Geochemical Prospecting Investigations in the Copper Belt of Vermont

GEOLOGICAL SURVEY BULLETIN 1198-B

Canney—GEOCHEMICAL PROSPECTING INVESTIGATIONS IN THE COPPER BELT OF VERMONT—Geological Survey Bulletin 1198-B

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By F. C. CANNEY

CONTRIBUTIONS TO GEOCHEMICAL PROSPECTING FOR MINERALS

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A study of the copper and zinc anomalies present in soils over near-surface pyrrhotitic copper deposits concealed by glacial till

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GEOCHEMICAL PROSPECTING INVESTIGATIONS IN THE COPPER BELT OF VERMONT

By F. C. Canney

ABSTRACT

Geochemical prospecting studies were made in 1954 and 1955 in the Copper Belt of Orange County, Vt. This district, which lies in the maturely dissected uplands of west-central New England, is underlain by highly deformed and metamorphosed rocks of early Paleozoic age. The ore in the various mines is principally pyrrhotite with subordinate amounts of chalcopyrite and sphalerite. The bedrock is covered nearly everywhere with a mantle of glacial deposits, which range from a thin veneer of basal till on the uplands to much thicker deposits of till and outwash in the valley bottoms. Podzolic soils are developed on this till.

The field studies were designed principally to (a) determine whether anomalous chemical patterns of copper and zinc exist in the glacial soils in the vicinity of concealed pyrrhotitic copper deposits, (b) measure the physical and chemical characteristics of the dispersion patterns, and (c) establish optimum field and laboratory procedures for the detection of these patterns. Most of these field studies were made in the area of the Elizabeth mine, which lies in the extreme southern part of the Copper Belt.

Anomalous patterns of copper are present in the soils over and adjacent to suboutcropping pyrrhotitic copper deposits concealed by a thin mantle of basal till. The total copper content of small soil samples collected in the top of the B soil horizon can be used as a guide in the search for anomalous areas. Copper values of 50 ppm (parts per million) and more are considered to be anomalous; background values range from 10 to 40 ppm. Anomalous values as high as 1,200 ppm were recorded from the B zone of soils located directly over suboutcropping ore containing about 1.1 percent copper.

The highly skewed asymmetrical copper anomaly at the Elizabeth mine was formed by means of mechanical dispersion by glacial ice of a preglacial copper-rich residual soil. Later, some copper was redistributed by ground water; thus, the original syngenetic pattern was modified and lateral seepage anomalies were produced on the west side of the ore zone. The presence of ore minerals and gossan in the till verifies the syngenetic origin of the pattern.

At the Elizabeth mine, where the probable direction of ice movement makes a small angle with the strike of the ore zone, the anomalous patterns are detectable as much as 1,000 feet away from the zone. In general terms, the lateral extent, shape, and contrast of an anomaly associated with any given ore body are dependent on the tenor of the ore deposit; the geometrical relationship between the shape of the deposit and the direction of glacial transport; the thickness and type of the glacial mantle together with the intensity of glacial erosion; and the extent to which the original pattern has been modified by ground-water movement.

Anomalies of cold-acid-extractable copper, according to limited data, have greater contrast than corresponding total-copper anomalies because most of the anomalous copper is in relatively soluble secondary minerals. The ratio of cold-acid-extractable copper to total copper, therefore, does not discriminate between syngenetic and superimposed lateral seepage patterns.

INTRODUCTION

Geochemical soil sampling is a reliable exploration tool in prospecting for mineral deposits that are concealed by overburden of residual origin. Little agreement exists, however, regarding the usefulness of soil sampling in areas where the bedrock is covered by surficial deposits of transported material.

Glacial debris is a variety of transported cover commonly found in geochemical surveys. For this reason, the principal aims of my geochemical studies were to determine whether anomalous chemical patterns exist in the glacial cover in the vicinity of known copper deposits, to ascertain the physical and chemical characteristics of any patterns found, and to use the resulting data as a guide for developing adequate prospecting techniques to be used in glaciated areas where the glacial history is reasonably similar to that in the Copper Belt.

Experiments were made to determine:

1. The distribution and values of metals in near-surface soil along traverses across the suboutcrops of mineralized zones.
2. The vertical distribution of copper in soil profiles in both background and anomalous areas.
3. The distribution of copper in the various size fractions of soil and till.
4. The range of copper background values in the overburden away from the influence of mineralization.
5. The effects of contamination from past mining and smelting operations.
6. The vertical distribution of metals in the till immediately over and adjacent to mineralized zones.

The fieldwork on which this report is based was done in August 1954 and September and October 1955. I wish to thank Appalachian Sulfides, Inc., who operated the Elizabeth mine at that time, for permission to work on its various properties. My investigations were greatly facilitated by its technical staff, especially Mr. J. F. Cowley, general manager, and Mr. R. C. Dwelley, chief geologist,

who furnished facilities for a field laboratory, provided detailed maps of several areas, and otherwise extended many courtesies.

The analytical data shown in the illustrations in this report were obtained by the following U.S. Geological Survey chemists: H. E. Crowe, C. E. Thompson, D. R. Bivens, G. C. Campbell, D. B. Hawkins, H. G. Neiman, R. R. Beins, and G. A. Nowlan.

DESCRIPTION OF THE AREA

The Copper Belt of Vermont, also known as the Orange County copper district, lies in the maturely dissected uplands of Central New England in the southeastern part of Orange County (fig. 1). It is a northward-trending belt about 20 miles long and as much as 5 miles wide. Altitudes range within the belt from about 700 to 2,300 feet; most of the land surface lies between altitudes of 1,000 and 2,000 feet. The precipitation in this part of Vermont averages 40–45 inches. The winters are long and cold, and snowfalls are heavy; the summers are short and ordinarily very cool. In the past this region was heavily farmed, but now many of the farms are abandoned. The rolling hills are covered mostly with second and third growth deciduous trees.

The mines and prospects of the Copper Belt are in highly metamorphosed and intensely deformed rocks of early Paleozoic age. These rocks are part of a thick series of metasedimentary and metavolcanic rocks that lie on the east limb of the Green Mountain anticlinorium. The western part of the district is underlain by a series of interbedded calcareous mica schists, impure limestones, and impure quartzites of the Silurian and Devonian Waits River Formation; the eastern part contains dominantly noncalcareous quartz-mica schists of the overlying Devonian Gile Mountain Formation.

The ore bodies of the Copper Belt are lenticular and generally lie parallel to the cleavage of the wallrock (White and Eric, 1944). Some deposits are composed of single elongated shoots whose plunge closely parallels the plunge of nearby minor folds; other deposits are made up of several overlapping lenses. Pyrrhotite is the principal sulfide mineral, and subordinate amounts of chalcopyrite and sphalerite occur with it. The average grade of mined ore ranged from about 1.5 to 3.5 percent copper.

The Elizabeth mine, on Copperas Hill about 2 miles southeast of South Strafford (fig. 1), is the southernmost mine of any significance in the Copper Belt. The ore zone strikes N. 5° E., and the dip ranges from 60° E. to vertical. The principal and most productive ore body is a northward-plunging continuous ore shoot. It is 11,400 feet in known length, and about 10,000 feet of this has been mined by both underground and open-pit operations (fig. 2). The mine was described by McKinstry and Mikkola (1954) and by Howard (1959a, b); the interested reader can refer to their reports for additional details.

