A

T H E S I S

entitled

REGIONAL GEOCHEMICAL RECONNAISSANCE OF EASTERN SIERRA LEONE

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ABSTRACT

The present study is concerned with the application of regional geochemical mapping to Pre-Cambrian schist belts and granites in Sierra Leone, the object being to delineate areas of economic mineral potential and gain information on the relationship of the geochemical patterns to the fundamental geology of the area as a whole.

Stream sediments were the primary sampling media. In the Kambui Schist areas of the Gori, Kambui and Nimini Hills stream sediments were collected over some 480 square miles at a density of 4-5 samples per square mile. The minus 80 mesh fraction of these samples has been analysed for 15 elements and data relating to 12 of these elements, which show significant patterns of areal distribution, are presented on a series of maps.

The majority of the minor elements display distribution patterns which can be broadly related to the bedrock geochemistry of the field areas. However, certain secondary environmental features, the most important of which is soil type, exercise a modifying influence of the patterns observed in the stream sediments. It is demonstrated that in addition to major differences in pattern relating to the main bedrock groups minor variations are also present which can be related to facies variations within the main bedrock groups.

Several scattered patterns of high metal content in the stream sediments are believed to be related to the presence of mineralisation in the field areas and in one instance a bedrock source of cassiterite has been indicated. A general relationship between areas of molybdenum concentration and tectonic features is also demonstrated.

In comparing the geochemistry of the present study areas with previously studied areas of Kambui Schist in Sierra Leone certain differences of both economic and fundamental significance are noted. As the basement granites surrounding the Kambui Schists are regarded as of metamorphic origin the investigation was extended to some 15,000 square miles of basement complex in order to study the distribution of a wide range of elements within the basement and delineate any large areas of increased mineral potential.

Stream sediments were collected in triplicate together with rocks and soils at 216 sample sites. These samples were analysed similarly to those of the schist belt survey. The results for 11 minor elements are presented on maps.

The stream sediments studied reveal a trough shaped distribution of the mafic elements with areas of high level in the northwest and southeast of the basement complex. The distribution of the remaining elements studied do not exhibit any similar regional trends. The soils and rocks reveal fundamentally similar patterns as the stream sediments so indicating a strong correlation between the geochemistry of the three sampling media. The distribution of chromium shows a relationship to the known occurrences of chromite, on the basis of this correlation several further areas characterised by high metal levels are postulated as of being of increased economic potential.

The interpretation of data has lead to the recognition of the major features of the geochemistry. However it was felt that many subtle features related to significant variations in the geochemistry probably remained unrecognised due to the subjective nature of the interpretation. In order to increase the objectivity of data interpretation a number of mathematical and statistical techniques, requiring the use of an electronic digital computer, have been investigated. It is demonstrated that these techniques are of value in the interpretation of geochemical data, and of greatest potential in this field are multivariate techniques such as factor analysis.

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TABLE OF CONTENTS

VOLUME I

CHAPTER 5 – DATA HANDLING TECHNIQUES

CHAPTER 6 – SAMPLING REPRESENTIVITY

CHAPTER 7 – REGIONAL METAL DISTRIBUTION

CHAPTER 8 – COMPARISON OF THE GEOCHEMISTRY OF THE KAMBUI SCHIST BELTS

LIST OF FIGURES AND TABLES

VOLUME I

VOLUME II

REGIONAL GEOCHEMICAL MAPS

Table of Figure Numbers for Schist Belt Surveys

	Nimini Hills	N. Kambui Hills	S. Kambui Hills	Gori Hills
As	53	65	76	87
Co	54	66	77	88
Cr	55	67	78	89
Cu	56	68	79	90
Mn	57	69	80	91
Mo	58	70	81	92
Ni	59	71	82	93
Pb	60	72	83	94
Sn	61	-	-	-
Ti	62	73	84	95
V	63	74	85	96
Zn	64	75	86	97

Table of Figure Numbers for Basement Survey

	Stream Sediment	Soil	Rock
Co	98	109	120
Cr	99	110	121
Cu	100	111	122
Mn	101	112	123
Mo	102	113	124
Ni	103	114	125
Pb	104	115	126
Sn	105	116	127
Ti	106	117	128
V	107	118	129
Zn	108	119	130

Fig.

CHAPTER I - INTRODUCTION

1.01. The present study is the third phase of a four phase programme initiated in 1960 with the aim of investigating the geochemistry of the Kambui Schists of central and southeastern Sierra Leone. The investigation has resolved itself into two sections, firstly, the continuation of the systematic stream sampling of the Kambui Schist areas of Sierra Leone, and secondly, an investigation into the distribution of trace elements in the surrounding basement granite areas.

The study of the Kambui Schists has been carried out with two main aims in view. The first, to identify large areas of increased mineral potential and the second, to compare the primary and secondary geochemistry of the previously studied Sula Mountains - Kangari Hills area with that of Nimini, Kambui and Gori Hills, areas of the present study, in order to establish if any large scale areal variations in geochemistry are present between the schist belts.

The granite basement surrounding the schist belts is thought to be predominantly of synkinematic metamorphic origin by Marmo (1955), thus it might be expected that some record of the primary geochemistry of the pre-existing metamorphic rocks would be retained in the geochemistry of the present granites. It was thus postulated that, if any major variations in the geochemistry of the Kambui Schists existed, they would be reflected in similar variations in the geochemistry of the basement. To test this hypothesis a rapid reconnaissance sampling programme based on experience gained during work in the shcist belts was undertaken.

The interpretation of geochemical data is generally based on the selection of samples or groups of samples which differ significantly from other groups of samples. When the differences are large interpretation is efficient, but when the differences being sought are small there is considerable risk that subtle features will not be recognised due to the subjective and empirical nature of the interpretation. In an attempt to remove this subjective element from interpretation the application of mathematical and statistical techniques in identifying and testing the significance of geochemical patterns has been investigated. The methods fall into two groups. The first, typified by trend surface and rolling mean analyses, is applicable to data of a homogenous nature derived from a single population. These techniques set out to determine the under-lying regional trends of the data, for each variable studied, and then to outline areas which differ significantly from the regional trend. The second method investigated, factor/vector analysis, utilises all available information on the samples and sets out to determine the underlying causal factors controlling the data. A model is developed and the degree to which the data fits this is calculated and samples which do not fit the model well must therefore contain information from some other source than the major factors and thus may be of considerable interest from a mineral exploration viewpoint.

CHAPTER 2 - REVIEW OF PREVIOUS WORK

2.01. General

Attention was first drawn to geochemical mapping in 1941 when Fersman stated that "The methods of geochemical mapping remain undeveloped even up to this time, and in reality, we have nothing systematic even now, by way of experimentation, that would give us a genuine geochemical map". Again in 1957 Ginzburg wrote "even by the time of this writing, there has been no definite solution or formalization for proceedures of preparation of the genuine geochemical map." Since that time work has been carried out in the U.S.S.R., by various Geological Surveys and the Applied Geochemistry Research Group (formerly known as the Geochemical Prospecting Research Centre of Imperial College) to develop techniques for the production of regional geochemical maps.

The recognition that certain areas of the earth's crust are characterised by abnormal trace elemental composition was by Goloubinoff in 1937, who noted that many granites from Malaya showed tin contents of up to 125 times the Clarke. Since that time many other authors have noted areas of provinces where a certain element or elements show abnormal values in the local bedrock: Oftedahl (1954), Coleman and Delavaux (1957), Burnham (1959), Slawson and Nackowski (1959), Putman and Burham (1962) and Parry and Nackowski (1963).

However in 1954-1955, Hawkes, Bloom, Riddell and Webb (1956), in a programme designed to delineate areas of base metal mineral potential, outlined a series of geochemically distinct areas in New Brunswick by the analysis of stream sediment material for cold-extractable heavy metals. The areas were characterised by changes in level and homogeniety of the metal content of the stream sediments, and this feature the authors termed geochemical relief. Mineralised areas were found to be characterised by a moderate or high relief and unmineralised areas by a generally low relief.

These observations led Webb (1956, 1958) to recognise the need for comprehensive regional geochemical surveys analagous to regional geological mapping. In order to delimit potentially mineralised provinces and provide fundamental geochemical information on a regional scale Webb proposed the determination of the regional patterns of metal distribution by the analysis of broadly spaced stream sediment samples for a wide range of elements.

Geochemical surveys can be divided into two types dependent on the problem being approached and the aim of the survey. The first is the reconnaissance survey whose aim is purely to detect mineral deposits of a particular metal and usually only those elements of direct economic importance are analysed. In the second method, mapping surveys, with a much wider aim in view, are concerned with the mapping of the geochemistry of the area in order to investigate fundamental aspects of the metal distribution as well as with the detection of mineral deposits. In order to achieve this aim the samples are analysed for a wide range of elements.

Since the first stream sediment reconnaissance survey described by Hawkes et al (1956) further examples of provincial distributions of specific elements have been recorded in other large drainage surveys, for example, studies in Nova Scotia (Holman 1959), Carolina (Bell and Overstreet 1960), the Namwala Concession area, Zambia (Webb et al, 1964) and Sierra Leone (Nichol et al, 1966).

The ultimate product of the regional survey is the regional geochemical map and these maps are being compiled in various countries of the Western World, but only a few, in Canada, the United States and Zambia have been published to date. The maps have been made by Geological Survey organizations as predicted by Webb (1958), when he stated that "It is believed to be only a matter of time before Geological Survey organisations must also accept responsibility for providing regional geochemical maps."

In an unpublished symposium held by the British Commonwealth Liason Office in 1962 the Geological Surveys of South Australia, British Guiana, Canada, Ghana, Tanganyika and the United Kingdom all contributed papers. A few of these papers are mentioned as they give an indication of the magnitude of the problem and the variety of approaches used in its study.

The results are described of the systematic sampling of 43,000 square miles of the Red Lake - Lansdowne House area of Northwestern Ontario. The area has been peneplained and there is a gentle regional slope to the northeast, the drainage is ill defined and consists mainly of lakes of glacial origin linked by meandering streams. Ten thousand samples of fresh bedrock were collected, mainly granites and granodiorites, at a sample density of about one per 3.5 square miles of land. Rock was chosen as a sampling media as it was considered that the stream sediments were derived by the erosion of the local soils which are in fact transported glacial overburden and thus not representative of the rock presently weathering. It is understood that the rocks are being analysed spectrochemically, but to date only zinc and copper have been determined using a partial chemical attack. The results show variations in the copper contents which are closely related to bedrock lithology, but it is not known whether any regional variations unrelated to lithology also exist.

A regional survey of mineralised Cambrian rocks in South Australia was based on twelve hundred composite rock samples analysed spectrochemically for Ag, Co, Cr, Cu, Ni, Pb, V and Zn. Rock was chosen in the survey as the sampling media as there was a shortage of drainage channels in the area and rock sampling was prefered to soils as it avoided the concentrating and leaching effects of weathering. The results show that there is a marked association of Cu, Pb and Zn with sedimentary facies. Superimposed on this pattern there are regional variations in the trace element content which probably indicate a primary sedimentary enviromental control.

The collection of active stream sediment, bank material, panned concentrates and fresh rock at 0.8 mile intervals along streams hasbeen undertaken over Pre-Cambrian areas in Ghana. These samples were analysed for As, Be, Cd, Cr, Cu, Ni, Mo, Pb, Sn and W, according to the geological environment. The results show that areas of gold mineralisation are persistently associated with high arsenic values, and that the volcanic facies of the Birrimian are characteristically high in nickel. Cr, Cu and Ni are also shown to be preferentially enriched in certain lithological units, whilst molybdenum tends to be concentrated along a particular contact zone between schists and granite gneisses. As a result of these preliminary studies regional geochemical prospecting is now being carried out as an integral part of the geological mapping of areas of favourable mineral potential.

In Malaya preliminary investigations have been made into the metal content of stream sediments from streams draining stanniferous and non-stanniferous granites (Research report of the Royal School of Mines, 1957-60). Considerable variations in tin content have been demonstrated, and in addition a number of other elements including Be, Co, Ni, V and Cr show significant distribution patterns.

Since 1956 a series of experimental surveys have been undertaken by the A.G.R.G. at Imperial College to test the hypothesis that geochemical provinces unrelated to bedrock and topography do exist, and that they can, in some cases, be related to metallogenic provinces. During studies by Jay (1959) and Watts (1960) in Zambia into the dispersions of cobalt and uranium, and pyrochlore respectively, additional samples were collected and analysed for a wide range of elements spectrochemically. The results showed that despite deep weathering and a mature land surface the overall geochemical patterns could be related to the bedrock geology on both local and regional scales (Webb et al, 1964).

Following this study an investigation into the dispersion of Co, Cu, Ni and Zn in rock soil and stream sediment in an area of strongly contrasting bedrock geology in the Nyawa area Zambia was carried out (Harden, 1962). It was not possible to distinguish between mixed schists and biotite schists on the basis of the analysis of stream sediments, although both were distinguishable from sediments derived from norite. In addition it was found that generally the trace element content of stream sediment and soils was related to the trace element content of the bedrock from which they were derived.

The culmination of the work in Zambia has been the compilation of regional geochemical maps of the 3,000 square miles of the Namwala Concession, based on the analysis of some 4,000 samples for ten elements each. A preliminary interpretation of the regional geochemical patterns in the Bilili area of the Namwala Concession is described by Fortescue (1962), who found that certain well defined element distribution patterns could be explained by the presence of known occurrences of mineralisation. However, he considered the relationship between lithology and the regional patterns less clear. Results based on further investigations are as follows, Webb et al (1964) :-

"(1) The major geological units are associated with broadscale patterns of variation in the range and mean concentration levels for several metals, the patterns appear in both mineralised and unmineralised formations.

(2) In ground underlain by unmineralised formations the patterns mostly appear as variations in level and range of normal background levels, and are related to the lithology and composition of the bedrock.

(3) In addition to the extensive patterns associated with the major geological units there are smaller scale patterns developed within the major units.

(4) Despite the generally weak nature of the mineralisation the more strongly mineralised rocks are associated with more or less extensive patterns of abnormally high metal content.

(5) Analysis of rocks, soils and sediments from the same area shows that in general similar trends are shown in all three materials.

(6) Examination of the geochemical patterns in relation to the topography shows that the patterns are related to topography only insofar as the latter is related to the geology.

(7) The degree of weathering, nature of the surface and other physical features may modify the major geochemical patterns but not override the dominant geological control.

(8) Rock and soil samples are representative of a small area in the vicinity of the sample site, whilst stream sediments approximate to a composite sample of the catchment area."

The technique of stream sampling, on both a mineral reconnaissance and regional mapping scale, has proved satisfactory and better than rock or soil sampling in areas of residual soil as the stream sediment is nature's composite sample of the environment upstream from the sampling point. Thus the stream sediment sample represents a much larger area than a rock or soil sample and a stream sediment anomaly related to mineralisation may be detected several thousands of feet downstream, whereas rock and soil samples, more than a few hundred feet away from mineralisation, would possibly not contain anomalous levels. Often stream sediments are composed of soil which has been washed into the stream channels and these soils have been formed by rock weathering and biological processes, thus the rocks which weather at the greatest rate will contribute the most into the soil and thus the sediments. In contrast the more resistant rocks, which are those generally sampled, outcrop and weather at the slowest rate do not contribute much to the soil in weathering products. Thus rock sampling in areas of low exposure often yields samples which are atypical in terms of soils and stream sediments taken from the same area. This criticism of rock sampling is less valid when applied to samples collected from the flanks of hill ranges where outcrop is plentiful relative to the areas of less rugged country surrounding the hills.

Experience from the surveys described, and many others carried out both by Government agencies and commercial undertakings, has shown stream sediments to be the best all round sampling medium in areas of residual soil with sufficient drainage density. In areas of low drainage density, soils and rocks may be sampled on a reconnaissance scale while in areas of transported overburden there is considerable controversy as to the best sampling medium. However if the overburden is of local origin on the scale of the survey either stream sediments or soils may be efficient sampling media. If, however, the transportation has been on a much larger scale stream sediment and soil samples may be meaningless in terms of the local bedrock and thus direct sampling of the bedrock would be undertaken.

2.02. Sierra Leone

Conventional prospecting is hampered in many parts of Sierra Leone due to the high degree of chemical weathering which masks surface indications of mineralisation and bed-rock lithology. The successful application in other parts of Africa of geochemical techniques, primarily in copper prospecting, led to several research projects being carried out in Sierra Leone.

A study into the dispersion of nickel in rocks and soils from areas of Pre-Cambrian granite, schist and norite revealed that basic rocks could be distinguished from granites on the basis of the nickel content of the overlying soils (Holman, 1956). It was observed that during weathering some nickel is lost, presumably in solution, but sufficient is retained in stable association in the soil to reflect the geochemistry of the bedrock. It also appeared that the amount of lateral migration of nickel in the residual soils was small, indicating that solution processes were acting vertically rather than horizontally, and that it could be expected that relatively sharp changes in the nickel content of soils would occur across geological contacts.

Investigation into the distribution of arsenic and molybdenum in soils in the Sula Mountains and Kangari Hills revealed zones of anomalously high metal content coinciding with known mineralisations (Webb, 1956). It was later demonstrated that arsenic was widely distributed in the stream sediments from the alluvial gold areas of Central Sierra Leone (Tooms, reported by Wilson and Marmo, 1958). The secondary dispersion of arsenic and molybdenum has been studied in the Sula Mountains and Kangari Hills by Mather (1959) and Elliott (1962). In the vicinity of molybdenum mineralisation anomalous molybdenum values were found throughout the profiles of residual concretionary and non-concretionary soils, with lateral dispersion taking place essentially within the illuvial horizon of the concretionary soil (Mather, 1959). In areas of arsenic mineralisation anomalous values of arsenic were found in weathered rock and soils over extensive zones and the dispersion patterns observed in duricrust suggested considerable migration of arsenic by solution processes.

In the cases of both arsenic and molybdenum extensive anomalous trains were observed in stream sediments downstream from mineralisations. Detailed investigations into the dispersion of arsenic and molybdenum in drainages indicated that several features strongly influenced the form of dispersion in stream sediments from mineralisation (Elliott, 1962). These features were, namely, the nature of the host rock, form of the mineralisation, size of barren catchment above the mineralisation and nature of the soil cover. In an area where molybdenite occurred in veinlets in amphibolite covered by duricrust an anomalous train of over two miles was noted, whilst in contrast, a molybdenite dissemination in granite gave rise to no anomalous train. This phenomenon was considered to be partly due to the size of the barren catchment above the mineralisation, but also to the lack of molybdenum accumulation in the loamy soils of the granite area in contrast with the marked molybdenum accumulation noted in duricrust soils. Dispersion trains of up to 4,000 feet in length were found in drainage crossing gold-arsenic mineralisation in talc schists. The dispersion of both arsenic and molybdenum was considered to be predominantly mechanical, and the role of transportation in solution very slight.

These two preliminary studies demonstrated the feasability of detecting areas of arsenic and molybdenum mineralisation within the Kambui Schists by systematic stream sediment sampling. They also formed the basis for the planning of large reconnaissance surveys aimed at detecting mineralised areas and gaining information of fundamental interest on the distribution of a wide range of elements. Previous experience gained in Africa and elsewhere suggested that the content of various other trace elements in the stream sediments would reveal information of fundamental interest on the bedrock geochemistry. It was decided, therefore, to carry out a regional geochemical survey of the Kambui Schists in order to, as stated previously, delineate areas of enhanced mineral potential and to provide fundamental information on the distribution of trace elements in the schist belt.

The study of the Sula Mountains-Kangari Hills schist belt, the largest continuous area of Kambui Schists in Sierra Leone, has been carried out in two phases by Viewing (1963) and James (1965). Viewing studied the central portion (400 square miles) and James the northern and southern extremities (440 square miles). The minus 80 mesh fraction of the stream sediments, collected at an average sample density of 4 samples per square mile, was analysed for up to 22 elements by a spectrographic technique, whilst arsenic and zinc were determined colorimetrically either manually or by autoanalyser. The data obtained was used to prepare regional geochemical maps for 11 trace elements.

The studies indicate that the schists are coincident with the highest levels of the mafic elements, and that the different geological units within the schist belt are reflected by different patterns. In contrast, levels of lead are highest in the surrounding granitic areas and it is the lead patterns which best reflect the differing geochemistry of the granites. In certain areas of basic and ultrabasic rock the patterns of trace element distribution appear to have been considerably modified by pedological and morphological influences. Detectable arsenic and molybdenum patterns show little relationship to the underlying geology, but limited detailed field studies proved some to be related to minor bedrock mineralisation. The existence of anomalous contents of arsenic in bedrock and stream sediments surrounding the area of greatest apparent gold potential demonstrates the existence of an aureole of abnormal arsenic levels associated with the gold mineralisation.

In conclusion the regional geochemical surveys in Sierra Leone, which have been undertaken in an area different both in bedrock geology and secondary environment from that of

Namwala in Zambia, confirmed the validity of the concept that regional geochemical maps based on systematic stream sampling have an important application, both in regional mineral reconnaissance surveys, and as a means of obtaining information of fundamental importance relating to geology as a whole.

The success of the surveys in the Sula Mountains - Kangari Hills in delineating areas of potential mineralisation and in gaining information on the regional distribution of metals has led to the extension of the surveys to cover the remaining major areas of Kambui Schist in Sierra Leone.

CHAPTER 3 - DESCRIPTION OF THE FIELD AREAS

3.01. General Geology

Sierra Leone is composed mostly of Pre-Crambrian rocks, the major exception being the broad belt of Pleistocene and recent sediments of the Bullom Series along the coast (Pollett, 1951). This belt extends for up to 25 miles inland before giving way to an undulating plain up to 60 miles wide which is underlain by crystalline basement rocks of the Kasila Series (fig. 1).

To the east of the Kasila Series is the basement granite which covers most of Sierra Leone, the contact between these rocks remains obscured but evidence from areas near the contact suggests that strong shearing has taken place (S.L.G.S. Ann. Rep. 1958/59) and that the granites are younger than the Kasila rocks (S.L.G.S. Ann. Rep. 1959/60).

A further four major rock types are in contact with the basement granite. The youngest of these is the Rokell River Series which is composed of arenaceous and argillaceous sediments intercalated with volcanic ashes and lavas. These rocks of Pre-Cambrian age lie unconformably upon the basement granite, but their relationship to the Kasila rocks is uncertain though they

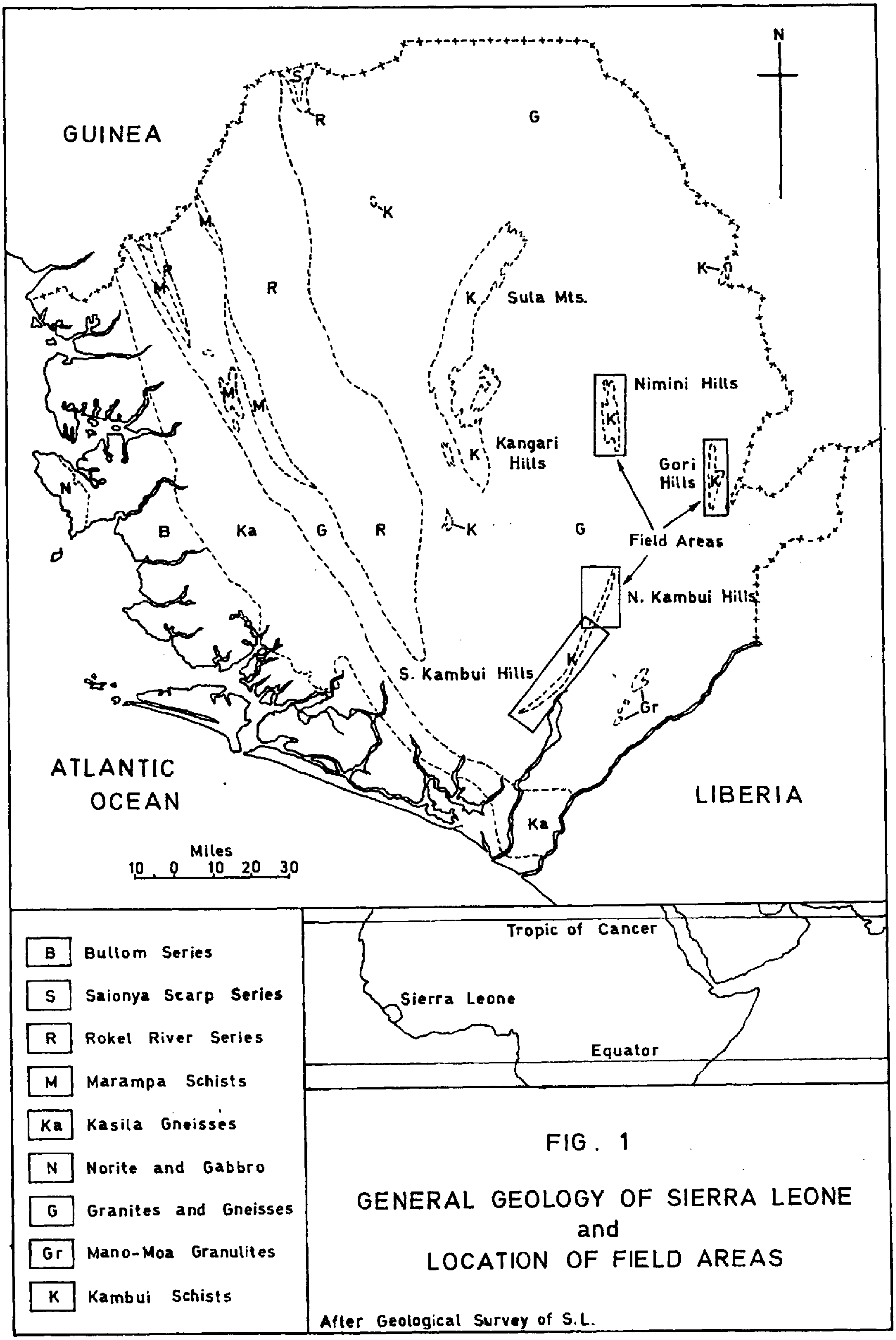


FIG. 1

GENERAL GEOLOGY OF SIERRA LEONE
and
LOCATION OF FIELD AREAS

are probably younger. The Rokell River rocks also lie unconformably upon the Marampa Schists, which are composed of metasediments and orthoschists, and which have an uncertain relationship with the granite.

The remaining two rock types, the Kambui Schist and Mano-Moa granulites are both older than the granites. The Kambui Schists consist of various metamorphic rocks of both sedimentary, volcanic and intrusive origin whose relationship with the granulites is unknown. It is probable that the Kambui Schists and Mano-Moa granulites are the last remnants of the rocks which were metamorphosed into the complex of rocks forming the basement granites. Late phases of the granites can be seen intruding both the schists and granulites in certain areas. Syenites have also been intruded into the granulites, some nepheline syenites have been found and although fenitisation has been observed in several areas no carbonatites have been observed.

3.02. Geology of the Field Areas

The geology of the various schist belts studied has not been described in detail. However, geological mapping programmes have been carried out by the Geological Survey in the Nimini and North Kambui Hills and a brief survey made of part of the Gori Hills. The results of these surveys are reported in the Annual Reports of the Geological Survey between 1957 and 1964, and it is on those reports that the following section is based. To date there is no definite knowledge of the geology of the South Kambui Hills and the larger part of the Gori Hills.

The schist belts include ultrabasic and basic schists of sedimentary and igneous origin, acid metasediments and an intrusive phase of granites known as latekinematic granite. This whole is surrounded by the basement or synkinematic granite which includes migmatitic, gneissic and porphyroblastic varieties in addition to the commoner evengrained type. The known geology of the field areas is shown in figures 2 - 5 and in comparing the different field areas several features are of note. Firstly, acid metasediments are only of widespread occurrence in the Nimini Hills. Secondly, intrusive ultrabasic rocks appear to be commonest in the Kambui Hills area, and thirdly, the geological complexity of the Kambui Hills sets them apart from the apparently less complex Gori and Nimini Hills. The trend of the schist belts within the basement is northerly in the Gori and Nimini Hills, however in a southerly direction the Kambui Hills change in trend from northerly to southwesterly.

