GEOCHEMISTRY AND MINERAL EXPLORATION IN GREECE

II. STREAM SEDIMENT SURVEYS *

by

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INTRODUCTION

The general principles of mineral exploration and the application of geochemistry to exploration were briefly reviewed in the first paper of this series; the concept of a geochemical anomaly was discussed and some general explanations of interpretations of geochemical data were given. In this first part of the present paper the results of some stream sediment surveys undertaken in Greece under the auspices of a project sponsored by the Technical Cooperation Service of O.E.C.D.[3] and G.E.M.E.E.[4] are described.

The fundamental premise upon which geochemical stream surveys depend is that the material passing down a drainage system reflects the average chemical character of the geology of the drainage basin. If some chemical abnormality exists in a drainage basin, such as mineralization, then this abnormality should be reflected in the chemical composition of the stream sediments and waters. Obviously, this abnormality, which in the general case is indentified as anomalous concentrations of one or more elements, is strongest close to the mineralization and becomes weaker with increasing distance from the mineralization until it becomes swamped by increasing contributions of normal background material. Therefore, chemical analyses of samples of stream sediment provide a means of assessing the composition of a drainage basin and, in the ideal situation, an increase in element concentration may be expected with decreasing distance from the source.

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* ΓΕΩΧΗΜΙΚΗ ΚΑΙ ΟΡΥΚΤΟΛΟΓΙΚΗ ΕΡΕΥΝΑ ΣΤΗΝ ΕΛΛΑΔΑ. II. ΔΙΕΡΕΥΝΗΣΗ ΠΟΤΑΜΙΩΝ ΙΖΗΜΑΤΩΝ.

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Stream sediment geochemistry may be employed in reconnaissance work to locate target areas within a large region or, for more detailed exploration, to define a small zone within a target area. The target area, in the latter application, may have been selected by a geochemical stream reconnaissance survey or by other exploration techniques such as airborne geophysics or geological mapping.

ORIENTATION SURVEYS

The main problem of interpretation of any type of geochemical survey is to determine which anomalies may be indicative of significant mineralization and which are due to minor, unimportant mineralization or simply to variations in the environment. This is especially important in stream reconnaissance surveys where the objective is to determine the small areas within large regions in which to concentrate detailed exploration. For example, a weak anomaly may represent minor mineralization very close to the stream, or it may represent major mineralization at a great distance from the stream. Similarly, the size of the stream, its rate of flow, the nature of the bank material, and the physical nature of the sample will all cause variations in geochemical response from a given mineralized occurrence. Many of these potential sources of variation can be assessed on the basis of detailed information collected at each sample site, combined with experience obtained elsewhere.

However, there is a great advantage in conducting a preliminary orientation survey which is designed to assess geochemical response in a particular region and to assess the effects of the variables mentioned above. It is an advantage if mineralization of the type being sought is present in the area in which the orientation survey is conducted in order that the character of anomalies related to mineralization can be determined; such mineralization does not have to be economic. The sample density is normally much greater for orientation surveys than for strictly exploration purposes since the objective is to obtain as much information as possible.

The reconnaissance stream survey described in this paper was intended to fulfill two objectives : to provide operational and interpretative guides for exploration in other, similar areas; and to provide exploration data for the reconnaissance area.

RECONNAISSANCE STREAM SEDIMENT SURVEY

An experimental stream reconnaissance survey was undertaken in an area of about 120 square kilometres near Kirki (Fig. 1). Because of the trial nature of this survey, a considerably higher sample density was used than is now employed in similar routine surveys in Greece. Thus, 336 locations were sampled, giving an average density of 2.8 samples per square kilometre; in routine reconnaissance

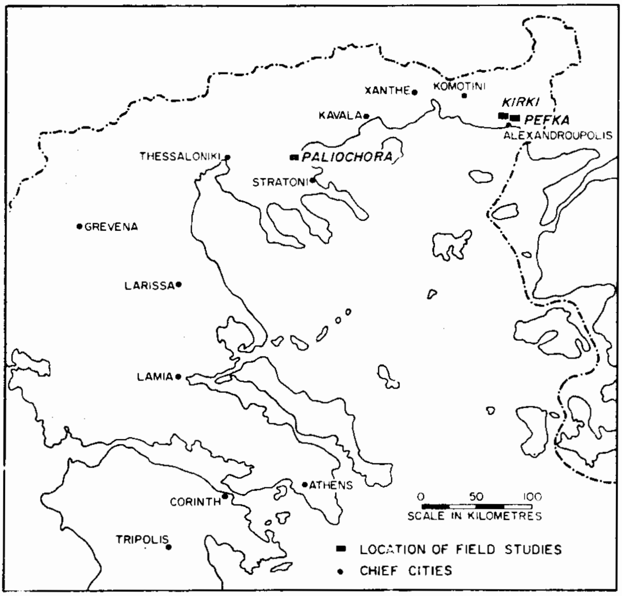

Fig. 1. Location of field studies.

surveys in northern Greece it has been demonstrated that an average density of 0.5 samples per square kilometre is adequate.