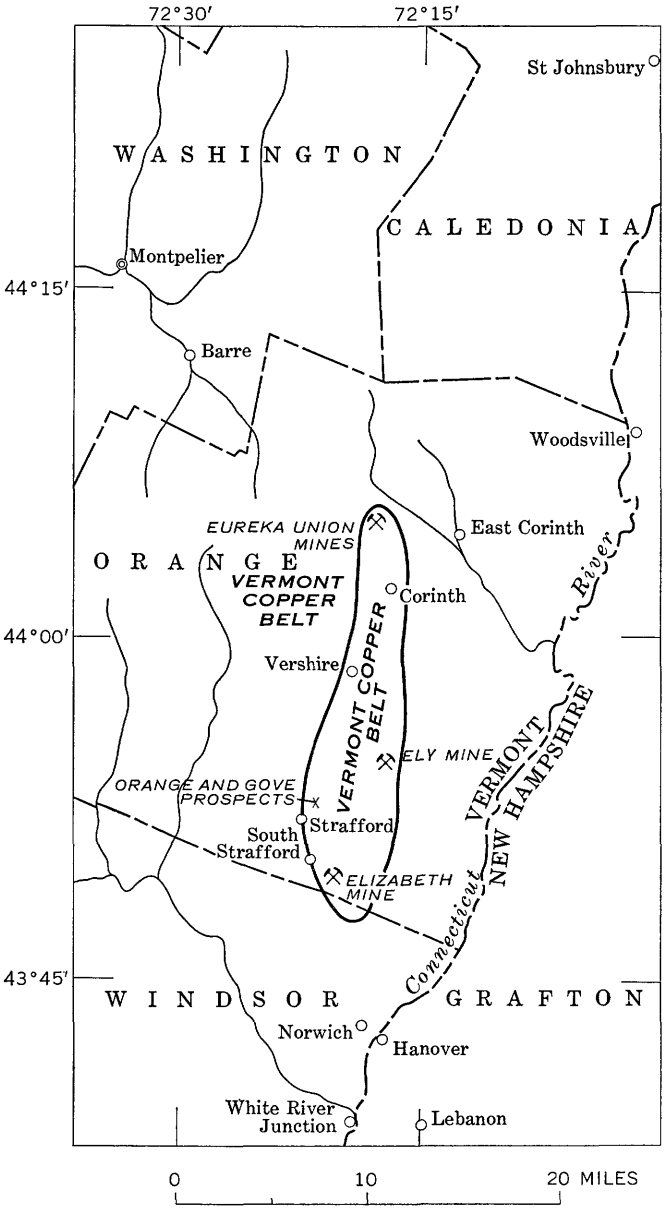

FIGURE 1.—Location of the Vermont Copper Belt and the principal mines and prospects. Adapted from map by White and Eric (1944).

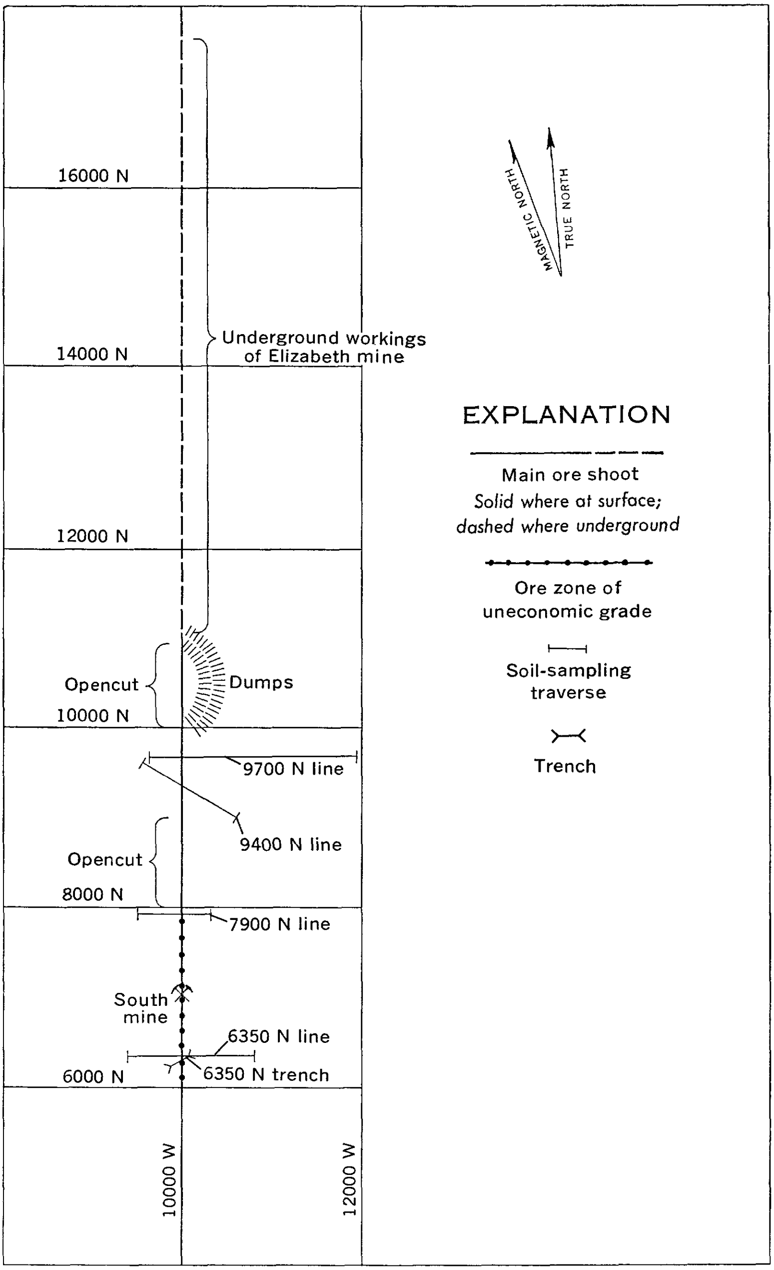

FIGURE 2.—The Elizabeth mine area; shown are the principal soil-sampling traverses and trench where detailed profile studies were made, and the mine coordinate system (grid north is N. 5° E.). Opencut 2 is between coordinates 8000 N. and 10000 N.

According to McKinstry and Mikkola (1954, p. 19), pyrrhotite constituted nearly 90 percent of the sulfide matter, and chalcopyrite, about 9 percent; these proportions were different in various parts of the ore body. They also reported that the ore contained about 0.4 percent zinc and small amounts of precious metals.

The Copper Belt was glaciated during Wisconsin time, and the ice movement was probably in a south-southeasterly direction. Bedrock in the Copper Belt is covered nearly everywhere with glacial deposits ranging from thick glaciofluvial deposits in the bottoms of the major valleys to thin, discontinuous patches of compact till on the hillsides. No exhaustive study was made of this surficial mantle, and most observations were confined to roadcuts and exploration trenches at the various mines and prospects. Where observed, the till cover ranged in thickness from zero to about 15 feet, but much greater thicknesses are inferred in many localities.

This till is a very tough, compact heterogeneous mass composed of pebbles, cobbles, and boulders of many different rock types in all stages of decomposition in a matrix of silt, sand, and clay. A weak horizontal fissility is usually present where the deposit is rich in clay and silt. The extreme compactness and rough fissility of this till suggest that it is a basal till deposited beneath the glacial ice.

Partial chemical analyses of five soil profiles (table 1) show that the range in composition in the several horizons is usually small, especially in profiles 1 and 5. Nevertheless, these data conform, though not in every instance, to the general concept of podzolic profiles in that there has been an apparent concentration of alumina and iron oxide in the B horizon; this trend is most noticeable in profiles 2, 3, and 4.

The soils range in thickness from about 15 to 30 inches (depth to top of C horizon) where the parent till is thick enough to allow full development of the soil profile. True Podzols, those soils characterized by the presence of a clean-cut gray or white layer in the upper part of the profile, are seen mainly in those localities where the soils are of somewhat lighter than average texture and have excellent internal drainage.

A few determinations of the acidity of the B and C horizons of soils showed the pH to range from 5.0 to 5.3.

TABLE 1.—*Partial chemical analyses of five podzolic soil profiles from Orange County, Vt.*

[Analyses based on −100-mesh fraction of air-dried soil. Analysts: P. L. D. Elmore and K. E. White, U.S. Geol. Survey]

Sample No.		Horizon	Element, expressed as oxide, in percent			
Field	Laboratory		SiO_2	Al_2O_3	Fe_2O_3 [1]	TiO_2
Profile 1						
Roadcut between South Strafford and Sharon, 2.4 miles west of South Strafford						
17	140880	A	65.4	11.3	5.5	0.78
18	140881	B	69.0	11.5	5.6	.78
19	140882	C	68.1	12.6	6.0	.85
Profile 2						
Roadcut between South Strafford and Sharon, 3.6 miles west of South Strafford						
20	140883	A	70.0	8.9	4.2	0.84
21	140884	B_1	62.6	12.4	6.0	.75
22	140885	B_2	69.7	13.1	5.5	.78
23	140886	C	68.1	12.2	6.4	.93
Profile 3						
Wall of trench across Elizabeth mine ore zone at about coordinate 9400 N.						
49	140887	A	72.3	9.1	4.6	0.79
50	140888	B	57.9	13.4	6.9	.76
51	140889	C	67.8	13.1	5.0	.76
Profile 4						
Wall of trench across Elizabeth mine ore zone, 5 ft east of profile 3						
53	140890	A	65.4	11.0	6.0	0.75
54	140891	B	61.0	13.3	7.6	.68
55	140892	C	69.4	12.0	4.8	.72
Profile 5						
Roadcut, about 2 miles north of Strafford						
138	140893	A	70.2	9.8	4.6	0.60
139	140894	B_1	68.0	11.6	4.6	.61
140	140895	B_2	71.1	11.2	4.4	.58
141	140896	C	71.2	11.2	5.0	.58

[1] Total iron, expressed as Fe_2O_3.

