TRACE METALS IN STREAM SEDIMENT
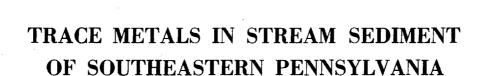# OF SOUTHEASTERN PENNSYLVANIA

Part I: Geochemical Prospecting Guide
Based on Regional Distribution of Zinc,
Copper, Nickel, Cobalt, Chromium and Vanadium

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MINERAL CONSERVATION SERIES

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INTRODUCTION

The investigation here reported deals with trace metals in stream sediments and is intended as a guide to selecting promising areas in which to prospect for metalliferous ore bodies. Geochemical exploration for ore deposits and metalliferous regions is based on the concept that the products of weathering and erosion of rocks are mainly distributed in local soils, plants and stream sediments. In areas such as southeastern Pennsylvania, which are essentially uncomplicated by glacial deposits and other surface materials from distant sources, the stream muds can be considered as transported and altered samples of the soils and source rocks of a drainage basin. Stream sediments of a metalliferous region generally will contain more than average amounts of ore mineral particles, precipitates from metal-charged ground-water and adsorbed metal ions. That ideal relationship is complicated, of course, by urban and industrial metal contamination, by variations due to different rock types and by the errors involved in sampling and analysing heterogeneous material. Some of the errors were minimized or compensated by eliminating probable contaminated samples and by statistical treatment of analytical results for large numbers of samples, grouped by drainage basins.

The surveyed area comprises about 7,600 square miles of southeastern Pennsylvania, encompassed by 33 standard 15' topographic sheets, within the limits 39° 45' to 40° 30' North and 75° 30' to 78° 15' West. The appropriate smaller scale topographic maps (1:250,000) are the Pittsburgh, Harrisburg and Newark sheets for the northern part, and the Cumberland, Baltimore and Wilmington sheets for the southern part of the area.

Within the surveyed area, over 3,000 samples of stream sediment were collected and analysed for the trace metals zinc, copper, nickel, cobalt, chromium and vanadium. Most of the samples also were analysed for manganese and iron, with the object of testing possible associations between manganese and iron oxides and the analysed trace metals. The manganese and iron analyses and the statistical correlation tests are not yet complete; they will be reported later as part of a continuing investigation of the modes of occurrence of trace metals in stream sediments.

SAMPLING METHODS

Samples were taken to represent fine mud from active stream channels at sample sites on principal tributaries and at a minimum spacing of about two miles along main streams.

Dry sediment was collected from the beds of a few intermittent streams, but the great majority of the samples were collected wet, by combining three or four hand grabs into a cloth sample bag. Samples were allowed to drain and air dry on aluminum mesh racks in the field truck and were oven dried at 110°C. The oven-dried samples were disaggregated in a mullite mortar and sized through 100-mesh stainless steel sieves soldered with pure tin; oversize was discarded. Tests showed no measurable contamination by addition of the analysed trace metals during treatment.

Preliminary analyses of different size fractions, from (—100 + 200) to —325 mesh, showed a negative correlation between trace metal concentration and sample grain size. In spite of that observation, it was decided to analyse the entire —100 mesh fraction rather than the —200 or —325 mesh fractions, because many of the sam-

ples contain an insufficient amount of extreme fines for replicate analyses.*

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* Hawkes and Webb (p. 257) conclude that maximum contrast between anomalous values (A) and background values (B) is brought out by analysis of intermediate grain sizes, between 80-mesh and 200-mesh. That conclusion appears to be based on defining "contrast" as A/B, a definition which is applicable to colorimetric methods of analysis and to readings of optical density on spectrographic plates. For those methods, analytical error is commonly expressed as a percentage of the result. For other analytical instruments, including the direct-reading spectrometer used in the present work, contrast may be more exactly defined as A-B.