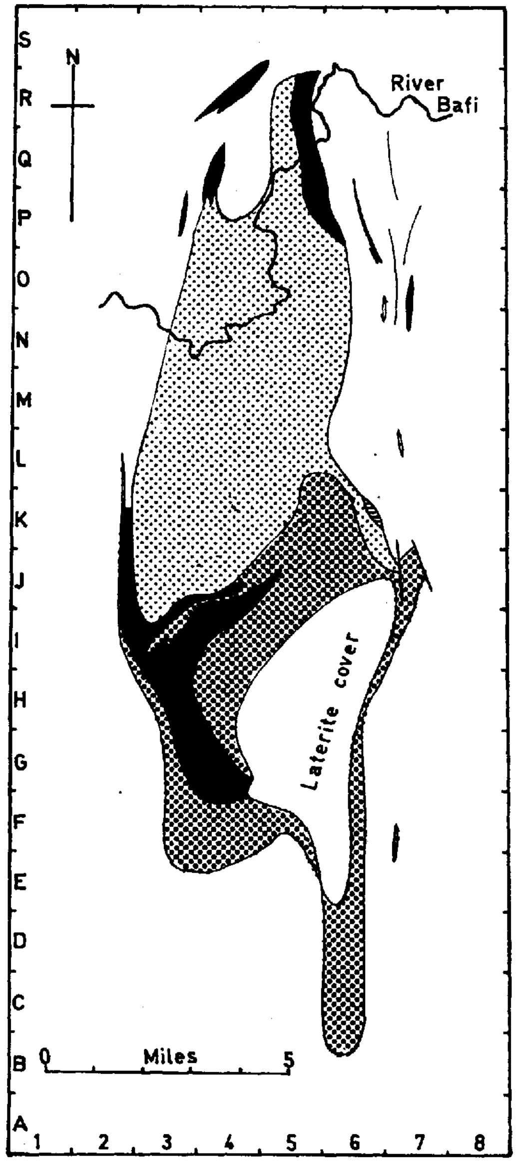


FIG. 2

NIMINI HILLS — GEOLOGY

LEGEND

Ultrabasic Schists

Basic Schists

Acid Metasediments

Late-kinematic Granite

Synkinematic Granite

Detail after S.L.G.S.

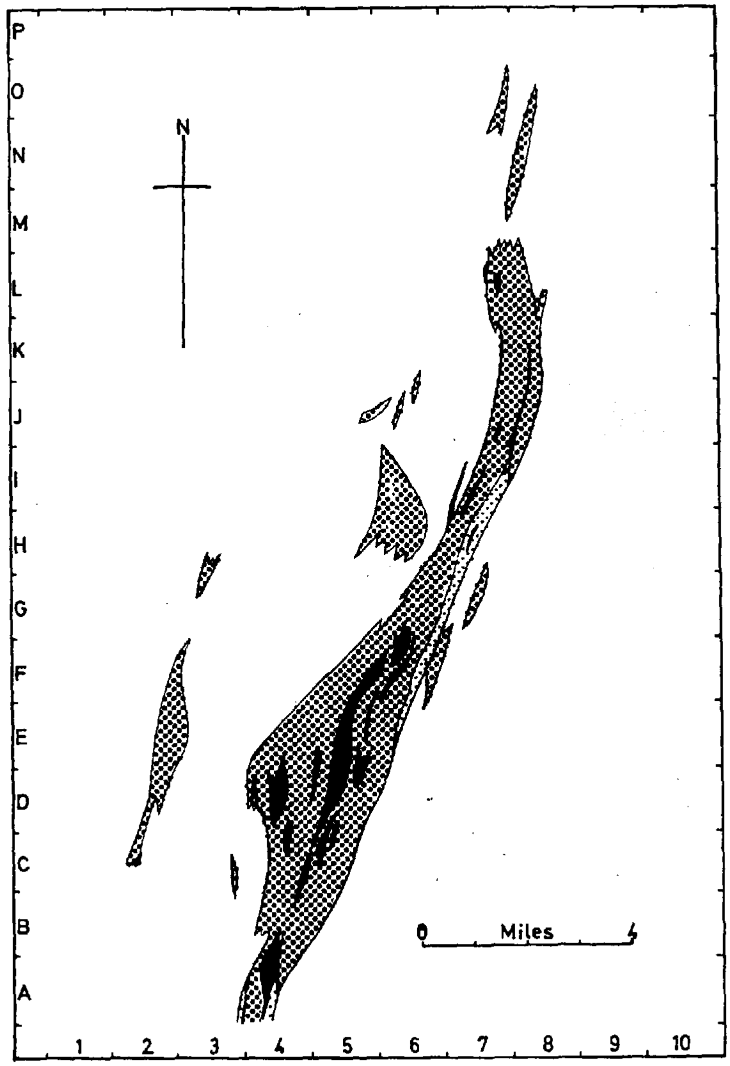


FIG. 3

NORTH KAMBUI HILLS — GEOLOGY

LEGEND

■	Ultrabasic Schists	□	Synkinematic Granite
▒	Basic Schists		
░	Acid Metasediments		

Detail after S.L.G.S.

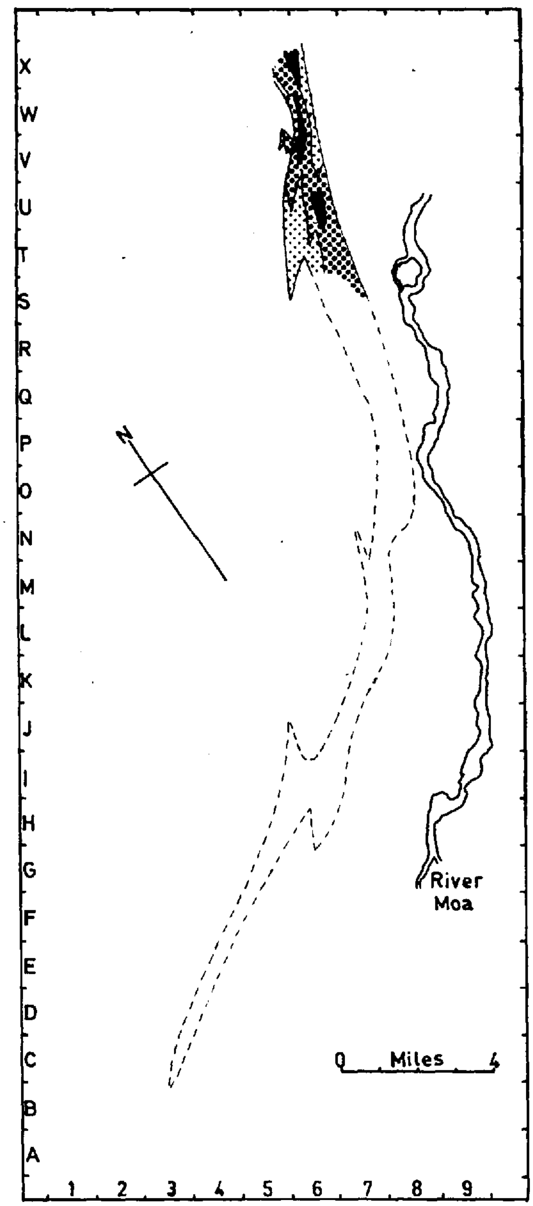
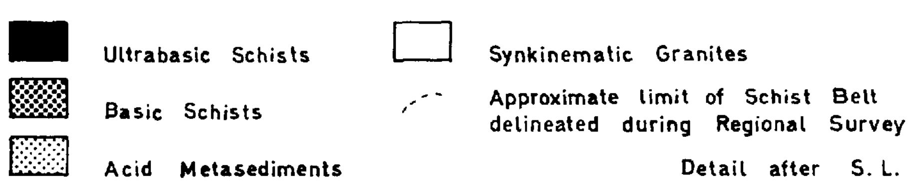


FIG. 4

SOUTH KAMBUI HILLS — GEOLOGY

LEGEND



Detail after S. L. G. S.

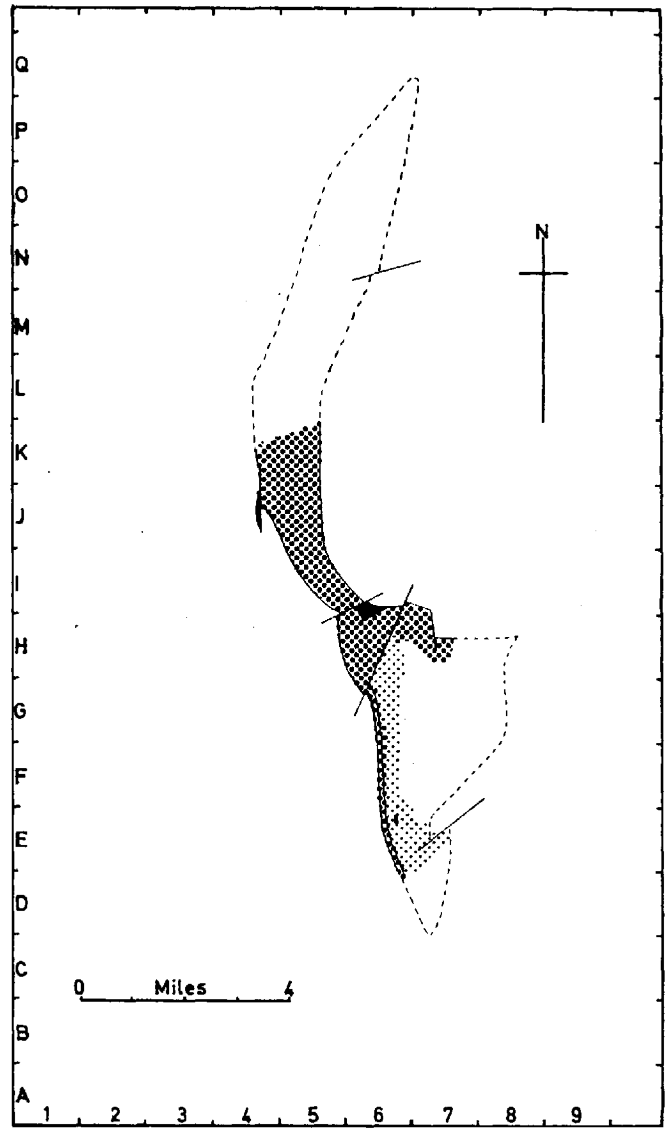


FIG. 5

GORI HILLS — GEOLOGY

LEGEND

■	Ultrabasic Schists	□	Synkinematic Granite
▩	Amphibolite	- - -	Appoximate limit of Schist Belt delineated during Regional Survey
░	Greenschists		

Detail after S.L.G.S.

3.03. Description of the Major Rock Types

Brief descriptions of the principle rock types are given in the following paragraphs:-

(A) Synkinematic Granites

The synkinematic granites vary widely in composition from quartz-diorites to true granite, but rocks of granodiorite composition are commonest. The feldspars are typically microcline and oligoclase, the commonest dark mineral is biotite though hornblende and muscovite are often present. A wide range of textures are present, including gneissic, porphyritic and evengrained.

The synkinematic granites in general are characterised by K_2O/CaO ratios of less than one. They are considered to be derived by the metamorphic processes of granitisation and locally they grade into mica gneisses, migmatites and ultimately schists (Marmo, 1956).

Synkinematic pegmatites are common and are mainly composed of quartz and plagioclase to the exclusion of other typically pegmatitic minerals.

(B) Late Kinematic Granite

Late kinematic granite is rare within the field areas and has only been recorded in the Nimini Hills area. The granites are typically fine to medium grained and composed of quartz, albite, microcline and muscovite. Occasionally biotite is present and in mica free varieties epidote is often found.

The late-kinematic granites are generally characterised by a K_2O/CaO ratio of greater than one. These granites are considered to be intrusive into their surroundings and may be the ultimate product of the granitisation processes which formed the basement.

Late-kinematic pegmatites are rare within the schist belts but are common around the edges. Both simple and complex varieties occur, the simple types being very similar mineralogically to the synkinematic pegmatites and they may be remobilised synkinematic pegmatites of local origin. The complex varieties contain muscovite, tourmaline, columbite cassiterite and beryl. Tourmaline and topaz bearing pegmatites may be associated with the source of gold on the Nimini Hills plateau.

(C) Metasediments

These rocks are mostly quartzofeldspathic gneisses and impure feldspathic quartzites. Locally garnet cummingtonite schists are found, these sometimes contain magnetite and grade into seams of compact magnetite quartzite, termed banded ironstones, which may also contain sulphides. Quartz cordierite schists are also common and often contain garnet and staurolite.

As the generic name indicates these rocks are of sedimentary origin and intraformational conglomerates have been found. These conglomerates are semipelitic quartzites and are lithologically homogenous, both the pebbles and the matrix being composed of impure quartzite. It has been suggested that the sulphides and iron in the banded ironstones were introduced into the sedimentary basin by submarine volcanic exhalations.

These rocks are better developed in the northern half of the Nimini Hills area than in the other field areas.

(D) Metamorphic Acid Volcanics

Metamorphic acid volcanics have been reported from only one locality in the areas studied. Within the quartzofeldspathic gneisses of the Nimini Hills there are rocks which, under the microscope, resemble recrystallised porphyry. These rocks indicate a minor intrusive phase prior to metamorphism and probably represent acid differentiates of the magma which formed the extensive basic intrusives of the central area of the Nimini Hills.

(E) Metamorphic Basic Schists

Amphibolites are of extremely widespread occurrence in the schist belts and generally consist predominantly of hornblende and plagioclase, though quartz is always present to a varying extent. Locally the amphibolites may contain sphene, cummintonite, biotite or pyroxene, and in all amphibolites small amounts of sulphides are present. Pyrite and pyrrhotite predominate but in some areas arsenopyrite and chalcopyrite are known to occur.

The dominant type is fine grained and locally displays pillow structure, and these rocks are thought to be derived by the metamorphism of basaltic lavas and tuffs. A second coarser textured amphibolite generally occurs as narrow seams and lenses enclosed by other rocks. Their composition varies considerably and all gradations from hornblende schist to true amphibolite exist with sphene as a constant accessory mineral. Their origin is uncertain as their composition resembles certain basalts as well as calcareous sediments and the metamorphism of either of these rocks could give rise to the observed amphibolite.

(F) Metamorphic Ultrabasic Schists

Ultrabasic schists occur throughout the schist belts and can be divided into two types, i.e. those of sedimentary origin and those of igneous origin.

In the Nimini Hills the sedimentary type predominates and varies in composition from tremolite schist to chlorite tremolite schist and tremolite serpentine. Olivine may occur in any of these varieties, as does anthophyllite. Narrow bands of ultrabasic schist occur within the amphibolites, and vice versa, and this complex interfingering is taken as evidence of sedimentary origin. Similar rock types occur in the Gori and Kambui Hills where synorogenic ultrabasics also occur. These ultrabasic bodies are concordant, or only slightly disconcordant with the local strike and when fresh consist almost entirely of olivine. Often, however, the dunite has been considerably serpentinised; and at one locality gravity banding of the rock has given rise to alternating bands of dunite and chromite.

3.04. Mineralisation and Mining History

The economic importance of the schist belts centres on the presence of chromium and gold mineralisation, but of the greatest economic importance to Sierra Leone are the alluvial diamonds found around the Nimini and North Kambui Hills.

The first diamonds were found in stream gravels near Sefadu and Kenema (fig. 6) in 1929 and 1930 and to date the

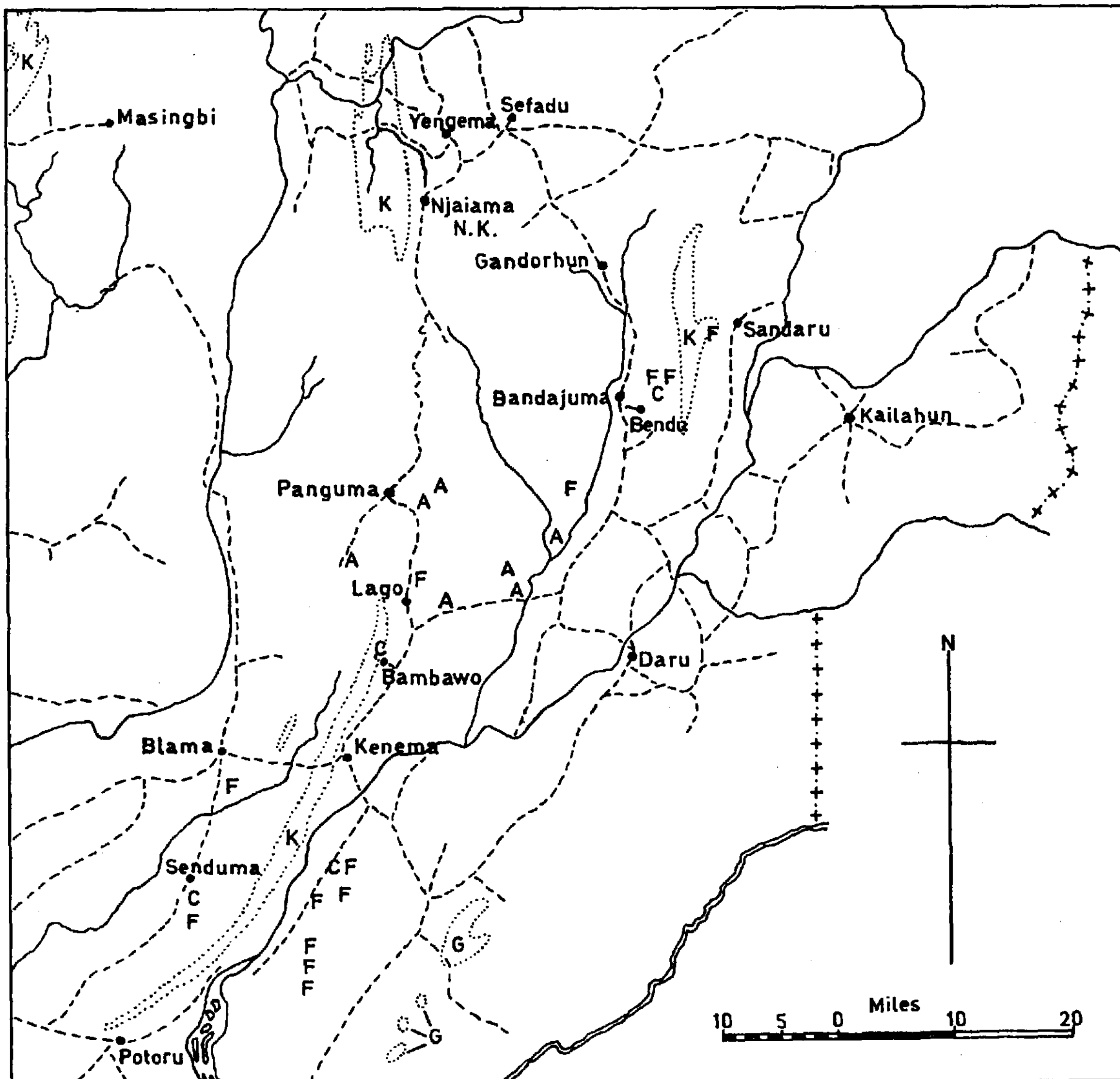


FIG. 6

CHROMITE OCCURRENCES
IN
SOUTH EAST SIERRA LEONE

LEGEND

	Basement Granites
K	Kambui Schists
G	Mano-Moa Granulites

CHROMITE

C	In Bedrock
F	As Blocks
A	In Alluvials

After Dunham (1958)

production amounting to some 20 million carats, has been entirely from alluvial deposits. It is believed that the diamonds found in the minor drainage are of local origin, except where they drain terrace gravels of major rivers (Hall, S.L.G.S. Ann. Rep. 1963/64). It is thus probable that there are extensive small kimberlite bodies within the basement granites occurring both as dykes and pipes. The dykes, in reality narrow dyke swarms, are the commonest mode of occurrence and trend at around 070° and where these dykes intersect fractures at appromimately 007° appear to be preferential sites for the formation of pipes. The Sierra Leone kimberlites are predominantly composed of serpentine pseudomorphs after olivine and phlogophite; calcite, perovskite and magnetite are present, as well as ilmenite and garnet in varying amounts (Grantham and Allen, 1960). It has been suggested that as there are areas where alluvial diamonds, of apparently local origin, occur without any associated heavy minerals there may be kimberlites, so far unfound, which do not contain ilmenite or garnet (Hall, pers. comm.). No kimberlites have been found within the schist belts, though it may be that some occur, as kimberlites are known, along a similar strike both east and west of the Nimini Hills schist belt. Diamonds do occur in one swamp underlain by meta-sediments a mile northwest of Jagbwema (fig. 7), so indicating the possible presence of kimberlites.

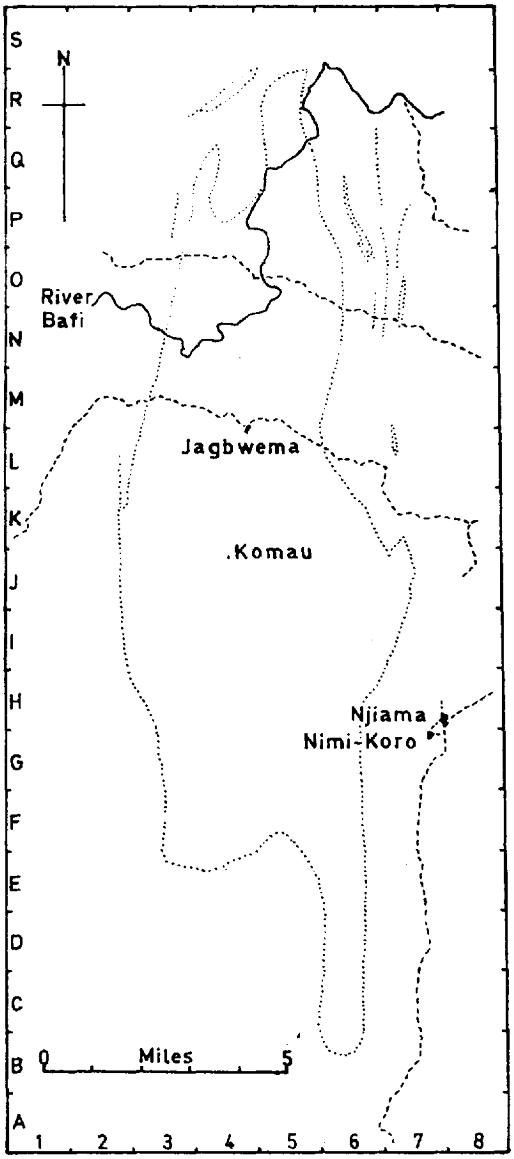


FIG. 7

NIMINI HILLS FIELD AREA

Granite/Schist Contact

Motorable Roads

Detail from Sierra Leone Geological Survey

Chromite was discovered to the west of the South Kambui Hills in quantity in 1929 by the Geological Survey near Senduma, and in the North Kambui Hills near Bambawo (fig. 6). Two types of chromite deposit are known. The first, typified by the Sierra Leone Chrome Mines, Ltd. workings near Bambawo, consists of chromite bands set in a dunite matrix (Dunham et al, 1958). These dunites are regarded as synorogenic intrusives and the chromite bands are probably the result of crystal settling during the solidification of the magma. The second type of occurrence, typified near Senduma, consists of dhromite lenses, sometimes associated with talc or anthophyllite schists, surrounded by synkinematic granites. The origin of these bodies is believed to be due to the granitisation of Bambawo type deposits. The chromite was mined at Bambawo and Senduma between 1938 and 1963 by Sierra Leone Chrome Mines, Ltd. and some 335,000 tons of lump ore produced. During prespecting by the company a small occurrence of the Senduma type was prospected in detail near Bendu on the western slopes of the Gori Hills and a similar body is suspected 7 miles northeast on the east flanks of the Gori Hills where chromite blocks have been found.

It is interesting to note that all the reported chromite occurrences have been found in a belt approximately 20 miles wide which trends at 040° and includes the Gori and Kambui Hills.

In contrast to the mining of chromite from a bedrock source all the gold mining has been from alluvial deposits. Of the four areas, the Nimini Hills, the Gori Hills, the South and North Kambui Hills gold production has been as the above order with the Nimini Hills producing by far the greatest quantity. A bedrock source for the alluvial gold has only been found near Komau in the Nimini Hills (fig. 7). The mineralisation consists of arsenopyrite with some pyrite in banded ironstone, amphibolite and quartz veins. The assay values were erratic and one zone 6.5 feet wide assayed at 44 dwts Au. It seems probable that much of the alluvial gold has been derived from scattered erratic occurrences in banded ironstones such as that at Komau. Sulphides are commonly found in small amounts in the banded ironstones. Their origin is thought to be sedimentary, with the introduction of iron and other chalcophile elements into the sedimentary environment by marine volcanic exhalations.

Disseminated molybdenite has been noted in several localities either in the synkinematic granites surrounding the schist belts or in late kinematic pegmatites.

The only other mineral of economic interest which has been reported from the schist belts is cassiterite in the Nimini Hills. Several grains were found during gold mining activity west of Njiama Nimi-Koro (fig. 7). This report was followed by an investigation by the Geological Survey, but as results were not encouraging work was discontinued.

3.05. Metallogenic Provinces in Sierra Leone

The types of mineralisation in Sierra Leone fall into distinct areal patterns which can be regarded as metallogenic provinces. The kimberlite swarms, from which the alluvial diamonds have weathered, are believed to be located at the intersections of major tectonic features and to fall into a systematic pattern covering the whole of West Africa (Bardet, 1964).

The non-diamondiferous mineral occurrences, when viewed in terms of metallogenic provinces, fall into three broad groups. Gold has been found to occur mainly in the two northwestern schist belts, the Sula Mountains - Kangari Hills and Nimini Hills, with lesser amounts in the Gori Hills and negligable amounts in the Kambui Hills. There is a common association of gold with arsenic, although both are known to occur separately. Also of some interest is the possible relationship of gold and molybdenum in the Sula Mountains. The origin of the mineralisation is obscure as there is evidence for both hydrothermal and sedimentary origin with the complicating factor of metamorphic remobilisation and local migration.

Secondly, the molybdenum occurrences of the Sula Mountains form a small but distinct province which may be partly tectonically controlled (James, 1965).

The third province occurs in a well defined belt in the southeast of the country and is characterised by the presence of chromite. The origin of the chromite bodies appears to be as magmatic segregations from synorogenic peridotite intrusions (Dunham et al, 1958).

3.06. Pedology

The soils of the field area are similar to those in the Sula Mountains - Kangari Hills area which have been previously described by Mather (1959), Elliott (1962), Viewing (1963) and James (1965). The soil profiles developed in the Sula Mountains are somewhat similar to those described by Scaetta (1940) in the Ivory Coast (Elliott, 1962).

The soils of the field area are predominantly latosols, these have been defined by Kellog (1949) as having:-

(i) Low silica/sesquioxide ratios in the clays.

(ii) Medium to low cation exchange capacity of the mineral fraction.

(iii) Low activity of the clays.

(iv) Low content of the soluble minerals.

(v) Low content of the primary minerals, excepting resistates.

(vi) A relative degree of aggregate stability.

and (vii) Red or reddish shades of colour.

Under suitable conditions, i.e. a surface of low relief and a fluctuating water table, the ground waters carry ferrous iron upward into the soil where it is precipitated as ferric oxide and hydroxide (Prescott and Pendleton, 1952). One particular form of latosol found in areas of mature soil on the Nimini Hills plateau is duricrust. Duricrust is a latosol with an intensely indurated B zone from which the A zone has been stripped so leaving a hard scoria like surface (Woolnough, 1927). Any scanty A horizon now found on the duricrust is believed to be due to the weathering of the surface and the activities of vegetation and soil organisms.

On the tops of the hill ranges in the field areas, in localities underlain by basic and ultrabasic schists, mature iron rich latosols of considerable thickness have developed. The depth of soil cover is not known in the present field areas, but similar soils in the Sula Mountains - Kangari Hills are up to 40 feet thick, (Viewing, 1963).

