UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A preliminary evaluation of stream sediment sampling for the detection of cobalt mineralization in the Bou Azzer district, Morocco

by

Michael P. Foose[1]

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1. Reston, Va.

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CONTENTS

	Page
Abstract	1
Introduction	1
Regional setting and character of the cobalt mineralization	1
Previous Exploration	3
Present study	4
Analytical Technique	4
Results and discussion	4
Conclusions	19
References	20

ILLUSTRATIONS

Figure 1. Index and geologic map of the Bou Azzer District, Morocco	2
Figure 2. Histogram showing the distribution of selected elements from the east Tamdrost area, Bou Azzer district, Morocco.	8
Figure 3. The distribution of arsenic in stream sediments	9
Figure 4. The distribution of barium in stream sediments	10
Figure 5. The distribution of boron in stream sediments	11
Figure 6. The distribution of cobalt in stream sediments	12
Figure 7. The distribution of chromium in stream sediments	13
Figure 8. The distribution of copper in stream sediments	14
Figure 9. The distribution of mercury in stream sediments	15
Figure 10. The distribution of nickel in stream sediments	16
Figure 11. The distribution of lead in stream sediments	17
Figure 12. Scatter plots and statistics for selected elements	18

TABLES

Table 1. Statistics on stream sediment samples from the east Tamdrost area, Bou Azzer district, Morocco	5
Table 2. Stream sediment analyses from the east Tamdrost area	6

Abstract

Analyses of 28 stream sediment samples collected in the Bou Azzer district, Morocco, show that this sampling technique may be useful in locating the cobalt arsenide mineralization that exists in this area. The absence of exceptionally high values of cobalt and arsenic, the nearly lognormal distribution of cobalt values, and the lack of correlation between the highest values of cobalt and arsenic were unanticipated results that do not support the use of this sampling technique. However, highest values of several metals, including cobalt, were associated with an identified area of cobalt mineralization, and high cobalt was present near a second area in which cobalt mineralization is suspected. Although probably mostly reflecting the geochemistry of unexposed ultramafic rocks, the association of these metals with mineralization shows that this type of sampling can independently locate areas of known or potential cobalt mineralization.

Introduction

In January and February of 1982 the Trade and Development Program of the International Development Cooperation Agency sponsored a technical mission to Morocco, the primary purpose of which was to evaluate the potential for additional sources of cobalt in that country. U.S. Geological Survey members of this mission were particularly concerned with assessing the reserves and resources of Morocco's principal cobalt area, the Bou Azzer district, and in recommending means by which additional cobalt could be located. Their report (Foose and Rossman, 1982) suggested a number of untried exploration techniques, and observed that analyses of fine grained sediments collected from stream drainages may be the quickest, easiest, and least expensive means for locating additional cobalt deposits.

In order to asses the feasibility of this exploration technique, stream sediment samples were collected over an approximately 1 km^2 area in the Bou Azzer district. Within the sampled area occur a small vein containing identified cobalt mineralization and a second location that is suspected to be mineralized. This study was intended to idependently identify by geochemical sampling both the known and suspected mineralized areas.

Regional Setting and Character of the Cobalt Mineralization

The Bou Azzer mining district is located in the Anti Atlas mountains of Morocco, approximately 160 km southeast of the city of Marrakech (Fig. 1). Since 1930, this area has produced over 50,000 tons of cobalt metal and, in recent years, has contributed between 4 to 8 percent of the annual world's cobalt mine production. Until low world cobalt prices forced the district to cease production at the end of 1982, it was the only area in the world where cobalt was produced as the principal product of mining. The region has a moderately rugged relief (elevations range from 1300 - 1600 m), and a dessert climate that causes vegetation to be sparse, soils to be poorly developed, and rocks to be well exposed.

The cobalt mineralization is located within a roughly east-west trending uplifted block of Precambrian rocks, approximately 50 km long by 5-20 km wide (Leblanc, 1981). The basement of this block is the northern edge of the 2,000 m.y. old West African Eburnean craton. During the major Pan African deformation (680 - 580 m.y.), south directed thrusting

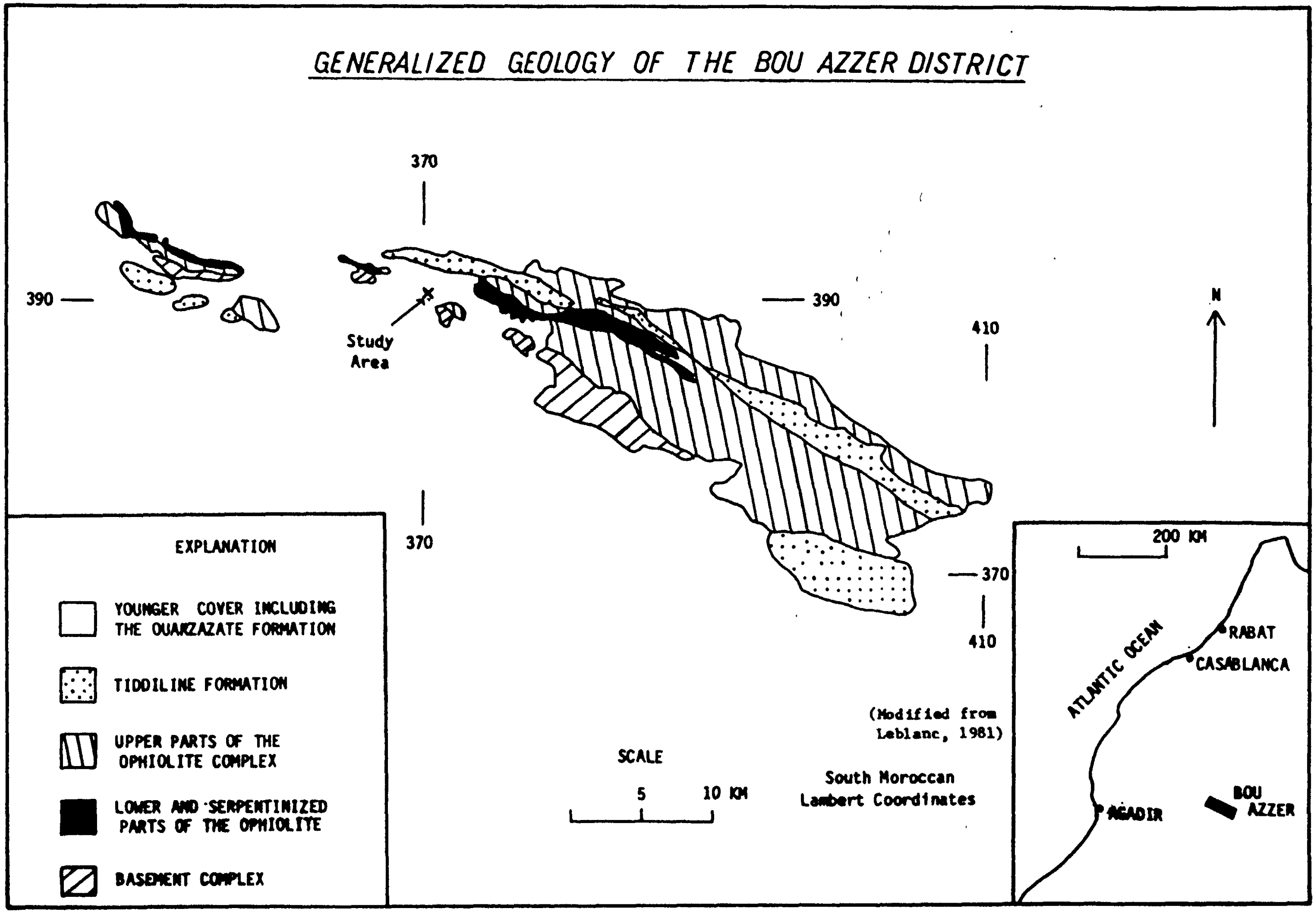


Figure 1. Index and geologic map of the Bou Azzer District, Morocco.

emplaced a fragment of oceanic crust (ophiolite) onto this basement. The basement and ophiolite complex were subsequently covered by 1,500 m thick detrital sediments and volcanics (Tiddiline Formation). The subsequent exposure of these rocks in horst blocks was accompanied by subaerial weathering of the ultramafic rocks and the formation of a siliceous and carbonaceous rock (the Ahmbed Formation) which now hosts most of the region's cobalt mineralization (Leblanc, 1981). Folding (580-615 m.y.), deposition of the volcanics of the Ouarzazate Formation (580-565 m.y.), and minor additional folding and faulting during the Hercynian deformation completed the general geologic history of the region.

Although varying widely in size and shape, the approximately 60 cobalt deposits in the Bou Azzer district display a number of common characterstics. Their most important feature is a close spatial association with serpentine which represents the lowermost parts of the Precambrian ophiolite complex (Fig. 1). Although occurring near serpentine, cobalt mineralization is almost never enclosed in serpentine. Instead, it is usually in a quartz-carbonate gangue that occurs along edges of serpentine masses. Plastic deformation of the serpentine has caused it to move into contact with a number of different rock units. In turn, this means that the associated quartz-carbonate rock and enclosed mineralization is within a variety of rocks that may be older, the same age, or younger than serpentine.