The general geology of the region is shown on Figure 2. Basement schists are overlain, or faulted against, a sedimentary-volcanic sequence. The sedimentary rocks are conglomerates, sandstones, shales, and limestones; the volcanic rocks comprise interbedded tuffs and sediments, and andesitic lava flows. Some dioritic intrusions occur within both the Basement and the sedimentary-volcanic sequence.

There are a number of known, but uneconomic, mineral occurrences containing chalcopyrite, galena, and sphalerite. Some of the larger occurrences have had considerable exploration work and the waste-tips of mineralized rock cause severe contamination in streams draining them. Disseminated pyrite with minor chalcopyrite has been noted in some of the andesites, tuffs, and sandstones.

Stream sediment samples were collected at the locations shown on Figure 2. Generally, samples were collected from all tributaries upstream from stream confluences; the sample station was chosen far enough upstream frum the confluence to avoid the effects of possible "backwash" during periods of high water. As far as possible, samples were collected from beneath flowing water in the centre of the stream; in narrow streams special care must be taken to avoid contamination from slumped back material.

The desirable sample type is fine sand or silt and, if the sediment at a simple station is particularly coarse grained, a large enough sample should be collected to provide at least 10 grams of sieved material. Detailed descriptive notes should

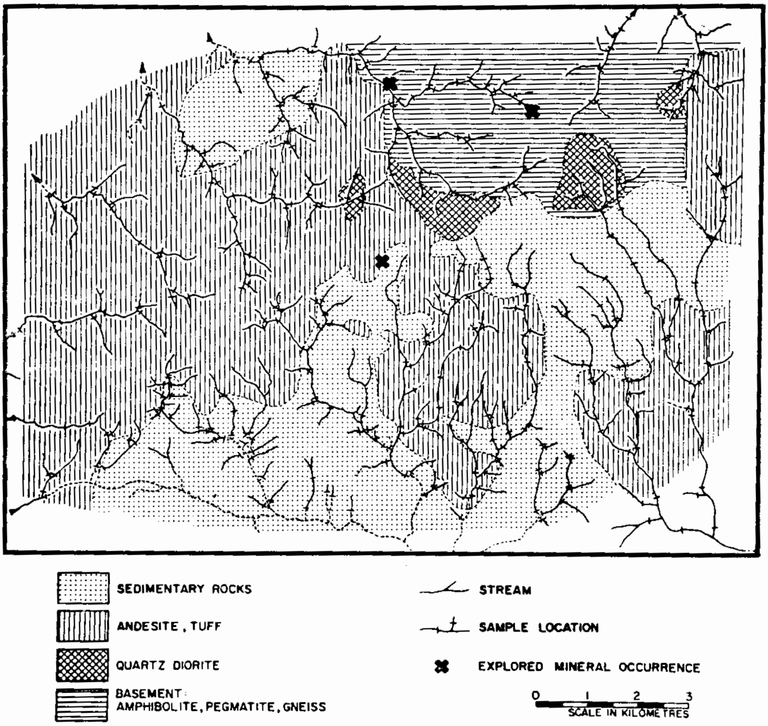

Fig. 2. General geology, location of known sulphide mineralization, and location of stream sediment sample locations, Kirki.

be made of the sample type, the stream environment (e.g., width and rate of flow of stream, nature of stream banks) and of the geology.

The samples were dried at 110°C and screened through an 80-mesh nylon sieve. The ninus 80-mesh fraction was retained for analyses of Cu, Pb, and Zn; the plus 80-mesh size fraction was discarded. The samples were digested with hot nitric acid, and the element concentrations were determined with a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer.

Frequency Distribution of Cu, Pb, and Zn

As an example of a typical preliminary data interpretation procedure, the frequency distribution of Pb in samples collected over all rock types combined, and over Basement, sedimentary rocks, and andesites separately is illustrated in Figure 3. The distribution is similar in sedimentary rocks and andesites; values in the Basement are generally higher. The threshold determined on the combined data (by the technique illustrated in the previous paper, Govett, 1973) is 60 ppm, while the values for the individual rock types is 45 ppm for sedimentary rocks,

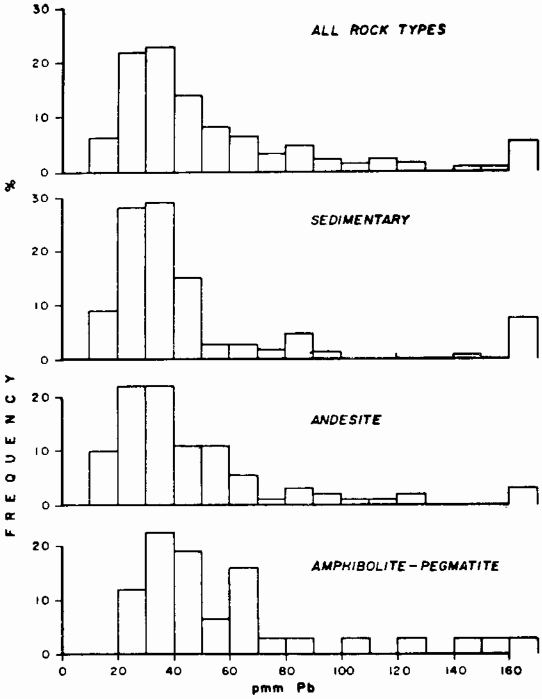

Fig. 3. Frequency distribution of Pb in stream sediments collected over different rock types, Kirki.