On the flanks of the hill ranges underlain by iron rich rocks, where erosion is active, the soils are immature latosols. These soils often do not have well developed concretionary B zones and in particularly steep areas where erosion appears to be more rapid than sesquioxide accumulation shallow rubbly kaolinitic soils are found.

The soils present over iron poor granites and metasediments lack the well developed iron sesquioxide accumulation in the B Zone found in areas of iron rich rocks. The soils in areas of low relief are mature and may be up to 12 feet deep and are essentially kaolinitic with few, if any, ferruginous concretions.

3.07. Topography

The schist belts of the study area all form hill ranges rising above the level of the surrounding basement granites. The level of the tops of the hills falls off towards the south, the Nimini Hills rise to 2,500 feet, the Gori Hills to 2,000 feet and the North Kambui Hills to 1,500 feet and the South Kambui Hills to 1,000 feet about half way along their length. Moreover the level of the basement granites surrounding the hills also falls off towards the south, but at a lesser rate, resulting in a general decrease in the height of the hills above the surrounding plain in a southerly direction. In the Nimini Hills the highest point is some 1,300 feet above the plain whilst in the south of the Kambui Hills the crest is only about 200 feet above the plain.

The hill masses of the Nimini Hills, Gori Hills, North Kambui Hills and the northern part of the South Kambui Hills are all steep sided and form serrate ridges. However, in the central part of the Nimini Hills there is an extensive plateau some 1,000 feet above the surrounding plain. In the south of the South Kambui Hills the hills lose their serrate nature and degenerate into low rolling features.

In the northern part of the Nimini Hills area much of the country is underlain by acid metasediments and is very similar in geomorphology to the surrounding granite plain. A similar area may be present along the southeast flank of the South Kambui Hills and here schists are suspected under the low rolling country between the foot of the hills and the Moa river. The cause, however, is not the same as in the Nimini Hills but is ascribed to the influence of the Moa river which is only three miles away to the east and is between a quarter and a half mile wide. Successive meanders could have removed much schist belt material from the east flank of the hills.

The presence of the hills is probably due not so much to the resistance of the schists to erosion but to the resistance of their laterite cover. During the Eocene peneplaination there was very extensive formation of indurated laterite, and this developed to the greatest extent over iron rich rocks, i.e. the schists. When the peneplain was elevated and tilted, with a resulting rejuvenation of the drainage, the rivers and streams eroded the mechanically weaker siliceous laterites of the granite areas, in preference to the stronger indurated iron rich laterites of the schist belts, thus leaving the schist belt areas as hill ranges.

3.08. Drainage

The major, and much of the minor, drainage in Sierra Leone is controlled by tectonic features in the basement complex such as faults and shatter planes and exhibits many differing degrees of maturity. However, over most of the basement complex the drainage is mature with streams and rivers flowing in broad gentle valleys.

In the relatively small areas of the schist belt hill ranges, where the drainage has been rejuvenated, the main drainage type is dendritic and is actively cutting into the flanks of the hills. However, two types of mature drainage are found associated with the schist belts. Firstly, on the Nimini Hills plateau the streams occupy mature, wide valleys at a low drainage density, which suggests some subterranean drainage is also present (Wilson and Marmo, 1958). Where the rejuvenated drainage is cutting into areas of mature drainage nick points are found at the junction between the two stream forms. This is well demonstrated by the Wongo river in the Nimini Hills where the nick point is marked by precipitous waterfalls. The second type of mature drainage is found in some granite areas surrounding the schist belts, here the streams occupy gentle broad valleys, often with much of the land being swampy in nature.

The stream banks fall into two categories, alluvial and colluvial. Alluvial banks are not usually steep, though sometimes the stream is incised into the alluvial material. The exception to this statement is in areas of piedmont deposits at the foot of the hills where steep banks of this material rise directly from the stream channel. The alluvial material is usually of a mixed nature containing a large range of material in size and origin. Colluvial banks are usually steep and consist of local soil material. Streams are often bounded by both bank types, this being especially noticeable on bends in streams on the flanks of the hills. In addition the alluvial material on one side is often covered by a sheetwash of colluvial material of local origin.

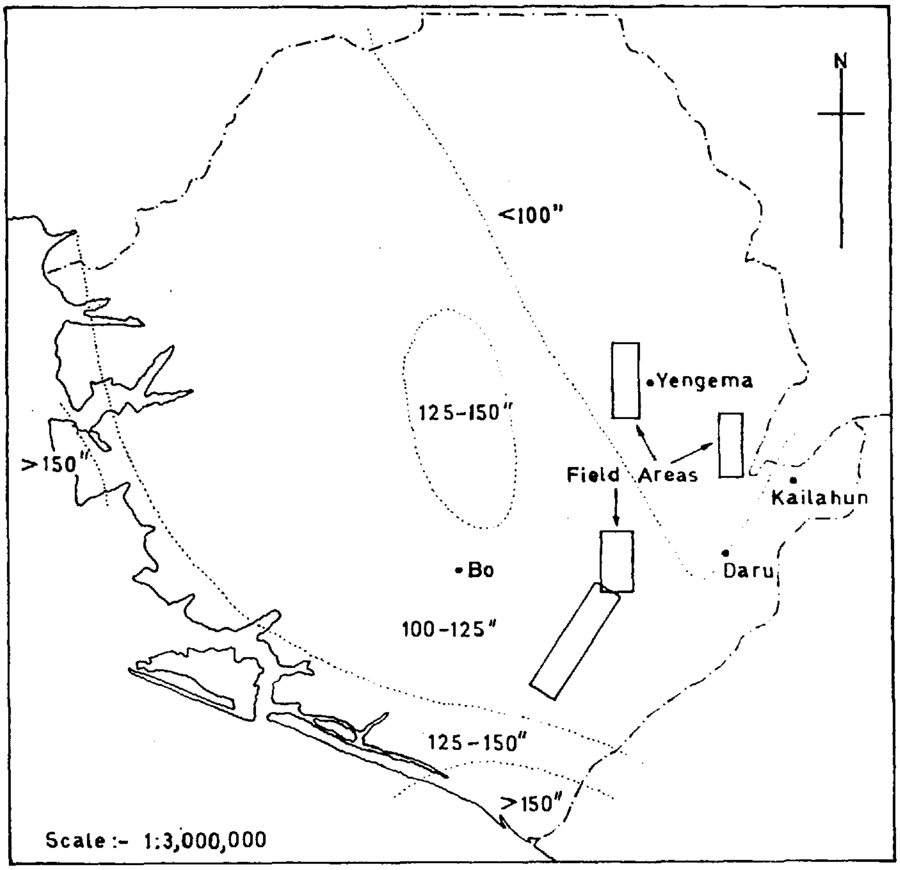
Piedmont type alluvial deposits are common at the foot of the hills where the often precipitous drainage of the hills reaches the gentler country of the surrounding plain. These features are well shown on the east flank of the North Kambui Hills and on the northern flank of the main mass of the Nimini Hills.

The stream sediments from the different geological and physical environments within the field areas display differing characteristics. The sediments from iron rich areas are often red in colour and contain sand and gravel size fragments of ferruginous concretions. In contrast, sediments from iron poor rocks are generally greyish in colour and rich in silica sand. It has been noted that there are small variations in particle size distribution from differing bedrocks and areas of duricrust soil, and that there is little redistribution of the particles with increasing distance downstream (Viewing, 1963).

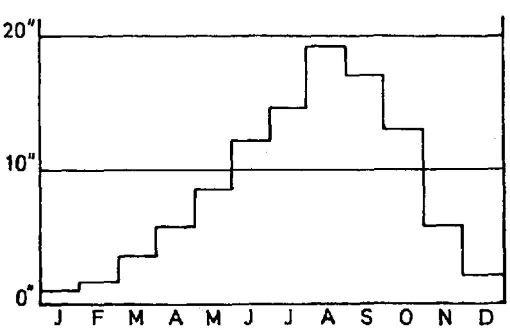
The mechanical composition of sediments in stream cross sections has not been investigated, but in areas where no bank collapse has occurred no marked differences in physical characteristics could be noted. In granitic areas many of the streams flowing in mature valleys are swampy in nature and in these layered sediments are sometimes observed, i.e. a bottom layer of coarser grained material is covered by a layer of fine black silt. These sediments probably arise from the rapid deposition of load from storm waters towards the end of the rainy season and into the dry season.

3.09. Climate

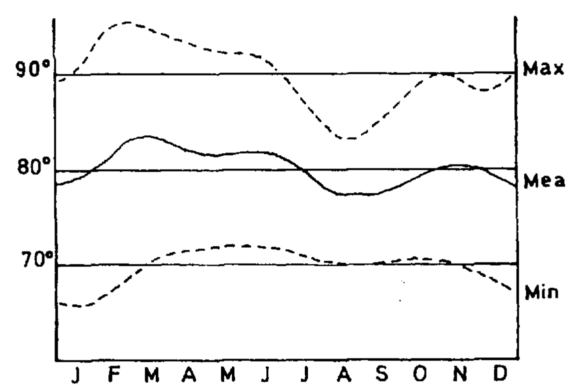
No specific climatic data is available for the Kambui Schist study areas. However, at several localities in the southeast of the country daily observations have been carried out, i.e. Bo, Daru, Kailahun and Yengema (Atlas of Sierra Leone, 1953). In general the climate is typically tropical, with an average rainfall over the whole country of 100 inches a year, mostly falling between July and September (fig. 8). Sporadic rainfall occurs during the rest of the year except from December to March when there is little or no precipitation.



Sierra Leone Mean Annual Rainfall



Mean Monthly Rainfall
(Bo, Kailahun & Yengema)



Mean Shade Temperature
(Daru)

FIGURE 8 SIERRA LEONE — CLIMATE

From Atlas of Sierra Leone, 1953

The mean shade temperature varies between 77° and 84° F. whilst the humidity is in the range 60-90%.

The Nimini and Gori Hills experience a rainfall of less than 100 inches a year, but southwards in the South Kambui Hills it reaches 125 inches. The summer temperatures are similar over the whole country, being around 80° F., however, in the winter the very south of the country, including most of the South Kambui Hills, is hotter than the interior with temperatures of the order of 90° F.

3.10. Vegetation

The vegetation is closely related to soil type with the result that immature latosols and duricrust support contrasting types of vegetation.

Only in the Nimini Hills is true duricrust and its associated flora found in the present study areas. The duricrust can only support sparse orchard bush and tussock grass, in contrast to the incised valleys on the flanks of the hill ranges where dense secondary growth and some large trees are found. The non-duricrusted mature soils on the plateau of the Nimini Hills and in parts of the Gori and Kambui Hills support good stands of timber in areas of primary forest. The crests of the Gori Hills, North Kambui Hills, most of the South Kambui Hills and the Nimini Hills plateau where the best stands of timber are found, are Forest Reserves in which farming is prohibited. Timber has been extracted in the Kambui Hills and forms the basis of the Sierra Leone timber industry.

Much of the non-duricrusted areas round the schist belts and within them are periodically cleared on a 7 - 10 year cycle in order to farm rice. This practise gives rise to extremely dense secondary growth with very few large trees.

Granite monadnock surfaces, found in the Gori Hills and to a lesser extent in the Nimini and North Kambui Hills generally support a little grass and a few stunted trees, otherwise the lack of soil cover often confines vegetation to a few rock plants.

CHAPTER 4 - FIELD AND ANALYTICAL PROCEEDURES

As the present study is an extension of the investigation of the Sula Mountains and Kangari Hills basically similar field, analytical and data presentation techniques have been used (Viewing, 1963 and James, 1965).

4.01. Sampling of the Schist Belts

Stream sediments have been the basis of the surveys and some 3,000 sites were sampled in the course of the present regional reconnaissance survey. The samples were collected over the schist belt and from synkinematic granite within a few miles of the schist belt limits. The average sample density was approximately 4 - 5 samples per square mile, the local differences in sample density being largely related to variations in drainage density or accessability.

Samples were collected as far as possible from the middle of the stream channels in an attempt to avoid excessive contamination by local bank material. Care was taken when sampling tributaries above confluences to avoid material which might have been deposited from backwash from the main stream in times of flood. Two samples, respectively approximately

200g and 1000g in weight were collected at each sample site and placed in prenumbered kraft paper envelopes and notes were made of the stream size, rate of flow, bank type and nature of the sediment material. Fresh rock samples of about 5 lbs weight were collected from the whole area of the reconnaissance survey in order to have a constant check on the local bedrock geochemistry.

In several areas where particular bedrocks predominated programmes of detailed sampling were undertaken which involved the collection of rocks, soils and stream sediments in order to investigate the relationship of the geochemical patterns in the three media. The soil and sediment samples were taken at 500 foot intervals, whilst the rocks were collected at similar intervals when outcrop permitted. The soil samples were collected from the B zone, usually about 12 to 15 inches below surface, above the break of slope to ensure that there was no contamination by alluvial material derived from upstream, sampling the B zone thus ensures constant soil conditions. In some areas, however, where soils were immature and no B zone was present, samples were taken from below the A zone to avoid any contamination by organic material. Soil samples were of a similar size to stream sediments and were dried and treated in the same manner.

4.02. Sampling of the Basement Granite

The basement survey covered some 15,000 square miles and four sampling media were available, i.e. rocks, soils, stream sediments and stream waters. Stream waters were ruled out on the basis of previous work which showed the metal content of the water to be very low and sample handling and analysis difficult (Mather, 1959 and Elliott, 1962). Stream sediments were chosen as the main sampling media as they are composite samples derived from small, but finite, areas and a supporting collection of rocks and soils was made in order to be able to assess the influence of the geochemistry of these media on that of the stream sediments.

The programme involved the sampling of streams having about 5-7 square mile catchment areas and these streams were spread at approximately 7 mile intervals along motor roads and tracks. Some 216 sites were sampled for soils and stream sediments, resulting in a density of approximately 1 site per 75 square miles. At each site triplicate samples of soil and and stream sediments were collected together with a rock sample if any outcrop was at hand. To test the efficiency of the sampling routine a drainage area of approximately 100 square miles was sampled in detail, samples being collected from all major and minor drainages in triplicate. The data from this survey was investigated to ensure correct sampling in terms of the geochemistry of the 100 square mile area.

The triplicate stream sediments were collected at 100 foot intervals, the first sample being taken 100 foot up-stream from the crossing point. The soil samples were collected from above the break of slope at a depth of 12 to 15 inches. This proceedure was adopted as often there was no clear indication of the top of the B zone in the iron poor latosols of the basement granites, and it also ensured sampling was below the influence of any agricultural disturbances.

The rocks collected serve only as a guide to the bedrock geology as those rocks which outcrop are certainly atypical in an area of such poor exposure as the basement.

4.03. Sample Preparation

After collection the soil and stream sediment samples were sun dried at field base camps. The smaller of the two samples was gently crushed with a pestle and mortar to liberate material held in lumps of clay or silt and then screened and the minus 80 mesh material retained. This size fraction of the material was chosen to ensure continuity with previous work in the Sula Mountains-Kangari Hills area. The original choice of the minus 80 mesh fraction was based on the representivity of this size fraction in that repeated analyses gave consistent results and also because the differing geochemistries of the bedrock encountered during the survey was best reflected by the minus 80 mesh fraction.

The larger of the two samples was retained for reference and checking purposes, whilst all routine analytical work was carried out on the minus 80 mesh material screened at the base camps.

The rocks were prepared for analysis by crushing about 100 grams to less than 20 mesh in a jaw crusher and then 10 grams of this material, selected by coning and quartering, was crushed to minus 80 mesh in a ceramic ball mill.

4.04. Measurement of pH

Measurements of the hydrogen ion concentration (pH) of stream waters were made at sample sites during detailed surveys. The observations were made with a portable pH meter manufactured by Analytical Instruments Ltd., and using 'Narrow Range Indicator Papers' supplied by British Drug Houses Ltd. However, as no significant variations could be observed in the results they are not presented.

4.05. Chemical Analysis

The chemical methods used were the standard rapid colorimetric techniques used at the Applied Geochemistry Research

Group. Arsenic and zinc were determined in the reconnaissance samples and in many of those collected during the detailed surveys, tin also was determined colorimetrically in selected samples (Stanton and MacDonald, 1961 and 1963 and Stanton, 1964).

4.06. Spectrochemical Analysis

The minus 80 mesh fraction of all the regional stream sediment samples, as well as a number of soil and rock samples, were analysed for a wide range of elements by an optical spectrochemical method.

The concentration of the following elements was estimated in all samples: Ag, Bi, Co, Cr, Cu, Ga, Mn, Mo, Ni, Pb, Sn, Ti and V. The analytical technique has been developed at the Applied Geochemistry Research Group and is described by Nichol and Henderson-Hamilton (1965), following the work of Kerbyson (1960) and Chartered Exploration Ltd. at Lusaka, Zambia.

During the course of the present study a modification was made to the method by changing from carbon to graphite electrodes. As a result of this the analysis of samples from the schist belt areas, both at the reconnaissance and detailed survey level, was undertaken with carbon electrodes, whilst samples from the basement survey were analysed using graphite electrodes.

All samples were estimated by visual comparison with a series of standards except the stream sediment samples from the basement survey which were estimated using a photo-densitometer in order to attain higher accuracy.

4.07. Analytical Accuracy

Variations in the bulk composition of samples has been observed to have an influence on the spectrographically estimated levels of minor element content (Scott, 1945 and Makitie and Lappi, 1958). The possibility of reducing this matrix effect by the addition of a buffer to samples was investigated using a series of synthetic mixtures by Kerbyson (1960). It was found possible to minimise the matrix effect by buffering the sample 1 : 1 with a 1 : 1 mixture of carbon and lithium carbonate and in addition it was found that the method gave satisfactory results for the standard rocks G.1. and W.1. (Fortescue, 1962).

In order to obtain an indication of the magnitude of the matrix effect an internal standard is added in a known amount to all the samples, by adding the internal standard to the buffer. In the present study, as in previous studies in Sierra Leone, germanium is used as it occurs at very low levels in the rocks, soils and stream sediments of the areas investigated. The concentration employed is 400 ppm in each sample, however, the apparent germanium content of the regional stream sediment samples varied more than could be explained on the basis of analytical variability (Viewing, 1963 and James, 1965). This same variation has been observed in the present study and it appears that germanium levels tend to be enhanced in areas of silica rich rocks and suppressed in areas of iron rich rocks despite the use of the carbon - lithium carbonate buffer.

The effect of extreme ranges of bulk composition on the apparent content of germanium and other trace elements has been investigated in a series of artificial matrices ranging from 100% SiO_2 to one which contained 10% SiO_2, 35% Fe_2O_3, 35% Al_2O_3, 10% CaO and 10% MgO (Nichol and Henderson-Hamilton, 1962).

Constant amounts of trace elements were added to the artificial matrices with the germanium internal standard and arced under the standard conditions employed in the A.G.R.G. spectrographic laboratory. The results are shown in Table I. It is apparent that the siliceous matrices tend to cause enhanced levels, whilst sesquioxide rich matrices caused depressed levels.

In the present survey the silica rich areas of granite and quartzites are those with the lowest levels of trace

TABLE I

The effect of major element composition upon the apparent concentration of the trace elements, in synthetic mixtures (Adapted from Nichol and Henderson Hamilton (1962) by by Viewing (1963), after James (1965))

Trace metal content 150 ppm; germanium content 950 ppm.

\+ positive; $\frac{\text{spectrochemical result}}{\text{true content}}$ – negative; $\frac{\text{true content}}{\text{spectrochemical result}}$

Major element composition %					Ti	V	Cr	Mn	Co	Ni	Cu	Ge	Mo	Ag	Sn	Pb	Bi
SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO													
100	-	-	-	-	+4.1	+2.6	+3.3	+2.0	+4.1	+5.3	+6.6	+2.1	+4.0	+2.6	+3.3	+4.0	+2.6
98.6	0.1	0.1	0.1	0.1	+4.0	+2.6	+2.3	+1.3	+4.1	+4.1	+3.3	+1.2	+4.0	+2.0	+2.0	+2.0	+2.0
99.2	0.2	0.2	0.2	0.2	+2.6	+1.3	+2.0	+1.3	+2.6	+4.0	+1.3	+1.1	+2.6	+1.2	+2.0	+1.0	+1.3
98.0	0.5	0.5	0.5	0.5	+3.3	+2.0	+2.0	+1.3	+2.6	+4.0	+3.3	+1.2	+3.3	+2.0	+2.0	1.0	+1.3
96.0	1.0	1.0	1.0	1.0	+2.6	+1.2	+2.0	+1.2	+2.0	+2.6	+1.3	+1.1	+2.0	1.0	+2.0	-1.5	1.0
92.0	2.0	2.0	2.0	2.0	+3.3	+1.3	+1.6	+1.4	+2.0	+2.6	+2.6	+1.1	+2.6	+2.0	+2.6	+2.6	+2.6
80.0	5.0	5.0	5.0	5.0	+2.0	+1.3	+1.6	+1.3	+2.0	+2.0	+2.0	-1.3	+1.0	1.0	+2.0	+1.3	1.0
60.0	10.0	10.0	10.0	10.0	+1.3	1.0	+1.3	+1.6	+1.3	+1.2	+2.0	-1.3	1.0	+1.2	+2.0	+2.6	+2.0
20.0	20.0	20.0	20.0	20.0	1.0	-1.5	-1.2	+2.0	1.0	1.0	+1.3	-2.6	-1.5	-1.2	+1.3	+3.3	+3.3
10.0	35.0.	35.0	10.0	10.0	-2.1	-2.1	-1.5	+2.6	-1.5	-1.2	+1.3	-3.8	-2.1	-1.9	+1.3	+2.6	+2.6

element concentration, while the reverse is true in the iron rich areas of basic and ultrabasic schists. Thus any bias imposed on the analysis will have the effect of increasing levels in granitic areas and depressing levels in iron rich areas, but as the differences in trace element content between siliceous and iron rich samples is large the reduction in contrast will only be small. On the basis of these results and also the fact that the composition of the samples was far less extreme than the composition of the artificial matrices it is concluded that the matrix effect should not be too serious.

A comparison of spectrochemical and chemical analyses on a series of samples with a wide range of bulk composition showed a correspondence that was within ±25% (Viewing, 1963).

4.08. Analytical Precision

During all analytical work, both chemical and spectrochemical, a constant check was kept on the level and precision of the analyses by the technique described by Craven (1954). This technique entails analysing a number of samples which are made up as a series of mixtures from two end-members representing the higher and lower limits of the concentration range being investigated. Usually the series consists of 12 samples, 8 of which are mixtures and the remaining 4 the high and low end-members. In chemical analysis these samples were analysed at a frequency of 1 in 11 and in spectrochemical work at a frequency of 1 in 14, i.e. 1 per plate of 14 samples.

There are two methods of assessing the analytical precision from the data obtained by the analysis of the statistical series samples. The first method is that described by Craven (1954) and involves the solution of two equations for the mean content of the high and low members and the variance of this determination. This method is sufficient for routine analysis and is rapidly calculated on a small desk calculator. However, there are objections to the method of calculation used by Craven, the most important being that unequal weight is given to the data during calculation; the higher concentration levels affecting the derived value to a greater extent than the lower concentrations. A method of calculation which gives equal weight to all determinations is described by Stern (1959). This calculation is time consuming, taking about 45 minutes using an electric desk calculating machine, however, the time has now been reduced to a few minutes by the use of an electric digital computer for which a program has been written in Fortran IV (see Appendix I).

In most cases the analytical precision computed by Stern's method is lower than that computed by Craven's method (Table II) indicating that certain of the high level determinations contain large errors. Conversely when Craven's value is lower than Stern's it indicates that large errors are present in the determinations at low levels.

TABLE II

Percentage Analytical Precisions

at the 95% Confidence Level

	Element	Craven	Stern
Schist Belt Surveys			
Nimini & N. Kambui Hills S.S.	Ni	19.4	8.2
Gori & S. Kambui Hills S.S.	Ni	9.9	9.1
Nimini Hills S.S. only	Ni	28.5	11.4
Detailed Survey S.S.	Ni	26.6	19.1
Detailed Survey Soils	Ni	20.0	9.3
Detailed Survey Rocks	Ni	22.7	19.5
Reconnaissance S.S.	Zn	14.7	10.6
Detailed Survey S.S.	Zn	16.4	15.8
Nimini Hills S.S.	As	10.9	6.0
Gori & Kambui Hills S.S.	As	42.7	27.2
Detailed Survey Soils & S.S.	As	11.3	5.4
Konkombadu Area Soils & S.S.	Sn	34.3	20.4
Basement Survey			
Stream Sediments	Ni	25.7	23.1
Soils	Ni	24.5	12.4
Rocks	Ni	36.9	17.6
Stream Sediments	Zn	10.6	11.0
Rocks and Soils	Zn	14.6	7.7
Stream sediments	As	5.1	17.0
Rocks and Soils	As	15.7	34.0

Note:- S.S. = Stream sediments

The statistical series technique is based on the assumption that both the samples for analysis and the statistical series samples are of equal grain size. In reality this is often not true as the samples being analysed contain coarser fragments than are found in the statistical series samples.

An investigation into the relationship between particle size, sample weight and analytical variance has revealed the following relationship (Gy, 1956):-

$$\frac{P \times \sigma^2}{d^3} = C \quad \text{where}$$

P = Sample weight

σ^2 = variance of percentage error of the true assay

d = size of the largest particle present

C = a constant characteristic of the nature of the sample

It is clear that a reduction in variance can only be attained by an increase in sample weight or a reduction in the particle size of the sample. The former of these two courses is not feasible as it could not be integrated with the standard spectrographic methods used by the A.G.R.G. However it is feasible to reduce the particle size of the sample by grinding.

Two sites were chosen which showed a large variation between the three individual samples. The bulk samples were screened and the resulting minus 80 mesh fraction divided into two parts. One half was retained and the other ground in an agate pestle and mortar until it would pass through a 120 mesh screen. Two 100 mg. aliquots were taken from each fraction of each sample and prepared for analysis. On analysis each preparation was analysed twice, thus resulting in 4 determinations on each fraction of each sample.

Overall geometric means and variances were computed for each sample site and these are plotted in figures 9 and 10. The results show that the means for the minus 80 mesh and minus 120 mesh determinations in general correspond to within ±25%. The variances, however, differ significantly, in nearly all cases the variance at a sample site was reduced by grinding to minus 120 mesh.

The reduction in variance, by a factor of about 2, due to grinding is as predicted by Gy and suggests that the original high variances encountered were due to the inhomogenous nature of the aliquots selected for analysis. The number of samples revealing large variances at a single site is small and it would be expected that grinding would have its maximum effect on these samples, and as the variance decreases so the effects of grinding would become less marked. Thus the effects of grinding would probably not improve the variance by more than a factor of 2, and that, in only a few samples.