The cobalt deposits are generally small. Most have less than 200,000 tons of ore, and only two have produced more than 1 million tons of ore (Leblanc and Billaud, 1982). Deposits generally do not exceed 20 m in thickness. Ore grades typically are 1.2 percent Co, 0.15 percent Ni, and 4 percent As. There is also usually minor amounts of Au, Ag, Mo, and Bi. Ore minerals are mostly skutterudite, safflorite, loellingite, rammelsbergite and gersdorffite.

Of the variety of genetic interpretations given to this cobalt mineralization, two are most widely accepted. Traditional interpretations which ascribe a hydrothermal origin for these deposits (Jouravsky, 1952; Goloubinow, 1956; Krutov, 1970), have recently been challenged by suggestions that the mineralization was initially stratabound within a weathering crust of quartz-carbonate rock (the Ahmbed Formation) that formed on serpentine (Routhier and others, 1970; Leblanc, 1981). Regardless of the initial means of ore concentration, the occurence of cobalt in veins hosted within a wide variety of lithologies and the estimated temperatures of ore paragenesis of between 200° and 450°C (Leblanc, 1981; Besson and Picot, 1978) indicate that hydrothermal solutions have played a critical role in forming the present mineralization.

Previous Exploration

Numerous exploration programs have been carried out in the Bou Azzer district by Moroccan, French, and Russian geologists. Exploration has included detailed geologic mapping, extensive rock sampling, magnetic surveys, and exploratory drilling. The most recent comprehensive exploration program was undertaken between 1969 and 1971 by geologists from the Soviet Union during which over 60,000 rock samples were collected. This study (Technoexport, 1969 - 1971) located a subsequently mined cobalt deposit; results of this program have been discussed by Leblanc (1981) and Leblanc and Billaud (1982).

Present Study

Despite extensive work, several exploration techniques have not been tried in the Bou Azzer district. Of these, stream sediment sampling is perhaps the easiest and least expensive. This sampling approach has proven to be very effective in North America where it is widely used by many private companies in their mineral exploration programs and by the U.S. Government in its regional resource evaluations of public lands. This type of sampling has successfully detected mineralization in a wide variety of environments, including arid regions such as exists in the Bou Azzer district.

An approximately 1 km^2 area was selected in order to make a preliminary evaluation of the usefulness of stream sediment samples in this district. This area (Fig. 1) is underlain by volcanics of the Ouarzazte Formation and is located between two of the three major exposures of serpentine in the Bou Azzer district. Exploration with a small drilling rig has shown the presence of a small mineralized vein within this area and surface geologic studies have identified an additional site that is considered to be favorable for cobalt mineralization.

Twenty-eight samples were collected from intermittent streams with the intent to geochemically locate both the known and suspected areas of mineralization. All samples were collected from the finest sediments available and, with one exception, were taken from centers of drainages. Sample number 12 differed from others as it is a composite sample made of two approximately equal sized samples taken from two adjoining small drainages.

Analytical Technique

All samples were dried and seived to less than 140 mesh (0.105 mm) and pulverized for analyses in the U.S. Geological Survey laboratory, Denver, Colo. Semi-quantitative analyses of 31 elements by optical emission spectrographic methods were made by D. E. Detra, U.S. Geological Survey. This method reports results by a "six-step" method that divides every ten-fold concentration of an element into six intervals that have mid points at 1.0, 0.7, 0.5, 0.3, 0.2 and 0.15. Analytical results are reported as these mid point values. Thus, a concentration of 0.68 ppm would report as 0.7 ppm, and a concentration of 550 ppm would be given as 500 ppm. Results have an expected precision such that 83 percent of the time the actual value is within the reported or adjacent higher or lower interval (Motooka and Grimes, 1976). Additional quantitative analyses were made for mercury by J. D. Sharkey and for arsenic by W. C. Martin because of their association with the cobalt mineralization. Analytical results were processed by C. M. Sears using a small desk-top computer and programs developed by J. T. Hanley and P. G. Schruben for use in the U. S. Geological Survey's program of mineral resource appraisal of public lands.

Results and Discussion

Analytical results (summarized in Table 1; listed in Table 2) do not reveal unusually high metal values. Values for chromium, copper, cobalt, and nickel are higher than in most stream sediments, but are well within ranges observed from areas such as this one that are associated with ultramafic rocks. Boron values, which are also slightly higher

BASIC STATISTICS

FILE NAME: MOROCCO

ELEMENT	MINIMUM	MAXIMUM	MEDIAN	ARITHMETIC MEAN	ARITHMETIC DEVIATION	GEOMETRIC MEAN	GEOMETRIC DEVIATION	UNQUALIFIED (VALID)	QUALIFIED N	QUALIFIED L	QUALIFIED G
FE	3	10	7	7.035	1.731	6.815	1.303	28	0	0	0
MG	1.5	7	2	2.732	1.280	2.527	1.454	28	0	0	0
CA	1	15	2	2.767	2.973	2.100	1.931	28	0	0	0
TI	.5	1G	1	.922	.155	.906	1.223	18	0	0	10
MN	700	2000	1500	1257.	303.593	1221.	1.277	28	0	0	0
B	200	500	300	285.714	111.269	268.343	1.415	28	0	0	0
BA	500	1000	700	710.714	191.174	686.837	1.303	28	0	0	0
BE	1	5	1.5	1.660	.805	1.536	1.455	28	0	0	0
CO	10	50	20	22.142	9.272	20.753	1.416	28	0	0	0
CR	100	700	150	182.142	129.967	158.336	1.614	28	0	0	0
CU	10	50	20	22.678	10.136	20.753	1.535	28	0	0	0
LA	50	150	70	73.928	24.242	70.578	1.354	28	0	0	0
NB	20N	20	20L	20	0	20	0	1	8	19	0
NI	20	300	50	63.214	74.239	45.758	1.983	28	0	0	0
PB	10	70	20	30.178	17.452	26.303	1.683	28	0	0	0
SC	10	30	20	20.535	5.666	19.805	1.316	28	0	0	0
SR	100N	150	100	101.923	9.805	101.571	1.082	26	2	0	0
V	100	300	200	189.285	34.311	186.120	1.211	28	0	0	0
Y	20	70	50	45.357	13.188	43.353	1.371	28	0	0	0
ZR	200	700	300	392.857	176.233	355.374	1.585	28	0	0	0
HG	.02	.08	.04	.045	.011	.044	1.296	28	0	0	0
ASAA	10L	40	10	17.380	8.309	15.746	1.565	21	0	6	0
AG	.5N	5N	.5N	N/C	N/C	N/C	N/C	0	28	0	0
AS	200N	200N	200N	N/C	N/C	N/C	N/C	0	28	0	0
BI	10N	10N	10N	N/C	N/C	N/C	N/C	0	28	0	0
CD	20N	20N	20N	N/C	N/C	N/C	N/C	0	28	0	0
MO	5N	5	5N	5	0	5	0	1	27	0	0
SB	100N	100N	100N	N/C	N/C	N/C	N/C	0	28	0	0
SN	10N	10N	10N	N/C	N/C	N/C	N/C	0	28	0	0
TH	100N	100N	100N	N/C	N/C	N/C	N/C	0	28	0	0
W	50N	50N	50N	N/C	N/C	N/C	N/C	0	28	0	0
ZN	200N	200L	200N	N/C	N/C	N/C	N/C	0	27	1	0

Table 1. Statistics on stream sediment samples from the east Tamdrost area, Bou Azzer district, Morocco. All analyses are in ppm except Fe, Mg, Ca, and Ti which are in percent; ASAA is Arsenic analyzed by atomic absorption. Symbols for qualified values are: N - not detected below the value shown; L -- detected but less than the value shown; G - greater than the value shown; N/C - not calculated.