Subsamples for analysis were obtained by rolling and stirring the —100 mesh fraction and then combining several small portions removed with a spatula. Subsequent tests made during the progress of the analytical work showed that much of the analytical variability is due to sub-sampling error and that it is desirable to homogenize sediment samples by pulverizing the —100 mesh material. That procedure is being adopted for future work at this laboratory.

ANALYTICAL METHODS

Preliminary analyses were made on a 21-foot Jarrell-Ash Wadsworth Spectrograph. Most of the subsequent analyses for trace metals, as well as for iron and manganese, were run on a direct-reading emission spectrometer, employing a D.C. arc technique.

Each sample, after being dried overnight in a muffle furnace at 250°C., was mixed in a "Wig-L-Bug" agitator (plastic vial), with one part internal standard mixture and two parts graphite (National Carbon S. P. 2). The internal standard mixture is 0.1% Lu_2O_3 and 0.1% GeO_2 in $Na_2B_4O_7$, thoroughly mixed, fused and ground to pass a 200-mesh nylon sieve. Packed electrodes were kept dry in an oven at 250°C. until used.

The spectrometer automatically prints out voltage ratios at the completion of each run. Working curves of voltage ratios versus concentration were constructed by burning prepared standards and were checked at intervals by replicate analyses of a stream sediment sample and a standard diabase (W-1).

APPARATUS AND OPERATING CONDITIONS:

Electrodes	⅛" preformed high purity graphite, U.C.P. 5185
Analytical gap, mm.	4
Current, amperes	15
Sample electrode charge, mg.	40
Gas flow, with Stallwood Jet, l.p.m.	6
Gas Composition	86% Argon, 14% Oxygen
Exposure	Sample burned to completion, approx. 2 min.
Emission Spectrometer	RCI (now Consolidated Electrodynamics Corp.) Spectrometer with reciprocal linear dispersion of 4Å/mm and sequential typewriter readout of voltage ratios ($^\text{unknown}$ /$^\text{×}$ internal standard)
Multiplier phototubes	RCA 1P28
Entrance slit, μ	25
Exit slits, μ	40, with the exception of a 75μ slit for Zn 2138.6

ANALYTICAL LINE PAIRS:

Internal Standard	Analytical Line	
Lu II 2911.39	V II	3102.30
	Mn II	2576.10
	Fe II	2755.74
Ge I 2651.18	Cu I	3273.96
	Zn I	2138.56
	Co I	3453.50
	Ni I	3114.76
	Cr I	4254.35

REPLICATE ANALYSIS AND RESAMPLING

The amount of sample actually used for spectrographic analysis is small*, and the sieved (—100 mesh) but unground samples cannot be considered as perfectly homogeneous. Consequently, one must allow for possible erratic high trace metal analyses due to inclusion of metal-rich particles which are not uniformly distributed. We therefore checked most of the anomalous high results by analysis of a second subsample. If a trace metal anomaly was confirmed by duplicate analyses within 20% of the mean, the sample site was classified as anomalous and the mean of the two analyses was used for determining the category (Class 2 or 3).

In cases where a moderate (Class 2) anomaly was not confirmed by duplicate analysis, the lower of the two analytical results was used for classification. Some samples were rejected from Class 2 on that basis and will be re-examined as time permits.

Samples which showed strong (Class 3) metal anomalies on the first analysis were similar-

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* 100 mg. mixed with internal standard and graphite, 40 mg. of mixture burned.

ly reanalysed, but no sample was rejected from Class 3 without further checking. In cases of doubt, one or two new sediment samples were collected and analyzed. The reported data for Class 3 samples (Table 3) are the means of replicate analyses of original and re-collected samples.

The reproducibility of the analytical results is dependent, of course, upon analytical error as well as upon sampling error. The following statistical summary of one hundred replicate analyses of a composite stream sediment sample is presented as an example of reproducibility:

Element	Mean (ppm)	Standard Deviation (ppm)
Zinc	103.2	12.4
Copper	27.6	7.3
Nickel	27.6	6.2
Cobalt	4.6	2.5
Chromium	105.6	16.9
Vanadium	92.2	6.2

Reproducibility is best for vanadium, in this example, but notably poor for cobalt (near lower limit of detection).