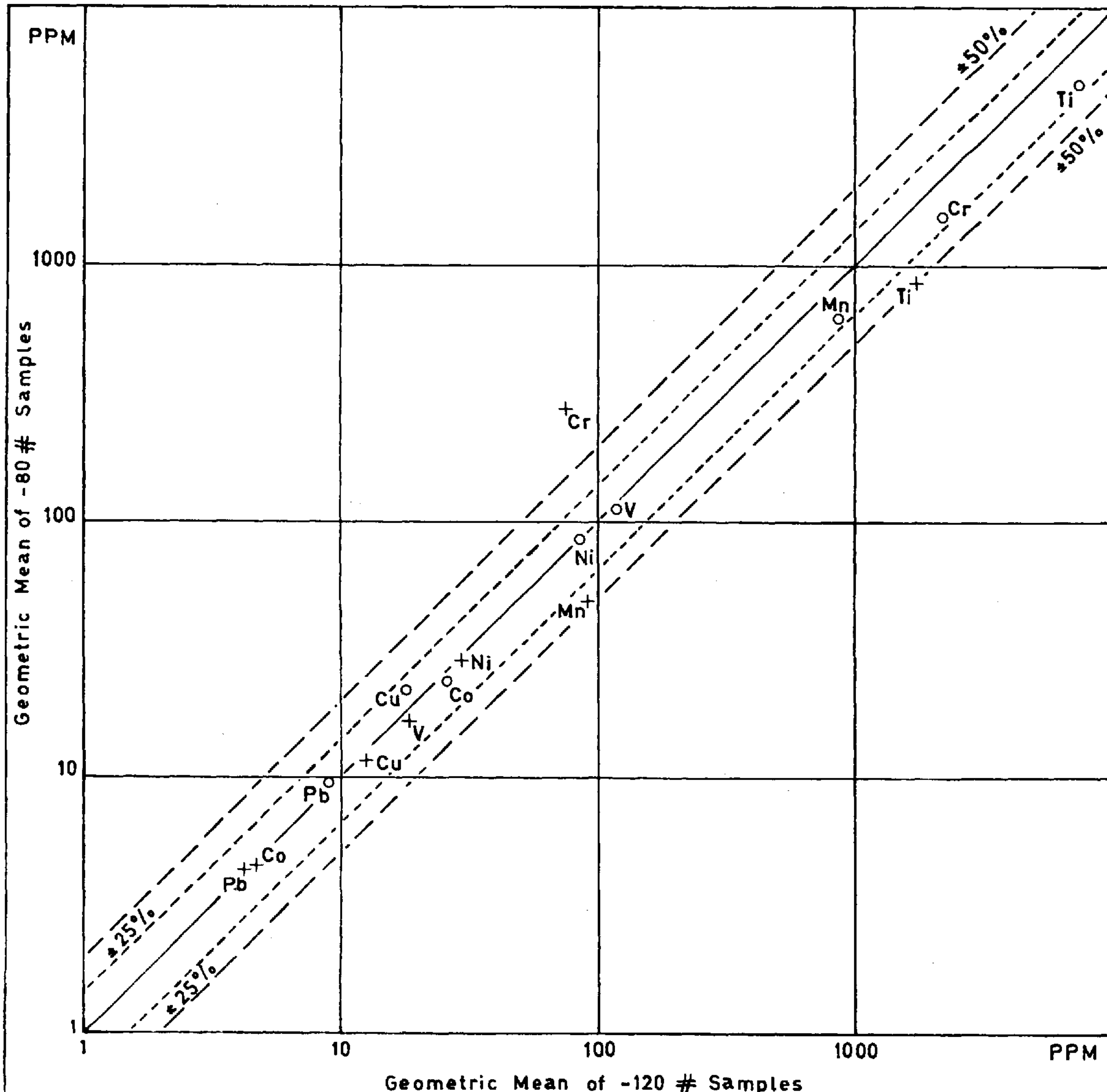


FIG. 9

COMPARISON OF MEANS
BETWEEN
GROUND AND UNGROUND -80 # MATERIAL

Samples 7271, 7272, 7273 +
Samples 7325, 7326, 7327 o

Determinations based on 12 Analyses

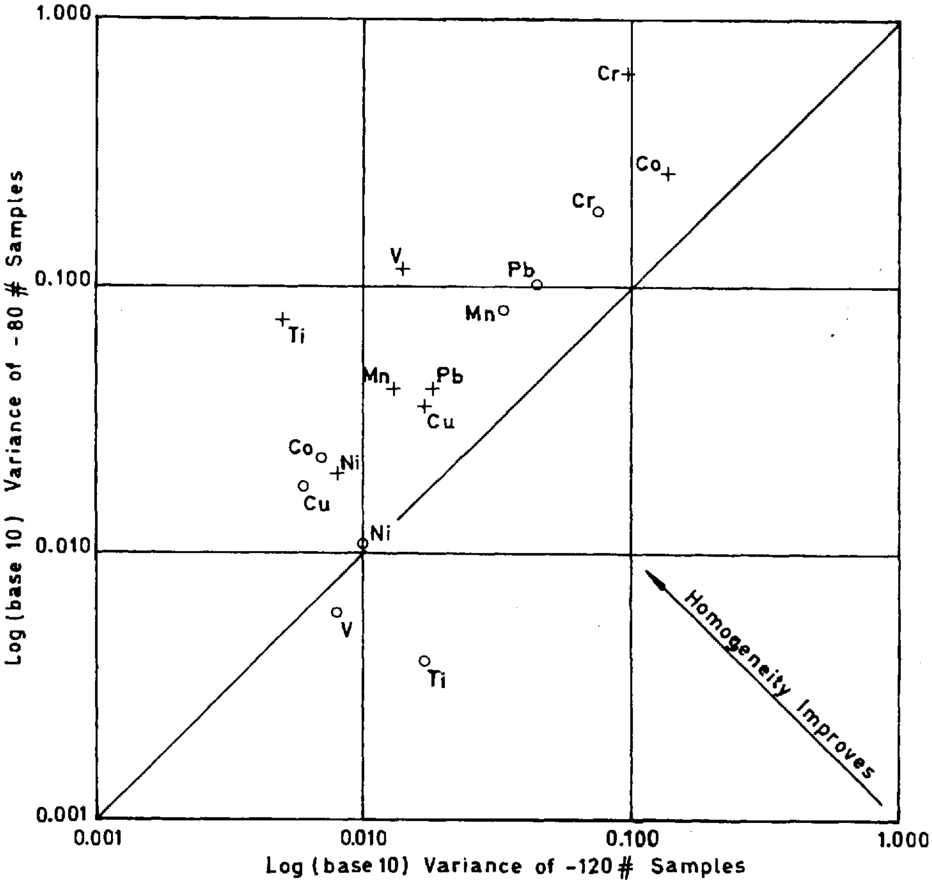


FIG. 10

COMPARISON OF VARIANCES
BETWEEN
GROUND AND UNGROUND -80 # MATERIAL

Samples 7271, 7272, 7273 +
Samples 7325, 7326, 7327 o

Determinations based on 12 Analyses

The only effect grinding all the samples to minus 120 mesh is likely to have is to cause a small reduction in the mean of variances of the triplicate samples; the reduction will only be small on account of the few samples exhibiting the high variances studied. This fact, combined with the good general correspondence of the means for the two size fractions, led to the conclusion that only marginal improvements could be made by grinding all the samples to minus 120 mesh and therefore grinding has not been undertaken.

CHAPTER 5 - DATA HANDLING TECHNIQUES

5.01. Presentation of Regional Geochemical Survey Data

In order to facilitate the interpretation of the large quantity of data obtained in regional geochemical surveys it is necessary to present the data in as simple form as possible. The raw data direct from the analytical laboratory is in general expressed to one or two figures in a range from 1 to 10,000 ppm resulting in around 100 possible numbers. To plot these numbers directly would make visual appreciation of patterns shown by the data impossible, so the data is split into 13 approximately logarithmic groups covering the range 1 - 10,000 ppm. The system of data grouping, identical to that used by Viewing (1963) and James (1965), was adopted following a comparision of germanium data obtained by the usual method of direct comparison with data obtained by the use of the densitometer. It was found that data obtained by direct comparison was unduly biased towards the standards. As this estimation bias was likely to be present in all results obtained by direct comparison it was considered desirable to evolve a method which minimised this feature and the best way was considered to be one which extended a group to an equal distance either side of the standards (Viewing, 1963). Thus, with standards at 1, 2, 5, 10, 20.....5,000 and 10,000 ppm the group boundaries fall at 1.47, 3.21, 7.1, 14.7.....7,070 ppm; these figures are however rounded off to 1.5, 3.0, 7.0, 15.....7,000 ppm. The single element maps show the trace element content of the sampling media (rock, soil or stream sediment) plotted as symbols over the sample sites, the symbol indicating the concentration group into which the data falls.

The maps of trace element content in the stream sediments of the schist belt areas are plotted at a scale of 1:40,000 to coincide with the scale of the topographic maps available and to the approximate scale of the aerial photographs in previously unmapped areas. These regional geochemical maps have been used to prepare a series of single element maps, at a scale of 1:250,000 which show the principal metal distribution patterns in the stream sediments.

In the case of the basement survey the regional maps were plotted at a scale of 1:1 million and the values ascribed to each sample site, for soil and stream sediment, are the arithmetic means of the three values obtained from the three samples collected at that site.

5.02. The Determination of Frequency Distribution

A common mode of analysis used on geochemical data is the determination of the frequency distributions of the data, as these indicate if more than one markedly divergent population is present. However, the apparent absence of more than one population does not necessarily indicate that the data is derived from a single population as the addition of populations can simulate a single larger population. A knowledge of the frequency distributions is also necessary for the drawing of histograms and the arranging of data into symbol groups for plotting on single element maps.

The determination of frequency distributions and calculation of simple statistical parameters is a lengthy process so it was considered desirable to develop a computer program for this task. The program, which is described in Appendix II, not only computes frequency distributions but after an optional logarithmic transformation computes the mean, variance, standard deviation, skew and kurtosis of each variable. Options are also available for four other tasks:-

(1) That the histograms may be plotted.

(2) A Chi Square test for normality may be carried out in order to assess the degree to which the data conforms to a normal, or lognormal distribution.

(3) An anomaly selection routine for selecting samples falling outside the ± 2 and 3 sigma limits is provided.

and (4) A correlation matrix may be computed in order to gain insight on the interrelations between the variables and a Student's t test to assess the statistical significance of the correlation coefficients.

The use of an electronic digital computer has necessitated the punching of data relating to each sample on punch cards. The cards employed are the standard 80 column type onto which have been punched project indentification number, sample type sample number, sample site co-ordinates and the analytical data in ppm (for details see Appendix II).

5.03. Trend Surface Analysis

Trend surface analysis has been used as an aid to interpreting the data collected during the basement survey. This technique was introduced into the geological sciences in late 1950's (Grant, 1957; Krumbein, 1959; Whitten, 1959) and aims to determine the broad underlying pattern of variation in a set of data and to separate out local minor fluctuations from this underlying trend.

The shape of the fitted surface represents the average trend in the observations, and the difference between the computed and observed value is known as the residual. The shape of the surface is determined by the method of least squares; thus the shape is that for which the sum of the squares of residuals has a minimum value. The surfaces used in trend surface analysis are polynomial and may be linear or curved; a first degree surface being linear and the higher degrees being curved; the complexity of the curved surface increasing with the degree.

Most applications of the technique to date have been in the fields of geophysics and petrology. However, the technique has been used to aid the interpretation of geochemical soil survey data in Utah, U.S.A. where surfaces up to the 7th degree have been fitted (Connor and Meisch, 1964). The first 4 degrees showed increasingly better spatial relationship to the known ore body, but the 5th - 7th degree surfaces did not appear to aid meaningful interpretation. The writers go on to point out that statistical tests of the significance of the trends are not strictly valid if local concentrations of positive or negative residuals occur. Thus the very property of the data being sought is a hindrance to an important part of the statistical analysis.

Trend surface analysis has been shown to yield significant results in sedimentary petrological investigations and although the method has limitations the results are informative (Allen and Krumbein, 1962). Subsequently an investigation into the problem of computing confidence intervals for low order polynomial trend surfaces showed that these could be an aid to interpretation (Krumbein, 1963).

The computations involved in determining the surfaces are not feasible without the aid of an electronic digital computer. In the present study a modified version of a program published by Whitten (1963) was used on the Imperial College IBM 7090/1401 computer. The modification to the program involved a transformation of the data to logarithms and a conversion of the results back into natural numbers prior to printing out.

5.04. Rolling Mean Analysis

Rolling mean analysis is the extension of the one dimensional data smoothing technique of moving averages to areally distributed data. The first applications of rolling mean analysis to geological data were in the field of sedimentary petrology where the technique was successfully used in elucidating trends in palaeocurrent data (Pelletier, 1958; Potter, 1955 and Schlee, 1957). The concept of rolling means has been much expanded by Krige and Ueckerman (1963) in their work in determining distribution trends in gold assay data from Witswatersrand.

In geochemistry rolling means have found little application to date. The technique has been employed to achieve preliminary smoothing in a study of copper distribution in alluvial soils where it was found useful in reducing the effect of random sampling and analytical errors as well as local minor fluctuations (Connor and Meisch, 1964). Other applications of the technique have been made with success in determining the underlying trends in complex data (Hawkes, pers. comm. and Holman, pers. comm.).

The calculation of rolling means is a long and tedious task and for this reason a computer program has been written to carry out the computations. The program, written in Fortran IV (see Appendix III), moves a search area across a map of the data stored in the computer. For each search area, after an optional logarithmic transformation, the mean and standard deviation of the values within the search area are calculated. In addition the mean is expressed as a standard normal deviate of the overall mean of the data and a variance ratio calculated between the variance of the search area and that of the area as a whole. These last two criteria, although not investigated during the present study, are believed to have considerable potential in aiding interpretation as they enable the degree by which the local values of mean and variance differ from the overall mean and variance to be assessed. The co-ordinates of the computed data are the arithmetic mean of the samples within the search area, and this is known as the centroid position. On completion of the searches over the whole area the percentage fit of the new surface is calculated relative to the original data.

5.05. Factor Analysis

Factor analysis sets out to determine the underlying causal factors effecting the distribution of data and then to express the observations as components of these factors.

The concept of factor analysis was introduced by Spearman (1904) as a tool for psychometric research. American workers expanded and generalised the theory in following years, Thurstone (1931), Holzinger and Harman (1941) and Harman (1960).

Factor analysis can be carried out in either R mode or Q mode. The choice of mode is a matter of objective as the same computional techniques and the same data may be used in both modes. R mode is used to study the relationship between measurements made on samples, whilst Q mode is used to elucidate the relationship between samples. In the present study Q mode factor analysis has been used.

The first published use of factor analysis in geology was made in sedimentary petrological studies (Krumbein, 1957) and this initial work was followed by an investigation into classification of recent Bahamian carbonate sediments (Imbrie and Purdy, 1962). Q mode factor analysis was used to investigate Permian stratigraphy in Kansas and it was found that the method was a successful supplement to other methods of interpretation (Krumbein and Imbrie, 1963). A further study of Permian stratigraphy in Kansas and Oklahoma led to the conclusion that factor analysis was a useful statistical tool in clarifying simple relations in complex data (Harbaugh and Demirmen, 1964). The most significant application of factor analytical techniques to date has been in the study of heavy mineral distribution patterns in the Gulf of California and on the Orinoco-Guayana Shelf (Imbrie and Van Andel, 1964). The authors set out to determine the provenance of the samples by a study of heavy mineral patterns and to relate these to known heavy mineral associations in the surrounding areas of land. However, the geological implications of the results was not discussed though it was pointed out that the results have effected a significant improvement in interpretation, the least of these being the abandonment of the 'pigeonhole' concept for data and the acceptance of a more dynamic end-member system of classification.

To date no published studies in the field of geochemistry have used the technique of factor analysis.

Two important features arise when handling the present data for Q mode factor analysis. Firstly, the data must be converted into logarithms as the distributions tend to be log-normal, and secondly, the data must be measured on the same scale. If data is not measured on the same scale unequal weight will be given to the different analyses i.e. concentrations in the range 1,000-10,000 ppm will be given greater weight than those in the range 10-100 ppm. This problem is avoided by expressing the data relating to each variable as a percentage of the highest and lowest observed levels; thus the highest level is equivalent to 100% and the lowest to 0%.

The computations have been performed using a computer program written by Manson and Imbrie (1964). A mathematical model of the data is made in an N dimensional space, where N is the number of measured variables. The model consists of a number of vectors, each representing a sample; the directions of the vectors relative to each other being a measure of the similarity of the samples they represent and their length being a measure of the metal contents in the samples. Having formed the model it is then necessary to locate a chosen number of axes, representing factors, in the hyperspace such that they express the observed variability with the greatest efficiency. This completed, the vectors (samples) are expressed in terms of the new axes which correspond to the factors of the factor analysis. The number of axes is chosen by the user of the program by trial and error. Usually a number of trials are carried out above and below the user's estimate of the number of factors involved, in order that the most suitable number of factors may be found.

CHAPTER 6 - SAMPLING REPRESENTIVITY

6.01. Schist Belt Sampling

The representivity of the regional stream sediment samples has been investigated by the detailed sampling of selected streams in the Nimini and North Kambui Hills. Streams draining areas of granite, metasediment, basic and ultrabasic schist were sampled at 500 feet intervals in addition to collecting the normal regional reconnaissance samples.

The geometric mean and range at the one standard deviation limits have been determined for Co, Cr, Cu, Mn, Ni, Pb, Ti and V in the detailed samples. As the values for the regional survey samples for a particular rock type generally fall within the ranges associated with that rock type, it is concluded that the regional reconnaissance samples are, in fact, representative of the catchments from which they were taken (Table III).

6.02. Basement Sampling

The sampling plan described (section 4.02.) was adopted as there was no previous experience in sampling very large catchments in Sierra Leone. It was questioned whether

TABLE III

Representivity of Regional Reconnaissance Sampling

		No.	Co	Gr	Cu	Mn	Ni	Pb	T	V
Ultrabasic Schist	R	3	210-640	4200-8800	250-560	2100-4750	2240->1%	16-32	>1%	400
	M		360	6070	380	3200	4800	22	>1%	400
	S		700	1%	300	3000	8000	30	>1%	400
Basic Schists	R	5	77-130	340-670	190-410	2200-5900	300	4-8	>1%	450-840
	M		100	480	280	3600	300	6	>1%	610
	S		180	600	180	4000	350	7	>1%	600
Acid Metasediments	R	5	7-38	72-460	34-71	500-1800	44-190	14-18	2400-6200	34-180
	M		16	180	50	950	92	16	3900	79
	S		50	400	50	800	300	15	5000	150
Granites	R	4	6-34	73-83	23-43	180-1050	23-43	12-53	3200-4300	48-115
	M		14	77	31	430	31	26	3700	75
	S		10	80	30	150	15	20	3000	60

R = Background Range for Stream (ppm) at the 1 S.D. limits.

M = Geometric Mean of Samples (ppm).

S = Value of Regional Reconnaissance Sample (ppm).

secondary alluvial processes might seriously distort the local patterns of metal distribution in samples from large catchments. However, as it was believed that within an area of 75 square miles the basement complex was relatively homogeneous and as experience gained around the schist belts indicated that the trace element patterns observed in catchments of up to 7 square miles faithfully reflected the bedrock geochemistry it was decided to sample catchments of 5-7 square miles. This size was considered to be the best compromise between the adverse effects of elutriation and maximum catchment size.

The choice of sampling programme, however, raises two points. Firstly, that as the programme only samples 10% of the study area, it is best suited to outlining the major features of change across the study area and not to outlining individual areas of interest. However, if any specific information should come to light, such as anomalously high levels of metals of economic interest, it should be given due attention. Secondly, it is of interest to know to what extent samples which are drawn from only 10% of the area are representative of the 75 square miles they are set in, or whether drainages of 75 square miles would have given a more representative picture of the local geochemistry.

In order to estimate the efficiency of the sampling programme a detailed survey of some 100 square miles was made (E4). Five sites were sampled in triplicate in the main drainage and two major tributaries. Fifteen minor sites on small drainages of 5-7 square miles of catchment area, which all eventually flowed to the five sites on the major drainage, were also sampled in triplicate together with the minor drainages sampled during the regional survey.

The geometric means and variances for Cr, Mn, Ni and Pb in each of the three groups were calculated and using this data a series of Student's t tests were carried out to compare the means of the three groups (Dixon & Massey, 1957). The lower the t value the smaller is the difference between the means being studied (Table IV). As lower t values result from comparing the reconnaissance data to the fifteen minor drainages than from comparing the major drainage to the fifteen minor drainages, it is indicated that the values obtained by the reconnaissance samples are closer to the fifteen minor drainages than are the samples from the major drainages. The actual magnitude of the t values gives a measure of the variability of the data. Thus manganese shows the greatest variability in the study area and chromium the least.

If it is accepted, on the basis of previous experience gained around the schist belts, that the fifteen minor drainages are giving a true picture of the geochemistry of the study area it is clear that the two sites sampled as part of the basement sampling programme are better estimates of the local geochemistry than the samples from the major drainage. It is concluded that

TABLE IV

Comparison of Means by Student's t Test

Data table

	No.		Cr	Mn	Ni	Pb
Major Drainages	5	M S.D.	24 .19	1700 .09	25 .38	26 .06
Minor Catchments	15	M S.D.	15 .25	870 .23	11 .33	23 .14
Reconnaissance Sites	2	M S.D.	17 .11	403 .55	15 .19	19 .13

M = Geometric Mean (ppm)
S.D. = Standard Deviation in log 10 units.

Table of t values

	Cr	Mn	Ni	Pb
Major Drainages .v. Minor Catchments	0.46	2.58	1.91	0.87
Major Drainages .v. Reconnaissance Sites	0.90	2.07	0.65	1.45
Minor Catchments .v. Reconnaissance Sites	0.15	1.43	0.55	0.61

For method of calculation see:-

Dixon and Massey (1957)

possibly alluvial processes are causing the sorting of the sediment in large drainages so producing atypical samples. In conclusion it is clear that the sampling programme undertaken is adequate and provides a more realistic measure of the local geochemistry than samples taken from the 75 square mile catchments.

CHAPTER 7 - REGIONAL METAL DISTRIBUTION

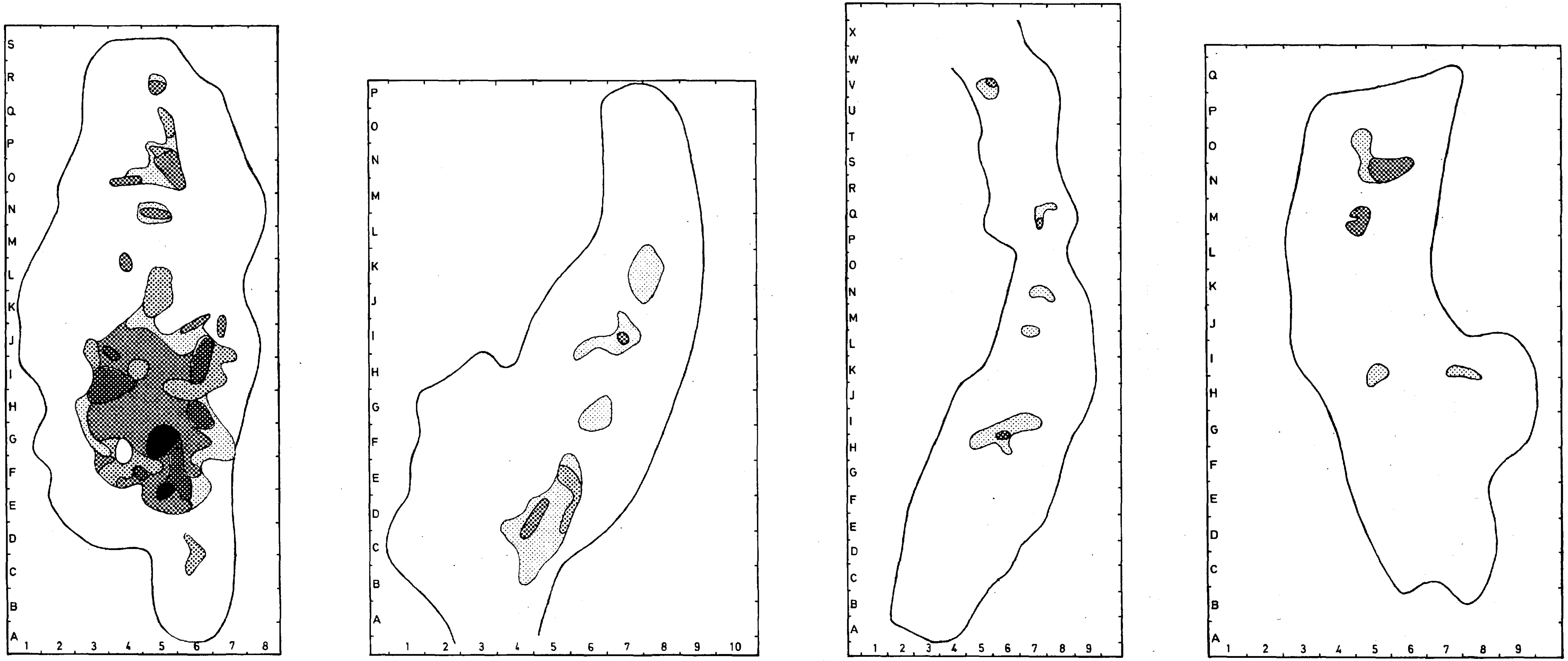
7.01. General Introduction

In the following description of the patterns of trace element content observed in the stream sediments from the field areas the patterns are described in terms of geochemical topography, i.e. by features of both the level and homogeneity of the data. This terminology was introduced by Hawkes and Webb (1962), however, the term 'geochemical landscape' is not employed as it is used in the U.S.S.R. to describe the physiochemical conditions of the present secondary environment.

The descriptions of the regional patterns of metal distribution are based on the series of single element 1:40,000 and 1:250,000 scale geochemical maps which show the metal content of the individual stream sediment samples and general patterns of metal distribution respectively. (The former are figs. 53-97 filed in Volume II and the latter are figs. 11-22 of the text).

Attention has only been drawn below to the major important features which are discernable through significant differences in level and relief, and particularly to those which are common to more than one element.