60 ppm for andesites, and 75 ppm for Basement. These data are summarized in Table 1, which also gives similar data for Cu anf Zn.

The conclusions from these combined results are :

Table 1

MODAL VALUES AND CALCULATED THRESHOLD VALUES FOR STREAM SEDIMENTS

Rock Type		parts per million		
		Cu	Pb	Zn
Andesite	Mode	20 - 30	30 - 40	50
	Threshold	45	60	100
Sediments	Mode	30 - 40	30 - 40	60 - 70
	Threshold	45	45	100
Basement	Mode	20 - 30	30 - 40	100 - 110
	Threshold	45	75	110
All rocks	Mode	30 - 40	30 - 40	60 - 70
	Threshold	45	60	90

(i) The background levels of both Pb and Zn are considerably higher in the Basement than in other rocks; Cu shows little difference between rock types.
(ii) A common threshold value for all rocks of 45 ppm for Cu and 110 ppm for Zn is adequate for preliminary interpretation.
(iii) A different Pb threshold for sedimentary-volcanic and for Basement rocks should be used.

These conclusions should be used only as a *guide* to interpretation and should not be rigidly applied. For example, it may be noted that although the threshold value for Pb in the Basement is 30 ppm higher than in sedimentary rocks, the modal value is the same in both cases. The possibility must be considered, therefore, that an unusually high proportion of low anomalous samples occurs in the Basement, or that there are two distinct rock types with overlapping frequency distributions.

Interpretation

The geographical distribution of Cu, Pb, and Zn is shown on Figures 4, 5, and 6, respectively. This mode of presentation is known as a "worm" diagram — a particular range of concentrations is shown by a particular thickness or type of line. The concentration level for each sample point is extended *upstream* to the next sample point. The concentration ranges are determined from the

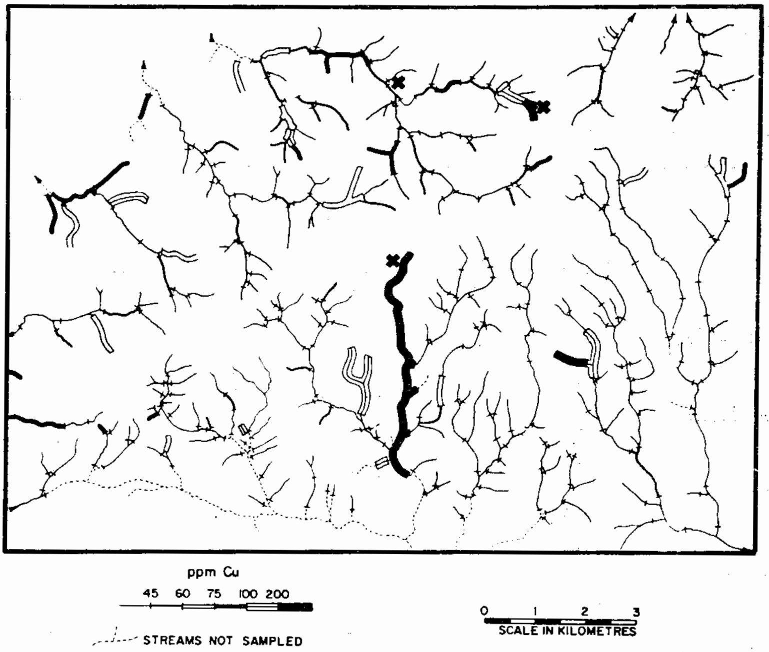

Fig. 4. Distribution of Cu in stream sediments, Kirki.

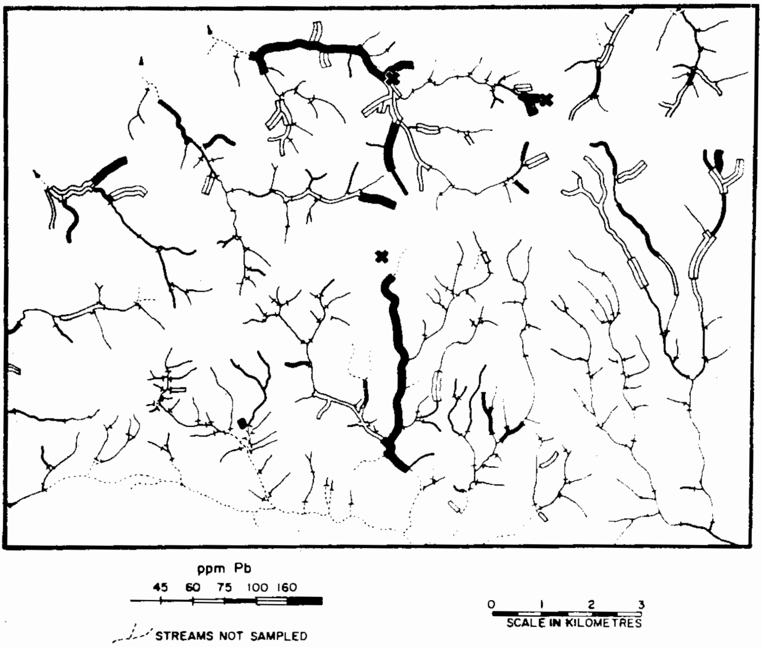

Fig. 5. Distribution of Pb in stream sediments, Kirki.

