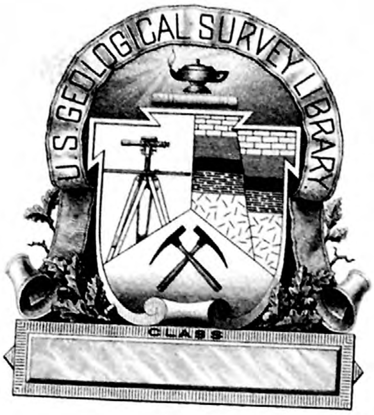

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PROJECT REPORT
Guyana Investigations
(IR) G-7

GEOLOGY AND GEOCHEMISTRY
WANAMU-BLUE MOUNTAINS AREA
WAINI SW, GUYANA

by

Bruce E. Kilpatrick 1938-
U. S. Geological Survey

68-157

1968

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ABSTRACT

The Wanamu-Blue Mountains area is situated in the Northwest District of Guyana, about 110 miles northwest of Georgetown. The Blue Mountains are low, but rugged, hills that have developed on mafic metamorphic rocks that occur in an arcuate "mantle" around a granite batholith, the Aranka-Wanamu Granite. The area lies within the Precambrian Guiana Shield and is entirely covered with tropical rain forest. The geology of the area is complex and is made up of an assemblage of metamorphic rocks consisting of phyllites, quartzites, amphibolites, and epidiorites that are intruded by serpentinites. The serpentinites occur as thin, tabular, dike-like bodies that trend northwest across the area. The serpentinites contain abundant magnetite, but very little chromite or sulfide minerals. Metasomatic reaction zones have developed around the serpentinite bodies at their contacts with country rock. These reaction zones consist of aureoles of actinolite schist, chloritic hornfels, and talcose zones in the phyllites.

The structure of the area appears to be complicated but it is poorly exposed. Field evidence points to more than one episode of faulting. Except for the phyllite and the actinolite schist, foliation is poorly developed in the area, but the general trend of the foliation appears to be nearly east-west.

Laterite duricrust is scarce in the area except as remnant boulders. Residual soils occur over most of the area and the soil colors vary with the parent bedrock. In general, these soils can be divided into three horizons: an upper, leached zone; a concretionary zone of sesquioxide accumulation; and a lower, clayey zone.

Soil samples were collected on a grid pattern over the area and these samples, in addition to representative serpentinite and laterite samples, were analyzed by rapid colorimetric and semiquantitative spectrographic methods at the U.S. Geological Survey laboratories in Denver, Colorado.

The analytical results show that the serpentinites contain nickel, chromium, cobalt, and manganese in amounts close to the average worldwide content of these elements in ultramafic rocks. The soils around the serpentinites have relatively high contents of nickel, chromium, cobalt, and manganese, probably due to concentration during weathering. However, the nickel content of the soils never exceeds 5,000 ppm and it is apparent that much nickel has been lost during weathering of the serpentinite. In contrast, cobalt has been considerably enriched during weathering, probably because of the scavenging action of manganese oxides. Chromium displays the strongest anomalies in the soils, but the chromium content appears to have remained essentially constant during weathering.

The cobalt content of the soils tends to vary with the manganese content, and as the highest cobalt and manganese values occur over the serpentinites, cobalt could be used as a pathfinder for nickel. Ammonium citrate-soluble cobalt closely reflects the total cobalt content of the soils.

The geochemical anomalies tend to coincide with the serpentinite bodies and closely follow their trend across the area. The anomalies are strongest in the eastern half of the area where the greatest concentration of serpentinite bodies occurs, and the anomalies are "open-ended" to the southeast.

The copper content of the soils is much lower than that of nickel or cobalt, and the copper peaks are displaced away from the serpentinite bodies. Copper tends to follow manganese in the soils, but not as closely as does cobalt.

Comparisons of colorimetric and spectrographic determinations for nickel, chromium, cobalt, and copper reveal that the spectrographic determinations probably extract more metal from the serpentinite than do the colorimetric methods. Similar comparisons of the analytical results from the soil samples reveal that the colorimetric nickel determinations are probably too high, and that the spectrographic nickel determinations are closer to the correct nickel values. The spectrographic and colorimetric chromium determinations corroborate each other fairly well, but the colorimetric determinations for cobalt and copper seem to be closer to the correct values than the spectrographic determinations.

The iron content and the titanium content of the soils are fairly uniform over the area, but the titanium content has probably remained constant during weathering while the iron content has been depleted. Vanadium has been enriched in the soils and the vanadium peaks are displaced away from the serpentinites.

The magnesium and calcium content of the soils is generally low, but relatively high magnesium and calcium values coincide with high nickel values in the soils. Barium, scandium, and zirconium also occur in significant amounts in the soils. The gold content of the soils is negligible.

A Jalander magnetometer survey was conducted over the area and the results show that some of the serpentinite bodies have a strong magnetic expression. The magnetic anomalies coincide closely with the geochemical anomalies and also are "open-ended" to the southeast.

The Wanamu-Blue Mountains area probably does not contain economic concentrations of lateritic nickel, but the unknown extent of the serpentinite bodies makes the area and its extensions very interesting prospects. In addition, the geologic environment of the mafic and ultramafic rocks is favorable for sulfide mineral deposits.

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INTRODUCTION

In the fall of 1966, the Government of Guyana, through the Agency for International Development, United States Department of State, requested that the Guyana Geological Survey undertake a program of mineral exploration in cooperation with the U. S. Geological Survey. Through this program funds were provided by AID with which to send two graduate students in geology from the United States to work with the Guyana Geological Survey.

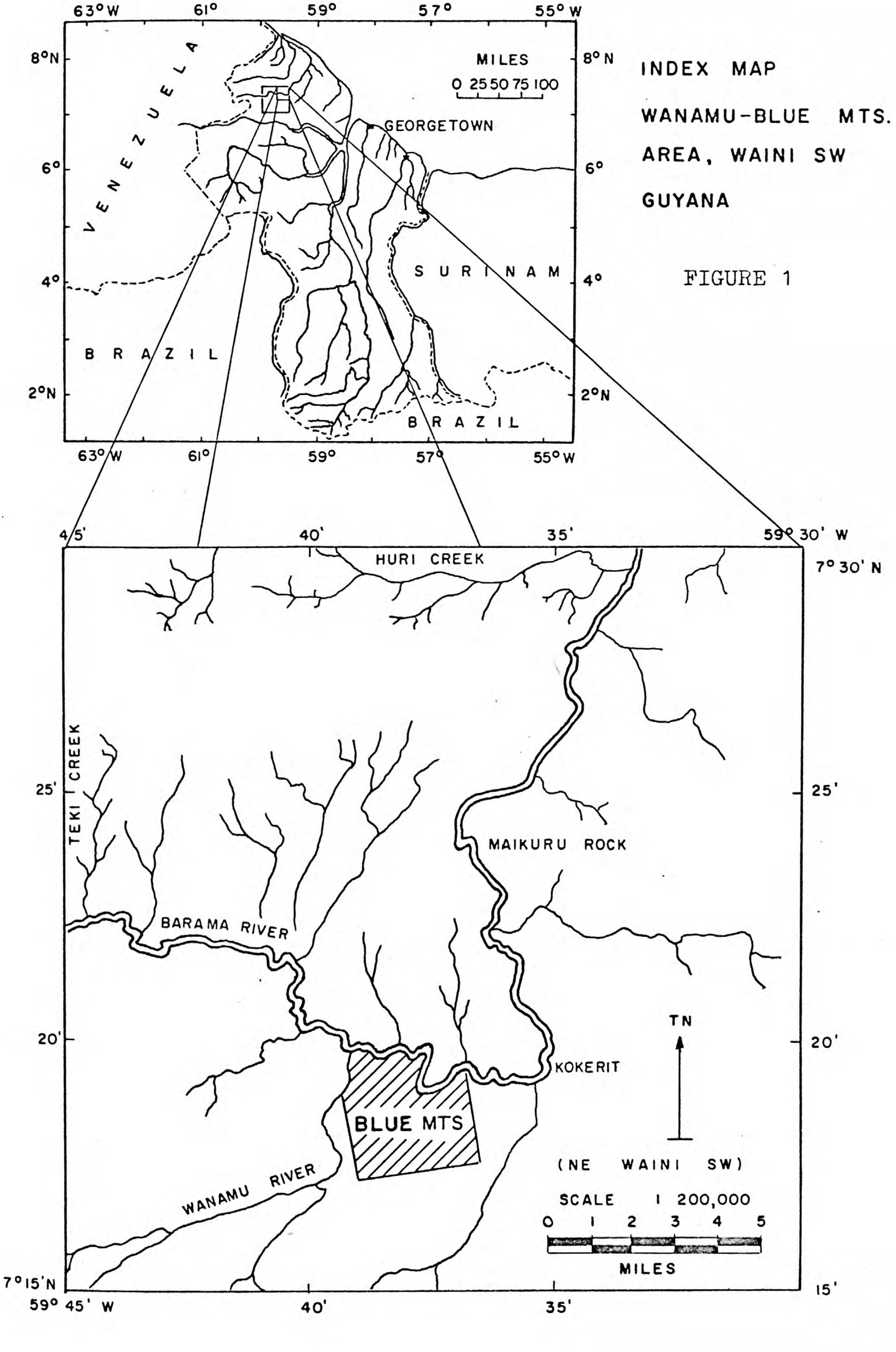
Under this program the author and another graduate student from the Colorado School of Mines went to Guyana in the spring of 1967, to do detailed geologic mapping and make geochemical surveys of selected areas in the interior of the country. The results of this work supplied the Guyana Geological Survey with information on the areas studied, and provided thesis material for the students. The students were employed by the U. S. Geological Survey as geologists, and worked under the general supervision of Lyman Huff. Expenses for the trips were paid by AID, and field support for the program was provided by the Guyana Geological Survey.

Dr. Sobharam Singh, Director of the Guyana Geological Survey, suggested the Wanamu-Blue Mountains area for the author's field work; the area was of interest because earlier investigations revealed anomalous contents of nickel and chromium in soil samples.

Location and Access

The Wanamu-Blue Mountains area is in the Northwest District of Guyana in the lower Barama River region. More specifically, the area lies in the northeast quarter of the Waini southwest quarter-degree square, about 110 miles northwest of Georgetown (Figure 1). The thesis area covers approximately 7 square miles and is situated south and east of the confluence of the Barama and Wanamu rivers, four miles west of Kokerit Mission.

The only access into this area is by flat-bottomed boat up the Barama River from its mouth on the Waini River. The trip up the Barama may require from one to two days depending upon water conditions. An amphibious aircraft can land on the Waini River at the mouth of the Barama, or this point may be reached by taking the weekly coastal steamer from Georgetown to Morawhanna and traveling by boat from there up the Waini River. This latter route was traveled by the writer when going into the area. Upon leaving, the return trip was made by plane to Georgetown from Baramanni, a government rest house 12 miles downstream from Barama mouth.



INDEX MAP
WANAMU-BLUE MTS.
AREA, WAINI SW
GUYANA

FIGURE 1

Previous Work

The area between the Barima and Barama rivers in the Northwest District has been of interest since the latter part of the nineteenth century when the alluvial and residual gold deposits of that region were worked most extensively. Most of the work was on a small scale (Stockley, 1955, p. 31), and now has largely ceased. Over a number of years, several studies of the gold fields and the geology of the region were made by the Geological Survey of British Guiana; from these studies a general picture of the regional geology has evolved. During 1937 and 1938, Bryn Davies (1940) examined the gold and manganese deposits of the lower Barama River region while outlining the general geology of that area. During the same period, Bracewell (1938) mapped the geology of the area between the Barama and Barima rivers from Tassawini to Arakaka. In his report, Bracewell (1938, p. 27) paid special attention to the gold fields of the region, but mentioned the Wanamu-Blue Mountains area, which he referred to as "Kauramembo Hill." Much later, Cannon and Carter (1960) briefly described the Wanamu-Blue Mountains area in a report on the geology of the Waini southwest quarter-degree square. Cannon (1964) followed this report with another concerning the geology of certain areas near the lower Barama and Waini rivers in which he included a geologic map of the area between Kokerit and the Wanamu River. In his second report, Cannon (1964, p. 2) pointed out the interesting laterite-capped (sic) "basic mantle" of amphibolites and "serpentiferous" rocks immediately north of the Aranka-Wanamu Granite. Soil samples that he obtained from this area were shown to have high nickel contents. Further pit-sampling work by Henry (1966) revealed that some of the lateritic soils of the area are anomalously high in chromium and nickel.

Additional work in the Northwest District that does not directly concern the Wanamu-Blue Mountains area is listed at the end of this report under "Selected References."

Organization of Thesis

Approximately nine weeks, from March 13, to May 12, 1967, was spent in the interior of Guyana during which time 7 actual weeks of field work was accomplished. The field work consisted of geological, geochemical, and ground magnetic surveys over an approximately 7-square-mile area. The rock and soil samples obtained during the field work were analyzed by the U.S. Geological Survey laboratories in Denver, Colorado, during the summer and fall of 1967.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cooperation and assistance from many individuals and from the Guyana Geological Survey as a whole, which was in large measure responsible for the success of this project. Dr. Singh was instrumental in initiating the field work, and Mr. Barron, Deputy Director of the Guyana Geological Survey, visited the field area and made many helpful suggestions. Dr. Muller of the Guyana Geological Survey was especially helpful in providing men, equipment, and advice during the field work, and the author is very grateful for this assistance. The assistance of Mr. Husbands and other members of the field party is gratefully acknowledged.

Members of the U. S. Geological Survey also gave much assistance for it was through that organization that the program was implemented; extensive analyses of rock and samples made in the U. S. Geological Survey laboratories in Denver provided the necessary analytical data with which to evaluate the field area. Lyman C. Huff supervised the work, and his advice was most useful. Mr. George L. Schoechle, U. S. Geological Survey gave enthusiastic support and assistance; R. L. Ericksen and his staff in Denver performed the analyses.

Drs. Lickus and Finney, and Professor Bloom, Colorado School of Mines, gave very helpful advice and guidance, which the author acknowledges with thanks.

GEOMORPHOLOGY

Bracewell (1938, p. 12-13) has described the geomorphology of the Barama River region, and he states that the Barama River follows the strike of the metamorphic rocks it traverses. In general, this trend is readily apparent in the Wanamu-Blue Mountains area. West of Kokerit the Barama flows in a generally east-southeasterly direction along the strike of the metamorphic rocks, but at Kokerit the river swings abruptly northward to follow the predominantly northeasterly strike of the metamorphic rocks further to the north.

The Blue Mountains consist of low, but rugged, hills arranged in a series of north-trending spurs off a central east-west-trending ridge south of the Barama River. The central ridge parallels the Barama River in the east and central parts of the map area and then swings to the south along the Wanamu River. The topography of the area is shown on Plate 1. Although the hills are low, their slopes tend to be steep; the maximum relief in the area is approximately 700 feet over a horizontal distance of about one-half mile. Jumbled masses of large boulders commonly occur on the steep slopes. The Blue Mountains mainly overlie an arcuate band of mafic metamorphic rocks which form a "mantle" around a large granite batholith immediately to the south.

Laterite duricrust, except as remnant boulders, is scarce in the area. Laterite capping in place was observed only on hill tops in the extreme southeast corner of the map area. A swamp has developed on top of one of the laterite-capped hills; similar occurrences have been described by Bleackley (1964, p. 85) in the Oko-Blue Mountains of the lower Essequibo region. The ubiquitous occurrence of remnant laterite boulders in the Wanamu-Blue Mountains area suggests that the area was once largely covered by a laterite cap, but the original extent of this cap is difficult to ascertain.

According to Bleackley (1964, p. 133-134), extensive laterite sheets develop most readily in low-lying peneplained areas, although some recemented colluvial laterites form on slopes as steep as 30 degrees. The Blue Mountains probably represent a formerly low-lying area that was protected from erosion by the development of a laterite cap over mafic rocks. As the surrounding less mafic areas were eroded, the laterite-protected area became prominent through an inversion of relief. Bleakley (1964, p. 134) describes similar occurrences in the Muruwa Hills of Guyana. Further erosion has destroyed most of the protective cap, and most of the hills are now covered only by residual lateritic soils.

Many small streams flow off the Blue Mountains, which create a minor east-west watershed in the region. Where the gradient of the streams is steep, erosion is very active and the streams cut across fresh bedrock. However, away from the hills, where the streams encounter low-lying areas, the meandering stream channels are cut into highly weathered rock.

The entire Wanamu-Blue Mountains area is covered by tropical rain forest, and the combination of rugged topography and thick vegetation makes the area difficult to traverse.

GEOLOGY

One of the major objectives of this thesis study was to study the geology of the Wanamu-Blue Mountains area in detail. The geology of the area was mapped, and descriptions of the method of mapping, regional geology, petrology and petrography, structure, and geologic history are presented in the following pages.

Method of Mapping

The Wanamu-Blue Mountains area is covered entirely by thick rain forest so that it is virtually impossible to traverse an area rapidly while tracing rock types and, at the same time, plot geology on a topographic map or air photo, as is done in more open country. The Guyana Geological Survey traditionally has cut trails or "lines" through the undergrowth which are measured and marked at 100- and 500-ft. intervals. These lines are surveyed with a compass and observations taken along the line. Topography may be surveyed by barometric methods or a hand level may be used; elevations and other pertinent information are referenced to the already-measured distances along the line. Usually three men are employed in cutting lines and they may cut from one and one-half to three miles in one day, depending upon the ruggedness of the terrain, density of the underbrush, etc. Two men are required to measure or "chain" the lines. Because the preliminary cutting and chaining of lines is generally more time consuming than the actual surveying of them, efficient planning is necessary to keep all of the field party, both laborers and geologists, profitably occupied.

During this study, the conventional method of line-cutting, etc. was employed along an arbitrary grid that was designed to cover the area as densely as possible during the time spent in the field. An east-west (magnetic) baseline was cut for 17,000 feet along the south bank of the Barama River and 16 north-south lines were cut at 1,000-ft. intervals along this baseline. All of these lines extended 8,500 feet south of the baseline, and two-thirds of them extended at least 2,500 feet north of the baseline. Other east-west tie lines were cut south of the baseline. The topography was mapped by sketching form lines along the traverse lines; lack of time prevented making a more accurate topographic survey. The traverse lines and topography are shown on Plate 1.

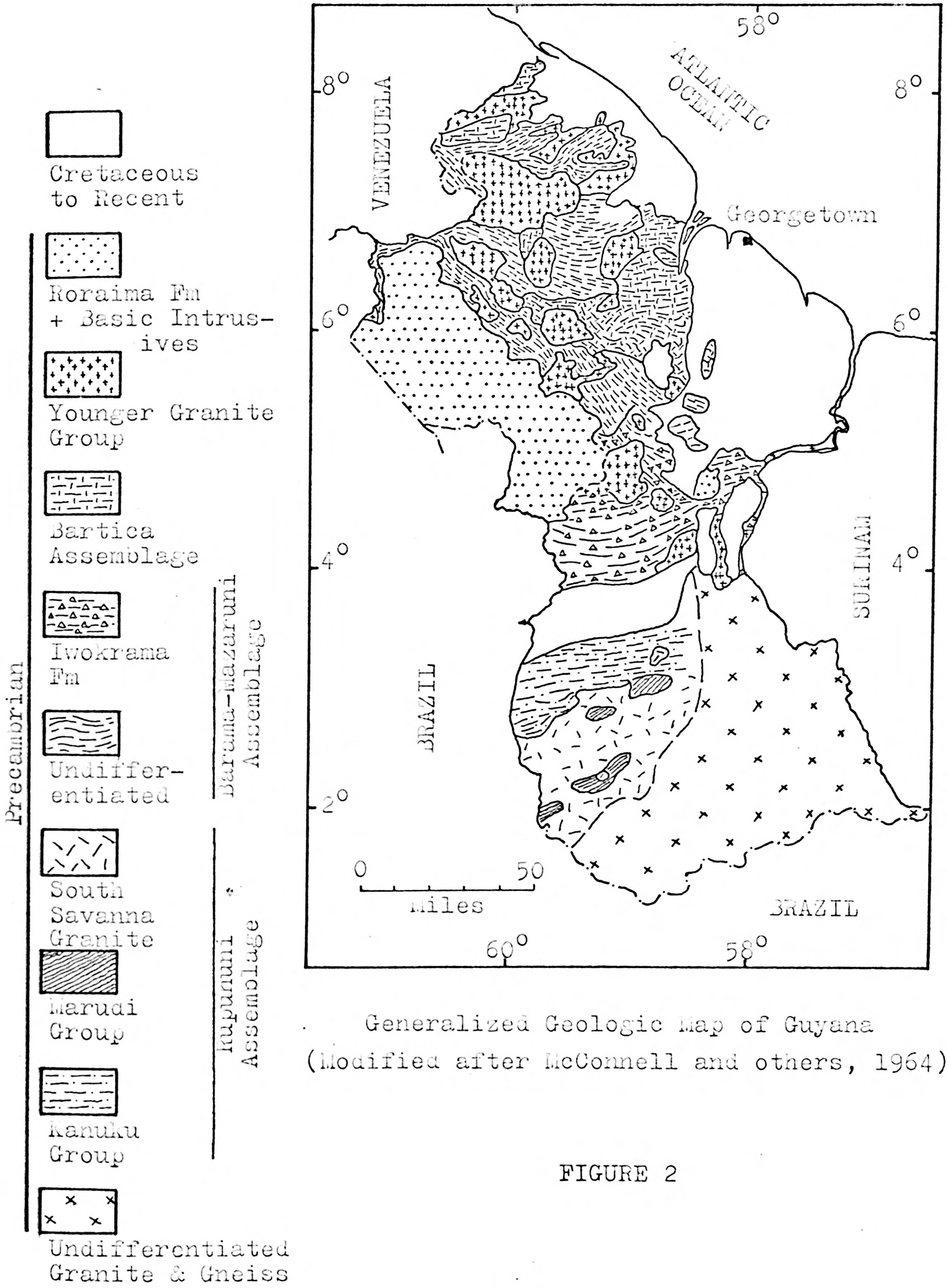
The geology was mapped along the survey lines and also between the lines, as well as was possible, by using compass-and-pacing methods. In some areas there was considerable outcrop along the lines on ridges and in stream beds; however, along many stretches of line no outcrop was seen and "float" was used as an indication of bedrock geology. More creek lines would have given additional bedrock information, but the general scarcity of exposure and the complexity of the geology made the construction of an accurate detailed geologic map very difficult. The geology of the area is shown on Plate 2.

Because of the general scarcity of exposures, the contacts shown are interpretive and have been inferred as well as possible from the available data.

Regional Geology

For more detailed accounts of the regional geology of Guyana, interested readers can consult the references which are given at the end of the thesis (Stockley, 1955; Dixon and George, 1964). In 1962, the Geological Survey of British Guiana published a provisional regional geologic map of the country; this map (McConnell, 1962), together with a description by R. B. McConnell and others (1964) has provided the basis for the following discussion. Further work by Cannon (1961; 1964), and also by Cannon and Carter (1960), has provided additional detail.

According to McConnell and others (1964, p. 115), Guyana can be divided into three major geologic and geomorphic provinces, most of which lie within the Precambrian Guiana Shield (Figure 2). Briefly, the three provinces are as follows: 1) a narrow strip of marine sediments along the coast; 2) a thick sequence of sandstones, quartzites, and shales known as the Roraima Formation (Proterozoic age?) which makes up the Pakaraima Mountains to the west; and 3) a vast area of Precambrian metamorphic and igneous rocks sporadically overlain by Tertiary to Recent sediments. This area consists largely of low hills, and except for the savannahs in the southwest, it is covered by tropical rain forest.



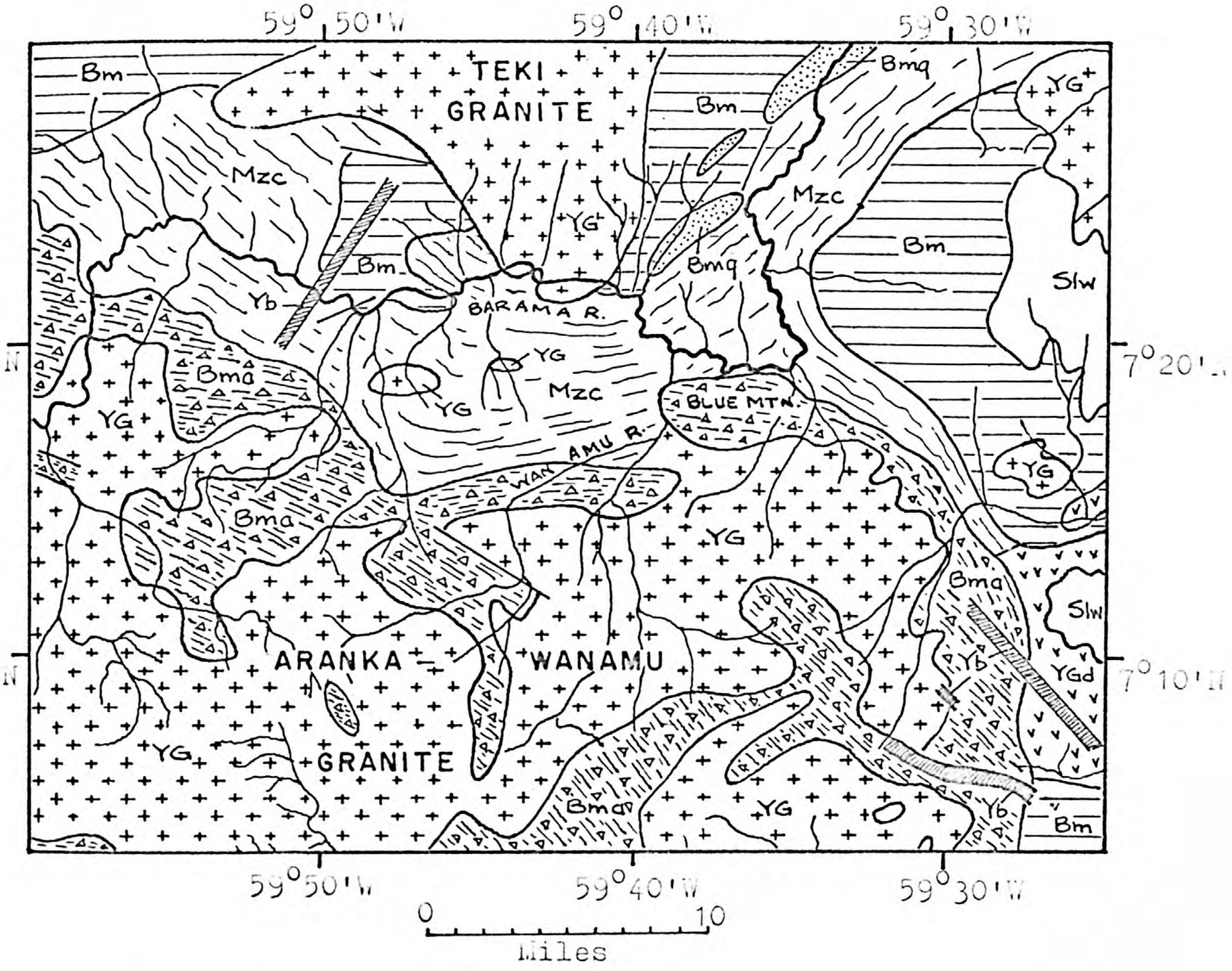
Generalized Geologic Map of Guyana
(Modified after McConnell and others, 1964)

FIGURE 2

As the Wanamu-Blue Mountains area lies within the heart of the Northwest District of Guyana, the discussion of regional geology will be confined to that general area. Apart from the narrow strip of coastal marine sediments, the Northwest District is underlain by Precambrian rocks; most of the Precambrian rocks of the northern part of Guyana are metavolcanics and metasediments which comprise a eugeosynclinal sequence known as the Barama-Mazaruni Assemblage. These rocks are Archean in age and they form a west-northwest-trending belt along the Atlantic coast of the Guiana Shield (McConnell and others, 1964, p. 115-116). There is a mass of gneisses and amphibolites to the south known as the Bartica Assemblage, lying within the Barama-Mazaruni Assemblage and which, according to McConnell and others (1964, p. 116), was derived by metamorphic processes from the Barama-Mazaruni Assemblage. The metamorphic rocks are intruded by Precambrian plutons of granitic through granodioritic composition that are known as the Younger Granites. Both the metamorphic and younger igneous rocks are intruded by dolerite sills and dikes of probable Proterozoic age (1,700 m.y.); these are known as the Younger Basic Intrusives (McConnell, 1964, p. 117).

The Barama-Mazaruni Assemblage, the Younger Granites, and the Younger Basic Intrusives are all represented within the immediate vicinity of the Wanamu-Blue Mountains area (Figure 3). The oldest rocks in the area are a sequence of metasandstones and metaconglomerates known as the Cuyuni Formation, a subunit of the Mazaruni Group. According to Cannon (1961), the

Geologic Map of Lower Barama River Area



EXPLANATION *

Rec. to Tert.	Slw	White Sands		
?	Yb	Basic Intrusives - Dolerite	Younger Basic Intrusives	
Precambrian	YG	Biot. & Biot. - Hbond. Granites	Younger Granite Group	
	YGd	Diorites & Granodiorites		
	Bma	Amphibolite & Amphib. Schist	Marginal Facies?	Barama-Mazaruni Assemblage
	Mzc	Cuyuni Formation & equivalents	Mazaruni Group	
	Bm	Pelitic + f.g. Igneous rocks	Barama Group	
	Bmq	Quartzite		

FIGURE 3

(Modified After McConnell, 1962)

* Only includes units shown on map.

metasediments of the Cuyuni Formation have intercalated layers of fine-grained meta-igneous rocks (possibly volcanics), but although some very fine-grained, possibly metavolcanic rocks were observed in outcrops along the bank of the Barama east of the mouth of the Wanamu, these rocks were not mapped in the thesis area.

The Cuyuni Formation west of Kokerit is intruded by two large granite batholiths of the Younger Granite Group: the Teki Granite to the north of the Barama River and the Aranka-Wanamu Granite to the south of the river. According to Cannon and Carter (1960), the Teki Granite is a dark hornblende-biotite granite and the Aranka-Wanamu Granite is a biotite granite which shows some east-west foliation near its margins. Cannon (1964, p. 3) suggests that the pre-existing foliation of the metamorphic rocks controlled the emplacement of the Aranka-Wanamu Granite. Areas of amphibolite which are accompanied by hornblende-biotite granite occur within the main biotite granite mass and probably represent roof pendants and hybrid granite (Cannon and Carter, 1960, p. 9). From the descriptions that are given, it seems possible that the Aranka-Wanamu Granite may be a complex of intrusives and gneisses rather than a single intrusive.

The Blue Mountains lie immediately to the north of the Aranka-Wanamu Granite and consist of low hills overlying a series of amphibolites and mafic metamorphic rocks that have been interpreted as a "basic mantle" or contact metamorphic aureole around the granite intrusive (Cannon, 1964). As shown on the regional geologic map of the Waini SW quarter-degree square, this "basic mantle" of amphibolites forms an arcuate band about one mile wide to the north and east around the granite contact. The strike of the amphibolites appears to be roughly concordant with that of the Cuyuni metasediments and is approximately east-west in the Blue Mountains area. There is at least one small diabase (dolerite) dike in the area that probably belongs to the Younger Basic Intrusives. The thesis area lies mainly within the "basic mantle" north of the Aranka-Wanamu Granite, but does not cover any of the granite itself.

Petrology and Petrography

The rocks of the Wanamu-Blue Mountains area consist of a complex assemblage of metamorphic rocks lying immediately north of the Aranka-Wanamu Granite. The contact zone between the granite and the metamorphics was not studied. Except for the phyllites and the actinolite schist, most of the rocks in the area are not appreciably schistose and megascopically they appear unmetamorphosed. Because of the apparently equigranular textures of the rocks, they were mapped in the field and described in a preliminary report as igneous rocks. However, even after petrographic study, the general rock units as distinguished in the field (although metamorphic rather than igneous) seem to be valid as mappable rock types.

The various rock types are described below in chronologic sequence, oldest through youngest. Both megascopic and microscopic properties are discussed together.

Phyllites

These rocks appear to be the oldest in the area and were assigned to the Cuyuni Formation by Cannon (1964). Megascopically the phyllites are soft, very fine-grained, foliated micaceous rocks, rich in chlorite or talc in many places. The talcose rocks have the typical greasy feel of talc and range in color from light tan to brown; those phyllites with more chlorite are light green to gray. Hematite is abundant in many places and colors the rocks red. Because most of the ferruginous phyllites were observed in weathered outcrops, it is difficult to say whether the iron represents a primary constituent of the rock or whether it was introduced later by secondary processes. The quartzites that are interfingered with the phyllites are also ferruginous.

The talc probably is related to the serpentinites which traverse the area, and the origin of the talc is discussed under the section dealing with the serpentinites.

Because the phyllites are soft, they tend to weather more readily and deeply than most of the other rocks of the area. Where exposed, the foliation is usually evident even though the rocks may be deeply weathered; the major foliation trend is west-northwest to nearly east-west.

Quartzites

The quartzites are white to gray, very fine-grained rocks that range from rather pure quartzose varieties with occasional streaks of black specular hematite to more ferruginous and argillaceous types. In some places the quartzites also appear to be graphitic. As seen in thin sections, the rock appears to be largely composed of well-sorted, equant, sutured quartz grains which display a banding of slightly different grain sizes. However, foliation is not conspicuous and the rocks (in thin section) do not seem to be very highly metamorphosed. The quartzites form lenses a few feet to probably several hundred feet wide which strike in a northwesterly direction across the northern part of the map area. The quartzites interfinger with the phyllites and are part of the Cuyuni Formation. They probably represent a sandy facies of the original sediments, and the phyllites probably represent a more shaly facies. In places the transition from quartzite to phyllite is gradational and the original sediments would probably be termed silty shales.

The quartzites are hard, resistant rocks that tend to be ridge-formers. They are massive and weather into angular blocks.

Clinozoisite Actinolite Amphibolite

These rocks are Precambrian in age and they are included with the "undifferentiated amphibolites" in the Mazaruni Group on the regional geologic map of the Waini SW quarter-degree square (Cannon, 1961). Later Cannon (1964) included them in the Cuyuni Formation. The amphibolite is a light green, very fine-grained to medium-grained rock that appears almost equigranular in hand specimen. Foliation is poorly developed in the amphibolite, except in a few places (usually near the serpentinites) where some elongate, medium-grained amphiboles are set in a finer-grained matrix.

In general, hand specimens appear to be fine-grained (but are sometimes medium-grained), with equant to tabular laths of green amphibole set in a lighter matrix which appears to be composed largely of light gray-green to white porphyroblasts or "eyes" of plagioclase feldspar. The amount of feldspar in the amphibolite varies and in some areas where the feldspar content is relatively high (about 50 percent), the rock becomes light gray in color. The feldspars are seldom fresh and they have a "greasy" appearance. Thin veins of milky white feldspar (shown by X-ray analysis to be oligoclase) up to 1-in. wide commonly occur in the amphibolite, especially in the vicinity of the serpentinite. In some areas the amphibolite becomes aphanitic and has a sugary texture; this finer-grained variety predominates along the northeastern margins of the amphibolite.

Petrographic examination confirms that this rock has been metamorphosed. The predominant texture is nematoblastic with a subordinate granoblastic matrix. Medium-grained, idioblastic laths of light-green actinolite with ragged terminations are set in a granular, fine-grained to aphanitic matrix. Often the actinolite crystals are bent or broken, or both, and two directions of foliation appear to have developed. Although strong foliation is never developed, there is usually a general alignment to the elongate actinolite crystals.

Superimposed upon this predominant lineation, there is often another less well-developed direction of crystal growth making an angle of about 40 degrees with the first. This subordinate foliation direction is manifested by an apparent second generation of actinolite-tremolite amphiboles which have grown at angles to first generation.

The broken and bent laths of actinolite suggest cataclasis, and the granoblastic texture of the matrix may be partly cataclastic also. The crystals in the matrix appear to be fragmented, and the amphibolite specimens collected near the shear zones in the area have a predominantly very fine-grained to aphanitic, granoblastic (cataclastic?) texture.