The reliability of the results will not be discussed at



NIMINI HILLS NORTH KAMBUI HILLS SOUTH KAMBUI HILLS GORI HILLS

REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

ARSENIC

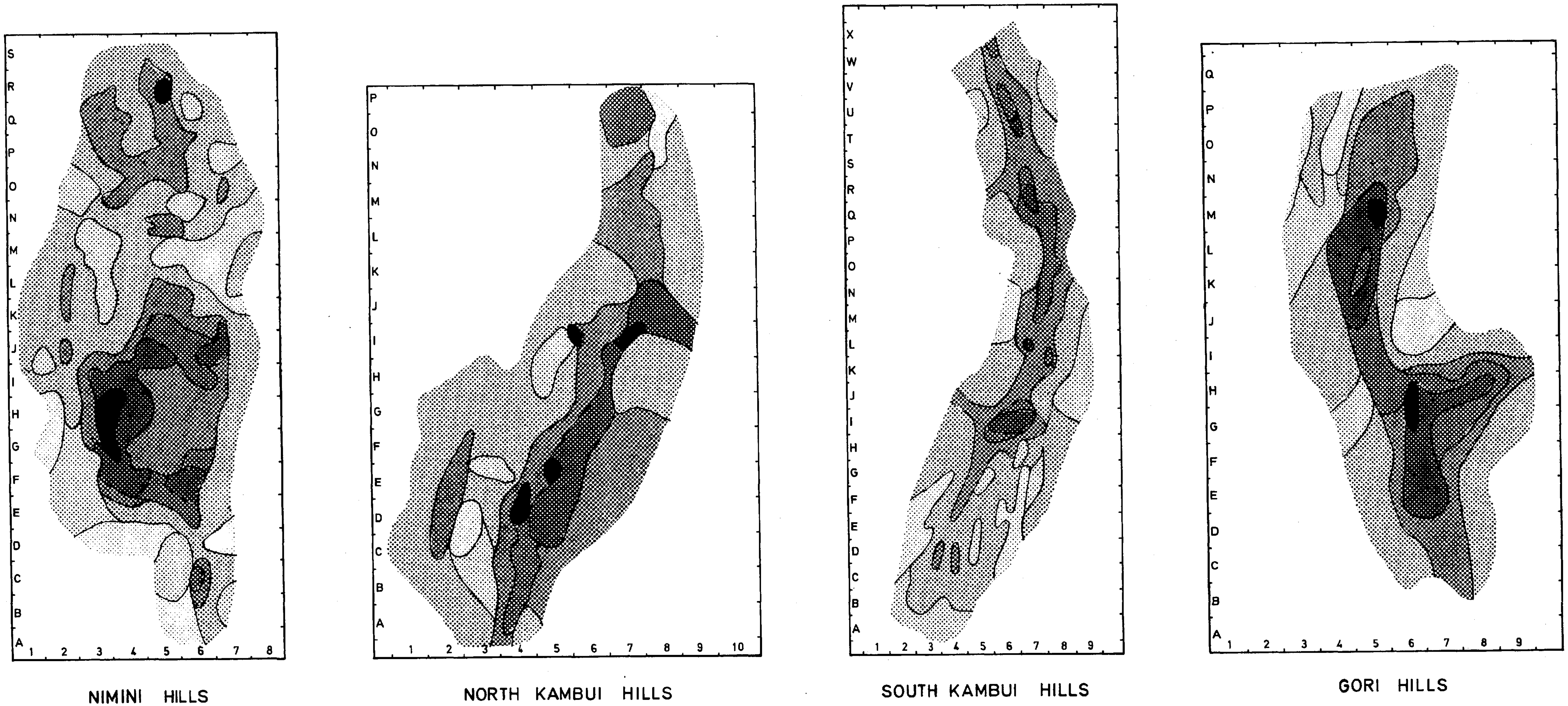
Scale approx. 1:250,000

Miles 5 0 5 10 Miles

LEGEND

<3 ppm As	15 - 30 ppm As
3-7 "	30-70 "
7-15 "	>70 "

FIG. 11



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

COBALT

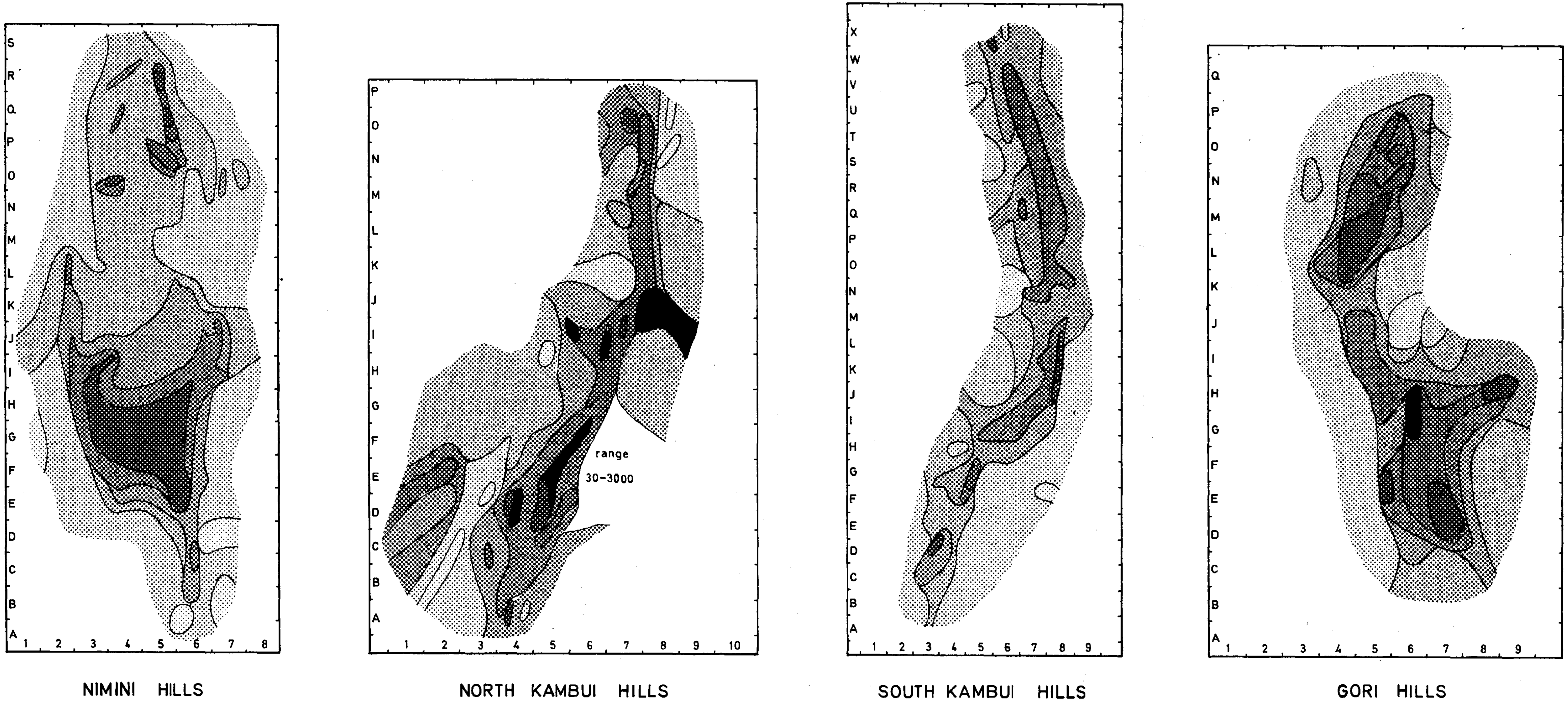
LEGEND

<7 ppm Co	70-150 ppm Co
7-15 "	150-300 "
15-30 "	>300 "
30-70 "	

Scale approx. 1:250,000

Miles 5 — 0 — 5 — 10 Miles

FIG. 12



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

CHROMIUM

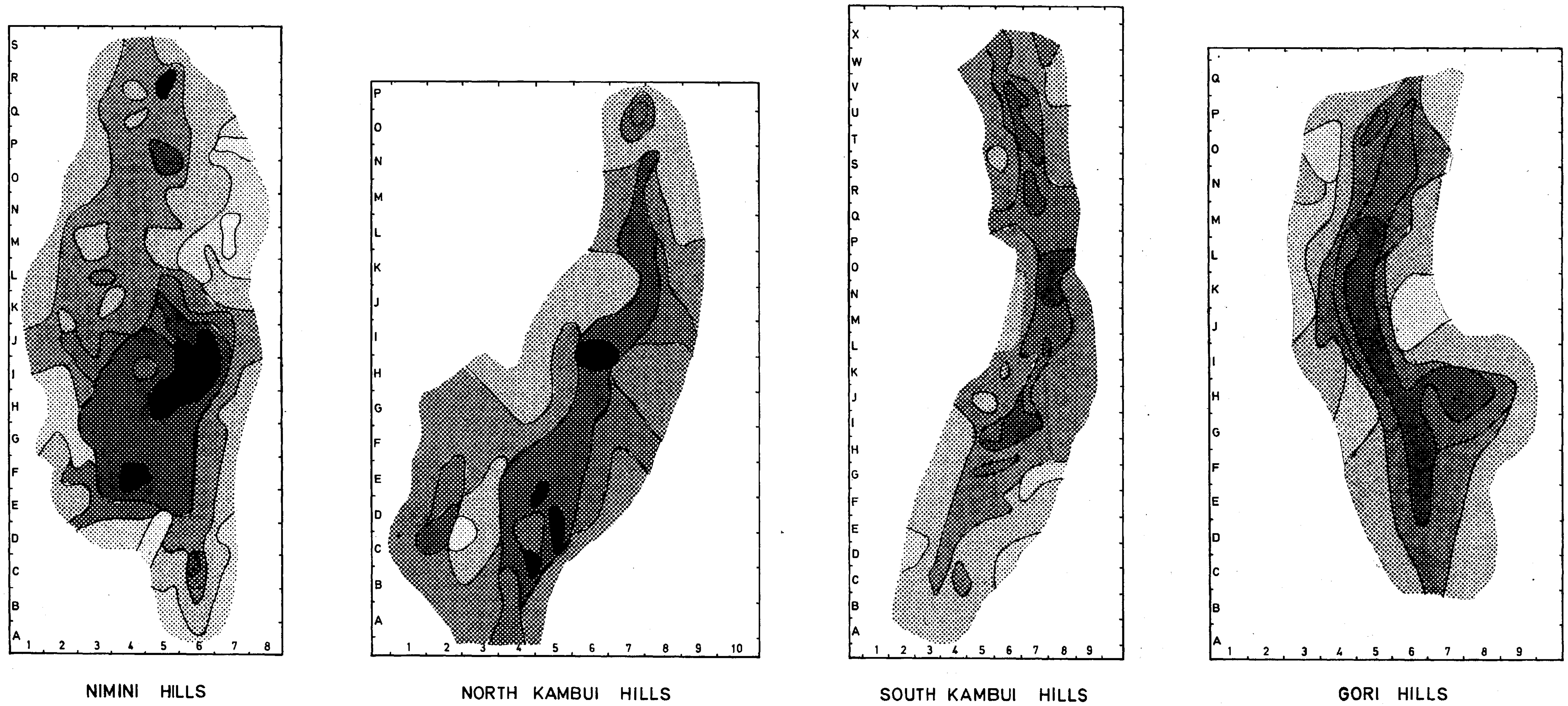
Scale approx. 1:250,000

Miles 5 0 5 10 Miles

LEGEND

<30	ppm Cr	700-1500	ppm Cr
30-150	"	1500-3000	"
150-300	"	3000-7000	"
300-700	"	>7000	"

FIG. 13



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

COPPER

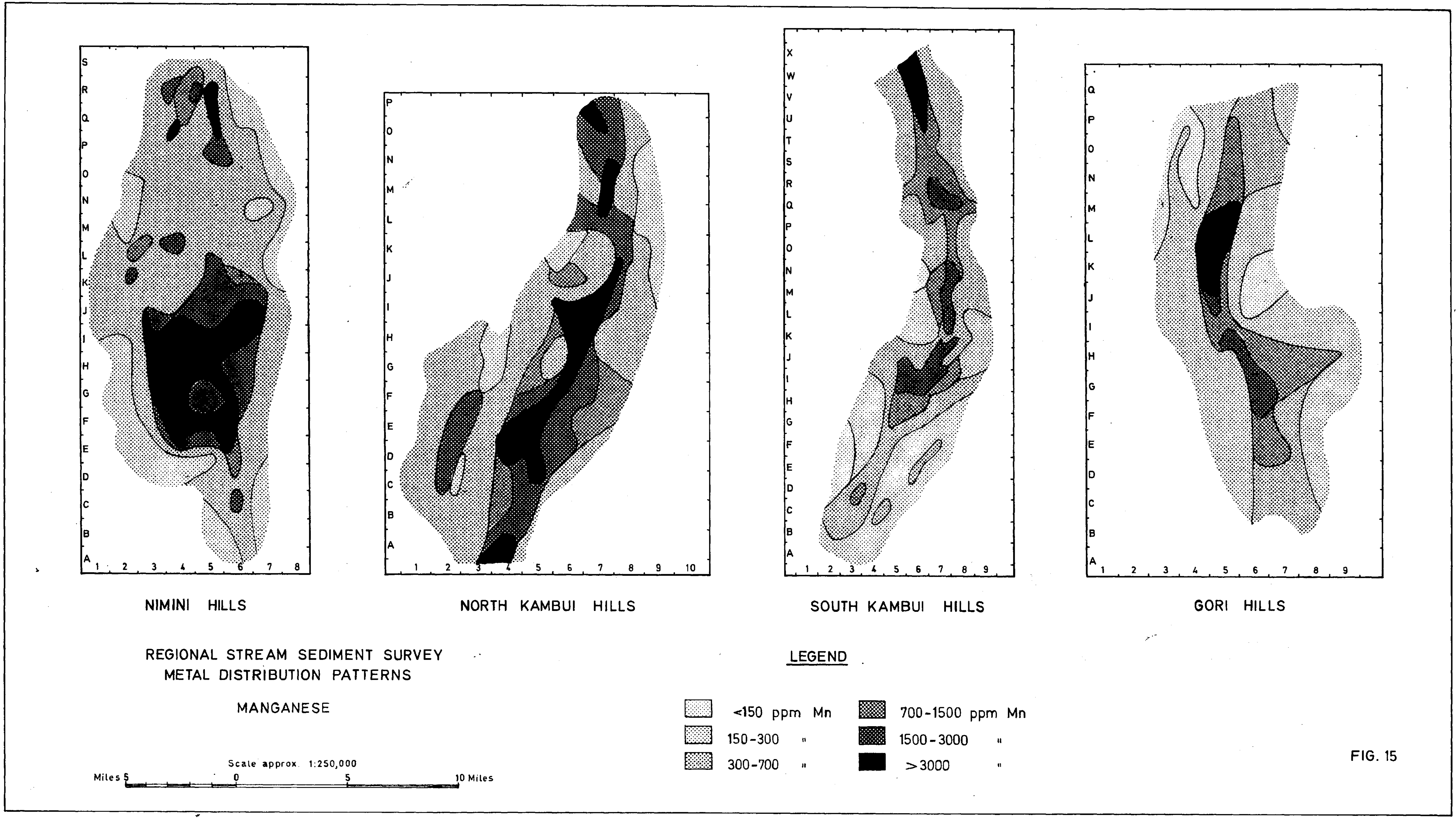
Scale approx. 1:250,000

Miles 5 — 0 — 5 — 10 Miles

LEGEND

<7	ppm Cu	70-150	ppm Cu
7-15	"	150-300	"
15-30	"	>300	"
30-70	"		

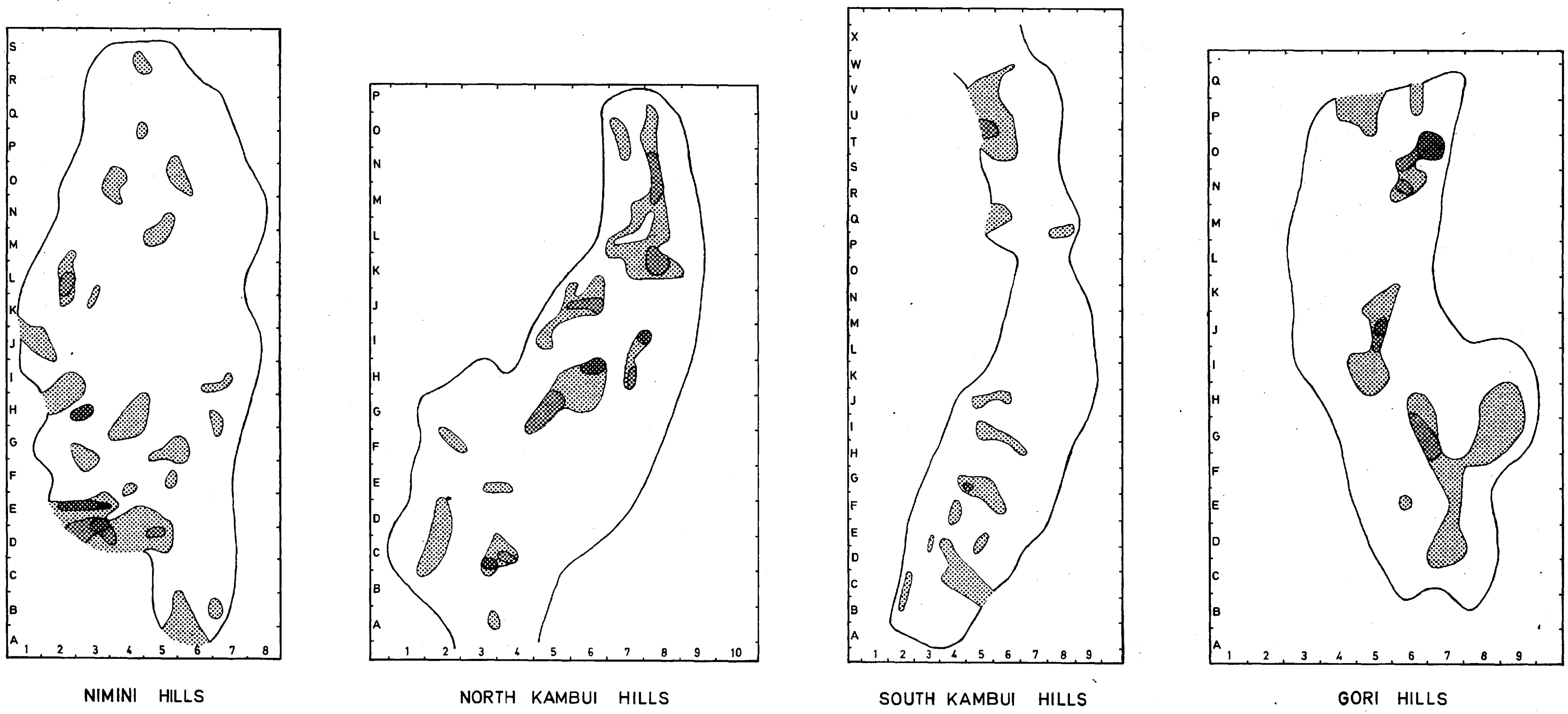
FIG. 14



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

MANGANESE

FIG. 15



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

MOLYBDENUM

Scale approx. 1:250,000

Miles 5 0 5 10 Miles

LEGEND

- <3 ppm Mo
- 3-7 "
- 7-15 "
- 15-30 "
- >30 "

FIG. 16

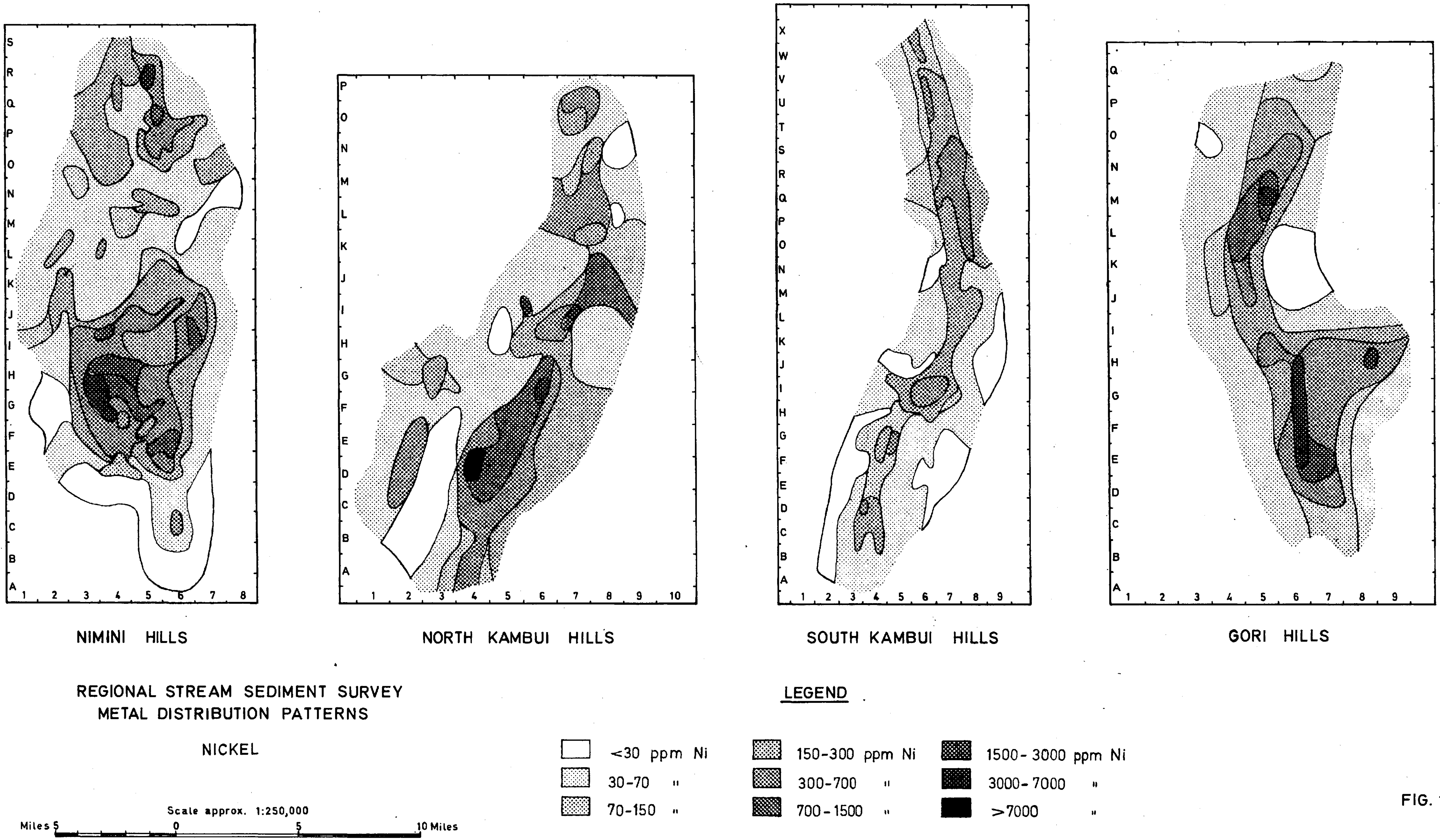

NIMINI HILLS
NORTH KAMBUI HILLS
SOUTH KAMBUI HILLS
GORI HILLS
REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS
NICKEL
Scale approx. 1:250,000
Miles 5 0 5 10 Miles
LEGEND
<30 ppm Ni
30-70 "
70-150 "
150-300 ppm Ni
300-700 "
700-1500 "
1500-3000 ppm Ni
3000-7000 "
>7000 "

FIG. 17

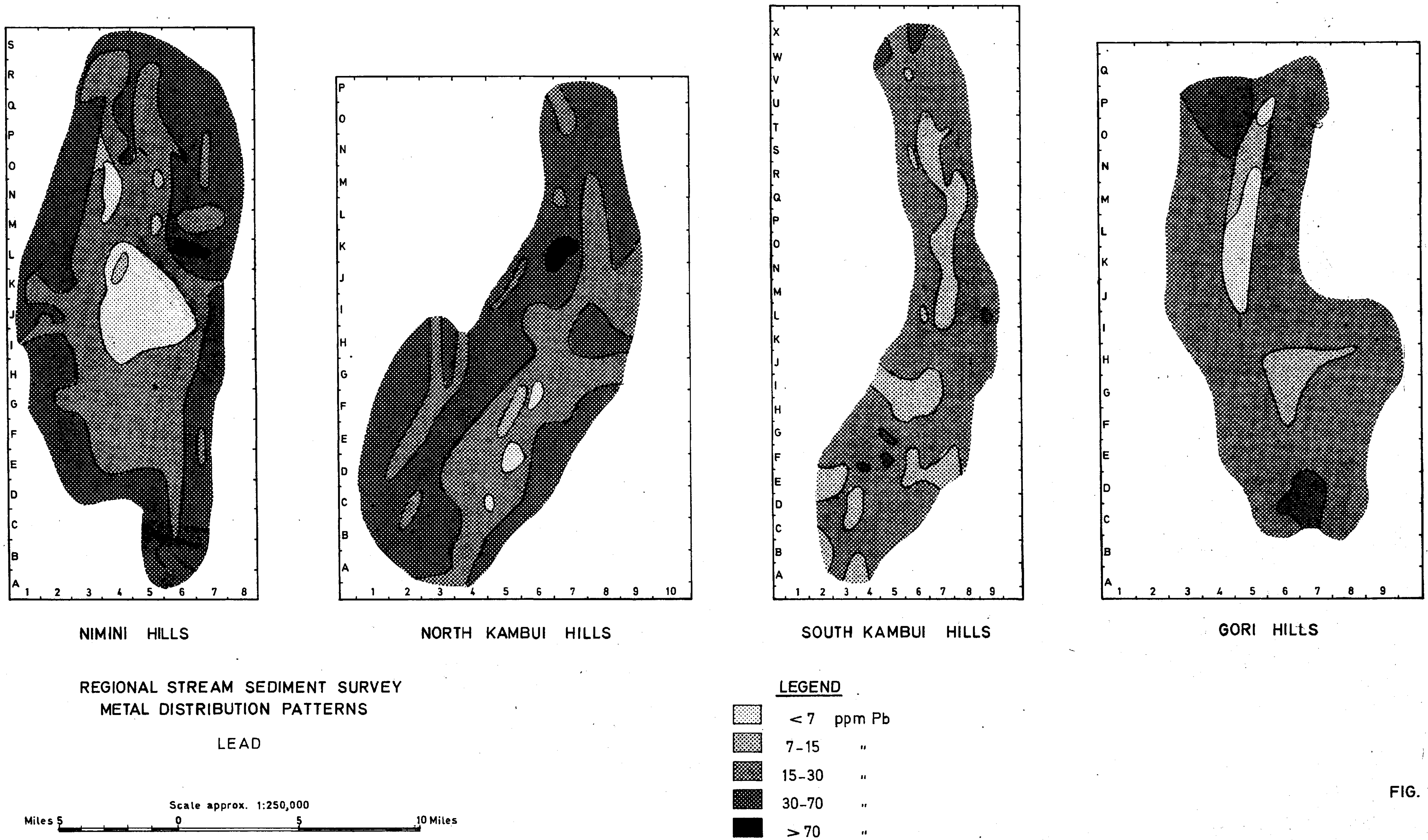
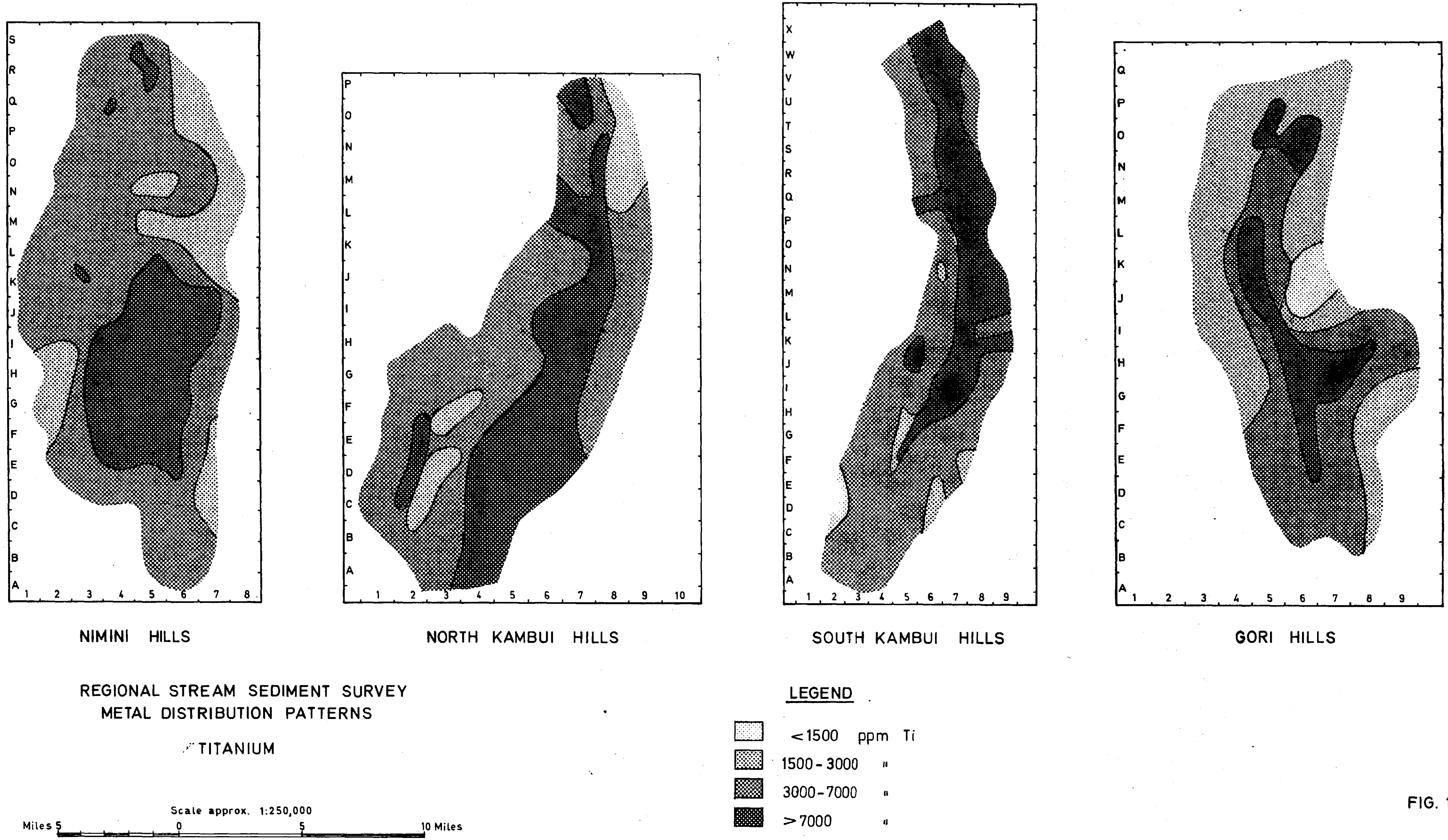