REPRESENTATION OF METAL ANOMALIES

The concept of a geochemical anomaly as a concentration level above some arbitrarily chosen background or "threshold" value for a particular element cannot be applied rigorously to regional variations over a large area encompassing different geologic regions with widely different rock types (Hawkes and Webb, 1962, p. 27). Consequently, we adopted the procedure of determining the frequency distribution for each trace metal and of defining anomalies in terms of the statistics, as presented in the succeeding section. Follow-up surveys for optimum identification of significant anomalies (related to ore bodies) will require separate statistical studies for each geologic terrane. We are currently mak-

ing a trend surface analysis to assist in defining the areas to be considered separately.

For the present reconnaissance map, individual sample anomalies are defined in terms of the means and standard deviations of logged data (Hawkes and Webb, p. 30), and are divided into three classes, the limits of which are given on the map legend.

Class 1 samples, with the lowest range of metal concentrations, are indicated by small black circles on the map. Anomalous samples are indicated by square symbols and those with the highest trace metal concentrations by ad-

jacent sample numbers corresponding to those in Table 3. Moderately anomalous samples are listed in Table 2.

In order to show regional variations and to minimize the complexities of color coding for six variables, the map area was divided into drainage basins and subdivided into small drainage cells, each cell comprising, where feasible, the area drained by one stream tributary, and with an average of 5 to 6 samples per cell. For each trace metal, the cell statistics were com-puted (see below) and the cells were divided into three classes, the limits and color codes of which are given on the map legend.

The anomalous metals at a particular location can generally be determined from the color code of the enclosing cell and can be con-firmed by reference to Tables 2 and 3. Anomalous metals in Class 2 samples which are not within a color coded cell are indicated by a small colored dot adjacent to the square symbol repre-senting sample location.

STATISTICS FOR MAP DATA

INDIVIDUAL SAMPLES

Examination of the frequency distribu-tions of the concentrations in parts per million (ppm) for Zn, Cu, Ni, Co, Cr and V in the indi-vidual stream sediment samples discloses a char-acteristic positive skewness, reflecting an excess of samples with high metal values. To minimize the effects of extreme values on estimates of the means and standard deviations, the individual concentrations were transformed to natural logs[*], thus:

$$Z = \ln X$$

where X = concentration in ppm of an element in one sample.

Histograms representing the distributions of the Z's were constructed. The mean ($\bar{Z}$) and standard deviation (λ) for each element were then com-puted by the method of moments.

$\bar{Z}$ is thus the mean of the natural logs of the concentration values for an element, and λ is the standard deviation of the logs of the concen-tration values for that element.

For interpreting anomalies, values in ppm are more convenient than logged data; therefore

the following statistics were derived for each element:

$\bar{X}_g$ = the geometric mean = antilog ($\bar{Z}$) in ppm

"Lower limit of Class 2" = antilog ($\bar{Z} + 2\lambda$), in ppm

"Lower limit of Class 3" = antilog ($\bar{Z} + 3\lambda$), in ppm

Class 1 includes samples with all of the trace metals in relatively low concentration, below the lower limits of Class 2.

DRAINAGE BASINS AND CELLS

The map was subdivided into 463 cells, each cell containing from 3 to 18 samples, with 5 or 6 being the most common.

For each cell, the geometric mean Y_g was computed for each element from all Z values in that cell.

$$Y_g = \text{antilog} \ \frac{\Sigma Z}{m}$$

where m = number of samples in the cell

Frequency histograms for the cell geo-metric means were derived, and the arithmetic mean of all cell means determined as $\bar{X}_c$. The standard deviation s_c was likewise computed for each trace metal.

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[*] The use of logged data is only a convenient transforma-tion; it is not implied that the trace metals have log-normal distributions. In fact, most of the distribution curves of the logged data are negatively skewed.