The amphibolite is mainly composed of light-green actinolite and amphiboles of the actinolite-tremolite series, with subordinate amounts of clinozoisite, plagioclase, and sometimes quartz. As previously mentioned, the actinolite occurs as idioblastic crystals; these are usually twinned and have ragged terminations. The plagioclase is altered so that little or no albite twinning is preserved. As a result, it was not possible to determine the composition of the plagioclase optically, but it may be oligoclase, for it is similar in appearance to the vein material. The clinozoisite occurs as minute idioblastic crystals that are randomly oriented in the matrix and appear to be replacing the amphiboles and plagioclase. Clinozoisite is a ubiquitous constituent of the amphibolite but the amount of clinozoisite in the rock varies according to location, from about 5 to 30 percent of total rock. Quartz occurs as aphanitic xenoblastic crystals in the matrix. The quartz appears to be later than the other minerals and in some specimens it has replaced part of the ground mass. However, this silicification is not extensive and usually amounts to less than one percent of the total rock. Very minor amounts of magnetite and a silvery-colored pyrite occur as accessory minerals.

The amphibolite is partly altered throughout to light-green and gray minerals that appear to be chlorite, serpentine and clays, although it is difficult to identify precisely the secondary minerals in the specimens that were studied. Minor amounts of carbonates occur also, together with some secondary iron oxides.

The amphibolite is resistant to weathering, and where it occurs in the eastern part of the map area, it weathers into large rounded to angular boulders.

It is difficult to state definitely what the origin of the amphibolite may be. Bracewell (1938, p. 28) suggested that the mafic metamorphic rocks in the Barama-Barima area represent an ancient northwest-trending complex of foliated rocks intruded by younger granite plutons and possibly by younger mafic rocks. Cannon (1964, p. 3) suggested that the "amphibolites appear to be basic igneous rocks amphibolitized by the granite" and this seems to be a reasonable hypothesis. Although the contact between the amphibolite and the phyllite is seldom exposed, field relations and the magascopic texture of the amphibolite indicate that it could represent a diorite which intruded the Cuyuni sediments and was later metamorphosed. It is possible that there were at least two episodes of metamorphism in the area: first an older, regional metamorphism of the Barama-Mazaruni Assemblage, then a later, more local, contact metamorphism by the Aranka-Wanamu Granite. The two apparent foliation directions in the amphibolite may support this idea.

The amphibolite could also be the result of a complex metamorphic differentiation process between the serpentinites and their host rocks. Metasomatic reactions at the contact of serpentinite can result in the formation of clinozoisite- and oligoclase-bearing amphibolites. However this hypothesis is difficult to prove, and is discussed at greater length under the heading "Serpentinite" in this thesis.

Epidiorite

The epidiorite consists of at least two rock types that have been grouped together for convenience in mapping. These two rock types are a medium-grained rock in the north and a fine-grained rock to the south which may or may not be related to the northern coarser-grained rock.

Medium-Grained Type

This is a dark, gray to green, medium-grained, equigranular rock that occurs in the western part of the map area. In hand specimen it resembles a gabbro or a diorite, and it was included in the Cuyuni Formation by Cannon (1964). The epidiorite seems to be intrusive into the previously discussed rock units, although it is impossible to state this fact with certainty. No actual contacts with the adjacent rock types were found, except in one location in the south-central part of the map area, where a dike of the epidiorite appears to be intruding the amphibolite. The margins of the epidiorite were defined as being somewhere between the last observed occurrence of that rock type and the first occurrences of another rock type. In a few places, the marginal areas of the epidiorite are finer grained than most of the mass; these finer-grained rocks may represent a chill border.

Petrographic examination reveals a predominantly granoblastic texture with large tabular crystals of hornblende set in an aphanitic to very fine-grained granular matrix. The hornblende crystals are pale green, have ragged terminations, and sometimes are poikiloblastic, with inclusions of plagioclase crystals. There are occasional intergranular aggregates of very fine-grained ilmenite and magnetite as accessories. The composition of the granular matrix, although difficult to determine because of the fine grain size of the constituents, seems to be minute crystals of hornblende and plagioclase which have been partly altered to chlorite, serpentine, and clay minerals. In some specimens, granular quartz also appears to be replacing part of the matrix. Minor amounts of clinozoisite and epidote sometimes occur as aphanitic, idioblastic crystals scattered through the matrix. The plagioclase is altered; however, it probably is andesine.

Both the texture and mineralogy of the rock suggest that it has been metamorphosed and probably was originally a gabbro. The granoblastic texture may be, in part, cataclastic, for many of the larger crystals, as well as those in the granular matrix, are broken and indicate that deformation of the rock has occurred. The inclusions of plagioclase within the hornblende crystals probably represent a sieve texture, or possibly a relict ophitic (blastophitic) texture.

Fine-Grained Type

The medium-grained epidiorite occurs in the northwestern part of the thesis area and appears to grade southward (toward the Aranka-Wanamu Granite) into a darker, fine-grained to very fine-grained mafic rock that was identified in the field as a diabase. However, petrographic examination of the few specimens that were collected showed that these fine-grained rocks have been metamorphosed and could be called amphibolites or epidiorites.

In thin section these fine-grained rocks display a predominantly nematoblastic texture with a subordinate granoblastic matrix. Idioblastic crystals of actinolite (and sometimes cummingtonite), together with xenoblastic crystals of plagioclase, are set in an aphanitic matrix composed of granular and fibrous crystals. This texture may be partly blastophitic. The amphibole crystals are usually twinned and often are bent or broken; there are also some spectacularly curved amphibole crystals. As in the other more schistose rocks of the area, two directions of foliation seem to have developed, and there is evidence of cataclasis.

The composition of these fine-grained rocks appears to be more mafic than that of the coarser-grained variety, for the rocks tend to be darker, almost black in color, and the plagioclase is labradorite. Very fine-grained crystals of magnetite and ilmenite occur as minor accessories. The amphiboles, especially those in the matrix, are partly altered to chlorite and serpentine, and the plagioclases are extensively altered to clay minerals. Appreciable amounts of quartz appear to be replacing the matrix in some specimens.

Because the contact between the fine- and medium-grained rocks was not found, it is uncertain whether these dark, fine-grained mafic rocks represent a fine-grained facies of the coarse-grained epidiorite or a different rock altogether. The mafic rocks may represent either or both cases. The changes in texture and mineralogy from the coarse-grained to the finer-grained rocks seem to indicate an increasing grade of metamorphism toward the granite intrusive. Because the coarse-grained and finer-grained mafic rocks appear to be closely related, they have been grouped together, both in the preceding description and on the geologic map of the thesis area.

Both the coarse-grained and the finer-grained mafic metamorphics are hard, tough rocks that are difficult to break with a hammer; however, they do not appear to be as resistant to chemical weathering as the amphibolites, for they weather into well-rounded boulders that are sheathed in thick rinds composed of concentric layers of secondary iron oxides. The weathered surface of these boulders is usually pitted, and they often superficially resemble the laterite boulders which are scattered over the map area.

Serpentinite

The serpentinite is a dark gray to black aphanitic rock which occurs in thin, 10- to 100-ft.-wide, tabular, dike-like bodies that trend northwest across the thesis area. Because of the thick soil cover in many areas, it was difficult to establish the continuity and extent of the serpentinite bodies; however, they appear to be most prevalent in the eastern part of the thesis area where they occur as an arcuate swarm intruding the amphibolites and phyllites. To the west, a few dikes appear to intrude the epidiorite. The appearance of the serpentinite is distinctive both in outcrops and in hand specimens. On fresh fractures it appears dark gray to black, sugary-textured and flecked with green. In some places thin, 1/16-in. to 1-in. veins of pale apple-green, fibrous serpentine cut across the rock in seemingly random orientations. X-ray analysis indicates this vein serpentine to be clinochrysotile. The clinochrysotile is brittle and usually occurs as fibers which are oriented perpendicular to the walls of fractures, although sometimes it appears to be massive and is slickensided on exposed surfaces. Rarely there may also be very fine stringers of white, asbestiform chrysotile as fracture fillings.

The serpentinite is sheared and fractured extensively; however, the intensity of fracturing differs from place to place. There are areas when the rock is cut by relatively few, widely spaced fractures, and in other areas, myriad randomly oriented fractures cut the rock into small polygonal blocks which are characteristic of serpentinites and have been called "shear polyhedrons" by Chidester (1962, p. 24, 71). The serpentine veining seems to be strongest in the most intensely sheared areas and may be entirely absent from the less fractured areas. There is one strong direction of fracturing along the strike of the dikes, but there are many other cross-cutting directions oriented transverse to the strike. In a few places, small, lenticular, serpentine-filled tension fractures were found. Differential weathering causes the uncut blocks of the serpentinite to stand out from the more deeply weathered fractures, giving the outcrops a ribbed appearance that resembles foliation. In the most intensely sheared rocks, the weathered surfaces resemble breccias. This appearance has been described as "thread-scored beeswax" (Chidester, 1962, p. 71) and the analogy is very apt. The weathered surfaces of the rock are covered by a paper-thin patina of black oxides, but beneath this coating the rock weathers into a dull white rind flecked with limonite.

Petrographically, the rock is composed mainly of serpentine with varying amounts of carbonates and magnetite, in addition to minor amounts of chromite. The texture of the serpentine varies considerably, but it most frequently occurs as dull-gray, fibrous crystals (probably antigorite) in felted aggregates known as "mesh structure." Occasionally, very fine veinlets of asbestiform chrysotile cut across the felted matrix as fracture fillings. In some specimens, relict textures are apparent and it is possible to see the crystal outlines or "ghosts" of former olivines and pyroxenes. In one specimen there are serpentine replacements of what appear to have been long, fibrous amphiboles between the pyroxene and olivine "ghosts." Also, in this specimen only, fine fibers of actinolite-tremolite occur in the matrix.

Magnetite is an opaque (in transmitted light), strongly magnetic spinellid, whereas chromite is a translucent, red-brown spinellid that is only weakly magnetic. Both minerals occur in the serpentinite, but magnetite greatly predominates over chromite. In addition to simple magnetite, there is probably another opaque spinellid which is a chromian magnetite and is indistinguishable from ordinary magnetite in thin sections. The magnetite comprises from 2 to 5 percent of the serpentinite and occurs as very fine-grained anhedral to subhedral crystals and dust-like particles. The coarser magnetite occurs along the boundaries of the "ghosts" of the former pyroxenes and olivine, while the dust-like material is disseminated throughout the serpentinite. As has been suggested by Chidester (1962, p. 77) for similar occurrences elsewhere, the magnetite probably is a product of the serpentinization process and represents iron from the olivine which could not be incorporated in the serpentine.

Chromite only occurs in the least altered specimens where the relict texture of the peridotite is readily apparent. The chromite occurs as very fine-grained anhedral crystals which are surrounded by opaque, granular material that may be chromian magnetite. The chromite is probably a primary mineral of the peridotite, and the chromian magnetite may represent an alteration product of the chromite.

The predominant carbonate mineral in the serpentinite is probably magnesite, although there may be some dolomite as well. Magnesite and dolomite commonly occur as hydrothermal replacement products of serpentine (Turner and Verhoogen, 1960, p. 578-581), and the Wanamu-Blue Mountain serpentinites are replaced by carbonates in varying amounts ranging from less than 1 to over 50 percent of the total rock. The carbonates occur as very fine-grained granular material replacing the serpentine, which is left as isolated grains in a carbonate matrix. The degree of carbonate replacement over the thesis area appears to be rather erratic, and some serpentinite specimens are essentially devoid of carbonates.

Minor amounts of iddingsite (after olivine) and limonite also occur as secondary minerals.

Contact Relationships Between Serpentinite and Host Rocks

The relationships of the serpentinites to their host rocks is complex, and these relationships differ from place to place, not only with changes in lithology of host rocks, but also within any one given lithology. It was not possible to study these relationships in any detail, but because the contact relationships are important in deciphering the petrogenesis of the area, they are briefly discussed below.

Three different types of contact relationships between the serpentinite and its host rocks were distinguished in the thesis area. Such a classification is preliminary and undoubtedly represents a gross over-simplification. The three types are: 1) hornfels, where the serpentinite appears to intrude the phyllites and the amphibolite and there is a 10-ft.-wide zone of chloritized, apparently hornfelsic rock between the serpentinite and its host rock; 2) actinolite schist, where bands up to 30 ft. wide parallel the serpentinite closely and definitely appear to be related to it; and 3) talc schist, where the margins of the serpentinite become talcose and the talc penetrates phyllite along its foliation, apparently replacing the phyllite.

Hornfels: The hornfelsic (?) zones resemble a contact metamorphic effect, for the alteration is most intense next to the serpentinite and becomes less distinct away from the contact. Near the serpentinite, where it intrudes the phyllites, the country rock is light green, aphanitic, sugary-textured, and chloritized. Approximately 10 feet away from the contact, the country rock grades into greenish, chloritized phyllite, which in turn grades into tan, talcose phyllite. Similar relationships occur where the serpentinite intrudes the amphibolite, where aphanitic, apparently hornfelsic, chloritized zones about 10 feet wide grade outward into the amphibolite. Occasionally, thin (1/2-in. to 1 in.) veins of plagioclase cut across the hornfels and out into the amphibolite near the contact of the serpentinite and the amphibolite, but it is difficult to ascertain the origin of the veins.

Actinolite Schist: The actinolite schist is perhaps the most distinctive rock type in the area, but because of its limited extent and unique association with the serpentinite, it will be discussed here rather than under a separate heading. The schist occurs in approximately 10- to 30-ft.-wide bands that closely parallel the serpentinite bodies and always occur between the serpentinite and its phyllite or amphibolite host rock. Where the actinolite schist occurs, it is invariably along the margins of the serpentinite; however, there are many places where the serpentinite occurs without the schist. The schist is mainly composed of spectacular 1-in. to 4-in. acicular crystals of light green actinolite, although the overall color of the rock usually appears to be gray. The actinolite crystals are sub-parallel and the foliation of the schist appears to parallel the strike of the serpentinite bodies. The length of the actinolite crystals is consistent at any given location, although the length of the crystals differs from place to place.

In some places where the serpentinite intrudes the amphibolite, although the schist is not developed, the amphibolite near the contact becomes schistose, because relatively large, elongate actinolite crystals are set in the predominantly fine-grained matrix. A similar effect was observed in one place where the serpentinite intrudes the epidiorite: schistose amphiboles had developed near the contact of the serpentinite and the epidiorite.

The actinolite schist is an extremely tough rock and is very resistant to weathering. As a result it weathers into large, angular boulders which may provide the first indication of the presence of a serpentinite body.

In thin section the schist displays a predominantly nematoblastic texture; idioblastic laths of actinolite are set in an aphanitic matrix composed of fibrous and granular crystals. Small amounts of altered plagioclase may occur also, but the predominant mineral is actinolite. The actinolite crystals are usually twinned, and often they appear splintery or are bent and broken. Generally there is a second generation of actinolite crystals replacing the first; the younger crystals are more stubby and are developed along the length of the first crystals with their C-axes oriented at an approximately 40-degree angle to the C-axes of the longer crystals. The second generation amphiboles are formed along a second subordinate foliation direction. The texture of the schist appears to be partly cataclastic.

Minor accessory minerals are magnetite and a silvery-colored pyrite which occurs along the boundaries of the actinolite crystals. Aphanitic, idioblastic crystals of clinozoisite commonly occur in the matrix, together with finely fibrous, shred-like actinolite-tremolite amphiboles. Serpentine, chlorite (?), quartz, and clays occur as secondary minerals. In thin section the overall appearance of the actinolite schist resembles that of the actinolite amphibolite, and where an appreciable amount of plagioclase is present, the rock could be called amphibolite.

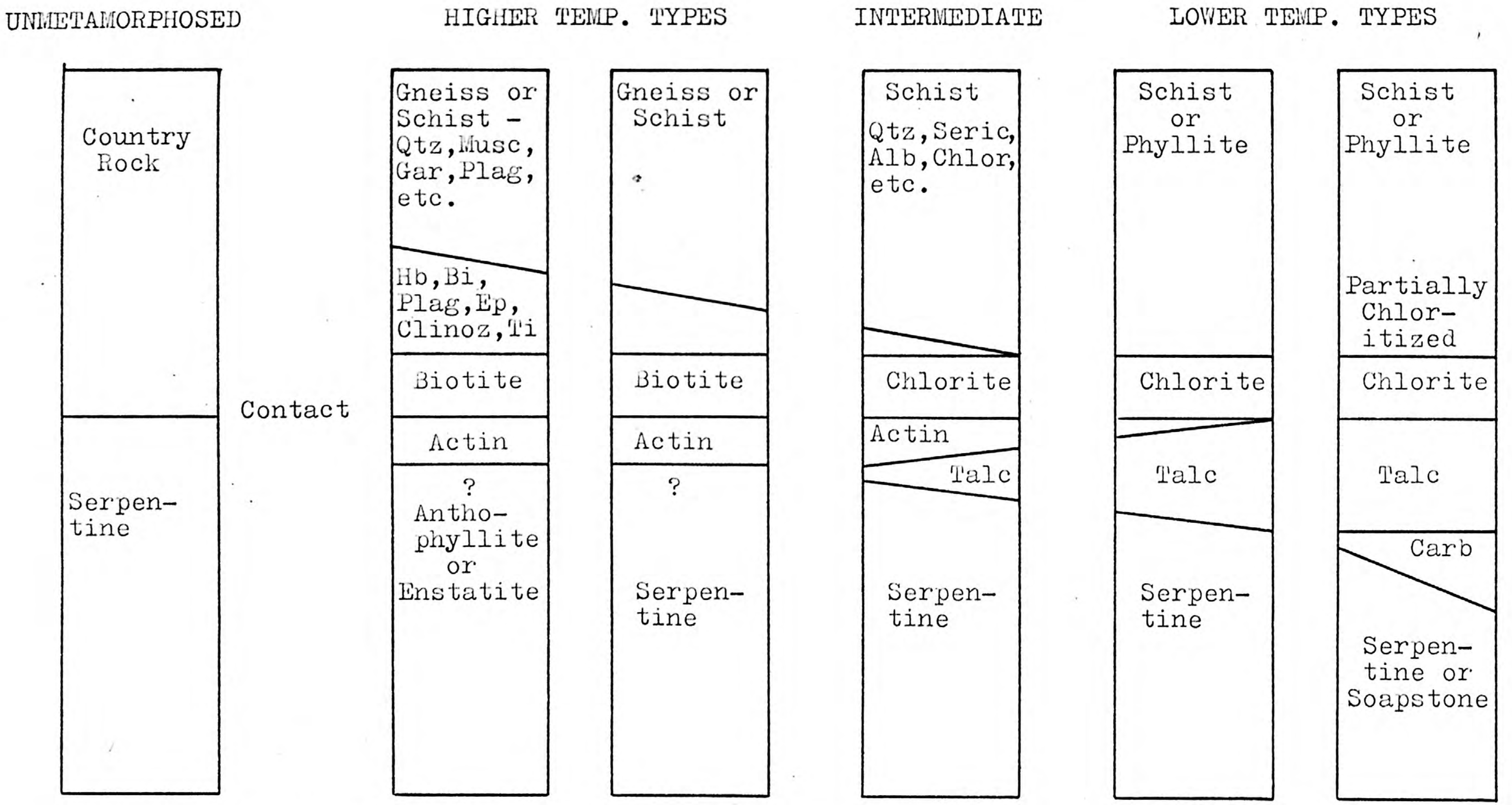
<u>Talc Schist</u>: The third general type of contact relationship (where the serpentinites have talcose margins which grade into the phyllite host rock) was not studied as closely as the other two types. Talcose margins were not observed often; however, this seemingly scarce development may be the result of poor exposure caused by the relatively soft nature of the talcose rocks. At the margins of the serpentinite a black, micaceous talc schist grades into the phyllite and replaces the phyllite in "tongues" that penetrate deeper along foliation planes. Because of the cursory examination of this phenomenon and because of the relatively poor exposure in the areas where it was observed, it is not possible to give the precise width of the talcose zones; however, the width is estimated to vary from a few inches to several feet.

Origin of Metamorphic Zones Around Serpentinite

The altered zones in the host rocks around the serpentinites resemble contact metamorphic effects, especially in the case of the hornfelsic zones, but it is very rare for ultramafic rocks to have contact metamorphism associated with them. Although various writers, among them Turner and Verhoogen (1960, p. 312) have pointed out that peridotite and dunite bodies seldom have contact metamorphic aureoles, a few workers in California (Chesterman, 1963; Taliaferro, 1943) have reported contact metamorphism around ultramafic intrusives.

Origin of Ultramafic Rocks: The problem of whether or not contact metamorphic effects occur around ultramafic intrusives is directly related to the classic problem of the origin of these rocks. Although early workers believed that peridotites and dunites were intruded as liquid ultramafic magmas, later workers, especially Bowen (1927), generally accepted the idea that peridotites and dunites originate from magmatic differentiation by crystal fractionation of early-forming pyroxenes and olivines. These crystal segregates are thought to be intruded as semi-solid masses or "crystal mushes." However, Hess (1933a; 1938) suggested that ultramafic rocks are derived from primary peridotite magmas that have large amounts of self-contained water which would tend to lower their fusion temperature -- enough in some cases to cause serpentine to crystallize directly from a melt. This idea was discredited by the experimental work of Bowen and Tuttle (1949), which demonstrated that the melting point of peridotite is well in excess of 1,000° C and that the existence of a peridotite, dunite, or serpentine magma is extremely unlikely. Furthermore, their work precluded the formation of serpentine above a temperature of 500° C. As a result, Bowen and Tuttle (1949) suggested that ultramafic bodies are intruded, at low temperatures, as crystalline matter that may be lubricated by water. According to Bowen and Tuttle (1949), serpentinization of ultramafic rocks probably occurs at temperatures between 200° and 400° C as the consequence of water from an external source being applied to an already-crystalline anhydrous rock. Chidester (1962, p. 88-89) has pointed out that the extreme fracturing characteristic of serpentinites, together with the general lack of contact metamorphism around ultramafic rocks, strongly supports the concept of these rocks being intruded as solids. Thus field evidence, combined with the experimental work of Bowen and Tuttle (1949), presents a convincing argument that serpentinization is a low-temperature process that occurs in already crystalline ultramafic rocks which themselves are probably intruded at relatively low temperatures. As a consequence, it is unlikely that ultramafic intrusives can cause extensive contact metamorphism. Therefore, the metamorphic aureoles around the Wanamu-Blue Mountains serpentinites are probably the result of some other process.

Metasomatic Reaction Zones: The metamorphic aureoles around the Wanamu-Blue Mountains serpentinites closely resemble the reaction zones around serpentinite bodies in the Appalachians, which have been described by Phillips and Hess (1936) (Figure 4). Serpentinite bodies in the Appalachians often have distinctive mineral assemblages (similar to those of the Wanamu-Blue Mountains area) at their contacts with the country rock. Phillips and Hess (1936) distinguished two main types of reaction zones: a low temperature type and a high temperature type. The low temperature type is characterized by the replacement of serpentine by talc and the country rock by chlorite. Carbonate veins are also formed in the serpentinite. The high temperature type is characterized by the formation of actinolite on the serpentine side of the contact and biotite on the country-rock side. The country rock of the high temperature type is gneiss or schist which may be altered to an oligoclase- and clinozoisite-bearing schist in a zone just beyond the biotite band. Low temperature effects may be superimposed on the high temperature zones, so that the biotite is chloritized and the serpentine is replaced by talc. Phillips and Hess (1936) ascribed these effects to metamorphic differentiation (i.e., metasomatism) which is a process whereby chemical constituents of rocks are transferred and rearranged on either side of their mutual contact under the influence of hydrothermal solutions, carbon dioxide, and elevated temperatures. Different temperature conditions, in



TYPES OF "CONTACT REACTION ZONES" AT CONTACTS BETWEEN SERPENTINE AND SILICIOUS COUNTRY ROCKS
(Modified after Phillips and Hess, 1936)
FIGURE 4

addition to varying compositions of aqueous solutions and volatiles, are inferred to result in different stable assemblages of minerals. Phillips and Hess (1936) maintained that the younger silicious intrusives which are associated with the Appalachian serpentinites could have been the source of hydrothermal fluids and volatiles, and also could have caused elevated temperatures.

Other writers, including Read (1934), Du Rietz (1935), Chidester (1962), and Coleman (1967) have described contact reaction zones around serpentinite bodies. The observations of Du Rietz (1935) in Sweden are very similar to those of Phillips and Hess in the United States. Du Rietz (1935), according to Phillips and Hess (1935, p. 351-352), describes the occurrence of clinozoisite amphibolites between the most intensely altered reaction zones and the schist host rocks. These amphibolites and those described by Phillips and Hess (1936) appear to be much like the clinozoisite actinolite amphibolite of the Wanamu-Blue Mountains area.

Chidester (1962) has made an intensive study of the talc deposits of Vermont, in which he presents very strong petrologic and chemical evidence for the formation of talc (steatization) by metasomatic reactions between serpentinites and their host rocks. Steatization, as Chidester (1962) describes the process, is the "lower temperature" type of metamorphic differentiation described by Phillips and Hess (1936). Chidester (1962, p. 91-97) demonstrates that steatization occurred later than serpentinization. According to Chidester (1962, p. 91-97), steatization and related processes probably occur at constant temperatures under similar conditions to that of the regional metamorphism of the host rocks. He thinks that changes in the chemical potential of water, carbon dioxide, and other constituents may cause the different reaction-zone effects attributed mainly to changes in temperature by Phillips and Hess (1936). In general, both steatization and the "higher temperature" reactions appear to be the products of carbon dioxide metasomatism and metamorphic differentiation between a serpentinite and its host rocks.

Coleman (1967) has described low-temperature reaction zones around ultramafic rocks of the Pacific Northwest of the United States and notes that similar zones occur in New Zealand. These reaction zones differ from those of the Appalachians in that the metasomatic zones in mafic country rocks consist largely of hydrogarnet, idocrase, diopside, chlorite, and prehnite, making up a "rodingite" rock. Coleman (1967) notes that where the reaction zones occur in silicious host rocks, a commonly occurring mineral assemblage is albite, potassium feldspar, and tremolite. This assemblage is closer to those described by Phillips and Hess (1936) and Chidester (1962). Coleman (1962) points out that reaction zones around serpentinites are characterized by an enrichment in calcium and magnesium. He feels that the metasomatic reaction zones in the Pacific Northwest were formed simultaneously with serpentinization and emplacement of the ultramafic rocks.

Chidester (1962) feels that the peridotites of the Appalachians also were serpentinized simultaneously with transport and emplacement of the ultramafic rocks; however, he states that steatization of the serpentinite was definitely later than serpentinization and is closely related to regional metamorphism of the serpentinite and its country rocks.

Thus it appears that contact reaction zones around ultramafic rocks are well documented from localities around the world. Differences between the many occurrences may be caused by variations in the bulk chemistry of the intruded rocks and differences in the conditions under which metasomatism occurred at various places. The metamorphic aureoles around the serpentinite bodies of the Wanamu-Blue Mountains area seem to be just one more example of this type of contact metasomatism. What makes the Wanamu-Blue Mountains occurrence especially interesting is the relatively wide reaction zones. The actinolite bands that Phillips and Hess (1936) describe are seldom more than a few inches wide, and the "rodingites" described by Coleman (1967) are all under one foot wide. The actinolite schist associated with the Wanamu-Blue Mountains serpentinites occurs in bands up to 30 feet wide. The clinozoisite actinolite amphibolite mass is even larger and it may also be the result of metasomatism between the serpentinites and the surrounding pelitic rocks of the Cuyuni Formation. The mineralogy of the amphibolite is very similar to more restricted occurrences described by Phillips and Hess (1936) and Du Rietz (1935), but the origin of the amphibolite could also be related to regional metamorphism of a mafic intrusive, rather than to a complex metasomatic process.

The Aranka-Wanamu Granite immediately to the south of the Blue Mountains could easily have provided the necessary source of volatiles both for serpentinization of the ultramafic dikes and for the contact metasomatism. Local variations in temperature, pressure, and concentration of water vapor and carbon dioxide could have caused different contact relationships between the serpentinites and their host rocks. It is possible that the ultramafic rocks may have been serpentinized prior to intrusion of the Aranka-Wanamu Granite, but even so, such a large intrusive must have affected the "basic mantle" around the margins of the batholith, and the proximity of the granite may account for the unusually wide reaction zones associated with the serpentinites.

Diabase

A small, 50- to 100-foot-wide, northeast-trending dike of black diabase (dolerite) is exposed on the bank of the Barama River in the central part of the map area. Cannon (1964) included this dike rock with the Younger Basic Intrusives. What appear to be related dikes occur further south in the western part of the map area and intrude both the phyllite and the epidiorite. The diabase is almost black in color, is very fine-grained, and in hand specimen it closely resembles the dark, fine-grained metamorphic rocks grouped with the epidiorite.

In thin section the diabase is shown to be largely composed of ophitic to subophitic intergrowths of labradorite and augite with very fine-grained magnetite and ilmenite as accessories. The diabase dikes were not studied in any detail, but samples obtained from apparently the same rock type further south show signs of being metamorphosed. Although the subophitic texture is preserved in these samples, the mafic mineral of the rock is hornblende which has been extensively altered to chlorite. The crystals have been fractured and are set in an aphanitic, granular groundmass. It is impossible to say whether the metamorphosed rock is the same dike rock as the fresher diabase; however, if it is, the diabase has been metamorphosed together with its host rocks near the Aranka-Wanamu Granite. It is also possible that there may be more than one age of mafic intrusive; i.e., some dikes were pre-metamorphism and some post-metamorphism, but with the sketchy information available, this concept is impossible to prove.

As with the other mafic rocks, the diabase is hard and tough, but weathers into rounded boulders that have thick rinds of secondary iron oxides around a core of fresh rock.

Quartz Veins

Quartz boulders of various sizes are scattered over most of the map area, and large quartz veins are exposed in several places. These veins may be up to 10 feet wide and are composed of massive, barren, milky-white "bull" quartz. These veins occur in the epidiorite, the amphibolite, and the phyllite, and may represent one or more generations of quartz. It is likely that the quartz veins were emplaced during a late hydrothermal stage of the cooling Aranka-Wanamu Granite.

Laterite

The term "laterite" is rather broad in meaning and has many different connotations. The original us~~e~~age of the word referred to indurated material or material that soon hardened on exposure to the atmosphere; however, the term has been expanded to include many kinds of ferruginous tropical soils which may not harden upon exposure. For example, nickel-enriched soils are often referred to as "laterites" (De Vletter, 1955; Esguerra, 1960). Sivarajasingham and others (1962, p. 5) have reviewed the laterite problem and restrict the use of the term "laterite" to

> highly weathered material (1) rich in secondary forms of iron, aluminum, or both; (2) poor in humus; (3) depleted of bases and combined silica; (4) with or without nondiagnostic substances such as quartz, limited amounts of weatherable primary minerals, or silicate clays; and (5) either hard or subject to hardening upon exposure to alternate wetting or drying.

In a more recent review, Maignien (1966) has recognized that "laterite" in the restricted sense refers to indurated occurrences; however, he also includes "lateritic soils" in his discussion of laterites in general. According to Maignien (1966, p. 26-51), the definition of a "lateritic soil" has become difficult to restrict, but he infers that "lateritic soils" have an encrusted horizon, a concretionary horizon that is becoming indurated, or soft horizons enriched in the sesquioxides of iron and/or aluminum with the silica to alumina ratio less than or equal to two.

Despite the diverse connotations of the term "laterite," it is apparent that recent workers tend to restrict its use to indurated occurrences. Therefore, in this thesis the term "laterite" will refer only to indurated "duricrust" material that is the product of intense weathering, desilication, and concentration of iron oxides.

Origin of Laterite

A detailed review of the origin of laterites is not given here; interested readers are referred to Sivarajasingham and others (1962), and Maignien (1966) who have reviewed the work done on laterites in recent years and have presented thorough bibliographies on laterites. Bleackley (1964) has made a study of the bauxites and laterites of Guyana.

In general, laterites are formed by the enrichment of material in iron and/or aluminum, either by the removal of other constituents or by accumulation from outside sources, or by various combinations of the two processes. There are many varieties of laterites, some of which develop in situ over the parent material and some of which develop from recemented transported lateritic colluvium. Further modifications may occur in a laterite because of the addition or removal of soluble constituents after formation of the laterite. Most laterites probably are the result of a complex mixture of several processes, rather than any one single process, and the forms which laterites can assume are diverse.

Laterites of Wanamu-Blue Mountains Area

In previous geologic reports, the Blue Mountains area has been described as being capped with laterite (Cannon and Carter, 1959), but very little duricrust capping actually occurs there. This discrepancy is probably a matter of definition, as discussed above. Laterite caps occur on hill tops in the extreme southeast part of the map area, but remnant boulders of laterite are widespread over the area and indicate that laterite may have formed on all the rock types (including the ferruginous quartzites), but it is difficult to ascertain the original extent of the laterite caps. Some recementation of laterite and other boulders by iron oxides is presently occurring in stream beds toward the base of slopes.

Several different varieties of laterite occur as remnant boulders scattered over the Wanamu-Blue Mountains area, but the most common type is hard, red-brown, hematitic, and vesicular. The vesicles are often filled with a soft, yellow, clayey material. The other common type of laterite is dense and laminated, and it seems to be composed of brown goethite. Laterites near the serpentinites tend to be dark brown in color.

There may be a serious problem in distinguishing between laterites formed over mafic and ultramafic rocks (such as in the Wanamu-Blue Mountains area) and gossans formed over massive sulfide bodies. Both gossans and laterites are the products of intense weathering and concentration of secondary iron oxides, and it is likely that they would closely resemble one another under similar conditions. No obvious gossans were observed during the course of mapping, but laterites in similar areas should probably be closely examined in order to determine whether or not they might be, in fact, gossans.

Structure

The structure of the Wanamu-Blue Mountains area may be complex, but because of the scarcity of outcrop, it is difficult to present an accurate picture of the structure. The general strike of the foliation in the phyllites is nearly east-west in the map area, and the "basic mantle" to the north of Aranka-Wanamu Granite, as shown by Cannon (1961), seems to follow this trend. With some exceptions, foliation is very poorly developed in the other metamorphic rocks of the area, but where it is developed, the general trend seems to be west-northwest and parallels the foliation of the phyllites. The predominant direction of jointing in the area also follows this trend.

The trend of the serpentinite bodies is generally west-northwest to northwest; some of the dike-like bodies essentially parallel the foliation of the host rocks, while others are apparently discordant. It was difficult to establish the continuity of the serpentinite bodies, although several attempts were made to "walk out" the ultramafic rocks. Some of the bodies may "pinch out" along strike, but many others appear to be offset by faults. Several en echelon faults cut north-northeast across the central and eastern part of the map area. These faults offset the serpentinite bodies, but because of the difficulty in tracing the serpentinites, the amount of offset could not be determined. The highly sheared nature of the serpentinites is characteristic of similar occurrences elsewhere in the world and is probably mainly related to the emplacement of the ultramafic rocks. However, some of the most intense fracturing may have been caused by later faulting, some of which may be related to the emplacement of the Aranka-Wanamu Granite.

Sheared and altered rocks are exposed in the creeks draining north off the Blue Mountains into the Barama River; the course of these creeks may be structurally controlled. The altered rocks exposed in the creek bottoms resemble phyllonites: they are gray to light green in color, are very fine-grained, and are schistose.

Silicified, pyrite-bearing float was found within the epidiorite; this float may indicate that faulting occurred in the epidiorite. Field evidence suggests more than one episode of faulting. Some of the faulting and folding in the mafic rocks around the Aranka-Wanamu Granite may be related to the emplacement of the intrusive, but some structures may be younger -- or older -- than this event. Emplacement of the older mafic intrusives may have been controlled by the west-northwest foliation trends in the Cuyuni Formation, whereas emplacement of the quartz veins and diabase dikes seems to have followed younger (?) north-northeast faults.