NIMINI HILLS
NORTH KAMBUI HILLS
SOUTH KAMBUI HILLS
GORI HILLS
REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS
LEAD
Scale approx. 1:250,000
Miles 5 0 5 10 Miles
LEGEND
< 7 ppm Pb
7-15 "
15-30 "
30-70 "
> 70 "

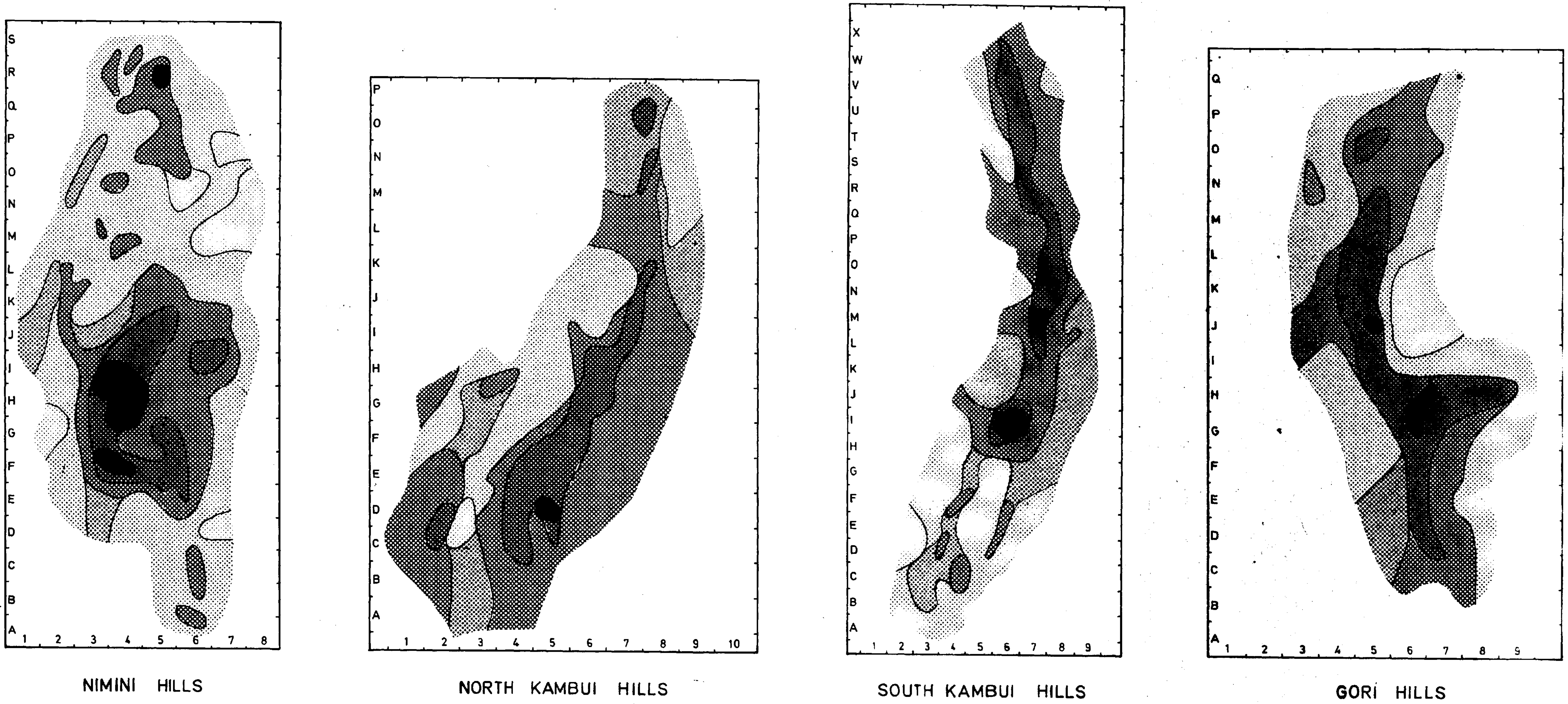
FIG. 18



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

TITANIUM

FIG. 19



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

VANADIUM

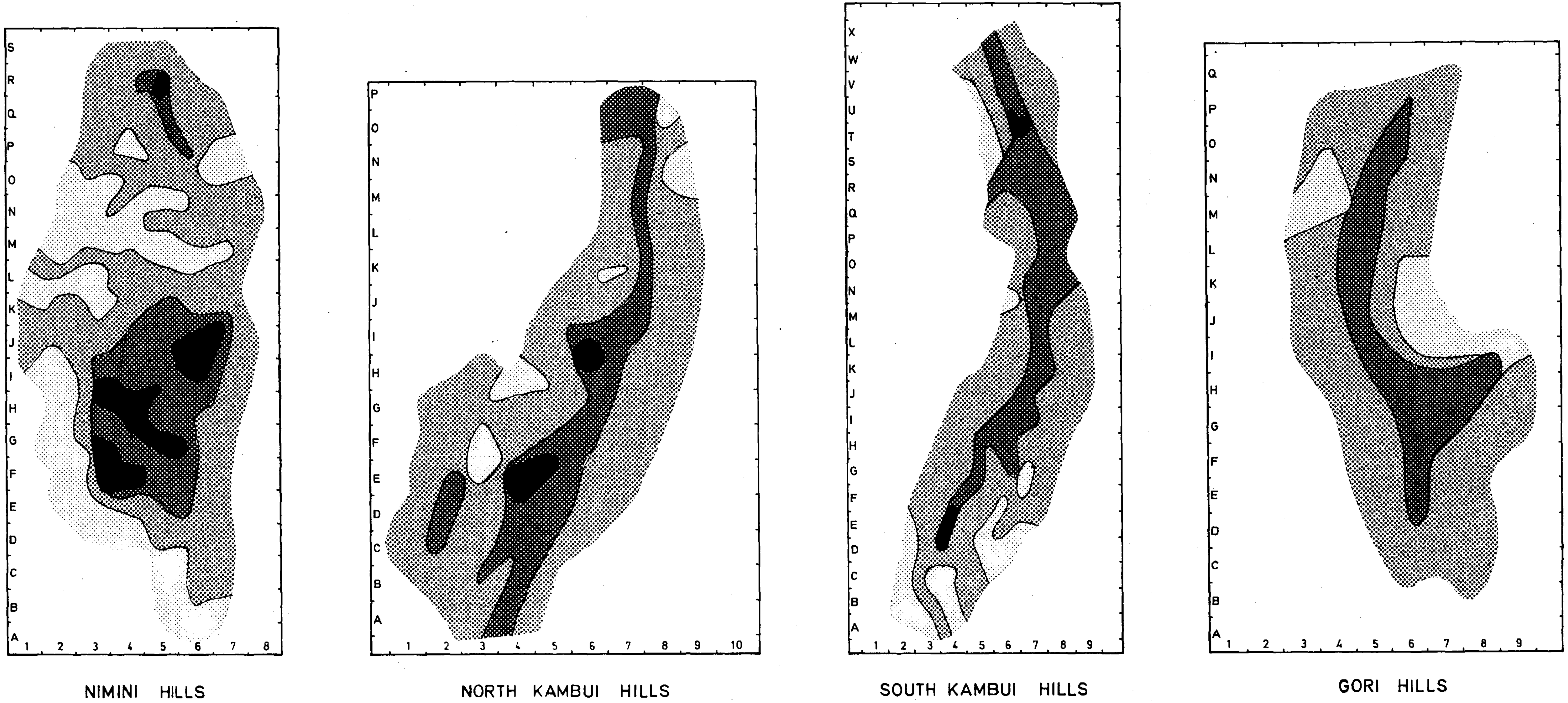
Scale approx. 1:250,000

Miles 5 — 0 — 5 — 10 Miles

LEGEND

<30 ppm V	150-300 ppm V
30-70 "	300-700 "
70-150 "	>700 "

FIG. 20



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

ZINC

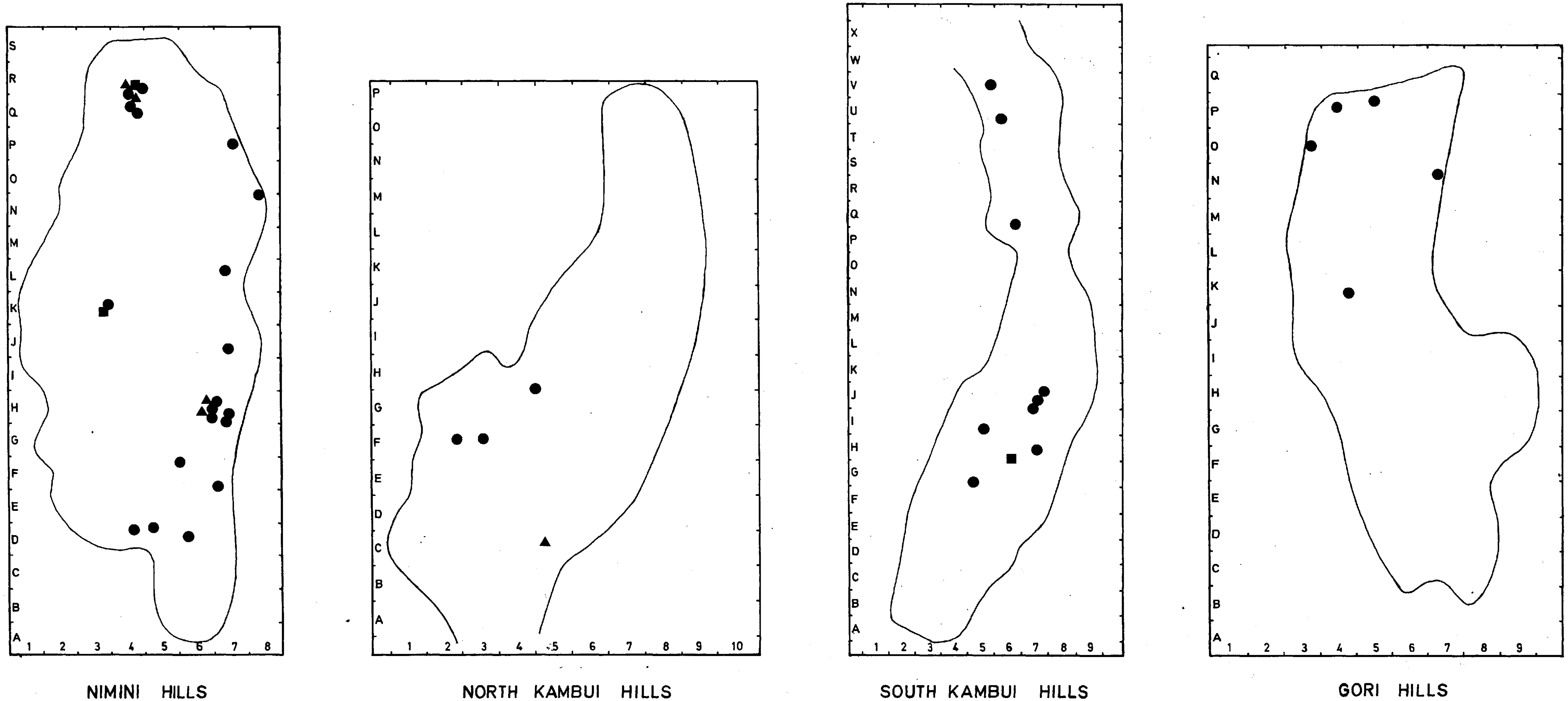
Scale approx 1:250,000

Miles 5 0 5 10 Miles

LEGEND

	<30 ppm Zn
	30 - 70 "
	70 - 150 "
	>150 "

FIG. 21



REGIONAL STREAM SEDIMENT SURVEY
METAL DISTRIBUTION PATTERNS

SILVER, BISMUTH AND TIN

Scale approx. 1:250,000

Miles 5 — 0 — 5 — 10 Miles

LEGEND

▲ > 0.2 ppm Ag

■ > 5 " Bi

● > 5 " Sn

FIG. 22

this point as this topic was investigated together with other problems during detailed studies. However, suffice it to say that the replicate sampling which was carried out some six months later than the reconnaissance sampling and at slightly different locations produced comparable results.

7.02 General Description

The contents of trace elements in the stream sediments of the field area vary considerably, and certain broad features of geographical distribution are common to many of the elements considered.

The mafic elements (Co, Cr, Cu, Mn, Ni, Ti, V & Zn) display the common feature of a pronounced, often complex, ridge or plateau of high levels overlying the schist belts. In contrast, the levels of these elements tend to be lowest in the surrounding areas of synkinematic granite, in which any features exhibited by the geochemical patterns tend to be parallel or sub-parallel to the schist belts.

The distribution of lead is markedly different to that of the mafic elements. Often there is no conspicuous difference between granite and schist areas, but when there is a significant pattern it is the inverse of that shown by the mafic elements.

The remaining elements studied, Ag, As, Bi, Ga, Mo & Sn, with the exception of gallium, generally occur at levels below the detection limit (i.e. 0.2, 3, 5, 2, 2 & 5 ppm respectively). In addition, unlike the previously mentioned elements they do not form patterns which can be related to the distribution of the different bedrock units. Both arsenic and molybdenum form distinct, if only small, patterns of occurrence in the field areas. Tin occurs erratically in all the field areas but in the Nimini Hills area exceptionally high levels are found. Lastly, the occurrence of detectable contents of bismuth and silver is so erratic that, apart from a few coincidences of detectable levels at particular sample sites, no distribution patterns are apparent.

The frequency distribution of the data sometimes shows a broad approximation to a lognormality, but in other cases the distribution tends to be multimodal. However, little significance can be attributed to these features as the plots are undoubtedly composed of many discrete populations.

7.03. The Relation of Geochemical Patterns to Geology

A. General Description

The majority of the elements studied (Co, Cr, Cu, Mn, Ni, Pb, Ti, V & Zn) have distribution patterns which when studied in relation to the geological maps show a general correlation with the major rock types (fig. 2-5 & 11-22).

Only in the Nimini Hills is the geology sufficiently well mapped and apparently simple for any detailed correlation to be made between geochemical patterns and bedrock geology. The mean, standard deviation and range at the one standard deviation limits were determined for the stream sediments of the major geological units in the Nimini Hills area. The decision as to the bedrock of the catchment areas was based on the available 1:40,000 scale geological maps.

The Co, Cr, Ni and V contents of the stream sediments are generally highest over ultrabasic schists (Table V, figs. 12, 13, 17 & 20). Due to the analytical method employed levels above 1% titanium cannot be estimated, but it may well be that the highest titanium levels are associated with basic schists (Table V, fig. 19). Patterns in the Cu, Mn and Zn distribution are less clear but copper and manganese levels appear to be higher over ultrabasic areas, whilst zinc contents are often similar over both rock types (Table V, figs. 14, 15 & 21).

The data relating to duricrusted areas of basic and ultrabasic schist must be interpreted with care as there is a very high degree of uncertainty with regard to the geology underlying the duricrust. This is particularly true in ultrabasic areas where siliceous banded ironstones are known to occur and the presence of acid pegmatites has been postulated. In areas of duricrusted basic schist levels of cobalt appear to be lower than in non-duricrusted areas, while concentrations of Cr, Cu, Ni and Pb all appear to be enhanced (Table V). In ultrabasic areas contents of Co, Cr, Ni and V are all lower relative to those

TABLE V

Nimini Hills Reconnaissance Stream Sediment Data

	No.		As	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb	Ti	V	Zn
Granite	115	R	-	4-33	28-280	8-51	20-42	120-780	2-5	21-154	28-62	1700-7300	19-145	22-52
		M	3	12	92	21	29	305	2	59	41	3555	54	34
		S.D	-	.48	.50	.40	.16	.41	.41	.42	.17	.32	.44	.19
Undifferentiated Metasediments	61	R	3-4	7-42	90-420	23-66	13-38	290-1080	2-4	42-151	7-23	2250-7800	30-145	21-48
		M	3	19	195	40	22	557	2	80	14	4244	66	31
		S.D	.43	.37	.34	.23	.23	.29	.30	.28	.26	.27	.34	.18
Basic Schists	33	R	3-21	60-200	280-290	86-340	18-30	1600-5800	2-3	160-520	4-23	8500- 1%	250-770	78-140
		M	6	111	515	173	23	2983	2	293	9	9571	448	104
		S.D	.51	.26	.24	.30	.11	.28	.23	.26	.38	.05	.23	.13
Duricrusted Basic Schists	21	R	10-60	48-177	1310-9600	173-480	22-33	2050-6400	2-3	214-1160	10-26	-	190-950	75-174
		M	23	92	3508	287	27	3631	2	501	16	>1%	427	114
		S.D	.40	.28	.43	.22	.09	.25	.32	.37	.21	-	.35	.18
Ultrabasic Schists	15	R	5-26	220-810	2600->1%	170-500	12-28	2550- >1%	-	2400-7800	7-19	6600->1%	560-1650	96-155
		M	12	424	5400	294	18	4835	2	4369	11	8694	960	123
		S.D	.36	.28	.31	.23	.18	.29	-	.26	.23	.11	.24	.11
Duricrusted Ultrabasic Schists	10	R	3-52	41-190	1000-8200	100-420	13-25	1580-8400	2-3	220-1250	10-28	8250- >1%	130-620	95-160
		M	11	88	2849	205	18	3764	2	518	17	9437	280	124
		S.D	.68	.34	.46	.32	.14	.37	.29	.38	.22	.06	.34	.11

R = Range at the 1 S.D. limits.

M = Geometric Mean (ppm).

S.D. = Standard Deviation in log 10 ppm.

observed in non-duricrusted areas and only lead appears to be enhanced (Table V).

In areas of metasediment lower values of Co, Cr, Cu, Mn, Ti, V and Zn are generally encountered than in areas of basic and ultrabasic schist. In granitic areas still lower values of these elements often occur, but it is in granite areas, however, that the lead levels are highest (Table V, figs. 12-15 & 17-21).

The distribution of the remaining elements, Ag, As, Bi, Ga, Mo and Sn, as mentioned previously, do not show any marked correlation to the major geological units (figs. 11, 16 & 22). However, attention is drawn to certain features of interest. Gallium, although exhibiting no marked correlation to geology, occurs at the highest values in granitic areas (Table V). Arsenic tends to be present in schist belt areas rather than over the granites, and the reverse is true of molybdenum (Table V figs. 11 & 16). Also of interest is the presence of arsenic at the highest levels in areas of mature soil and duricrust in the Nimini Hills. It is possible that arsenic has been fixed in these mature soils more efficiently than in the immature latosols of other areas and thus the patterns being observed may not be truly related to the bedrock geology (Table V, fig. 11).

Determinations of the geochemical relief of the major rock types have only been made in the Nimini Hills (Table V). The relief for most elements (Co, Cr, Cu, Mn, Ni & V) is markedly higher in granite areas than elsewhere. Lesser relief is generally observed in the metasedimentary areas, whilst the lowest relief is often found in areas of basic schist. It is suggested that the relief reflects the homogeneity of the bedrock source of the elements, thus a low relief would indicate a homogeneous bedrock and a higher relief a more heterogeneous source. This hypothesis fits well into the field observations on the various bedrocks, as the granites and metasediments are mineralogically far more variable than either the basic or ultrabasic schists.

The effects of human contamination have only been recognised at one locality within the field areas. Mill tailings from the Sierra Leone Chrome Mines Ltd. workings near 'Bambawo in the North Kambui Hills (J7) have caused the presence of high levels of Co, Cr, Cu, Mn and Ni which cannot be reconciled with the known granitic bedrock of the area (figs. 12-15 & 17).

B. Relationship of Stream Sediment Patterns to Bedrock Geochemistry

During the present study this topic has not been investigated on a regional scale as previous work in the Sula Mountains - Kangari Hills area has resulted in the following conclusion (Nichol et al, 1966):-

> "The distribution of elements of no apparent economic significance shows variations expressed in terms of their range, mean and standard deviation which are principally related to similar variations in the bedrock geochemistry."

Suffice it to say at this point that the results of a number of detailed surveys carried out in field areas substantiated the authors' conclusions.

7.04. Variations of Pattern within Individual Geological Formations

In certain areas in the Sula Mountains-Kangari Hills minor variations of geochemical pattern were observed in the stream sediments from the major bedrock types (Viewing, 1963 & James, 1965) and it was concluded that the variations were largely due to differences of bedrock geochemistry. However, in some areas the patterns were related to secondary environmental features such as variations in soil type and erosion level. Similar variations in pattern have been noted within areas of granite, metasediment, basic and ultrabasic schist in the Nimini Hills area. It is probable that such variations also occur in the Gori and Kambui Hills areas, but as these areas tend to be geologically complex or insufficiently mapped detailed correlation has not been possible.

In order to establish the significance of the patterns observed in the Nimini Hills area a number of limited detailed surveys in which rocks, soils and stream sediments were collected were carried out in selected areas (fig. 23).

The analysis of the reconnaissance survey stream sediment samples had been carried out a year earlier than those of the detailed survey samples. A drop in level was noted in many

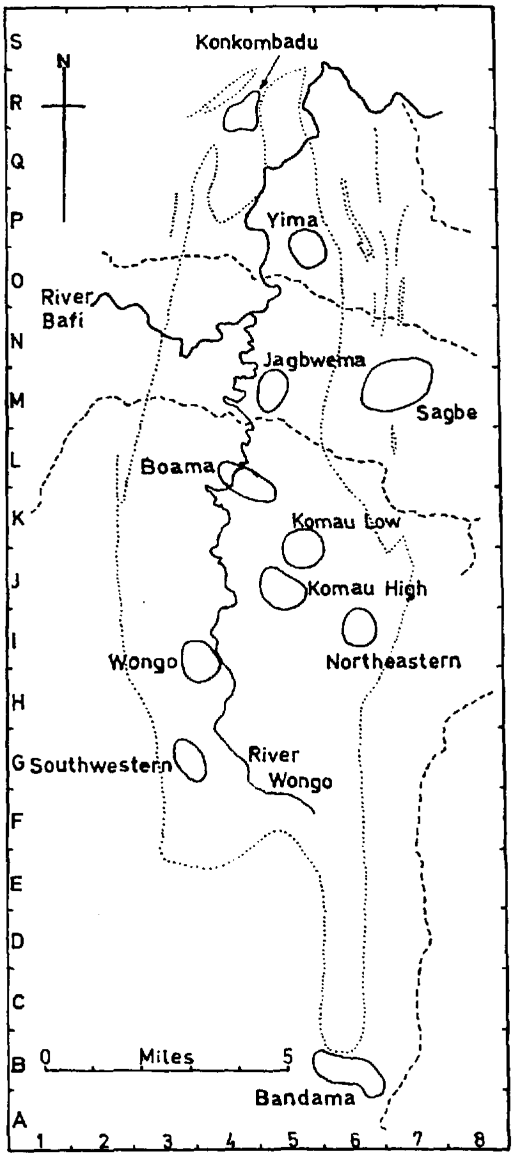


FIG. 23

NIMINI HILLS DETAILED STUDY AREAS

Granite/Schist Contact

Motorable Roads

Detail from Sierra Leone Geological Survey

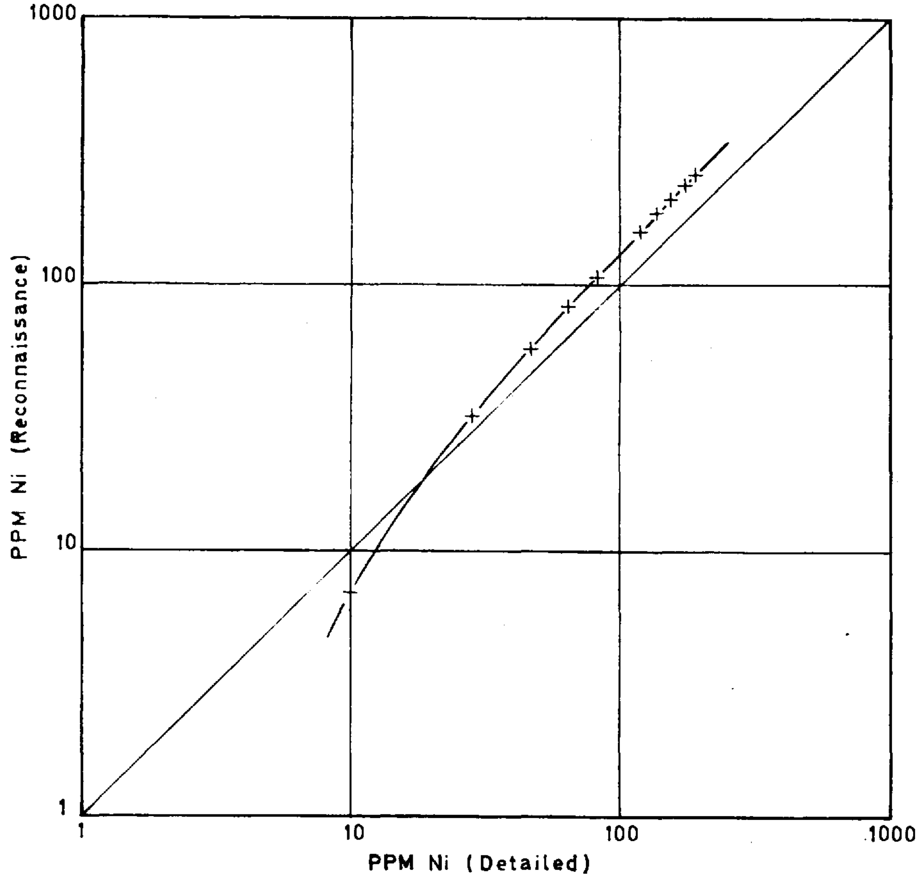


FIG. 24

PLOT OF CALCULATED NICKEL VALUES
OF
STATISTICAL SERIES SAMPLES
FROM
RECONNAISSANCE AND DETAILED STREAM SEDIMENT SURVEYS
IN
THE NIMINI HILLS
(Calculated after Stern, 1959)

elements, Co, Cr, Mn, Ni and Ti and it was considered that this drop could not entirely be due to random analytical errors. An investigation into the results of the statistical series samples revealed that although the precisions of the two sets of analyses were comparable there had been a 30% fall with time in the absolute level of the analyses at the upper limit of the series (fig. 24). The upper limit of the series is about 300 ppm nickel and assuming the trend depicted continues towards the 1% level the drift will be significantly more serious at higher levels. This feature makes the direct comparison of data between the two periods difficult, however, the patterns can be compared relatively within the two groups and then these relative results compared successfully between the two groups.

A. Granites

The majority of the granitic areas around the Nimini Hills exhibit similar geochemical patterns. However, near Sagbe (M7) the stream sediments contain significantly lower levels of Co, Ti and V relative to the normal pattern as displayed by sediments from the Bandama Area (B6) (Table VI). Extensive areas of high lead values (> 70 ppm) do not occur within the field area, but where high values do occur they can often be correlated with the presence of porphyritic synkinematic granites as noted in the Kangari Hills (Viewing, 1963 & James, 1965).