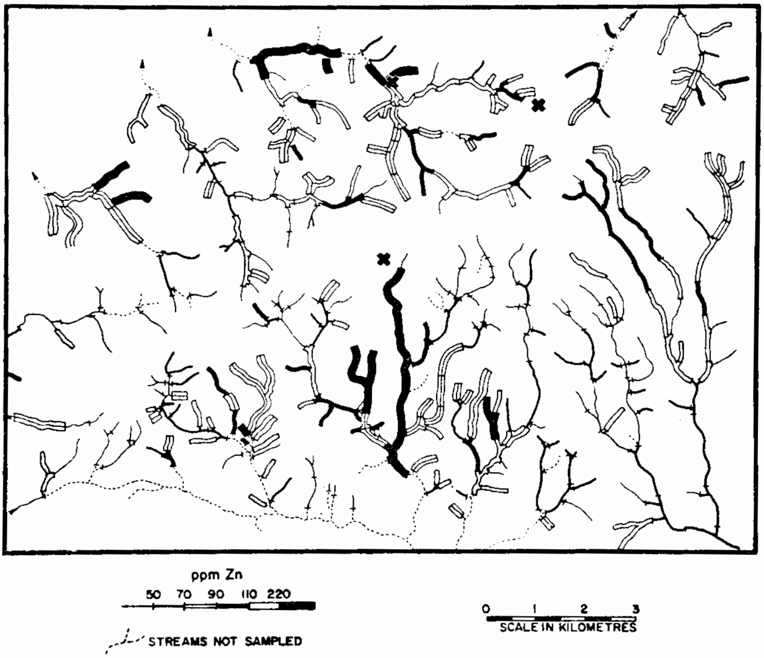

Fig. 6. Distribution of Zn in stream sediments, Kirki.

frequency distributions (Fig. 3) and the data in Table 1. For example, three different threshold values for Pb are calculated for the three main different rock types; these are 45 ppm, 60 ppm, and 75 ppm Pb and are used for the first three concentration divisions. To illustrate the general magnitude of the anomaly, two other divisions were chosen at 100 ppm and 160 ppm Pb. Thus, the distribution of Pb is shown as less than 45 ppm, 45 ppm to 60 ppm, 60 ppm to 75 ppm, 75 ppm to 100 ppm, 100 pqm to 160 ppm, and greater than 160 ppm. Similar reasoning is used to present the data for Cu and Zn.

Very clearly there are many streams which are anomalous with respect to one or more of the metals being considered, in addition to the anomalies from the known sources. Since this is intended to provide orientation data, many more of these anomalies are designated for detailed examination than would normally be the case in routine reconnaissance. The anomalous concentrations are graded into two levels for each element and are illustrated by symbols on Figure 7. On the basis of this, a series of eight first-priority anomalous areas are identified for more detailed work (see next section).

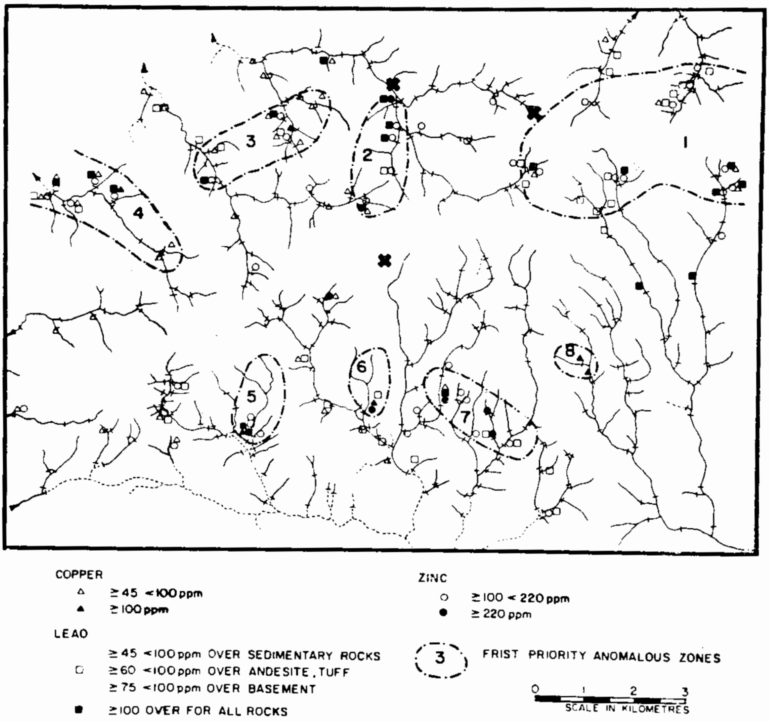

Fig. 7. Composite stream sediment anomaly map, Kirki.

DETAILED STREAM SURVEY

Detailed stream sediment samples were collected at approximately 100 metre intervals along all the anomalous stream within the eight first-priority areas. On the basis of these results, four of the eight first-priority areas were rejected from further consideration, while within the remaining four areas, six small zones were selected for further exploration.