Geologic History

The geologic history of the area is complex, and it is difficult to do more than present a very general outline of this history because the detailed relationships of the rock units are poorly exposed. The geologic history commences in the Precambrian with the deposition of the Cuyuni sediments in the Barama-Mazaruni geosyncline. McConnell and others (1964, p. 116) give a minimum age of 2,500 million years for the "final filling of this geosyncline." Uplift occurred later, and during this time, intermediate to mafic intrusives (diorites and gabbros) were emplaced in the host rocks of the Cuyuni Formation. After the mafic intrusions were emplaced, ultramafic rocks, (peridotites and other types, perhaps of the alpine type) were intruded into the older rocks. Serpentinization of the ultramafic rocks probably occurred simultaneously with their emplacement. After intrusion of the ultramafic rocks, the Aranka-Wanamu Granite was emplaced. Some regional metamorphism may have occurred prior to emplacement of the granite and subsequent to intrusion of the ultramafic rocks, but it is also possible that regional metamorphism occurred later. McConnell and others (1964, p. 117) give a date of approximately 2,000 million years for intrusion of the

Younger Granite Group. Thermal effects, volatiles, and fluids emanating from the batholith probably further metamorphosed the rocks around its margins. The contact reaction zones between the serpentinites and their host rocks probably developed during the emplacement of the batholith. Faulting may also have occurred during this interval. Large quartz veins were emplaced in the rocks around the Aranka-Wanamu Granite as it cooled. Diabase dikes were intruded into the rocks of the Wanamu-Blue Mountains area, probably after the emplacement of the Aranka-Wanamu Granite, although there is evidence that some of the diabase dikes in the area may have been metamorphosed during the emplacement of the batholith. Whether or not the dikes were metamorphosed is questionable, however, and there may also be more than one age of diabase intrusive. The diabase dikes probably belong to the Younger Basic Intrusives, which are Proterozoic in age (1,700 million years) according to McConnell and others (1964, p. 117).

Subsequent events in the Wanamu-Blue Mountains area have been obscured by erosion. There may have been considerable deposition of sediments during later geologic time, but none of these have been preserved. Deep soil and laterites have developed on the rocks of the area in Tertiary (?) through Recent time. Streams have deeply incised the hills of the Wanamu-Blue Mountains area and have largely removed the protective laterite caps that developed over the mafic rocks.

SOILS

Except for the swampy areas adjacent to the Barama River which are covered with light gray clays, most of the Wanamu-Blue Mountains area is well drained and is covered by residual soils. Although most of the soils seem to be residual, there may have been considerable downslope creep of materials, especially on the steeper hills. The depth of the soils varies considerably over the area. On ridges and steep slopes, bedrock may be within a few inches to a few feet from the surface, but over most of the area the soil depth seems to be well in excess of 15 feet. Fresh bedrock is well exposed in many creeks draining off the hills, but the rock exposed in creek bottoms of flat areas usually is deeply weathered. Although different soil colors were noted in traverses over the area, no attempt was made to map different soil types.

Soil Profiles

Soil profiles were studied in six of the pits that Henry (1966) sank in the eastern part of the area, but no additional pits were excavated. The location of these pits is shown on Plates 1 and 2. Two of the pits (2 and 3) are over serpentinite bedrock and the others (1, 4, 8, and 9) appear to be over amphibolite. Pits 1 and 8 are close to serpentinite bodies. Representative profiles are shown in Figure 5. The soils in the pits differ somewhat, but in general the soils are clayey and yellow-brown to red-brown in color. Fairly distinct soil horizons (Figure 5) are observable; however, the transitions between horizons are more subtle than the diagrams make them appear. The various soil horizons can be distinguished only by close study, and some of the changes between horizons are gradational.

There are no observable humus horizons in the soils, although there is usually a thin layer of leaves and plant material littering the surface of the ground. A line of quartz pebbles occurs at a depth of about 1 foot in some of the pits. The uppermost horizons of the soil profiles tend to be lighter in color and less clayey than the lower horizons. These lighter-colored soils probably represent a leached zone, for where the soils become more clayey there is a zone of sesquioxide accumulation which commences at a depth of from two to six feet and averages about four feet thick. The upper limit of the zone of sesquioxide accumulation tends to be abrupt and is usually marked by a relatively dense concentration of manganese (as black wad) and hematite concretions which become sparser with depth. Most of the concretions are concentrated in a band a few feet wide, although scattered concretions may occur throughout the soil profile, especially in the lower horizons. The transition from the zone of sesquioxide accumulation to the lower soil horizons is gradational. The lower soil horizons tend to be mottled.

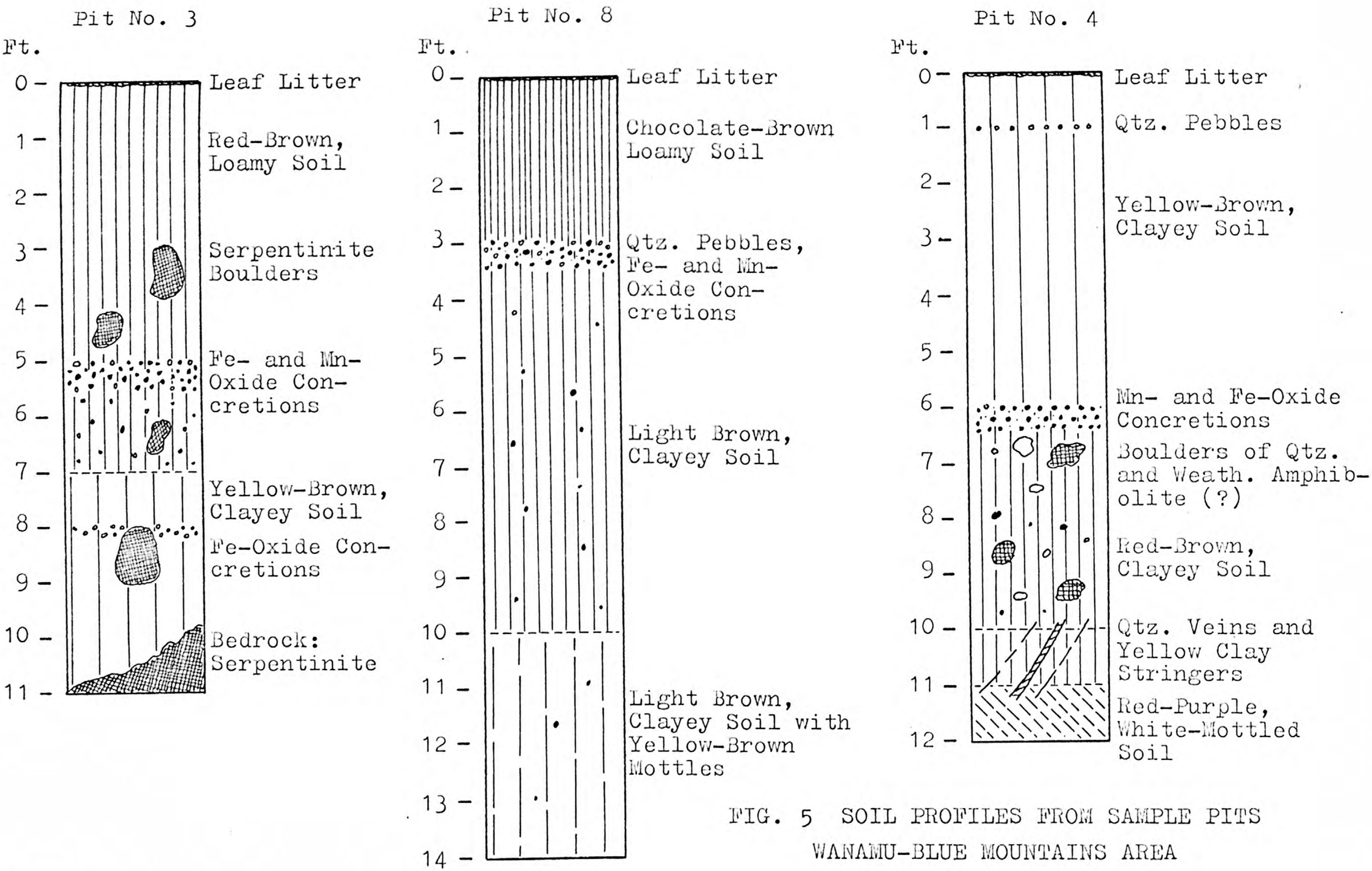


FIG. 5 SOIL PROFILES FROM SAMPLE PITS
WANAMU-BLUE MOUNTAINS AREA

Bedrock was encountered only in the two pits over serpentinite, where the transition from the parent material to the soil is abrupt, and there seems to be no zone of weathered rock material. In the other pits thin, discontinuous veins of gray quartz cut through the soil. These veins appear to be stable relicts remaining after the weathering of the less stable surrounding rock, which most probably was amphibolite. Boulders of bull quartz and highly weathered rock occur throughout the soil profiles of the pits over the amphibolite.

In general, the soil profile can be divided into three major horizons: an upper, leached zone from 2 to 6 feet thick; a concretionary zone of sesquioxide accumulation; and a lower zone of more clayey, mottled soil.

Soil Colors

The soil colors vary with the parent bedrock. Over the serpentinites the soils tend to be a dark chocolate-brown color, and over the rest of the area the soils are lighter in color. The soils over the amphibolite are light yellow-brown and over the epidiorite they tend to be a light red-brown. Toward the base of slopes, in creek bottoms, the soils tend to become red. As mentioned previously, the soils tend to become darker-colored and redder in depth, although the color changes are subtle.

Soil Type

The criteria for identifying lateritic soils were discussed under the heading "Geology" in the section on laterite (page 45). The soils in the Wanamu-Blue Mountains area do not have encrusted horizons, nor are their concretionary zones becoming indurated. The contents of silica and alumina are not known, so it is not possible to use these factors in criteria in identifying the soil type as being lateritic, as defined by Maignien (1966, p. 33). Although some of the soils may be lateritic, they are probably closer to being ferruginous tropical soils as described by Maignien (1966, p. 35).

GEOCHEMISTRY

It was originally anticipated that the thesis work would include a large amount of geochemical work but, as mentioned in the introduction, the type of area in which the thesis work would be done was not known until the author reached Guyana. Once there, the Wanamu-Blue Mountains area was decided upon, as high nickel and chromium values had been reported by Henry (1966) from soils in that area and it seemed worthwhile to investigate the area more closely. Although it would have been helpful to have a field test for nickel to guide a geochemical sampling program, it was not possible to obtain all the necessary reagents because of the haste with which the project was organized. As a result, an arbitrary sample grid was established along the traverse lines in the thesis area in the hope of "blanketing" any anomalies which existed there.

Sampling Methods

All of the north-south traverse lines were sampled at 500-foot intervals; then the eastern one-third of the area was re-sampled at intermediate stations between the original ones so that this part of the area was sampled at an interval of 250 feet. The sample sites are shown on Plate 1. Soil samples were collected from the bottom of two-foot-deep "post holes." These holes were rapidly dug with a spade; the two-foot sample depth represents a compromise between a desire to obtain as deep a sample as possible and the necessity to cover the area quickly.

In addition to the samples obtained along the lines, a limited number of soil samples were obtained from the pits sunk by Henry (1966). A total of 457 soil samples was collected.

Samples of the serpentinites and laterites were collected over the area in order to determine the metal content of these rocks. Most of the 26 serpentinite samples were taken from bedrock, but the 18 laterite samples were collected mainly from remnant boulders.

Analytical Procedures

The soil samples were dried and crushed, then sieved to minus 80 mesh; only the minus-80-mesh fraction was analyzed. The rock samples were also finely crushed and sieved to minus 80 mesh prior to analysis.

The soil samples were analyzed in two groups: the first set consisted of the initial samples collected at the 500-foot interval and the second set consisted of the intermediate samples from the eastern one-third of the area plus the pit samples and a few of the initial samples not analyzed with the first set. A distinction is made between the two groups of samples because there are some apparent differences in the analytical results between the two groups.

The initial set of soil samples was analyzed for nickel (by colorimetric methods, using dimethylglyoxime as a reagent) by personnel in the geochemical laboratory of the Guyana

Geological Survey. In addition, all of the rock and soil samples were sent to the geochemical laboratories of the U.S. Geological Survey in Denver, Colorado, where they were further analyzed, by various means, for several elements.

Both the rock and soil samples were analyzed in Denver for nickel, chromium, cobalt, and copper by the standard rapid colorimetric procedures employed by the U.S. Geological Survey. These methods are outlined in the U.S. Geological Survey Bulletin 1152 (Ward and others, 1963). The rock samples and the first set of soil samples were also analyzed for gold using the rapid atomic absorption method as described by Thompson, Nakagawa, and Van Sickle (1968). In addition, all the samples were analyzed by semiquantitative spectrographic methods for nickel, chromium, cobalt, copper, lead, zinc, tin, tungsten, vanadium, molybdenum, iron, manganese, titanium, magnesium, calcium, bismuth, arsenic, antimony, calcium, barium, strontium, boron, beryllium, niobium, indium, scandium, lanthanum, yttrium, zirconium, cadmium, gold, and silver.

Ninety soil samples from the second set of samples were analyzed by the author for ammonium citrate-soluble cobalt using the Canney and Nowlan (1964) method.

The results of the various analyses are discussed in the following sections under specific elements.

Data Processing

As was mentioned previously, 457 soil samples were collected and these were analyzed for several elements both by colorimetric and semiquantitative methods. As the analytical results represented a large quantity of values to be examined and compared, it was decided to punch the more significant values on data cards so that the geochemical data could be treated on a computer. The computer was used to calculate mean values and standard deviations (refer to Tables 1 and 2) for groups of elements and to calculate metal ratios. The computer was also used to plot profiles of the geochemical data and metal ratios along the sample lines.

One can compute a mean value and a standard deviation for a given set of geochemical data and then statistically calculate the background, threshold, and anomalous values; the computer facilitates this type of treatment. Hawkes and Webb (1962, p. 30) suggest that for a single population of values distributed symmetrically, "the threshold for that material may be conventionally taken as the mean plus twice the standard deviation." It is interesting to note that when this technique is applied to the geochemical data from the Wanamu-Blue Mountains area, the calculated threshold is very close to the threshold that can be visually estimated from a graphical plot of the data. In other words, it is simpler to plot the data graphically and visually estimate

TABLE 1

Comparison of Mean Values and Standard Deviations for Colorimetric and Spectrographic Determinations for Initial Set of 319 Soil Samples

			Parts Per Million	
Element	Analysis	** Mean Value	** Standard Deviation	** High Value
Ni	Color	500	1,200	10,000
	Spec	350	640	5,000
Cr	Color	1,100	1,900	15,000
	Spec	1,200 *	1,500	5,000
Co	Color	150	250	1,500
	Spec	86	150	700
Cu	Color	86	51	300
	Spec	91	39	300

TABLE 2

Comparison of Mean Values and Standard Deviations for Colorimetric and Spectrographic Determinations for Second Set of 90 Soil Samples

			Parts Per Million	
Element	Analysis	** Mean Value	** Standard Deviation	** High Value
Ni	Color	1,500	1,700	9,000
	Spec	660	680	3,000
Cr	Color	2,400	2,800	38,000
	Spec	2,000 *	1,700	5,000
Co	Color	150	200	1,000
	Spec	100	130	700
Cu	Color	98	48	160
	Spec	44	18	100

* Values reported as "greater than" a limiting value have been averaged as that limiting value.

** Computed values rounded off to two significant figures.

a threshold value. The estimated value is probably as valid as the calculated value, and the graphical presentation of the data, when juxtaposed with other information, will illustrate relationships that might not be readily apparent otherwise.

Regional and local thresholds are probably most easily shown on map presentations of geochemical data. Again this is shown in the Wanamu-Blue Mountains area (refer to Plates 3, 4, and 5), where the eastern one-half of the area has generally higher metal contents in the soils than the rest of the area. Metal values which might be considered anomalous with respect to the western part of the area might be below the local threshold in the eastern part of the area. The significance of these variations in the distribution of values over a given area is probably more easily understood by a simple map presentation of the data than by elaborate statistical treatments. In general, for limited problems such as that of the Wanamu-Blue Mountains area, simple graphical and map presentations of geochemical data are probably the most rapid and effective way to understand the information given by analyses of the soil samples.

Nickel

Anomalous nickel values (greater than 3,000 ppm) had been reported from the soils of the Wanamu-Blue Mountains area by Henry (1966) and the results of the present thesis study confirmed that the soils contain high concentrations of nickel.

However, questions arise such as: in what form does the nickel occur in the area, and how much nickel is there, both in the soils and in the bedrock? Some problems were encountered in evaluating the nickel determinations in the soils; the significance of the results is discussed in the following section.

In addition to the colorimetric and semiquantitative spectrographic nickel analyses, 25 samples from the second set of soil samples were analyzed for nickel by atomic absorbtion in order to compare the results of the various analytical methods. The results of the various nickel analyses are tabulated in Appendix B and Table 3.

Serpentinite

The rock samples were collected from scattered localities over the area, and although the nickel content of the rocks varies somewhat over the area, there seems to be no definite pattern to the variation.

Comparison of Colorimetric and Spectrographic Determinations

The colorimetric nickel determinations (alpha-furildioxime, performed by the U.S.G.S.) for the rocks are consistantly lower than the spectrographic determinations. These values are tabulated in Appendix D. This difference probably is caused by an incomplete extraction of nickel from the sample by the bisulfate fusion used in the colorimetric test. (See Ward and others, 1963, p. 37-38). The spectrographic determinations lack this extraction problem and probably are closer to the true total nickel values for the serpentinite samples. The spectrographic determinations range from 1,500 ppm to 5,000 ppm nickel; the mean value is 3,300 ppm, which is somewhat higher than the average value of 2,000 ppm nickel for ultramafic rocks (Vinogradov, 1962, p. 641-664).

Nickel Substitution in Serpentine

It is difficult to be certain of how the nickel is held in the rocks; however, most of it is probably held in the lattices of the serpentine minerals. According to Faust and Fahey (1962, p. 2), the general formula for serpentine is $X_6Y_4O_{10}(OH)_8$, where several elements may be substituted in the X and Y positions. Generally silicon, with minor substitution by aluminum and ferric iron, occupies the Y position, but several elements including magnesium, iron, nickel, cobalt, manganese, and zinc can occupy the X position to form hypothetical end-members such as $Mg_6Si_4O_{10}(OH)_8$, $Ni_6Si_4O_{10}(OH)_8$, and $Co_6Si_4O_{10}(OH)_8$. However, Faust and Fahey (1962, p. 2) state that natural serpentines are rarely composed of pure end-members, and usually contain more than one element substituting in the X position. An example of the formula of such a serpentine is $[Mg_{5.0}Ni_{0.5}Fe^{2+}_{0.5}]Si_4O_{10}(OH)_8$.

The serpentinites collected from the Wanamu-Blue Mountains area most probably have several different elements, including nickel, substituting for magnesium.

At one sample locality where prominent veins of clinochrysotile cut across the serpentinite, a sample of pure clinochrysotile and one of the darker serpentinite host rocks were collected in order to compare their metal contents. Both samples contain 5,000 ppm nickel and although it is impossible to draw definitive conclusions on the basis of just two samples, the results indicate that most of the nickel in the rock occurs in the serpentine minerals, rather than in some other form. Some of the serpentinites contain appreciable amounts of magnetite and it is possible that some nickel may be contained in the magnetite also.

Soils

High nickel values were found in the soils associated with the serpentinite bodies. These high values were first indicated by the dimethylglyoxime colorimetric analyses done at the Guyana Geological Survey on the initial set of soil samples. Further analytical work by the U.S. Geological Survey laboratories confirmed that many of these soil samples have anomalously high nickel contents; however, the values obtained from spectrographic and colorimetric determinations differ considerably from one another.

Comparison of Analyses

The results of the colorimetric analyses using dimethylglyoxime and those done by the U.S. Geological Survey using alpha-furildioxime agree fairly well, although the former values tend to be lower than the latter values, especially for the samples that are relatively high in nickel. The maximum nickel value obtained by the former method is 6,000 ppm, whereas that of the U.S. Geological Survey determinations is 10,000 ppm.

The spectrographic determinations for nickel in the first set of soil samples are consistantly lower than the colorimetric determinations (U.S.G.S.) and this discrepancy is accentuated in the anomalous samples, where the spectrographic value may be 3,000 ppm nickel versus 10,000 ppm nickel for the colorimetric determination. The maximum spectrographic nickel determination is 5,000 ppm. The spectrographic and colorimetric values (U.S.G.S.) are much closer, and essentially agree with one another, for the samples that have relatively low nickel values. Despite the difference between the results of the two methods of analysis, the relative high and low values, as determined by each method, follow one another closely. A comparison of the spectrographic and colorimetric determinations (U.S.G.S.) is tabulated in Appendix B.

Similar results were obtained from the second set of soil samples, although the difference between the spectrographic and colorimetric results seem to be greater for these samples. The accentuated discrepancy between the spectrographic and colorimetric determinations for the second set of soil samples is probably explained by the fact that these samples have a much higher average nickel content than the first set. The second set of soil samples was collected in the eastern one-third of the area, which is generally anomalous in respect to the western two-thirds of the area; the mean nickel value (spectrographic) for the first set of samples is 350 ppm, while that of the second set is 660 ppm.

The second set of soil samples was collected from points between the original sample sites of the first set and while most of the intermediate sample values should be closely related to the adjacent sample values, the colorimetric values for the second set of samples tend to be much higher than the adjacent set of samples. This tendency is shown with the spectrographic determinations as well, but the difference is more subdued. These relationships are illustrated in Figures 6 and 7. Although there seems to be some bias toward higher values in the colorimetric results from the second set of samples, they generally reflect the adjacent high values of the first set. In general, the apparent discrepancies between the analytical results from the two groups of samples illustrates the advisability of analyzing all samples together, in one batch, when conducting geochemical surveys.

The discrepancy between the analytical results of the spectrographic and colorimetric nickel determinations (U.S.G.S.) caused some concern as to which might more closely represent the "true" nickel values in the soils. As a consequence, 25 of the samples which display the greatest difference between the two results were analyzed for nickel by atomic absorption. The atomic absorption nickel determinations correspond much more closely with the spectrographic determinations than with the colorimetric determinations; therefore, the spectrographic analyses are regarded to be closer to the "true" values than the colorimetric determinations. The results of the different methods of analysis are compared in Table 3.

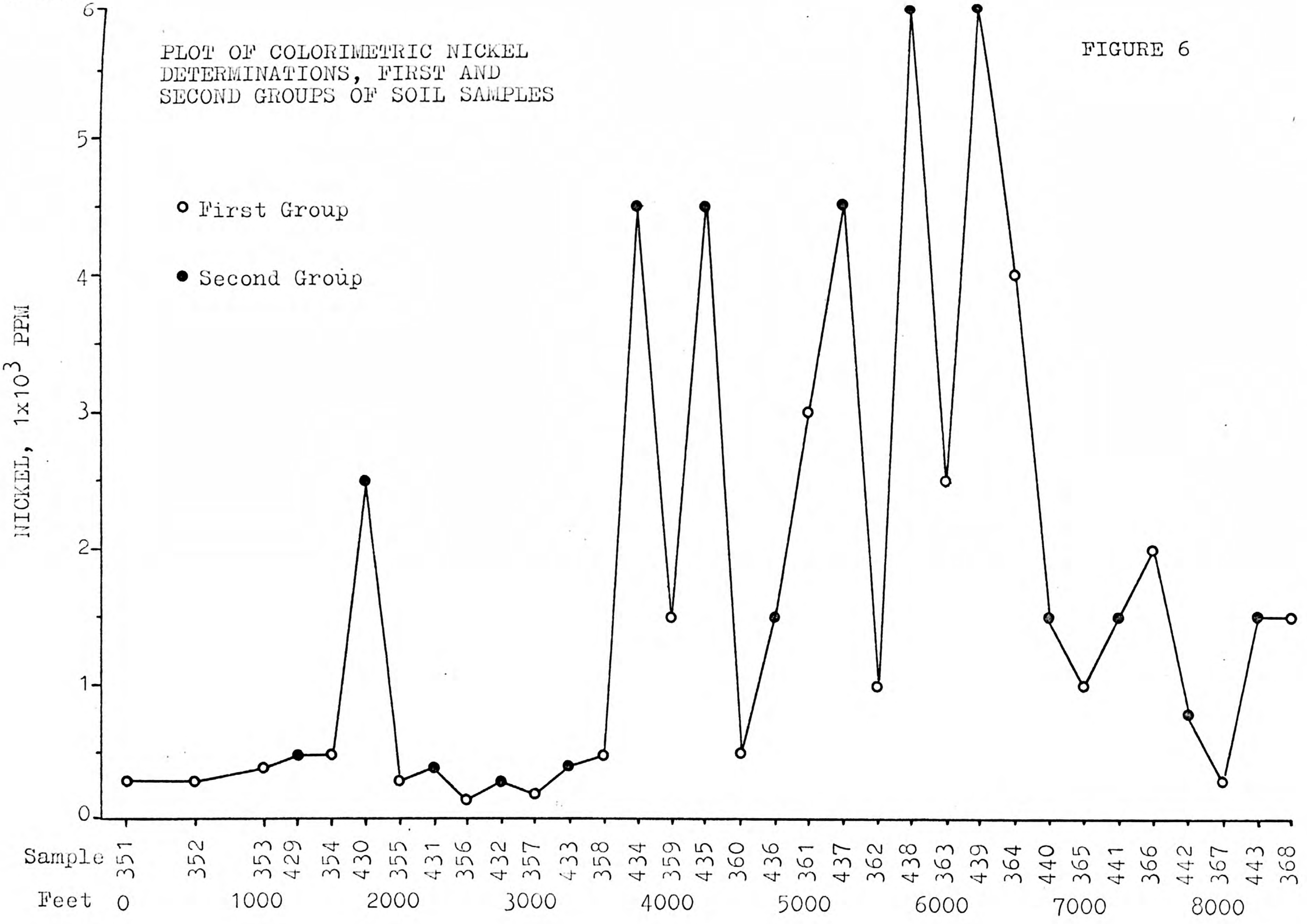
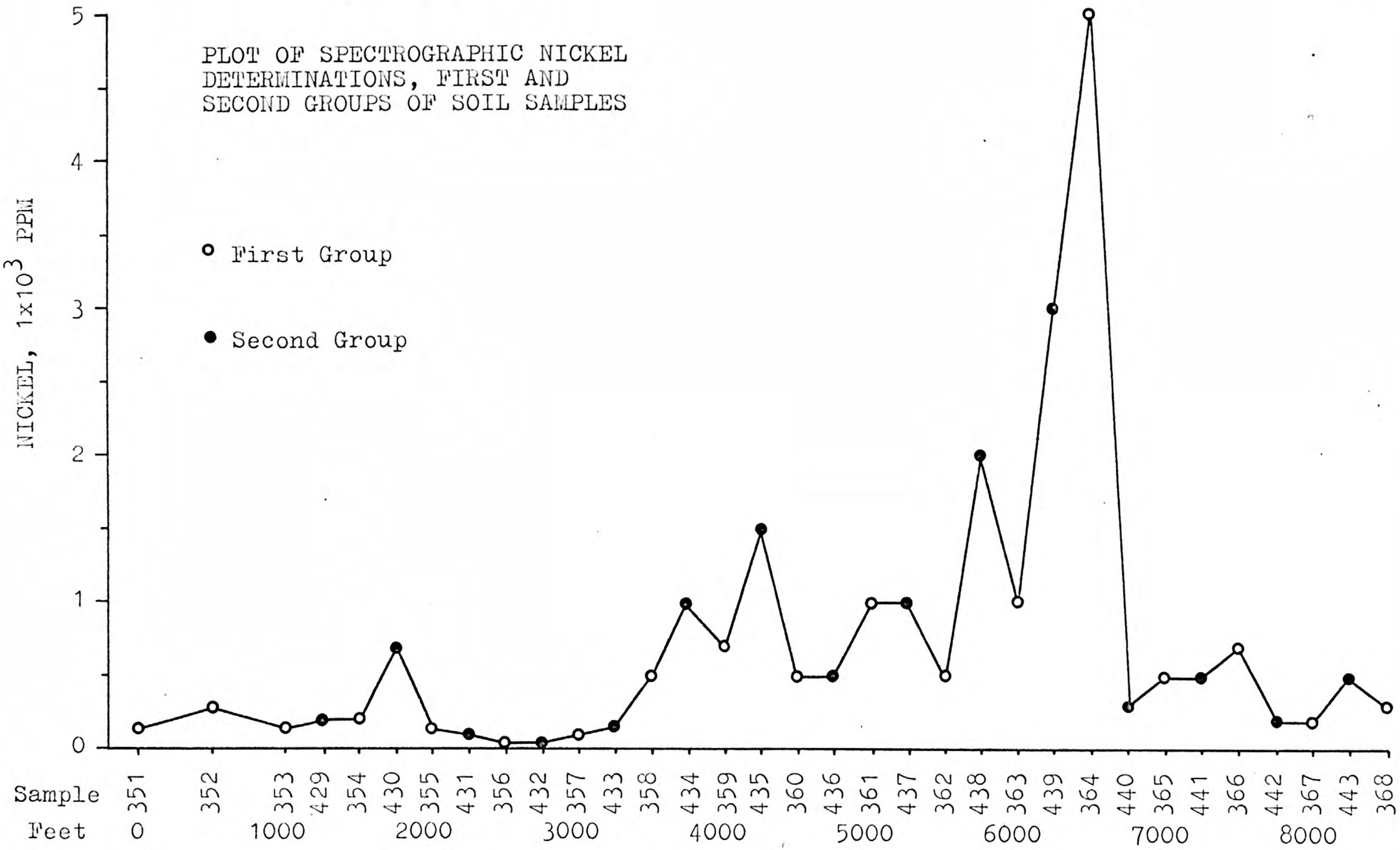


FIGURE 6

PLOT OF COLORIMETRIC NICKEL DETERMINATIONS, FIRST AND SECOND GROUPS OF SOIL SAMPLES

FIGURE 7



PLOT OF SPECTROGRAPHIC NICKEL DETERMINATIONS, FIRST AND SECOND GROUPS OF SOIL SAMPLES

This interpretation is open to question, however, because the method of extraction employed in each case is different. The sample digestion that is used for the atomic absorption method is a 30-minute hot extraction in concentrated nitric acid. The spectrographic determination is a <u>total</u> extraction, whereas the bisulfate and nitric acid extractions are more apt to be partial extractions. According to Bloom (1962, p. 598), nickel in silicates may not be entirely extracted by a nitric acid digestion, and digestion in hydrofluoric acid is necessary to achieve a total extraction. However, according to Canney (personal communication), comparisons of hydrofluoric and concentrated nitric acid digestions used in the atomic absorption method indicate that there is little difference between the results obtained from the two methods of extraction. Because these comparisons were not made with the soil samples from the Wanamu-Blue Mountains area, it cannot be stated with certainty that the atomic absorption and spectrographic nickel determinations represent truly comparable results, as there is a chance for compensating errors. Nevertheless, because the supposedly partial colorimetric nickel determinations are consistently <u>higher</u> than the total spectrographic determinations, combined with the fact that two very different methods of analysis (atomic absorption and spectrographic) yield comparable results, the author believes that the spectrographic results are more reliable than the colorimetric results in this case. Thus the real maximum value of nickel

TABLE 3

COMPARISON OF SPECTROGRAPHIC, COLORIMETRIC, AND ATOMIC ABSORPTION (A.A.) DETERMINATIONS FOR NICKEL, COBALT, AND COPPER

Sample Number	Parts Per Million								
	Nickel			Cobalt			Copper		
	Spec	Color	A.A.	Spec	Color	A.A.	Spec	Color	A.A.
373	2,000	6,000	2,160	700	1,000	1,120	30	20	30
375	2,000	9,000	2,560	100	250	208	50	60	46
377	1,500	4,500	1,720	500	1,000	720	50	40	34
383	2,000	6,000	2,240	500	900	800	50	80	44
389	1,500	4,500	2,160	100	300	220	20	40	46
393	1,000	3,000	2,480	500	900	1,440	50	80	62
394	1,000	6,000	1,920	500	1,000	1,440	30	40	52
398	500	2,500	500	100	300	260	50	80	68
402	1,000	4,500	2,080	100	250	184	30	60	56
409	1,000	6,000	2,000	150	700	400	50	120	98
411	200	1,500	290	50	250	150	50	120	84
415	300	1,500	170	50	80	68	50	120	78
419	1,500	4,500	1,560	200	450	370	30	40	42
421	1,000	6,000	2,880	200	700	270	20	40	58
424	2,000	9,000	1,960	70	300	560	30	60	42
430	700	2,500	3,280	50	80	270	20	40	62
434	1,000	4,500	1,520	50	120	124	30	60	68
435	1,500	4,500	1,280	100	300	192	30	80	58
437	1,000	4,500	1,560	100	150	176	50	120	76
438	2,000	6,000	2,133	150	300	220	30	60	50
439	3,000	6,000	2,400	500	700	930	50	40	44
446	200	1,200	144	70	80	66	70	120	96
450	30	400	8	5	30	8	70	120	66
455	3,000	6,000	2,560	200	450	300	30	60	46
456	500	2,500	720	70	250	124	30	80	58

Determinations by U.S.G.S. laboratories, Denver, Colorado

in the soils is probably much closer to 5,000 ppm (0.5 percent) than 10,000 ppm (1 percent).

The reason for the discrepancy between the spectrographic and colorimetric nickel analyses (U.S.G.S.) is not known; however, it is possible that the high iron content of the soils may interfere with the colorimetric nickel determination. According to Ward and others (1963, p. 37), copper and ferrous iron may interfere with the alpha-furildioxime colorimetric determinations when there is a very high ratio of copper and/or iron to nickel. The soils of the Wanamu-Blue Mountains area do not have high copper contents (usually less than 300 ppm), but the iron content does tend to be high, with a mean value of approximately 11 percent and a maximum value of greater than 20 percent. The higher iron contents in the soils tend to be associated with the higher nickel values; this relationship is illustrated in Figure 8, although it can be seen that the iron content of the soils is generally high.

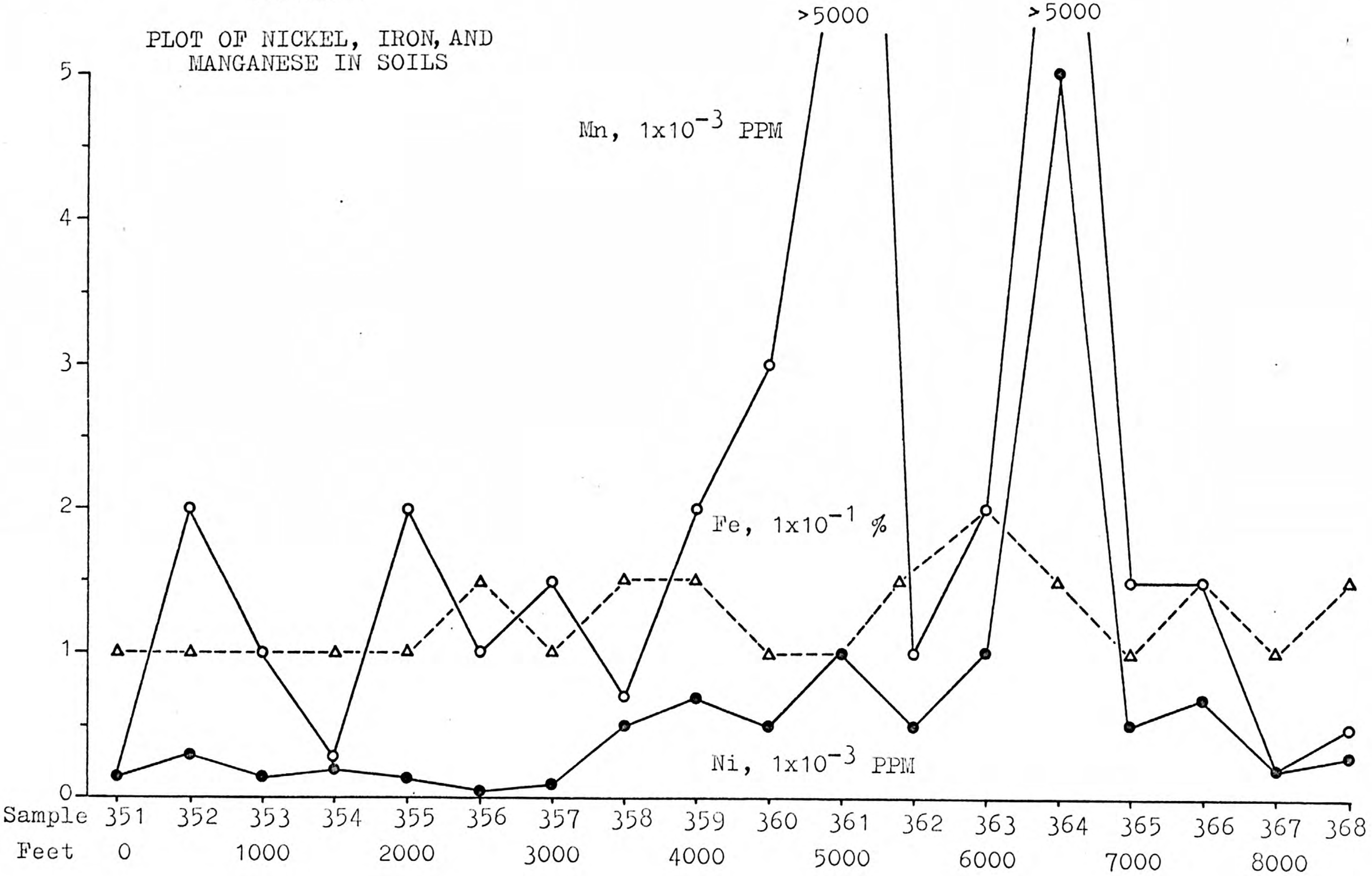
However, it would require detailed laboratory work to ascertain just why the colorimetric nickel determinations are excessively high. Imperfections in the method of analysis (dilution factors, range of standards, etc.) may accentuate errors in samples that are exceptionally high in nickel.