The detailed stream sediment sampling confirmed the

TABLE VI

Trace Element Concentrations in Granitic Areas

		Bandama Area					Sagbe Area		
		Reece	Detailed Survey			Reece	Detailed Survey		
		S.S.	S.S.	Soil	Rock	S.S.	S.S.	Soil	Rock
Co	M	17	7	13	10	7	4	11	4
	S.D.	.30	.56	.48	.34	.42	.42	.43	.45
Cr	M	41	74	176	5	62	78	251	4
	S.D.	.45	.45	.35	.17	.34	.41	.29	.53
Cu	M	10	14	27	33	8	15	24	14
	S.D.	.23	.30	.33	.11	.25	.31	.28	.34
Mn	M	445	248	214	283	378	207	196	80
	S.D.	.50	.28	.25	.15	.25	.36	.28	.29
Ni	M	38	29	68	9	41	50	109	6
	S.D.	.33	.45	.29	.09	.39	.29	.31	.50
Pb	M	38	38	49	60	30	36	34	19
	S.D.	.09	.06	.16	.20	.14	.19	.20	.21
Ti	M	3608	3451	7782	3608	1631	1960	5603	422
	S.D.	.14	.17	.08	.14	.40	.29	.12	.33
V	M	53	52	121	62	11	12	75	11
	S.D.	.15	.26	.21	.19	.46	.50	.16	.33
Zn	M	33	22			34	25		
	S.D.	.14	.24			.18	.29		
No. of samples		9	29	52	11	11	23	27	8

M = Geometric Mean (ppm)

S.D. = Standard Deviation in log 10 ppm

features noted during the reconnaissance survey. The soils, which are freely drained latosols, reveal the same patterns of metal distribution as the stream sediments of the two areas, except that cobalt shows no significant difference and nickel is higher in the Sagbe Area. The analysis of the rock samples reveals the same pattern of variation between the two areas as the stream sediments, but in addition, Cu, Mn and Pb are lower near Sagbe than at Bandama. The fact that the feature of the Cu, Mn and Pb results are not reflected in the soils and stream sediments of the Sagbe area may be due to the sampling of atypical rocks in an area of low topographical relief and thick soil cover.

In conclusion, the lower Co, Ti and V levels observed in the Sagbe Area have been confirmed by further stream sediment sampling. Patterns generally similar to the stream sediments have been observed in the rocks and soils of the two areas studied, thus indicating that the bedrock geochemistry is the major influence controlling the stream sediment patterns.

B. Metasediments

Variations in the trace element content of the stream sediments also occur in areas of metasediment. At Yima (O5) Co, Cr, Cu, Mn, Ni, Ti and V are significantly higher than the normal pattern typified at Jagbwema (M5) (Table VII). In addition, at Baoma (L4) Pb values are lower, whilst Co, Cr, Cu, Mn, Ti, V and

TABLE VII

Trace Element Concentrations in Metasedimentary Areas

		Yima Area					Baoma Area				Jagbwema Area			
		Reece	Detailed Survey				Reece	Detailed Survey			Reece	Detailed Survey		
		S.S.	S.S.	Soil	Rock	Schist	S.S.	S.S.	Soil	Rock	S.S.	S.S.	Soil	Rock
Co	M	59	51	32	45	500	45	8	11	7	14	15	5	20
	S.D.	.09	.29	.31	.46		.10	.47	.34	.15	.33	.40	.53	
Cr	M	1758	647	453	249	1300	235	109	244	35	114	202	259	400
	S.D.	.37	.36	.24	.68		.24	.18	.23	.06	.30	.39	.13	
Cu	M	124	76	66	85	50	76	38	54	55	27	32	41	50
	S.D.	.18	.28	.24	.30		.15	.09	.19	.04	.20	.30	.09	
Mn	M	1212	910	645	484	8500	1465	420	356	141	332	144	162	400
	S.D.	.39	.28	.23	.52		.10	.19	.19	.15	.27	.38	.21	
Ni	M	344	404	226	235	2000	120	44	88	29	79	89	107	200
	S.D.	.12	.36	.36	.68		.17	.21	.14	.46	.07	.13	.16	
Pb	M	23	14	17	17	6	11	6	10	12	29	13	9	16
	S.D.	.10	.21	.28	.29		.20	.12	.17	.39	.47	.16	.16	
Ti	M	5170	6004	5413	3065	4000	> 1%	3071	8260	2000	1931	1090	5528	850
	S.D.	.14	.11	.16	.17			.16	.07	.30	.27	.40	.11	
V	M	324	153	99	118	200	232	30	149	72	49	40	74	85
	S.D.	.11	.29	.20	.33		.11	.24	.20	.26	.07	.59	.11	
Zn	M	55	50				66	48			32	31		
	S.D.	.11	.14				.13	.14			.28	.28		
No. of Samples		7	15	14	11	1	5	10	14	2	3	9	13	1

M = Geometric Mean (ppm)

S.D. = Standard Deviation in log 10 units

Zn are higher than at Jagbwema. The soils of the areas are predominantly freely drained latosols, but at Baoma transported alluvial soils are also found.

The detailed stream sediment survey carried out at Yima confirmed the patterns originally observed in the reconnaissance sampling. The soil samples reveal these same features except that the level of titanium shows no significant difference from that in the control area at Jagbwema. Care must be taken in comparing the results of rock analyses, due to the atypical nature of many of the samples, but it would appear that in general the features of the soils and sediments are also reflected in the rocks. Several rock samples were noted as being garnetiferous and on the crest of the hill in the centre of the area considerable ultrabasic float was observed (Analysis presented in Table VII). It is concluded that the high levels of the mafic elements observed in the Yima Area are due to the basic nature of the metasediments coupled with the inclusion of detritus from lenses of ultrabasic schist which occur in the area.

During re-sampling of the Baoma Area care was taken to sample drainages well away from the terraced banks of the Wongo river. The high levels of the mafic elements originally observed were not substantiated, the new pattern being similar to that at Jagbwema except for slightly higher Mn and Ti contents. The soil and rock patterns are in close agreement with those of the detailed survey stream sediments and with the soils and rocks of the Jagbwema Area. In conclusion, it seems probable that the high levels of the mafic elements observed around Baoma are due to the contamination of local stream sediments with transported alluvial material of a basic nature and not of local origin.

C. Basic Schists

Three different patterns were observed in areas of basic schist. The Wongo Area (I4) is characterised by higher than normal contents of Cr, Ni, Pb, V and Zn (Table VIII). The commonest patterns are observed in the Komau High Area (J5), so named in order to distinguish it from the Komau Low Area (K5 & J5) with which it shares a common watershed and where lower levels of Cr, Ni, Ti and V are observed. The soils of these areas are freely drained immature latosols except in the upper reaches of the Wongo Area where mature soils are found.

The detailed sampling of the Wongo Area substantiated the original observations except for those of Pb and V. However, the high lead values were repeated at the original sample sites and the mean level for the detailed survey was depressed due to the large number of lead poor samples collected. There are no significant differences between the soil and rock patterns of the Wongo and Komau High Areas except for increased titanium levels in the rocks of the Wongo Area. The stream sediments of the Wongo Area are thus characterised by increased levels of Cr, Ni,

TABLE VIII

Trace Element Concentrations in Basic Schist Areas

		Wongo Area				Komau High Area				Komau Low Area			
		Reece	Detailed Survey			Reece	Detailed Survey			Reece	Detailed Survey		
		S.S.	S.S.	Soil	Rock	S.S.	S.S.	Soil	Rock	S.S.	S.S.	Soil	Rock
Co	M	246	135	74	55	139	110	86	49	80	71	113	45
	S.D.	.52	.34	.22	.04	.08	.10	.11	.18	.00	.04	.13	.12
Cr	M	902	522	359	224	677	435	354	281	393	350	289	40
	S.D.	.16	.17	.10	.15	.06	.07	.17	.36	.08	.20	.23	.63
Cu	M	300	198	199	127	173	157	138	110	145	129	250	72
	S.D.	.00	.23	.12	.19	.06	.13	.14	.32	.11	.16	.19	.32
Mn	M	6649	2560	2565	975	2720	2078	2445	740	1524	849	2527	590
	S.D.	.03	.28	.25	.11	.21	.24	.29	.26	.20	.16	.24	.18
Ni	M	824	532	140	199	493	311	127	190	228	163	202	67
	S.D.	.29	.33	.17	.10	.07	.24	.15	.47	.13	.18	.28	.33
Pb	M	31	9	7	2	6	2	4	2	5	4	7	2
	S.D.	.54	.33	.26	.17	.20	.19	.17	.20	.14	.21	.24	.26
Ti	M	> 1%	> 1%	> 1%	5030	> 1%	9861	9802	2745	9457	8036	> 1%	3017
	S.D.				.11		.02	.03	.44	.04	.12		.21
V	M	2289	590	440	275	545	620	399	225	372	485	653	223
	S.D.	.08	.25	.16	.11	.06	.11	.07	.31	.05	.16	.11	.22
Zn	M	212	189			87	103			88	89		
	S.D.	.14	.16			.05	.13			.09	.13		
No. of Samples		3	14	11	6	6	16	20	13	4	12	18	9

M = Geometric Mean (ppm)

S.D. = Standard Deviation in log 10 units.

Pb and Zn. It is suggested that the high Cr and Ni levels are due to detritus of ultrabasic origin being washed into the stream at the headwaters where ultrabasic schists outcrop. The erratic nature of the Pb and Zn values indicates a localised origin for these elements i.e. mineralisation. Apart from these features it would appear that the bedrock geochemistry is closely controlling the patterns observed in the stream sediments.

The detailed sampling of the Komau Areas confirmed the results of the reconnaissance surveys. The soil data, however, does not reflect these same variations as the levels of Cu, Ni and V are significantly higher in the Low Area. The results of the rock analyses reveal similar features to the stream sediments except that no significant differences in Ti and V were observed. A marked difference was noted in the hand specimens from the two areas. The amphibolites of the High Area are mostly fine grained and very probably of volcanic origin, whilst in the Low Area a coarser grained variety predominates and this may well be of sedimentary origin. Although there are discrepancies in the soil data the stream sediment patterns are generally similar to those observed in the rocks. Thus the bedrock geochemistry is the dominant factor controlling the stream sediment patterns, which in this case may be reflecting along strike facies variations.

D. Ultrabasic Schists

Two detailed studies have been carried out in areas of ultrabasic schist, the first in the Southwestern Area (G3) and the second in the Northeastern Area (J6). The Northeastern Area is of interest as the reconnaissance survey revealed levels more characteristic of basic schists, but it had been suggested that the area was underlain by ultrabasic schists (Laing, pers. comm.) (Table IX). The Southwestern Area was studied as a control area with which to compare the results of the Northeastern Area survey. The soils of the Southwestern Area are freely drained immature latosols, in contrast the soils of the Northwestern Area are mature latosols believed to be of considerable thickness.

The detailed survey of the Southwestern Area substantiated that levels of the mafic elements were higher there than anywhere else, however, the absolute values of the detailed survey analyses are decreased due to the previously mentioned analytical drift. The high contents of the mafic elements are maintained in the soils and rocks of the Southwestern Area relative to other study areas, indicating a sympathetic relationship between the geochemistry of the three sampling media.

The reconnaissance sampling of the Northeastern Area did not bear out the suggestion that this area of mature soils was underlain by ultrabasic rocks as the detailed stream sediment sampling confirmed the original patterns which suggested a basic rather than ultrabasic bedrock. The soils are in fact similar in pattern to those of the Komau High Area except for a depletion

TABLE IX

Trace Element Concentration in Ultrabasic Schist Areas

		Southwestern Area				Northeastern Area			
		Reece	Detailed Survey			Reece	Detailed Survey		
		S.S.	S.S.	Soil	Rock	S.S.	S.S.	Soil	Rock
Co	M	700	214	112	100	89	49	19	50
	S.D.	.00	.16	.22	.00	.05	.32	.33	
Cr	M	1%	3719	4637	2449	866	1189	854	200
	S.D.	.00	.23	.35	.20	.24	.38	.39	
Cu	M	184	84	69	89	632	219	192	200
	S.D.	.03	.06	.19	.52	.10	.24	.30	
Mn	M	7483	2265	2048	1788	4899	1245	1115	600
	S.D.	.03	.23	.32	.14	.09	.33	.40	
Ni	M	3741	2294	996	1000	316	198	130	200
	S.D.	.27	.21	.37	.00	.20	.37	.23	
Pb	M	15	6	6	2	8	10	8	2
	S.D.	.00	.05	.15		.08	.37	.15	
Ti	M	5000	8242	9031	922	> 1%	9104	> 1%	3000
	S.D.	.00	.06	.07	.01		.04		
V	M	700	434	525	126	346	374	415	200
	S.D.	.00	.08	.13	.22	.06	.25	.18	
Zn	M	135	211			179	179		
	S.D.	.05	.31			.06	.21		
No. of Samples		2	6	7	2	2	7	10	1

M = Geometric Mean (ppm).

S.D. = Standard Deviation in log 10 units of Co and an enhancement in Cr, Cu, Mn, Ni, Pb and V, as might be expected in an area of mature latosol covering rocks basically similar to those of the Komau High Area. Only one rock sample was found in the area and that was a cobble size piece of amphibolite similar to that found in the Komau High Area. In conclusion it is most probable that the area is underlain by basic schists and that the erratically high Cu and Zn levels observed in the reconnaissance stream sediments are possibly related to the mineralisation associated with the source of alluvial gold known to occur in the area.

E. General Conclusions

From the limited number of detailed surveys carried out several conclusions are drawn. In areas of homogeneous geology the major controlling factor in the formation of the geochemical patterns of the stream sediments appears to be the bedrock geochemistry via the weathering stages of soil formation. However, in areas of mixed or complex geology the patterns observed in the stream sediments are composite and tend to reflect the geochemistry of the different bedrock units.

Secondary environmental factors have an important modifying effect on stream sediment and soil patterns and two particular instances have been highlighted by the detailed studies. Firstly care must be taken when sampling tributaries close to major rivers as it has been shown that misleading patterns can be obtained by the sampling of re-worked alluvium which is not of local origin. Secondly the effects of soil type have a considerable modifying influence on the patterns observed in soils and stream sediments in areas of similar bedrock. This feature has only been studied in areas of basic schist where the patterns, although considerably modified, are still recognisable as being derived from that rock.

In conclusion it can be stated that observed variations of pattern within individual major rock units are often related to features of the bedrock geochemistry, though factors such as the heterogeneity of the local bedrock and soil type may also exert a strong influence on the stream sediment patterns.

7.05. Investigations into the Relationship of Rock, Soil and Stream Sediment Patterns in the Gori and Kambui Hills.

As pointed out in the previous section the geology of the Gori and Kambui Hills areas is either complex or unmapped. However, in order to investigate the relationship of the geochemical patterns in the three sampling media four traverses were made across the schist belts and into the surrounding granites.

A. Gori Hills

Two traverses were made across the Gori Hills in which soils were collected at 500 foot intervals and rocks whenever outcrop was available (fig. 25). The regional reconnaissance survey results indicated that relative to the surrounding granites

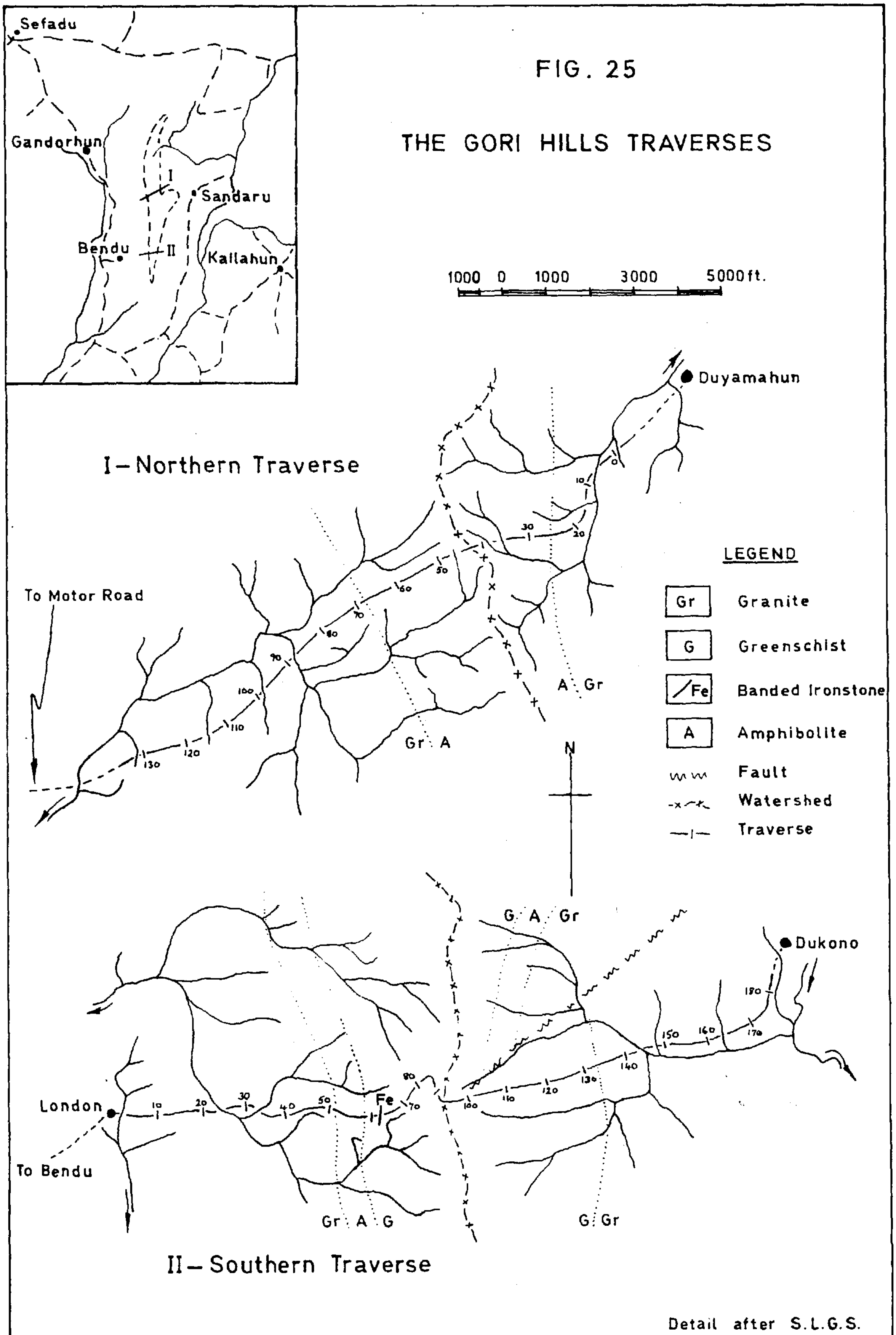
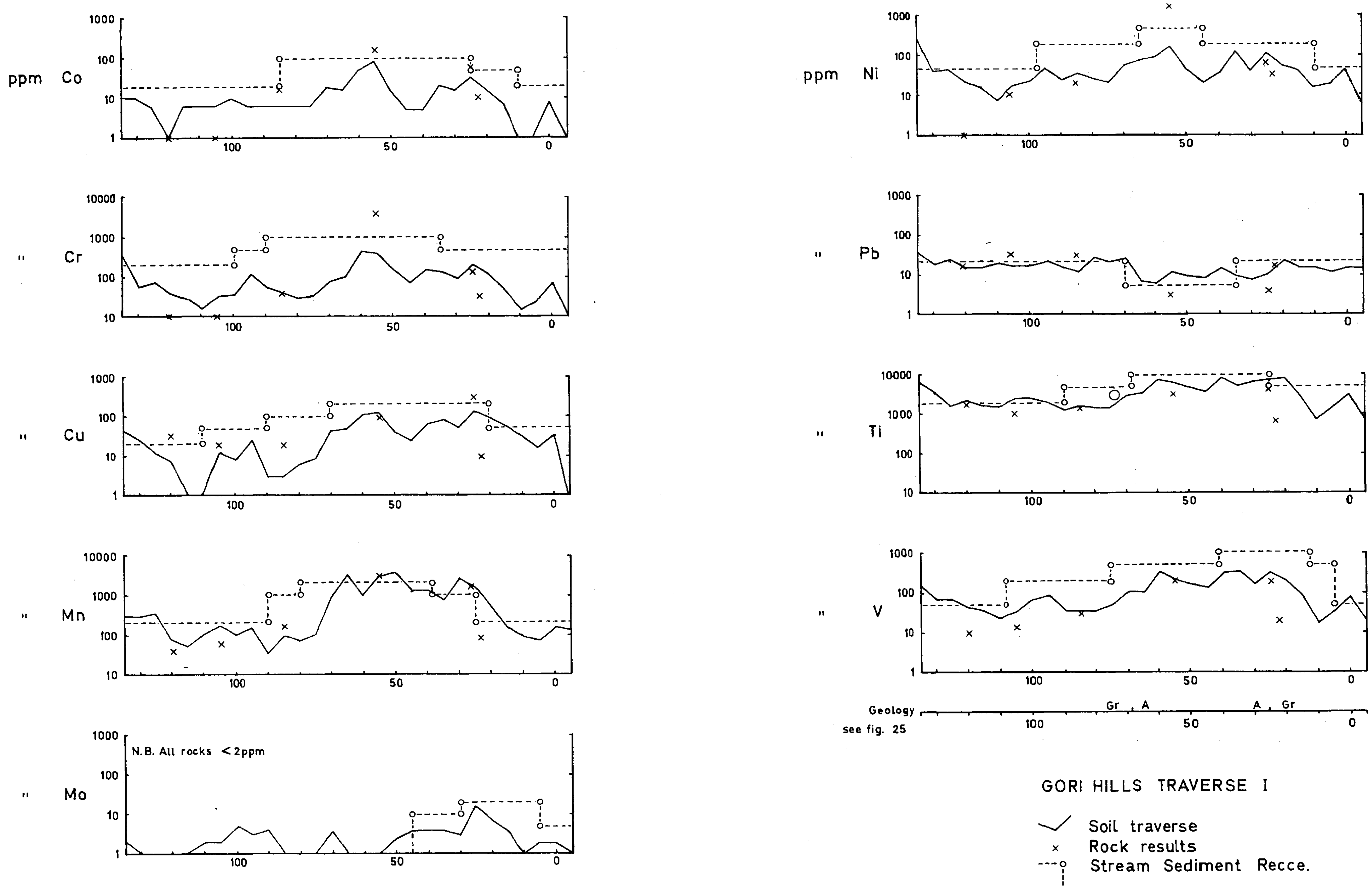


FIG. 25

THE GORI HILLS TRAVERSES



GORI HILLS TRAVERSE I

FIG. 26

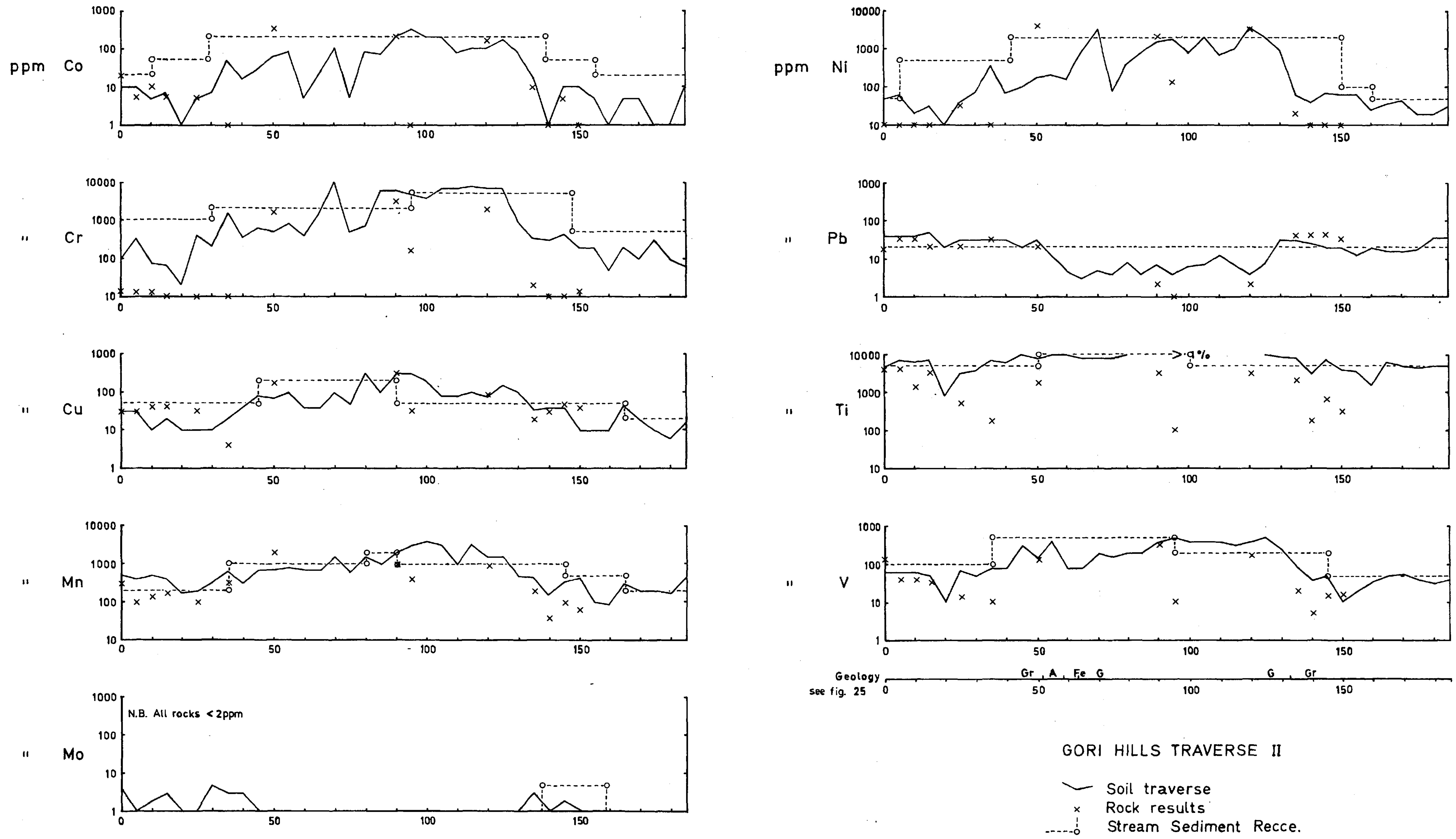

ppm Co
" Cr
" Cu
" Mn
" Mo
N.B. All rocks <2ppm
ppm Ni
" Pb
" Ti
" V
9%
Geology see fig. 25
Gr A Fe G G Gr
GORI HILLS TRAVERSE II
Soil traverse
Rock results
Stream Sediment Recce.

FIG. 27

both areas reveal generally increased levels of the mafic elements over the schist belt (figs. 26 & 27). In addition, on Traverse I, on the eastern flank of the schist belt, several stream sediments were observed to contain high molybdenum levels.

The soil traverses generally reflect the features exhibited by the reconnaissance stream sediments and several points of interest relating to the results should be noted. The trough of low lead levels in the areas of schist is better developed in Traverse II than in Traverse I where it is hardly recognisable. The fact that the soils reveal markedly depressed lead levels in Traverse II whilst the reconnaissance stream sediments do not is of interest. This feature is believed to be the result of collecting stream sediments from below the granite/schist contact with the result that they contained a certain amount of lead rich granitic detritus in addition to material derived from the schist belt rocks. The area of high molybdenum levels on Traverse I, site 20, corresponds to the area where high contents were observed in the regional stream sediment survey. At sites 60 and 75 in Traverse II low levels of Co, Cr, Ni and V are present, the trough at site 60 coincides with a known banded ironstone zone and, maybe, the trough at site 75 is reflecting a further occurrence. A similar trough is present at site 45 in Traverse I where levels of Co, Cr, Cu and Ni are depressed and this too may possibly be related to banded ironstones. The increase in level of many of the mafic elements at the western end of Traverse

I is due to the presence of ultrabasic schists within the granites, relict structures of these schists were observed in the soils, but no fragments of fresh schist remained due to intense weathering. The analyses of the rocks indicate a generally sympathetic variation with the geochemistry of the soils. This feature is best observed in Traverse II where the three schist samples (sites 50, 90 & 120, the chert sample from site 95 is excepted) indicate generally lower levels of lead and increased levels of the mafic elements, except titanium, relative to the remaining, granitic, samples. The rock data from Traverse I is not so conclusive; in the two schist samples (sites 25 & 55) lead levels tend to be depressed whilst levels of Co, Mn and V are enhanced relative to the surrounding granitic samples. No detectable levels (> 2 ppm) of molybdenum were noted in any of the samples.

