated by the intercept at 952.5 to 977 feet. It is an intrusion breccia which appears to predate both the Middle Grandiorite Unit and the Late Vent Breccia Unit. The reason for this interpretation is that the matrix is dioritic. The fragments are a mixture of diorite and intermediate composition rock. The fragments are smaller than 5 cm in diameter and subrounded. The intermediate composition debris can not be correlated with anything observed elsewhere in the drill hole or on the surface. It is possible that these fragments are related to an eruptive event or are country rock fragments. The diorite fragments can be correlated to the diorite observed on the surface and in the drill hole. This intercept is interpreted to be a remnant or offshoot of a volcanic conduit for a late eruptive or intrusive event of the Early Diorite Unit.

Discussion of Geology

Because of the deep dissection of the Summer Coon volcano, the Early Diorite Unit is interpreted to be a part of a composite sub-volcanic stock which intruded the lower levels of the volcanic edifice (Fig. 8). Williams and McBirney (1979) state that these stocks appear to have risen late in the history of the deeply dissected volcanos where they are noted. Regardless of the mode or time of emplacement of the Early Diorite Unit at the Summer Coon intrusive center, evidence points to at least three more eruptive events after the emplacement of the unit. The first is the event preserved by the breccia with a dioritic matrix in drill hole SC-1. Postdating that event is the development of the 2500-foot diameter central conduit for the granodiorite porphyry. It is possible that the granodiorite is the remnant of a dome-building event, which was shattered by an explosive event represented by the Late Vent Breccia Unit.

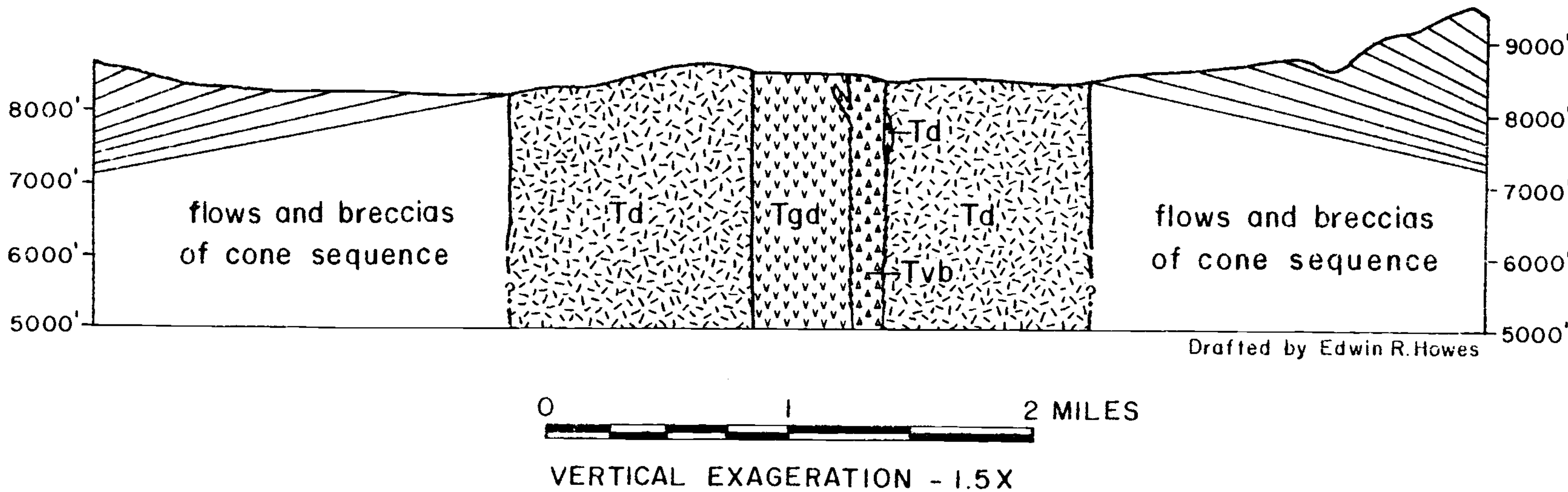


Figure 8. Generalized cross-section through the Summer Coon intrusive center based on surface geology and diamond-drill data; looking east.

The assignment of early, middle, and late relative age relationships is based on what is exposed in the core of this composite volcano. The implication is that these units represent the last three major central events in the complex history of a large stratovolcano.

The relationship of the dikes is still unclear. The rhyodacitic dikes could be related to the granodiorite porphyry, and the rhyolitic dikes could be related to the vent breccia. The andesitic dikes could be related to the event which caused the intrusion breccia in drill hole SC-1. The picture is complicated by the fact that some of the dikes at the Summer Coon volcano intrude only the extrusive rocks of the cone sequence and could therefore predate the intrusive core stocks and dikes.

HYDROTHERMAL ALTERATION

Introduction

Hydrothermal alteration at the Summer Coon intrusive core centers on the 2500-foot pipe-like body of granodiorite porphyry and vent breccia. Four alteration types were identified: propylitic, intermediate argillic, quartz-sericite, and vuggy silica (Plate II). The zones are easily identifiable in the field on the basis of color, hardness, and megascopic mineralogy, but the alteration mineral assemblages defined on Plate II were determined through thin-section study. Meyer and Hemley's (1967) classification scheme forms the basis for the following discussion.

Propylitic Alteration

Propylitic alteration dominates the alteration of the Early Diorite Unit. The alteration mineral assemblage of the propylitic zone is calcite + actinolite + chlorite $\pm$ epidote. Traces of secondary clay, sericite, opaque minerals, and quartz are also found in the propylitic zone. Intensity of alteration generally increases with depth and decreases with distance from the center of the intrusive core. From field evidence, the propylitic zone merges with a weaker regional deuteric alteration of similar mineralogy out in the extrusive rocks of the cone. Percentages of alteration minerals within the propylitic zone are summarized in Table 4.

Thin-section study shows variably selective alteration of

Propylitic Assemblage

MINERAL	actinolite	calcite	chlorite	epidote	clay	sericite	opaques (primary & secondary)
PERCENT	2 to 6	1 to 5	trace to 4	trace to 3	0 to trace	0 to trace	2 to 8

Intermediate Argillic Assemblage

MINERAL	clay	sericite	quartz	pyrite	jarosite
PERCENT	10 to 30	10 to 25	5 to 20	1 to 5	0 to trace

Quartz-Sericite Assemblage

MINERAL	quartz	sericite	opaques, accessories, clay and voids
PERCENT	80 to 90	5 to 15	traces to 5

Vuggy Silica Assemblage

MINERAL	quartz	vugs	opaques and accessories
PERCENT	75 to 85	10 to 20	traces

Table 4. Hydrothermal alteration mineral percentages of the four alteration mineral assemblages at the Summer Coon intrusive center, surface and subsurface.

plagioclase along microfractures and in patches, and in some instances total or pervasive replacement. Alteration minerals commonly noted are calcite, minor clay, and chlorite (Fig. 9). Traces of sericite are sometimes noted as an alteration product of plagioclase in the most severely altered rocks in the propylitic zone in addition to calcite and chlorite. The mafic minerals show several mineralogical effects that vary from patchy to total replacement. Pyroxene usually alters to actinolite, chlorite, and local epidote (Fig. 10). In certain cases this assemblage has been augmented by the development of calcite, quartz, and opaque minerals. If alteration of pyroxene to mainly actinolite and chlorite is complete, the crystal form is rarely preserved, being a fuzzy and fibrous aggregate of these secondary crystals. Hornblende does not appear to alter as readily as pyroxene. Where altered, it is replaced by patches of actinolite, chlorite, and chloritic clays. Biotite is locally in juxtaposition to hornblende and pyroxene, and seems to be an alteration product of these minerals.

The rhyolitic dike at location 41 is an exception to the alteration usually noted in the dikes of silicic composition. Plagioclase is partly altered to sericite, and biotite and hornblende are partly altered to epidote and chlorite. The devitrified groundmass is light green in hand specimen, indicating a considerable amount of chlorite and epidote. This alteration suggests that the dike should be included in the zone of propylitic alteration.

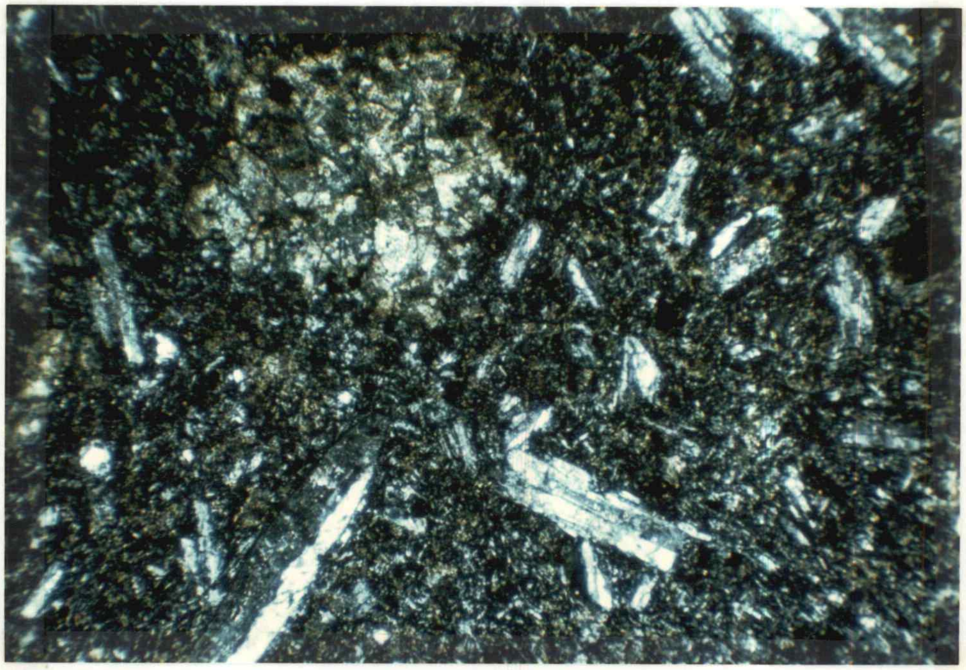


Figure 9. Photomicrograph of the replacement of plagioclase by calcite and chlorite in fine grained porphyritic diorite from location 35. Field of view is 3.8 mm. Crossed nicols.

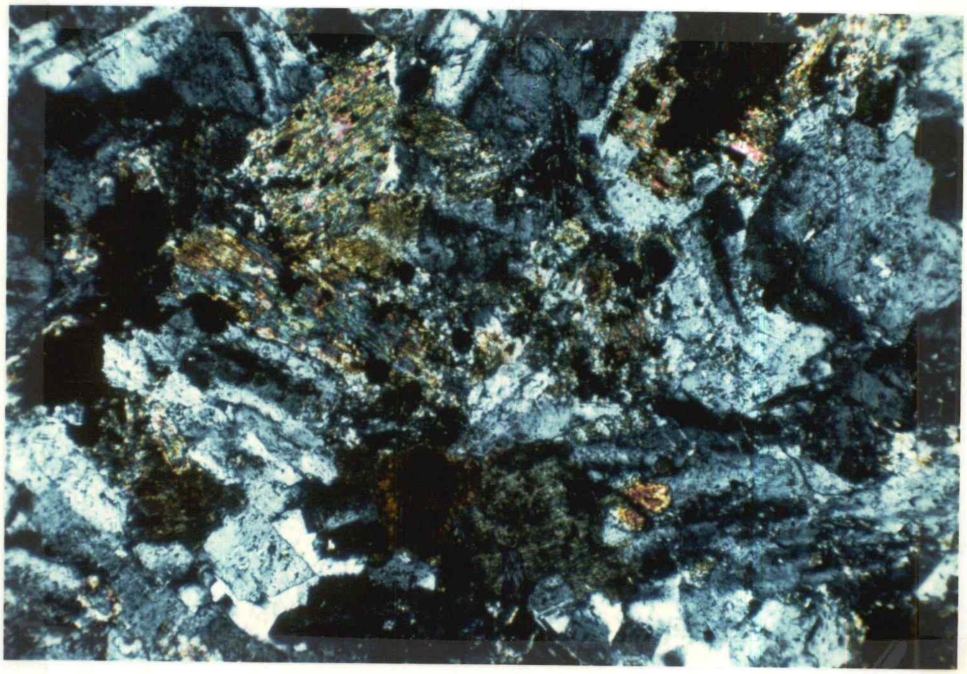


Figure 10. Photomicrograph of the replacement of pyroxene by actinolite, chlorite, and epidote in fine-grained holocrystalline diorite from drill hole SC-1 at a depth of 93 feet. Field of view is 1.2 mm. Crossed nicols.

Diagnostic megascopic features of the propylitic zone are the greenish color of the rocks and the presence of calcite and magnetite. Pyrite is not particularily abundant and is confined to fractures and is entirely oxidized at surface exposures. In diamond-drill cores, the fractures are filled by calcite and locally by quartz, or coated lightly by cubic pyrite.