FLD	FE	MG	CA	TI	MN	B	BA	BE	CO	CR	CU	LA	NB	NI	AG	AS
TE1	5	2	1.5	7	1000	200	500	1.5	15	150	10	50	20L	20	5N	200N
TE2	5	2	1.5	7	1000	500	700	2	15	150	20	70	20L	20	5N	200N
TE3	7	3	1	1	1500	200	1000	2	20	100	20	70	20L	20	5N	200N
TE4	7	2	2	1	1500	500	700	1.5	20	200	20	70	20N	50	5N	200N
TE5	7	5	1	1	1500	200	500	2	20	100	20	50	20N	20	5N	200N
TE6	7	2	1.5	1	1000	300	700	2	20	150	20	100	20N	50	5N	200N
TE7	7	2	2	1G	1500	500	700	1.5	20	150	30	50	20L	50	5N	200N
TE8	5	3	2	1	1000	300	700	1.5	15	100	20	70	20N	20	5N	200N
TE9	7	2	2	1	1000	500	500	1.5	20	200	15	50	20N	30	5N	200N
TE10	5	2	5	1	1000	200	1000	1.5	15	100	15	70	20L	30	5N	200N
TE11	7	2	2	1	1000	200	500	1.5	15	100	10	70	20N	30	5N	200N
TE12	7	3	2	1G	1000	200	500	1.5	20	150	20	70	20L	50	5N	200N
TE13	10	2	3	1G	1500	300	1000	1	20	200	20	50	20N	50	5N	200N
TE14	10	5	3	1G	2000	200	700	1	30	200	30	50	20L	200	.5N	200N
TE15	7	2	1	1	1000	200	700	2	20	150	50	70	20L	50	5N	200N
TE16	5	2	1.5	7	1500	500	500	5	15	100	20	100	20L	30	5N	200N
TE17	3	1.5	15	5	700	200	500	3	10	100	10	100	20N	20	5N	200N
TE18	7	5	3	1	1500	200	1000	1	20	500	20	70	20L	200	5N	200N
TE19	7	2	1	1	1000	200	700	2	20	200	20	150	20L	50	.5N	200N
TE20	10	7	3	1G	1500	300	700	1.5	50	700	30	100	20L	200	5N	200N
TE21	7	2	1	1	1000	200	700	2	20	150	30	100	20L	30	5N	200N
TE22	7	2	3	1G	1000	200	500	1.5	30	150	20	100	20	50	.5N	200N
TE23	10	2	1.5	1G	1500	200	700	1	20	100	20	100	20L	30	5N	200N
TE24	7	2	1	1G	1500	200	500	1	20	100	15	50	20L	30	5N	200N
TE25	7	2	3	1G	1500	200	1000	1	20	150	50	50	20L	50	5N	200N
TE26	7	2	10	1	1000	200	700	1.5	50	150	10	50	20L	20	5N	200N
TE27	10	2	3	1G	1500	200	1000	1	20	200	20	70	20L	50	5N	200N
TE28	7	3	2	1	1500	200	1000	1	20	200	30	70	20L	50	5N	200N

FLD	BE	BI	CD	MO	PB	SB	SC	SN	SR	V	W	ZN	ZR	TH	HG	ASAA
TE1	1.5	10N	20N	5N	20	100N	15	10N	100	200	50N	200N	200	100N	04	20
TE2	2	10N	20N	5N	30	100N	15	10N	100	150	50N	200N	700	100N	04	10L
TE3	2	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	500	100N	04	10
TE4	1.5	10N	20N	5N	30	100N	20	10N	100	150	50N	200N	700	100N	06	10
TE5	2	10N	20N	5N	50	100N	20	10N	100	200	50N	200N	500	100N	04	20
TE6	2	10N	20N	5N	50	100N	20	10N	100	200	50N	200N	500	100N	06	20
TE7	1.5	10N	20N	5N	50	100N	20	10N	100	200	50N	200N	500	100N	.06	10
TE8	1.5	10N	20N	5N	70	100N	15	10N	100	200	50N	200N	500	100N	.08	0.08
TE9	1.5	10N	20N	5N	20	100N	15	10N	100	200	50N	200L	300	100N	06	10
TE10	1.0	10N	20N	5N	20	100N	15	10N	100N	100	50N	200N	700	100N	.04	10L
TE11	1.5	10N	20N	5N	20	100N	15	10N	100	200	50N	200N	500	100N	04	10L
TE12	1.5	10N	20N	5N	30	100N	20	10N	100	200	50N	200N	500	100N	06	10L
TE13	1	10N	20N	5N	20	100N	20	10N	100	300	50N	200N	300	100N	04	30
TE14	1	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	500	100N	04	10
TE15	3	1GN	20N	5N	70	100N	20	10N	100	150	50N	200N	300	100N	.08	15
TE16	5	10N	20N	5N	20	100N	15	10N	100N	150	50N	200N	500	100N	.04	30
TE17	3	10N	20N	5N	10	100N	10	10N	100	150	50N	200N	200	100N	04	20
TE18	1	10N	20N	5N	15	100N	20	10N	150	150	50N	200N	200	100N	06	20
TE19	2	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	200	100N	02	40
TE20	1.5	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	200	100N	04	10
TE21	2	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	300	100N	04	10
TE22	1.5	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	700	100N	04	20
TE23	1	10N	20N	5N	30	100N	20	10N	100	200	50N	200N	300	100N	04	10L
TE24	1	10N	20N	5N	30	100N	30	10N	100	200	50N	200N	200	100N	04	10L
TE25	1	10N	20N	5N	70	100N	20	10N	100	200	50N	200N	200	100N	.04	10
TE26	1.5	10N	20N	5N	20	100N	20	10N	100	200	50N	200N	300	100N	04	20
TE27	1	10N	20N	5N	10	100N	20	10N	100	200	50N	200N	200	100N	04	10
TE28	1	10N	20N	5	20	100N	30	10N	100	200	50N	200N	200	100N	06	20

TABLE 2: Stream sediment analyses from the east Tamdrost area, Bou Azzer District, Morocco. All data are in ppm, except Fe, Mg, Ca, and Ti which are in percent. All elements were analyzed semiquantitatively except mercury and arsenic listed as ASAA which were analyzed quantitatively. The semiquantitative analyses are reported by the six-step method discussed in the text. Other symbols are: G - greater than the value shown; N - not detected below the value shown; L - detected, but less than the value shown.

than usually observed, are probably due to the presence of the mineral tourmaline, a common accessory in volcanic rocks. With the exception of nickel, lead, and arsenic, elements have geometric means that are nearly equal to their median value, a relationship that suggests values for these elements are nearly lognormally distributed (Levinson, 1980, p. 218).

Histograms for ten elements are plotted in figure 2. Values for arsenic, boron, cobalt, chromium, mercury, titanium, and vanadium show approximately symmetrical distributions that are slightly skewed to higher values or show regularly increasing or decreasing values that are truncated by upper or lower determination limits. These patterns may be interpreted as either complete or truncated lognormal distibutions and are thus similar to patterns typically obtained from areas where only one sample population is present. In contrast, a mixing of two populations, each with differing background concentrations, may be indicated by the non-symmetric distribution shown by nickel, copper, and lead. The bimodal distribution shown by nickel is particularly striking and may indicate a mixing of a background population with a second, more nickel-rich population that may be associated with mineralization.

Distribution maps (Fig. 3 to 11) show concentrations of nine elements relative to the area of each sampled stream drainage and the known and suspected areas of mineralization. The known area of mineralization is drained by streams from which samples 16, 19, and 20 were taken. Samples from either one or several of these drainages contain the highest observed values of arsenic, boron, cobalt, chromium, and nickel and show this location to have a relatively high concentration of several metallic elements. Contamination from the small drilling operation that is exploring this mineralization could be responsible for some of these high values. However, this drilling is located in the drainage immediately north of that sampled by sample 16 and apparently has not directly contaminated any of the sampled drainages. Therefore, it is considered unlikely that this drilling is responsible for these high values.

In contrast, highest values for most metallic elements are not found near the area of suspected mineralization (drainages 22, 23, 24, 26). Cobalt, however, is an important exception, as the cobalt concentration of 50 ppm found in sample 26 is equal to that observed associated with the identified cobalt mineralization (sample 20), thus showing this area as a potential host of cobalt mineralization.

Lead, copper, mercury, and barium show no association with either target area. Lead and copper do, however, appear to occur together (high values in samples 25 and 15). The occurrence of high barium values in the northern parts of the area suggests that rocks richer in barium occur in the topographically high regions that lie to the north of the studied area.

Scatter plots of element concentrations more clearly show the geochemical associations of elements (Fig. 12). In these diagrams, cobalt, nickel and chromium display a close association as also do lead and copper. Low correlations, however, exist in plots of nickel versus copper, showing that there is little relationship between the Co-Ni-Cr and the Cu-Pb associations. Arsenic and mercury, which are