Anomalous cells are defined as those for which Y_g for any trace metal exceeds $\overline{X}_c + 2s_c$ (Class 2) or $\overline{X}_c + 3s_c$ (Class 3). The numerical values for these statistics appear on the map legend and are summarized below along with some comparable published data. By comparison, stream sediments of southeastern Pennsylvania have relatively high concentrations of zinc and relatively low concentrations of the other five trace metals.

TABLE 1

STATISTICAL SUMMARY OF
TRACE METAL CONCENTRATIONS (ppm)

TRACE METAL	COMPARABLE DATA		S. E. PENNSYLVANIA			
	Continental Crust	Shale Average	Drainage Cells		Lower Limits of Classes of Anomalous Samples	
	(A)	(B)	(N = 463)		Class 2	Class 3
			$\overline{X}_c$	s_c	Antilog $\overline{Z} + 2\lambda$	Antilog $\overline{Z} + 3\lambda$
Zinc	70	95	107	35	317	551
Copper	55	45	29	9	85	143
Nickel	75	68	27	8	72	121
Cobalt	25	19	11	5	41	79
Chromium	100	90	56	17	156	262
Vanadium	135	130	86	21	175	251

(A) Taylor, 1964
(B) Turekian and Wedepohl, 1961

TABLE 2
LIST OF CLASS 2 METAL ANOMALIES
BY DRAINAGE BASINS

Sample No.	Anomalous Metals	Lat.*	Long.*
AUGWICK BASIN			
2384	Co	40.19	77.90
2761	Ni	40.08	78.14
2776	Ni	40.12	78.02
3004	Co	40.37	77.77
BRANDYWINE BASIN			
1812	(Cu)	40.04	75.80
2329	Cr V	40.46	75.72
2594	(V)	39.87	75.59
2595	Ni Cr	39.85	75.59
2605	Ni	39.90	75.63
2611	Ni	39.93	75.63
2615	Cr	39.93	75.56
2626	Cr	39.96	75.79
3165	(V)	39.78	75.74
3171	Ni Cr	39.90	75.68
3172	Cr	39.90	75.67
3181	Zn Cr	39.96	75.64
BREECHES BASIN			
548	Co	40.04	77.26
683	(Co)	40.06	77.24
697	Cr V	40.12	77.00
908	(Cu)	40.16	76.98
BUFFALO BASIN			
354	(Cu)	40.43	77.25
377	Co	40.50	77.28
CODORUS BASIN			
1219	V	39.80	76.71
1230	Co	39.87	76.68
CONESTOGA BASIN			
1004	Cr	40.12	76.71
1032	Cr	40.13	76.55
2032	Cu	40.11	76.43
2035	Cu	40.10	76.46
2061	(Cu)	40.23	76.29
2904	V	40.15	75.98
CONEWAGO BASIN			
483	(Zn)	39.93	77.32
485	(Zn)	39.94	77.31
495	(Zn)	39.95	77.37
501	(Zn)	39.99	77.29
505	(Zn)	39.99	77.26
577	(Zn)	39.94	77.19
688	(Zn)	40.03	77.10
722	Cr	39.99	77.04
724	Cr	39.98	77.04
734	Cr V	39.95	77.06
735	Cr	39.96	77.05
737	Ni Co V	39.94	77.03
740	V	39.97	77.02
741	Co Cr V	39.98	77.02
769	Cr	39.89	77.10
770	Cr	39.89	77.11
776	(Cu)	39.89	77.08
783	Ni	39.92	77.04
785	Cr	39.93	77.02