Intermediate Argillic Alteration

The contact of the intermediate argillic zone with the propylitic zone is sharp as it also is a lithologic contact. Rock types affected by intermediate argillic alteration are the granodiorite porphyry, the vent breccia, and the rhyodacitic and rhyolitic dikes. The geometry of the zone in plan view crudely resembles the hub and spokes of a broken wagon wheel. The intermediate argillic zone is characterized by the assemblage clay + sericite + quartz + pyrite ± jarosite. Abundances of the alteration minerals are listed in Table 4. The bases for distinguishing between the intermediate argillic zone and the propylitic zone are the intensity of alteration, alteration mineralogy, rock color, and rock hardness. Alteration is more intense in the intermediate argillic zone, and the high clay content softens the rock and bleaches the color appreciably. The intermediate argillic zone is defined by the high clay, sericite, and quartz content and the lack of calcite, chlorite, epidote, and magnetite. As the contact between the intermediate argillic and propylitic zones is sharp, no transitional zone was defined. Calcite is formed, in addition to clay and sericite, from phenocrysts of plagioclase feldspar at location 39 (dike). Based on the high clay, sericite, and quartz content and the low calcite content, the rhyolitic dike is included in the intermediate argillic zone.

Within the intermediate argillic zone, plagioclase feldspar is variably altered to clay and sericite (Fig. 11). Alteration can affect the entire crystal, or just the core, the edges, or patches along microfractures. Where alteration is severe, quartz accompanies the clay and sericite. Alteration mineralogy and replacement texture of plagioclase does not vary below the zone of supergene weathering.

Except for the weakly altered zones, the mafic minerals are totally altered at all surface exposures. Biotite and hornblende are distinguishable only on the basis of pseudomorphic crystal habits. The outlines and cleavage traces are marked by opaque mineral stringers which form skeletal overgrowths of the original crystal. The mafic minerals are replaced by sericite and opaque minerals, and locally by clay and (or) quartz. The alteration mineralogy and replacement textures do not always vary with depth. However, the mafic minerals from drill core exhibit some variation in the intensity of alteration. Below the effect of supergene weathering, biotite is commonly unaltered or partly replaced by actinolite.

Pyrite is totally obliterated at surface exposures.

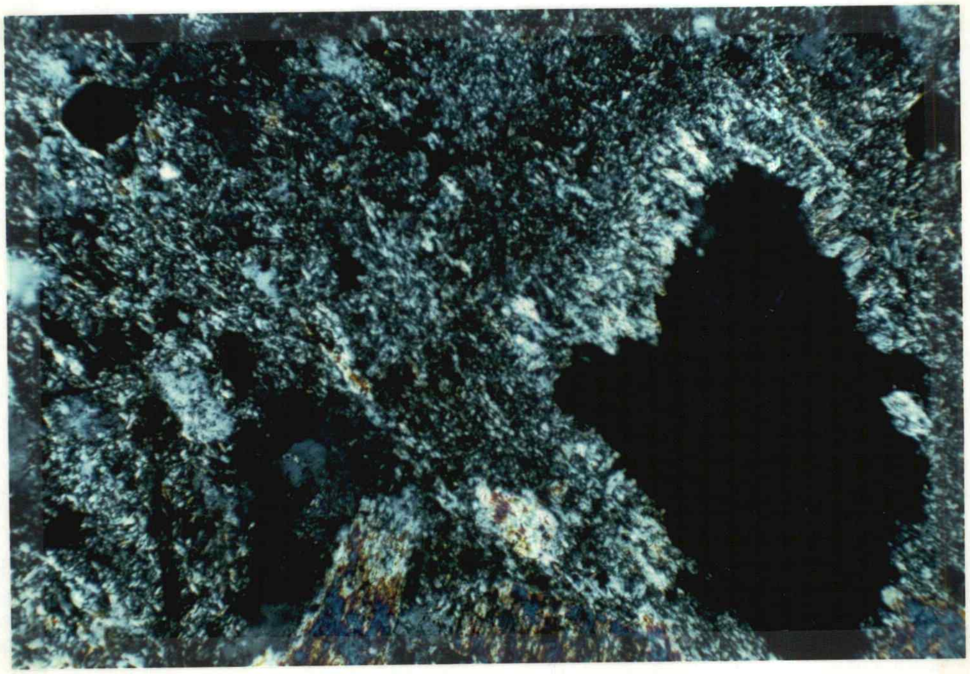


Figure 11. Photomicrograph of the replacement of plagioclase feldspar phenocrysts by sericite in vent breccia from location 30. Large void is the result of improper impregnation of secondary clay after plagioclase. Additional clay and sericite are visible in the matrix. Field of view is 1.2 mm. Crossed nicols.

Oxidation of pyrite in surface exposures has produced variable amounts of iron oxides and jarosite that stain the host rocks in and adjacent to fractures. Stains of limonite and goethite are heaviest at locations 32 and 33 in the breccia zone. Jarosite is present at location 23 in heavily fractured granodiorite porphyry, and sporadically throughout the vent breccia. At depth, 2 to 5 percent pyrite is disseminated in the rock and coats fractures.

Supergene processes have had a significant effect that has been superimposed on hypogene hydrothermal alteration in the intermediate argillic zone. Pyrite and mafic minerals are totally destroyed at surface exposures, and clay and sericite are more abundant than at depth. The only exception to this is the two weakly altered areas (Plate II). Exposures in these areas are not so heavily bleached or as stained by oxidized iron. Percentages of alteration minerals are lower than the lower limits of Table 4. Whole-rock X-ray diffraction of intensely altered specimens yields broad clay peaks which are indicative of supergene amorphous clays. The color and odor of the rock suggest that kaolinite is a component of the clay, but montmorillonite may also be present. Oxidized iron has apparently been mobilized and deposited to the east in ferricrete accumulations. The ferricrete fragments are colluvial and cemented by heavy accumulations of dark brown goethite. The percolation of meteoric waters has resulted in the formation of a leached and oxidized cap zone that is defined by increased amounts of clay and sericite, and decreased amounts of pyrite, mafic minerals, and iron oxides.

The intermediate argillic zone is not homogeneous. At locations 11 and 21, the granodiorite porphyry is only weakly altered. At location 21, the rock is fresh in appearance and might be classified as unaltered. Phenocrysts of hornblende and biotite are partly replaced by actinolite, and the plagioclase feldspar contains but small amounts of sericite. Both plagioclase feldspar and the groundmass in the specimen from location 11 are weakly argillized and sericitized. Phenocrysts of the mafic minerals are weakly sericitized. The porphyry is intensely fractured and full of quartz veinlets.

Veinlets observed from diamond-drill cores are of four types that consist of: light gray quartz, light gray quartz and pyrite, pyrite and petroleum, and white calcite. On the surface, only quartz ± pyrite veinlets are observed. The texture and abundance of veinlets are that of stockwork towards the southern end of the zone of intermediate argillic alteration.

Silicification

Silicification at the study area occurs only within parts of the zone of intermediate argillic alteration. The spatial distribution of strong silicification is irregular. Two types of silicification are noted: quartz-sericite replacement of the host, and vuggy silica replacement of the host.

The largest area of quartz-sericite replacement is at the southern margin of the granodiorite porphyry, confined largely to the zone of brecciation. Quartz and sericite have replaced the host to such an extent that the only other minerals present are opaque and accessory minerals and traces of clay (Table 4). Sericite accompanies quartz in the replacement of plagioclase feldspar and mafic minerals. Quartz that replaces the groundmass averages about 0.03 mm in diameter. Coarser grained (0.3 mm) quartz fills the sites of former plagioclase phenocrysts. Opaque minerals form the familiar skeletal ghosts of the replaced mafic minerals. Sericite is not as abundant at locations 24 and 25 as it is in the breccia zone.

Vuggy silica constitutes the remainder of the silicified rock exposures. Silica has flooded the host to the extent that the groundmass has been totally replaced by quartz, leaving solution cavities which are nearly perfect molds of the plagioclase phenocrysts originally present in the rock. The rock types which are affected by this type of alteration are the granodiorite porphyry and the vent breccia. The vugs in the altered vent breccia tend to be larger than in the altered granodiorite porphyry because fragments up to a centimeter in diameter have been removed. Chalcedony fills some of the vugs in the altered vent breccia at location 1 (Fig. 12).

The mafic minerals are replaced by quartz and opaque minerals. Minor amounts of iron oxide stain all exposures of silicified rock except at locations 21-A, 32, and 33 where the rock is heavily stained.

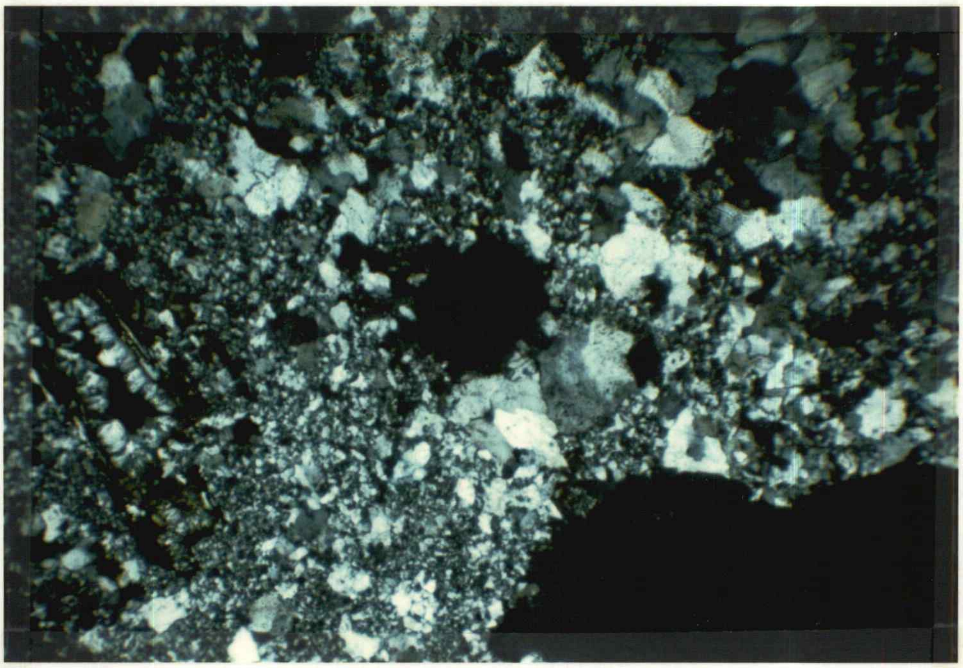


Figure 12. Photomicrograph of vuggy silica replacement of vent breccia host from location 1. Chalcedony partly fills cast of a plagioclase feldspar phenocryst (left). Larger vug is a mold of a fragment. Field of view is 3.8 mm. Crossed nicols.

Contacts between the zones of intermediate argillic alteration and silicification are sharp. The best exposure of the alteration contact is in a prospect pit at location 26. The contact is nearly vertical and undulatory. It is not known to what depth the silicified zones persist, because none were intercepted by the drill holes.