As an illustration of the detailed stream survey, results from part of First-Priority Area VI are illustrated in Figure 8. The magnitude of the anomalies for Cu, Pb, and Zn suggests that the zone is worthy of more detailed investigation. A hypothetical interpretation of the data is also shown by two northwest trending mineralized zones crossing the two tributaries. There are many other possible interpretations of the stream data and clearly the next step in exploration in this area should be a series of three soil traverses more or less at right angles to the probable trend of mineralization — one located just west of the western stream, one just east of the eastern stream, and one between the streams. These traverses should be about 1,000 metres long and should be sampled at 20 metre intervals; they would be used as a preliminary assessment before proceeding to more detailed soil sampling.

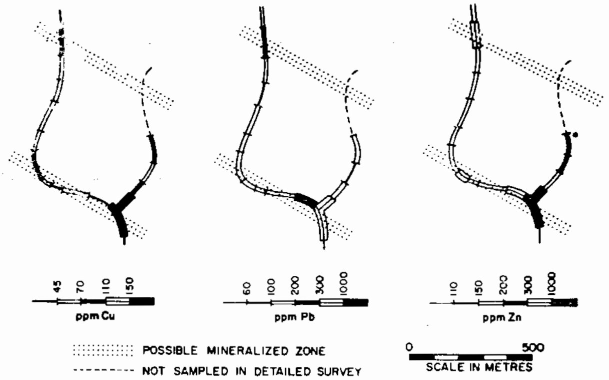

Fig. 8. Distribution of Cu, Pb, and Zn in stream sediments, First Priority Area VI, Kirki.

CONCLUSIONS

In this part an attempt has been made to show how stream sediment geochemistry may be used to assess the mineral potential of a region of more than 100 square kilometres and to outline a few small target areas of less than one square kilometre in which detailed mineral exploration should be concentrated. This illustrates Phase I (Reconnaissance) and Phase 2 (General Follow-up), respectively, of the exploration sequence defined in the first paper of this series. Some of the prerequisites for geochemical interpretation have been illustrated, the most important of which is the necessity of good reconnaissance-level geological mapping to determine the effect of the geology on the background level of elements of interest.

The results conclusively demonstrate that stream sediment geochemical surveys are an effective means of mineral exploration in Greece. The principles illustrated in this part can be extended to cover very large areas, such as the reconnaissance project of some 30,000 square kilometres of Macedonia and Thrace being undertaken by the International Atomic Energy Agency - Democritos programme.

3. SOIL SURVEYS

INTRODUCTION

In the second part of this paper, the application of geochemical soil surveys is discussed (see Fig. 1 for location of field studies).

The analyses of surface soil samples as a means of detecting mineralization in bedrock covered by thick soil cover has been used successfully in exploration in all parts of the world. In places where the soil is residual (that is, developed directly by weathering of the bedrock), the cumposition of the soil will reflect to some extent that of underlying bedrock. For example, the presence of a zone of copper sulphide in bedrock should be indicated by abnormally high concentrations of Cu in the overlying soils.

The cost per unit area of soil geochemistry is much higher than that of stream surveys, because of the high sample density necessary — a 10 to 50 metre interval between samples, depending upon the width of the anomaly. (For the same reasons the cost per sample is, of course, much cheaper than in the case of stream geochemistry). Because of the relatively high costs of soil geochemistry, it is normally used only as a follow-up technique in a closely-defined target area. Thus, in general exploration, soil geochemistry may be used to locate and assess the source of a detailed stream survey anomaly, to assess the significance of a geophysical anomaly, to investigate a geologically favourable zone, or to seek extensions to known mineralization.

All analytical results in this paper were obtained by a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer on hot nitric acid digestions of the minus 80-mesh size fraction of the sample.

ORIENTATION SURVEYS

The distribution of trace elements in soils is influenced by a wide variety of environmental factors of which the presence of mineralization is only one.

As in the case of stream surveys, it is desirable to conduct a preliminary orientation survey to determine the geochemical response to mineralization and to establish the background conditions for a region. The concentration of trace elements in soils will vary according to bedrock, soil-type, soil horizon sampled (see below), and local geomorphological conditions.

The development of soils is characterized by the differential vertical movement of material and its preferential concentration into horizons. In its simplest form, a soil profile comprises three horizons, designated as the A horizon, the B horizon, and the C horizon. The A horizon is the upper zone, and it may characteristically be divided into a surface A_{0-1} horizon, rich in organic material, and an A_2 horizon which is generally leached and therefore impoverished in soluble elements and clay minerals. The B horizon is a zone of accumulation of material and normally is reddish-brown coloured due to the precipitation of Fe. The C horizon is not properly part of the true soil, being the parent material from which the true soil soil is developed.

Recognition of soil horizons is vital to successful exploration soil geochenistry· The distribution of trace elements varies significantly through the profile, some elements being enriched in the surface A_{0-1} horizon, others in the B horizon. Typically Cu, Pb, and Zn are impoverished in the A_2 horizon; Cu generally increases down-profile, while Pb is enriched in the A_{0-1} horizon, and Zn in enriched in the B horizon.