Sample No.	Anomalous Metals	Lat.*	Long.*
800	Cr	39.82	77.01
807	Cr	39.82	77.06
820	Cr	39.87	77.13
933	V	40.08	76.93
934	V	40.08	76.92
942	Cr	40.01	76.85
1074	(Cu)	40.06	76.75
1088	V	39.91	76.98
1096	(Cr)	39.89	76.95
1097	(V)	39.88	76.95
1111	Ni	39.92	76.97
1130	Cr V	39.96	76.98
1144	Cu	39.79	77.00
1158	Cr V	39.83	76.96
CONOCOCHEAGUE BASIN			
46	Co	39.84	77.53
50	(Zn)	39.87	77.48
75	(Cu)	39.98	77.73
91	(Zn)	39.95	77.60
98	Co	39.91	77.51
107	Co	39.92	77.46
108	(Co)	39.93	77.48
136	(Zn)	39.98	77.42
139	Co	39.81	77.49
2511	Ni Co	39.97	77.90
3087	Co	39.88	77.95
3106	Co	39.94	77.92
3110	Ni	39.96	77.84
CONODOGUINET BASIN			
186	(Cu)	40.19	77.42
207	(Zn)	40.24	77.35
2447	(Ni Cr)	40.12	77.56
2463	(Cu)	40.17	77.70
2466	Co	40.12	77.72
JUNIATA BASIN			
1864	Ni	40.47	77.78
MARSH BASIN			
127	Zn	39.89	77.33
144	V	39.77	77.45
512	V	39.81	77.35
524	V	39.77	77.41
526	V	39.80	77.38
527	V	39.80	77.42
528	(Zn)	39.81	77.41
529	V	39.82	77.37
839	Cr	39.76	77.12
862	(Cu)	39.80	77.19
863	Cr	39.77	77.24
868	Cr	39.79	77.22
882	Zn Cu Cr	39.80	77.22
893	(Cu)	39.82	77.14
895	(Cr)	39.84	77.18
897	Cr	39.82	77.20
MUDDY BASIN			
1064	Zn	40.04	76.56
1252	(Cu)	39.88	76.55

* Latitude and longitude in decimal degrees, as shown on on map borders.
  Parenthesis around metal symbol indicates single analysis, not confirmed.

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Sample No.	Anomalous Metals	Lat.*	Long.*
1297	(Ni)	39.84	76.57
1327	Co	39.77	76.44
1355	(Cu)	39.76	76.28
OCTORARA BASIN			
1461	Ni	39.90	76.08
1462	Ni	39.88	76.10
2017	Ni	39.76	76.16
RAYSTOWN BASIN			
2720	Co	40.34	78.12
2722	Ni Co	40.28	78.12
SCHUYLKILL BASIN			
1724	V	40.34	75.57
1758	Zn Ni Co	40.11	75.60
2298	(Cu)	40.25	75.82
2300	V	40.25	75.78
2301	Cu	40.21	75.77
2340	(V)	40.10	75.64
2341	Zn Ni Co	40.10	75.63
2941	(V)	40.15	75.63

Sample No.	Anomalous Metals	Lat.*	Long.*
SHERMAN BASIN			
400	(Zn)	40.30	77.19
651	Zn	40.31	77.00
656	Zn	40.37	77.07
SWATARA BASIN			
981	Zn Cr	40.19	76.70
1040	V	40.25	76.55
1041	(V)	40.24	76.55
1044	Cu	40.24	76.52
1045	Cr V	40.23	76.53
1639	(Cu)	40.43	76.35
2204	Co	40.29	76.42
TONOLOWAY BASIN			
2862	V	39.79	78.23
2883	Ni V	39.77	78.15
3073	Ni Co	39.85	77.96
TUSCARORA BASIN			
284	(Zn)	40.48	77.45
1920	Zn	40.50	77.63