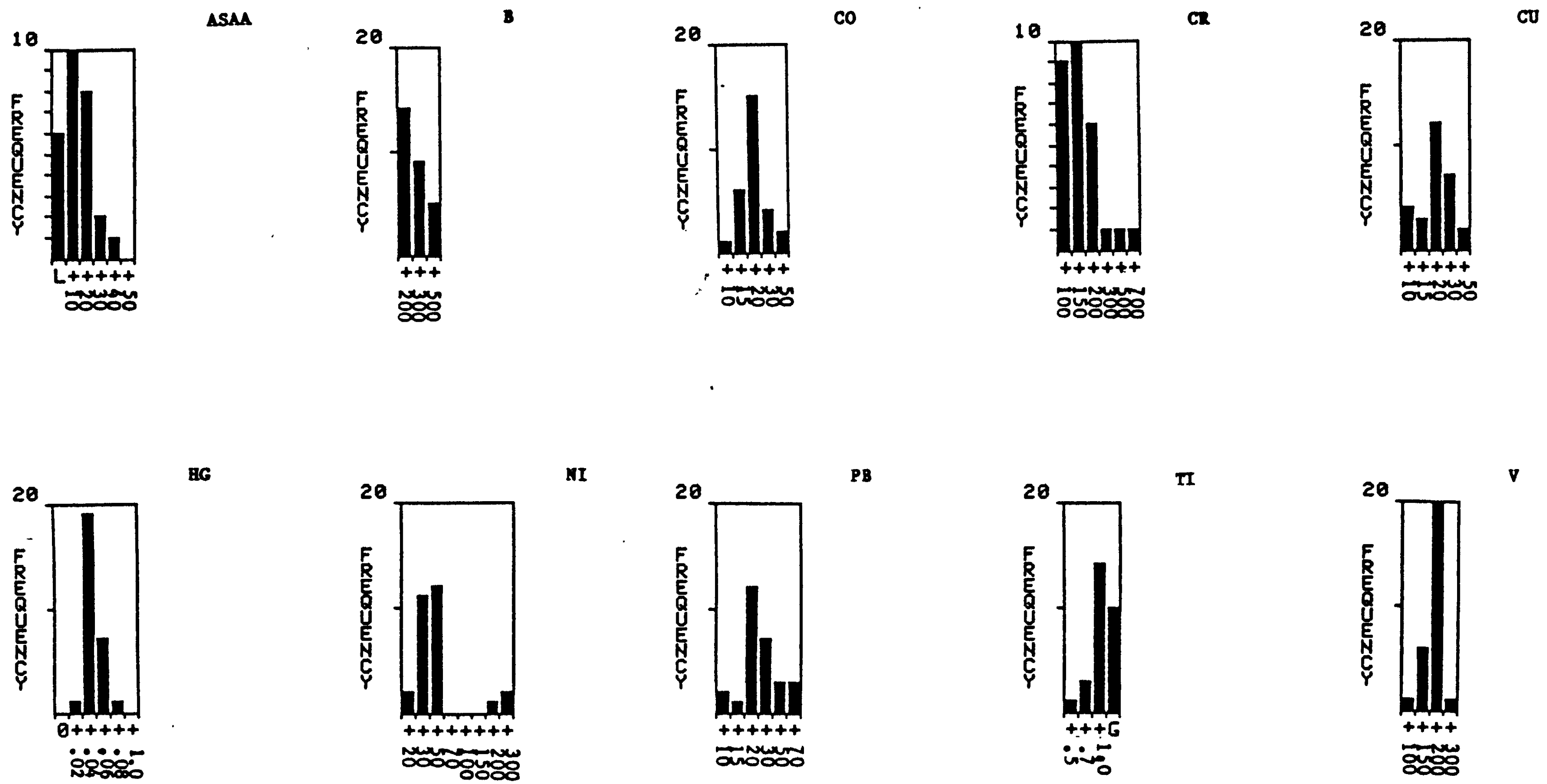


Figure 2. Histograms showing the distribution of selected elements from the east Tamdrost area, Bou Azzer district, Morocco. All data are in ppm, except Ti which is in percent. L - detected but less than lowest value shown; G - greater than highest value shown.

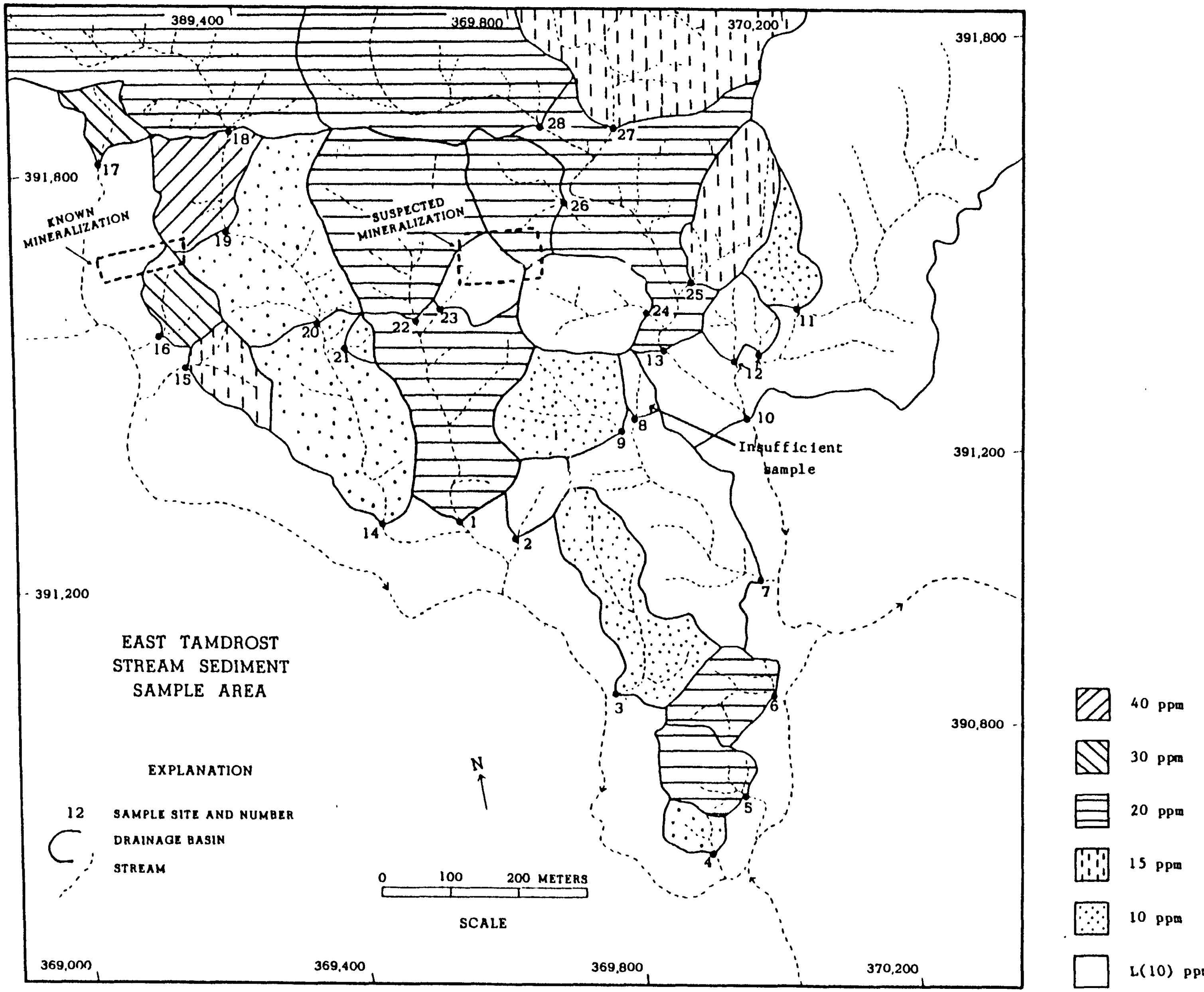


Figure 3. The distribution of Arsenic in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