Discussion

Hydrothermal alteration at the Summer Coon intrusive center grades inward from a propylitic zone to an intermediate argillic zone. The intermediate argillic zone has scattered pods of quartz-sericite and vuggy silica alteration. The alteration mineral assemblages and the concentric zoning of the most intense alteration toward the center of the study area are similar to those previously described in the literature on porphyry copper-molybdenum deposits. Because of the concentric zonation of hydrothermal alteration assemblages, and the mineral assemblages defined in this study, the Summer Coon intrusive center fits the Lowell and Guilbert (1970) stockwork type model (Fig. 6). Application of this hypothesis implies that there exists at depth well-developed zones of phyllic (sericitic) and potassic alteration. For this interpretation, allowance must be made for the difference in geometry between the model and reality at the study area. At the Summer Coon intrusive center, only the high level effect of hydrothermal alteration is observed within the restricted area of a volcanic conduit. At greater depth, where

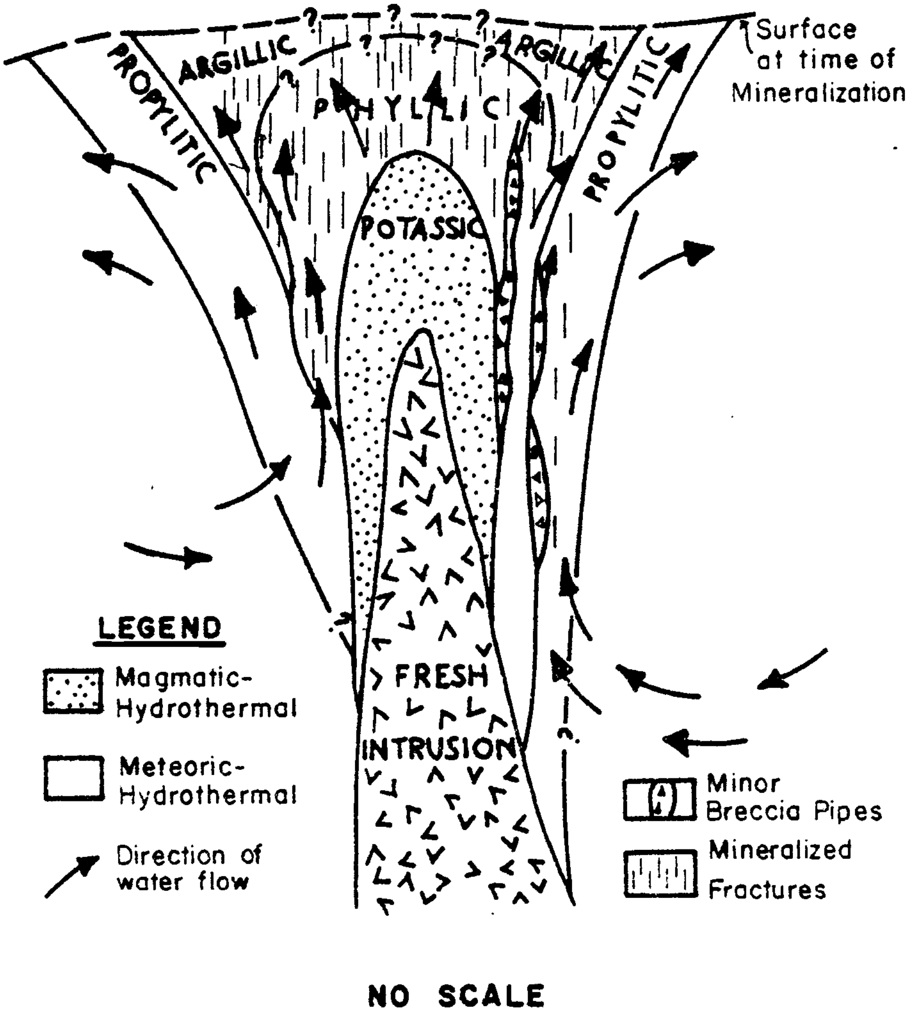


Figure 13. Model of the development of alteration zoning for a hypothetical stockwork type porphyry copper-molybdenum system. From Lowell and Guilbert (1970).

a larger composite subvolcanic stock may be present, proportionately larger zones of hydrothermal alteration may also be present. Evidence such as the large amounts of clay and silica suggest that alteration at the study area was caused by hot spring activity beneath the water table. The hydrothermal fluid would have been nearly neutral with chloride as the major anion (Rose and Burt, 1979). The alteration mineral assemblages and the confinement of the strongest alteration to the 2500-foot diameter conduit are consistent with such an interpretation.

METALLIZATION AND ALTERATION GEOCHEMISTRY

Introduction

This section will present and discuss geochemical data from a C-horizon soil sampling grid, rock chips, and diamond-drill cores. Because of the thin and poorly developed soil at the study area, the C-horizon soil sample analyses will be compared directly to rock chip analyses. All samples were analyzed by Specomp Services, Inc. in Hayden, Colorado, by D. C. arc emission spectrography. The multi-element analysis yields values for 35 elements.

Soil Geochemistry

W. A. Bowes, Inc. completed a C-horizon soil sampling grid over the central part of the claim block before this study was undertaken. The grid measures 6,000 by 6,000 feet, with samples taken every 300 feet along north-south lines and every 750 feet along east-west lines. Contour maps were prepared by W. A. Bowes, Inc. for molybdenum (Plate III), lead, zinc, and silver (Plate IV), copper (Plate V), and nickel (Plate VI). Computer generated perspective diagrams were prepared for nickel, cobalt, manganese, magnesium, and calcium by W. A. Bowes, Inc. The diagrams were reduced and are Figures 14, 15, 16, 17, and 18, respectively. Arithmetic contours were used on the geochemical contour maps to emphasize a bullseye effect in an essentially geochemically barren terrain. The contour maps and perspective diagrams permit evaluation of anomalous zones of enrichment and depletion of metals related to metallization and hydrothermal alteration at the study area.

A twin-lobed molybdenum anomaly (Plate III) centers on the zone of intermediate argillic alteration. Values of 6 to 15 ppm define the anomaly over the sampled area with values lower than 5 ppm for background. The lower limit of determination by emission spectrographic analysis is 5 ppm (Nelson, 1972). Rose, Hawkes, and Webb (1979) list an average abundance of 1.3 ppm molybdenum in granitic igneous rocks. Given the analytical lower limit and a general impression of the average abundance of molybdenum, there is a small, but significant, enrichment of molybdenum in the zone of intermediate argillic alteration caused by metallization processes.

The lead anomaly (Plate IV) is similar in shape to the molybdenum anomaly, but it covers a larger area. Two lobate areas of 100 ppm center on the zone of intermediate argillic alteration. Values of 30 to 50 ppm extend outward to the east along exposures of argillized dikes. Background values for lead over the sampled area are on the order of 10 to 20 ppm. The average abundance of lead in granitic igneous rocks is 18 ppm (Rose, Hawkes, and Webb, 1979). The lower analytical limit for emission spectrographic analysis is 10 ppm (Nelson, 1972). Lead has been significantly enriched in the intermediate argillic zone by metallization processes. The main lead anomaly straddles the molybdenum anomaly. Other metals plotted on Plate IV are zinc and silver. Along with lead, these metals are commonly present as peripheral deposits at porphyry-type deposits. At the study area, only isolated values of 200 ppm zinc and 0.5 ppm silver are encountered in the vicinity of altered dikes. Zinc and silver were detected in the main zone of intermediate argillic alteration, but the abundances of the elements were below the lower limit of determination of 200 ppm for zinc and 0.5 ppm for silver. The amount of zinc and silver was high enough to be above the limit of detection, but too low for accurate determination. Average quantities of zinc and silver in granitic igneous rocks are 51 and 0.037 ppm, respectively (Rose, Hawkes, and Webb, 1979).

The copper anomaly (Plate V) is not well defined. Background values over the sampled area are approximately 30 to 40 ppm. Several zones of weakly anomalous copper values (about 70 ppm) are present, as is a doubtful value of 500 ppm. The median abundance of copper is 12 ppm for granitic igneous rocks and 72 ppm for mafic igneous rocks (Rose, Hawkes, and Webb, 1979). Because the distribution of copper is irregular, and the apparent anomalies straddle changes in alteration zones and lithology, it is difficult to evaluate the apparent anomalies. On the basis of these observations, concentrations of copper in soils from the Summer Coon intrusive center do no constitute a significant anomaly.

Nickel (Plate VI) shows a dramatic depletion over the main zone of intermediate argillic alteration. Values over the propylitized diorite are in the range of 70 to 150 ppm. Values over the zone of intermediate argillic alteration decrease to 10 ppm. There is also a change to more silicic rock types in this zone, which, prior to hydrothermal processes, probably had a much lower nickel content.

Rose, Hawkes, and Webb (1979) list averages of 130 and 4.5 ppm for mafic and granitic igneous rocks, respectively. Interpolation of these abundances to fit the rock types at the study area is possible, but also highly speculative. The dramatic apparent depletion of nickel is probably due more to a change in lithology than to hydrothermal alteration. Within the zone of intermediate argillic alteration there is a depleted zone, however. The depletion is strongest near the contacts to the zone of propylitic alteration. The depletion pattern forms a ring about a less depleted core. This depletion suggests strongly that depletion of nickel has occurred within the intermediate argillic zone.

All other alteration-related depletions will be presented in terms of computer-generated perspective diagrams. The perspective diagrams are useful for presenting large amounts of geochemical data in a graphic manner, and for permitting rapid visualization of the depletion or enrichment of elements. The perspective diagrams of geochemical data from the study area are particularily graphic in the way that abundances of certain elements mimic the geology and the zones of hydrothermal alteration. The perspective diagram for nickel (Fig. 14) is included for comparison to a contour map (Plate VI) of the same data. The grid interval is different on the perspective diagrams because the computer interpolated data - points to square off and smooth out the grid for better visual effect.

Cobalt depletion (Fig. 15) over the intermediate argillic zone yields a pattern nearly identical to that of the nickel

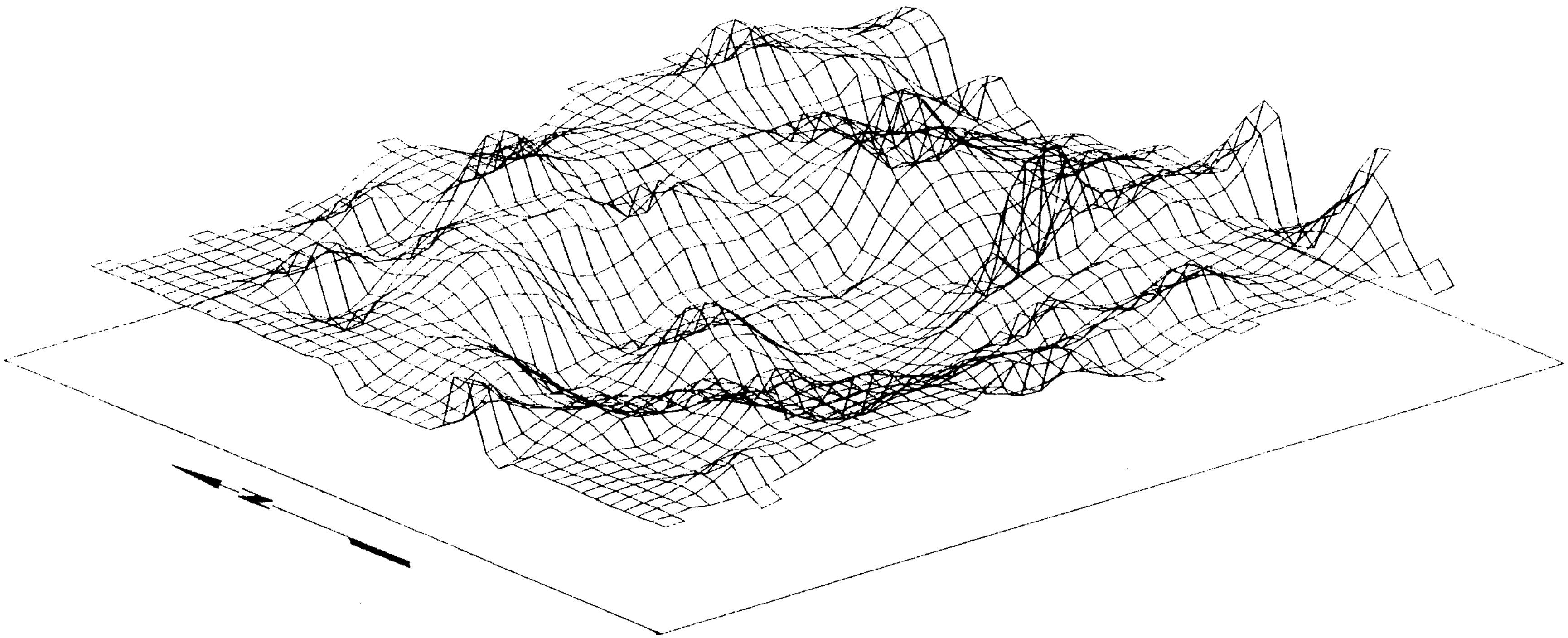


Figure 14. Computer generated perspective diagram of nickel geochemical values for surface samples at the Summer Coon intrusive center. Grid interval = 150 feet. Horizontal angle = 45°. Vertical angle = 25°. Vertical exaggeration = 0.045.