Distribution of Nickel

High nickel values in the soils are closely associated with the serpentinites, and the nickel anomalies tend to follow the trend of these rocks. Most of the high nickel values occur

FIGURE 8

PLOT OF NICKEL, IRON, AND MANGANESE IN SOILS



in the eastern part of the map area and the anomalies there are "open-ended" to the southeast. Because the spectrographic nickel determinations seem to be the most reliable, they have been plotted on Plate 3, which is a map of the nickel concentration in the soils of the area. For the sake of simplicity, only the values from the original samples collected at 500-foot interval have been shown; however, the intermediate sample values (not plotted) largely corroborate the adjacent values which are presented on the map.

The high nickel values coincide with high cobalt, chromium, magnesium, and manganese values. These relationships are shown in Figures 8 and 9. Plate 6 shows the relationship of the metals in the soils to bedrock geology. The magnesium content of the soils tends to vary with the nickel content. The mean magnesium content of the soils is about 0.60 percent (and often is much less), but where the nickel content of the soil is high, the magnesium content may be from 1.0 to 7.0 percent. This relationship is shown on Figure 10. Much of the nickel in the soils may occur in secondary magnesium silicates; however, nickel undoubtedly occurs in other forms also, as is indicated by the pit samples.

As explained in the section on soils, soil profiles were studied only in a few sample pits sunk by Henry (1966). These pits were re-sampled during the present thesis study, but with the limited amount of information that was obtained it is not possible to make definitive statements about the behavior of

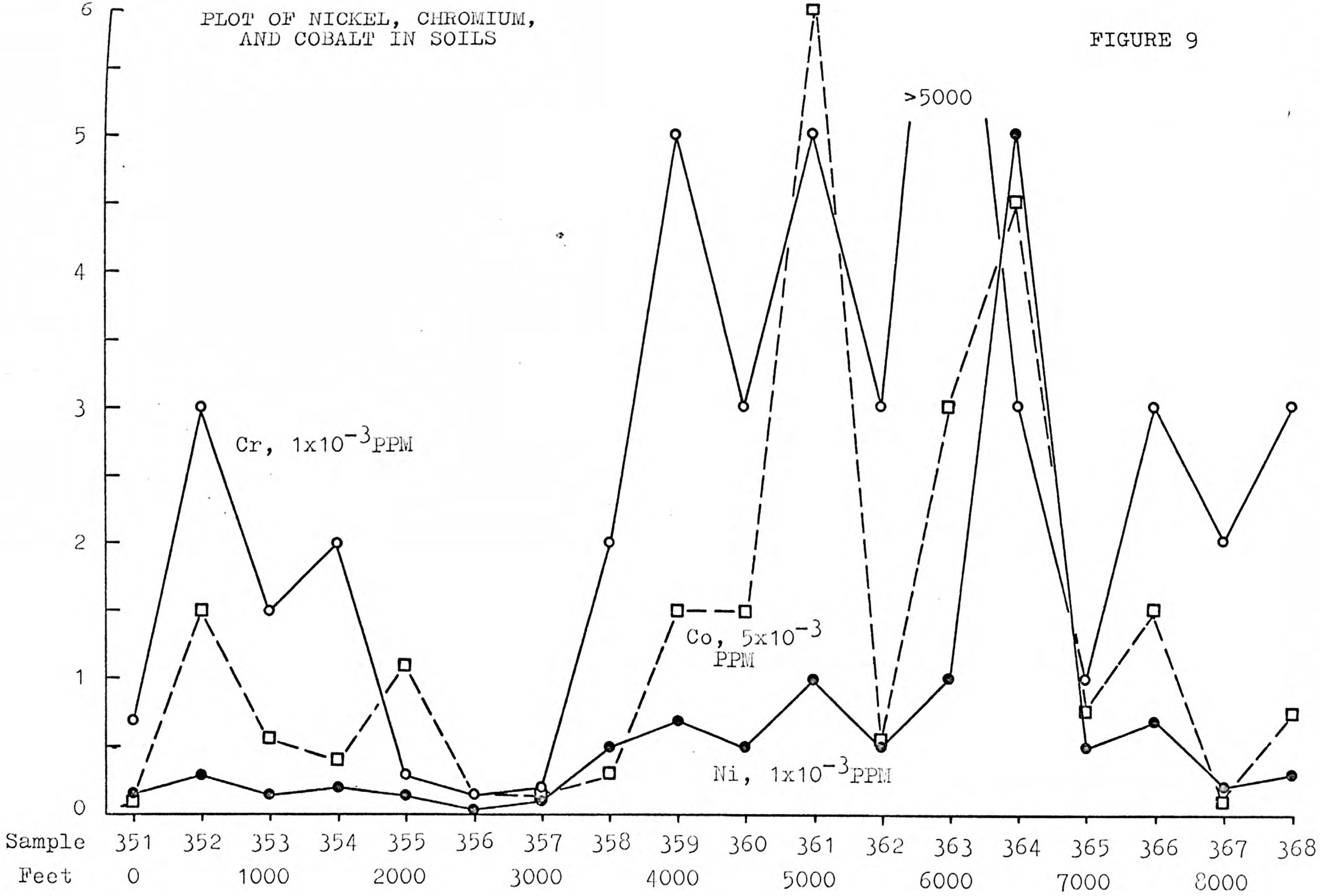


FIGURE 9

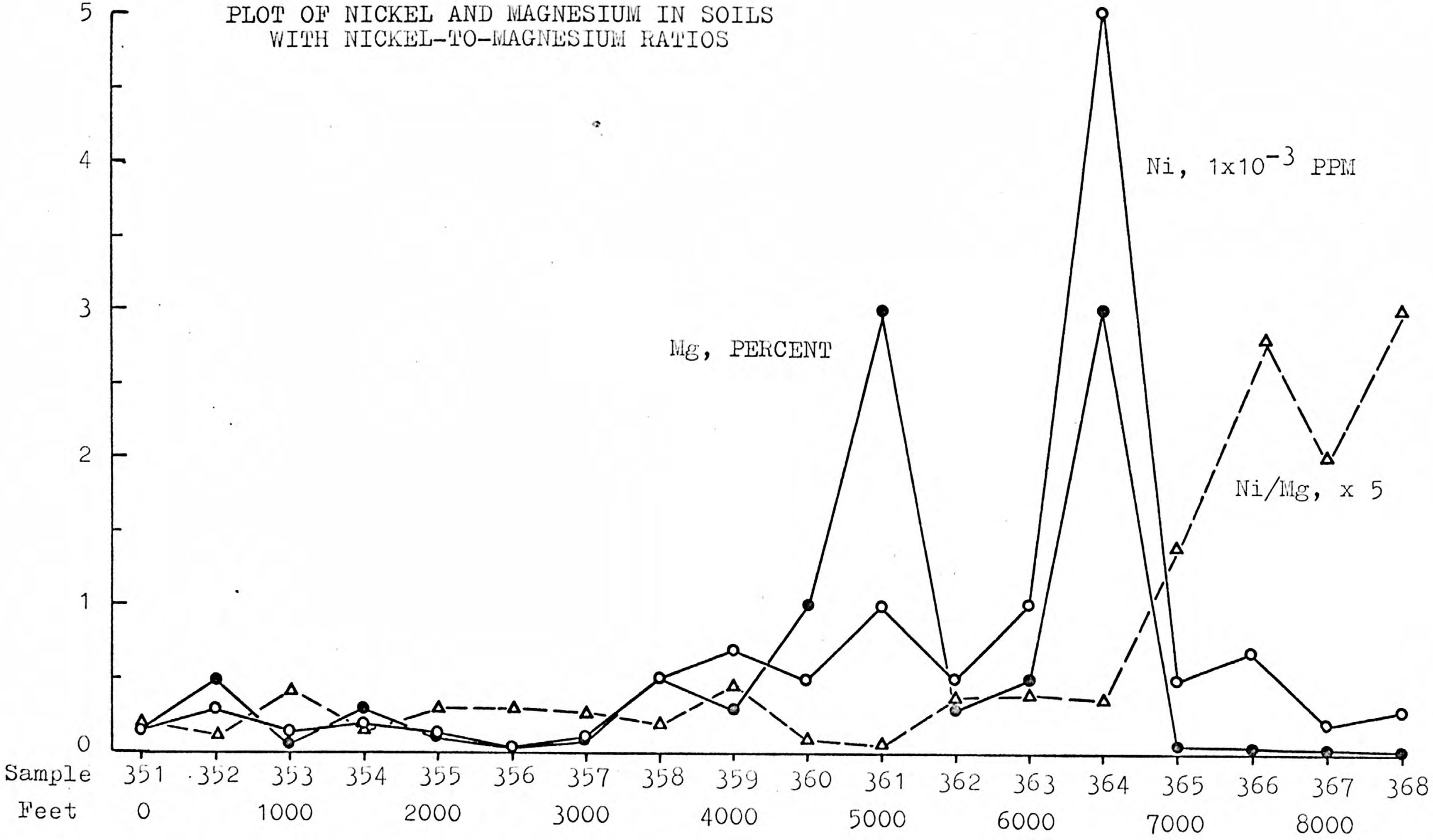
PLOT OF NICKEL, CHROMIUM, AND COBALT IN SOILS metals throughout the soil profiles. The results of the pit-sample analyses are presented in Tables 4 and 6.

In the deeper pit (11 feet) over serpentinite bedrock (pit 3, shown on Figure 5), the nickel content of the soil remains fairly constant with depth, although there is a slight apparent enrichment toward the top of the zone of sesquioxide accumulation. The spectrographic nickel determinations, which are probably the most reliable, show a maximum nickel concentration of 3,000 ppm (versus 9,000 ppm for the colorimetric determinations which are probably too high). Pit 2, also over serpentinite, is 6 feet deep and shows a constant nickel content throughout of 2,000 ppm. As the mean nickel value in the serpentinites is 3,300 ppm and the nickel content of the serpentinite bedrock in pit 3 is 5,000 ppm, the nickel values in the soils hardly represent much enrichment. Rather, it appears that much nickel has been leached from the soils, because the soils represent a residual concentration of weathered rock materials, and if no leaching has occurred, nickel should be concentrated to a much greater degree. By assuming that the titanium content remains constant during weathering, one can calculate the approximate depletion of nickel in the soils to be minus 88 percent of what the nickel concentration in the soil would be had there been no leaching, as is explained in Appendix A.

In the other pits (1, 4, 8, and 9), which are apparently over amphibolite bedrock, the behavior of the nickel with

FIGURE 10

PLOT OF NICKEL AND MAGNESIUM IN SOILS
WITH NICKEL-TO-MAGNESIUM RATIOS



depth is similar: the nickel content remains nearly constant, although pit 1 shows a slight enrichment of nickel with depth. In pits 4 and 9, the maximum nickel content is 150 ppm, but in pits 1 and 8, which are close to serpentinite bodies, the maximum nickel content is 2,000 ppm. This high value probably indicates lateral movement of nickel in solution from soils over serpentinites to nearby soils. The distribution of nickel in soils over the area, as shown on Plate 3, also indicates that some lateral migration of nickel has occurred, although the anomalies tend to follow the serpentinite bodies rather closely. In pit 4, manganese concretions were handpicked from the soil so that both the concretions and the soil could be analyzed separately for comparison of their metal contents. Although it is impossible to make a definite statement on the basis of just two samples, the results indicate that more nickel is held in the manganese concretions than in the ferruginous soil.

The close correspondence between the nickel and magnesium contents of the soils collected at a two-foot depth along the lines is not apparent in the pit samples, and the two elements appear to vary independently of one another in depth. In most of the pits, the magnesium content remains fairly constant with depth, but in pit 3 (over serpentinite) the magnesium content of the soil increases with depth.

Thus it seems that the behavior of nickel in the soils is complex. Much of the nickel may occur in secondary magnesium silicate minerals such as clays. Pecora (1944, p. 267-269) has described nickel-bearing clays from Goiaz, Brazil, which occur over ultramafic rocks. The lowermost clays in the soil profiles are magnesium-rich, green in color, and have a higher nickel content (2 to 5 percent) than the overlying ferruginous clays, which are purple to red in color and have nickel contents of from 0.5 to 1.5 percent. Hotz (1964, p. 371) has studied nickeliferous lateritic soils over ultramafic rocks in Oregon and California; he suggests that nickel substitutes for magnesium in montmorillonite, talc, and chlorite. According to Pecora and others (1949), nickel is often enriched in lateritic deposits as "garnierite," a green secondary hydrous magnesium silicate that Montoya and Gretta (1963) found to be mainly serpentine minerals. No garnierite was observed in the soils of the Wanamu-Blue Mountains area.

Appreciable amounts of nickel are probably held by secondary iron and manganese oxides. According to De Vletter (1955, p. 84), much of the Cuban lateritic nickel ore consists "essentially of iron ore," but he does not state how the nickel occurs in the iron oxides. In studies of the Cuban ores, Fisher and Dressel (1959, p. 49) found that nickel occurs as nickel-bearing goethite and as replacements associated with cobalt in manganese and iron oxides, as well as being a constituent of serpentine minerals. According to Pecora (1944, p. 274), nickel occurs at Goiaz, Brazil, in manganese oxides in amounts up to 2.8 percent.

Although the maximum nickel values in the soils coincide with high manganese values (some in excess of 5,000 ppm), and some nickel is undoubtedly scavenged by manganese oxides, in soils with low nickel concentrations in the Wanamu-Blue Mountains area, the nickel does not appear to follow the manganese content very closely. There is evidence that considerable amounts of nickel have been leached and have moved about in solution, but most of the nickel remaining in the soils is concentrated near the serpentinites, which are the source of the nickel. According to Garrels and Christ (1965, p. 244-247), nickel oxides and hydroxides are soluble through a wide range of acid and alkaline conditions in an oxidizing environment. The soils around the serpentinites tend to be shallow and some of the nickel may be held in finely divided, partly weathered rock material. The fact that samples with a high nickel content also have a high magnesium content indicates that these samples came from relatively deep parts of the soil profile and may represent truncated soil horizons. An exceptionally high content of magnesium in soils may indicate that they contain unweathered rock material.

De Vletter, (1955, p. 87) in a discussion of the Cuban nickeliferous laterites, has shown that magnesium and nickel concentrations increase with depth in lateritic soils over serpentinites; the maximum nickel concentration occurs in the transition zone just above the partly weathered serpentine bedrock. The magnesium concentration increases into the unweathered parent serpentinite, where the nickel concentration sharply decreases. A similar enrichment of nickel with depth has been reported elsewhere (Esguerra, 1961; de Chételat, 1947; Heidenreich and Reynolds, 1959). According to De Vletter (1955, p. 86), serpentine is broken down by the carbonic acid of meteoric waters; magnesium (as a bicarbonate) and silica are removed until sufficient carbonic acid is available to leach nickel and cobalt, which migrate as bicarbonate ions and are re-deposited where the magnesia and silica contents increase and cause a corresponding decrease in the availability of carbonic acid.

These relationships are only poorly developed in the soils of the Wanamu-Blue Mountains area, for the nickel content of the soils over serpentinite seems to remain fairly constant with increasing depth and seldom exceeds that of the parent serpentinite. However, the highest nickel values over the area do coincide with relatively high magnesium values near serpentinite bedrock.

Laterite

The spectrographic and colorimetric nickel determinations for the laterites are very close to one another. (Refer to Appendix D.) The close correspondence of the two determinations in the laterites, as opposed to the results for the serpentinite samples, indicates that the nickel in the laterites is more easily extracted by the bisulfate fusion than it is in the serpentinite.

Laterites which appear to be associated with serpentinite have a much higher nickel content (up to 3,000 ppm) than the other laterites in the area. Although the results are not conclusive, they indicate that geochemical surveys for nickel could be successfully carried out in residual laterite duricrust as well as in residual soils.

Chromium

High chromium values are associated with high nickel values in the serpentinite and in the soils, as is described below.

Serpentinite

The differences between the spectrographic and colorimetric chromium determinations in the serpentinites are very similar to those for nickel. The colorimetric chromium determinations are consistantly lower and more erratic than the spectrographic determinations. These values are tabulated in Appendix D. Because of the apparently incomplete chromium extraction from the sample in the colorimetric test, it is probable that the spectrographic determinations are closer to the true total chromium values, but additional work would be necessary to prove this point. The maximum spectrographic chromium determination was reported as greater than 5,000 ppm; that of the colorimetric determinations is 6,000 ppm. The chromium content of most of the samples is 5,000 ppm or greater, but the "true" maximum content was not established. Steuber and Goles (1967) have suggested that the average chromium content in ultramafic rocks is 2,400 ppm, so it seems that the serpentinites of the Wanamu-Blue Mountains area have a chromium content of approximately twice that of the "typical" ultramafic rock. However, the chromium content of the rocks is not unusually high in comparison to similar occurrences elsewhere.

The form in which the chromium occurs in the serpentinites is not known. Petrographic examination of the serpentinites revealed very little chromite, but did reveal abundant magnetite which, as was discussed earlier, may be chromium-bearing. Analyses of the clinochrysotile sample and its associated serpentinite reveal upon comparison that most of the chromium occurs in the serpentinite and not in the clinochrysotile; i.e., the chromium is probably concentrated not in the serpentine minerals but in the magnetite. Some chromium is probably held in the serpentine, as discussed previously in the section on nickel, but the amount must be small compared to the amount held in the magnetite. There seems to be no correspondence between the chromium and nickel contents of the serpentinite.

Soils

Anomalous chromium values (reported as greater than 3,000 ppm) occurred in conjunction with high nickel values in the pit samples obtained by Henry (1966). The results of the soil sampling program during the present thesis study confirm that the soils of the Wanamu-Blue Mountains area do have generally high chromium contents.

Comparison of Colorimetric and Spectrographic Determinations

The difference between the spectrographic and colorimetric determinations for chromium in the soils is not pronounced and the two sets of results corroborate each other very well, although it is difficult to compare the very high sample values. (Refer to Appendix B.) The maximum colorimetric values reported for the first group of samples is 15,000 ppm while the maximum spectrographic value is reported simply as greater than 5,000 ppm. The maximum colorimetric value for the second group of samples is 38,000 ppm and the maximum spectrographic value is reported as greater than 5,000 ppm.

Although the absolute chromium values of the few samples reported as "greater than 5,000 ppm" are not known, it is felt that the spectrographic chromium determinations are somewhat more reliable than the colorimetric determinations because the spectrographic determinations are more apt to represent total values than the colorimetric determinations. However, the spectrographic and colorimetric determinations are reasonably close, and both methods of analysis should be adequate for geochemical prospecting in soils under conditions similar to those of the Wanamu-Blue Mountains area.

Distribution of Chromium

The high chromium concentrations in the soils occur in the vicinity of the serpentinite bodies and generally tend to coincide with high nickel values. Because the spectrographic chromium determinations appear to be the most reliable, they have been plotted on Plate 4, which is a map of the chromium concentration in the soils of the Wanamu-Blue Mountains area. The chromium anomalies are stronger and broader than the nickel anomalies, and the average chromium content of the soils in the area is much higher than the average nickel content. Like the nickel anomalies, the chromium anomalies are "open-ended" to the southeast. The relationship of the chromium content in the soils to the underlying geology is shown on Plate 6. Although the maximum chromium values tend to coincide with the high nickel, cobalt, magnesium, and manganese values in the soils, there does not seem to be as close a correspondence between chromium and any other element as there is between nickel and magnesium or cobalt and manganese. There is a slight tendency for the iron content of the soils to increase where the chromium content increases. The coincidence of the nickel and chromium anomalies is probably caused more by their common source, the serpentinite bodies, than by any chemical affinity between the elements in the soils.

The behavior of chromium in the soil profiles examined in the sample pits is interesting, for although in some pits the concentration of chromite is rather erratic throughout the soil profile, in others there is a tendency (refer to Table 4) for the chromium concentration to decrease with depth -- which is contrary to what would be expected for a purely mechanical accumulation of detrital material.

Hotz (1964, p. 368) reports that the chromium content of the nickel-bearing lateritic soils of Oregon and California also decreases with depth and decreasing intensity of weathering. The Wanamu-Blue Mountains soils do not show any visibly pronounced changes in intensity of weathering throughout the profile, although it is very possible that the upper portions of the soil profile are more weathered than the lower portions. Thus there may be an increased concentration of resistant chromium-bearing minerals remaining in the more weathered upper parts of the soil profile, but the form in which the chromium occurs in the soils is not known. Much of the chromium may occur in detrital accumulations of very fine-grained magnetite, but some chromium is probably held by secondary oxides of iron and manganese, and it is possible that some chromium may be held by clay minerals as well. In the comparison that was made between the manganese concretions and their soil matrix in pit 4, the manganese concretions have a slightly higher chromium content than that of the soil. A few heavy mineral concentrates were obtained (by panning) from the streams draining north off the Blue Mountains into the Barama River; these concentrates were rich in magnetite and indicate that detrital accumulations of chromian magnetite could occur in low areas. Some of the relatively high concentrations of chromium in soils of low-lying areas may be largely caused by detrital accumulations of chromian magnetite; such an occurrence is indicated by the northernmost chromium peak shown on Plate 6 and Figure 9.

TABLE 4

Ni, Cr, Co, and Mn in Soils From Sample Pits

s = Spectrographic Determination
c = Colorimetric Determination

	Depth Ft.	Samp. No.	Parts Per Million				
			Ni(s)	Cr(s)	Co(c)	Cu(c)	Mn(s)
Pit No. 1	1	31	1,000	2,000	250	40	1,000
	2	23	1,000	3,000	250	30	1,000
	3	24	1,000	5,000	300	20	1,500
	4	25	1,000	3,000	300	20	1,000
	5	26	1,000	3,000	250	40	2,000
	7	27	1,500	3,000	250	40	1,500
	9	28	1,500	5,000	250	30	2,000
	11	29	1,000	3,000	160	40	1,500
	13	30	2,000	5,000	300	80	1,500
Pit No. 2	1	17	2,000	5,000	300	40	1,000
	2	18	2,000	3,000	300	20	1,000
	3	19	2,000	3,000	450	30	1,000
	4	20	2,000	5,000	500	30	1,500
	5	21	2,000	5,000	450	40	2,000
	6	22	2,000	3,000	450	40	1,500
Pit No. 3	1	32	1,500	5,000	450	30	1,500
	2	33	2,000	5,000	450	120	2,000
	3	34	2,000	5,000	450	120	1,500
	5	35	3,000	5,000	900	160	2,000
	7	36	2,000	3,000	450	120	1,000
	9	37	2,000	3,000	300	40	1,000
	11	38	2,000	2,000	300	60	1,000
Pit No. 4	1	1	50	500	30	80	500
	6	2 *	150	500	900	250	+5,000
	6	3	50	300	30	80	700
	12	4	30	100	10	20	500
Pit No. 8	2	15	2,000	5,000	250	20	1,000
	3	16	2,000	5,000	1,500	450	5,000
	4	14	2,000	+5,000	900	60	3,000
	6	13	1,500	3,000	160	40	1,000
	8	12	2,000	5,000	900	80	5,000
	10	11	2,000	5,000	250	40	1,500
	12	10	2,000	3,000	160	40	1,000
	14	9	2,000	5,000	300	20	2,000
Pit No. 9	2	6	150	1,000	30	20	500
	3	5	150	1,000	20	20	500
	6	7	150	700	20	10	300
	14	8	150	300	30	40	1,000

* #2 is mainly Mn concretions; #3 is soil matrix

Determinations by U.S.G.S. laboratories, Denver, Colorado

The high concentrations of chromium which occur in the soils of the Wanamu-Blue Mountains area are not unusual for lateritic soils over ultramafic rocks. Esguerra (1961, p. 15) has reported chromium contents of from 0.5 to 3.0 percent in the Surigao nickeliferous laterites, and De Vletter (1955, p. 87) has reported similar concentration from the Cuban nickeliferous laterites.

Although the chromium and nickel contents of the serpentinite are roughly equivalent, the chromium content of the soils is much higher than the nickel content, because nickel has been leached during weathering while the chromium content has remained essentially constant. This relationship is explained in Appendix A.

Laterite

As with nickel, the spectrographic and colorimetric chromium determinations for the laterites correspond closely, in contrast to the determinations for the serpentinites. (Refer to Appendix D.) The chromium content of the laterites varies considerably over the area, and the laterites which are associated with serpentinite have much higher chromium contents (up to 15,000 ppm) than the other laterites. High chromium values are associated with high nickel values, much as in the soil samples. It is probable that chromium determinations could be useful in geochemical surveys of residual laterite duricrust to delineate areas underlain by bedrock with a high chromium content.

Cobalt

Cobalt is closely associated with chromium and nickel in the Wanamu-Blue Mountains area, most probably because the three elements have a common source in the serpentinites.

Serpentinite

The differences between the colorimetric and spectrographic cobalt determinations are very similar to those for nickel and chromium. (Refer to Appendix D.) The spectrographic determinations for cobalt in the serpentinites are consistently higher (about two times) and less erratic than the colorimetric determinations. Again, it is likely that the bisulfate fusions used in the colorimetric analyses do not extract the total amount of cobalt in the rock samples; thus the colorimetric determinations are probably less representative of the "true" value than the spectrographic determinations.

The cobalt content of the serpentinites is very consistent over the area: the maximum cobalt content is 150 ppm and the mean value is 140 ppm. Most of the cobalt is probably held in the lattices of the serpentine minerals, as was discussed in the section on nickel. A comparison of the analyses of the clinochrysotile and its associated serpentinite indicates that most of the cobalt is held in the serpentine. The mean cobalt content of the Wanamu-Blue Mountains serpentinite, 140 ppm, is close to the average cobalt value of 110 ppm suggested by Stueber and Goles (1967) for ultramafic rocks.

Soils

The amount of cobalt in the soils greatly exceeds that in the serpentinites and the behavior of cobalt with respect to nickel and other elements in the soils, as discussed below, is most interesting.

Comparison of Analyses

The spectrographic cobalt determinations are consistently lower than the colorimetric determinations, but the two sets of results increase and decrease together, so that the relative high and low values are adequately shown by both types of determinations. (Refer to Appendix B.) The 25 soil samples from the second group of soil samples that were analyzed for nickel by atomic absorption were also analyzed for cobalt by the same method. The results of the atomic absorption determinations tend to be closer to the colorimetric determinations (especially for the higher values) than the spectrographic determinations. A comparison of the three types of cobalt determinations is given in Table 3 . The colorimetric cobalt determinations are probably closer to the "true" values than are the spectrographic determinations, but while the spectrographic determinations seem somehow less sensitive than the colorimetric determinations, they appear to adequately display the variation in the cobalt content of the soils. The high spectrographic cobalt determination is 700 ppm, and the maximum colorimetric determination is 1,500 ppm.

Distribution of Cobalt

High cobalt values are closely associated with the serpentinite bodies, and the cobalt anomalies closely follow the nickel and chromium anomalies, although the cobalt anomalies are not as strongly developed as the others. The superposition of anomalous values of these three elements seems to be an almost certain indication of the presence of a serpentinite body; this relationship is illustrated on Figure 9 and on Plate 6. A map of the cobalt concentrations (colorimetric determinations) in the soils of the Wanamu-Blue Mountains area is presented on Plate 5.

Although the average cobalt content of the serpentinites is 140 ppm, concentrations of cobalt as high as 1,500 ppm occur in the soils over the serpentinites. It is obvious that cobalt has been enriched in the soil (by an apparent factor of approximately 10 to 1) and that the enrichment has been much greater than for nickel which, as was pointed out previously, has been leached during weathering. By assuming the titanium content to remain constant during weathering, the cobalt content can be calculated to be enriched 39 percent over what it would have been had it remained constant during weathering, as is explained in Appendix A. The enrichment of cobalt with respect to nickel is borne out by a comparison of the average cobalt-to-nickel ratio in the soils, 0.442 (calculated from the first group of soil samples), and the average cobalt-to-nickel ratio in the serpentinite, which is 0.0425.

This cobalt enrichment is of considerable interest because it sheds some light on the behavior of cobalt in the supergene environment. De Vletter (1966, p. 87) has noted that cobalt tends to be concentrated higher in the profile than nickel in the Cuban ore, and he attributes this fact to the different solubilities of nickel and cobalt bicarbonates in solution (nickel bicarbonate is more soluble). Garrels and Christ (1965, p. 247-250) present additional evidence to demonstrate that small amounts of carbonate in solution cause cobalt to precipitate as cobalt carbonate much more readily than nickel carbonate. However, they state that in the absence of carbonate, the behavior of Ni^{+2} and Co^{+2} ions is very similar. Both nickel and cobalt are soluble as Ni^{+2} and Co^{+2} in acid to mildly alkaline solutions under oxidizing conditions.

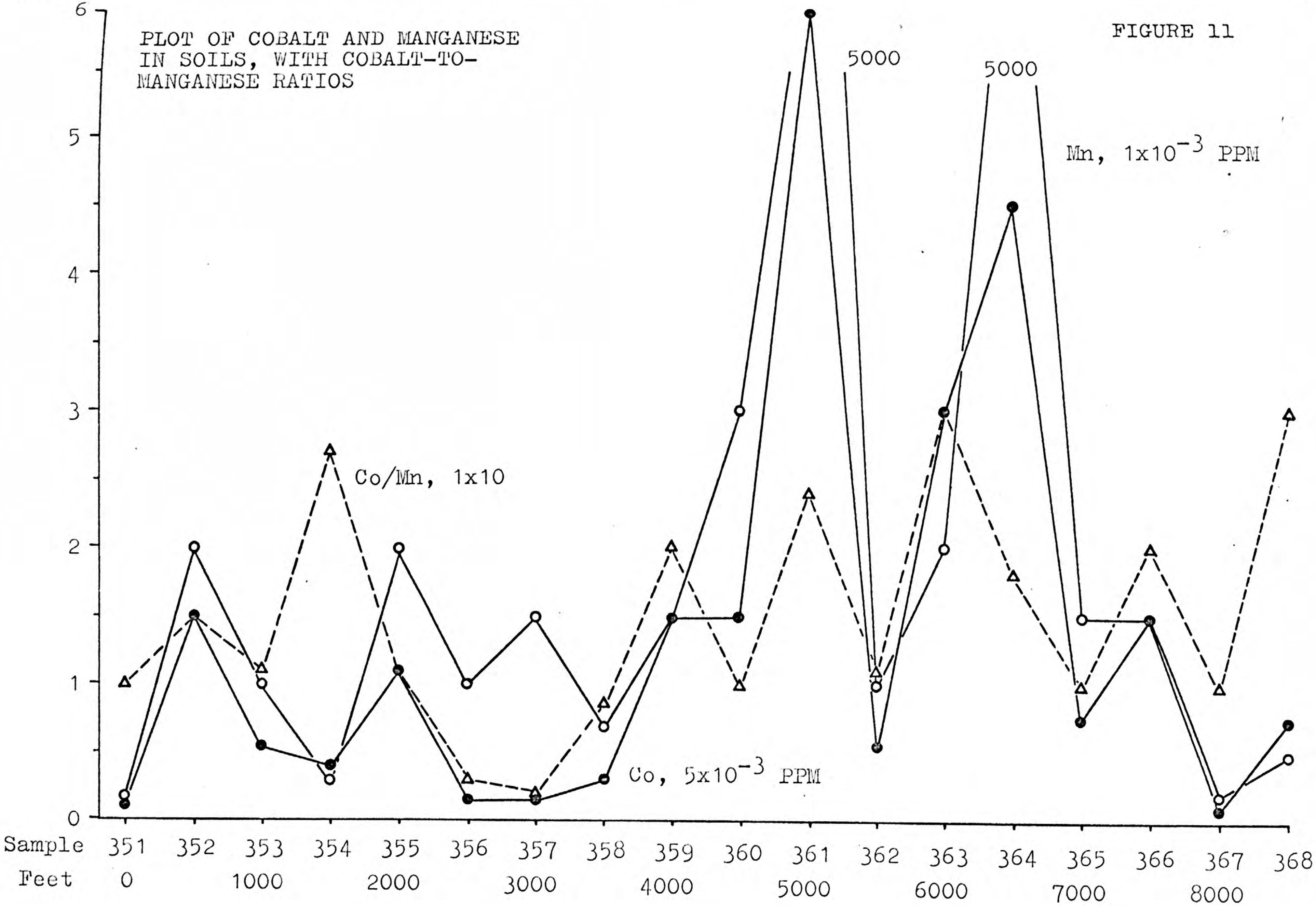
The highly leached nature of the Wanamu-Blue Mountains soils makes it unlikely that there is much carbonate available to react with either cobalt or nickel, although the calcium content of some of the anomalous samples reaches one percent and indicates that locally there may be appreciable amounts of carbonates in the soils. However, most of the enrichment of cobalt with respect to nickel must be due to some cause other than the relative insolubility of cobalt carbonate as compared to nickel carbonate. Furthermore, there is an additional complication in that Canney and Wing (1966) have presented evidence to show that cobalt tends to be mobile in an iron-rich, oxidizing environment.

In the soils of the Wanamu-Blue Mountains area, the cobalt and nickel maxima occur together over the serpentinite bodies, but away from these centers the cobalt-to-nickel ratio tends to increase, thus possibly indicating that cobalt is moving farther in solution than nickel. However, the probable explanation is that nickel is more thoroughly leached than cobalt and thus causes the higher cobalt-to-nickel ratios away from the serpentinites.

The large concentrations of manganese in the soils (in some cases greater than 5,000 ppm) probably can be used to explain the cobalt enrichment, for the nickel-cobalt anomalies coincide with the highest manganese concentrations in the soils, and even away from the main anomalies the cobalt content tends to vary with the manganese content. However, although cobalt tends to follow manganese closely, the cobalt content of the soils does not vary in direct proportion with the manganese content, because the cobalt-to-manganese ratio varies considerably (although generally within a restricted range of values, 0.1 to 0.5). The relationship of cobalt to manganese along one of the sample lines is shown on Figure 11.

The close correspondence of cobalt and manganese in the soils is well illustrated by the pit samples, where cobalt varies closely with manganese. (Refer to Table 4.) In the comparison between the manganese concretions and their soil matrix in pit 4, the concentration of cobalt in the concretions is about 25 to 30 times that of the soil. The pit

FIGURE 11


PLOT OF COBALT AND MANGANESE IN SOILS, WITH COBALT-TO-MANGANESE RATIOS
6
5
4
3
2
1
0
5000
5000
Mn, 1x10^{-3} PPM
Co/Mn, 1x10
Co, 5x10^{-3} PPM
Sample 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368
Feet 0 1000 2000 3000 4000 5000 6000 7000 8000

samples indicate that cobalt tends to be concentrated in zones of manganese accumulation, which usually are the concretionary zones in soil profiles.

The evidence indicates that cobalt moves readily in solution, but is scavenged by manganese oxides. Whether or not the cobalt is more mobile than nickel in an oxidizing, iron-rich environment is difficult to ascertain from the data because of the complicating factor of the manganese scavenging. Apparently nickel is scavenged less readily by manganese oxides than is cobalt, and it is obvious that cobalt is less mobile than nickel in a high-manganese environment, because cobalt has been enriched severalfold in the manganese-rich soils over the serpentinites, while nickel has been leached.