PREVIOUS GEOCHEMICAL-PROSPECTING INVESTIGATIONS

The only earlier geochemical-prospecting investigation in the Copper Belt known to me was a brief reconnaissance of the area around the Ely mine in 1947 by H. L. Cannon (written commun.). Mrs. Cannon's study—devoted mainly to a survey of vegetation that had regained a footing on the old dumps, slime ponds, and roast beds—showed a striking absence of all higher forms of life with the exception of two species of white birch trees (*Betula alba* and *Betula populifolia*). These species were stunted, however, and displayed other morphological changes and symptoms of physiological disease. Mrs. Cannon showed an example of a chlorotic leaf pattern developed on a maple tree growing in copper-rich soil in the area (1960, p. 593). She also noted that for a distance of 1,500 feet along the strike of the mineralized zone, the flora consisted almost entirely of birch trees.

Geophysical and geochemical work was done during 1954–56 by Appalachian Sulfides, Inc., in connection with its exploration program in the Copper Belt, but those data are not available.

COLLECTION AND ANALYSIS OF SAMPLES

Except as otherwise noted, the soil samples were "grab" samples that weighed 25–30 grams. They were collected from the top of the B horizon at an average depth of 6–9 inches. The soil profiles and vertical sections of till that were exposed in exploration trenches were channel sampled. On some traverse lines, samples of humus from the A_0 horizon were collected in addition to the sample of mineral soil from the B horizon. Because of the thinness of the A_0 layer, many of these humus samples contained variable amounts of material from the A_1 horizon.

All soil samples except those that had high humus content were slightly pulverized with a wooden roller to break up the soil structure and sieved to either −80 or −100 mesh, and the fines were saved for analysis. Humus samples were pulverized and heated to 450°C for 1 hour to destroy the organic matter. The analytical data on these humus samples were recalculated back to the original sample.

All the samples collected in this investigation were analyzed for total copper content by rapid field methods that have been developed for use in geochemical prospecting; 22 were also analyzed by precise laboratory methods. Total copper was determined by two methods, both of which utilize a bisulfate fusion to decompose the sieved sample and then use dilute hydrochloric acid to leach the melt. Total copper refers to that amount of copper—generally most of the copper present in the sample—that is released from the sample by this method of decomposition. Copper in the leachates from the bisulfate fusion was determined by a dithizone procedure (Bloom and Crowe, 1953) on the samples collected in 1954. A newer procedure that utilizes biquinoline dissolved in an isoamyl alcohol extract as the copper reagent was used on the remaining samples (Almond, 1955). Cold-acid-extractable copper—that amount of copper which is dissolved from a sample by shaking it with 6N hydrochloric acid at room temperature—was determined on some samples (method described by Canney and Hawkins, 1958).

The zinc determinations were made by use of a dithizone procedure described by Ward and others (1963, p. 19–25).

The results of the determination of the copper content in the 22 samples by both rapid field and precise laboratory methods (table 2) indicate that the agreement of data from the two methods is reasonably good. The rapid-determination values tend to be somewhat lower than the quantitative values, perhaps due to incomplete decomposition of the soils by the bisulfate fusion used in the field procedure. The quantitative spectrophotometric copper method utilizes a more rigorous digestion that completely decomposes the sample, and the values are generally correct to within ±10–15 percent.

TABLE 2.—*Comparison of copper content as determined by rapid field and by laboratory methods*

[Analysts: H. E. Crowe and C. E. Thompson]

Sample No.		Copper content (ppm)		Sample No.		Copper content (ppm)	
Field	Laboratory	Rapid field method	Laboratory method	Field	Laboratory	Rapid field method	Laboratory method
16	55-366	30	32	53	382	80	125
17	367	15	20	54	383	500	750
18	368	15	26	55	384	450	650
19	369	25	30	138	385	15	14
20	370	10	7	139	386	15	16
21	371	15	18	140	387	10	20
22	372	25	30	141	388	15	20
23	373	25	28	346	389	15	26
49	378	70	150	347	390	15	30
50	379	270	400	348	391	15	20
51	380	450	575	349	392	10	16

ESTIMATION OF COMBINED ANALYTICAL AND SAMPLING ERROR

To evaluate the magnitude of the combined sampling and analytical error, I resampled 19 sites selected to show a wide range in the copper content. These samples were analyzed for copper, and the values obtained on the 19 duplicate pairs (fig. 3) show that 14 pairs plot on or within the +50-percent −33-percent limits, and 18 pairs plot within the +100-percent −50-percent limits. Thus, if the copper content of two soil samples differs by a factor of more than 1.5, the chances are slightly better than two out of three that there is a true difference in their copper content, and almost definitely so if the copper content differs by a factor of 2 or more.

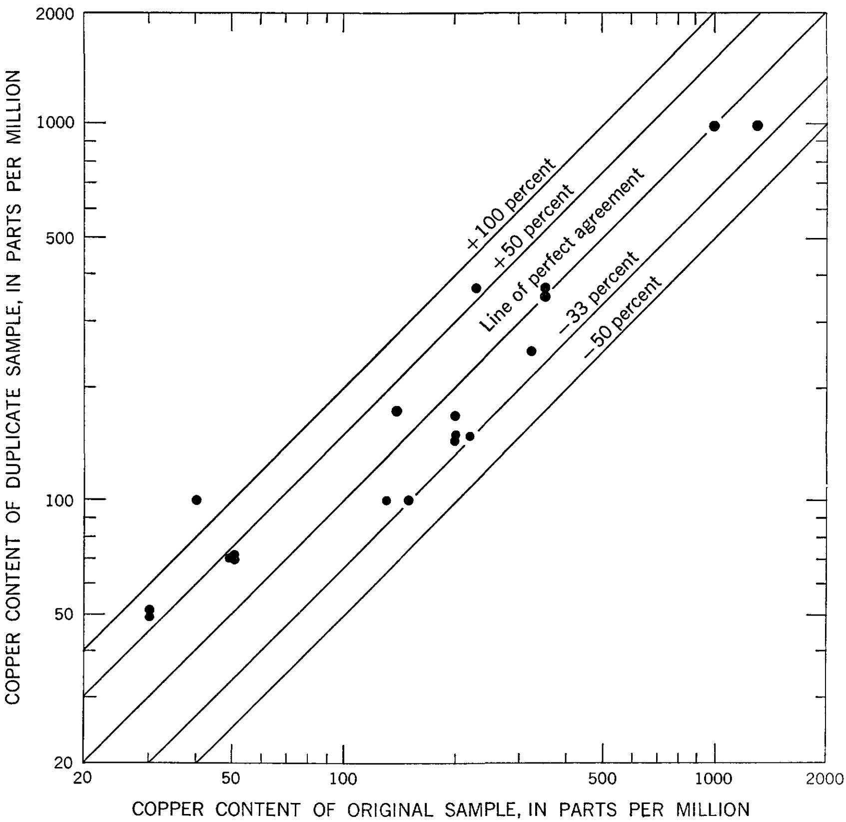

FIGURE 3.—Comparison of copper content of 19 pairs of duplicate samples. Fourteen pairs plot within the +50-percent −33-percent limits; 18 pairs plot within the +100-percent −50-percent limits.

ESTIMATION OF BACKGROUND COPPER CONTENT

Data on the distribution of copper within the soil profile (table 3) show that there has been a relative impoverishment of copper in the A horizon. In this respect the distribution of copper is similar to that of iron and aluminum (table 1). No obvious corresponding enrichment of copper has occurred in the B horizon as compared with the C horizon. The high value of 1,500 ppm in the B_2 horizon of profile 6 probably reflects erratic original differences in the copper content of the parent till rather than enrichment by soil-forming processes. The distribution of copper in the three anomalous profiles (table 3; profiles 3, 4, 6) may have been affected both by original compositional variations and by laterally moving, copper-rich ground water.

The copper content of the suites of samples collected in profiles 1, 2, and 5 (table 3), and of additional samples collected in locations believed unaffected by glacial dispersion of copper from mineralized areas, established the background copper content in the B and C horizons as 10–40 ppm. Based on these figures the threshold value (the limiting anomalous value) is 50 ppm.