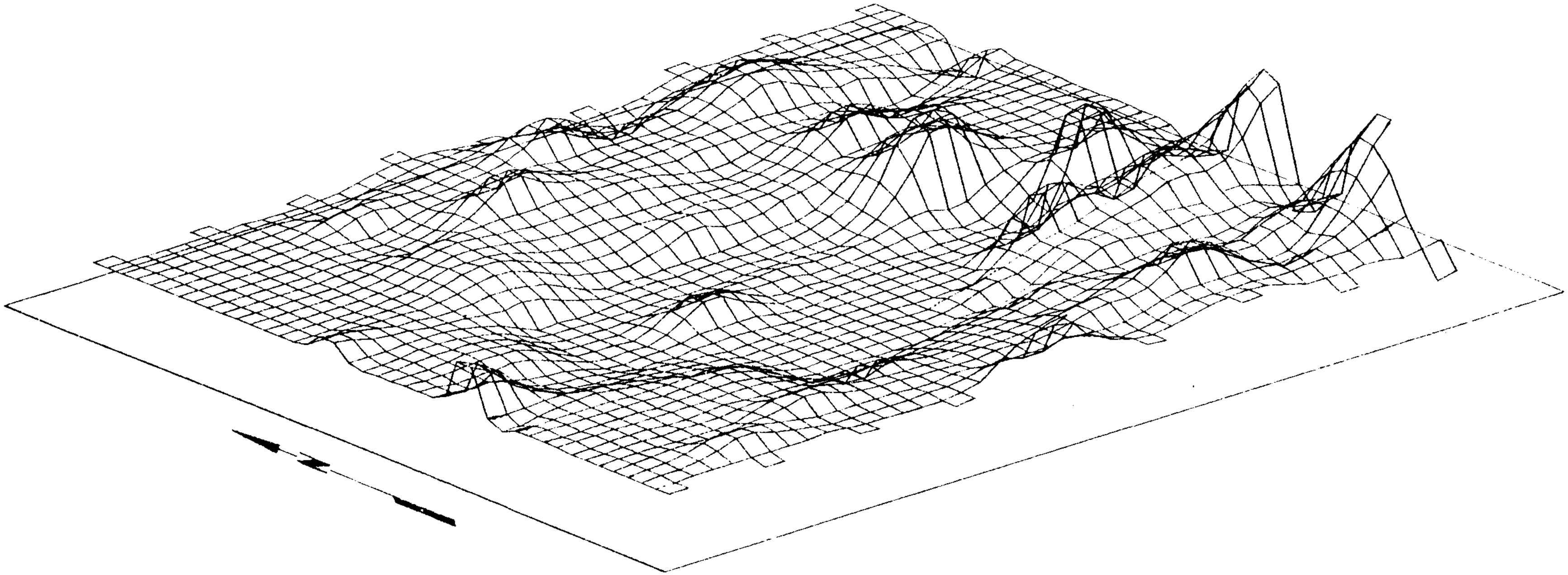


Figure 15. Computer generated perspective diagram of cobalt geochemical values for surface samples at the Summer Coon intrusive center. Grid interval = 150 feet. Horizontal angle = 45°. Vertical angle = 25°. Vertical exaggeration = 0.070.

diagram. This demonstrates that both elements were similarily affected by hydrothermal alteration. Manganese also is depleted over the central intermediate argillic zone, and sporadically along altered dike traces on the eastern edge of the sampled area (Fig. 16). The magnesium and calcium perspective diagrams (Figs. 17 and 18) mirror the patterns described for nickel, cobalt, and manganese. The depletion of these is directly linked to the partial-to-full destruction of minerals such as plagioclase, hornblende, and biotite, and the subsequent leaching of these elements out of the rock by hydrothermal fluids.

Rock Chip and Drill Core Geochemistry

Rock chip samples were collected by the author to check for mineralization. Six samples of silicified rock (locations 1, 3, 21, 26, 32, and 33) were analysed by atomic absorption for gold. The sample from location 1 analyzed 0.15 ppm gold. All the rest of the samples had a gold content below the lower limit of determination of 0.10 ppm. The samples were also analyzed by emission spectrography, and the results showed strong depletion of all elements except silicon, as expected. A fragment of granodiorite porphyry, coated and stained by goethite, from the ferricrete accumulation at location 29 was also analyzed. This sample was enriched in iron, zinc, manganese, and vanadium compared to other surface samples. Iron was considerably enriched at 10 percent, while zinc, manganese, and vanadium were weakly enriched at 200 ppm each.

Prior to this study, William A. Bowes, Inc. analyzed core from

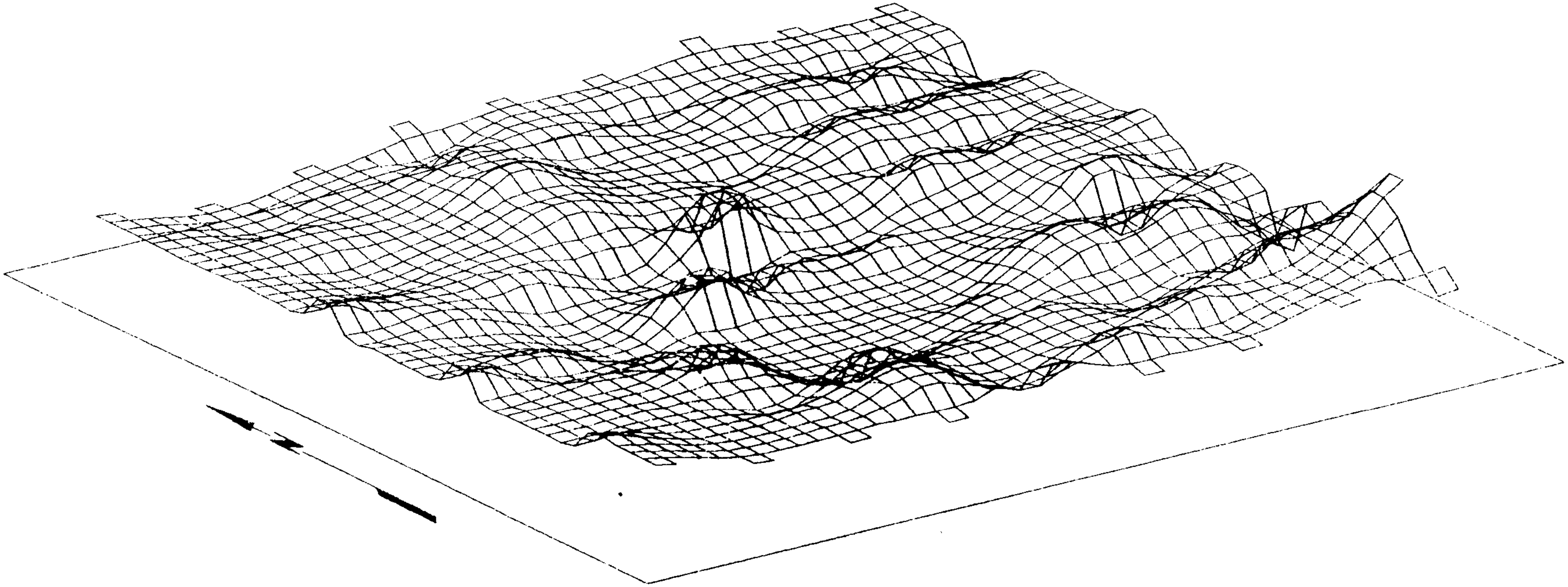


Figure 16. Computer generated perspective diagram of manganese geochemical values for surface samples at the Summer Coon intrusive center. Grid interval = 150 feet. Horizontal angle = 45°. Vertical angle = 25°. Vertical exaggeration = 0.0032.

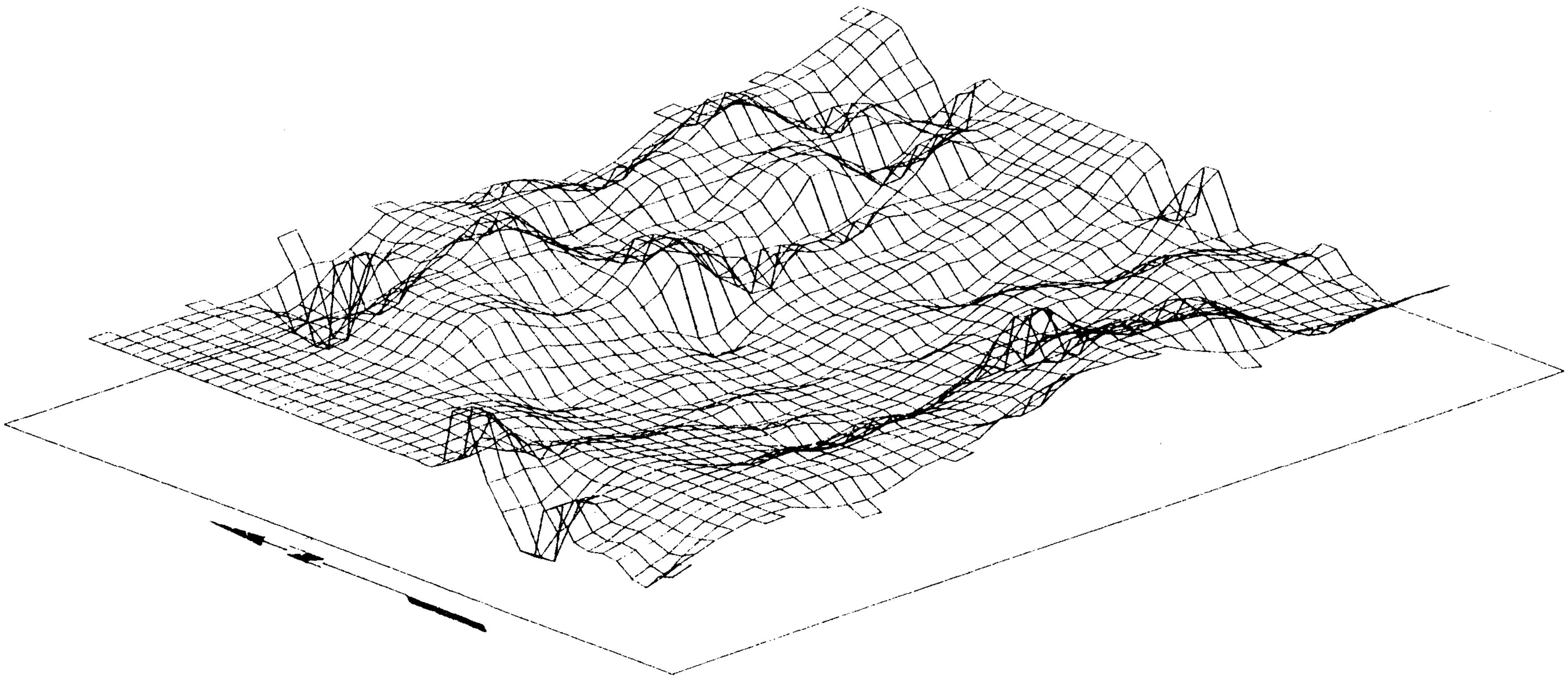


Figure 17. Computer generated perspective diagram of magnesium geochemical values for surface samples at the Summer Coon intrusive center. Grid interval = 150 feet. Horizontal angle = 45°. Vertical angle = 25°. Vertical exaggeration - 0.0003.

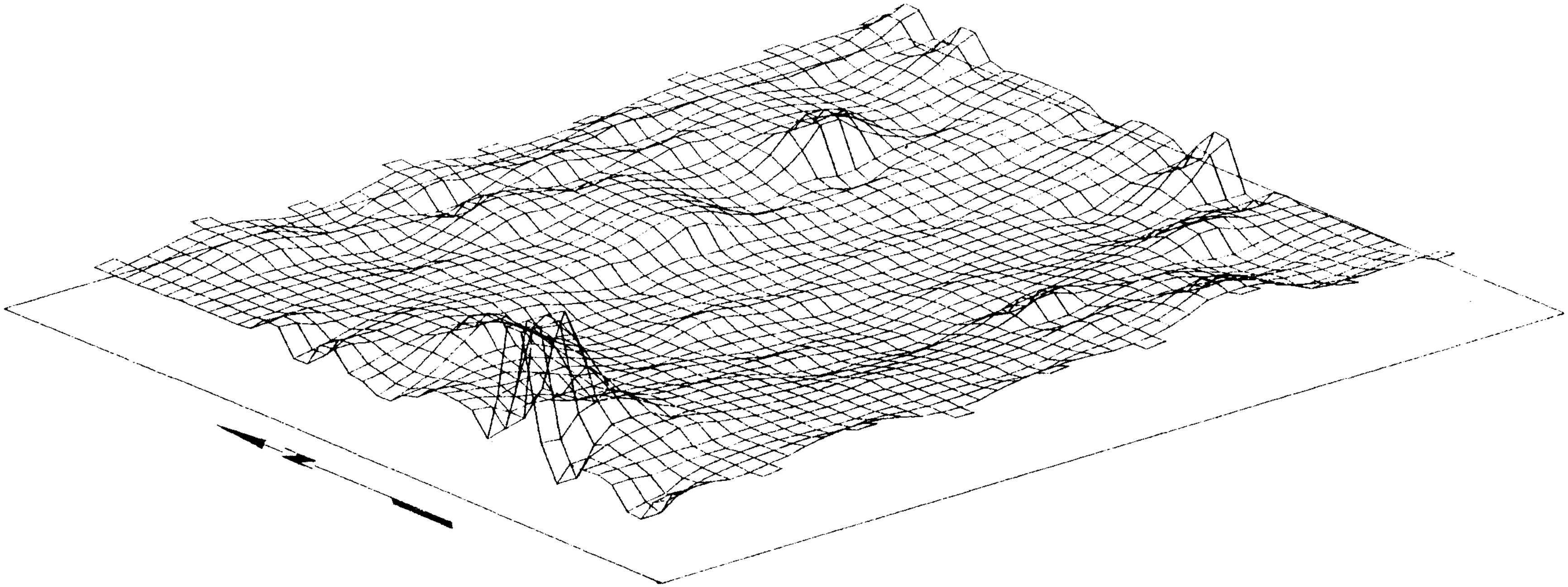


Figure 18. Computer generated perspective diagram of calcium geochemical values for surface samples at the Summer Coon intrusive center. Grid interval = 150 feet. Horizontal angle = 45°. Vertical angle = 25°. Vertical exaggeration = 0.0002