Thus most of the cobalt in the soils probably occurs as cobaltian wad or "absolan;" some cobalt may also occur together with nickel in secondary magnesium silicates. The occurrence of cobalt with manganese oxides has been confirmed by Pecora (1944), Fisher and Dressel (1959), and many other workers. According to Pecora (1944), there are extensive concretionary "pebble" manganese oxide deposits that are associated with the nickeliferous clays of Goiaz and contain between 1 and 2 percent cobalt. The manganese oxide "pebbles" occur within one meter of the surface in ferruginous soils. Fisher and Dressel (1959, p. 49) state that cobalt in the Cuban ores is exclusively associated with manganese oxide, although manganese may occur without cobalt.

Ammonium Citrate-Soluble Cobalt

The 90 soil samples that were collected from intermediate stations between the original sample sites were tested by the author for ammonium citrate-soluble cobalt using the Canney and Nowlan (1964) method. With this method, readily extractable cobalt is dissolved in an aqueous ammonium citrate-hydroxylamime hydrochloride solution and the filtered extract is reacted with 2-nitroso-1-napthol to form a pink-colored cobalt complex in a mixture of carbon tetrachloride and cyclohexane.

The results of this test were particularly satisfying, for the cold-extractable cobalt values consistently reflect the total cobalt values, as illustrated in Table 5 and Figure 12. The cxCo:Co ratio is approximately 1:10. Because the anomalous cobalt values coincide with the anomalous nickel values, ammonium citrate-soluble cobalt may provide an excellent pathfinder for nickel.

In an attempt to ascertain whether a cold-extractable nickel test might be feasible, the same buffer solution that was used for the cold-extractable cobalt test was reacted with the 90 soil samples that were tested for cobalt, and the citrate extract was reacted with alfa-furildioxime in the same procedure that is used in the total nickel colorimetric test (Ward and others, 1963, p. 37-38). Although a longer extraction time was used for the nickel test, the results indicate that nickel (even where the total value is around

TABLE 5

Comparison of Total Cobalt (Colorimetric) and Ammonium Citrate-Soluble Cobalt in Soils

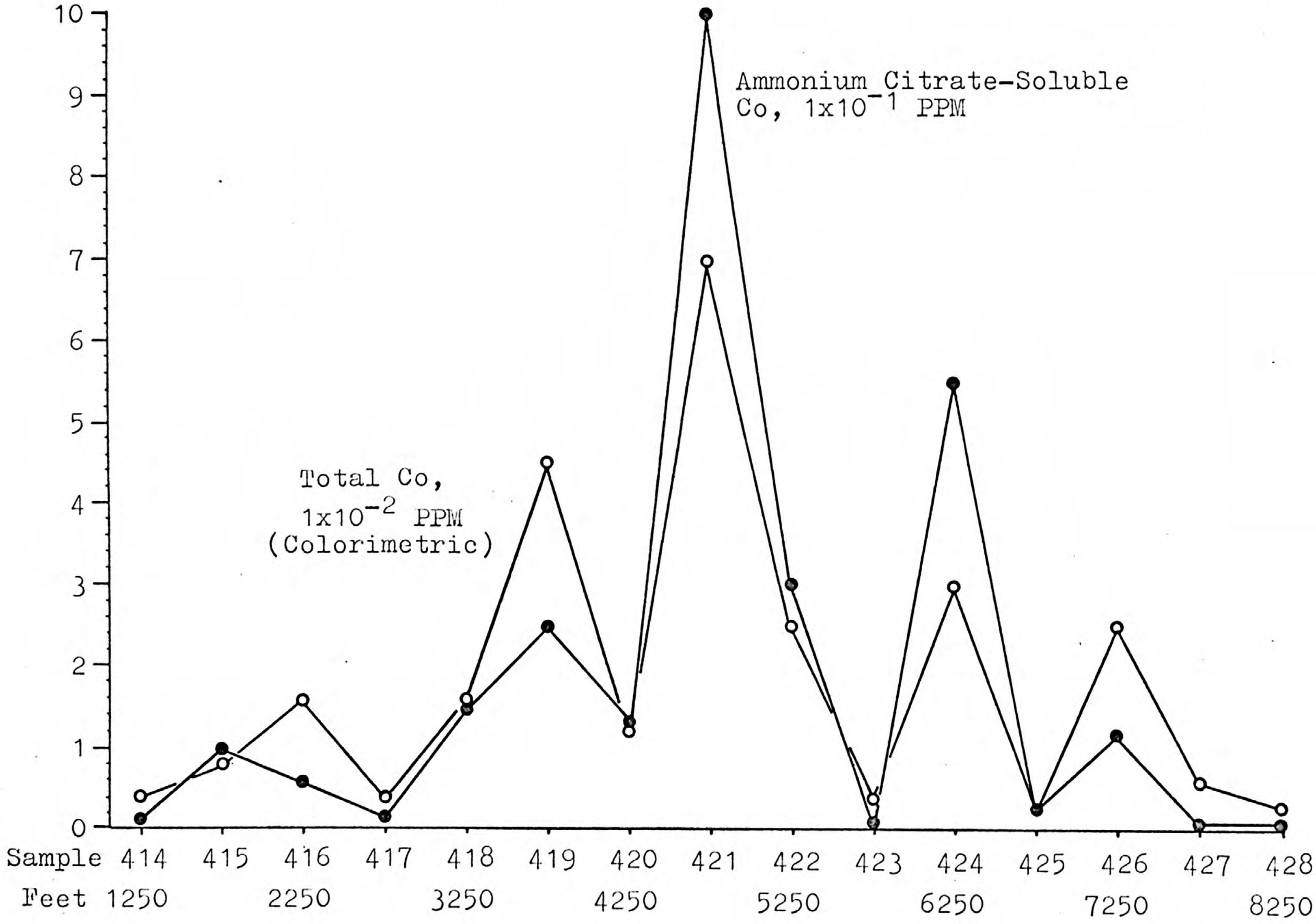
(Taken from second group of soil samples)

	PPM			PPM			PPM			PPM	
Samp. No.	Total Co	Amm.Cit.-Sol. Co	Samp. No.	Total Co	Amm.Cit.-Sol. Co	Samp. No.	Total Co	Amm.Cit.-Sol. Co	Samp. No.	Total Co	Amm.Cit.-Sol. Co
369	40	7.5	393	900	60	417	40	1.5	441	120	1
370	120	25	394	1,000	80	418	160	15	442	30	1
371	160	40	395	40	2.5	419	450	25	443	80	1
372	450	80	396	20	2.5	420	120	12.5	444	80	10
373	1,000	90	397	160	10	421	700	100	445	120	5
374	900	90	398	300	50	422	250	30	446	80	4
375	250	30	399	250	25	423	40	1	447	120	2.0
376	160	40	400	160	10	424	300	55	448	80	15
377	1,000	70	401	250	5	425	40	3	449	80	5
378	160	12.5	402	250	5	426	250	12.5	450	30	1
379	20	2.5	403	300	10	427	60	1	451	20	1
380	80	15	404	160	3.5	428	30	1	452	60	1
381	20	2.0	405	160	20	429	60	1	453	40	1
382	40	2.0	406	450	120	430	80	14.0	454	30	1
383	900	80	407	30	1.0	431	30	1	455	450	40
384	120	4.5	408	120	6	432	20	1	456	250	15
385	30	2.0	409	700	120	433	30	1	457	120	5
386	80	10	410	300	60	434	120	7.0	458	30	1.0
387	250	20	411	250	10	435	300	5			
388	60	1.0	412	160	10	436	250	30			
389	300	45	413	60	2.5	437	150	25			
390	450	90	414	40	1.0	438	300	20			
391	250	15	415	80	10	439	700	70			
392	250	50	416	160	6	440	120	1			

Total Co determinations by U.S.G.S. laboratories; ammonium citrate by author.

COMPARISON OF TOTAL COBALT (COLORIMETRIC) AND AMMONIUM CITRATE-SOLUBLE COBALT IN SOILS

FIGURE 12



1,000 ppm) is not nearly as readily available in the soils as is cobalt. However, more laboratory work would be necessary to confirm whether or not nickel is definitely more tightly held in the soils than is cobalt.

It appears that the ammonium citrate-soluble cobalt test designed by Canney and Nowlan (1964) could be very useful for geochemical prospecting in highly weathered tropical soils such as those in Guyana. However, because of the remarkable affinity of cobalt for manganese oxides, any attempts to use cobalt for a pathfinder should be used with the realization that manganese scavenging may cause spurious anomalies.

Laterites

The spectrographic and colorimetric cobalt determinations practically coincide and they corroborate each other very well. (Refer to Appendix D.) The cobalt content of the laterites generally is lower than that of the soils, although one sample has a cobalt content of 1,500 ppm. Cobalt follows manganese in the laterites as it does in the soils. The laterites that are associated with serpentinites tend to have slightly higher cobalt contents (and definitely higher manganese contents) than the other serpentinites. The one high cobalt value is associated with a high manganese content (greater than 5,000 ppm). Cobalt may not be as useful an indicator as nickel or chromium in laterite duricrust, but significant low-level cobalt anomalies conceivably could occur in residual laterite duricrusts.

Copper

Compared to the amounts of nickel, chromium, and cobalt that occur in the Wanamu-Blue Mountains area, the amount of copper that occurs there is small; however significant concentrations of copper occur in some soil samples.

Serpentinite

As with nickel, chromium, and cobalt, the colorimetric copper determinations are lower than the spectrographic determinations, but the difference between the two types of determinations is not as pronounced as with the other elements. (Refer to Appendix D.)

The copper content (spectrographic determinations) of the rocks varies considerably between 5 and 100 ppm. The mean copper content is 34 ppm, which is close to the average copper content of 20 ppm for ultramafic rocks, as reported by Vinogradov (1962). Most of the copper probably occurs in the serpentine minerals, but some may also occur in the magnetite. The comparison of the clinochrysotile and associated serpentinite samples reveals that very little copper is held in the clinochrysotile and most is held in the serpentinite. There seems to be no close correspondence between the copper content and that of any other element in the rocks.

Soils

The distribution of copper in the soils is more uniform than that of nickel, chromium, and cobalt, although the behavior of copper in the soils is similar to that of cobalt.

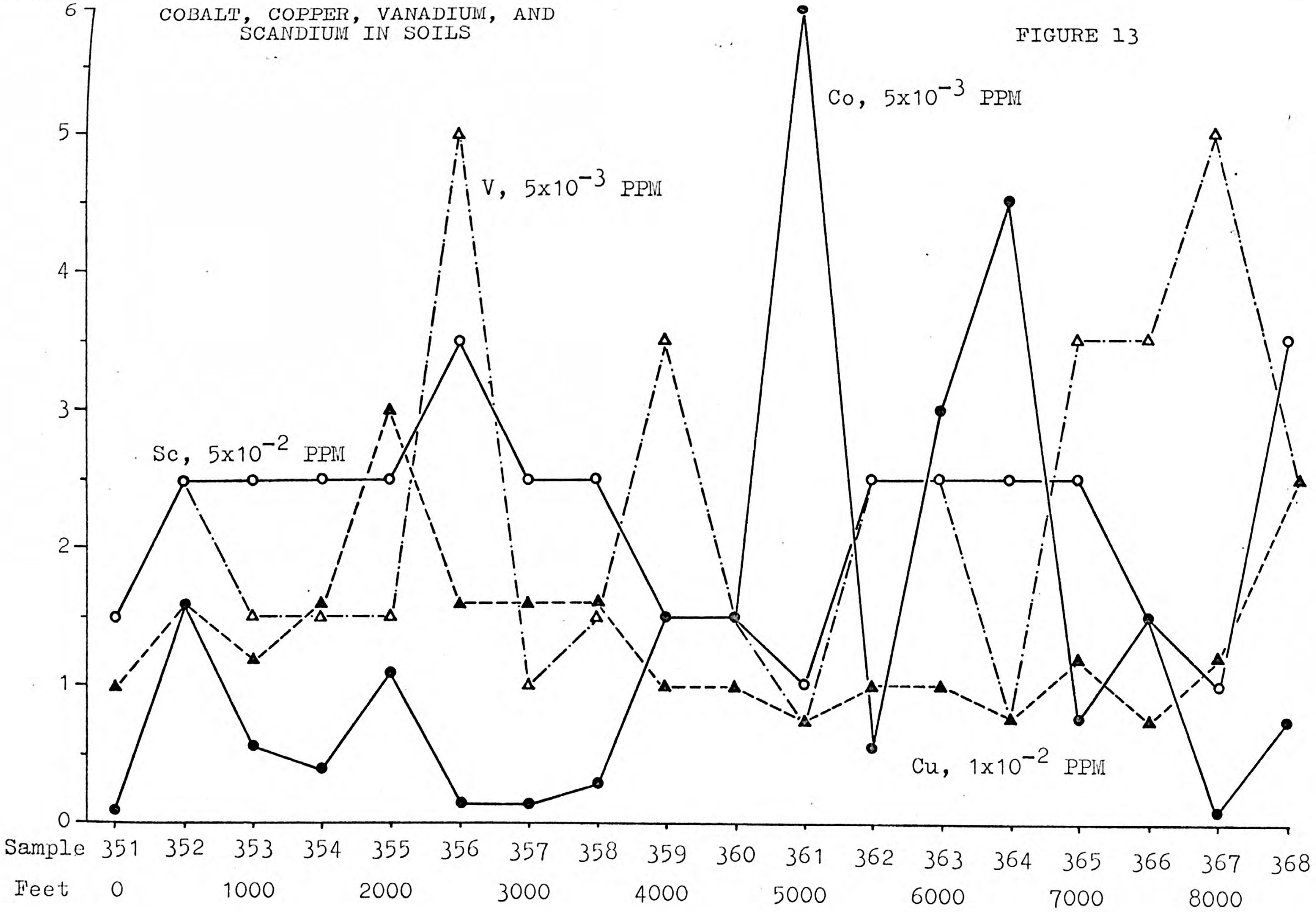
Comparison of Analyses

The spectrographic copper determinations are consistently lower and more uniform in value than the colorimetric determinations. (Refer to Appendix B.) Atomic absorption determinations for copper were made on the 25 samples that were analyzed for nickel and cobalt by the same method. The colorimetric determinations tend to be closer to the atomic absorption determinations than do the spectrographic determinations, but the colorimetric determinations are generally higher than the atomic absorption determinations. The results of the three sets of analyses are compared in Table 2. The colorimetric determinations seem to be more sensitive to low amounts of copper than do the spectrographic determinations.

Distribution of Copper

The maximum copper content (colorimetric determination) is 450 ppm, but the copper peaks do not coincide with the nickel-chromium-cobalt anomalies. In fact, the lowest copper values tend to occur with the high nickel, chromium, and cobalt values, and the highest copper values are displaced on either side of the main anomalies, as is illustrated by Figure 13. There does not seem to be a close correspondence between copper and any other element along the sample lines, although there is a slight tendency for copper to follow manganese. However, in the pit samples, the copper content tends to vary more closely with the manganese and cobalt contents. Why copper should tend to vary with manganese in

FIGURE 13


COBALT, COPPER, VANADIUM, AND SCANDIUM IN SOILS
Co, 5×10^{-3} PPM
V, 5×10^{-3} PPM
Sc, 5×10^{-2} PPM
Cu, 1×10^{-2} PPM
0
1
2
3
4
5
6
Sample 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368
Feet 0 1000 2000 3000 4000 5000 6000 7000 8000

depth but not over the area is not known, but the copper may be somewhat leached from the upper two feet of the soils. If the manganese scavenges copper as readily as it does cobalt, it would seem that copper should be concentrated over the serpentinites where the highest manganese values occur, but this is not the case.

The form in which the copper occurs is not known, but it probably is mainly held by manganese and iron oxides; some copper may also be held by clay minerals. According to Hawkes and Webb (1962, p. 364), copper in the soil phase occurs in limonite, manganese dioxide, organic matter, and clay minerals. The mobility of copper is mainly determined by pH; below a pH of 5.5, copper is very mobile, but it becomes immobile and precipitates out of solution at a neutral to alkaline pH. Because of the relatively high solubility of copper, one would expect it to be thoroughly leached from the highly weathered soils of the Wanamu-Blue Mountains area, but significant amounts of copper are concentrated in the soils. Hotz (1964, p. 375) has reported an enrichment of copper of up to 20 times that of the parent peridotite in the lateritic soils of Oregon and California. There the copper content of the soils is highest in the upper portions of the soil profile and decreases with depth, but this relationship is not apparent in the Wanamu-Blue Mountains soils.

The copper lows associated with nickel-chromium-cobalt highs over the serpentinites may represent some differential leaching of copper, but this seems unlikely. The serpentinites probably have much lower copper contents than their surrounding host rocks, and the relatively high copper values in the soils away from the serpentinites probably reflect a relatively higher copper content in the host rocks.

Laterite

The spectrographic and colorimetric copper determinations follow each other closely, although the colorimetric determinations tend to be slightly higher. (Refer to Appendix D.) The copper values in the laterites are similar to those in the soils, except for one high value of 700 ppm in a laterite with a high manganese content (greater than 5,000 ppm) that is associated with serpentinite. It appears that significant concentrations of copper can occur in laterites, but variations in the copper content of laterites may be more a result of differential manganese scavenging than variations in bedrock copper content.

Other Elements

The semiquantitative spectrographic determinations of the rocks and soils turned up significant concentrations of several other elements including manganese, iron, titanium, vanadium, magnesium, calcium, barium, zinc, scandium, and zirconium. Gold determinations were made by atomic absorption. The values of these elements in rocks are tabulated in Appendix E; values for soils are tabulated in Appendix C. Pit-sample results are presented in Table 6.

Manganese

The manganese content of the serpentinites varies from 300 to 2,000 ppm, with a mean content of 1,100 ppm, which is very close to the average manganese content of 1,000 ppm suggested for ultramafic rocks by Stueber and Goles (1967). Most of the manganese probably occurs in the serpentine minerals, as discussed previously, and as is indicated by a comparison of the clinochrysotile and its associated serpentinite. Some manganese may also occur with the magnetite. There seems to be no close correspondence between manganese and any other element in the rocks.

Significant concentrations of manganese occur in the soils and affect the behavior of several other elements, especially cobalt. The manganese content of the soils ranges from 20 ppm to greater than 5,000 ppm, but most of the samples are close to the mean content of 1,300 ppm (calculated from the first group of soil samples). As reported in the previous sections, the highest concentrations of manganese in the soils occur over the serpentinites, together with high concentrations of nickel, chromium, and cobalt. (Refer to Figures 9 and 11.) The relatively large concentration of manganese oxides in the soils over the serpentinites probably causes the characteristic dark brown color of these soils. The very high manganese contents in the soils are probably caused by the lateritic concentration of the manganese over the serpentinites, although local concentrations of manganese elsewhere in the area may have originated from some source other than the serpentinites. Pecora (1944) has reported that extensive manganese oxide deposits are intimately associated with nickel-bearing clays developed over ultramafic rocks in Goiaz, Brazil. Manganese oxides occur there as concretions in ferruginous soils, thin veinlets in near-surface clays, and as massive cappings on near-surface garnieritized weathered pyroxenite.

Manganese occurs in the Wananu-Blue Mountains area as thin black oxide coatings on outcrops and as sooty black wad in the soils. The wad is probably mainly pyrolusite (manganese dioxide), and occurs as minute particles and larger concretions up to one inch in diameter. The pit samples indicate that manganese tends to be concentrated in the concretionary zone of the soil profile, but isolated manganese concretions occur scattered throughout the profile, especially in the lower portions.

According to Krauskopf (1967, p. 262-268), the behavior of manganese in sediments is similar to that of iron. Manganese goes into solution as Mn^{+2} and does not precipitate under acidic and mildly oxidizing conditions. Under more oxidizing or alkaline conditions, manganese will be precipitated. According to Krauskopf (1967, p. 265-266), manganese oxides are often precipitated in colloidal form and migrate long distances as sols. Because these oxide sols have a negative charge, they adsorb cations (e.g., Ni^{+2}, Co^{+2}, Ba^{+2}, and Cu^{+2}) out of solution.

Why manganese should separate from iron in the supergene environment has long been a subject of study. Krauskopf (1967, p. 267-268) points out that when the pH of an iron- and manganese-bearing solution is increased slowly, iron compounds will reach their limit of solubility and precipitate prior to manganese, which is left in solution. He suggests that differential oxidation and differential solubility of iron and manganese probably cause their separation in the sedimentary environment.

The abundant discrete manganese concretions in the ferruginous soils of the Wanamu-Blue Mountains area demonstrate the separation of manganese from iron, and the close association of cobalt, copper, and nickel with manganese in the soils confirms the ability of manganese oxides to adsorb metal ions.

There is also evidence that manganese has migrated, both downward and laterally, in the soils. Manganese apparently is concentrated in soils during tropical weathering, and the propensity that manganese oxides have to adsorb and concentrate metals such as cobalt and copper should be carefully considered in evaluating the results of geochemical surveys.

The manganese content of the laterites is similar to that of the soils and varies considerably, from 50 ppm to greater than 5,000 ppm. Those laterites which are associated with serpentinite tend to have the highest manganese contents.

Iron

The iron content of the serpentinites ranges from 2 to 20 percent, with a mean value of 8 percent. Some of the iron probably occurs in the serpentine minerals, as discussed earlier, but most of it probably occurs in the magnetite. During the serpentinization of ultramafic rocks, iron is removed from olivine and magnetite is formed from that iron which cannot be incorporated in the serpentinite lattice (Chidester, 1962, p. 77).

Iron has a rather monotonous distribution in the soils of the area. The iron content ranges from 0.5 to greater than 20 percent, with most of the contents being concentrated near the mean value of 11.5 percent (calculated from the first group of soil samples). The iron content of the soils tends to be highest around the serpentinites, where the values range from 15 to 20 percent. (Refer to Figure 8.) The iron content of swampy soils is much lower than the mean value. There does not seem to be a pronounced enrichment of iron with depth in the soil profiles that were examined, for the iron content varies rather erratically between 10 and greater than 20 percent, although there is a tendency for slight enrichment at various levels in the concretionary zone.

Garrels and Christ (1965, p. 178-229) have studied the stability fields of iron compounds in relation to weathering processes. Their work shows that iron is soluble in acidic solutions under reducing conditions as the ferrous ion, Fe^{+2}.

Several different ions can cause the precipitation of iron under various conditions of Eh and pH; the most common are carbonate, sulfide, and silicate ions. The oxidation of Fe^{+2} to hematite or geothite can occur under oxidizing conditions throughout a wide pH range, although the reaction is more common under alkaline conditions. According to Krauskopf (1967, p. 260-261), ferric oxide can precipitate as a colloid and travel long distances as a sol, and he states that this is the principal means by which iron is transported in aerated surface waters.

Most of the iron in the Wanamu-Blue Mountains soils probably occurs in the oxidized ferric state, because the soil colors are reds, browns, and yellows. The precise form in which most of the iron occurs is unknown, but it probably occurs as various forms of ferric hydroxide, including goethite. Some of the iron concretions appear to be hematitic. It is probable that some iron is being leached out of the soils, which tend to be well drained, and as was mentioned earlier, there is some recementation of boulders in creeks by recently precipitated iron oxides. As is explained in Appendix A, iron has been depleted during weathering, for if it remained constant it would be concentrated to a greater degree than it presently is in the soils. In swampy areas the soils tend to be light gray in color and have low iron contents; in these areas the iron probably exists in the mobile ferrous form and is being actively leached.

TABLE 6

Spectrographic Determinations of Fe, Mg, Ti, V, Sc, Zr, and Ba in Soils From Sample Pits

	Depth Ft.	Samp. No.	Percent			Parts Per Million			
			Fe	Mg	Ti	V	Sc	Zr	Ba
Pit No. 1	1	31	15	0.1	0.5	150	30	30	30
	2	23	15	0.1	0.3	100	15	100	10
	3	24	20	0.5	0.3	200	20	50	50
	4	25	15	0.05	0.3	150	20	50	30
	5	26	20	0.07	0.3	150	30	30	50
	7	27	20	0.02	0.3	150	30	30	50
	9	28	+20	0.05	0.5	200	30	30	30
	11	29	15	0.05	0.3	150	30	30	30
	13	30	20	0.15	0.3	150	50	30	70
Pit No. 2	1	17	15	1.0	0.2	100	15	30	15
	2	18	15	1.0	0.2	100	15	30	20
	3	19	15	1.0	0.3	100	15	30	20
	4	20	20	1.0	0.2	150	15	50	20
	5	21	15	1.0	0.2	100	15	50	30
	6	22	15	0.7	0.2	70	15	50	50
Pit No. 3	1	32	15	0.7	0.3	100	20	20	20
	2	33	15	0.7	0.2	150	20	50	20
	3	34	20	1.0	0.3	150	30	30	20
	5	35	20	1.5	0.2	150	30	30	20
	7	36	15	3.0	0.2	70	15	20	10
	9	37	15	3.0	0.2	70	15	30	15
	11	38	15	2.0	0.2	50	15	20	10
Pit No. 4	1	1	7	0.1	0.5	100	30	30	10
	6	2 *	15	0.05	0.3	200	50	30	300
	6	3	15	0.02	0.5	300	30	50	10
	12	4	7	0.2	0.2	200	20	20	300
Pit No. 8	2	15	15	0.1	0.3	150	30	50	20
	3	16	20	0.07	0.2	200	30	50	20
	4	14	20	0.1	0.3	200	30	50	30
	6	13	15	0.1	0.2	100	20	30	15
	8	12	15	0.07	0.2	150	30	30	50
	10	11	20	0.1	0.2	200	30	30	20
	12	10	15	0.1	0.2	150	30	30	15
	14	9	15	0.1	0.2	100	20	20	15
Pit No. 9	2	6	10	0.1	0.3	150	20	70	50
	3	5	10	0.3	0.3	200	20	200	500
	6	7	10	0.1	0.5	200	30	100	50
	14	8	10	0.1	0.5	200	30	70	100

* #2 is mainly Mn concretions; #3 is soil matrix

Determinations by U.S.G.S. laboratories, Denver, Colorado

As would be expected, the iron content of the laterites is generally higher than that of the soils, for the iron content is either 20 percent or greater. The laterite is probably composed of both hematite and goethite, but which form is predominant is not known. According to Bleackley (1964, p. 27), goethite is "one of the main iron minerals" in the laterites of Guyana.

Titanium

The titanium content of the serpentinites varies from 0.05 percent to 0.2 percent, with a mean value of 0.09 percent (900 ppm), which is 3 times the average value of titanium (300 ppm) in ultramafic rocks given by Vinogradov (1962). The titanium probably occurs in the magnetite, although it may occur in other forms as well.

Titanium is rather uniformly distributed in the soils of the area. The titanium content of the soils ranges from 0.1 percent to greater than 1 percent, with a mean content of approximately 0.7 percent (calculated from the first group of soil samples), but most of the soil samples have titanium contents close to the mean value, and there seems to be very little correspondence between variations in the titanium content and that of any other element.

The form in which the titanium occurs in the soils is not known; some titanium may occur in detrital ilmenite derived from the epidiorite, and some titanium may occur as titanium dioxide in various forms (e.g., rutile and anatase).

Goldschmidt (1954, p. 419) and Vinogradov (1959, p. 101, 105) state that titanium is notably enriched in laterites and bauxites formed on mafic rocks, but they do not define the form in which the titanium occurs. According to Bleackley (1964, p. 31-32), ilmenite, rutile, and anatase occur in heavy mineral concentrates from the bauxites and laterites of Guyana. Rutile is especially common in the bauxites. Bleackley (1964, p. 105) states that the average laterite in Guyana has a TiO_2 content that ranges from 1 to 8 percent.

Generally titanium is concentrated to the same degree as aluminum in laterites and bauxites. It is possible that titanium, like aluminum, goes into solution during weathering, but is re-deposited as an oxide without appreciable leaching. The alumina content of rocks is generally assumed to remain constant during their weathering and transformation into soils; so the titanium content of the rocks and soils should serve to calculate the percent increase or decrease in rock constituents during weathering. These calculations are explained in Appendix A.

The titanium content of the laterites is generally less than that of the soils but ranges from 0.05 percent to greater than 1 percent.

Vanadium

The vanadium content of the serpentinites varies considerably over the area, from 15 ppm to 70 ppm, with a mean value of 40 ppm, which is the average content of vanadium for ultramafic rocks as reported by Vinogradov (1962). There does not seem to be a close correspondence between vanadium and any other element in the serpentinites. Some vanadium may be held in the lattices of the serpentine minerals, but it is likely that much of the vanadium occurs in the magnetite.

The vanadium content of the soils tends to be much greater than that of the serpentinites; however, the maximum values of vanadium (greater than 1,000 ppm) in the soils do not occur over the serpentinite bodies, but are displaced on either side of them, much like the copper peaks. This relationship is shown on Figure 13. It is probable that the vanadium peaks in the soils represent higher vanadium contents in the bedrock adjacent to the serpentinites. Even so, there appears to be a significant enrichment of vanadium in the soils -- probably severalfold over the bedrock values. Other workers have commented on the enrichment of vanadium in lateritic soils. Goldschmidt (1954, p. 492-493) has noted the tendency of vanadium to become enriched in bauxites and iron-rich sediments. Von Gaertner (1963, p. 71-74) states that vanadium is enriched more than any other element in lateritic soils. He suggests that the vanadium is held by iron oxides, because vanadium tends to be enriched in zones of iron concentration in the soil profile. This tendency also occurs in the pit samples of the Wanamu-Blue Mountains area, although the correspondence is not as clear-cut as it is for cobalt and manganese. (Refer to Table 6.) It is also possible that some vanadium could be held by clay minerals; vanadium-bearing clays are common in the ore deposits of the Colorado Plateau (Fisher, 1959).

The chemistry of vanadium is complex, for vanadium can exist in several valence states (V^{+3}, V^{+4}, or V^{+5}) in many different compounds and as many different complex ions, depending upon Eh and pH conditions (Garrels and Christ, 1965, p. 389). According to Evans (1959), vanadium is most soluble under oxidizing conditions, in the pH range from 2.2 to 6.7. Vanadium probably goes into solution readily during the initial weathering of the bedrock, but it is probably rapidly adsorbed and tightly held by clays and iron oxides.

The vanadium content of the laterites varies considerably, from 30 to 700 ppm, with an average value of 180 ppm. It is not known how the vanadium is held in the laterites, but it may occur with the iron oxides.

Magnesium

The magnesium content of most of the serpentinites is reported as greater than 10 percent, and the lowest magnesium content is 10 percent. These high magnesium values reflect the ideal chemical formula of serpentine, which is $Mg_6Si_4O_{10}(OH)_8$, although several elements may substitute for magnesium. According to Vinogradov (1962), the average content of magnesium in ultramafic rocks is 25.9 percent. Relatively low magnesium values in the serpentinite may be caused by the substitution of other elements, such as nickel, for magnesium in serpentine, and by alteration -- e.g., the replacement of the rock by carbonates.

The magnesium content of the soils is generally low, with a mean content of 0.6 percent (calculated from the first set of soil samples) and many soil samples contain less than 0.1 percent magnesium. Low magnesium contents in soils result from the leaching of magnesium through chemical weathering; as discussed earlier, the magnesium content generally tends to increase with depth in the soil profile as the intensity of weathering decreases. This tendency is not well developed in the sample pits of the Wanamu-Blue Mountains area, and probably indicates a general leaching of magnesium (and other elements) throughout the soil profile. (Refer to Table 5.) According to Pecora (1944), Hotz (1964), and other workers, magnesium may be enriched in the lower portions of the soil profile by deposition of secondary magnesium silicates in the form of clays and garnierite.

As discussed in the section on nickel, the magnesium content of the soils that have a high nickel content ranges from 1 to 7 percent, but whether this increased magnesium content is caused by a relatively high content of secondary nickel-bearing magnesium silicates in the soils or by the inclusion of finely divided, only partly weathered rock material (mainly serpentinite) is difficult to ascertain. Probably both forms of magnesium silicate occur in varying amounts, and as mentioned earlier, relatively high magnesium contents in the soils may represent the lower portions of truncated soil horizons.

As would be expected, the magnesium content of the laterites is very low -- around 0.02 percent and less.

Calcium

The calcium content of the serpentinites varies considerably over the area from less than 0.05 percent to 5.0 percent; the mean value is approximately 0.84 percent, which is close to the average value of 0.7 percent calcium for ultramafic rocks (Vinogradov, 1962). It is not known how the calcium occurs in the serpentinite, but the calcium probably occurs with carbonates that replace the serpentinite in varying amounts. A comparison of the clinochrysotile and its associated serpentinite reveals that very little calcium occurs with the clinochrysotile, which indicates that hardly any calcium is incorporated in the pure serpentine. The calcium in the serpentinites could have been introduced with the carbonates during alteration of the rocks by carbon dioxide metasomatism. Variations in the amount of calcium occurring in the serpentinites may be caused by differences in the amount of carbonates in the rocks.

The calcium content of the soils is very low (less than 0.05 percent) over most of the area, although there are a few samples that contain from 1 to 3 percent calcium. These high calcium values are usually associated with relatively high magnesium values. The form in which the calcium occurs is not known, but it may occur mainly as calcite. Calcium compounds, especially calcite, are readily attacked by carbonic acid in ground waters, so that calcium is generally leached from the soils of humid regions (Krauskopf, 1967, p. 51-54, 200). Magnesium is leached together with calcium, so local concentrations of these elements in well-drained soils of humid regions may indicate less intense local weathering and leaching. As noted previously, the soils with relatively high magnesium and calcium contents tend to be shallow and thus may represent truncated, less weathered soil horizons. However, local concentrations of these elements in the soils of the Wanamu-Blue Mountains area could also indicate relatively high concentrations of magnesium and calcium in the bedrock, rather than differences in intensity of weathering.

According to Krauskopf (1967, p. 51-54), the solubility of calcium carbonate is mainly dependent upon the pH of its environment, which in soils is largely controlled by the content of carbonic acid in the ground water. Relatively high contents of magnesium in the soils may restrict the amount of carbonic acid in solution through the formation of magnesium carbonates and bicarbonates, as suggested by De Vletter (1955, p. 86), and thus cause the precipitation of calcium carbonate.

The calcium content of the laterites is uniformly low -- less than 0.05 percent -- much like the soils.

Barium

The barium content of the serpentinites ranges from less than 10 ppm to 100 ppm; the mean barium content is 26 ppm, which is much greater than the average content of 1 ppm reported for ultramafic rocks by Vinogradov (1962). There is no close correspondence between the barium content and that of any other element in the rocks, except that some of the high barium values coincide with relatively high calcium values. Just how the barium occurs in the serpentinites is difficult to say, for the large ionic radius of barium should prevent it from substituting from magnesium (Goldschmidt, 1954, p. 252). Barium may substitute for calcium in carbonate minerals replacing serpentine.

Barium is closely associated with potassium in igneous rocks, where barium substitutes for potassium in potash feldspars (Goldschmidt, 1954, p. 253). During the processes of magmatic differentiation by fractional crystallization, barium is captured and concentrated by the potassium minerals of the later differentiates. Barium is also a common element in hypogene hydrothermal deposits, and the apparently high barium content of the Wanamu-Blue Mountains serpentinites may have been introduced by hydrothermal fluids which were active in altering the serpentinites.

The barium content of the soils varies considerably over the area and ranges from less than 20 ppm to 1,500 ppm. There is little pattern to this variation except that the higher barium values tend to occur in topographically low areas over the phyllites, although there are exceptions to this rule. Relatively high barium values coincide with relatively high zirconium values, but the converse does not hold, and there does not seem to be a close correspondence between the relative high and low values of the two elements. Some of the high barium values coincide with high manganese values, but this relationship does not always hold true, for high barium values may occur with low manganese values. Furthermore, many high manganese values coincide with low barium values.

According to Vinogradov (1959, p. 88), barium may occur in soils in silicates such as potash feldspar or hydromicas, or in carbonates, bicarbonates and sulfates. As has been noted previously, barium also may be adsorbed by manganese oxides. Pecora (1944, p. 273-274) has reported high barium contents in the manganese oxides of Goiaz, Brazil. He attributes these high barium contents to a barium-rich manganese oxide mineral, hollandite.

The form in which the barium occurs in the Wanamu-Blue Mountain soils is unknown, but because of their highly leached nature, it seems unlikely that significant amounts of relatively soluble barium carbonates or bicarbonates could exist. Barium sulfate is very insoluble and it is possible that some barium may exist in this form. However, much of the barium probably occurs with manganese oxides or with micas in the clay fraction of the soils. Some barium may also occur in finely divided detrital feldspars.