TABLE 3.—*Copper content of anomalous and background soil profiles*

[Copper determined by quantitative laboratory method except as noted. See table 1 for location of profiles 1-5. −80-mesh fraction used for analysis. Analysts: H. E. Crowe and C. E. Thompson]

Soil horizon	Copper content (ppm)					
	Profile					
	1	2	3	4	5	6[1]
A	20	7	150	125	14	400
B_1	[2] 26	18	[2] 400	[2] 750	16	400
B_2	None	30	None	None	20	1, 500
C	30	28	575	650	20	900

[1] Profile located over Elizabeth mine ore zone 10 ft west of profile 3. Determinations by rapid field method.
[2] Undifferentiated B horizon.

CONTAMINATION STUDIES

In the Copper Belt much ground that was disturbed and perhaps seriously contaminated by early mining operations has regained an apparently undisturbed surface appearance. That the soil-forming processes could have regenerated a normal-appearing soil profile in such a short time seems unlikely. Accordingly, the presence of a normal podzolic soil profile at sites along a sample traverse was used as a criterion that the surface had not been physically disturbed.

Possible contamination of large areas by condensation from smelter fumes and by windblown material from tailings ponds and dumps was of still greater concern. Contamination of this type is serious because it can radically raise the metal content of a soil without visibly changing the appearance of the soil profile.

To determine the extent of any contamination, I collected profile samples at several localities over unmineralized ground in the Elizabeth mine area where a study of the geography and topography indicated that contamination should have been most intense. The copper content of these samples showed negligible contamination by copper. These data also were confirmed by an overall appraisal of the copper content of all soil samples collected during the study.

RELATION BETWEEN COPPER CONTENT AND SOIL PARTICLE SIZE

The distribution of copper in the various size fractions was determined by an examination of several pounds of soil collected from the B zone at three sample sites. These sites were chosen to represent both background and anomalous conditions in the vicinity of the Elizabeth ore zone. The −2-mm parts of these samples were screened into five size groups. The data in table 4 show that there is no significant variation in the copper content of the various size fractions when the probable precision of the chemical field method is taken into consideration. The data also show that much of the soil in each sample is in the finer sizes. Some material in the clay- and silt-size range may be included in the coarser fractions because the mechanical method of pulverization used probably failed to completely break up all the smaller lumps of silt and clay. Chemical methods of dispersing the samples were not used because of their possible effects on the copper content.

TABLE 4.—*Relation between copper content and soil particle size in three soil samples*

Copper content expressed in parts per million. Weight-percent values based on −2-mm part of bulk sample.[1] Analyst: H. E. Crowe]

Diameter of soil particle (mm)	Copper content (upper figure) and weight percent (lower figure) of soil in fraction		
	B-2	*B-3*	*B-4*
1–2	1, 500 / 10. 2	600 / 9. 7	20 / 5. 6
0. 5–1	800 / 12. 9	600 / 10. 3	20 / 8. 5
0. 25–0. 5	800 / 15. 8	800 / 19. 7	20 / 16. 3
0. 125–0. 25	800 / 19. 4	800 / 24. 4	20 / 22. 9
0. 062–0. 125	600 / 17. 8	800 / 17. 7	30 / 16. 3
<0. 062	800 / 23. 9	800 / 18. 2	30 / 30. 4

[1] Material larger than 2 mm in diameter made up 16.1 percent of B-2, 26 percent of B-3, and 11 percent of B-4.

A comparison of the copper contents of the fine versus the coarse fractions of 27 samples (fig. 4) provided additional evidence that the copper content of the fine fraction is representative of that of the entire sample. Of the 27 pairs plotted, 24 differed by a factor of 1.5 or less and none differed by more than a factor of 1.75. The points falling off the line of perfect agreement are also symmetrically arranged about it. These slight differences in values did not exceed the variations introduced by the analytical field method used.

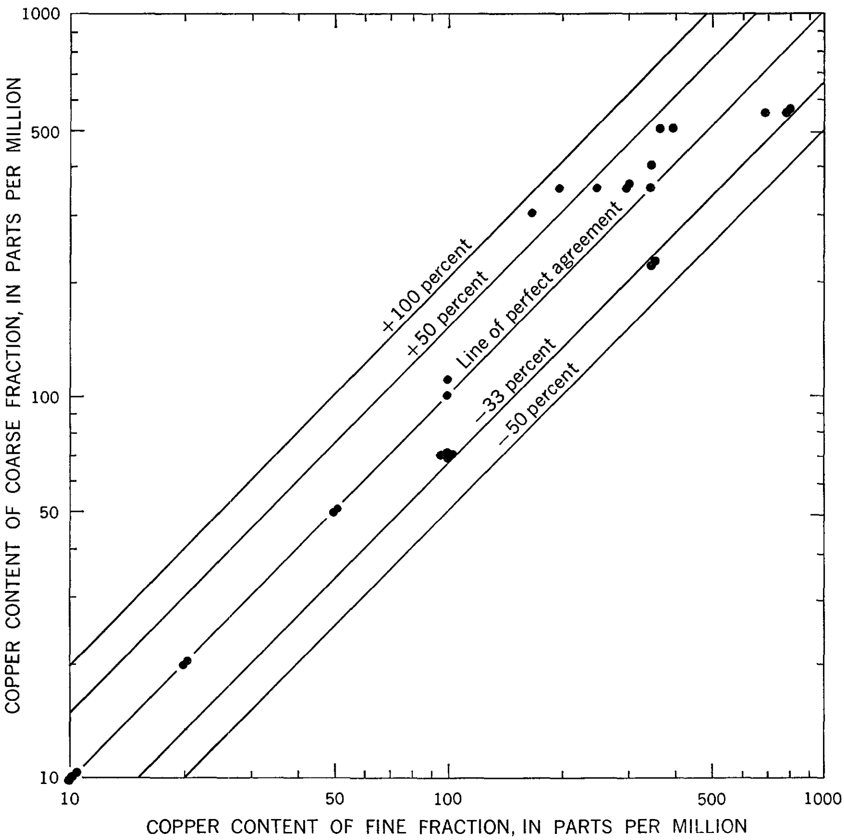

FIGURE 4.—Comparison of copper content of fine and coarse fractions of soil. Fine fraction is −80-mesh (0.177 mm) material; coarse fraction is 0.177- to 2-mm material.

LATERAL DISTRIBUTION OF METAL IN SOIL OVER ELIZABETH ORE ZONE

Much of the geochemical prospecting in the Copper Belt was devoted to detailed studies of the distribution of copper and zinc in soil and till over and closely adjacent to the ore zone of the Elizabeth mine. The optimum sampling scheme for detailed outlining of the shape and extent of the dispersion pattern would be a rectilinear grid of samples taken at regular intervals along closely spaced traverse lines. Such a scheme was impossible for the Elizabeth mine area, however, because samples could not be obtained directly over much of the mineralized zone and because much of the ground had been disturbed. Accordingly, most of the information about the lateral dispersion of copper was obtained from the analyses of samples from four traverses (9700 N., 9400 N., 7900 N., 6350 N., fig. 2) that crossed the mineralized zone at points where copper content varied considerably. The grades ranged from slightly more than 1 percent north of opencut 2 to probably only a few tenths of a percent in the zone south of the South mine (fig. 2). Because many of the other factors that influence the contrast of secondary anomalies are reasonably similar along the four traverse lines, the data afforded an opportunity to appraise the influence of ore grade and width on the shape and contrast of the anomalies. Sample collection points were spaced from as little as 5 feet apart over and adjacent to the ore zone to as much as 100 feet apart at the ends of the traverses.

The presence of numerous exploration trenches across the ore zone as well as information shown on detailed geologic maps supplied by Appalachian Sulfides, Inc. made it possible to locate within a few feet the position of the mineralized zone with reference to the location of the soil samples.

Dissimilarity between the northwesterly direction of near-surface ground-water movement in the ore zone and the probable south-southeasterly direction of glacial transport is another factor of considerable importance in the interpretation of the geochemical data in the Elizabeth mine area. The topography over much of the ore zone is such that soil moisture and near-surface ground water probably flow westward into a topographically low area which parallels the mineralized structure, as can be seen in figures 5 and 7, where generalized profiles of the land surface accompany the geochemical data.

TRAVERSES NORTH OF OPENCUT 2

In the fall of 1954, stripping operations in front of the advancing north face of opencut 2 (fig. 2) had not yet obliterated all the vegetation and virgin soil cover over the main ore zone, and meaningful geochemical data seemingly could be obtained over a strike length of at least several hundred feet. Through the courtesy of Appalachian Sulfides, Inc., a trench was bulldozed across the suboutcrop of the ore zone to furnish a site for preliminary sampling and determination of the depth and composition of the overburden; this trench was also used to study the vertical distribution of copper in the soil profile.