the three shallow holes SC-2, 3, and 4. W. R. Grace and Company assayed core from drill holes SC-1 and SC-5. At the time this study was pursued, these assay results were proprietary information. Ore grade mineralization was not intercepted in any of the drill holes. The main characteristic of these analyses is the great variability in abundances of most elements. However, there are overall chemical differences between the supergene leached and oxidized cap zone and the unweathered sulfide zone at depth. The oxidized cap zone was defined in the alteration chapter by the increased amounts of clay and sericite, and the destruction of pyrite and mafic minerals at near-surface and surface exposures in the zone of intermediate argillic alteration. The oxidized cap zone is about 35 feet thick. The overall chemical difference is demonstrated by frequency histograms of the abundances of elements in the oxidized cap zone versus the sulfide zone (Fig. 19). Seventeen samples were analyzed from the first 35 feet of drill holes SC-2, 3, and 4, and 80 samples were analysed from greater depths. Leaching caused by percolating groundwater has resulted in detectible depletions of the elements Ca, Na, K, Fe, Mg, Mn, Co, Mo, Cu, and Zn in the oxidized cap aone. Elements which do not show appreciable changes are Pb, Ag, Ba, Ni, Ti, Cr, and V. There is no evidence for a blanket zone of supergene enrichment at the study area. Isolated high values for the elements Cu, Mo, Pb, Zn, Ag, and Fe are directly related to a greater density of pyrite-coated stockworks and (or) to quartz-pyrite stockworks. Typical high values encountered are 400 ppm Cu, 60 ppm Mo, 500 ppm Pb, 5000 ppm Zn, and 10 ppm Ag.

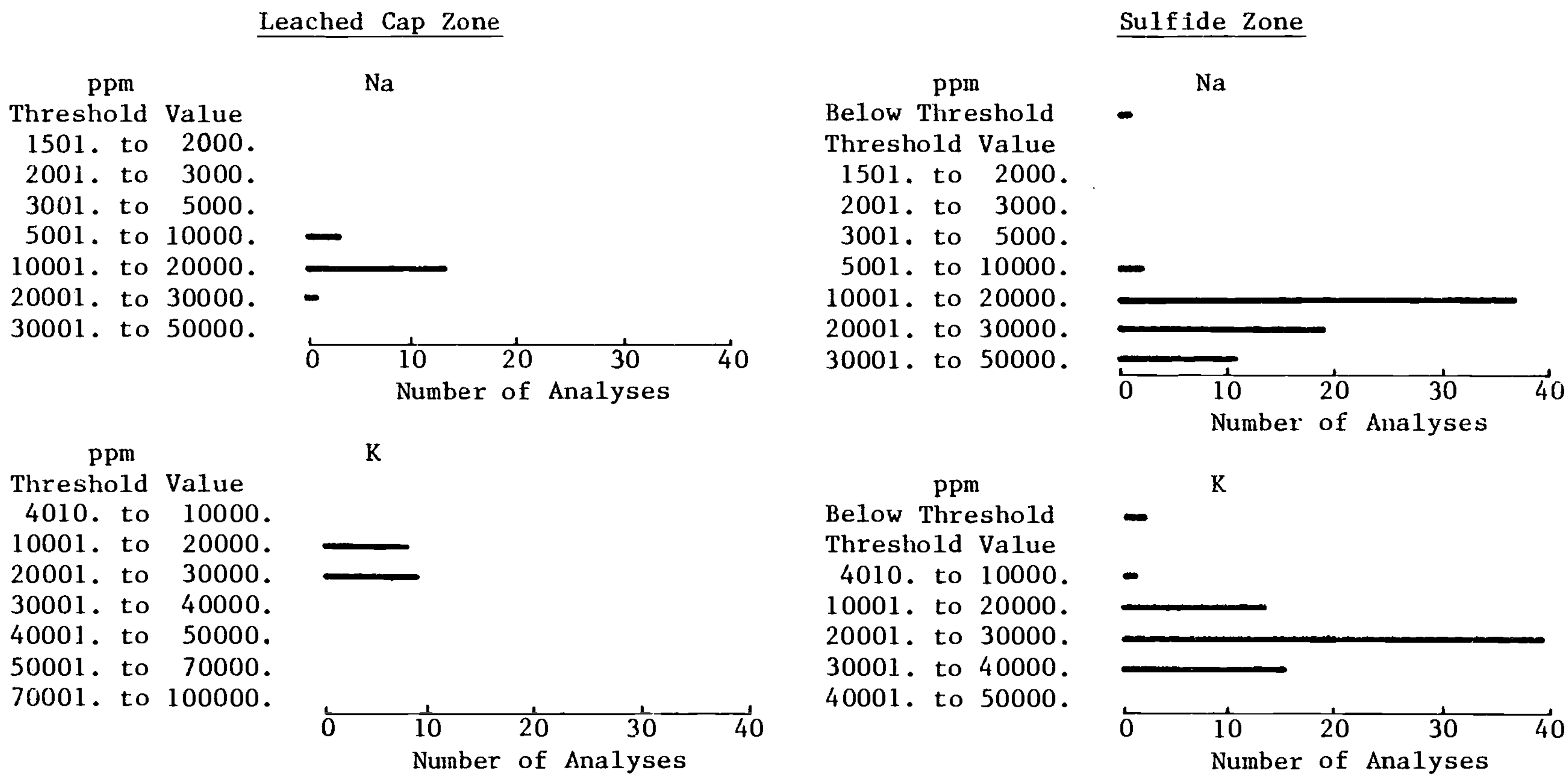
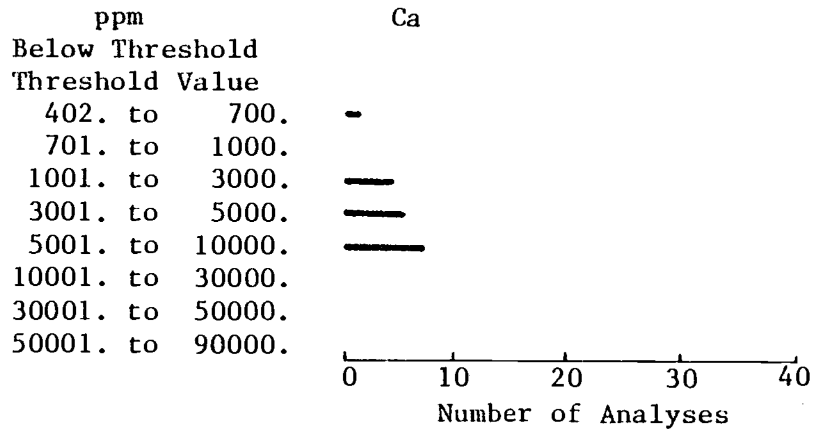
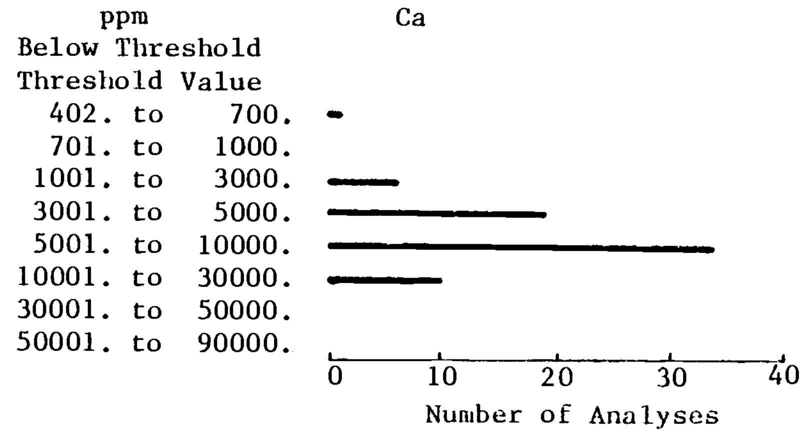


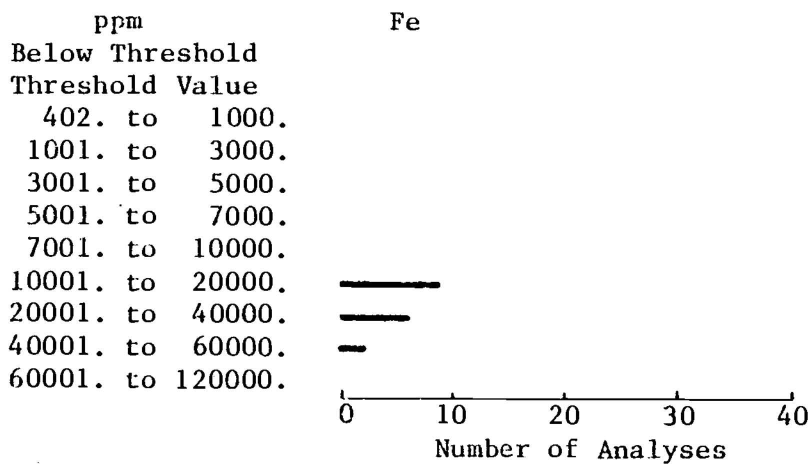
Figure 19. Frequency histograms of elements analyzed by emission spectrography. Leached cap zone versus sulfide zone; combined analyses from drill holes SC-2, 3, and 4 at the Summer Coon intrusive center.

Leached Cap Zone

Sulfide Zone







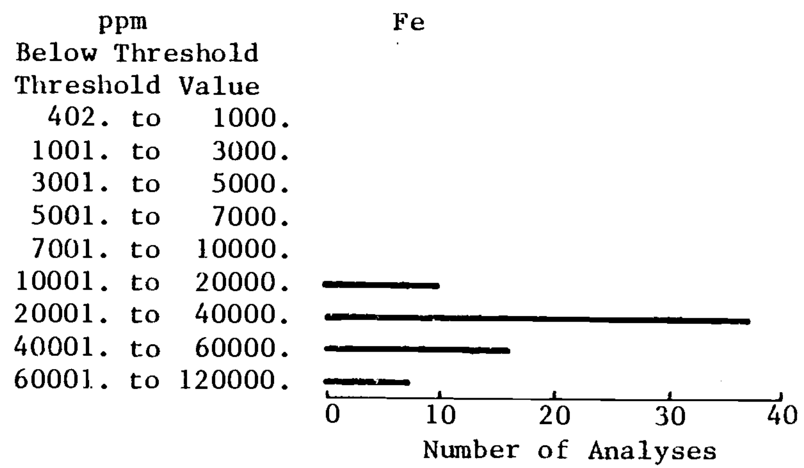
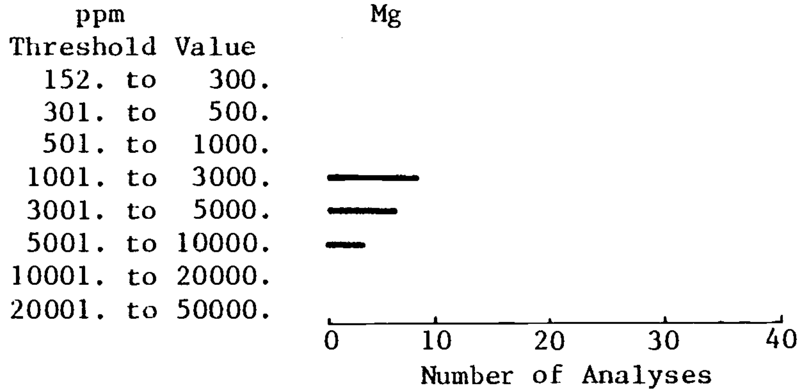
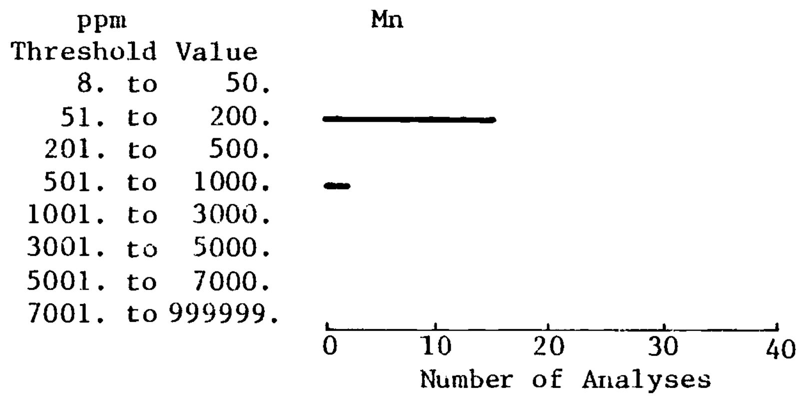