TABLE 3
STREAM SEDIMENT SAMPLES WITH HIGH TRACE METAL CONCENTRATION

Sample Number	Drainage Basin	Zn	Cu	Ni	Co (ppm)	Cr	V	Mn	Fe (%)	N
143	Marsh	108	75	*89*	28	150	**259**	1339	**10**	2
449	Buffalo	**1633**	47	61	19	67	79	1515	5	3
738	Conewago	66	28	47	37	398	*175*	1105	5	3
739	Conewago	93	31	42	32	285	162	1481	6	3
763	Conewago	123	23	45	27	*256*	**264**	1705	11	3
896	Marsh	137	38	*79*	33	389	*203*	1622	7	4
932	Conewago	125	44	50	*56*	*172*	**288**	1634	8	3
938	Conewago	116	62	27	35	63	**294**	1953	**10**	3
1042	Swatara	86	**227**	41	*50*	62	69	1125	**13**	5
1357	Muddy	109	42	**483**	*44*	290	85	1282	6	2
1444	Octorara	282	**173**	43	7	81	96	1005	6	2
1467	Octorara	81	**249**	**220**	21	128	79	1075	4	2
1468	Octorara	35	**247**	**199**	15	120	44	613	4	2
1723	Schuylkill	147	71	57	34	*161*	**256**	2028	8	7
1925	Augwick	120	19	66	**81**	115	83	2096	3	2
2157	Schuylkill	179	**196**	33	15	87	154	2184	7	7
2168	Conestoga	102	**170**	31	11	55	162	1162	6	4
2169	Conestoga	94	**255**	32	10	61	128	1221	6	3
2724	Raystown	273	43	*100*	**90**	56	63	1622	6	2
3176	Brandywine	243	*106*	**300**	23	325	121	1301	7	5
3215	Brandywine	**1060**	26	29	9	16	61	1795	5	2

CONCENTRATION LEVELS: Italics = Class 2. Boldface = Class 3.
N = number of subsamples analysed.

FREQUENCY DISTRIBUTIONS AND CORRELATIONS OF TRACE METALS

Frequency distributions and correlations were studied as an initial step in deriving a model of metal associations and underlying factors. An element disseminated randomly within one rock type should generate a normal type of frequency distribution. On the other hand, an element occurring in more than one rock type or mineral, at least one of which is concentrated in local bodies, should generate a skewed or complex type of frequency distribution.

The distribution curves for all of the analysed trace metals were found to be positively skewed, i.e., there is an excess of high values. On the assumption that the data may represent log-normal parent populations, the log transformed data were also plotted. Log transformation yields a slight improvement toward normality for five of the six trace metals; the vanadium distribution plot is not improved. The principal effects of log transformation are to change positive skewness to negative, and to increase peakedness for some element distributions, notably those of zinc, chromium and vanadium. There is therefore no statistical evidence for log normality. It is concluded that the distributions probably represent mixed populations (i.e. metals in different forms and associations) and are neither normal nor log normal.

Log normal distributions were assumed, as a rough approximation for defining sample classes on the map, but the non-parametric Kolmogorov-Smirnov statistic* was used for comparing data between areas, as below.

A preliminary test was made to determine whether the trace metal distributions differ from one geologic region to another. The map area was divided into three geologically different provinces, as follows:

(A) A western Valley and Ridge province and adjacent parts of the Great Valley, underlain by Paleozoic clastic sediments and by limestone and dolomite.

* (Siegel, 1956, p. 127)

(B) A central province underlain by Triassic shale, siltstone and sandstone, intruded by diabase.

(C) An eastern province characterized by Precambrian and early Paleozoic schist and gneiss with lesser amounts of greenstone and various intrusives, including gabbro, anorthosite and serpentinite.

The non-parametric tests show that provinces (A) and (C) have significantly different distributions for all six trace metals. Province (B) differs from (A) in respect to all but copper and from (C) in respect to all but cobalt and chromium. It is thus confirmed that geochemical background and metal anomalies should be treated differently in geologically different regions. We are currently making a trend surface analysis which should help in determining the geologic provinces to be treated separately. We are also completing a multivariate analysis to determine whether useful information can be obtained by plotting "factor scores" representing groups of trace elements.

A general idea of metal associations can be obtained by examining the data regarding the numbers of drainage cells which are relatively enriched in two trace metals (Table 4).