After the results of preliminary sampling established that anomalous concentrations of copper were present in the soil directly over the zone, samples of near-surface soil were collected along two traverses that intersect the ore zone near coordinates 9400 N. and 9700 N.(fig. 2). The data on the metal content of the samples collected on these lines are presented in figures 5–8.

The 9700 N. profile (fig. 5) shows a strong asymmetrical copper anomaly skewed to the east. The copper content of the soil equals or exceeds the 50-ppm threshold figure over a distance of 1,000 feet. From the peak value (800 ppm) the anomaly decreases regularly to a constant level of 20 ppm about 1,300 feet east of the ore zone. (The sample collected just east of the road probably was contaminated, possibly by dump material used as road metal.) The shape of this anomaly indicates that it resulted from glacial ice scouring and smearing the copper-rich soil and gossan that must have overlain the mineralized zone originally.

Examination of the detailed soil data (fig. 6) reveals several significant features. Copper content increases markedly at a point about 125 feet west of the ore zone. Between this point and the ore zone, the content is constant at a level of 100 ppm over an interval of 40 feet. East of this 100-ppm plateau, the copper values rise rapidly until the anomaly peak of 800 ppm is reached.

The distribution patterns of copper and zinc are roughly the same (fig. 6), but that of zinc varies considerably less than that of copper. Zinc background is probably about 50–75 ppm.

Correlation of the troughs and peaks with the configuration of the land surface is of particular importance in the interpretation of the genesis of these anomalies. Ridges are present on both sides of the ore zone (fig. 5). On this traverse the highest copper values were in samples collected on the nose of the larger ridge on the east side of the ore zone. Ground water along this section of the ore zone probably moved northward and northwestward, as mentioned before, so it is unlikely that the copper content of the soil samples collected east of the zone had been affected by adsorption of copper from the copper-rich ground water. On the other hand, the anomalous copper content in samples collected west of the zone probably was derived from such waters. The secondary peak in the western part of the copper profile coincides with the northward-trending gully that parallels the ore zone on the west. This gully receives surface water that has passed through the copper-rich till and soil over and adjacent to the ore zone. The anomalous copper content in samples from the nose of the small ridge immediately west of the ore zone does not invalidate this theory, because the ground surface here is lower than the surface of the ore zone a short distance to the south.

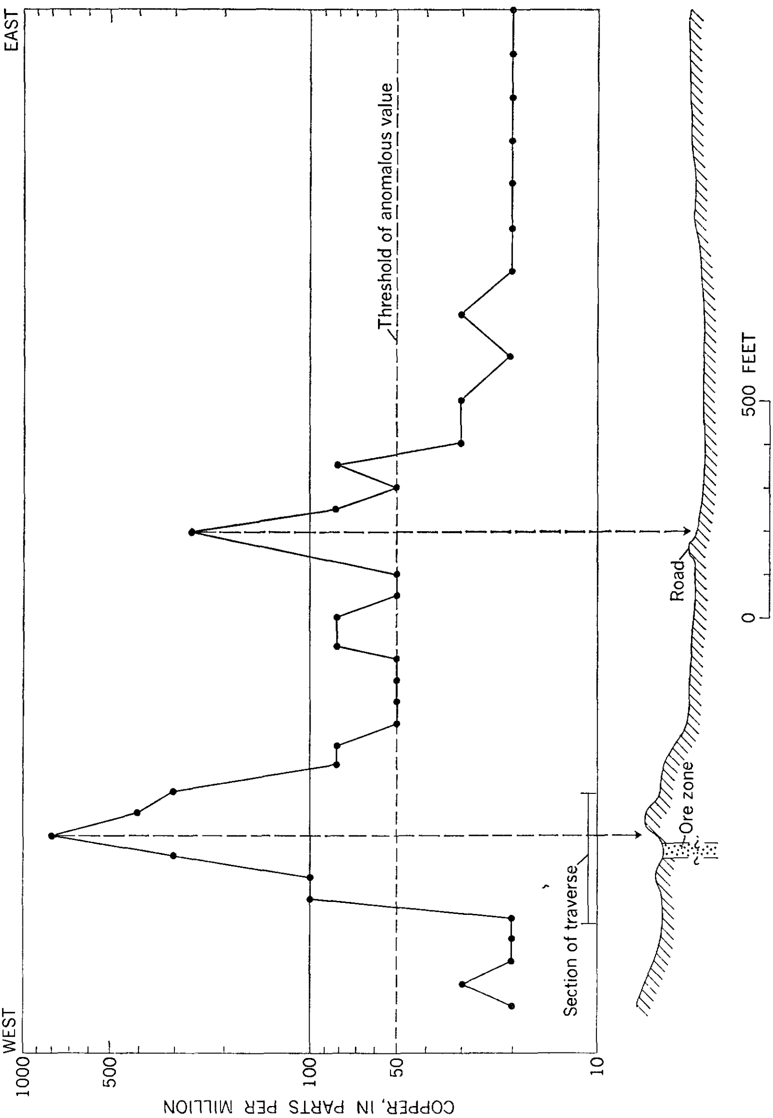

FIGURE 5.—Copper content of soil across Elizabeth ore zone at coordinate 9700 N. Additional data for section of traverse over ore zone are shown in figure 6.

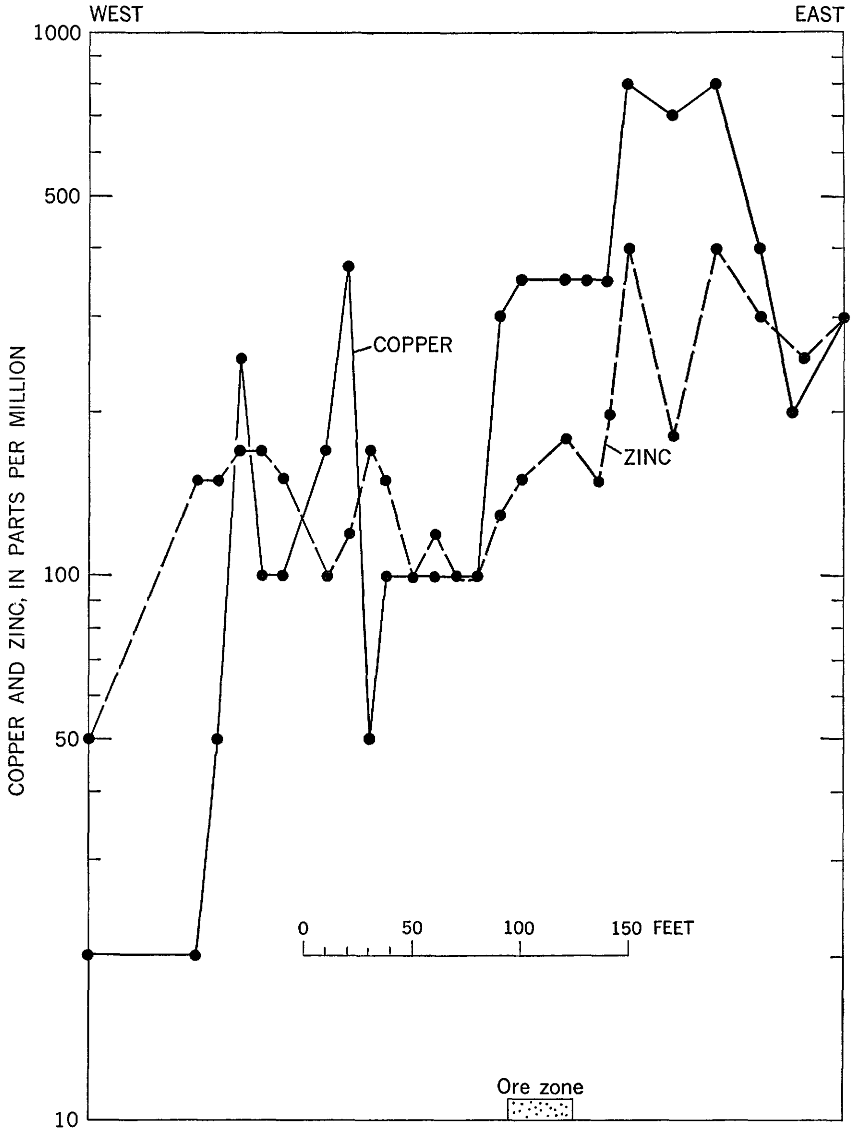

FIGURE 6.—Detailed lateral distribution of copper and zinc in near-surface soil over Elizabeth ore zone at coordinate 9700 N.