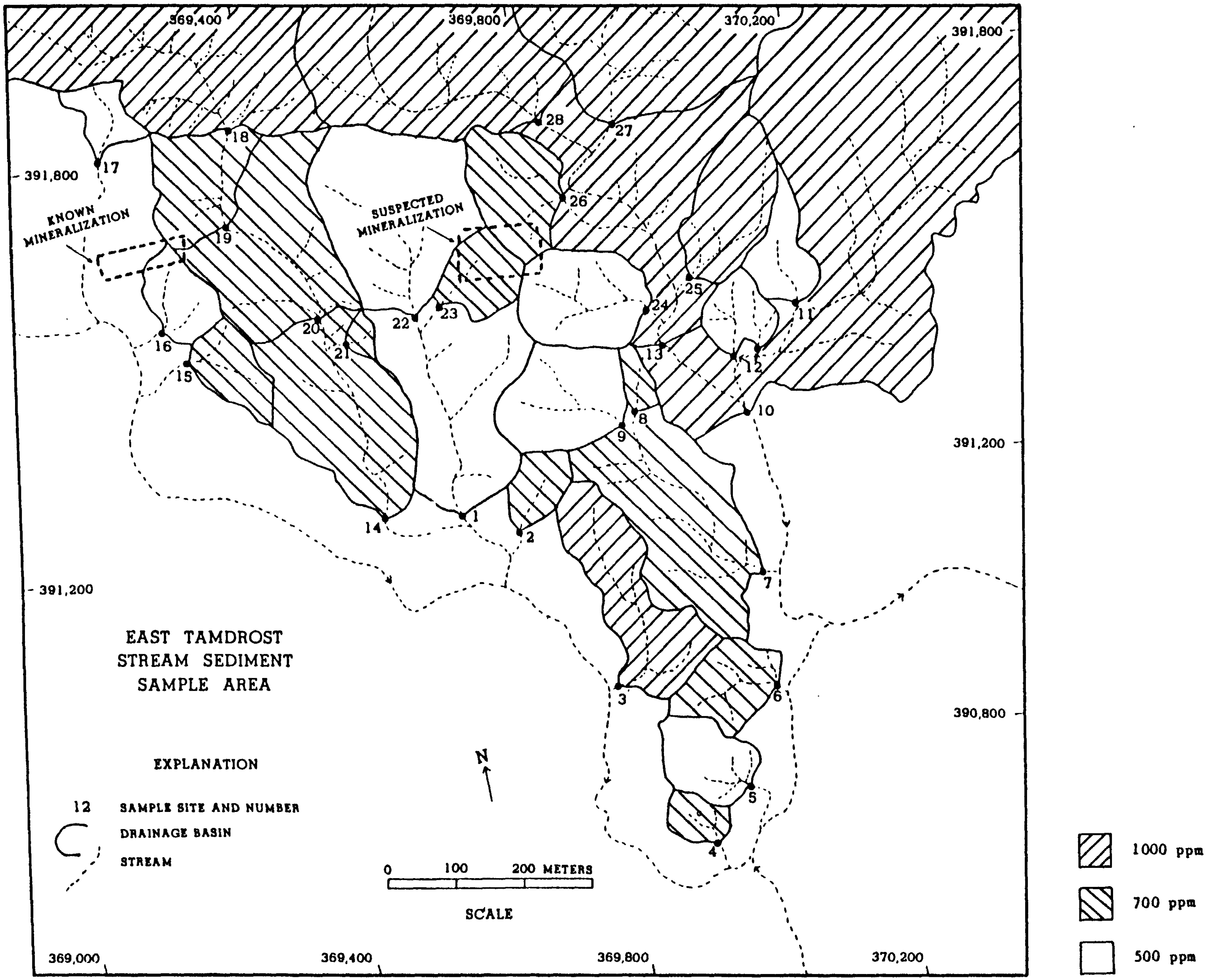
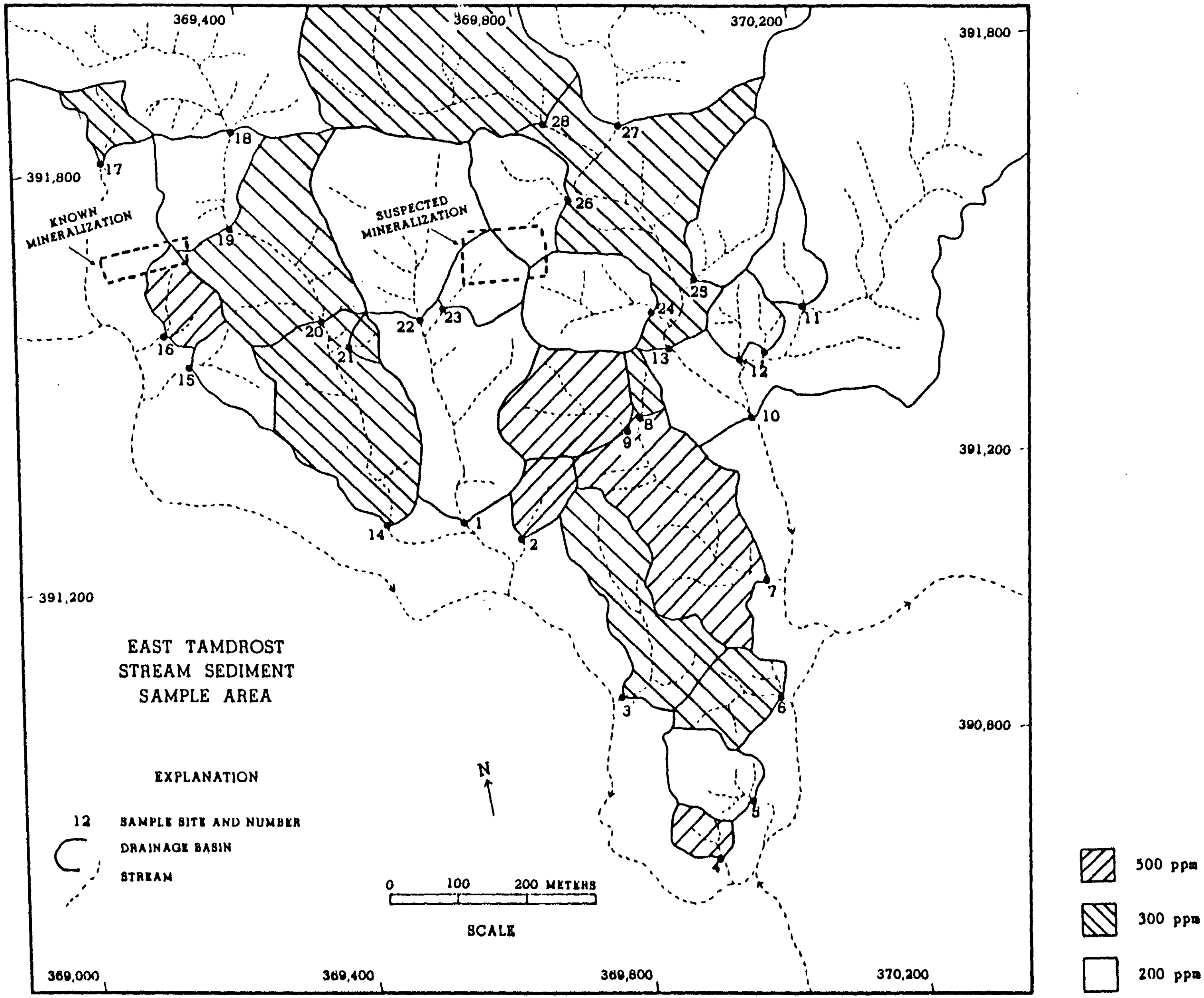


Figure 4. The distribution of Barium in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.



<u>Figure 5.</u> The distribution of Boron in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

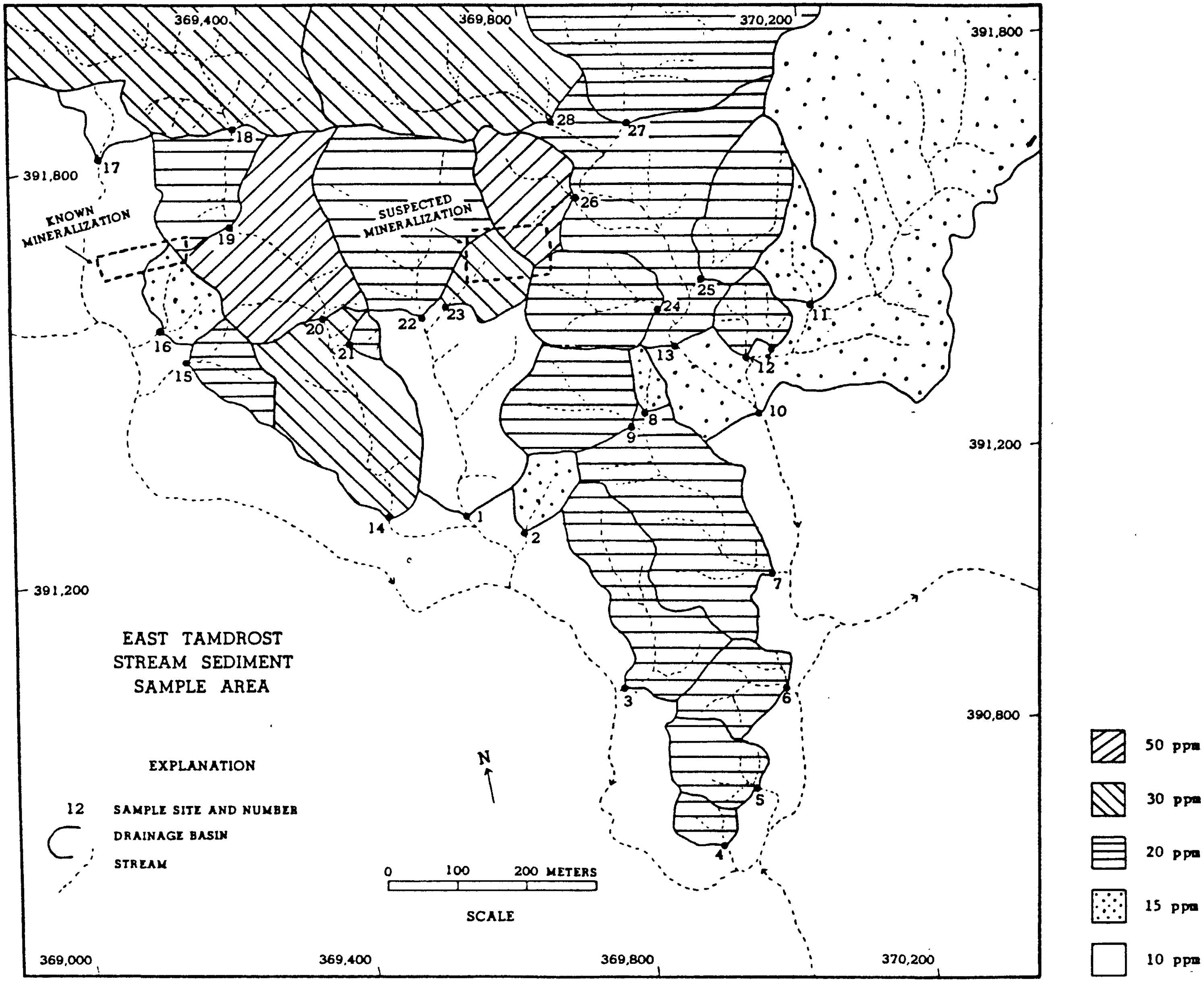


Figure 6. The distribution of Cobalt in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