The barium content of the laterites tend to be much lower than that of the soils, except for a few high values of 500 and 1,000 ppm, which are associated with high manganese values. Barium probably occurs with manganese in the laterites.

Zinc

The maximum zinc content of the serpentinites is 200 ppm, but most of the samples contain less than that value. Most of the soil samples also contain less than 200 ppm zinc, but a few which are high in nickel, chromium, cobalt, and manganese are also high in zinc (up to 1,500 ppm). According to Hawkes and Webb (1962), zinc is a very mobile element in the supergene zone, although zinc may be adsorbed by iron oxides, manganese oxides, clays, and organic matter. Because of the high mobility of zinc and the low zinc content of the serpentinite, the occasional high zinc concentrations in the soils are difficult to explain other than by manganese scavenging. The high zinc values in the soils are invariably associated with high manganese values, so the zinc is most probably adsorbed by manganese oxides.

In general, the laterites tend to have higher zinc contents than the soils, although the highest value is only 500 ppm. The higher zinc contents in the laterites tend to be associated with the higher manganese contents, although the relationship is not as definite as it is for the soils. Some zinc is probably held by the iron oxides of the laterites, as well as by manganese oxides.

Scandium

The scandium content of the serpentinites ranges between 5 and 20 ppm, with a mean value of 14 ppm, which is very close to the average value of 15.7 ppm for ultramafic rocks as determined by Stueber and Goles (1967). According to Borisenko (1963), scandium is widely distributed in rocks of the earth's crust, but the highest scandium contents (except in certain rare earth minerals of pegmatites) occur in mafic and ultramafic rocks, because scandium is concentrated in mafic minerals, especially pyroxenes. Stueber and Goles (1967) state that the process of serpentinization probably has no effect on the content of scandium (and several other elements including nickel) in ultramafic rocks. Because of the close affinity of scandium for pyroxenes where, according to Borisenko (1963, p. 48-50), Sc^{+3} substitutes for Fe^{+2} and Mg^{+2}, the scandium content of serpentinite may be used as a clue to the composition of the original ultramafic rock. According to Borisenko (1963, p. 11), dunites contain an order of magnitude less scandium than pyroxenites and much less scandium than peridotites. Thus a relatively low scandium content in the serpentinite would indicate that it was derived from a dunite, while a moderately high content would indicate that the original rock was a peridotite, as is the case for the Wanamu-Blue Mountains serpentinites. Variations in the scandium content between different serpentinite samples probably indicate differences in the relative proportions of olivine and pyroxene in the original rock.

The scandium contents of the soils tend to be considerably higher than that of the serpentinites and ranges from less than 5 ppm to greater than 100 ppm, with a mean content of approximately 50 ppm. Interestingly enough, the maximum scandium contents in the soils do not overlie the serpentinites, but are displaced on either side of them, much like the vanadium and copper peaks. In fact, the scandium content tends to vary with the vanadium content and the maximum vanadium values tend to coincide with the maximum scandium values. The relationship is shown in Figure 13. It is difficult to explain why the scandium peaks should be displaced away from the serpentinites, for although it is possible that the surrounding host rocks contain more scandium, it seems probable that the ultramafic rocks contain the highest scandium contents of the rocks in the area. Both vanadium and scandium may be preferentially adsorbed by certain clays and by oxides of iron and aluminum.

According to Borisenko (1963, p. 68-69), during processes of weathering and sedimentation, scandium migrates as Sc^{+3} in acid solutions, but in neutral to alkaline solutions scandium precipitates as scandium hydroxide. However, he notes that scandium may migrate as fluoride or carbonate complexes in neutral and alkaline solutions. When mafic minerals are broken down by weathering, scandium is freed; however, it is re-deposited and concentrated in clays, bauxites, and lateritic soils (Borisenko, 1963, p. 68-69). As is explained in Appendix A, the scandium content of the rocks and soils probably remains constant during the weathering process.

Scandium shows no consistent variation with depth in the pit samples, nor does it appear to vary closely with any other element. Hotz (1964, p. 375) reports that the scandium content of the lateritic soils of California and Oregon is highest near the surface and decreases steadily with depth, but this tendency was not observed in the Wanamu-Blue Mountains soils. (Refer to Table 6.)

The scandium content of the laterites is generally lower than that of the soils. The mean scandium content of the laterites is 26 ppm, and there is no close correspondence between the vanadium and scandium contents of the laterites.

Zirconium

The zirconium content of the serpentinites ranges from less than 10 ppm to 30 ppm; the mean zirconium content is approximately 10 ppm, which is about one-third of the average content of 30 ppm reported for ultramafic rocks by Vinogradov (1962). Although the chemical characteristics of zirconium and scandium are somewhat similar, the lowest contents of zirconium in the earth's crust occur in ultramafic rocks, and the zirconium content of igneous rocks increases as the rocks become more felsic -- quite the contrary to the behavior of scandium (Vinogradov, 1962).

The content of zirconium in the soils varies from 20 ppm to 1,000 ppm over the area, although most of the values are below 150 ppm. There seems to be no definite pattern to the distribution of zirconium in the soils, although the soils of the low-lying areas near the Barama River generally tend to have relatively high zirconium contents. It is difficult to say how the zirconium occurs in the soils. Goldschmidt (1954, p. 426) reports that secondary concentrations of nearly pure zirconium dioxide occur with some processes of soil formation over nepheline syenites in the tropics. It is possible that lesser amounts of zirconium may be concentrated by lateritic processes in the Wanamu-Blue Mountains area, but much of the zirconium in the low-lying areas may occur as very finely divided zircon which has been derived from the Younger Granite Intrusives of the region. According to Cannon and Carter (1960, p. 8), the Aranka-Wanamu Granite has zircon as an accessory mineral.

The zirconium content of the laterites is generally less than that of the soils and ranges from 10 ppm to 150 ppm. The form in which the zirconium is held is not known, but it may occur as zircon.

Gold

The gold content of all the serpentinite samples is below the limit of detection of the atomic absorption method, 0.02 ppm.

A few soil samples contain 0.02 to 0.06 ppm gold, and one contains 0.3 ppm but the rest contain less than 0.02 ppm. Measureable quantities of gold also occur in some of the laterites associated with serpentinite; 0.1 ppm is the highest value reported. It is apparent that the amount of gold in the area must be negligible.

Summary of Geochemical Investigations

High nickel, chromium, cobalt, and manganese values occur in the soils over the serpentinite bodies. The chromium anomalies are the strongest and broadest in the area, and it appears that the chromium content of the rocks has remained constant during weathering. The nickel anomalies are stronger than the cobalt anomalies, but nickel has been severely depleted during weathering while cobalt has been enriched. The enrichment of cobalt is caused by the scavenging action of manganese oxides, and the cobalt content of the soils closely follows the manganese content. Ammonium citrate-soluble cobalt closely reflects the total cobalt content.

The copper content of the soils is much lower than that of nickel, chromium and cobalt. The copper content of the soils tends to follow the manganese content, but the maximum copper values in the soils are displaced away from the serpentinite bodies and probably represent higher bedrock copper contents in the surrounding rocks than in the serpentinites.

A comparison of spectrographic and colorimetric determinations for nickel, cobalt, and copper in the serpentinites reveals that the spectrographic determinations extract more metal than does the bisulfate fusion used in the colorimetric analyses. Similar results were obtained from the colorimetric and spectrographic chromium determinations. A comparison of spectrographic and colorimetric determinations for the same elements in soils reveals that the colorimetric nickel determinations are too high and the spectrographic nickel determinations are probably more reliable. The colorimetric and spectrographic determinations for chromium agree fairly well, while the colorimetric cobalt and copper determinations are higher than the spectrographic determinations for cobalt and copper. The colorimetric cobalt and copper determinations are probably closer to the true values than are the spectrographic determinations.

The iron and titanium contents of the soils are fairly uniform over the area. The titanium content of the rocks has probably remained constant during weathering, but the iron content, while apparently high, has been depleted during weathering. Vanadium has been significantly enriched in the soils, probably more so than any other element.

The magnesium and calcium content of the soils are generally low, thus indicating well-leached profiles, but relatively high magnesium and calcium values occur with the high nickel and cobalt values. Relatively high magnesium and calcium values in the soils may indicate truncated soil horizons. Apparently high barium contents occur in the serpentinites and in some of the soils. The barium in the serpentinites may have been introduced by hydrothermal fluids which were active in altering the rocks. The barium in the soils has an erratic distribution, although some barium may occur with manganese oxides.

The scandium content of the serpentinites indicates that these rocks were originally peridotites. Significant concentrations of scandium occur in the soils, but the maximum scandium values are displaced away from the serpentinite bodies. High zirconium values occur in the soils, although there is no definite pattern to the distribution of zirconium in the soils.

The gold content of the serpentinites, laterites, and soils is negligible.

MAGNETICS

A Jalander magnetomer survey was conducted over all the traverse lines. (The Jalander magnetometer measures the vertical intensity of the earth's magnetic field.) In areas of great variation in readings between stations, a 100-foot sample interval was used, and in other areas a 200-foot sample interval was used. No attempt has been made to refine the raw field data which was obtained. Th~~i~~ese data ha~~s~~ve been plotted on a map of the area (Plate 7), and even though the recorded values are rather erratic, they indicate that strong magnetic anomalies are associated with some of the serpentinite bodies.

The magnetic anomalies consist of narrow, elongate "lows" and "highs" paralleling the serpentinite bodies. The "lows" consist of negative values which generally occur north of the positive "highs." The vertical magnetic intensity in the vicinity of the serpentinite varies from a negative 6,000 gammas to a positive 9,000 gammas. In profile the anomalies run from a low north of the serpentinite outcrop through a sharp upswing to high positive values over the serpentinite. The rather erratic nature of the magnetic curves may be partly due to the effect of large boulders along the line of traverse.

The anomalies are largely confined to the southeast part of the area, and in other parts of the area where the serpentinite bodies occur, they have little or no magnetic expression.

Most of the area, especially that over the epidiorite, displays very little contrast in magnetic intensity. The readings in the western part of the area vary monotonously in the range between 0 and a positive 500 gammas, which is very different from the sharp contrast in large negative and positive values associated with the serpentinites in the southeast part of the area. The reason for the inequal magnetic expressions of the serpentinite bodies is not clear, but the differences in magnetic expression may be caused by different contents of magnetite in the serpentinites. The strongest magnetic anomalies tend to coincide with the strongest geochemical anomalies, and the magnetic anomalies are "open-ended" to the southeast, as are the geochemical anomalies.

CONCLUSIONS

The Blue Mountains probably represent a laterite-protected area that developed over mafic rocks and became prominent through an inversion of relief. Further erosion has destroyed most of the former laterite cap so that there is little laterite duricrust left in the area except as remnant boulders.

The geology of the Wanamu-Blue Mountains area is complex. A series of Precambrian mafic and ultramafic intrusives, now metamorphosed, is emplaced in the metasedimentary rocks (phyllites and quartzites) of the Cuyuni Formation. The mafic and ultramafic rocks probably represent an ancient alpine-type peridotite-gabbro complex (see Thayer, 1960). The trend of the mafic rocks tends to follow the general west-northwest strike of the older metasediments. The metamorphic rocks are intruded by north-northeast-trending diabase dikes which probably belong to the Younger Basic Intrusives. The metamorphic rocks form an arcuate rim or "mantle" around a large Precambrian granite batholith to the south, the Aranka-Wanamu Granite, which was not mapped.

The ultramafic rocks are now serpentinites and originally were peridotites. They occur in a swarm of narrow, subparallel, dike-like bodies which are mainly concentrated in the south-eastern part of the map area and extend to the southeast for an unknown distance. The serpentinites are highly sheared and have a distinctive appearance both in outcrop and hand specimen. They contain abundant magnetite, but very little sulfides.

Minor amounts of chromite occur in the serpentinite, and while it is possible that significant segregations of chromite may occur in the ultramafic bodies, the general lack of chromite in the area is discouraging. The scarcity of sulfides in the rocks is also discouraging, but it is possible that sulfide segregations could occur within the mafic and ultramafic rocks of the area or its extensions. Extensive metasomatic contact reaction zones occur around many of the serpentinite bodies; these reaction zones are probably the result of carbon dioxide metasomatism induced by volatiles from the Aranka-Wanamu Granite.

Large, barren quartz veins occur in most of the rocks of the area. These veins may have been emplaced during the late hydrothermal stages of the cooling Aranka-Wanamu Granite.

The structure of the area, while poorly exposed, appears to be complex. Evidence points to more than one episode of faulting in the area.

Because alpine-type mafic and ultramafic intrusives often form extensive belts, the mafic "mantle" around the Aranka-Wanamu Granite should be investigated to determine the extent of the ultramafic rocks. These rocks and their associated mafic intrusives have definite economic potential, both as potential hosts for sulfide deposits and for residual lateritic nickel deposits.

Most of the Wanamu-Blue Mountains area is well-drained and is covered by residual soils of varying depth. Soils in the vicinity of the serpentinites tend to be shallow, and erosion may have removed considerable thicknesses of overlying soil. Soil colors vary with the parent bedrock, from light yellow-brown over amphibolite, through red-brown over epidiorite, to dark-brown over serpentinite. In general the soil profile may be divided into three major horizons: an upper leached zone; a concretionary zone of sesquioxide accumulation; and a lower zone of more clayey, mottled soil.

The serpentinites contain nickel, chromium, cobalt, copper, and manganese in amounts similar to the average amounts reported for ultramafic rocks on a world-wide basis. Nickel, cobalt, and manganese probably occur mainly in the serpentine lattice, while chromium probably occurs in chromian magnetite. Iron probably occurs in serpentine minerals as well as in magnetite. The scandium content (as well as relict textures) of the serpentinites indicates that they originally were peridotites. There is an apparently abnormal amount of barium in the serpentinites and it may have been introduced by hydrothermal fluids which altered the serpentinites.

While the highest nickel contents in the soils occur over the serpentinite bodies, the amount of nickel in the soils seldom exceeds that in the serpentinites. The maximum nickel content in the soils is 5,000 ppm, and it is unlikely that economic concentrations of lateritic nickel occur in the area that was sampled. The nickel anomalies are most probably related to the relatively high nickel content of the serpentinites and not to sulfide mineralization. The maximum cobalt contents in the soil coincide with the maximum nickel contents but the cobalt has been considerably enriched during weathering, in contrast to the nickel, which has been severely depleted. The enrichment of cobalt in the soils is caused by manganese oxide scavenging, because the highest manganese contents in the soils coincide with the maximum cobalt contnets, and the cobalt content of the soils tends to vary with the manganese content. Cobalt apparently is much less mobile than nickel in a manganese-rich environment. Ammonium citrate-soluble cobalt in soils closely reflects the total cobalt content and may provide a good field test where cobalt can be used as a pathfinder element for nickel.

The maximum chromium contents in the soil are greater than the maximum nickel and cobalt values, although high chromium values generally coincide with the high nickel and cobalt values. However, the chromium content of the serpentinite seems to remain constant during weathering, so the high chromium values are probably the result of a residual concentration of resistant chromium-bearing minerals.

Significant concentrations of copper (although low in comparison to nickel and cobalt) occur in the soils of the area. Copper tends to be leached from the uppermost soil horizons, but the copper content tends to follow the manganese content in samples taken deeper than two feet from the surface. Copper maxima in the soils are displaced away from the serpentinite bodies and probably reflect higher bedrock copper contents than in the serpentinites.

The soils have generally high iron contents (up to 20 percent), but much iron has been lost during the weathering process. Iron oxides, as well as manganese oxides, may hold nickel and several other elements, but manganese oxides (while occurring in considerably lesser amounts than iron oxides) are probably much more effective in scavenging metals, especially cobalt, than are iron oxides. As a consequence, the evaluation of geochemical surveys under conditions similar to those of the Wanamu-Blue Mountains area should take into account the manganese content of the soils.

Vanadium is enriched in lateritic soils during weathering, more so than any other element, and it probably occurs in iron oxides and clays. Thus, seemingly anomalous concentrations of vanadium in soils may develop over rocks bearing only background amounts of vanadium.

Laterites may contain anomalous amounts of nickel, chromium, and cobalt, and it is possible that residual laterites could be sampled in geochemical surveys much as soils are.

Comparisons of semiquantitative spectrographic and colorimetric determinations for nickel reveal that the spectrographic nickel determinations are too high. Thus the maximum value of nickel in the soil is closer to 5,000 ppm (0.5 percent) than

10,000 ppm (1 percent). Spectrographic and colorimetric chromium determinations tend to corroborate one another. The spectrographic cobalt and copper determinations are generally lower than the colorimetric cobalt and copper determinations, although the spectrographic cobalt determinations seem to be more sensitive than the spectrographic copper determinations. The colorimetric determinations are probably closer to the "true" values.

The serpentinites have a definite magnetic expression which makes them easy to distinguish from their host rocks. As a consequence, magnetic surveys may be very useful in prospecting for mineral deposits associated with serpentinite. Surveys made with portable instruments such as the Jalander magnetometer are very rapid and should be effective in ground surveys.

APPENDIX A

Calculation of Gains and Losses of Rock Constituents During Weathering.

In his textbook, Introduction to Geochemistry, Krauskopf (1967, p. 100-104) lucidly explains how gains and losses in rock constituents during weathering may be calculated from analyses of soil and parent bedrock. In these analyses the various constituents are conventionally given as oxides; e.g., silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3), etc. The analyses are given as weight percents of the total sample and these are recalculated to 100 percent by distributing the analytical error. The assumption is made that the Al_2O_3 content remains constant during weathering, and with this fact it is possible to calculate a concentration factor against which the other constituents may be checked to ascertain whether they have been enriched or depleted during weathering processes. This gain or loss is expressed as a percentage gain or loss in comparison to the content of the constituent in the rock.

No analyses for Al_2O_3 were made for the soils and rocks from the Wanamu-Blue Mountains area, so the above procedure cannot be used. In addition, the analyses are not complete or precise enough to permit a recalculation to 100 percent by distributing the analytical error. Determinations were not made for Al_2O_3 or SiO_2, and many determinations that were made are often reported only as greater than a certain limiting value.

Despite these objections, some idea of the "true" enrichment or depletion of rock constituents during weathering may be obtained by comparing the contents of titanium or chromium in the rock with their contents in the overlying soil in a procedure similar to that outlined above. Some workers, including Esguerra (1961, p. 4-7), have assumed the chromium content to remain constant during weathering and have used Cr_2O_3 instead of Al_2O_3 to calculate gains and losses during weathering. As was discussed in the section on titanium, the titanium content varies directly with the aluminum content during weathering, so the content of titanium can be assumed to remain constant during weathering and can also be used to calculate gains and losses.

As both chromium and titanium analyses were made on the serpentinites and soils from the Wanamu-Blue Mountains area, this data can be used to make a rough approximation of the gains and losses of other constituents during weathering. If one compares the mean titanium content of the serpentinites with the mean titanium value of the soils (which seems to be a fair representation of the titanium content over the serpentinites), a concentration ratio of 0.09/0.7 or 0.129 is obtained. Expressed another way (assuming that the titanium content remains constant during weathering), 100 grams of the original rock will be reduced to 12.9 grams during weathering. The same calculation can be made for chromium, by using a chromium content of 5,000 ppm for the serpentinite and the maximum chromium content of the soils, 38,000 ppm. The concentration ratio then becomes 5,000/38,000 or 0.132, which is remarkably close to the concentration ratio calculated for titanium. The figures used in these calculations are admittedly rough, especially for chromium, but the close agreement of the two concentration ratios indicates that both chromium and titanium are concentrated to the same degree during weathering. The titanium figure is probably more reliable than the chromium figure because the maximum value of chromium in the serpentinites is not known.

The approximate gains and losses of nickel, chromium, cobalt, and iron during weathering can be calculated by assuming that the titanium content remains constant; these calculations are outlined below in Table 7. Other elements have not been treated here, because their maximum values in the soils or rock is not known.

TABLE 7

Calculation of Gains and Losses During Weathering

Element	A Content of Serpentinite	B Content of Soil	C B x 0.129	D A - C	E % Change D/A
Ti	0.09 %	0.7 %	0.09	0	0
Cr	0.500 %	3.80 %	0.490	-0.010	- 2
Ni	0.330 %	0.300 %	0.0387	-0.2913	-88
Co	0.014 %	0.150 %	0.0194	+0.0054	+39
Fe	8.0 %	20.0 %	2.6	-5.4	-68
Sc	0.0014 %	0.01+?%	0.0013	-0.0001	- 8

It is apparent that nickel has been severely depleted during weathering, by a factor of 88 percent, while cobalt has been enriched by a factor of 39 percent. Chromium has apparently been depleted by a factor of 2 percent, but considering the crude nature of these calculations, such a small number probably indicates no real loss of chromium. Such is probably the case for scandium also, for the true maximum value in the soils is not known (reported as greater than 100 ppm) and the small calculated loss probably indicates that the scandium content also remains essentially constant during weathering. Iron is obviously depleted during the weathering process.

These figures are admittedly crude; however, they give some idea of the actual degree of enrichment or depletion of several important elements during weathering.

APPENDIX B

Spectrographic and Colorimetric Determinations for Nickel, Chromium, Cobalt, and Copper in Soils[1]

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
1*	50	300	500	800	20	30	50	80
2*	150	600	500	1,500	500	900	100	250
3*	50	400	300	600	20	30	70	80
4*	30	300	100	200	5	10	50	20
5*	150	600	1,000	1,200	10	20	30	20
6*	150	1,500	1,000	1,500	15	30	30	20
7*	150	400	700	600	10	20	50	10
8*	150	600	300	300	20	30	50	40
9*	2,000	9,000	5,000	6,000	150	300	30	20
10*	2,000	6,000	3,000	6,000	70	160	30	40
11*	2,000	6,000	5,000	9,000	100	250	50	40
12*	2,000	9,000	5,000	10,000	500	900	70	80
13*	1,500	6,000	3,000	12,000	70	160	30	40
14*	2,000	4,500	+5,000	15,000	700	900	70	60
15*	2,000	4,500	5,000	12,000	150	250	30	20
16*	2,000	6,000	5,000	8,000	1,000	1,500	100	450
17*	2,000	6,000	5,000	8,000	100	300	50	40
18*	2,000	6,000	3,000	6,000	100	300	50	20
19*	2,000	9,000	3,000	6,000	100	450	30	30
20*	2,000	9,000	5,000	6,000	200	500	50	30
21*	2,000	6,000	5,000	15,000	200	450	50	40
22*	2,000	9,000	3,000	8,000	100	450	30	40
23*	1,000	4,500	3,000	6,000	70	250	30	30
24*	1,000	4,500	5,000	6,000	150	300	30	20
25*	1,000	3,000	3,000	6,000	100	300	20	20
26*	1,000	3,000	3,000	12,000	100	250	50	40
27*	1,500	4,500	3,000	8,000	100	250	50	40
28*	1,500	6,000	5,000	12,000	150	250	50	30
29*	1,000	6,000	3,000	12,000	100	160	30	40
30*	2,000	9,000	5,000	12,000	200	300	70	80
31*	1,000	4,500	2,000	12,000	100	250	30	40
32*	1,500	6,000	5,000	15,000	200	450	30	30

[1] Note: Asterisk (*) indicates second group of soil-sample analyses; other sample numbers are from first group. "Less than" indicated by (-); "greater than" indicated by (+).

Sample locations plotted on Plate 1.

Analyses by U.S.G.S. laboratories, Denver, Colorado

Sample Number	Parts Per Million Nickel Spec	Nickel Color	Chromium Spec	Chromium Color	Cobalt Spec	Cobalt Color	Copper Spec	Copper Color
33*	2,000	6,000	5,000	15,000	200	450	30	120
34*	2,000	9,000	5,000	12,000	200	450	50	120
35*	3,000	6,000	5,000	12,000	500	900	70	160
36*	2,000	6,000	3,000	12,000	100	450	20	120
37*	2,000	6,000	3,000	6,000	100	300	20	40
38*	2,000	9,000	2,000	12,000	100	300	20	60
39	1,500	1,500	3,000	2,250	700	300	70	30
40	150	150	300	300	20	20	150	100
41	10	25	30	200	5	- 10	50	40
42	150	200	200	300	30	30	100	150
43	100	100	70	200	20	20	150	125
44	150	300	300	800	20	40	100	125
45	100	100	100	600	20	40	70	75
46	300	400	1,000	800	20	10	70	75
47	300	400	1,000	600	70	80	70	100
48	50	100	300	300	100	80	70	75
49	30	100	70	400	20	30	100	75
50	300	400	1,500	1,150	200	250	100	75
51	30	100	50	300	30	40	100	75
52	30	100	150	200	5	10	100	75
53	200	300	500	800	30	30	70	75
54	300	300	1,500	1,150	150	80	70	75
55	70	100	70	1,500	20	30	100	100
56	500	600	2,000	2,250	70	30	70	75
57	70	100	150	100	30	30	100	75
58	50	100	100	400	700	400	70	100
59	50	100	50	300	50	60	150	150
60	200	200	300	400	30	60	100	150
61	100	150	300	200	50	60	150	75
62	30	150	100	800	5	30	100	75
63	100	200	500	300	100	80	150	75
64	70	150	100	400	7	10	100	30
65	150	150	700	800	100	100	100	40
66	30	150	100	400	20	40	150	40
67	30	150	150	300	30	20	150	30
68	20	100	150	600	150	120	150	40
69	700	1,500	+5,000	6,000	700	1,200	100	20
70	200	300	700	1,500	10	10	150	40
71	300	300	2,000	800	300	450	200	10
72	300	300	1,000	1,150	700	1,500	150	40
73	150	300	300	200	20	30	150	40
74	200	400	300	300	500	700	150	75
76	100	150	200	200	30	40	150	100
77	150	200	300	300	20	40	150	100
78	100	150	70	600	10	10	150	100
79	100	100	150	100	30	40	150	100
80	200	300	300	400	50	100	200	75
81	150	200	200	200	7	10	150	20

Sample Number	Parts Per Million Nickel Spec	Nickel Color	Chromium Spec	Chromium Color	Cobalt Spec	Cobalt Color	Copper Spec	Copper Color
82	50	100	50	600	10	40	150	40
83	50	100	70	200	10	60	150	40
84	70	100	70	100	20	40	150	40
85	700	750	2,000	1,200	150	300	100	20
86	300	400	1,500	600	50	60	100	40
87	200	400	1,000	800	150	220	100	40
88	300	400	2,000	600	70	40	100	20
89	100	300	500	300	20	30	100	50
90	150	300	300	400	10	20	150	75
91	200	400	700	800	200	300	150	100
92	200	200	1,000	600	100	60	100	50
93	100	100	150	300	70	220	70	50
94	50	100	70	100	10	10	150	75
95	150	100	700	400	15	60	150	150
96	100	100	150	200	20	30	100	75
97	30	50	70	- 100	30	60	100	40
98	50	50	300	200	30	60	100	75
99	20	25	50	400	30	30	100	75
100	50	100	200	100	20	30	100	50
101	70	100	300	300	15	60	70	40
102	200	200	1,000	600	150	100	150	75
103	150	100	700	600	10	20	100	75
104	20	50	70	600	5	10	100	75
105	300	200	1,000	400	200	300	150	75
106	300	200	300	200	20	80	150	75
107	300	300	1,000	800	30	80	150	75
108	500	750	1,000	800	150	500	150	150
109	200	200	200	300	100	220	150	75
110	100	100	1,500	1,500	5	20	100	40
111	100	100	150	600	70	60	150	75
112	150	300	700	800	10	30	100	75
113	50	50	70	- 100	15	30	150	75
114	150	100	100	- 100	5	20	100	40
115	70	100	300	400	30	100	150	150
116	20	25	10	- 100	100	150	100	20
117	100	100	200	200	30	40	200	10
118	200	150	1,500	400	150	220	70	40
119	70	100	150	300	10	40	100	75
120	100	100	100	100	10	20	100	75
121	200	300	1,000	800	30	40	150	75
122	100	200	150	100	10	10	150	100
123	150	200	200	600	15	30	100	75
124	200	200	1,000	600	100	110	150	40
125	200	150	1,500	600	20	30	200	40
126	150	150	300	200	100	110	100	40
127	150	200	500	200	20	30	100	20
128	50	100	200	200	- 5	10	100	20
129	150	200	500	200	30	60	100	40

Sample Number	Nickel Spec	Nickel Color	Chromium Spec	Chromium Color	Cobalt Spec	Cobalt Color	Copper Spec	Copper Color
	Parts Per Million							
130	200	300	2,000	1,500	5	- 10	100	10
131	150	300	150	- 100	30	100	300	100
132	100	100	150	200	10	20	100	20
133	70	100	150	- 100	5	20	100	20
134	100	150	200	100	10	30	100	20
135	100	150	200	- 100	5	20	150	40
136	200	300	1,000	300	15	30	100	30
137	150	200	700	100	50	80	100	30
138	300	500	1,000	800	30	60	100	30
139	100	200	150	100	5	20	150	50
140	100	100	150	100	15	30	100	50
141	200	200	2,000	600	20	30	100	50
142	200	200	1,500	600	30	60	150	100
143	50	100	300	200	7	30	100	40
144	20	50	150	- 100	10	30	100	40
145	200	400	1,000	600	100	150	100	75
146	100	100	300	100	30	80	100	75
147	20	100	70	- 100	5	20	100	75
148	15	25	300	200	- 5	10	70	100
149	50	100	100	200	- 5	- 10	150	75
150	200	200	300	400	15	20	150	75
151	30	100	200	100	5	20	100	75
152	200	200	300	200	10	30	100	75
153	150	200	300	400	10	30	100	75
154	700	2,000	2,000	1,500	150	150	100	75
155	300	500	2,000	1,500	30	60	100	100
156	200	150	700	600	300	200	100	75
157	200	200	300	300	20	30	100	75
158	150	150	300	200	30	60	100	75
159	100	150	300	300	20	40	100	75
160	200	300	700	100	50	60	100	75
161	150	200	300	200	15	40	100	75
162	150	150	70	100	50	100	100	40
163	100	150	150	200	20	20	100	50
164	50	100	200	100	15	40	100	75
165	30	50	300	100	10	30	100	75
166	70	50	700	400	7	20	50	40
167	300	600	3,000	1,500	7	40	70	40
168	30	50	200	- 100	20	40	100	40
169	20	100	200	200	30	80	70	40
170	30	50	500	100	20	40	70	40
171	300	600	3,000	2,250	30	60	100	75
172	70	100	2,000	800	30	80	70	40
173	30	50	200	100	- 5	- 10	100	40
174	50	50	300	200	5	10	70	40
175	100	100	500	200	20	20	100	40
176	3,000	3,000	5,000	1,150	500	700	70	40
177	200	200	1,000	400	20	30	150	75

Sample Number	Parts Per Million: Nickel Spec	Nickel Color	Chromium Spec	Chromium Color	Cobalt Spec	Cobalt Color	Copper Spec	Copper Color
178	150	200	1,000	400	30	60	100	75
179	20	25	300	200	- 5	- 10	20	10
180	20	25	300	200	- 5	- 10	30	40
181	100	150	700	300	20	30	150	125
182	30	100	300	200	30	40	150	75
183	100	150	700	100	10	20	100	40
184	10	25	150	- 100	- 5	- 10	70	40
185	15	50	500	300	- 5	- 10	70	10
186	100	100	500	300	15	30	150	75
187	30	100	150	100	30	80	100	75
188	20	50	200	200	- 5	- 10	20	20
189	10	50	200	200	- 5	- 10	20	20
190	10	25	100	100	5	- 10	50	40
191	100	150	200	200	10	20	100	10
192	10	25	150	200	- 5	30	20	20
193	10	25	70	- 100	- 5	- 10	15	20
194	10	100	200	- 100	- 5	- 10	20	30
195	300	750	3,000	1,500	15	20	70	75
196	100	100	300	200	200	220	100	120
197	30	50	300	300	10	20	70	75
198	20	50	200	200	- 5	10	30	40
199	500	400	700	400	30	60	70	50
200	20	50	300	300	5	- 10	50	40
202	30	50	150	100	- 5	- 10	50	50
203	50	150	1,500	800	- 5	- 10	50	40
204	20	50	150	200	- 5	- 10	30	40
205	30	100	700	600	- 5	- 10	30	30
206	100	150	500	300	30	80	70	100
207	500	500	3,000	3,000	70	110	50	40
208	200	200	3,000	2,250	5	10	50	100
209	100	150	300	200	100	150	70	120
210	300	200	1,000	300	30	60	70	100
211	50	100	300	200	20	30	70	160
212	100	150	300	300	50	60	70	250
213	700	1,500	1,000	300	50	60	70	160
214	300	400	500	300	100	110	150	250
215	300	300	1,500	800	30	60	70	160
216	100	100	200	- 100	20	30	100	100
217	100	160	300	100	10	10	150	200
218	70	300	200	300	7	10	100	160
219	150	300	1,000	300	7	10	70	75
220	30	160	50	- 100	5	- 10	70	40
221	20	100	30	- 100	30	80	100	100
222	50	300	200	200	20	40	100	100
223	100	200	500	300	5	20	70	100
224	50	200	200	400	30	60	100	100
225	30	100	500	300	- 5	- 10	30	20
226	200	500	1,500	1,500	10	20	70	75

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
227	3,000	2,500	3,000	3,500	200	500	50	50
228	700	2,000	+5,000	15,000	500	700	70	50
229	300	500	3,000	3,000	50	150	50	75
230	500	1,500	3,000	4,000	70	220	100	75
231	700	2,500	5,000	5,750	50	80	50	40
232	1,000	4,000	5,000	11,250	300	600	50	40
233	3,000	4,000	+5,000	7,500	700	700	70	40
234	300	800	2,000	200	50	80	70	100
235	300	700	700	200	100	150	100	160
236	20	160	70	- 100	100	150	100	160
237	20	100	200	100	5	20	70	100
238	150	200	300	600	7	40	100	120
239	20	50	150	100	- 5	10	70	100
240	100	200	150	100	30	80	70	100
241	50	150	150	300	5	20	100	160
242	30	50	150	- 100	5	60	70	75
243	150	150	1,500	600	10	80	70	160
244	100	150	200	200	100	110	70	160
245	100	150	200	300	50	60	70	160
246	100	150	50	- 100	10	20	100	160
247	30	150	100	200	5	20	70	120
248	20	100	70	100	100	300	70	120
249	200	200	1,000	400	20	40	150	250
250	30	150	100	100	- 5	20	100	200
251	300	500	1,500	1,500	70	110	70	100
252	300	800	2,000	1,500	70	150	70	120
253	300	500	3,000	3,000	50	110	70	100
254	700	1,500	5,000	2,250	200	450	70	100
255	1,000	2,000	+5,000	5,750	700	900	100	100
256	50	150	200	200	70	150	70	160
257	50	150	200	100	7	30	100	160
258	30	100	200	200	50	80	70	100
259	20	100	100	- 100	70	110	100	100
260	70	100	300	- 100	15	30	100	160
261	100	150	500	300	15	30	70	100
262	150	150	500	300	50	110	70	100
263	150	150	200	200	10	20	100	160
264	500	500	2,000	600	150	150	50	130
265	300	400	1,500	800	20	60	70	100
266	300	500	1,500	1,150	70	110	70	160
267	50	150	150	- 100	20	60	70	160
268	30	200	150	300	7	30	50	100
269	30	50	300	100	10	30	100	100
270	20	50	70	- 100	- 5	- 10	100	75
271	70	150	30	- 100	5	10	300	300
272	500	500	2,000	1,150	500	700	100	160
273	200	200	1,000	800	100	220	70	75