This westernmost pattern is therefore considered to be a lateral seepage anomaly.

On the 9400 N. traverse (fig. 7) the distribution of copper is similar to that on the 9700 N. traverse. The ore zone could be located precisely because it was exposed in the 9400 N. experimental trench just north of the soil-sample line. A minor parallel zone, which con-

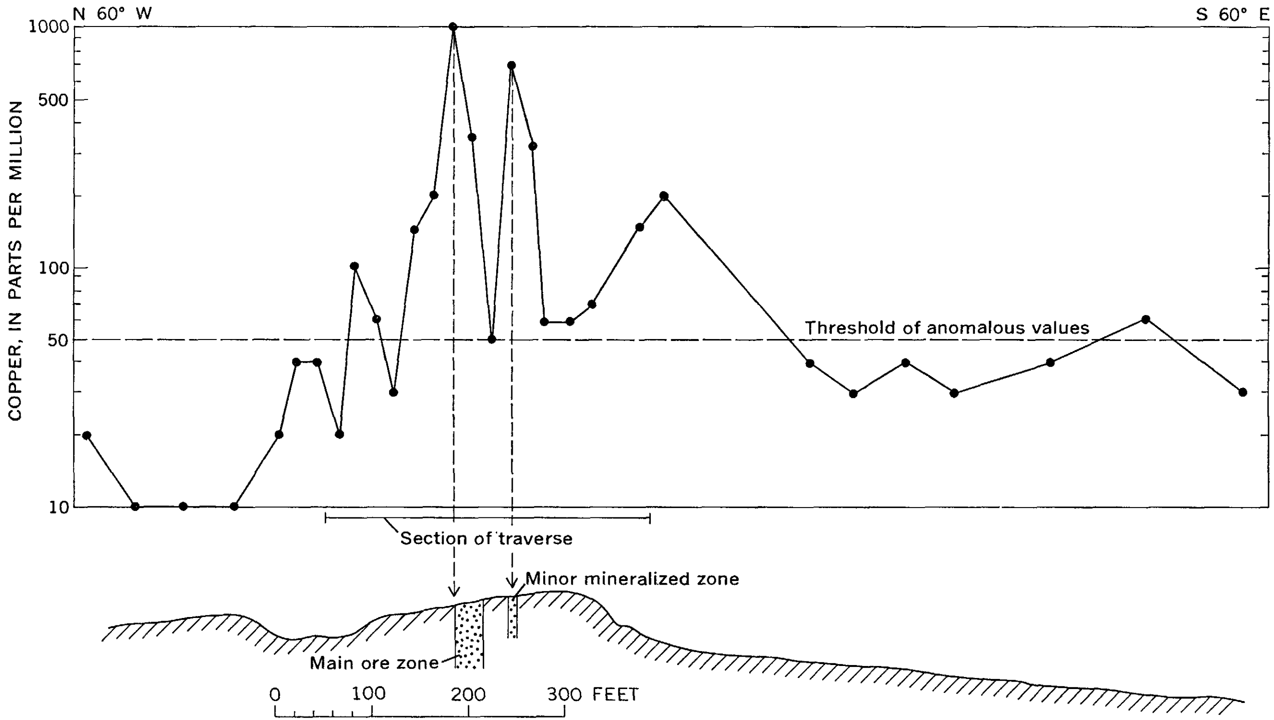

FIGURE 7.—Copper content of soil over Elizabeth ore zone at coordinate 9400 N. Additional data for section of traverse over ore zone are shown in figure 8.

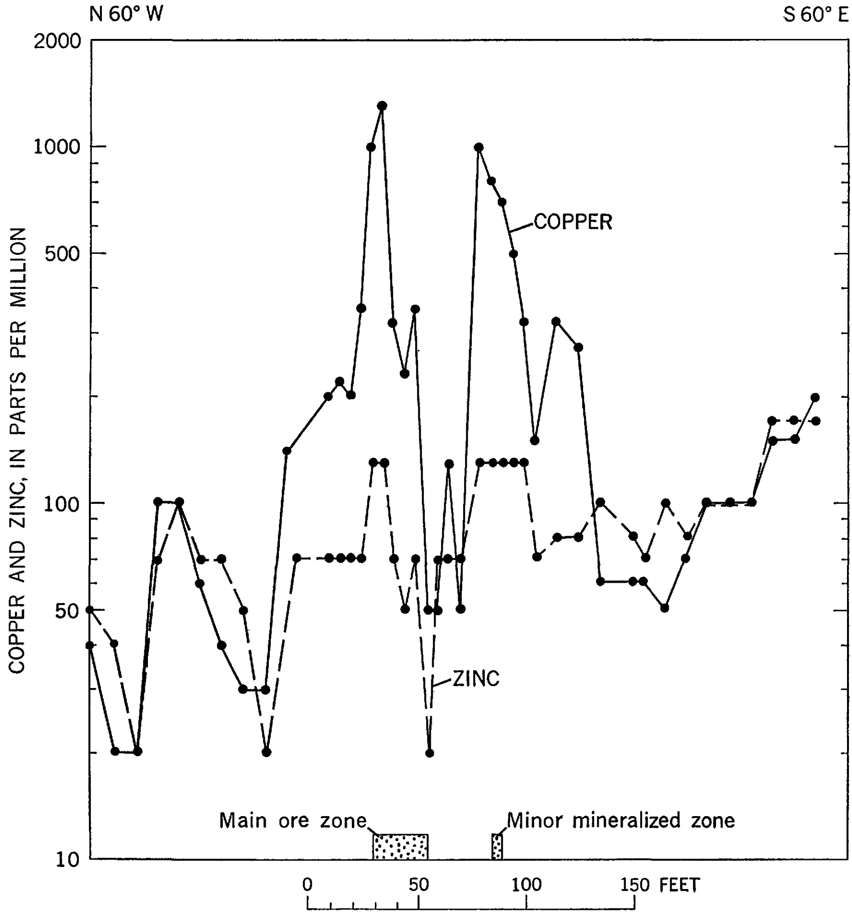

FIGURE 8.—Detailed lateral distribution of copper and zinc in near-surface soil over Elizabeth ore zone at coordinate 9400 N.

tains chalcopyrite and pyrrhotite in a matrix of siliceous schist over a width of about 5 feet, lies just east of the main ore zone (fig. 8).

In the near-surface soil along the 9400 N. traverse, the distribution pattern for copper shows a strong asymmetrical anomaly directly over the ore zone. This anomaly is not as wide as the anomaly on the 9700 N. line, for above-threshold values extend only about 350 feet east of the zone.

The detailed study of copper and zinc distributions (fig. 8) shows two major anomalous peaks (1,200 and 1,000 ppm, respectively) that are separated by a trough of lower values. The west peak is directly over the major ore zone, and its companion peak, 50 feet to the east, is directly over a minor mineralized zone. The presence of these high values over the ore zone indicates that copper-rich solutions moved upward from the ore zone to the surface to form the geochemical anomaly. Vertical distribution of copper in the till, however, indicates that this did not happen. Foreign rock fragments in this area are much less abundant than normal, and pieces of copper-bearing dark-red-brown gossan and sulfide-bearing rock from the ore zone are much more abundant. Glacial ice probably modified the original anomaly at this point only slightly if at all.

Copper is present in anomalous amounts for at least 100 feet northwest of the ore zone (figs. 7, 8). In the graph (fig. 7) the point where the profile of the copper content begins to rise from that of a background level of 10 ppm coincides with a break in the topographic slope.

The zinc values (fig. 8) reveal a similar but much more subdued pattern. The zinc content has a variation between the higher anomalous values and the background (50 ppm) of approximately 3 to 1, whereas the contrast of the anomalous copper values to the background is approximately 40 to 1. These contrasting ratios indicate that copper is the more useful element in prospecting by soil sampling.

The coarse fractions (+80 mesh) of the soil samples that were collected on the two traverses just discussed were examined with a binocular microscope. Small particles of a red-brown material resembling gossan were noted in many of the samples collected above and immediately east of the ore zone. Sufficient amounts of this material could not be collected for wet chemical analysis because of its fine texture, but enough for spectrographic analysis was obtained from each of several samples; highly anomalous amounts of copper were found. West of the ore zone only a few limonite-rich particles were found, and they resembled decomposed ferromagnesian minerals rather than oxidized sulfide minerals.