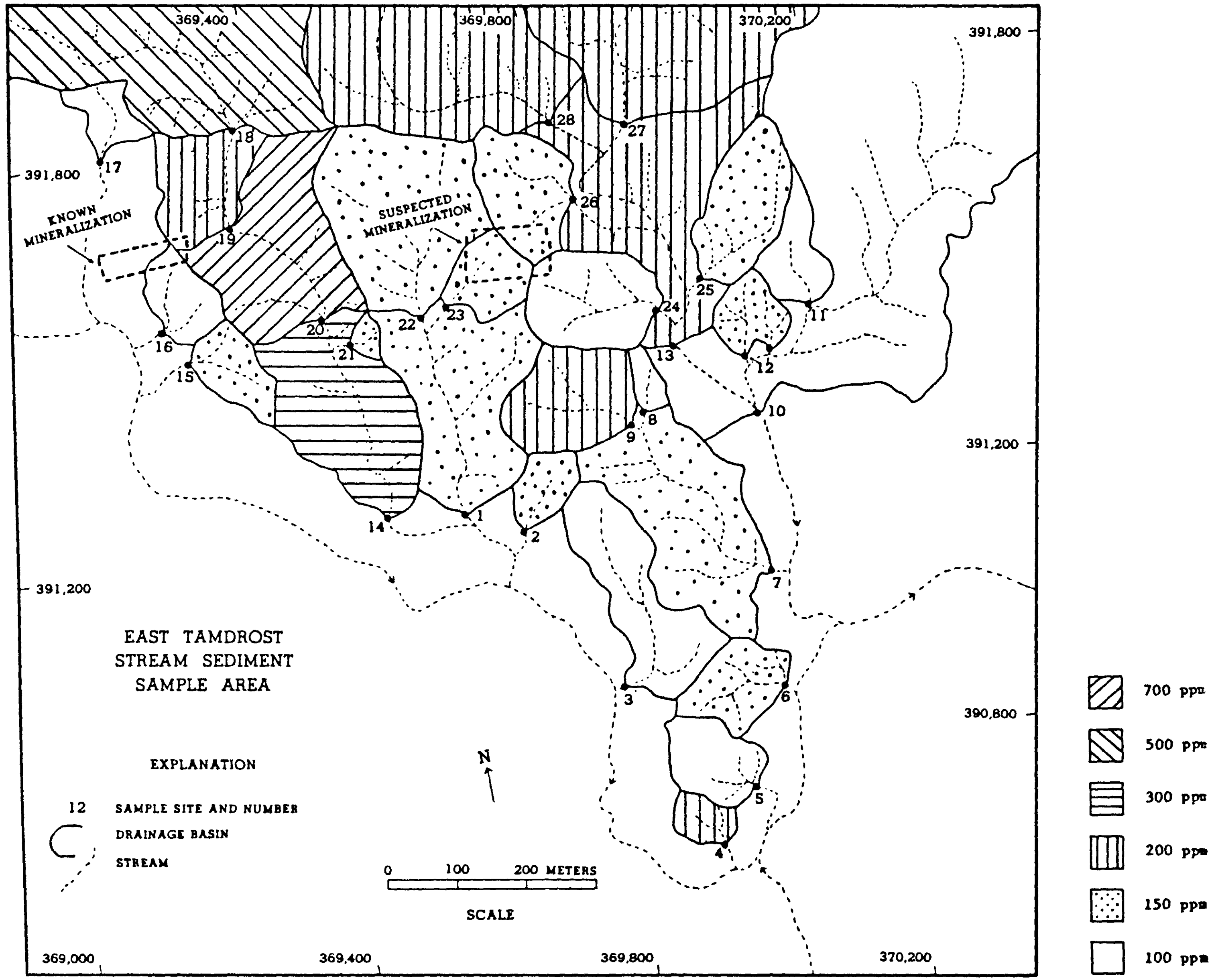


Figure 7. The distribution of Chromium in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

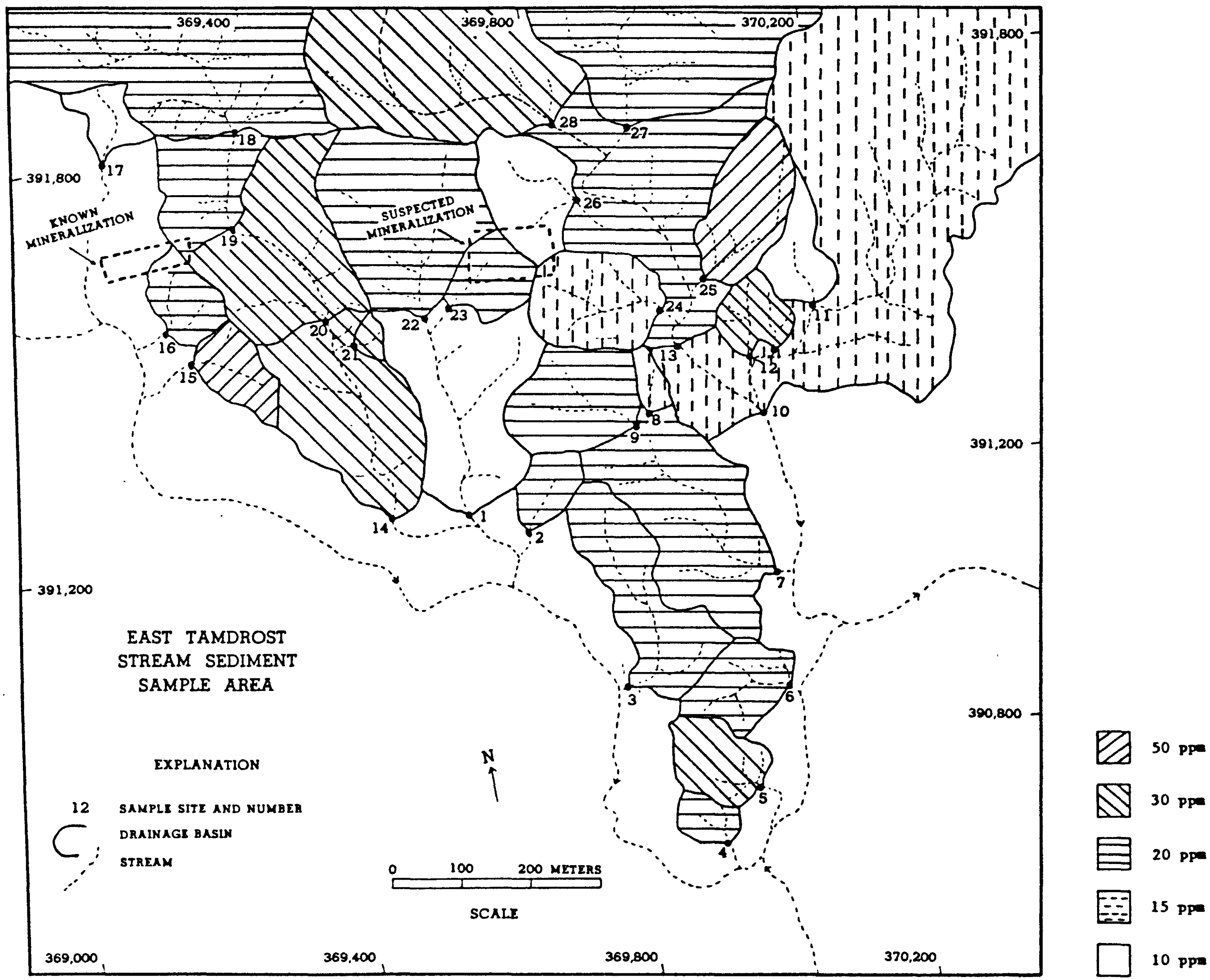


Figure 8. The distribution of Copper in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