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
274	3,000	4,000	+5,000	7,500	700	1,200	70	40
275	500	1,000	5,000	4,000	150	300	70	100
276	300	500	1,000	400	15	60	150	120
277	300	400	1,500	1,500	70	220	100	160
278	15	50	100	200	5	10	70	75
279	70	100	500	400	5	10	70	50
280	200	150	700	400	100	220	70	75
281	500	500	3,000	2,250	70	80	100	120
282	700	2,000	3,000	3,000	200	600	70	75
283	1,000	1,000	5,000	3,000	300	500	70	40
284	300	500	2,000	800	100	200	70	120
285	700	1,000	5,000	4,000	150	220	100	100
286	3,000	4,000	+5,000	7,500	500	700	70	50
287	3,000	4,000	5,000	7,500	500	900	100	120
288	150	300	1,000	400	10	30	70	100
289	200	500	2,000	1,150	30	60	100	120
290	100	150	200	100	5	20	70	75
291	100	300	700	400	5	20	70	100
292	150	160	1,000	1,150	30	80	70	100
293	150	300	500	400	50	150	70	200
294	2,000	2,500	3,000	3,000	200	600	70	120
295	3,000	10,000	+5,000	15,000	700	900	50	30
296	300	100	1,500	800	10	80	70	160
297	150	200	500	300	20	110	50	50
298	100	100	300	100	20	30	70	50
299	100	100	30	200	50	110	70	100
300	200	200	500	400	10	10	70	75
301	700	2,000	1,500	800	100	110	150	160
302	300	500	2,000	1,150	50	110	100	75
303	3,000	2,500	+5,000	5,750	700	1,200	70	75
304	2,000	2,500	5,000	4,000	500	900	70	75
305	2,000	3,000	5,000	5,750	500	1,000	50	75
306*	150	600	300	1,200	20	20	70	160
307*	500	3,000	2,000	4,500	100	250	50	60
308*	200	800	1,500	1,500	20	60	50	160
309*	100	800	500	600	5	30	30	80
310*	100	800	500	1,600	50	160	50	160
311*	100	800	500	1,200	30	80	50	160
312*	200	400	1,000	800	10	30	50	120
313*	700	3,000	+5,000	9,000	200	700	20	40
314*	2,000	6,000	5,000	6,000	100	300	15	60
315	300	400	1,500	600	50	150	50	75
316	500	500	3,000	3,000	100	220	70	75
317	300	400	1,500	600	20	40	50	40
318	2,000	800	+5,000	3,000	300	450	70	50
319	1,000	1,500	5,000	4,000	300	500	50	40
320	3,000	3,000	+5,000	5,750	700	1,500	50	50
321	500	2,000	3,000	3,000	100	220	50	50

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
322	700	2,500	+5,000	6,500	200	600	70	75
323	1,000	3,000	3,000	2,250	150	450	70	100
324	50	150	700	200	- 5	60	50	40
325	100	150	200	- 100	10	40	50	160
326	300	500	2,000	1,150	15	40	70	100
327	700	2,000	5,000	1,150	300	700	50	100
328	1,000	2,000	5,000	1,150	200	600	70	100
329	3,000	10,000	+5,000	4,000	300	700	70	120
330	700	2,000	+5,000	3,000	300	900	70	160
331	300	400	1,000	1,150	20	80	50	75
332	300	400	1,500	600	20	80	70	160
333	30	100	200	200	5	40	50	75
334	500	300	1,000	400	30	60	70	100
335	150	150	300	200	200	300	50	100
336	500	500	500	600	150	220	70	200
337	300	400	700	600	30	80	70	200
338	100	150	150	- 100	10	40	100	250
339	150	150	300	200	30	80	70	200
340	200	500	1,000	1,150	10	60	70	160
341	700	2,000	3,000	3,000	150	500	50	100
342	300	500	1,000	400	30	80	70	160
343	3,000	10,000	5,000	4,000	300	700	30	50
344	700	2,000	3,000	3,000	100	250	70	160
345	300	500	1,000	1,150	30	110	70	160
346	1,000	3,000	2,000	1,500	200	300	70	100
347	200	400	1,500	2,250	20	60	70	160
348	300	1,000	3,000	5,750	50	150	50	100
349	300	500	3,000	4,000	30	60	70	100
350	200	400	5,000	4,000	5	20	50	75
351	150	300	700	600	5	20	70	100
352	300	300	3,000	1,500	150	300	100	160
353	150	400	1,500	1,500	30	110	70	120
354	200	500	2,000	2,250	20	80	70	160
355	150	300	300	300	50	220	100	300
356	30	150	150	100	10	30	70	160
357	100	200	200	400	10	30	70	160
358	500	500	2,000	800	15	60	70	160
359	700	1,500	5,000	4,000	70	300	70	100
360	500	500	3,000	1,150	50	300	100	100
361	1,000	3,000	5,000	2,000	500	1,200	30	75
362	500	1,000	3,000	1,500	30	110	100	100
363	1,000	2,500	+5,000	2,250	200	600	70	100
364	5,000	4,000	3,000	2,250	500	900	50	75
365	500	1,000	1,000	800	30	150	70	120
366	700	2,000	3,000	3,500	200	300	70	75
367	200	300	2,000	2,250	5	20	50	120
368	300	1,500	3,000	1,500	30	150	70	250
369*	70	300	150	200	30	40	70	160
370*	1,500	3,000	2,000	3,000	70	120	50	60
371*	500	1,500	1,500	3,000	70	160	30	80

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
372*	1,500	3,000	+5,000	12,000	300	450	50	60
373*	2,000	6,000	+5,000	38,000	700	1,000	30	20
374*	2,000	6,000	5,000	12,000	300	900	30	60
375*	2,000	9,000	5,000	12,000	100	250	50	60
376*	1,500	3,000	2,000	4,500	70	160	30	40
377*	1,500	4,500	+5,000	23,000	500	1,000	50	40
378*	500	1,500	2,000	4,500	100	160	70	120
379*	70	300	300	300	15	20	50	80
380*	70	600	500	1,500	50	80	30	120
381*	70	300	300	300	10	20	30	40
382*	150	600	700	600	20	40	70	80
383*	2,000	6,000	+5,000	27,000	500	900	50	80
384*	100	300	500	300	50	120	50	40
385*	100	300	700	400	30	30	30	40
386*	100	300	500	400	50	80	30	80
387*	1,000	1,500	3,000	4,500	100	250	50	60
388*	70	300	300	600	20	60	50	80
389*	1,500	4,500	+5,000	15,000	100	300	20	40
390*	1,500	3,000	3,000	12,000	150	450	30	60
391*	500	2,500	3,000	6,000	100	250	50	80
392*	1,000	3,000	5,000	6,000	100	250	50	120
393*	1,000	3,000	5,000	12,000	500	900	50	80
394*	1,000	6,000	5,000	15,000	500	1,000	30	40
395*	150	800	700	1,200	30	40	50	80
396*	150	400	500	800	10	20	30	60
397*	300	1,200	1,500	2,500	50	160	70	80
398*	500	2,500	2,000	4,000	100	300	50	80
399*	700	2,500	1,000	1,500	70	250	20	40
400*	1,500	3,000	5,000	6,000	100	160	20	20
401*	1,000	2,500	2,000	3,000	100	250	20	30
402*	1,000	4,500	2,000	6,000	100	250	30	60
403*	1,000	3,000	3,000	7,500	100	300	30	40
404*	700	3,000	2,000	6,000	70	160	30	60
405*	150	800	1,000	2,500	70	160	30	60
406*	700	2,500	3,000	3,000	200	450	50	120
407*	200	600	1,500	3,000	15	30	30	60
408*	300	2,500	2,000	4,500	70	120	50	40
409*	1,000	6,000	5,000	9,000	150	700	50	120
410*	700	2,500	3,000	9,000	70	300	50	120
411*	200	1,500	1,000	4,500	50	250	50	120
412*	500	1,500	1,000	2,500	50	160	50	120
413*	200	800	700	1,500	20	60	15	30
414*	100	400	500	600	7	40	20	20
415*	300	1,500	500	800	50	80	50	120
416*	300	1,500	700	2,500	50	160	30	120
417*	150	400	500	400	50	40	100	160
418*	700	2,500	2,000	3,000	70	160	50	60
419*	1,500	4,500	5,000	9,000	200	450	30	40

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
420*	700	3,000	2,000	4,500	70	120	50	80
421*	1,000	6,000	5,000	12,000	200	700	20	40
422*	1,000	3,000	1,500	2,500	70	250	50	120
423*	200	600	200	400	15	40	50	80
424*	2,000	9,000	1,500	4,500	70	300	30	60
425*	200	800	300	600	20	40	50	80
426*	500	1,500	2,000	4,500	50	250	30	60
427*	200	1,200	2,000	6,000	15	60	20	40
428*	200	600	2,000	4,500	15	30	20	30
429*	200	600	1,500	2,500	20	60	50	120
430*	700	2,500	2,000	4,500	50	80	20	40
431*	100	400	150	200	15	30	70	80
432*	50	300	50	200	10	20	30	80
433*	150	400	300	300	15	30	50	160
434*	1,000	4,500	2,000	4,500	50	120	30	60
435*	1,500	4,500	3,000	5,500	100	300	30	80
436*	500	1,500	5,000	4,500	100	250	30	60
437*	1,000	4,500	3,000	2,500	100	150	50	120
438*	2,000	6,000	5,000	4,000	150	300	30	60
439*	3,000	6,000	+5,000	7,500	500	700	50	40
440*	300	1,500	1,500	3,000	70	120	30	60
441*	500	1,500	2,000	4,500	70	120	30	40
442*	200	800	5,000	4,500	20	30	50	40
443*	500	1,500	2,000	4,500	20	80	50	80
444*	150	600	500	600	70	80	50	60
445*	200	600	1,000	600	100	120	70	120
446*	200	1,200	1,000	2,500	70	80	70	120
447*	150	800	700	2,500	30	120	50	120
448*	300	800	1,000	1,200	100	80	100	80
449*	150	600	500	600	70	80	70	120
450*	30	400	30	200	5	30	70	120
451*	30	400	20	200	5	20	70	300
452*	100	600	500	600	30	60	70	80
453*	100	800	700	1,200	20	40	50	120
454*	150	800	1,000	800	20	30	70	60
455*	3,000	6,000	5,000	4,500	200	450	30	60
456*	500	2,500	700	1,500	70	250	30	80
457*	200	800	1,000	1,200	70	120	100	120
458*	20	400	100	300	10	30	50	80

APPENDIX C

Spectrographic Determinations for Fe, Mg, Ca, Ti, Mn, V, Ba, Sc, Zr, and Zn, And Atomic Absorption Determinations for Au in Soils[1]

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
1*	7	0.1	-0.05	0.5	500	100	10	30	30	-200	NA
2*	15	0.05	-0.05	0.3	+5,000	200	300	50	30	-200	NA
3*	15	0.02	-0.05	0.5	700	300	10	30	50	-200	NA
4*	7	0.2	-0.05	0.2	500	200	300	20	20	-200	NA
5*	10	0.3	-0.05	0.3	500	200	500	20	200	-200	NA
6*	10	0.1	-0.05	0.3	500	150	50	20	70	-200	NA
7*	10	0.1	-0.05	0.5	300	200	50	30	100	-200	NA
8*	10	0.1	-0.05	0.5	1,000	200	100	30	70	-200	NA
9*	15	0.1	-0.05	0.2	2,000	100	15	20	20	-200	NA
10*	15	0.1	-0.05	0.2	1,000	150	15	30	30	-200	NA
11*	20	0.1	-0.05	0.2	1,500	200	20	30	30	-200	NA
12*	15	0.07	0.05	0.2	5,000	150	50	30	30	-200	NA
13*	15	0.1	-0.05	0.2	1,000	100	15	20	30	-200	NA
14*	20	0.1	0.05	0.3	3,000	200	30	30	50	-200	NA
15*	15	0.1	-0.05	0.3	1,000	150	20	30	50	-200	NA
16*	20	0.07	0.07	0.2	5,000	200	20	30	50	-200	NA
17*	15	1	-0.05	0.2	1,000	100	15	15	30	-200	NA

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[1] Note: Second group of soil-sample analyses indicated by asterisk (*); other sample numbers are from first group. "Less than" indicated by minus sign (-); "greater than" indicated by plus sign (+). Samples not analyzed for gold indicated by NA. Sample locations plotted on Plate 1.

Analyses by U.S.G.S. laboratories, Denver, Colorado.

Sample Number	Percent				Parts Per Million						
	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
18*	15	1	-0.05	0.2	1,000	100	20	15	30	- 200	NA
19*	15	1	-0.05	0.3	1,000	100	20	15	30	- 200	NA
20*	20	1	-0.05	0.2	1,500	150	20	15	50	- 200	NA
21*	15	1	-0.05	0.2	2,000	100	30	15	50	- 200	NA
22*	15	0.7	-0.05	0.2	1,500	70	50	15	50	- 200	NA
23*	15	0.1	-0.05	0.3	1,000	100	10	15	100	- 200	NA
24*	20	0.5	-0.05	0.3	1,500	200	50	20	50	- 200	NA
25*	15	0.05	-0.05	0.3	1,000	150	30	20	50	- 200	NA
26*	20	0.07	-0.05	0.3	2,000	150	50	30	30	- 200	NA
27*	20	0.02	-0.05	0.3	1,500	150	50	30	30	- 200	NA
28*	+20	0.05	-0.05	0.5	2,000	200	30	30	30	- 200	NA
29*	15	0.05	-0.05	0.3	1,500	150	30	30	30	- 200	NA
30*	20	0.15	-0.05	0.3	1,500	150	30	50	30	- 200	NA
31*	15	0.1	-0.05	0.5	1,000	150	20	30	30	- 200	NA
32*	15	0.7	-0.05	0.3	1,500	100	20	20	20	- 200	NA
33*	15	0.7	-0.05	0.2	2,000	150	20	20	50	- 200	NA
34*	20	1	-0.05	0.3	1,500	150	20	30	30	- 200	NA
35*	20	1.5	0.05	0.2	2,000	150	20	30	30	- 200	NA
36*	15	3	-0.05	0.2	1,000	70	10	15	20	- 200	NA
37*	15	3	-0.05	0.2	1,000	70	15	15	30	- 200	NA
38*	15	2	-0.05	0.2	1,000	50	10	15	20	- 200	NA
39	15	7	-0.05	0.3	1,000	150	- 20	20	50	- 200	-0.02
40	10	0.3	-0.05	0.7	700	300	500	50	200	- 200	-0.02
41	3	0.5	-0.05	0.5	300	70	700	15	300	- 200	-0.02
42	10	0.1	-0.05	0.5	1,000	500	30	70	50	- 200	-0.02
43	15	0.07	-0.05	0.7	1,500	500	20	70	70	- 200	-0.02
44	10	- 0.02	-0.05	0.5	700	500	- 20	50	30	- 200	-0.02
45	10	0.07	-0.05	0.5	1,500	500	30	50	30	- 200	-0.02
46	15	0.05	-0.05	0.7	1,000	500	- 20	70	50	- 200	-0.02
47	10	0.02	-0.05	0.5	1,500	500	- 20	50	50	- 200	-0.02
48	7	0.1	0.05	1	2,000	300	50	20	100	- 200	-0.02
49	10	0.05	-0.05	+1	1,500	300	20	50	150	- 200	-0.02

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
50	15	0.7	0.5	0.5	3,000	500	300	50	70	- 200	-0.02
51	7	1	0.7	0.7	1,000	500	70	30	100	- 200	-0.02
52	7	0.15	-0.05	0.5	500	300	50	20	150	- 200	-0.02
53	7	0.2	-0.05	0.7	1,000	200	- 20	50	50	- 200	-0.02
54	10	3	1.5	0.5	1,500	300	30	50	20	- 200	-0.02
55	10	0.05	-0.05	0.7	1,000	300	- 20	50	50	- 200	-0.02
56	15	0.5	-0.05	0.5	500	300	- 20	50	30	- 200	-0.02
57	15	0.05	-0.05	1	1,500	1,000	- 20	70	150	- 200	-0.02
58	7	0.05	0.05	0.7	+5,000	700	200	20	100	- 200	0.02
59	10	0.15	-0.05	0.7	1,500	1,000	50	70	150	- 200	-0.02
60	10	0.2	-0.05	0.5	1,000	500	- 20	50	30	- 200	-0.02
61	15	0.1	-0.05	0.7	1,500	700	- 20	70	100	- 200	-0.02
62	7	- 0.02	-0.05	0.5	500	300	- 20	30	30	- 200	-0.02
63	10	0.7	0.7	0.7	1,000	500	30	50	50	- 200	-0.02
64	15	0.02	-0.05	1	1,000	1,000	20	70	200	- 200	-0.02
65	7	0.1	0.05	0.7	1,500	200	30	20	150	- 200	-0.02
66	7	0.15	-0.05	0.5	1,000	300	100	20	50	- 200	-0.02
67	10	0.02	-0.05	0.7	1,500	500	- 20	70	50	- 200	-0.02
68	15	0.1	-0.05	+1	5,000	500	200	30	200	- 200	-0.02
69	10	7	1	0.7	+5,000	150	300	20	100	200	-0.02
70	10	0.3	-0.05	0.7	1,000	300	- 20	70	70	- 200	-0.02
71	10	1	-0.05	0.5	1,500	200	30	50	70	- 200	-0.02
72	15	0.7	0.7	+1	+5,000	1,000	500	30	100	- 200	-0.02
73	15	0.05	-0.05	0.7	1,500	500	- 20	70	30	- 200	-0.02
74	10	0.05	-0.05	0.5	5,000	200	70	70	30	- 200	-0.02
76	10	0.05	-0.05	0.5	1,500	700	50	50	50	- 200	-0.02
77	15	0.1	-0.05	0.7	1,500	1,000	- 20	70	70	- 200	-0.02
78	15	0.03	-0.05	0.7	1,500	500	- 20	70	50	- 200	-0.02
79	10	0.03	-0.05	0.7	1,500	700	- 20	50	70	- 200	-0.02
80	15	0.3	-0.05	0.5	1,000	700	70	70	30	- 200	-0.02
81	10	0.1	-0.05	0.7	300	300	100	30	200	- 200	-0.02
82	15	0.07	-0.05	1	1,500	1,000	- 20	100	70	- 200	-0.02
83	10	- 0.02	-0.05	0.7	1,000	700	- 20	70	30	- 200	-0.02

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
84	15	0.2	0.05	1	1,000	700	30	50	150	- 200	-0.02
85	7	7	0.5	0.3	700	150	- 20	15	20	- 200	-0.02
86	15	0.2	-0.05	1	1,000	1,000	20	70	70	- 200	-0.02
87	10	0.5	0.05	0.5	1,000	300	- 20	70	50	- 200	-0.02
88	10	5	3	0.5	1,000	200	- 20	50	30	- 200	-0.02
89	10	0.05	-0.05	0.5	500	500	- 20	70	50	- 200	-0.02
90	15	0.03	-0.05	0.7	500	500	- 20	70	50	- 200	-0.02
91	10	0.02	-0.05	0.5	2,000	200	20	30	30	- 200	-0.02
92	15	2	0.7	0.7	1,000	1,000	70	70	100	- 200	-0.02
93	7	0.1	-0.05	0.5	2,000	150	100	15	50	- 200	-0.02
94	15	0.07	-0.05	0.7	1,500	700	- 20	70	100	- 200	-0.02
95	15	0.05	-0.05	0.7	500	+1,000	20	100	50	- 200	-0.02
96	7	0.07	-0.05	0.5	1,000	200	- 20	50	30	- 200	-0.02
97	10	1	0.3	1	1,000	1,000	150	70	150	- 200	-0.02
98	10	2	0.3	0.5	500	500	150	30	100	- 200	-0.02
99	15	0.05	-0.05	+1	1,500	+1,000	20	100	150	- 200	-0.02
100	15	0.05	-0.05	1	1,500	1,000	100	70	150	- 200	-0.02
101	5	0.3	0.2	1	300	200	30	20	150	- 200	-0.02
102	15	0.2	-0.05	0.7	1,500	700	20	100	100	- 200	-0.02
103	10	0.5	-0.05	0.7	1,000	200	150	50	200	- 200	-0.02
104	10	- 0.02	-0.05	1	300	700	- 20	70	150	- 200	-0.02
105	15	0.7	0.5	1	2,000	700	150	70	100	- 200	-0.02
106	10	0.05	-0.05	0.7	1,000	200	- 20	70	30	- 200	-0.02
107	10	0.02	-0.05	0.7	1,500	300	- 20	50	30	- 200	-0.02
108	10	0.5	0.05	0.5	1,000	500	- 20	50	20	- 200	-0.02
109	7	0.05	-0.05	0.7	2,000	300	20	50	30	- 200	-0.02
110	15	- 0.02	-0.05	0.5	200	1,000	- 20	30	30	- 200	-0.02
111	15	0.02	-0.05	1	1,000	+1,000	- 20	100	100	- 200	-0.02
112	7	0.5	-0.05	0.5	300	300	50	50	50	- 200	-0.02
113	15	0.02	-0.05	1	1,000	1,000	- 20	70	100	- 200	-0.02
114	15	0.03	-0.05	+1	500	100	20	100	150	- 200	-0.02
115	10	0.5	-0.05	0.7	1,000	300	50	70	200	- 200	-0.02
116	15	0.5	0.2	1	2,000	700	70	50	150	- 200	-0.02

Sample Number	Percent				Parts Per Million						
	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
117	10	0.1	-0.05	0.7	1,000	700	30	70	50	- 200	-0.02
118	7	2	1.5	0.7	3,000	500	100	20	150	- 200	-0.02
119	10	0.02	-0.05	1	1,000	500	- 20	70	100	- 200	-0.02
120	10	0.02	-0.05	0.5	500	300	- 20	70	30	- 200	-0.02
121	15	0.1	-0.05	0.7	1,500	300	- 20	100	70	- 200	-0.02
122	10	0.02	-0.05	0.5	1,000	300	- 20	70	50	- 200	-0.02
123	10	0.02	-0.05	0.5	1,000	500	- 20	70	30	- 200	-0.02
124	15	0.5	0.05	1	1,500	500	20	70	100	- 200	-0.02
125	20	0.2	0.05	0.7	500	700	- 20	70	70	- 200	-0.02
126	10	0.07	-0.05	0.7	1,500	300	50	70	100	- 200	-0.02
127	10	0.02	-0.05	0.5	700	500	- 20	70	30	- 200	-0.02
128	10	- 0.02	-0.05	0.5	300	300	- 20	50	30	- 200	-0.02
129	10	0.05	-0.05	0.7	1,500	500	20	50	30	- 200	-0.02
130	15	0.5	-0.05	0.7	200	500	- 20	50	50	- 200	-0.02
131	15	0.5	0.1	0.5	1,500	500	20	50	50	200	-0.02
132	10	0.15	-0.05	0.7	300	200	100	30	200	- 200	-0.02
133	10	0.2	-0.05	0.7	300	200	150	20	150	- 200	-0.02
134	10	0.1	-0.05	0.5	500	500	- 20	50	20	- 200	-0.02
135	10	0.15	-0.05	0.7	1,000	+1,000	- 20	70	30	- 200	-0.02
136	10	0.7	-0.05	0.7	1,000	500	- 20	50	50	- 200	-0.02
137	10	2	1	0.5	1,000	300	- 20	50	20	- 200	-0.02
138	15	0.07	-0.05	0.7	1,500	200	- 20	70	30	- 200	-0.02
139	15	- 0.02	-0.05	0.7	700	+1,000	- 20	70	30	- 200	-0.02
140	10	- 0.02	-0.05	0.7	1,500	500	- 20	50	30	- 200	-0.02
141	15	0.1	-0.05	0.7	1,500	+1,000	100	70	70	- 200	-0.02
142	10	0.07	-0.05	0.7	1,500	300	50	100	70	- 200	-0.02
143	15	0.02	-0.05	0.7	700	300	- 20	100	50	- 200	-0.02
144	15	- 0.02	-0.05	0.7	1,500	500	- 20	70	70	- 200	-0.02
145	10	0.7	0.7	0.7	1,500	500	50	30	50	- 200	-0.02
146	10	0.07	-0.05	0.7	1,500	150	- 20	50	30	- 200	-0.02
147	15	0.05	-0.05	0.7	1,000	700	- 20	70	30	- 200	-0.02
148	10	0.07	-0.05	0.5	50	200	30	10	200	- 200	-0.02
149	15	0.02	-0.05	0.7	1,000	1,000	- 20	70	30	- 200	-0.02

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
150	15	0.07	-0.05	0.5	700	500	20	50	50	-200	-0.02
151	10	0.02	-0.05	0.7	700	700	-20	50	50	-200	-0.02
152	10	0.07	-0.05	0.5	1,000	300	-20	50	30	-200	-0.02
153	15	0.1	-0.05	0.7	1,000	300	20	70	50	-200	-0.02
154	15	5	0.7	0.5	2,000	200	30	20	50	-200	-0.02
155	15	0.05	-0.05	0.5	1,000	300	-20	100	30	-200	-0.02
156	10	0.3	-0.05	0.5	2,000	500	30	30	30	-200	-0.02
157	10	0.05	-0.05	0.5	1,500	200	-20	50	50	-200	-0.02
158	10	0.02	-0.05	0.5	1,500	150	-20	50	50	-200	-0.02
159	10	0.02	-0.05	0.5	700	200	-20	70	20	-200	-0.02
160	10	0.05	-0.05	0.7	1,500	300	20	70	100	-200	-0.02
161	10	0.05	-0.05	0.5	700	300	-20	50	30	-200	-0.02
162	10	0.02	-0.05	1	1,500	500	20	50	30	-200	-0.02
163	10	0.02	-0.05	0.5	1,000	200	-20	70	50	-200	-0.02
164	15	0.1	-0.05	0.7	1,000	300	70	70	150	-200	-0.02
165	15	0.02	-0.05	1	700	700	20	50	150	-200	-0.02
166	5	0.2	-0.05	0.5	100	150	300	15	150	-200	-0.02
167	15	0.2	-0.05	0.7	300	300	-20	50	70	-200	-0.02
168	7	0.2	-0.05	0.7	500	150	150	20	150	-200	-0.02
169	5	0.07	-0.05	0.7	500	150	150	15	150	-200	-0.02
170	7	0.2	0.1	1	1,000	150	200	15	300	-200	-0.02
171	15	2	-0.05	0.7	500	700	-20	50	100	-200	-0.02
172	20	0.2	-0.05	0.5	1,500	200	200	20	150	-200	-0.02
173	7	0.2	-0.05	0.5	50	200	300	20	150	-200	-0.02
174	3	0.2	-0.05	0.7	100	150	200	15	150	-200	-0.02
175	10	0.3	0.05	0.7	500	300	300	30	150	-200	-0.02
176	15	5	-0.05	0.5	2,000	150	-20	20	30	-200	-0.02
177	15	0.05	-0.05	0.7	1,000	+1,000	-20	100	70	-200	-0.02
178	10	0.3	-0.05	0.7	200	500	50	50	70	-200	-0.02
179	15	0.1	-0.05	0.7	20	300	150	15	150	-200	-0.02
180	7	0.15	-0.05	0.7	20	200	700	10	200	-200	-0.02
181	15	0.02	-0.05	0.7	1,500	+1,000	-20	100	30	-200	-0.02

Sample Number	Percent				Parts Per Million						
	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
182	15	0.02	-0.05	0.7	1,500	500	30	100	100	- 200	-0.02
183	7	0.3	-0.05	0.7	200	200	300	30	150	- 200	-0.02
184	10	0.1	-0.05	0.5	50	200	200	15	100	- 200	-0.02
185	10	0.2	-0.05	0.7	30	200	300	15	200	- 200	-0.02
186	15	0.05	-0.05	1	1,500	+1,000	- 20	70	30	- 200	-0.02
187	7	0.2	0.2	0.7	1,500	150	30	30	70	- 200	-0.02
188	7	0.1	-0.05	0.7	30	150	150	15	150	- 200	-0.02
189	5	0.15	-0.05	0.7	50	150	700	10	150	- 200	-0.02
190	7	0.5	-0.05	0.7	30	150	500	10	150	- 200	-0.02
191	10	0.2	-0.05	0.7	30	200	200	30	100	- 200	-0.02
192	0.5	0.05	-0.05	0.3	70	30	150	- 5	150	- 200	-0.02
193	0.7	0.02	-0.05	0.5	50	30	150	- 5	300	- 200	-0.02
194	2	0.05	-0.05	0.5	30	70	200	5	200	- 200	-0.02
195	15	0.15	-0.05	0.7	300	300	300	50	100	- 200	-0.02
196	15	0.3	0.05	1	+5,000	700	150	30	100	- 200	-0.02
197	7	0.05	-0.05	0.7	200	300	20	20	150	- 200	-0.02
198	5	0.02	-0.05	0.5	50	150	50	10	100	- 200	-0.02
199	7	0.1	-0.05	0.7	1,000	200	300	50	100	- 200	-0.02
200	5	0.2	-0.05	0.5	30	150	300	15	150	- 200	-0.02
202	5	0.03	-0.05	0.5	70	100	200	7	100	- 200	-0.02
203	10	0.05	-0.05	0.5	50	300	150	20	100	- 200	-0.02
204	7	0.1	-0.05	0.5	100	150	30	15	100	- 200	-0.02
205	7	0.15	-0.05	0.5	20	150	300	15	300	- 200	-0.02
206	5	0.2	-0.05	0.5	1,500	200	150	15	70	- 200	-0.02
207	7	1	-0.05	0.5	500	200	150	20	100	- 200	-0.02
208	10	0.1	-0.05	0.5	150	300	500	20	150	- 200	-0.02
209	10	- 0.02	-0.05	0.7	1,500	1,000	20	100	150	- 200	-0.02
210	10	0.02	-0.05	0.5	1,500	700	- 20	50	70	- 200	-0.02
211	7	0.2	-0.05	0.5	1,000	300	20	50	70	- 200	-0.02
212	10	0.02	-0.05	0.5	1,500	500	- 20	70	30	- 200	-0.02
213	10	0.15	-0.05	0.7	1,000	500	- 20	70	50	- 200	-0.02
214	10	0.5	0.5	0.7	1,500	700	30	70	50	- 200	-0.02
215	10	0.02	-0.05	0.7	1,000	700	- 20	50	50	- 200	-0.02

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
216	15	0.03	-0.05	1	1,500	700	- 20	70	50	- 200	-0.02
217	15	0.05	-0.05	0.7	500	1,000	20	100	50	- 200	-0.02
218	15	0.05	-0.05	0.7	700	500	20	70	70	- 200	-0.02
219	10	0.5	-0.05	0.7	150	200	- 20	30	100	- 200	-0.02
220	7	0.2	-0.05	0.7	300	150	- 20	15	150	- 200	-0.02
221	15	0.7	0.7	0.7	1,500	700	70	50	50	- 200	-0.02
222	15	0.05	-0.05	0.7	1,500	700	50	70	100	- 200	-0.02
223	10	0.07	-0.05	0.5	500	500	- 20	50	30	- 200	-0.02
224	15	0.05	-0.05	1	1,000	700	20	70	70	- 200	-0.02
225	10	0.05	-0.05	0.5	100	200	100	30	100	- 200	-0.02
226	10	0.1	-0.05	0.5	500	300	- 20	50	30	- 200	-0.02
227	10	3	0.1	0.3	1,500	100	20	20	20	- 200	-0.02
228	15	2	0.2	0.7	5,000	500	30	30	100	300	-0.02
229	15	0.1	-0.05	0.5	1,500	300	- 20	30	100	- 200	-0.02
230	15	1	-0.05	0.5	1,000	300	50	70	30	- 200	-0.02
231	15	0.1	-0.05	0.5	700	500	- 20	50	100	- 200	-0.02
232	15	0.3	-0.05	0.5	1,500	200	- 20	20	50	200	-0.02
233	20	0.7	-0.05	0.7	3,000	500	- 20	30	70	700	-0.02
234	10	0.02	-0.05	0.7	1,000	700	- 20	50	50	- 200	-0.02
235	15	0.3	0.05	0.7	1,000	+1,000	- 20	70	30	- 200	-0.02
236	15	0.02	-0.05	1	1,500	700	- 20	50	100	- 200	-0.02
237	15	- 0.02	-0.05	0.7	300	1,000	- 20	50	50	- 200	-0.02
238	15	0.03	-0.05	0.7	1,000	1,000	- 20	100	50	- 200	-0.02
239	7	0.05	-0.05	0.7	100	300	150	50	200	- 200	-0.02
240	10	0.2	0.2	0.5	1,000	700	20	50	30	- 200	-0.02
241	10	0.02	-0.05	0.7	700	700	- 20	70	30	- 200	-0.02
242	10	0.1	-0.05	0.7	1,000	500	70	50	150	- 200	-0.02
243	15	0.07	-0.05	0.5	700	500	150	50	100	- 200	-0.02
244	10	0.07	-0.05	0.7	2,000	500	30	30	70	- 200	-0.02
245	10	0.02	-0.05	0.7	1,500	700	20	30	30	- 200	-0.02
246	15	0.1	-0.05	0.7	1,500	700	- 20	70	50	- 200	-0.02
247	10	- 0.02	-0.05	0.7	500	700	- 20	50	50	- 200	-0.02

Sample Number	Percent				Parts Per Million						
	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
248	7	0.02	-0.05	0.7	2,000	300	50	20	70	- 200	-0.02
249	15	0.05	-0.05	0.7	1,000	500	30	50	70	- 200	-0.02
250	10	0.03	-0.05	0.7	200	700	- 20	70	30	- 200	-0.02
251	10	1	0.2	0.5	1,000	500	- 20	50	20	- 200	-0.02
252	10	0.07	-0.05	0.5	1,500	300	- 20	30	30	- 200	-0.02
253	15	0.05	-0.05	0.5	1,000	500	20	30	70	- 200	-0.02
254	15	0.3	-0.05	0.5	1,500	500	- 20	30	70	- 200	-0.02
255	15	0.7	-0.05	0.7	2,000	700	100	30	100	300	-0.02
256	15	0.02	-0.05	0.7	1,500	500	20	50	50	- 200	-0.02
257	15	0.05	-0.05	0.7	1,000	500	20	50	50	- 200	-0.02
258	15	0.03	-0.05	0.7	1,500	700	70	30	150	- 200	-0.02
259	15	0.3	0.3	1	1,500	1,000	30	30	50	- 200	-0.02
260	15	0.1	-0.05	1	1,000	+1,000	- 20	100	50	- 200	-0.02
261	10	0.05	-0.05	0.7	500	700	20	50	30	- 200	-0.02
262	10	0.7	0.5	0.7	1,500	700	20	30	50	- 200	-0.02
263	15	0.05	-0.05	1	1,000	+1,000	- 20	100	50	- 200	-0.02
264	10	3	1.5	0.7	1,500	500	20	30	50	- 200	-0.02
265	10	0.1	-0.05	0.7	1,000	700	- 20	70	30	- 200	-0.02
266	10	1	0.3	0.5	1,000	500	- 20	50	30	- 200	-0.02
267	7	0.02	-0.05	0.7	700	700	- 20	30	50	- 200	-0.02
268	3	0.03	-0.05	0.5	500	150	- 20	20	20	- 200	-0.02
269	10	0.1	0.05	0.7	1,500	500	- 20	50	150	- 200	-0.02
270	10	0.02	-0.05	0.7	300	1,000	- 20	70	70	- 200	-0.02
271	15	0.1	-0.05	0.7	1,500	700	- 20	+100	50	- 200	-0.02
272	15	1	0.5	0.7	3,000	300	30	50	50	- 200	-0.02
273	10	0.1	-0.05	0.7	3,000	500	150	50	150	- 200	-0.02
274	20	7	0.07	0.7	+5,000	200	70	20	150	1,000	-0.02
275	15	0.7	0.5	0.7	1,500	300	30	20	150	300	-0.02
276	15	0.05	-0.05	1	1,000	+1,000	- 20	100	150	- 200	-0.02
277	10	0.1	-0.05	1	1,500	500	- 20	70	100	- 200	-0.02
278	7	0.1	-0.05	0.7	700	200	150	30	300	- 200	-0.02
279	7	0.15	-0.05	0.7	200	200	150	30	200	- 200	-0.02
280	7	0.7	0.7	1	3,000	300	70	20	150	- 200	-0.02