In anomalous soil profiles the metal concentrations are much higher, and there are also some differences in distribution patterns; thus Cu, Pb, and Zn tend to be enriched in the A_{0-1} horizon and show secondary peak concentrations in the B horizon. High, but erratic, concentrations of the three elements occur in the C horizon.

Since the thickness of the different soil horizons can vary considerably, it is not adequate to sample at a fixed depth in soil surveys; obviously such a procedure could lead to the misleading comparisons between A_2 horizons and B horizon samples which have vastly different element concentrations even in the same vertical profile. The recommended procedure in Greece is to sample to the B horizon which has the advantage of being clearly recognizable by its colour.

Orientation over a Pb-Cu Vein, Pefka

The results from a small orientation survey for B. horizon soils over a narrow (uneconomic) Pb-Cu vein in andesites near Pefka (Fig. 1) is shown in Figure 9. The traverse was sampled along the side of a steep hillside and there is a small slope to the southeast. The soil is thin (15 to 25 centimetres), and stony and the vegetation is grass and low scrub. There is no indication of a mineralized vein at the surface along the traverse, and the position shown on Figure 10 is projected from an outcrop about 100 metres to the south-west. A similar traverse over unmineralized andesite about 1,500 metres away was sampled to provide back-

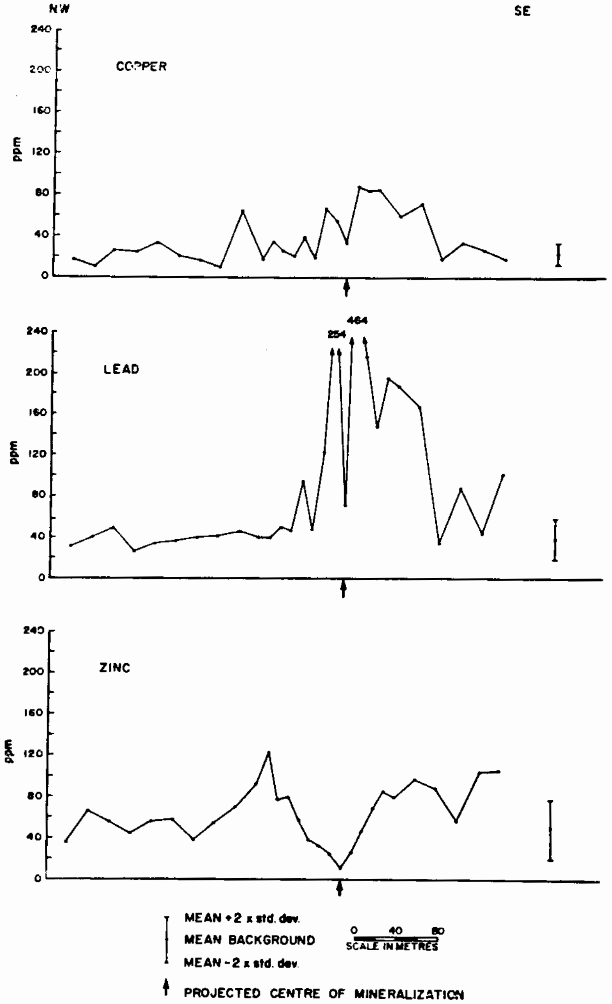

Fig. 9. Distribution of Cu, Pb, and Zn in B horizon soils, Pefka

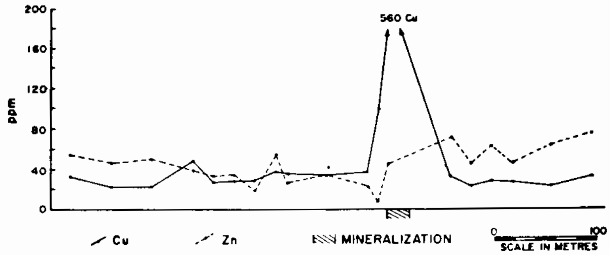

Fig. 10. Distribution of Cu and Zn in B horizon soils, Paliochora (Chalkidiki).

ground data. The content of Cu, Pb and Zn of the background samples is normally distributed, and therefore threshold values can be expressed as the mean ± two times the standard deviation at the 95 per cent confidence level.

Compared to background, Pb shows a very strong anomaly over the presumed position of mineralization; there is a slight tendency for it to be displaced downslope (i.e., to the southeast). The distribution of Cu shows a much more moderate anomaly, with the greatest values occuring downslope from mineralization. The distribution of Zn shows a very pronounced negative anomaly over mineralization and moderate positive anomalies either side of the mineralization. The distinctive behaviour pattern of Zn is similar to that noted for many mobile elements over well-defined mineralization rich in pyrite elsewhere in the world (Govett, 1973a, 1973b).

Orientation Traverse over Cu Mineralization, Chalkidiki

An orientation soil survey was also conducted in the Chalkidiki where there is Cu mineralization in pegmatite within Basement schist and gneiss (Fig. 11). The area is wooded and drainage is deeply incised, giving valley slopes of up to 70^0 in places. The soils are thin and immature, but a distinct A_{0-1} and B horizon is normally developed.