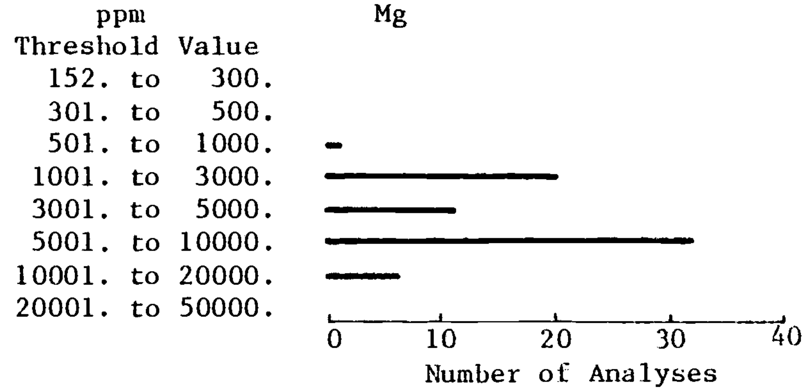
Figure 19. (continued)

Leached Cap Zone





Sulfide Zone



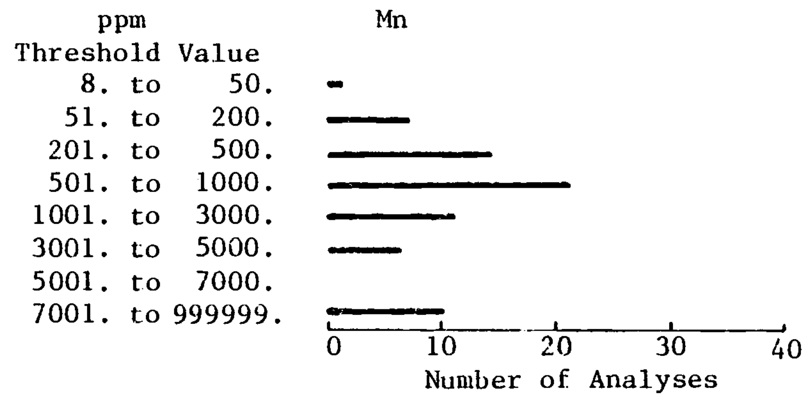


Figure 19. (continued)

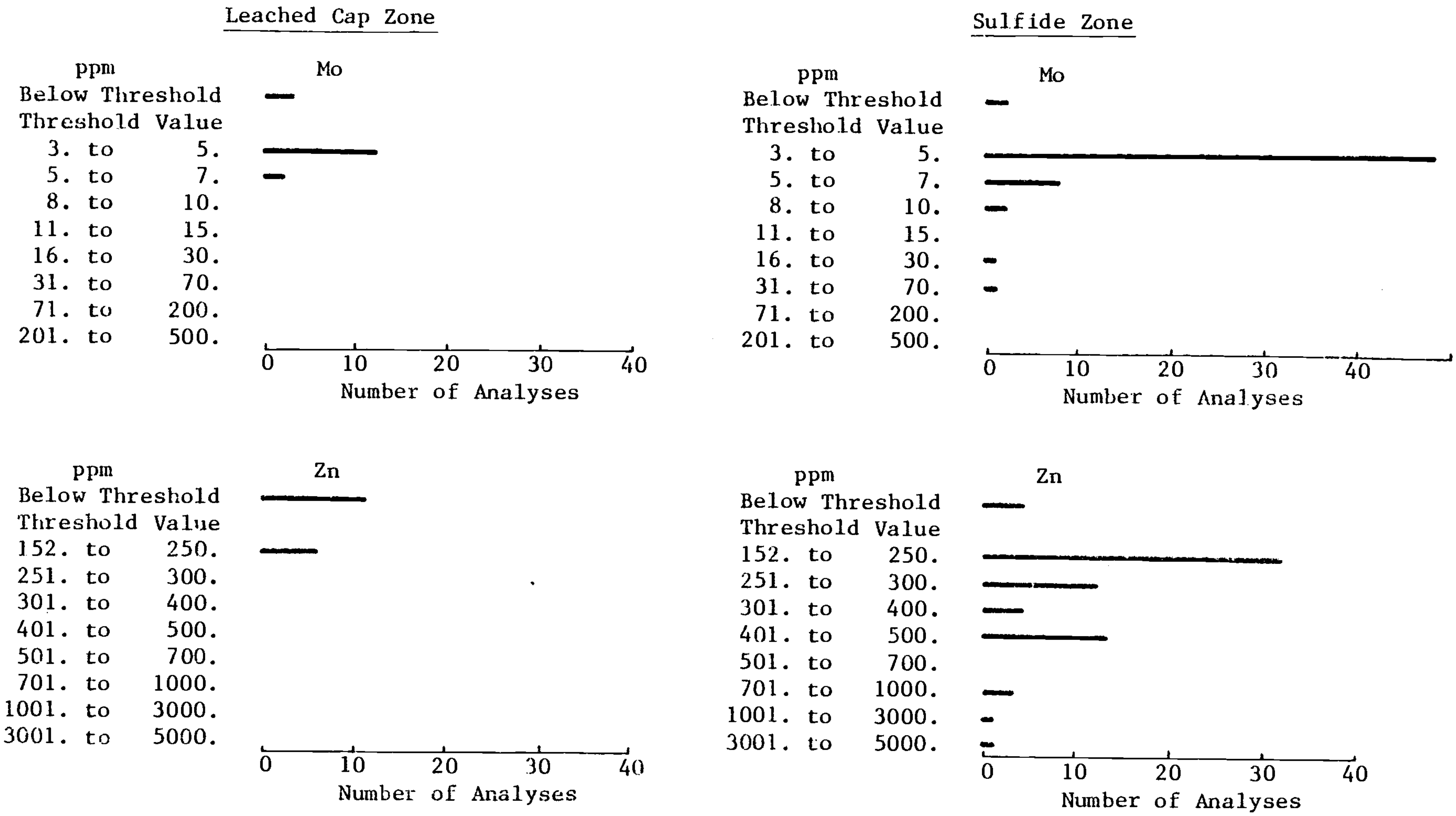


Figure 19. (continued)

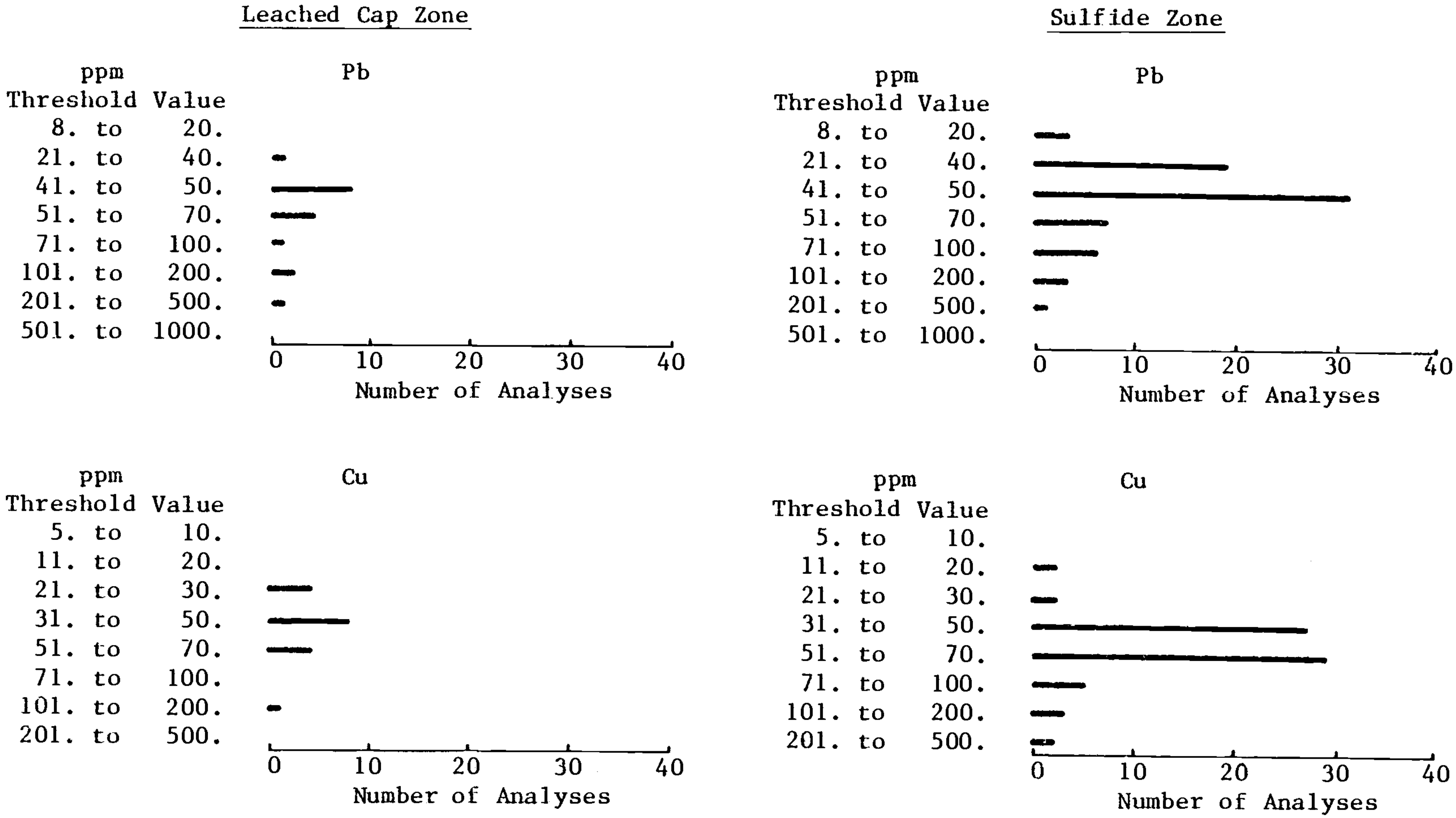


Figure 19. (continued)

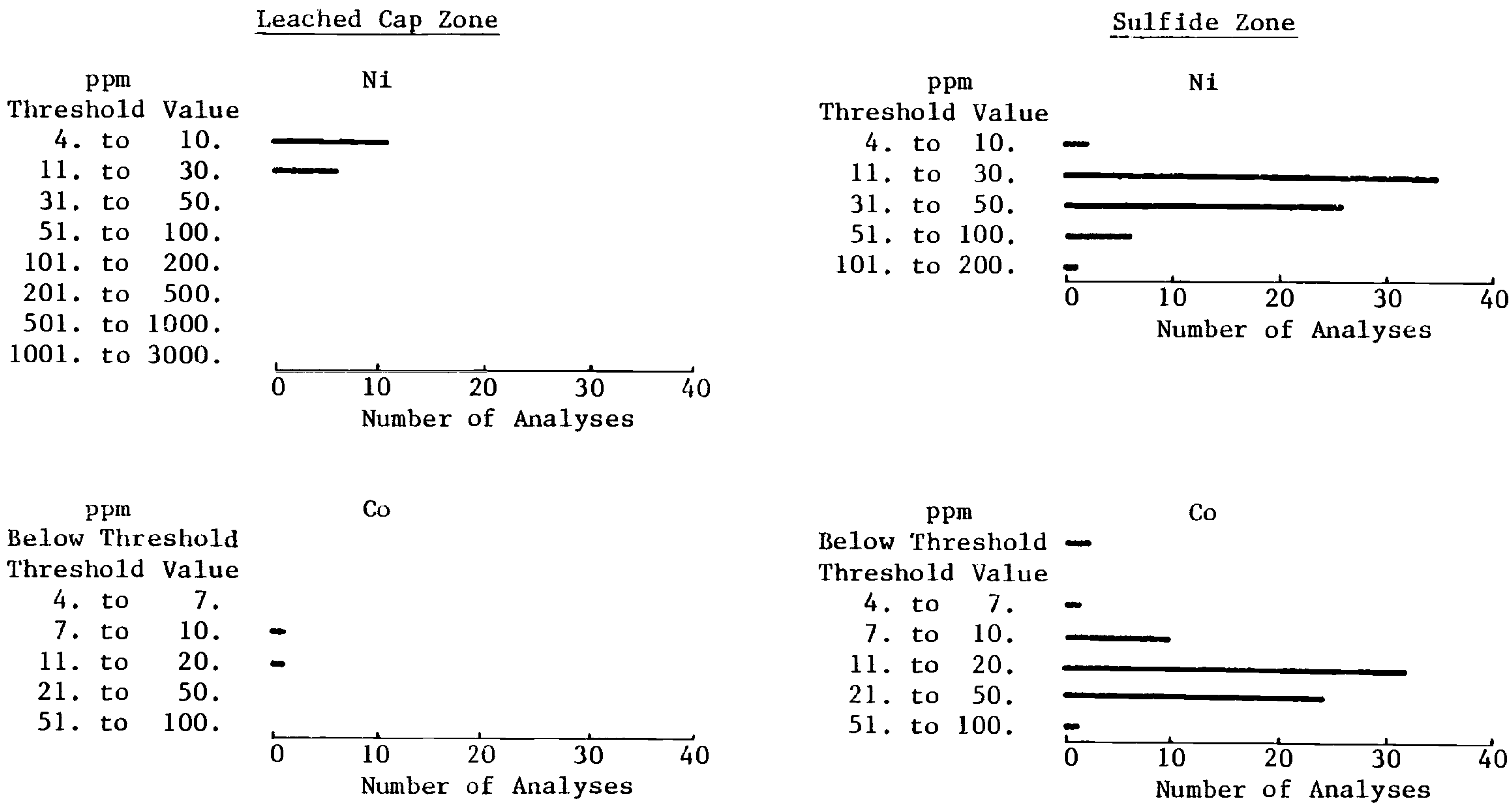


Figure 19. (continued)