TABLE 4

NUMBERS OF DRAINAGE CELLS WHICH SHOW CONCENTRATIONS $> (\overline{X} + s)$ FOR TWO METALS

	Cu	Ni	Co	Cr	V
Zn	18	15	7	12	26
Cu	—	28	21	24	24
Ni	—	—	9	20	15
Co	—	—	—	28	16
Cr	—	—	—	—	32

$\overline{X}$ = average of all cell means, in parts per million.
s = standard deviation of cell means

The most extensive associations of trace metal concentrations are those of *chromium* with vanadium, cobalt, copper and nickel, those of *copper* with nickel, vanadium and cobalt, and a local zinc:vanadium association in the southeastern part of the map area.

METAL CONTAMINATION

Sixty-three samples with Class 2 or 3 trace metal concentrations were judged to be "probably-contaminated" on the basis of field examination of sample sites and upstream industrial plants or towns. Samples placed in the "probably-contaminated" category are indicated by triangular symbols on the map and are excluded from Tables 2 and 3.

Fifty-eight of the sixty-three probably-contaminated samples show high concentrations of zinc or copper or both. The other metals which appear in high concentration in some of these samples are nickel (14 samples), chromium (12 samples) and cobalt (7 samples).

It should be emphasized that we have no independent criterion of metal contamination other than the patterns of metal distribution in streams; some of the samples judged to be contaminated may actually represent natural metal anomalies. Some are being re-examined. Contamination is to be suspected, however, where a metal anomaly appears immediately downstream from a town or industrial plant, as for example in Oil Creek, to the northeast of Hanover in southern York County. Immediately downstream from Hanover, the stream sediments show high concentrations of zinc, copper, nickel and chromium, decreasing in a downstream direction*. At 3.5 miles downstream zinc and copper are still in high concentration (Class 3). At about 6 miles downstream, just above the confluence with the west branch of Codorus Creek, zinc and copper contamination is still detectable, at concentration levels just below the lower limit of Class 2. Throughout this 6-mile length of Oil Creek, no trace metal anomalies occur on any tributaries, and it seems evident that the source of metal contamination is one or more of the industrial plants in Hanover.

No attempt was made to pinpoint sources of metal contamination. Unknown amounts may come from copper pipes, galvanized fittings and culverts, etc. and from some types of fertilizers and insecticides. Industrial plants involved in metal processing, plating or finishing or in tanning of leather are among those which may discharge metals in dissolved or suspended forms. Metal contamination, and disposal procedures for industrial metal-bearing solutions probably deserve investigation by those who are concerned with public health or with preserving fish populations.

* Sample numbers, in downstream sequence from Hanover: 1156, 1154, 1163. 1167.

METALLIFEROUS REGIONS

A principal objective of the investigation was to outline regions or clusters of drainage cells with relatively high concentrations of one or more trace metals. Regional metal distribution patterns may serve as a general guide in selecting areas for prospecting and are required for establishing background levels and recognizing significant anomalies, i.e., those with concentrations appreciably above background.

Metal distribution patterns are shown by the map color code. Some apparent metalliferous regions are briefly described below, in terms of the dominant or widespread trace metals and the nature of the underlying rocks:

(1) The *Juniata-Sherman Region,* in the western part of the map area*, is characterized by clusters of drainage cells with relatively high nickel concentration. Some cells, including the four with highest nickel concentration, are also high in zinc, and three of them are high in cobalt. The dominant trace metals probably are derived mainly from sedimentary red beds rather than from ore bodies. The lowest red beds in the

* The region is considered to include the following drainage basins, from west to east: Juniata, Raystown and Tonoloway, Augwick and Tuscarora, Buffalo and Sherman, and Powell basin east of the Susquehanna River. The long southwestern extremity of Conodoguinet should also be included.

stratigraphic sequence are in the Ordovician (Juniata formation). At higher stratigraphic levels there are red beds in the Silurian (Clinton iron sandstone), Devonian (Catskill formation) and Mississippian (Mauch Chunk formation).