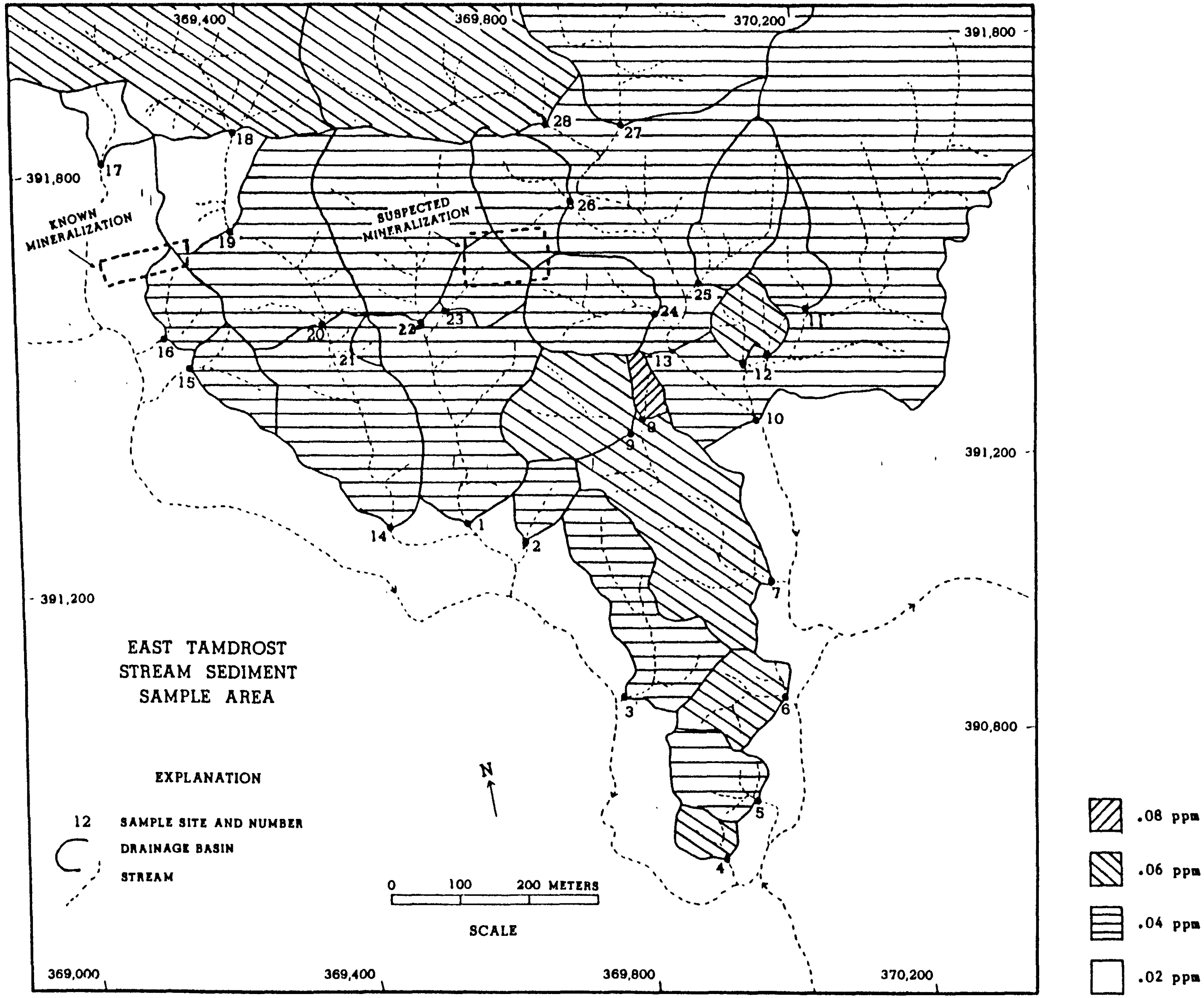


Figure 9. The distribution of Mercury in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

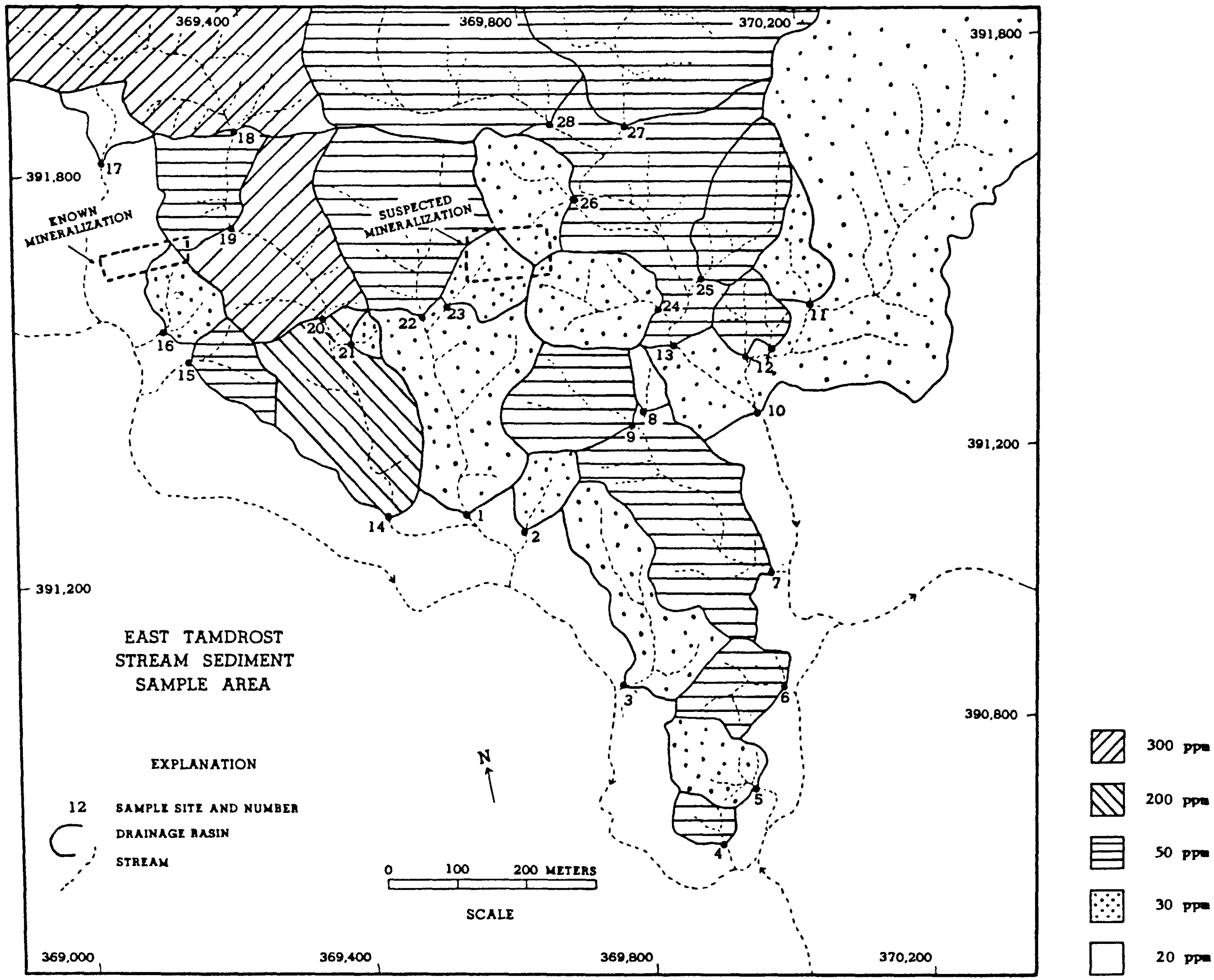


Figure 10. The distribution of Nickel in stream sediments from the east Tamdrost area, Bou Azzer district, Morocco.

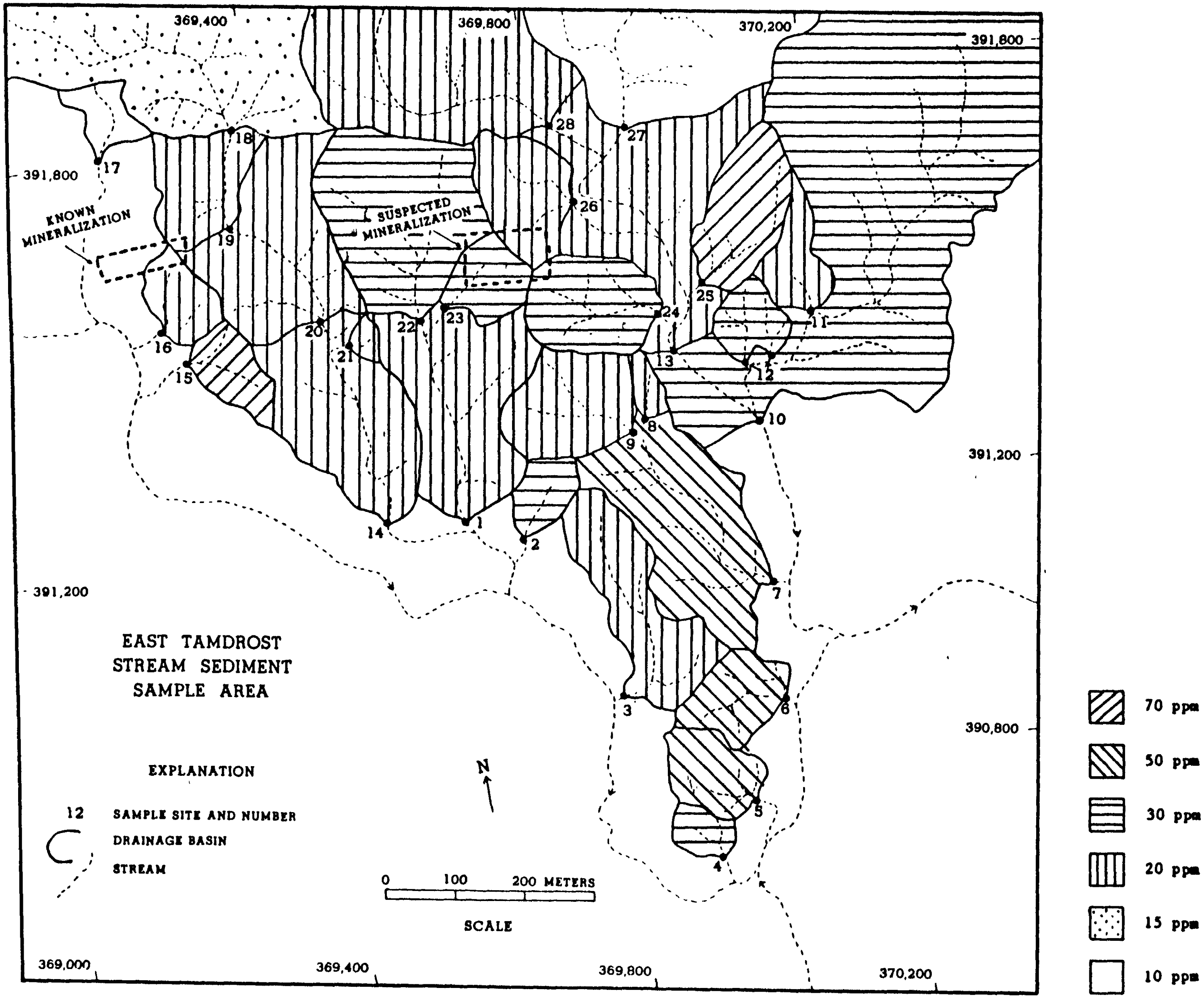
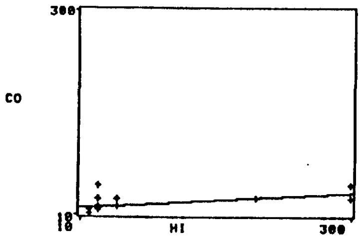
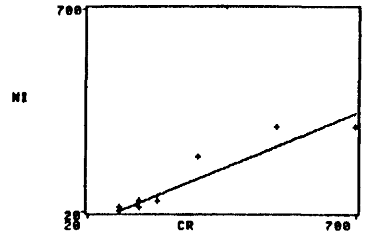