TRAVERSES SOUTH OF OPENCUT 2

Most of the investigations described in the previous section were made during 1954. In 1955, fieldwork was done to obtain additional data on the lateral distribution of copper in near-surface soil and the humus, to study the vertical distribution of copper over the mineralized zone, and to investigate the usefulness of a recently developed method for measuring readily extractable copper. Field studies in 1955 were concentrated south of opencut 2 because the ore zone north of opencut 2, which had been used the previous year, had been partly mined out and the land surface so disturbed that it could not be used for additional studies.

Copper distribution in the B-horizon soil and in the humus layer that directly underlies the loose organic litter was determined from samples collected on east-west traverses across the zone at coordinates 7900 N. and 6350 N. Figures 9 and 10 show the copper distribution in these two types of materials.

The copper anomalies in soil are asymmetrically skewed to the east, similar to those on the northern pair of traverses, but are much weaker both in contrast and lateral extent. Copper content in the mineralized zone south of opencut 2 is much lower than it is north of opencut 2. The 7900 N. traverse (fig. 2) crossed the south end of the main Elizabeth ore shoot; there, the rock probably contained considerably less than 1 percent copper over a width of about 40 feet. The 6350 N. traverse crosses the zone south of the South mine ore shoot (fig. 2), where only scattered sulfides are present.

Many factors can influence the intensity and shape of anomalous chemical patterns in soils overlying mineralized rock. On the four traverses in the Elizabeth mine area, however, where many of these controlling factors are reasonably constant, the strength and lateral

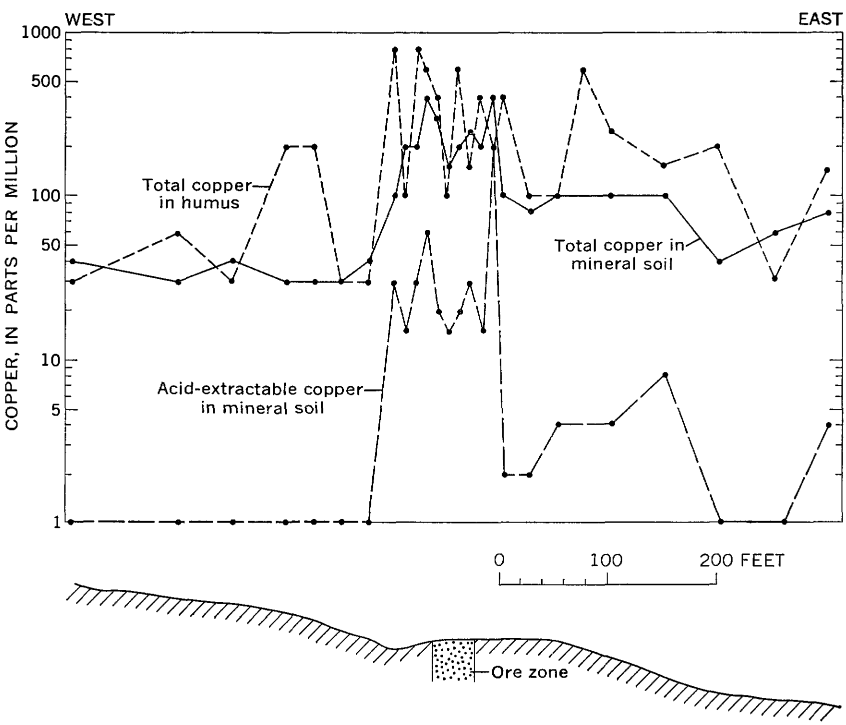

FIGURE 9.—Comparative copper content of humus and near-surface soil over Elizabeth ore zone at coordinate 7900 N.

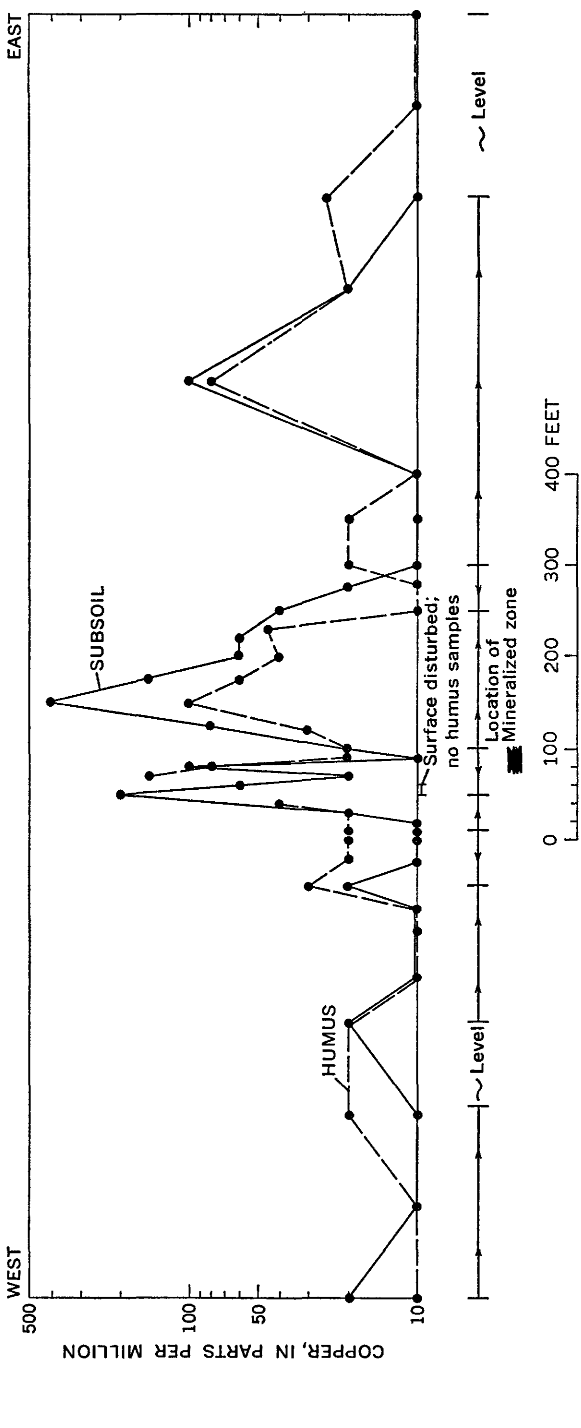

FIGURE 10.—Comparative copper content of humus and near-surface soil on traverse across mineralized zone at coordinate 6350 N. Arrows below profile show direction of slope.

extent of the anomalous patterns probably reflect, in part, the grade and width of the underlying mineralized zone.

As was already noted on the two northern traverses, the 6350 N. and 7900 N. profiles show anomalous amounts of copper in the soil on the west side of the ore zone to the point where there is a change in direction of the topographic slope. The differentiation of the geochemical profiles into two separate anomalous components is especially well marked on the 6350 N. line. There, a narrow anomalous peak on the west side of the zone is separated from the main anomaly by a trough of background values.

DISTRIBUTION OF ACID-EXTRACTABLE COPPER

The pattern of acid-extractable copper along the 7900 N. line (shown as the long-dashed line in fig. 9) resembles the total copper pattern, but the contrast between background and the anomaly peak is markedly higher than that of the total copper pattern. The anomaly for acid-extractable copper has a maximum contrast of 200 to 1 and an average contrast of at least 25 to 1 compared with the maximum contrast of 16 to 1 in the total-copper anomaly.

The ratio of cold-acid-extractable metal to total metal is often used to distinguish between epigenetic- and syngenetic-metal patterns. Epigenetic patterns, such as lateral seepage anomalies, generally show a higher ratio than do the syngenetic patterns. On the geochemical profile along the 7900 N. line, however, the ratio of cold-acid-extractable copper to total copper is about the same for that part of the anomalous profile west of the ore zone (where most of the anomalous metal is probably epigenetic in origin) as it is over and east of the ore zone (where the pattern is probaly mostly of clastic origin). The probable mode of origin of the syngenetic pattern—the incorporation of a mass of fine-grained particles of copper-rich gossan and residual soil in a mass of glacial till—is consistent with these findings, because most of the anomalous copper in this material should be amenable to leaching by the cold 6N hydrochloric acid that is used as the extractant in the cold-copper chemical procedure.

DISTRIBUTION OF COPPER IN HUMUS

Anomalous amounts of metal in soil are normally reflected in anomalous concentrations of the metal in the vegetation rooted in that soil. The organic litter on the land surface that results from the decay of this material may retain all or part of the anomalous metal. Characteristics of the copper pattern in the organic debris were studied from the samples of humus collected at each sample site along the 6350 N. and 7900 N. traverse lines.