(2) The *Marsh-Conewago Zinc Region* is defined as the northeast-trending group of zinc cells in the western part of the Marsh and Conewago basins, underlain by metarhyolite and associated rocks of the South Mountain volcanic belt.

(3) The *Gettysburg-Oxford Metal Region* is defined for descriptive purposes as extending from the Gettysburg area (Marsh basin) eastward across the southern parts of Conewago, Codorus, Muddy and Octarara basins, to the vicinity of the town of Oxford on the boundary between Octorara and Brandywine basins. The western part of the region, in Marsh and Conewago, is characterized by chromium, cobalt and sporadic vanadium enrichment and is underlain by Triassic rocks, including large diabase intrusions. Eastward through Codorus and Muddy basins, cobalt becomes dominant over chromium, and farther east, copper and nickel become the dominant trace metals. Zinc enrichment appears to be peripheral to a copper-nickel center in Codorus basin, in an area partly underlain by metavolcanics. Throughout the central and eastern part of the Gettysburg-Oxford region, the underlying rocks are mainly metasediments and volcanics of the Wissahickon formation. There are transecting diabase dykes at intervals and a few intrusions of serpentinite and gabbro.

The nickel anomaly in the northern part of Octorara basin is partly derived from a known ore body and old mine workings: the Gap Nickel Mine to the north of Bart.

(4) A *Central Copper-Nickel Region* extends from the area south of Harrisburg (Breeches and Conewago basins), to the northeast and east through Swatara and northern Conestoga basins and probably farther east into southern Schuylkill. The region is mainly underlain by Triassic rocks, including large diabase intrusions, and by bordering Paleozoic rocks including Cambro-Ordovician limestone and dolomite. It seems likely that the observed metal dis-

tribution patterns are derived from diabase and from related mineral deposits. The iron ore deposits at Cornwall and Morgantown are within this general region.

The southwestern extension of the Triassic belt, around Gettysburg (Marsh and southern Conewago basins) shows entirely different trace-metal patterns, characterized by drainage cells with moderate to high concentrations of chromium, cobalt and vanadium, rather than copper and nickel; (see Gettysburg-Oxford region).

(5) The *Schuylkill Zinc Region,* mainly in the northern part of Schuylkill basin, lies partially along the Reading prong, characterized by granite gneiss enclosing roof pendants of hornblende gneiss. Northern lobes of the Schuylkill Zinc Region extend into areas underlain by Cambro-Ordovician limestones and dolomites which overlap the Precambrian basement. The general geologic setting in some parts of the region may be similar to that around the Friedensville zinc mine farther to the east. Southern lobes of the Schuylkill Zinc Region, south of Reading and Boyertown, extend into the Triassic belt.

Three zinc cells to the west, between Harrisburg and Annville (Swatara basin) might be considered as a western extension of the above Region, on the grounds that they are within the area of Cambro-Ordovician rocks bordering the Triassic belt. However, the two most northerly zinc cells in Swatara should be grouped with the Juniata-Sherman Region; drainage is mainly from an area of Devonian red beds and underlying Silurian beds, including the Clinton iron sandstone.

(6) The *Brandywine Region,* in the southeastern corner of the map area, is characterized by extensive zinc and vanadium enrichment and by more localized areas of enrichment in copper, nickel and chromium. One of those local areas is in a northern lobe extending into part of the Schuylkill basin, there underlain by graphitic gneiss intruded by quartz monzonite. The old Phoenixville lead-zinc mines are to the east, just outside of the map area. The other localized area of copper, nickel and chromium cells is in the West Chester vicinity, where the underlying rocks are gabbroic and granitic gneiss and metasediments of the Wissahickon formation.

POSSIBLE LARGE - SCALE PATTERNS

The choice of regional limits of metal distribution patterns is arbitrary and mainly for descriptive purposes. Some of the regions as described are undoubtedly local or related to specific rock formations or structures. Others may be related to one another as parts of very large scale zonal patterns which cut across geologic formations. That aspect is being further investigated.

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