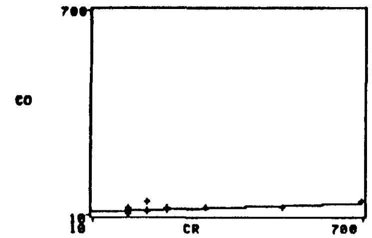
Figure 11. The distribution of Lead in stresm sediments from the east Tamdrost stea, Bou Azzer district, Morocco.



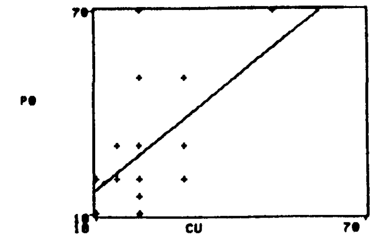
	NI	CO
MINIMUM	20	10
MAXIMUM	300	50
MEAN	63.2142857	22.1428571
STD DEV	74.2395309	9.27247734
B1	2.62003711	1.94289283
B2	8.41030302	6.53279855
CORRELATION COEF.	.584145168	
SLOPE	.0729594163	
Y INTERCEPT	17.5307798	
NUMBER OF POINTS	28	



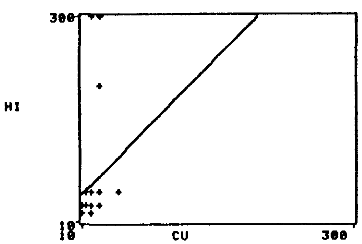
	CR	NI
MINIMUM	100	20
MAXIMUM	700	300
MEAN	182.142857	63.2142857
STD DEV	129.967436	74.2395309
B1	2.87497616	2.62003711
B2	11.1300229	8.41030302
CORRELATION COEF.	.9427737	
SLOPE	.5305278	
Y INTERCEPT	-34.0747063	
NUMBER OF POINTS	28	



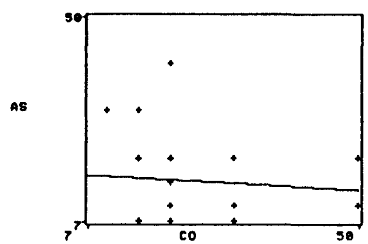
	CR	CO
MINIMUM	100	10
MAXIMUM	700	50
MEAN	182.142857	22.1428571
STD DEV	129.967436	9.27247734
B1	2.87497616	1.94289283
B2	11.1300229	6.53279855
CORRELATION COEF.	.647509628	
SLOPE	844282836	
Y INTERCEPT	13.7274863	
NUMBER OF POINTS	28	



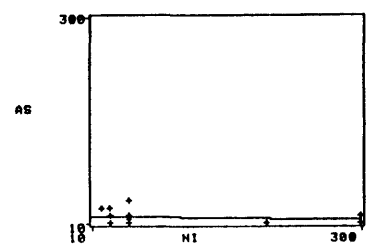
	CU	PB
MINIMUM	10	10
MAXIMUM	50	70
MEAN	22.6785714	30.1785714
STD DEV	10.1363065	17.452695
B1	1.22398855	1.27863509
B2	4.54489501	3.52725292
CORRELATION COEF.	.614880489	
SLOPE	1.05857741	
Y INTERCEPT	6.17184812	
NUMBER OF POINTS	28	



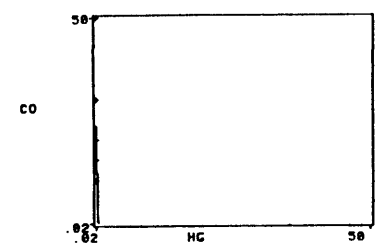
	CU	NI
MINIMUM	10	20
MAXIMUM	50	300
MEAN	22.6785714	63.2142857
STD DEV	10.1363065	74.2395309
B1	1.22398855	2.62003711
B2	4.54489501	8.41030302
CORRELATION COEF.	.182544921	
SLOPE	1.33698181	
Y INTERCEPT	32.8934664	
NUMBER OF POINTS	28	



	CO	AS
MINIMUM	10	7
MAXIMUM	50	40
MEAN	22.4074074	15.0740741
STD DEV	9.34000898	8.51289966
B1	1.98512296	1.19214662
B2	6.35816178	3.96723240
CORRELATION COEF.	-.0797263181	
SLOPE	-.0734538411	
Y INTERCEPT	16.7828401	
NUMBER OF POINTS	27	



	NI	AS
MINIMUM	20	10
MAXIMUM	300	40
MEAN	73.0095238	17.3809524
STD DEV	82.3352382	8.3894897
B1	2.15524519	1.00873032
B2	6.01178720	3.73953924
CORRELATION COEF.	-.201486193	
SLOPE	-.0208985181	
Y INTERCEPT	18.8638234	
NUMBER OF POINTS	21	



	HG	CO
MINIMUM	.02	10
MAXIMUM	.08	50
MEAN	.0457142857	22.1428571
STD DEV	.0119964721	9.27247734
B1	.077400295	1.94289283
B2	3.95155713	6.53279855
CORRELATION COEF.	-.0475651578	
SLOPE	-36.7647125	
Y INTERCEPT	23.8235297	
NUMBER OF POINTS	28	

Figure 12. Scatter plots and statistics for selected elements from the east Tamdrost area, Bou Azzer district, Morocco. All concentrations are in ppm.

present in the cobalt deposits of this district, fail to correlate either with cobalt or nickel.

The good correlation in the stream sediments between cobalt, nickel, and chromium is an expected association in areas associated with ultramafic rocks, and may indicate that such rocks provided sediment to the sampled stream drainages. This conclusion is supported by the best fit line to the cobalt verses nickel plot (Fig. 12) which has a slope that closely matches the average Co/Ni for ultramafic rocks in this area (Leblanc, 1981). Ratios of chromium to cobalt and chromium to nickel in the stream sediments are much higher than in ultramafic rocks and may show that chromium in sediments is enriched by the stream concentration of detrital chromite. However, the sampled area is one in which exposures of ultramafics are not identified (Fig. 1). Although it is possible that some ultramafic detritus could be introduced from higher elevations to the north of the sampled area, no ultramafics are mapped in this area and samples along the northern margin of the area do not have the highest concentrations of cobalt, nickel, and chromium. It is, therefore, also possible that these three elements have been introduced along veins emanating from underlying and unexposed ultramafic rocks and that their concentration is thus an expression of potential mineralization in this area.

Conclusions

The small number of samples (28) collected in this study do not provide unambiguous support for stream sediment sampling in the Bou Azzer district. The absence of obviously high metal values in the stream samples, the general lack of bimodal or clearly non-lognormal element distributions, and the failure to find statistically significant correlations between arsenic and cobalt, and mercury and cobalt are unanticipated results and suggest that these stream sediments do not closely reflect the chemical patterns known to be associated with cobalt mineralization. However, nickel shows a well developed bimodal distribution of values that could be the result of the mixing of material from both mineralized and unmineralized areas, and a close correlation exists between cobalt, nickel, and chromium. Although no obvious source of ultramafic detritus exists in this area, the association of these three elements probably largely reflects the presence of ultramafic rocks. The occurrence of high cobalt (sample site 26, near the area of suspected mineralization) with no corresponding high nickel or chromium also shows that the close association expected of these elements were they to have been derived from eroded ultramafic rocks does not always exist. Instead these features may indicate that cobalt, nickel, and chromium may have been introduced in varying proportions by veins derived from underlying and unexposed ultramafic rocks. The absence of high arsenic and boron in these areas may also show these veins to be relatively unmineralized.

Ultimately, the most significant result of this study is that the geochemical maps show highest values of cobalt and other metals near the known mineral occurrence and high cobalt near the area of suspected mineralization. These results, in turn, identify these two areas as having potential economic intrest. This sampling thus succeeds in geochemically locating the two target areas identified before this study by other means.

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