The humus samples were pulverized, and the copper content of a weighed part of the material was determined after the material had been decomposed by nitric and perchloric acids. Because the true humus layer was very thin, most of the samples contained a variable amount of mineral soil from the A_1 horizon. As a rough approximation of the amount of organic matter present, the weight loss on ignition at 450°C was 17–79 percent for the 20 samples examined.

The lateral distribution of copper in the humus layer (figs. 9, 10) shows a similarity to the patterns in the near-surface mineral soil. A much closer correspondence exists, however, on the 6350 N. traverse than on the 7900 N. line, where the metal pattern in the humus is considerably less homogeneous. The profile of the 7900 N. traverse (fig. 9) shows a small anomalous peak on the hillside west of the ore zone, but the cause of this peak is not known.

VERTICAL DISTRIBUTION OF COPPER IN SOIL AND TILL

Vertical channel samples of overburden that represent an interval of about 3 inches were collected from the wall of a trench cut across the suboutcrop of the mineralized zone at 6350 N. (fig. 11). The overburden consists of brown podzolic soil developed on a compact till made up of a variety of rock fragments in a silt-clay matrix. The mineralized zone, which is exposed in the trench floor, has a minimum width of 15 feet and consists of scattered sulfides in a band of altered rock; the copper grade is not known, but it is no greater than a few tenths of 1 percent.

Interpretation of the copper pattern is hindered by the fact that the profiles were not sampled down to the bottom of the trench. The vertical distribution pattern as revealed by the available data, nevertheless, shows two significant features:

1. No copper anomaly was detected in B-horizon soils directly over or immediately east of the mineralized zone; some above-threshold values are present at greater depth, but these are distributed erratically.
2. Anomalous copper values occur in the lower part of the profile in the western section of the trench.

The surface of this band of higher values—if a 100-ppm contour were to be drawn to outline it, starting at the base of the 35-foot profile—is somewhat irregular, but it has a definite gentle westerly slope and intersects the standard 6- to 9-inch sampling depth about 15 feet west of the apparent west edge of the zone.

North of this trench, on the 6350 N. traverse, anomalous values were detected at approximately this same distance from the mineralized zone. The anomalous copper pattern in the west end of the

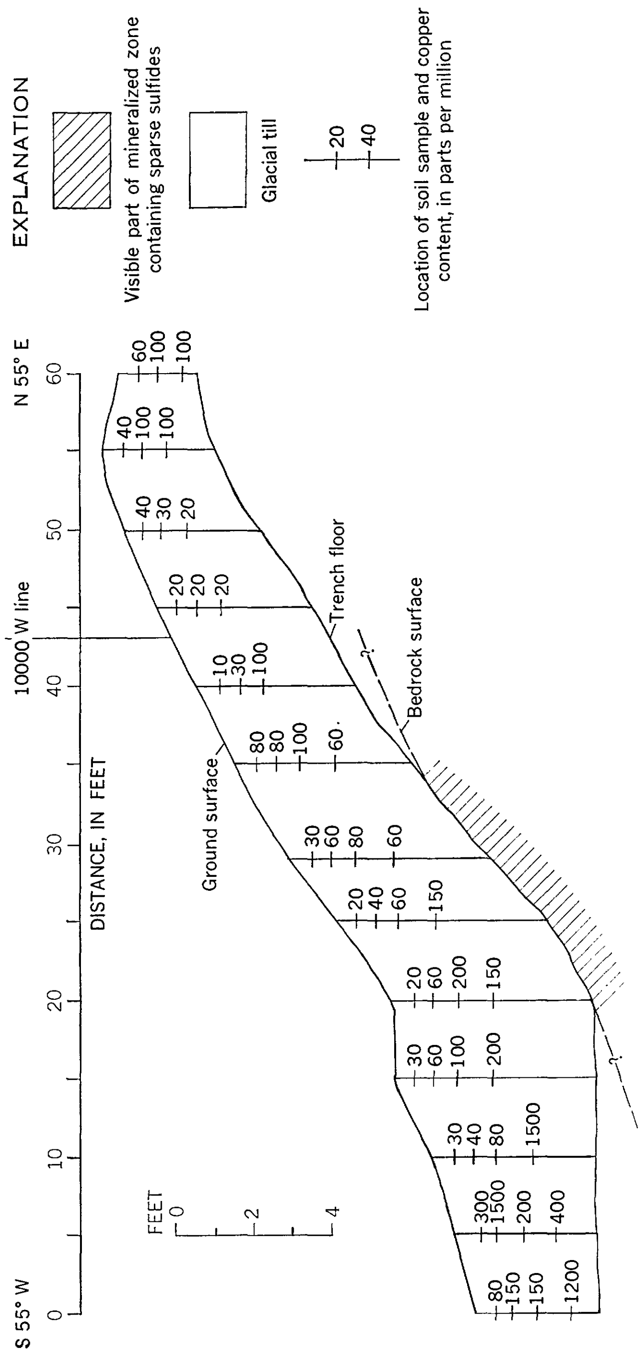

FIGURE 11.—*Vertical distribution of copper in soil over mineralized zone near coordinate 6350 N.*

trench is probably an epigenetic pattern produced by copper-bearing ground water that migrated westward after passing through the sulfide-bearing zone. The wide range of copper values in this area is consistent with this theory because, accordingly, the metal content would vary with the permeability of the soil and till.

Directly over the mineralized zone, no consistent pattern of anomalous values is present; this lack of a homogeneous anomaly in the till over the zone correlates with the lateral distribution pattern noted on the 6350 N. traverse (fig. 10), where the anomaly peak occurs about 50 feet east of the east edge of the zone. The trench did not extend far enough for the vertical distribution pattern to be studied in the area where the anomaly is presumably of syngenetic origin. The somewhat greater copper content found in samples from the two profiles at the east end of the trench does, however, indicate that the belt of copper-rich soils lies immediately to the east. Lack of an anomaly directly over the mineralized zone probably indicates that glacial scouring and transport were more intense in this area.

SUMMARY AND CONCLUSIONS APPLICABLE TO PROSPECTING

Although this investigation was centered principally in the Elizabeth mine area, the conclusions and recommendations that follow should generally be applicable in the Vermont Copper Belt and perhaps in other areas that have had a similar glacial history.

1. Anomalous patterns of copper are present in the soil over and adjacent to pyrrhotitic copper deposits that are concealed by a thin mantle of basal till. The content of total copper in soils collected from the top of the B soil horizon can be used as a guide in the search for other such anomalous areas. Copper values of 50 ppm or more are probably anomalous; background values range from 10 to 40 ppm. Anomalous values as high as 1,200 ppm were noted in the B zone of soils that lie directly over ore containing about 1.1 percent copper.

2. The skewed copper anomaly at the Elizabeth mine is predominantly of syngenetic origin. It was formed by the smearing and scattering action of glacial ice from a preglacial copper-rich mantle of soil and gossan. Dispersion of copper by ground water has modified the original clastic pattern and produced lateral seepage anomalies on the west side of the ore zone.

3. At the Elizabeth mine, where the probable direction of ice movement makes a small angle with the strike of the ore zone, the copper anomaly is detectable as far as 1,000 feet away from the ore zone. The lateral extent, shape, and contrast of a metal anomaly in

soil associated with an ore body is generally dependent on (a) the tenor of the ore deposit, (b) the geometrical relation between the shape of the deposit and the direction of glacial transport, (c) the thickness and type of the glacial mantle together with the intensity of the glacial erosion, and (d) the extent to which the original pattern has been modified by ground-water movement.

4. Anomalies produced by cold-acid-extractable copper show a greater contrast with background than do total copper anomalies, because most of the anomalous copper is in relatively soluble secondary minerals. The ratio of cold-acid-extractable copper to total copper, however, does not discriminate between syngenetic and hydromorphic lateral seepage patterns.

5. Anomalous amounts of copper occur in the humus layer of soil over copper deposits. These anomalies are of the same magnitude as those in the underlying mineralized soil, but these are more erratic. Therefore, sampling and analysis of humus are not recommended as testing procedures.

6. Soils in the Vermont Copper Belt belong to the Grey-Brown Great Soil Group. Soil-forming processes have resulted in slight leaching of copper from the A horizon, but the copper contents of the B and C horizons are generally comparable. The total copper content of different size fractions of the soil does not vary significantly, but the −80- or −100-mesh fraction is recommended to eliminate the need to grind the sample.

7. The analytical and sampling errors associated with the collection and analysis of small samples of mineral soil are small compared to the magnitude of the anomalies associated with mineralized rock of economic grade.

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