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
281	15	0.7	-0.05	0.7	1,000	700	30	100	70	- 200	-0.02
282	10	3	1	0.5	2,000	150	100	30	50	- 200	-0.02
283	15	7	-0.05	0.5	1,500	200	- 20	30	70	200	-0.02
284	15	1	1	0.5	1,500	700	50	70	100	- 200	-0.02
285	15	5	0.1	0.5	1,500	200	30	50	150	- 200	-0.02
286	15	5	-0.05	0.5	2,000	150	- 20	30	30	500	-0.02
287	15	0.5	-0.05	0.7	+5,000	200	30	50	150	300	-0.02
288	15	0.05	-0.05	0.7	1,000	1,000	- 20	70	150	- 200	-0.02
289	15	0.1	-0.05	0.5	1,000	500	- 20	70	50	- 200	-0.02
290	10	0.02	-0.05	0.7	500	500	- 20	70	50	- 200	-0.02
291	10	0.02	-0.05	0.5	500	300	- 20	50	30	- 200	-0.02
292	15	0.05	-0.05	0.5	1,000	500	- 20	50	50	- 200	-0.02
293	10	0.1	0.05	0.7	1,500	300	100	50	150	- 200	-0.02
294	15	1	-0.05	0.5	5,000	300	1,000	50	100	200	0.04
295	20	5	0.05	0.7	+5,000	1,000	30	15	200	1,500	-0.02
296	10	0.1	-0.05	0.7	1,000	300	- 20	70	100	- 200	-0.02
297	5	0.5	0.07	1	1,000	200	150	20	150	- 200	-0.02
298	5	0.3	-0.05	1	1,000	200	150	30	150	- 200	-0.02
299	10	0.5	-0.05	1	1,500	500	- 20	100	100	- 200	-0.02
300	10	0.7	-0.05	0.7	700	300	300	50	300	- 200	-0.02
301	15	5	0.05	1	3,000	300	200	70	1,000	- 200	-0.02
302	10	0.07	-0.05	0.7	1,000	700	20	70	150	- 200	-0.02
303	15	2	-0.05	0.7	+5,000	500	150	50	100	200	-0.02
304	15	1	-0.05	0.7	+5,000	300	150	30	150	- 200	-0.02
305	15	0.5	-0.05	0.5	3,000	300	30	20	70	300	-0.02
306*	20	0.07	-0.05	0.5	300	200	30	30	50	- 200	NA
307*	15	0.3	-0.05	0.5	1,500	100	30	20	100	- 200	NA
308*	15	0.2	-0.05	0.5	500	100	50	20	150	- 200	NA
309*	15	0.1	-0.05	0.5	300	150	10	30	50	- 200	NA
310*	10	0.05	-0.05	0.2	700	100	10	20	20	- 200	NA
311*	10	0.3	-0.05	0.3	500	100	50	20	50	- 200	NA
312*	10	0.15	-0.05	0.3	500	150	200	15	150	- 200	NA
313*	10	2	1	0.3	5,000	150	300	15	70	500	NA

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
314*	15	0.7	0.05	0.3	1,000	100	30	20	50	- 200	NA
315	10	0.2	-0.05	0.7	1,500	500	150	30	150	- 200	-0.02
316	15	0.3	-0.05	0.7	2,000	300	20	50	150	- 200	-0.02
317	7	0.5	-0.05	0.7	700	200	700	30	150	- 200	-0.02
318	15	+10	-0.05	0.5	1,500	150	30	30	70	200	-0.02
319	15	3	-0.05	0.5	1,500	150	- 20	30	100	300	-0.02
320	15	5	0.05	0.7	+5,000	150	150	15	100	500	0.30
321	15	0.1	-0.05	0.5	1,000	700	- 20	50	100	- 200	-0.02
322	20	0.07	-0.05	0.5	2,000	300	- 20	50	100	300	-0.02
323	15	0.3	-0.05	0.3	1,500	200	- 20	50	50	200	-0.02
324	7	0.07	-0.05	0.7	70	300	100	20	150	- 200	-0.02
325	7	0.1	-0.05	0.3	500	300	30	70	50	- 200	-0.02
326	15	0.05	-0.05	0.7	700	700	30	100	150	- 200	-0.02
327	10	0.07	-0.05	0.3	1,500	300	- 20	50	50	200	-0.02
328	15	0.1	-0.05	0.7	1,500	500	- 20	50	100	200	-0.02
329	15	2	-0.05	0.5	2,000	300	- 20	50	30	500	-0.02
330	15	0.15	-0.05	0.7	3,000	300	20	70	70	500	-0.02
331	10	0.05	-0.05	0.7	1,000	200	100	20	200	- 200	-0.02
332	15	0.02	-0.05	0.7	1,000	700	20	70	150	- 200	-0.02
333	7	0.2	-0.05	0.7	100	200	150	20	150	- 200	-0.02
334	10	1	-0.05	0.7	1,500	200	150	50	150	- 200	-0.02
335	7	0.3	-0.05	0.5	3,000	150	1,500	15	150	- 200	-0.02
336	10	0.7	-0.05	0.7	3,000	200	20	70	100	- 200	-0.02
337	10	0.3	-0.05	0.7	700	300	- 20	70	50	- 200	-0.02
338	10	0.15	-0.05	0.7	700	500	20	70	50	- 200	-0.02
339	10	0.07	-0.05	0.7	1,000	500	- 20	70	70	- 200	-0.02
340	10	0.05	-0.05	0.7	3,000	300	20	70	100	- 200	-0.02
341	15	0.3	-0.05	0.7	2,000	200	20	50	100	200	-0.02
342	10	1	0.07	0.7	1,000	300	100	70	70	- 200	-0.02
343	15	3	0.05	0.7	2,000	200	150	20	150	300	-0.02
344	10	1	0.05	0.7	500	300	- 20	50	100	200	-0.02
345	10	0.15	-0.05	0.7	700	200	20	50	150	- 200	-0.02

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
346	15	5	0.1	0.5	700	150	- 20	30	30	200	-0.02
347	10	0.1	-0.05	0.7	700	500	20	50	200	- 200	-0.02
348	15	0.05	-0.05	0.7	700	300	- 20	30	150	- 200	-0.02
349	10	- 0.02	-0.05	0.7	500	500	30	50	150	- 200	-0.02
350	20	0.03	-0.05	0.7	200	700	50	20	200	- 200	-0.02
351	10	0.15	-0.05	0.7	200	300	100	30	200	- 200	-0.02
352	10	0.5	-0.05	0.7	2,000	500	150	50	150	- 200	0.06
353	10	0.07	-0.05	0.7	1,000	300	30	50	150	- 200	0.04
354	10	0.3	-0.05	0.7	300	300	20	50	100	- 200	0.06
355	10	0.1	-0.05	0.7	2,000	300	20	50	100	- 200	-0.02
356	15	0.02	-0.05	1	1,000	1,000	- 20	70	150	- 200	-0.02
357	10	0.07	-0.05	0.5	1,500	200	- 20	50	30	- 200	-0.02
358	15	0.5	-0.05	0.5	700	300	20	50	50	- 200	-0.02
359	15	0.3	-0.05	0.5	1,500	700	30	30	100	- 200	0.02
360	10	1	0.5	0.7	3,000	300	70	30	150	- 200	-0.02
361	10	3	0.1	0.5	+5,000	150	300	20	50	200	-0.02
362	15	0.3	-0.05	0.5	1,000	500	70	50	200	- 200	-0.02
363	20	0.5	-0.05	0.5	2,000	500	- 20	50	100	500	0.02
364	15	3	-0.05	0.3	+5,000	150	100	50	50	- 200	-0.02
365	10	0.07	-0.05	0.7	1,500	700	- 20	50	150	- 200	-0.02
366	15	0.05	-0.05	0.7	1,500	700	- 20	30	150	- 200	-0.02
367	10	0.02	-0.05	0.1	200	1,000	- 20	20	300	- 200	-0.02
368	15	0.02	-0.05	0.7	500	500	- 20	70	50	- 200	0.02
369*	10	0.1	-0.05	0.7	1,000	200	20	30	70	- 200	NA
370*	15	2	-0.05	0.3	1,000	150	50	20	100	- 200	NA
371*	10	1.5	-0.05	0.3	1,000	150	50	30	50	- 200	NA
372*	15	3	0.2	0.3	1,500	150	70	15	30	- 200	NA
373*	15	2	0.7	1	5,000	300	200	20	100	500	NA
374*	15	1	0.5	0.5	3,000	100	150	20	50	- 200	NA
375*	15	3	-0.05	0.2	1,000	100	10	20	20	- 200	NA
376*	10	3	-0.05	0.2	1,000	100	10	20	30	- 200	NA
377*	20	2	0.15	0.5	3,000	200	100	10	30	500	NA

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
378*	15	2	-0.05	0.3	1,000	150	20	30	30	- 200	NA
379*	10	0.2	-0.05	0.5	500	150	300	20	150	- 200	NA
380*	10	0.05	-0.05	0.5	1,000	150	20	30	30	- 200	NA
381*	15	0.05	-0.05	+1	700	300	10	50	100	- 200	NA
382*	15	0.15	-0.05	0.5	700	200	10	50	50	- 200	NA
383*	20	1	0.1	+1	+5,000	200	300	15	150	700	NA
384*	15	0.3	0.05	1	1,000	200	200	20	200	- 200	NA
385*	10	2	2	0.5	500	150	150	20	100	- 200	NA
386*	10	2	1	0.5	1,000	150	150	20	70	- 200	NA
387*	15	3	-0.05	0.3	1,000	150	50	20	50	- 200	NA
388*	15	0.15	-0.05	0.5	700	200	10	30	50	- 200	NA
389*	10	1.5	0.5	0.3	1,500	70	20	15	50	- 200	NA
390*	10	1	-0.05	0.3	1,500	70	100	20	50	- 200	NA
391*	15	0.2	-0.05	0.5	1,500	150	70	30	100	- 200	NA
392*	10	2	0.05	0.3	1,500	70	30	20	70	- 200	NA
393*	15	0.3	-0.05	0.3	3,000	100	150	20	70	- 200	NA
394*	15	1	0.7	0.5	5,000	100	150	15	100	300	NA
395*	10	0.1	-0.05	0.3	700	150	20	50	50	- 200	NA
396*	10	0.05	-0.05	0.5	500	100	10	50	30	- 200	NA
397*	15	0.5	-0.05	0.5	1,000	100	50	30	70	- 200	NA
398*	15	0.7	-0.05	0.3	1,000	100	50	20	50	- 200	NA
399*	10	3	-0.05	0.2	700	30	10	10	20	- 200	NA
400*	15	5	-0.05	0.5	1,000	70	10	15	70	- 200	NA
401*	15	5	-0.05	0.2	1,000	70	20	15	50	- 200	NA
402*	15	0.3	-0.05	0.3	1,000	70	15	30	70	- 200	NA
403*	15	1	-0.05	0.3	1,000	100	15	20	70	- 200	NA
404*	15	0.1	-0.05	0.3	700	100	10	15	50	- 200	NA
405*	10	0.1	0.05	0.5	1,500	100	100	20	100	- 200	NA
406*	15	0.7	-0.05	0.5	5,000	100	200	20	100	- 200	NA
407*	10	0.7	-0.05	0.3	200	100	20	20	70	- 200	NA
408*	15	0.1	-0.05	0.5	1,000	100	15	20	100	- 200	NA
409*	15	0.15	-0.05	0.3	2,000	100	15	20	50	- 200	NA
410*	15	0.1	-0.05	0.3	1,500	150	15	15	50	- 200	NA
411*	10	0.7	-0.05	0.3	1,500	100	150	15	50	- 200	NA
412*	10	0.1	-0.05	0.3	1,500	100	100	20	100	- 200	NA

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
413*	5	0.05	-0.05	0.2	500	30	100	15	200	- 200	NA
414*	10	0.15	-0.05	0.3	200	150	300	20	100	- 200	NA
415*	7	0.3	-0.05	0.3	1,000	100	150	20	50	- 200	NA
416*	7	0.3	-0.05	0.5	700	100	20	20	70	- 200	NA
417*	15	0.15	-0.05	0.5	1,000	200	30	50	50	- 200	NA
418*	15	0.3	-0.05	0.3	1,000	100	20	20	100	- 200	NA
419*	15	1.5	0.1	0.3	1,500	150	20	20	70	500	NA
420*	15	0.7	-0.05	0.3	1,000	150	100	20	50	- 200	NA
421*	10	5	1.5	0.5	2,000	100	100	15	70	200	NA
422*	15	1	-0.05	0.5	1,000	150	100	30	70	- 200	NA
423*	15	0.1	-0.05	0.5	500	150	10	50	50	- 200	NA
424*	15	1.5	-0.05	0.2	1,000	100	20	20	20	- 200	NA
425*	15	0.05	-0.05	0.5	700	200	30	30	100	- 200	NA
426*	15	0.05	-0.05	0.5	1,000	150	10	20	70	- 200	NA
427*	15	0.05	-0.05	0.3	200	150	15	10	70	- 200	NA
428*	15	0.05	-0.05	0.5	200	200	20	15	100	- 200	NA
429*	10	0.2	-0.05	0.5	500	200	30	20	70	- 200	NA
430*	10	2	0.05	0.3	700	100	100	15	70	- 200	NA
431*	15	0.15	-0.05	0.3	700	200	10	30	50	- 200	NA
432*	10	0.1	-0.05	0.3	200	100	100	15	100	- 200	NA
433*	15	0.1	-0.05	0.5	500	200	10	30	50	- 200	NA
434*	15	1	-0.05	0.2	700	150	15	20	30	- 200	NA
435*	15	0.5	-0.05	0.3	1,000	150	70	20	30	- 200	NA
436*	15	0.5	0.05	0.5	1,500	200	70	20	150	- 200	NA
437*	15	0.7	0.05	0.5	1,000	150	150	20	70	- 200	NA
438*	15	1	-0.05	0.3	1,000	150	70	20	50	- 200	NA
439*	20	0.7	0.05	0.5	3,000	200	200	30	50	- 200	NA
440*	15	0.7	0.2	0.3	700	150	50	30	30	- 200	NA
441*	15	0.03	-0.05	0.3	500	200	10	20	50	- 200	NA
442*	20	0.1	-0.05	0.7	300	500	20	20	100	- 200	NA
443*	15	0.05	-0.05	0.2	200	150	10	20	20	- 200	NA
444*	10	0.15	-0.05	0.5	1,000	150	10	30	30	- 200	NA

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
445*	10	2	1	0.5	1,000	200	10	20	100	- 200	NA
446*	10	1	0.5	0.5	300	200	50	50	30	- 200	NA
447*	15	0.1	-0.05	0.5	700	150	10	50	30	- 200	NA
448*	15	1.5	1.5	0.5	1,500	200	50	50	30	- 200	NA
449*	15	0.2	-0.05	0.3	500	300	20	50	30	- 200	NA
450*	15	0.02	-0.05	0.7	300	200	10	30	70	- 200	NA
451*	15	0.05	-0.05	1	1,000	200	10	30	50	- 200	NA
452*	15	0.15	-0.05	0.5	700	150	20	30	30	- 200	NA
453*	15	0.2	-0.05	0.5	1,000	150	50	30	70	- 200	NA
454*	20	0.2	-0.05	0.5	1,000	300	50	50	100	- 200	NA
455*	20	5	0.05	0.3	2,000	100	50	20	50	- 200	NA
456*	15	3	0.07	0.3	1,500	100	70	20	30	- 200	NA
457*	20	0.2	-0.05	1	1,500	200	20	50	50	- 200	NA
458*	15	0.02	-0.05	1	700	200	10	30	50	- 200	NA

APPENDIX D

Spectrographic and Colorimetric Determinations for Nickel, Chromium, Cobalt, and Copper in Rocks[1]

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
8(s)	5,000	2,250	3,000	1,500	150	75	100	60
9(s)	5,000	3,000	5,000	2,200	150	75	15	10
9a *	5,000	4,500	300	200	300	150	2	10
10(s)	5,000	1,500	5,000	3,000	150	75	50	20
20(s)	3,000	1,500	3,000	1,200	100	60	15	20
26(s)	3,000	1,500	5,000	3,000	150	75	30	10
27(s)	5,000	2,250	+5,000	6,000	150	75	70	10
29(s)	5,000	4,500	3,000	1,500	150	75	5	10
40(l)	500	750	5,000	7,500	50	40	50	75
41(s)	3,000	2,250	2,000	800	150	75	100	60
48(l)	100	200	3,000	6,000	20	30	30	40
51(s)	1,500	1,100	5,000	1,500	100	40	10	10
70(l)	20	50	50	100	- 5	20	70	75
79(l)	100	200	70	800	30	30	50	75
85(s)	2,000	1,500	5,000	3,000	150	75	50	20
87a(l)	200	400	1,000	800	70	75	100	150
89(s)	2,000	1,500	5,000	3,000	150	60	10	- 10
90(l)	200	400	2,000	2,200	30	40	100	150
91(s)	3,000	1,500	3,000	1,500	150	75	30	10
94(l)	70	200	1,500	4,000	- 5	30	20	75
95(l)	50	100	100	200	30	20	200	300
96(s)	3,000	1,500	5,000	1,500	150	40	20	10
97a(l)	700	600	1,500	400	100	40	700	600
98(l)	150	400	2,000	1,500	20	30	100	225
99(l)	100	100	2,000	3,000	10	20	30	30
101(l)	150	400	+5,000	12,000	30	30	50	75
104(s)	5,000	1,500	5,000	2,200	150	75	50	10
105(s)	5,000	2,250	5,000	3,000	150	60	20	10
108(s)	3,000	1,500	5,000	1,500	150	40	30	20
109(l)	500	750	+5,000	15,000	30	40	30	60
110(s)	3,000	1,500	5,000	1,200	150	75	30	10
112(l)	700	1,100	+5,000	15,000	50	75	30	40
113(s)	3,000	1,500	5,000	2,200	150	75	30	20

[1] Note: Serpentinite indicated by (s); laterite indicated by (l). "Less than" indicated by (-); "greater than" indicated by (+).

* Sample 9a is clinochrysotile associated with serpentinite sample 9.

Sample locations plotted on Plate 1.

Analyses by U.S.G.S. laboratories, Denver, Colorado

Sample Number	Parts Per Million							
	Nickel		Chromium		Cobalt		Copper	
	Spec	Color	Spec	Color	Spec	Color	Spec	Color
115(s)	3,000	2,250	+5,000	2,200	150	110	15	10
116(s)	3,000	2,250	3,000	1,200	100	75	20	20
117(s)	2,000	1,500	5,000	3,000	150	75	30	30
118(l)	3,000	3,000	5,000	15,000	1,500	1,500	50	60
120(l)	200	400	300	200	30	30	70	110
122(l)	50	100	1,500	4,000	15	40	50	60
123(l)	700	1,100	5,000	8,000	200	300	70	150
124(s)	2,000	1,500	+5,000	2,000	150	60	30	40
125(l)	1,500	1,500	3,000	6,000	150	300	50	75
126(s)	2,000	2,250	5,000	1,500	150	75	15	10
127(s)	2,000	1,500	+5,000	1,500	100	75	30	60
128(l)	2,000	3,000	5,000	4,000	50	40	50	300

APPENDIX E

Spectrographic Determinations for Fe, Mg, Ca, Ti, Mn, V, Ba, Sc, Zr, and Zn, And Atomic Absorption Determinations for Au in Rocks[1]

Sample Number	Percent				Parts Per Million						
	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
8(s)	5	+10	0.1	0.1	500	30	20	15	10	200	-0.02
9(s)	5	+10	0.7	0.1	500	50	50	15	10	-200	-0.02
9a *	2	10	0.05	0.05	1,500	20	100	10	15	-200	-0.02
10(s)	5	+10	0.1	0.05	500	30	30	10	- 10	-200	-0.02
20(s)	2	+10	1.5	0.05	500	30	20	10	15	-200	-0.02
26(s)	3	+10	1	0.05	1,000	30	10	10	- 10	-200	-0.02
27(s)	3	10	0.1	0.05	1,000	50	30	15	- 10	-200	-0.02
29(s)	3	+10	0.1	0.05	500	50	20	10	20	-200	-0.02
40(l)	15	0.15	-0.05	0.5	1,000	200	50	30	70	-200	-0.02
41(s)	5	+10	-0.05	0.2	1,500	30	15	10	10	-200	-0.02
48(l)	15	0.15	-0.05	0.5	200	200	30	15	70	-200	-0.02
51(s)	3	10	5	0.2	1,500	70	- 10	20	20	-200	-0.02
70(l)	20	0.1	-0.05	0.15	30	50	30	10	100	-200	-0.02
79(l)	20	0.02	-0.05	0.05	150	50	10	20	- 10	-200	-0.02
85(s)	5	+10	1	0.1	1,500	50	100	15	- 10	-200	-0.02
87a(l)	20	0.05	-0.05	0.05	500	70	20	20	- 10	-200	-0.02
89(s)	10	+10	1	0.1	1,500	50	10	10	- 10	-200	-0.02
90(l)	20	0.15	-0.05	0.05	150	100	- 10	50	- 10	-200	-0.02

[1] Note: Serpentinite indicated by (s); laterite indicated by (l). "Less than" indicated by (-); "greater than indicated by (+).

* Sample 9a is clinochrysotile associated with serpentinite sample 9.

Sample locations plotted on Plate 1.

Analyses by U.S.G.S. laboratories, Denver, Colorado

Sample	Percent				Parts Per Million						
Number	Fe	Mg	Ca	Ti	Mn	V	Ba	Sc	Zr	Zn	Au
91(s)	10	+10	1.5	0.07	1,500	50	10	10	10	-200	-0.02
94(l)	15	0.03	-0.05	0.15	300	300	15	10	50	-200	-0.02
95(l)	20	- 0.02	-0.05	0.2	100	100	- 10	30	20	-200	-0.02
96(s)	10	+10	-0.05	0.1	300	50	10	20	10	-200	-0.02
97a(l)	10	0.05	0.1	0.2	+5,000	200	500	20	150	300	0.08
98(l)	20	- 0.02	-0.05	0.1	200	150	10	20	20	200	-0.02
99(l)	+20	- 0.02	-0.05	0.3	50	200	10	50	70	200	0.8
101(l)	20	0.02	-0.05	0.3	500	700	50	30	100	-200	0.1
104(s)	5	+10	1.5	0.1	2,000	20	50	15	10	200	-0.02
105(s)	10	+10	0.05	0.05	500	15	10	10	10	-200	-0.02
108(s)	7	10	0.5	0.1	500	50	20	10	20	-200	-0.02
109(l)	20	0.05	-0.05	0.5	200	500	10	20	100	200	-0.02
110(s)	5	+10	0.7	0.1	1,000	30	15	15	10	-200	-0.02
112(l)	20	0.05	-0.05	0.2	500	300	20	20	100	200	-0.02
113(s)	10	10	0.05	0.1	1,000	50	15	15	10	-200	-0.02
115(s)	10	+10	1.5	0.07	2,000	30	20	15	- 10	-200	-0.02
116(s)	5	+10	0.5	0.05	1,500	30	30	15	20	-200	-0.02
117(s)	10	+10	1	0.05	1,500	30	30	15	15	200	-0.02
118(l)	20	0.05	-0.05	0.5	+5,000	100	1,000	20	70	300	0.04
120(l)	+20	0.07	-0.05	0.2	200	70	500	20	50	500	0.02
122(l)	20	- 0.02	-0.05	0.2	150	200	50	30	50	500	-0.02
123(l)	+20	- 0.02	-0.05	0.05	2,000	50	100	70	- 10	500	-0.02
124(s)	20	+10	0.05	0.1	1,000	30	20	20	10	200	-0.02
125(l)	+20	0.02	-0.05	0.07	2,000	30	70	20	30	500	-0.02
126(s)	20	+10	0.05	0.07	1,500	50	10	15	20	-200	-0.02
127(s)	7	10	2	0.1	1,500	50	100	15	30	-200	-0.02
128(l)	20	0.02	-0.05	+1	150	100	10	20	150	200	-0.02

SELECTED REFERENCES

Alexander, L. T. and Cady, J. G., 1962, Genesis and hardening of laterite in soils: U.S. Dept. Agriculture, Tech. Bull. no. 1282.

Bishopp, D. W., 1941, Geology and geography of the Towaikaima region, upper Barama Valley, Northwest District: British Guiana Geol. Survey Bull. no. 16.

Bleackley, D., 1956, Geology of the superficial deposits and coastal sediments of British Guiana: British Guiana Geol. Survey Bull. no. 30.

_____, 1964, The bauxites and laterites of British Guiana: British Guiana Geol. Survey Bull. no. 34.

Bloom, Harold, 1962, Field methods for the determination of nickel using dimethylglyoxime: Econ. Geol., v. 57, no. 4, p. 595-604.

Borisenko, L. F., 1963, Scandium, its geochemistry and mineralogy (trans. from Russian): Consultants Bureau, New York.

Bowen, N. L., 1927, The origin of ultramafic and related rocks: Am. Jour. Sci., 5th. ser., v. 14, p. 89-108.

Bowen, N. L., and Schairer, J. F., 1936, The problem of the intrusion of dunite in the light of the olivine diagram: Internat. Geol. Cong., 16th, Washington, 1933, Rept. v. 1, p. 391-396.

Bowen, N. L., and Tuttle, O. F., 1949, The system MgO - SiO_2 - H_2O: Geol. Soc. America Bull., v. 60, p. 439-460.

Bracewell, S., 1938, Report on the area between Arakaka and Kokerit, Northwest District: British Guiana Geol. Survey Bull. no. 19.

Bryn Davies, D. A., 1940a, Report on the gold and manganese deposits of the lower Barama River: British Guiana Geol. Survey Bull. 14.

_____, 1940b, Report on the geology and mineral deposits of the upper Waini River, Northwest District: British Guiana Geol. Survey Bull. no. 15.

Canney, F. C., 1966, Hydrous manganese-iron oxide scavenging: its effect on stream sediment surveys, _in_ Geochemical prospecting symposium: Ottawa, April, 1966, Geol. Survey of Canada.

Canney, F. C., and Nowlan, G. A., 1964, Determination of ammonium citrate-soluble cobalt in soils and sediments: Econ. Geol., v. 59, no. 7, p. 1361-1367.

Canney, F. C., and Wing, L. A., 1966, Cobalt: useful but neglected in geochemical prospecting: Econ. Geol., v. 61, p. 198-203.

Cannon, R. T., 1961, Notes on Waini southwest quarter-degree sheet: British Guiana Geol. Survey.

_____, 1964a, A preliminary report on the geology of areas in the lower Barama and Waini rivers: British Guiana Geol. Survey, unpublished report.

_____, 1964b, The geology of the Bartica Assemblage: British Guiana Geol. Survey Bull. no. 35.

Cannon, R. T., and Carter, J. W., 1959, A preliminary report on the geology of the Waini (SW) quarter-degree square: British Guiana Geol. Survey, unpublished report.

Chesterman, C. W., 1963, Intrusive ultrabasic rocks and their metamorphic relationships at Leech Lake Mountain, Mendocino County, California, <u>in</u> Short Contributions to California Geology: California Div. Mines and Geology, Spec. Rept. 82, p. 5-10.

Chidester, A. H., 1962, Petrology and geochemistry of selected talc-bearing ultramafic rocks and adjacent country rocks in north-central Vermont: U.S. Geol. Survey, Prof. Paper 345.

Coleman, R. G., 1967, Low-temperature reaction zones and alpine ultramafic rocks of California, Oregon, and Washington: U.S. Geol. Survey, Bull. 1247, 49 p.

Cornwall, H. R., 1966, Nickel deposits of North America: U.S. Geol. Survey, Bull. 1223, 62 p.

de Chételat, E., 1947, La genese et l'evolution des gisements de nickel de la Nouvelle Caledonie: Soc. Geol. France Bull. ser. 5, no. 17, p. 105-160.

De Vletter, D. R., 1955, How Cuban nickel ore was formed: Eng. Min. Jour., p. 84.

Dixon, C. G., and George, H. K., 1964, Bibliography of the geology and mining of British Guiana: British Guiana Geol. Survey Bull. no. 32.

Du Rietz, Torstein, 1935, Peridotites, serpentines, and soapstones of northern Sweden: Geol. Foren. Stockholm Forh. band 57, Left. 2, no. 401, p. 133-260.

Esguerra, F. B., 1960, Morphological study of the Surigao nickeliferous laterites, Mindanao, Philippines: Philippine Geologist, v. 14, no. 2, p. 29-53.

_____, 1961, Geochemistry and mineralogy of the Surigao nickeliferous laterites, Mindanao, Philippines: Philippine Geologist, v. 15, no. 1, p. 1-26.

Evans, H. T., Jr., 1959, The crystal chemistry and mineralogy of vanadium, in Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, p. 91-102.

Faust, G. T., and Fahey, J. J., 1962, The serpentine-group minerals: U.S. Geol. Survey Prof. Paper 384-A.

Fischer, R. P., 1959, Vanadium and uranium in rocks and ore deposits, in Geochemistry and mineralogy of the Colorado Plateau uranium deposits: U.S. Geol. Survey Prof. Paper 320, p. 219-230.

Fisher, R. B., and Dressel, W. M., 1959, The Nicaro (Cuba) nickel ores; basic studies, including differential thermal analysis in controlled atmospheres: U.S. Bur. Mines, Rept. Invest. 5496.

Garrels, R. M., and Christ, C. L., 1965, Solutions, minerals, and equilibria: New York, Harper and Row, 450 p.

Garrett, R. G., and Nichol, Ian, 1967, Regional geochemical reconnaissance in eastern Sierra Leone: Trans. Inst. Min. Metall., Sect. B: Earth Sci., v. T6, p. 97-112.

Goldschmidt, V. M., 1954, Geochemistry: London, Oxford Univ. Press.

Hawkes, H. E., and Webb, J. S., 1962, Geochemistry in mineral exploration: New York, Harper and Row, 415 p.

Heidenreich, W. L., and Reynolds, B. M., 1959, Nickel-cobalt-iron-bearing deposits in Puerto Rico: U.S. Bur. Mines, Rept. Invest. 5532.

Henry, R., 1966, Report on the pitting prospection in the Wanamu area: Guyana Geol. Survey, unpublished report.

Hess, H. H., 1933a, The problem of serpentinization, and the origin of certain chrysotile asbestos talc and soapstone deposits: Econ. Geol., v. 28, p. 634-657.

_____, 1933b, Hydrothermal metamorphism of an ultrabasic intrusion at Schulyer, Virginia: Am. Jour. Sci., v. 26, p. 377-408.

_____, 1938, A primary peridotite magma: Am. Jour. Sci., v. 35, p. 321-344.

_____, 1955, Serpentinites, orogeny and epeirogeny: Geol. Soc. America Special Paper, no. 62, p. 391-408.

Hill, V. G., 1961, Geochemical prospecting for nickel in the Blue Mountains area, Jamaica, W.I., Econ. Geol., v. 56, no. 6, p. 1025-1032.

Hotz, P. E., 1964, Nickeliferous laterites in southwestern Oregon and northwestern California: Econ. Geol., v. 59, no. 3, p. 355-396.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill Book Company, 721 p.

Lloyd, J. W., 1960, Report on the geology of the lower Barama and Waini rivers: British Guiana Geol. Survey, unpublished report.

Lloyd, J. W., and Williams, E., 1960, Traverse of part of the Barama River: British Guiana Geol. Survey, unpublished report.

Maignien, R., 1966, Review of research on laterites: Liege, UNESCO, Natural Resources Research IV.

McConnell, R. B., 1962, Provisional geological map of British Guiana, 1:1,000,000: British Guiana Geol. Survey.

_____, 1966, Notes on the erosion levels and geomorphology of British Guiana: Caribbean Geol. Conf., 3rd, Trans., p. 151-157.

McConnell, R. B., and others, 1964, A new interpretation of the geology of British Guiana: Nature, v. 204, no. 4954, p. 115-118.

Miller, C. P., 1961, Plant and soil prospecting for nickel: Am. Inst. Min. Met., and Petroleum Eng., Trans., v. 220, p. 255-260.

Mohr, E. C. J., and van Baren, F. A., 1954, Tropical soils: New York, Interscience Publishers.

Montoya, J. W., and Gretta, S. B., 1963, Nickeliferous serpentinites, chlorites, and related minerals found in two lateritic ores: Am. Mineralogist, v. 48, no. 11/12, p. 1227-1238.

Nichol, Ian, Horsnail, R. F., and Webb, J. S., 1967, Geochemical patterns in stream sediment related to precipitation of manganese oxides: Trans. Inst. Min. Met., Sect. B: Earth Sci., v. 76, p. B113-B114.

Pecora, W. T., 1944, Nickel-silicate and associated nickel-cobalt-manganese oxide deposits near Sao Jose de Tocantins, Goiaz, Brazil: U.S. Geol. Survey Bull. 935-E, p. 247-305.

Pecora, W. T., and Hobbs, S. W., 1942, Nickel deposit near Riddle, Douglas County, Oregon: U.S. Geol. Survey Bull. 935-I, p. 205-226.

Pecora, W. T., and others, 1949, Variations in garnierite from the nickel deposit near Riddle, Oregon: Econ. Geol., v. 44, p. 12-23.

Phillips, A. H., and Hess, H. H., 1936, Metamorphic differentiation at contacts between serpentine and silicious country rock: Am. Mineral., v. 21, p. 333-362.

Read, H. H., 1934, On the zoned associations of talc, actinolite, chlorite, and biotite in Unst, Shetland Islands: Mineral. Mag., v. 33, p. 519-540.

Routhier, 1952, Les gisements de fer de la Nouvelle Caledonie: Int. Geol. Cong., 19th, Algiers, Symposium on Iron, p. 567-587.

Sivarajasingham, S., and others, 1962, Laterite: Adv. Agronomy, v. 14, p. 1-60.

Stockley, G. M., 1955, Geology of British Guiana and the development of its mineral resources: British Guiana Geol. Survey, Bull. no. 25.

Stoll, W. C., 1958, Geology and petrology of the Masinloc chromite deposit, Zambales, Luzon, Philippine Islands: Geol. Soc. America, Bull. 69, no. 4, p. 419-448.

Stueber, A. M., and Goles, G. C., 1967, Abundances of Na, Mn, Cr, Sc, and Co in ultramafic rocks: Geochem. et Cosmochim. Acta, v. 31, p. 75-93.

Suvanasingha, Akanist, 1963, Geochemical study of chromium in soil over the chromite deposit of the Narathivas province, southern Thailand: in Proceed. of the seminar on geochem. prospecting methods and techniques, U. N. Mineral Resources Develop. Ser. no. 21, New York.

Taliaferro, N. E. L., 1943, Franciscan Knoxville problem: Am. Assoc. Petroleum. Geologists Bull., v. 27, p. 109-219.

Thayer, T. P., 1956, Mineralogy and geology of chromium: in Chromium, Udy, M. J., ed.: Am. Chem. Soc. Mon. 132, v. 1, chap. 2, p. 14-52.

_____, 1960, Some critical differences between alpine-type and stratiform peridotite-gabbro complexes: Int. Geol. Cong., Rept. 21, Session, Norden; pt. 13, p. 247-259.

_____, 1961, Application of geology in chromite exploration and mining: in symposium on Chrome ore: Ankara, CENTO.

Thompson, C. E., Nakagawa, H. M., and van Sickle, G. H., 1968, Rapid analysis for gold in geologic materials: U.S. Geol. Survey, Prof. Paper (in press).

Turner, F. J., and Verhoogen, John, 1960, 2nd. ed., Igneous and metamorphic petrology: New York, McGraw-Hill Book Company, Inc., 694 p.

Vinogradov, A. P., 1959, 2nd. ed., The geochemistry of rare and dispersed chemical elements in soil (Trans.): New York, Consultants Bureau, 209 p.

_____, 1962, Average contents of chemical elements in the principle types of igneous rocks of the earth's crust: Geochemistry, v. , no. 7, p. 641-664.

Von Gaertner, H. R., 1963, Geochemistry of lateritic deposits; some general patterns of lateritic weathering, in Proceedings of the seminar on geochemical prospecting methods and techniques: U.N. Min. Res. Develop. Ser. no. 21, p. 67-75.

Ward, F. N., and others, 1963, Analytical methods used in geochemical exploration by the U.S. Geological Survey: U.S. Geol. Survey Bull. no. 1152.

Webb, J. S., 1958, Observations on geochemical exploration in tropical terrains: Int. Geol. Cong., 20th, Explor. Geochim. Symp., t. 1, p. 143-173.

Webber, B. N., 1952, Manganese deposits in the Northwest District, British Guiana: British Guiana Geol. Survey Bull. no. 23, pt. 1.

Williams, E., ed., 1961, Waini southwest quarter-degree sheet: British Guiana Survey.

Williams, Howel, Turner, F. J., and Gilbert, 1954, Petrography, an introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Company.

Worthington, J. E., 1964, An exploration program for nickel in the southeastern United States: Econ. Geol., v. 59, no. 1, p. 97-109.

Wyllie, P. J., ed., 1967, Ultramafic and related rocks: New York, John Wiley and Sons, Inc., 464 p.

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