The distribution of Cu and Zn in the B horizon of one traverse is illustrated in Figure 10. The contrasting behaviour of Cu and Zn is important : over mineralization the concentration of Cu is much greater than that of Zn, while away from mineralization the concentration of Zn is generally greater than the concentration of Cu. In a background traverse the mean values for the Cu : Zn ratio is 0.34, with a standard deviation of 0.095. Thus, a threshold value of the ratio is 0.535 at the 95 per cent confidence level and 0.925 at the 99 per cent confidence level (mean ± three times the standard deviation). Using these calculations, the Cu : Zn ratio for the entire area is countoured at 0.6, 1.0, 2.0, and 10.0 in Figure 11. The known mineralization clearly lies within zones of high Cu : Zn ratios (there is also an implication that additional mineralization is present towards the south). As illustrated here, metal ratios provide a particularly useful interpretative technique which reduces the effects of minor scattered dispersion and enables interpretation of the combined effect of two metals.

SOIL SURVEYS IN EXPLORATION

One of the most useful applications of soil geochemistry is as a follow-up technique to assess a target area which has been defined by some other method. A summary of results from a detailed stream sampling survey which defined an anomalous area near Kirki (Fig. 1) are shown in Figure 12. Also shown on the same figure are the location of five preliminary soil traverses which were sampled to assess the target area and to determine the location, trend, and extent of miner-

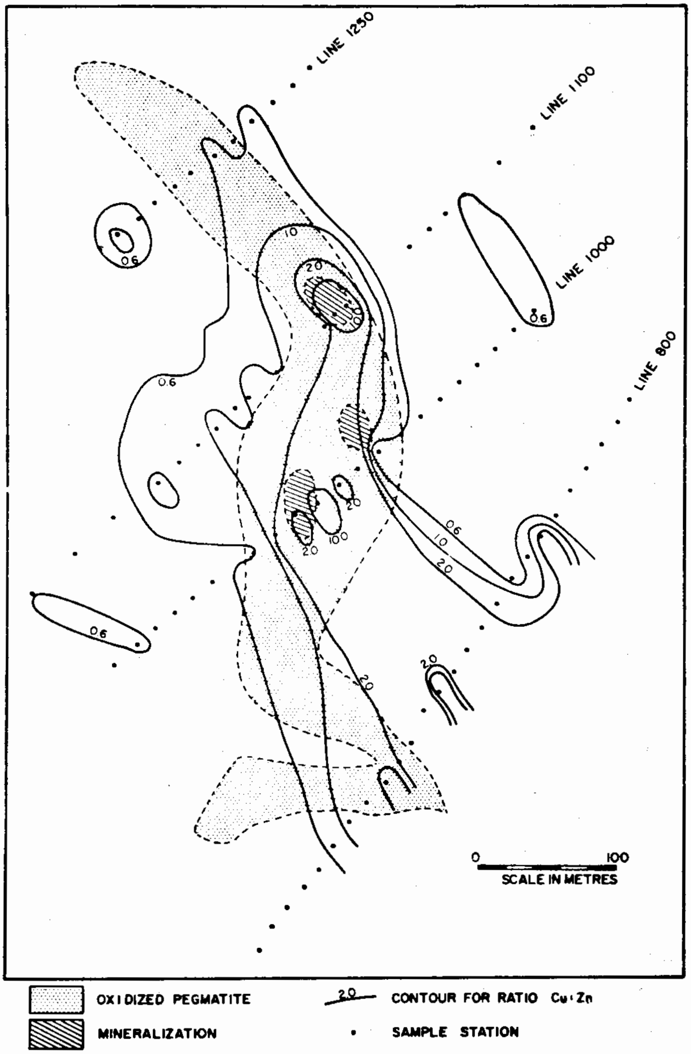

Fig. 11. Distribution of Cu:Zn ratio in B horizon soils, Paliochora (Chalkidiki).

alization (Galanos, 1973). Illustrative results of the distribution of Cu, Pb, and Zn in Traverses 3 and 4 are shown in Figure 13; a summary interpretation of all traverses is shown on Figure 12.

On the basis of detailed stream sediment data alone, two NW-SE trending mineralized zones were postulated (see the second part); this is not substantiated by the preliminary soil data which generally suggest a NE-SW trend for minerarization. During the soil sampling a number of faults and fault zones trending north to