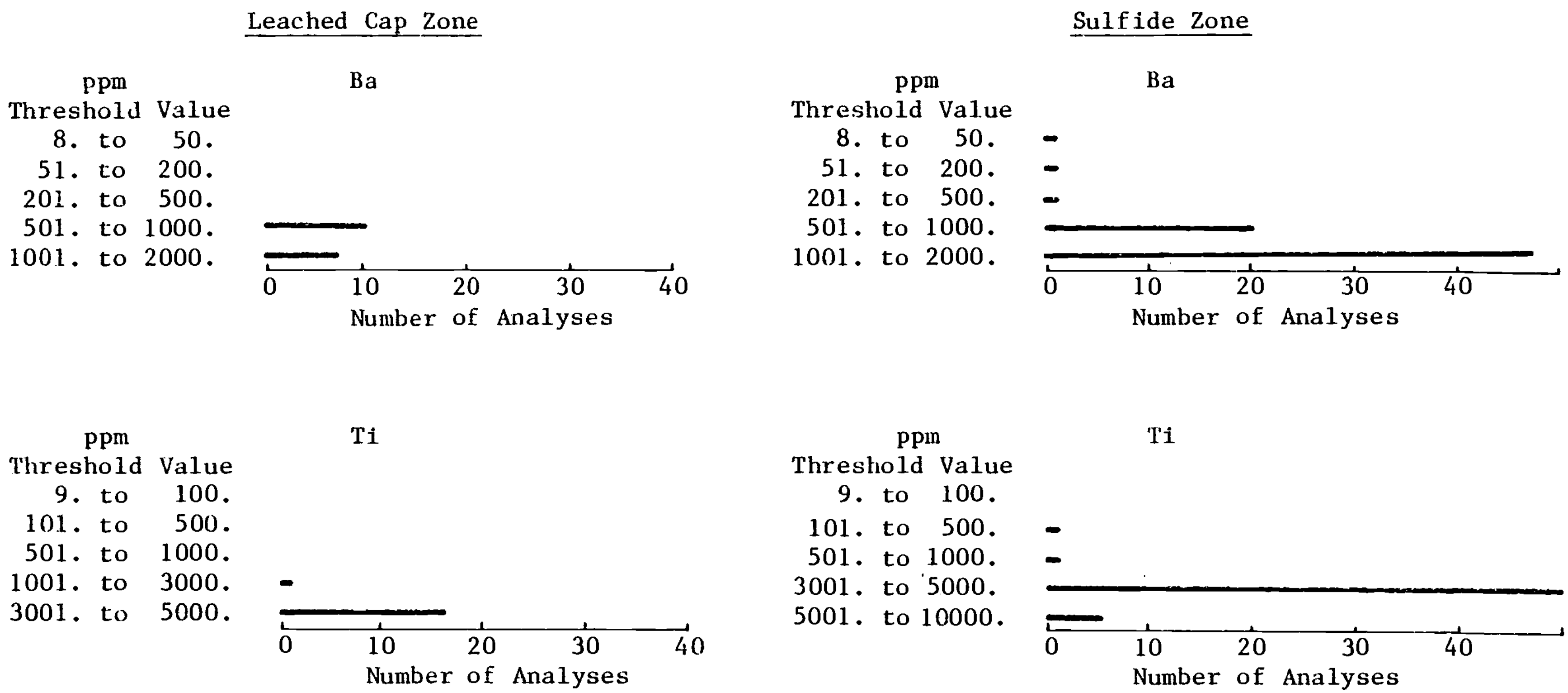


Figure 19. (continued)

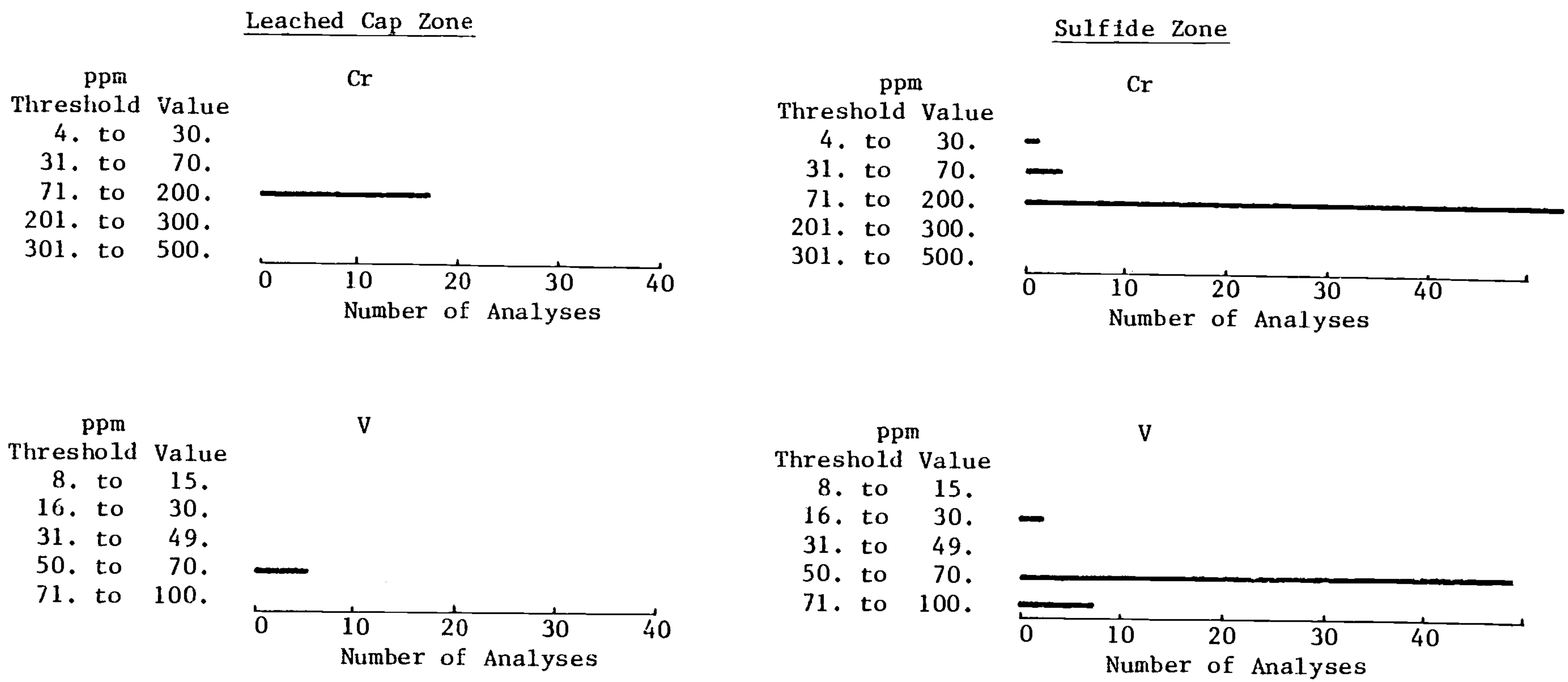


Figure 19. (continued)

None of these intercepts persist for more than a few feet because of the structural control (veinlets and fractures) that served to localize the metals.

Discussion

The Summer Coon intrusive center is characterized by centrally located anomalies for molybdenum and lead, weak peripheral anomalies for zinc, and depletions for calcium, magnesium, manganese, nickel, and cobalt. Supergene processes have formed an oxidized cap zone which is additionally leached in the mobile elements such as calcium, sodium, potassium, iron, magnesium, manganese, molybdenum, copper, and zinc.

The process responsible for hypogene and supergene alteration at the study area is hydrogen metasomatism. The propylitic zone is the result of weak hydrolytic alteration, and the intermediate argillic zone is the result of moderate hydrolytic attack (Hemley and Jones, 1964). Hydrolytic decomposition of plagioclase feldspar forms kaolinite, montmorillonite, and sericite. This type of reaction leads to the removal, or base leaching, of Ca, Na, and some Mg, and to the addition of chemically equivalent amounts of H. The chemical destruction of mafic minerals is similar and has the same end result, the removal of major cations from the rock and the addition of hydrogen.

Metallization at the study area is related to the introduction of sulfides to the rock after rock preparation by hydrothermal alteration. Pyrite is the only sulfide present at the study area.

This suggests that small quantities of ore sulfides exist in solid solution in pyrite. This would account for the detection of variable amounts of ore metals at the study area.

EXPLORATION GEOPHYSICS

Introduction

In 1969, W. A. Bowes, Inc. had an induced polarization and resistivity ground survey performed by Canadian Aero Mineral Surveys Ltd. Measurements were made in the time-domain mode of operation over five north-south-trending lines across the claim block. A conventional dipole-dipole electrode configuration was used with a separation of 600 feet. Measurements were made for dipole separation factors (n) of 1 to 6. In 1974, Glynn Cress conducted a resistivity induced polarization survey along one central line using a Wenner Array of electrodes on a 400-foot spacing. The Wenner Array responds to shallower variations than a dipole-dipole array on the same spacing. W. A. Bowes, Inc. also performed a magnetic survey of the study area.

Discussion of Results

The summary which follows is from reports by Canadian Aero Mineral Surveys Ltd. and Glynn Cress. The results of the resistivity induced polarization surveys indicate strong anomalous IP response in low resistivity zones below the surface in the central area of the intrusive core. The major trend of response is northwesterly on a contour map for electrode separation (n) of 3. At n=3, effects from depths greater than 600 feet begin to dominate the pattern. The strongest response which defines the anomaly is 60 to 90 millivolt-seconds per volt. The area of low resistivity is not perfectly coincident with the IP anomaly, but lies immediately adjacent to the east and overlaps the anomaly. In quasi-section, the IP response is irregular, suggesting a complicated occurrence of sulfide mineralization. As noted in the diamond-drill holes, pyrite distribution is irregular and is likely to be the reason for the complex response pattern. An abrupt drop in IP response at the northern contact of the Late Vent Breccia Unit with the Early Diorite Unit indicates a nearly vertical dip of the contact. Resistivity is highest at shallow levels in the diorite exposed at the south end of the study area. In general, resistivity shows an increase outward from the central area.

The magnetic contour map shows a general zoning of a magnetically high area around an inner area of lower values. This is the result of the magnetite content of the propylitized inhomogeneous diorite unit. Overall there is a good correspondence of low magnetic values, low resistivity, and anomalously high IP response to the central intermediate argillic zone.

THE PETROLEUM OCCURRENCE

Petroleum was present in the core from diamond-drill holes SC-1, 3, and 5. In SC-1 and 5 petroleum was commonly observed, whereas in SC-3 it was an isolated occurrence. The petroleum is present in pyrite-coated fractures, either as a yellowish-brown spreading stain or as gummy brownish-black tar globs (Fig. 20). Because the petroleum coats the pyrite, it clearly postdates the pyrite.

The analysis by Amoco Production Company of the oil from drill hole SC-1 indicates that it is Cretaceous, probably of the type KL which is locally generated from Cretaceous shales within the region. Difficulties were encountered in analysis because of biogradation and devolatilization of light hydrocarbons and normal paraffins. The combination of whole extract chromatograms, carbon isotope analyses of both whole extracts and saturate fractions, infrared analysis of the aromatic fractions, and one pristane/phytane ratio from the whole extract chromatograms, was used to identify and date the oil.