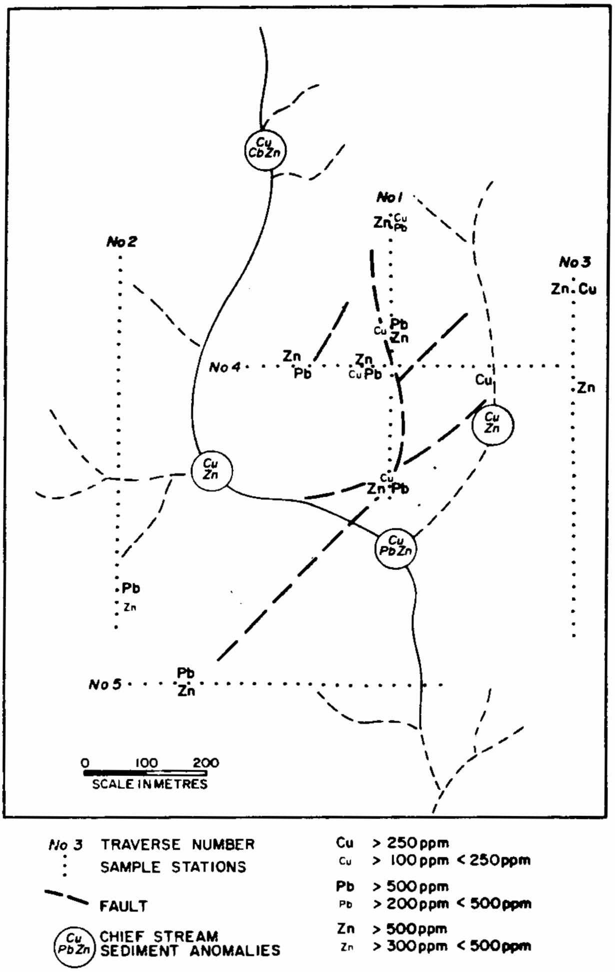

Fig. 12. Summary of detailed stream sediment survey and B horizon soil survey for Cu, Pb, and Zn in a target area identified by a reconnaissance stream sediment survey, Kirki.

northeast were identified, and significant soil anomalies occur in the vicinity of the faults.

There is sufficient evidence to warrant further work in this zone, and soil sampling should be extended to completely define the limits of mineralization before deciding whether to proceed with the next stage of exploration, i.e., trenching and deep geochemical sampling.

CONCLUSIONS

In this part some typical geochemical soil sampling data from Greece have

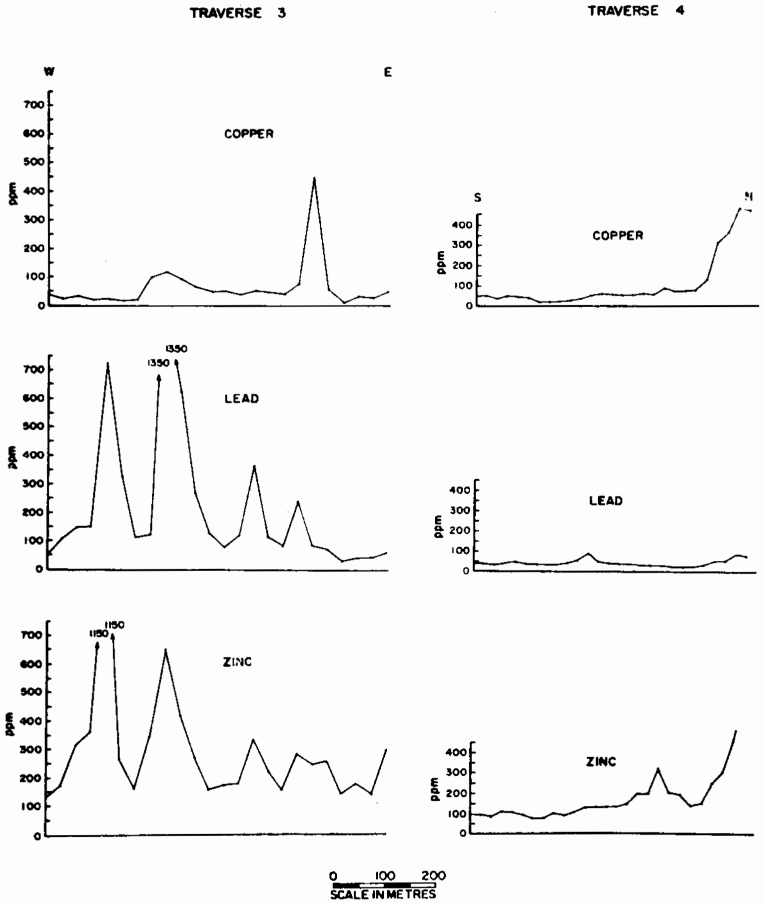

Fig. 13. Distribution of Cu, Pb, and Zn in B horizon soils, Kirki (see Fig. 5 for location of soil traverses).

been described to show the general procedures which should be followed and to illustrate the typical geochemical response to be expected. It is obvious that with careful sampling and analytical techniques distinctive geochemical patterns related to mineralization can be identified. The example given of an actual exploration survey shows how extremely effective soil geochemistry is in precisely locating mineralization.

In the first paper of this series a logical sequence of four phases of exploration was suggested :

Phase 1 — Reconnaissance to define an area within a region that warranted more detailed study.

Phase 2 — General follow-up to restrict the size of the area defined in Phase 1.

Phase 3 — Detailed follow-up to locate mineralization within the area defined by Phase 2.
Phase 4 — Exploration drilling.

In the previous part, Phases 1 and 2 were illustrated by the use of reconnaissance and detailed level stream sediment sampling, respectively, to define a small target area. Phase 3 is illustrated in this part by the use of soil geochemistry to locate actual mineralized zones within a target area defined by Phase 2 exploration. Thus, the application of a logical sequence of geochemical techniques has been shown capable of locating narrow zones of mineralization a few hundred metres in extent within an initial target area of 120 square kilometres. This is regarded as an adequate demonstration of the effectiveness of stream and soil geochemistry as mineral exploration techniques.

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