This type of petroleum occurrence is not unique. Gerrild (1971), in a Colorado School of Mines Master's thesis, reports a similar occurrence of Cretaceous oil in metalliferous veins of the Idarado Mine in Ouray County. The mine is located in the western San Juan Mountains near Telluride, Colorado, and is close to exposed Cretaceous strata and relatively close to the Paradox Basin and San Juan Basin oil fields. Possible underlying source sediments probably exist about 400 feet beneath the volcanic

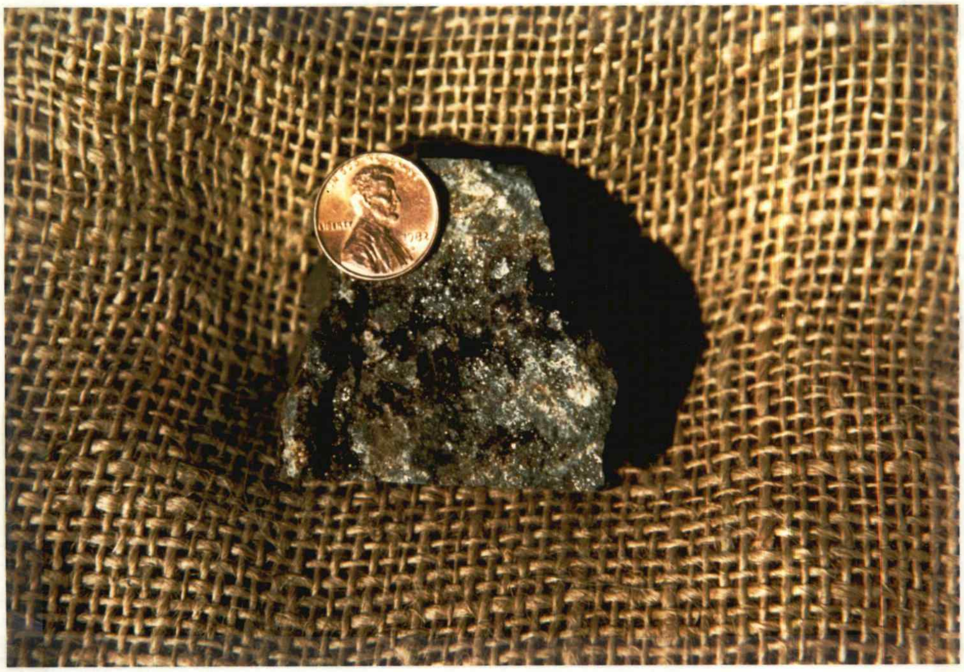


Figure 20. Piece of core from drill hole SC-1 at 775-foot depth showing tarry petroleum globs coating a fracture.

rocks of the mine (Gerrild, 1971). At the Summer Coon intrusive center the situation is markedly different. The nearest exposure of Cretaceous rocks is about 30 miles away in the areas of Saguache to the north or Wolf Creek Pass to the southwest. At the study area, the petroleum occurs in stocks related to a volcano, not in extrusive rocks. Tertiary volcanic rocks are believed to be on the order of 2,000 to 3,000 feet thick in the vicinity of the study area (Larson and Cross, 1956). It is further presumed that the bulk of the San Juan volcanic field directly overlies pre-Cambrian rocks as the result of the erosion of Mezozoic and Paleozoic strata during the Laramide orogeny (Butler, 1971). There is no production of petroleum from the San Luis Basin adjacent to the thesis area. However, minor gas shows have been encountered in wells drilled in the San Luis Valley (R. Gries, personal communication).

The significance of the oil show at the Summer Coon intrusive center is that it indicates that oil sources have generated and expelled oil in a region not known for oil production. The show at the study area does not have any related shows nearby, and is unique for the eastern San Juan Mountains. Other oil shows in the San Juan Mountains reported, in addition to the Idarado Mine, are: an oil seep in the vicinity of the Mount Hope caldera (R. Gries, personal communication) and oil in vesicles in a sill near Dulce, New Mexico (Fassett and others, 1977).

A possible route of migration for the oil is as follows. The oil generated, at some unknown depth and location, from

Cretaceous shales moved upward until it reached an impermeable barrier of extrusive rocks and then migrated up into the fractured rocks of the intrusive center of the Summer Coon volcano. Emplacement of the oil occurred after the cessation of major hydrothermal activity, but before the center had completely cooled. The petroleum clearly postdates the pyrite in the fractures, but the severe biogradation and devolatilization of the crude oil indicate that the migration and emplacement of the oil took place at an elevated temperature. The location of the source beds is not known, but it is deduced to be nearby. If the petroleum migrated a considerable distance laterally (circa 30 miles), it is likely that oil shows would be noted in other volcanic centers in the vicinity. The closest volcanic centers are the Twin Mountains center about six miles to the west and the Embargo center about 12 miles to the west. The implication is that the Summer Coon intrusive center oil show is a local phenomenon. If better reservoir rocks exist in the area, it is possible that a significant oil deposit may be found.

In the spring of 1982, Robbie Gries had a drill hole collared about six miles south of Del Norte as a result of developing a play which was fanned by the analysis of the oil from the thesis area. The intent of the well is largely to obtain stratigraphic information at depth, and also to obtain indications of petroleum. No information has been released.

SUMMARY AND CONCLUSIONS

William A. Bowes, Inc. staked claims over the intrusive core of the Summer Coon volcano with the intent of developing a porphyry copper-molybdenum target. Sillitoe (1980) has proposed that many porphyry copper deposits are generated in the high level magma chambers beneath andesitic-dacitic stratovolcanos during the fumarolic stage.

Certain geological aspects merit consideration of the study area as a porphyry copper-molybdenum target. The intrusive core of the calc-alkaline Summer Coon stratovolcano is characterized by multiple intrusions, which probably widen with depth to become part of a large composite sub-volcanic stock. Concentric hydrothermal alteration zones grade inward from a propylitic zone to an intermediate argillic zone with pods of silicification. The alteration mineral assemblages are consistent with the interpretation that fumarolic hot spring activity beneath the water table was the major cause of alteration. The chemical process of alteration was hydrogen metasomatism, as indicated by the alteration mineral assemblages and the depletion of calcium, magnesium, manganese, nickel, and cobalt in the host rock. Enrichment of copper, molybdenum, lead, zinc, silver, and iron is noted, and is directly related to the abundance of pyrite. This indicates that modest amounts of sulfide ore minerals may be associated with pyrite. Sulfides other than pyrite and minute blebs of chalcopyrite are not observed. Pyrite deposition in fractures is related to two discrete pulses, one in conjunction with silica, and the other alone in "dry" fractures. The hydrothermal alteration appears to have occurred during only one hypogene episode of unknown duration. A leached capping has formed on the surface of the intermediate argillic zone as the result of supergene processes. Good correspondence is noted between the IP anomaly, low resistivity zones, low magnetic value zones, the intermediate argillic zone, and the Mo, Pb, and Zn anomalies.

Unfavorable aspects of the study area for potential porphyry-type mineralization include the lack of structures and the lack of peripheral lead, zinc, silver, and gold mineralization. There are no faults exposed and only one probable fault was intercepted by drill hole SC-5. A sample from the high angle shear zone at 288 to 300 feet did not analyze appreciably higher in ore metals. The lack of structures and the small extent of brecciation at the study area possibly inhibited preparation of the rock for mineralization. The lack of peripheral mineralization does not lead to an optimistic interpretation of a large low grade ore body at an economic depth either. Deeper drill holes are required for a better evaluation of potential mineralization at the study area. The best location for a deep vertical hole is in the vicinity of location 3 in the breccia zone.

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APPENDIX

APPENDIX A. Alteration mineral assemblages identified by thin-section examination of surface and sub-surface samples at the Summer Coon intrusive center.

Sample Location	Rock Type	Texture	Zone of Hydrothermal Alteration	Alteration Minerals Identified in Thin-Section
1	vent breccia	bx	vuggy silica	quartz, chalcedony
2	diorite	m. g. holocryst.	propylitic	clacite, chlorite, actinolite epidote
3	granodiorite	f. g. porph.	quartz-sericite	quartz, sericite, trace clay
4A	diorite	f. g. holocryst.	propylitic	actinolite, chlorite, epidote, calcite
4B	rhyodacitic dike	m. g. porph.	int. argillic	clay, sericite, quartz
5	vent breccia	bx	int. argillic	sericite, clay, quartz
6	vent breccia	bx	int. argillic	clay, sericite, quartz
7A	vent breccia	bx	int. argillic	clay, sericite, quartz, jarosite
7B	vent breccia	bx	int. argillic	clay, sericite, quartz, jarosite
8	vent breccia	bx	int. argillic	clay, sericite, quartz
9	vent breccia	bx	int. argillic	clay, sericite, quartz
10A	vent breccia	bx	int. argillic	clay, sericite, quartz

APPENDIX A. (cont.)

Sample Location	Rock Type	Texture	Zone of Hydrothermal Alteration	Alteration Minerals Identified in Thin-Section
10B	vent breccia	bx	int. argillic	clay, sericite, quartz
11	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
12	vent breccia	bx	int. argillic	clay, sericite, quartz
13	vent breccia	bx	int. argillic	clay, sericite, quartz
14	vent breccia	bx	int. argillic	clay, sericite, quartz
15	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
16	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
17	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
18	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
19	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
20	vent breccia	bx	int. argillic	clay, sericite, quartz
21A	granodiorite	m. g. porph.	vuggy silica	quartz
21B	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz, actinolite
22	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz

APPENDIX A. (cont.)

Sample Location	Rock Type	Texture	Zone of Hydrothermal Alteration	Alteration Minerals Identified in Thin-Section
23	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz, jarosite
24	granodiorite	m. g. porph.	quartz-sericite	quartz, minor sericite
25	granodiorite	m. g. porph.	quartz-sericite	quartz, minor sericite
26A	granodiorite	f. g. porph.	int. argillic	clay, sericite, quartz
26B	granodiorite	f. g. porph.	vuggy silica	quartz
27	vent breccia	bx	int. argillic	clay, sericite, quartz
28	vent breccia	bx	int. argillic	clay, sericite, quartz
29	granodiorite	m. g. porph. fragment in ferricrete	int. argillic	clay, quartz, iron oxide
30	vent breccia	bx	int. argillic	clay, sericite, quartz
31A	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz
31B	granodiorite	m. g. porph.	quartz-sericite	quartz, sericite
32	granodiorite	f. g. to m. g. porph.	quartz-sericite	quartz, sericite
33	granodiorite	f. g. to m. g. porph.	quartz-sericite	quartz, sericite

APPENDIX A. (cont.)

Sample Location	Rock Type	Texture	Zone of Hydrothermal Alteration	Alteration Minerals Identified in Thin-Section
34	diorite	f. g. holocryst.	propylitic	actinolite, epidote, calcite
35	diorite	f. g. porph.	propylitic	chlorite, calcite, trace clay
36	diorite	m. g. porph.	propylitic	calcite, chlorite, actinolite
37A	rhyodacitic	m. g. porph.	int. argillic	clay, quartz, sericite
37B	dike	m. g. porph.	int. argillic	clay, quartz, sericite
38	diorite	m. g. porph.	propylitic	calcite, actinolite, chloritic clay, epidote
39A	rhyolitic	f. g. porph.	int. argillic	clay, quartz, sericite, trace calcite
39B	dike	f. g. porph.	int. argillic	clay, quartz, sericite, trace calcite
40	diorite	f. g. porph.	propylitic	calcite, chlorite, actinolite
41	rhyolitic dike	m. g. porph.	propylitic	chlorite, epidote, minor sericite, minor clay
42	diorite	f. g. holocryst.	propylitic	calcite, actinolite, epidote, chloritic clay

APPENDIX A. (cont.)

Sample Location	Rock Type	Texture	Zone of Hydrothermal Alteration	Alteration Minerals Identified in Thin-Section
43	diorite	m. g. porph.	propylitic	calcite, actinolite, chlorite, quartz
44	rhyolitic dike	m. g. porph.	int. argillic	clay, sericite, quartz
SC-1 93'	diorite	f. g. holocryst.	propylitic	calcite, actinolite, chloritic clay, epidote, (biotite)
SC-1 202'	diorite	f. g. holocryst.	propylitic	calcite, actinolite, chloritic clay, epidote
SC-1 235.5'	diorite	f. g. holocryst.	propylitic	actinolite, epidote, chlorite, calcite
SC-1 663.5'	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz, pyrite
SC-1 828'	rhyolitic dike	m. g. porph.	int. argillic	clay, sericite, quartz, pyrite
SC-1 929'	diorite	f. g. holocryst.	propylitic	chlorite, actinolite, calcite, (biotite)
SC-1 1048'	diorite	f. g. holocryst.	propylitic	calcite, chlorite, actinolite, epidote, trace sericite
SC-5 209'	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz, pyrite, minor actinolite

APPENDIX A. (cont.)

Sample Location	Rock Type	Texture	Zone of Hydrothermal Alteration	Alteration Minerals Identified in Thin-Section
SC-5 282'	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz, pyrite
SC-5 407'	granodiorite	m. g. porph.	int. argillic	clay, sericite, quartz, pyrite