B. Kambui Hills

Two traverses were made across the Kambui Hills (figs. 28 & 30). During the reconnaissance survey many samples were collected from streams around the foot of the serrate Kambui Hills range, these streams, often only a quarter to a half mile long, drained a variety of bedrocks and it was considered necessary to study the relationship of the collected samples to the often complex geology of the catchment. Thus the first traverse, in which soils and sediments were collected every 500 feet and rocks whenever outcrop permitted, was made across the North Kambui Hills west of

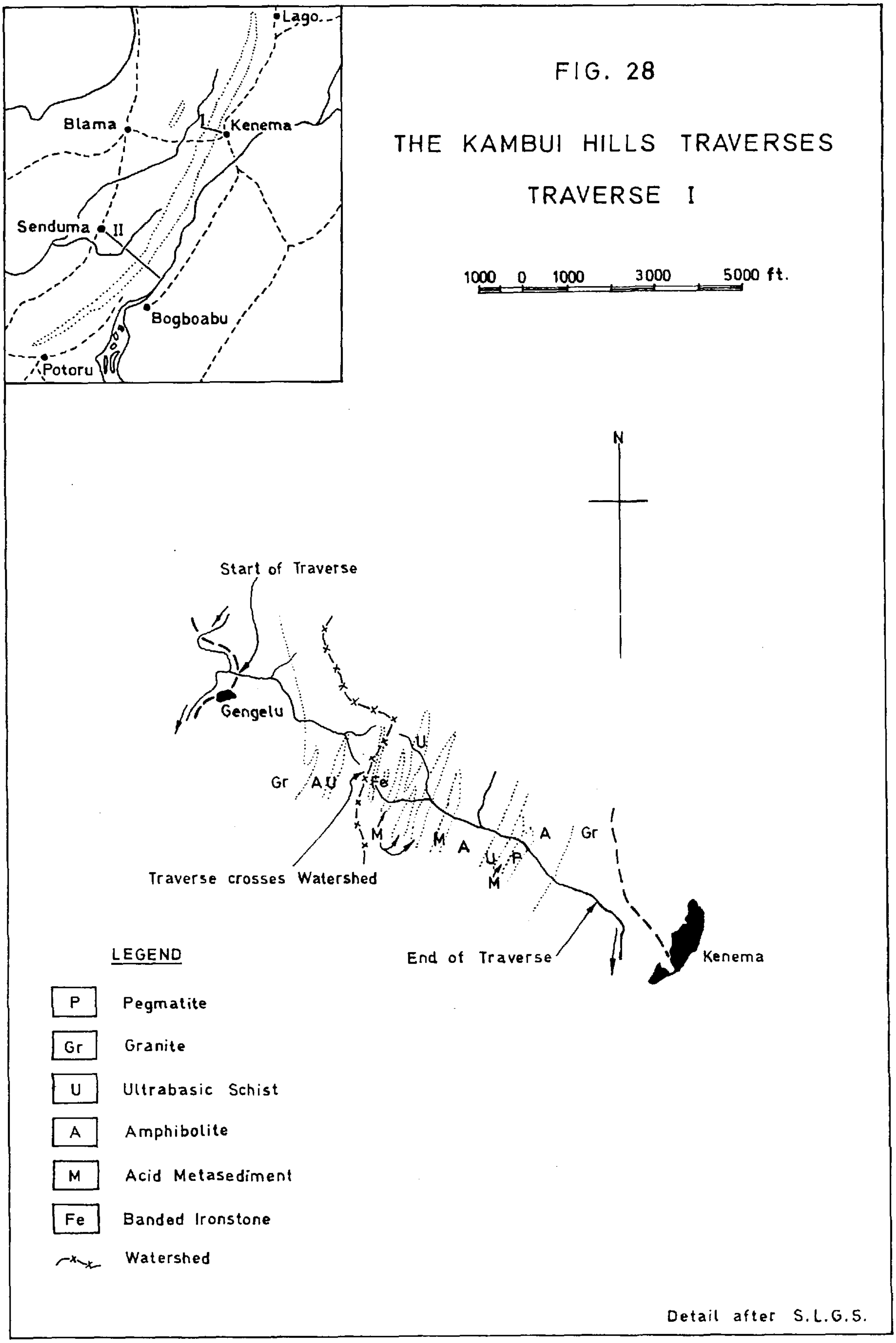


FIG. 28

THE KAMBUI HILLS TRAVERSES

TRAVERSE I

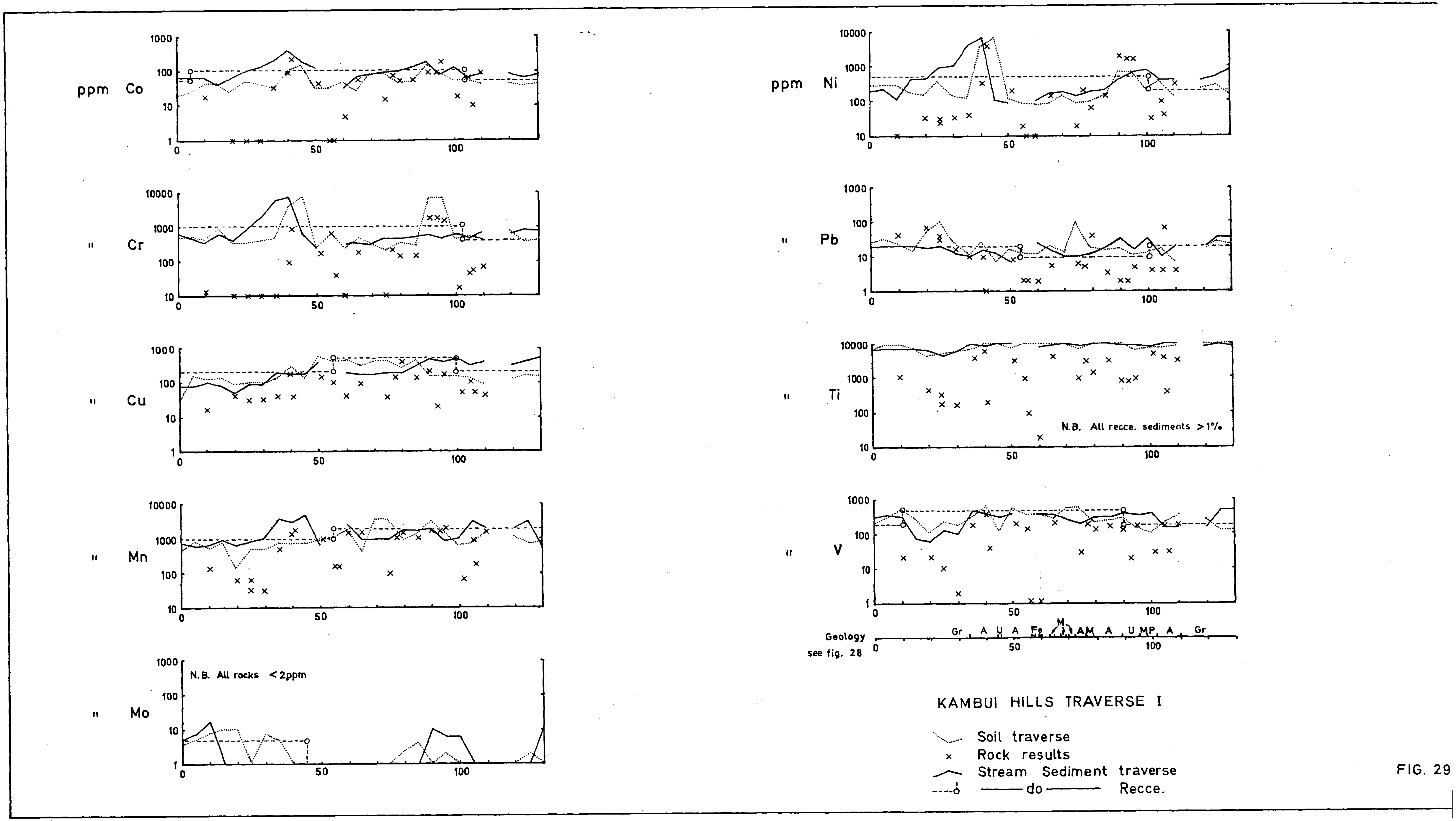

ppm Co
" Cr
" Cu
" Mn
" Mo
N.B. All rocks < 2ppm
ppm Ni
" Pb
" Ti
N.B. All recce. sediments > 1%
" V
Geology see fig. 28
KAMBUI HILLS TRAVERSE I
Soil traverse
Rock results
Stream Sediment traverse
—do— Recce.

FIG. 29

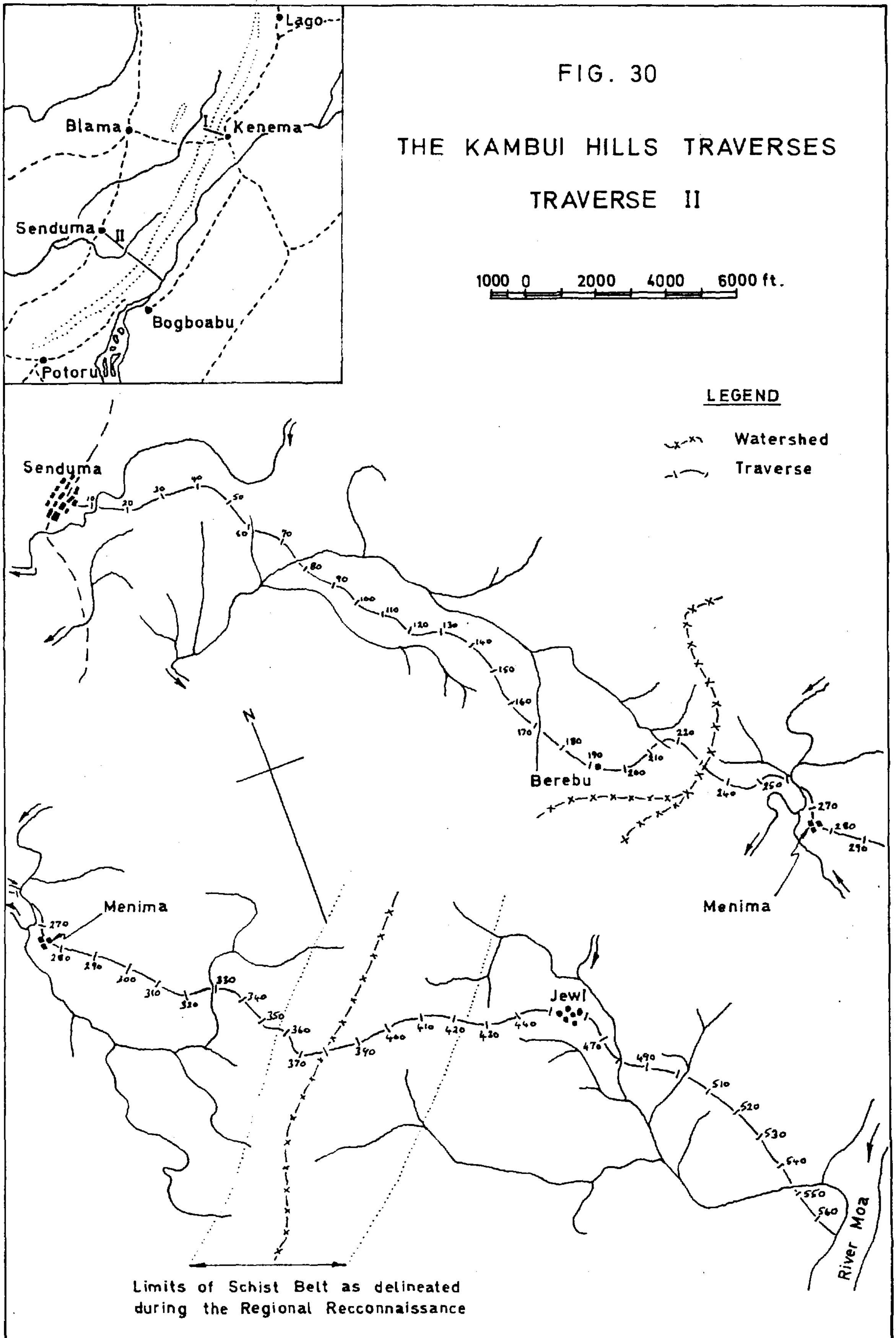
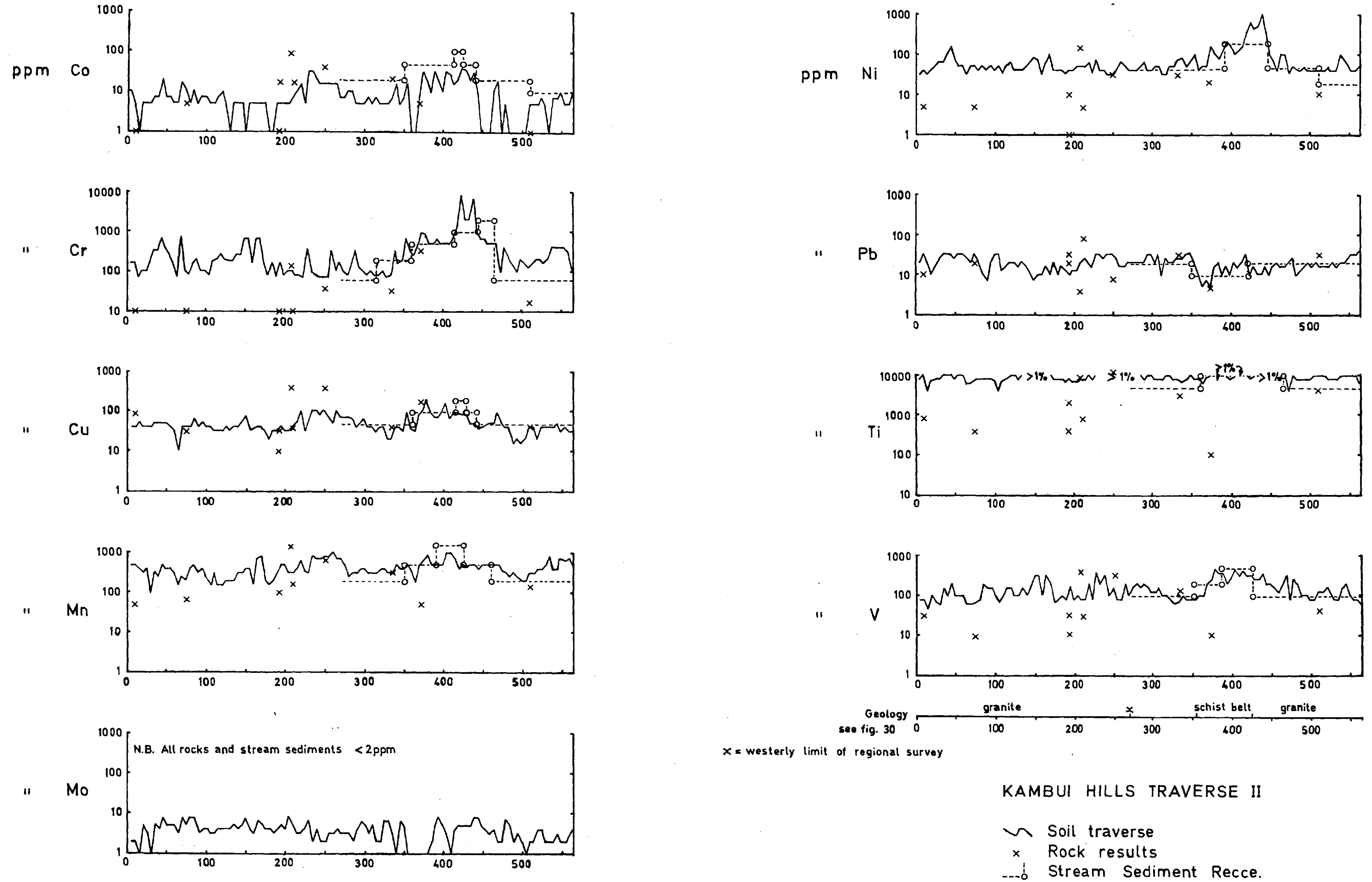


FIG. 30

THE KAMBUI HILLS TRAVERSES

TRAVERSE II



ppm Co
" Cr
" Cu
" Mn
" Mo
N.B. All rocks and stream sediments <2ppm
ppm Ni
" Pb
" Ti
" V
>1%
>1%?
Geology
see fig. 30
granite
schist belt
granite
x = westerly limit of regional survey
KAMBUI HILLS TRAVERSE II
Soil traverse
Rock results
Stream Sediment Recce.

FIG. 31

Kenema where the schist belt is geologically complex and only about a mile wide. The second traverse was made across the South Kambui Hills in an area where nothing was known of the geology. The schist belt here was delineated as being about a mile wide by field observations, however, the reconnaissance stream sediment results indicated that the schist belt extended some 2000 feet further east. Thus as well as investigating the general relationship between soils and sediments the traverse also set out to delineate the width of the schist belt. In the past an extension of the South Kambui schist belt has been mapped some 4 miles west of the surveyed area along strike from the chromite occurrences at Senduma and the traverse also investigated the existence of this extension.

The stream sediments of the reconnaissance survey indicate that over the schist belt levels of the mafic elements are higher than over the granites. Unlike the Gori Hills the lead levels are often not significantly depressed over the schist belt, and similar levels are observed in both granite and schist areas.

The results for Traverse I are strongly influenced by the complex geology which is reflected by the rock analyses (fig. 29). The detailed stream sediment sampling has revealed the trend of higher levels of the mafic elements only on the west side of the schist belt where the geology is relatively less complex. On the east side levels tend to be uniform but increasing slightly in the area of a belt of ultrabasic rocks at site 95. The soils do, however, reflect certain significant variations. The most notable of these are, firstly, the peaks of Co, Cr and Ni at sites 45 and 95 coinciding with outcrops of ultrabasic schist. Secondly, the general increased levels of copper across the major part of the schist belt between sites 50 - 90, and lastly, the peak of lead levels at site 75 which it is believed is reflecting an acid pegmatite. The reason that the stream sediments do not reflect the variations of the soils on the east side of the hills is believed to be due to the increased size of the stream. A large stream carries a considerable bed load from upstream and this effectively buffers any material being added in lower reaches resulting in a composite pattern being developed rather than any sharp change in pattern.

The results of the soil analyses of Traverse II (fig. 31) reveal a peak in the contents of Cr and Ni in the area of the South Kambui Hills schist belt and the probable easterly extension. This feature is also weakly reflected by the Co, Cu and V values; in contrast lead is slightly depressed over parts of the schist belt. The traverse indicates the easterly extension to amount to some 1500 feet and does not indicate any major schist outcrop to the west of the schist belt. However, slightly increased levels of Co, Cr, Cu, Mn and V are observed around site 240 which is coincident with a minor hill range in which quartzite amphibolites were noted. Of interest are scattered high values of chromium at sites 45, 70, 150 and 170, cobalt at sites 45 and 70 and nickel at sites 45, 150 and 170. It is suggested that these isolated peaks may be related to relicts of possibly chromitiferous ultrabasics such as are found along strike to the south.

In general the Kambui Hills traverses have emphasized the difficulties encountered in areas of complex geology. From the North Kambui Hills traverse it is clear that stream sediments are not altogether suited to yielding specific information relating to the fundamental features of the bedrock geochemistry in areas of complex geology. However, strongly contrasting features, such as ultrabasic rocks, are often revealed due to the great contrast of their geochemistry with that of their surroundings. It is also apparent that the steep streams flowing off the Kambui Hills carry a large bedload of detritus and that if any feature is to be reflected the latter must increase its size with that of the stream in order not to have the effect of its addition to the stream bed swamped by the large mass of detritus already present. However, general features of increased levels of the mafic elements over the schist belts observed in the reconnaissance survey have been substantiated by further rock, soil and stream sediment sampling.

7.06. The Relation of Geochemical Patterns to Mineralisation

Hitherto attention has been focussed on the distribution of elements of no apparent economic significance but as discussed previously a variety of mineral occurrences are known to occur in the schist belts. In the Sula Mountains - Kangari Hills schist belt, the widespread occurrence of molybdenum anomalies in the stream sediments associated with molybdenum mineralisation, and arsenic variously associated with gold mineralisation, has been demonstrated (Viewing, 1963 & James, 1965).

The interpretation of the data in terms of economic potential is in some cases confused by the presence of elements of interest in other than mineable forms. In the present study this problem has been encountered with Cr, Cu, Pb and Zn. Chromium is only of economic interest when present in the oxide form, chromite, but detectable concentrations of chromium are present in all areas due to the inclusion of chromium into the lattices of the silicate minerals. The chalcophile elements, Cu, Pb and Zn, are only of economic interest when they are present as sulphides or as their secondary products, but again, as with chromium these elements also occur in the silicate minerals forming the bulk of the rocks of the field areas.

In mineralised areas it is, however, probable that the element under consideration will be present in both forms. Thus extra amounts of these elements will be added to the local, or regional, background, which is derived predominantly from metals held in silicate form, resulting in abnormally high levels. The interpretation of the data for elements such as Cr, Cu, Pb and Zn is therefore based on the recognition of levels which are abnormally high for metal held in silicate form.

Variations in background are apparent between different bedrocks and areas within the present study. In the Nimini Hills area it has been possible to establish threshold levels for the elements of interest based on the mean plus two standard deviation level and then to select anomalous samples on the basis of this threshold. In the remaining areas it has not been possible to establish objectively a threshold value, but attention is focussed on samples not fitting into the local patterns of level and relief.

A. Arsenic

The distribution of arsenic is more widespread in the Nimini Hills than in the other schist belts presently under study (fig 11.) In terms of the Sula Mountains - Kangari Hills area a large part of the Nimini Hills schist belt is potentially anomalous (>3 ppm As). However although the Nimini Hills may be anomalous on a regional scale a further set of threshold values have been derived on the local scale to outline what, on a regional scale, would be highly anomalous.

In the streams draining granitic areas around the Nimini Hills no anomalous levels of arsenic (>3 ppm) were detected. In the metasedimentary areas the threshold is 12 ppm and three localities are of interest. Firstly, around Yima (O5), levels rise to about 20 ppm; secondly, south of Yima (I5) is a small area where levels are around 18 ppm, and lastly, near Jagbwema (L4), levels rise to 20 ppm. The threshold calculated for basic and ultrabasic schists is 60 ppm and only two samples reveal levels above this (F5 & G5). However, by inspection the levels in the vicinity of the mineralisation at Komau are somewhat above 40 ppm and by using a value of 30 ppm as threshold a number of further areas are delineated as being of interest. One mile to the south of Komau (I4) lies a broad area of values around 40 ppm. In the northeast of the main mass of the Nimini Hills in the Wasakoyie drainage (I6) are several tributaries flowing from the east containing around 40 ppm arsenic. An extensive area where levels average 60 ppm is present in the south of the Nimini Hills and adjoins the two samples where levels in excess of the calculated threshold were found (F5 & G5). Lastly there are streams flowing down the east flank of the hills west of Njaiama Nimi-Koro (H6) where levels are around 55 ppm. It is of note that all the areas described show evidence of having been worked for alluvial gold. Also it is of interest that the northernmost of the two samples containing arsenic in excess of the calculated threshold comes from a stream where mineralised banded ironstones have been found (G5).

The possibly anomalous patterns in the remaining schist belts are far less extensive. In the Gori Hills three areas are of interest, and it is noteworthy that alluvial gold has been recovered from all three of them. The first, on the west flank of the hills on the Banga drainage (M5), has a pattern of values around 25 ppm. The second area, to the Northeast, on the Sunga drainage (N5), exhibits levels of about 30 ppm, and lastly, there is a small area on the Wonki drainage (H7) where levels of the order of 25 ppm were encountered. In the North Kambui Hills two areas are of particular interest. The first, on the west flank of the hills (I7) exhibits levels of the order of 30 ppm and the second, and more extensive area, lies northwest of Kenema (D5) where levels around 50 ppm were detected. It may be of significance that outcrops of banded ironstone are to be found in the area. Only one sample is considered of interest in the South Kambui Hills and this lies in a belt of detectable arsenic (> 3 ppm) levels west of Serabu (I5, 6 & 7) and contains 60 ppm arsenic. In addition, high Cu and Zn levels are observed in the area together with evidence of alluvial gold digging. The association of elements, As, Au, Cu and Zn is significant as it coincides with that observed at Yirisen in the Sula Mountains where a bedrock source of gold has been found (Mather, 1959; Elliot, 1962 & Viewing, 1965).

B. Bismuth and Silver

The levels of these elements are mostly below the detection limits (5 & 0.2 ppm), but certain patterns do exist in the Nimini Hills area and two of these are of interest (fig. 22). Firstly a pattern of silver levels is present near Njiama Nimi-Koro (H7) where there is also a significant As, Mo and Sn pattern. Secondly, detectable Bi and Ag values are coincident with the anomalous tin zone north of Konkombadu (R4 and Q4). No patterns of any significance were observed in the Gori or Kambui Hills field areas.

C. Chromium

Occurrences of chromite, which are associated with ultrabasic intrusives, are confined to the Gori and Kambui Hills areas (fig.6) In the North Kambui Hills areas of chromitiferous ultrabasics are marked by chromium levels in excess of 1% (D4, J7 & I7) and further areas, characterised by similar levels (G6, I5 & I6), may also contain chromitiferous rocks. In the Gori Hills two areas are known to be chromitiferous. The first, northeast of Bendu (E5) contains chromitiferous lenses in the granites which give rise to patterns around 5000 ppm chromium. In the second, north of Madina (H9), chromite blocks have been found in an area of granitic bedrock and here levels of around 5000 ppm are again encountered. Within the Gori Hills schist belt no chromite occurrences have been noted, however, in one area (H6 & G6) levels exceed 1% and chromite may possibly be present. An extensive zone of high chromium levels in the range of 4000-8000 ppm is present east of Gandorhun in the main mass of the hills (L5 & M5) and this area could also be of interest. At the southern limit of the Gori Hills in the granitic area surrounding the schists two samples contain 4000 ppm chromium (D7 & D8), and on the basis of the levels near Bendu, there may be further chromitiferous bodies in this area. No chromitiferous bodies are known to occur in the South Kambui Hills field area, however, two areas are of interest as they exhibit high chromium levels and may be related to ultrabasic intrusives. The first area is at Joi (K8) where two samples within a larger zone of increased chromium levels (fig. 13) contain 7000 and 8000 ppm respectively. The second area is near the southern extremity of the schist belt (D3) where three samples in adjacent drainages contain 7000, 4000 and 7000 ppm chromium.

D. Copper, Lead and Zinc

The chalcophile elements Cu, Pb and Zn are dealt with together due to their association as sulphide minerals in mineralisation.

In the Nimini Hills a total of four areas are of interest. No anomalous levels of the chalcophile elements are observed in granitic areas but two areas of interest were outlined in the metasediments. The Yima area (O5) is characterised by levels of copper a little above threshold, 110 ppm, and it is of note that anomalous arsenic levels were also reported in the same area. The second area is south of Titambaia (I3) where one sample from a stream draining predominantly metasedimentary rocks contains 80 ppm lead; the threshold being 50 ppm. It is of interest that mineralised rocks have been discovered in this area, which is also characterised by structural disturbance. The high copper levels in the metasediments north of Titambaia (K3) are not considered to be significant but are probably related to ultrabasic schists occurring in the area. The remaining two areas of interest are in areas of basic schist. Firstly, anomalous Cu and Zn levels are observed in the Wasakoyie drainage (I6), already mentioned in connection with As and Au, where the threshold for copper is 700 ppm and 250 ppm for zinc with levels rising to 800 ppm and to 390 and 340 ppm respectively. Secondly, anomalous levels of Pb and Zn are present south of the Komau gold occurrence in minor drainages flowing into the Wongo (I4). The threshold for lead is 50 ppm and 130 ppm for zinc and in this area levels reach 150 and

330 ppm respectively.

In the remaining field areas several localities are of interest. In the Gori Hills a number of samples contain high copper levels, 300 ppm (K4), one of these contains 600 ppm copper and exhibits a high level of lead, 60 ppm. A number of samples in this same area contain high levels of zinc, between 150 and 250 ppm. Due to the presence of possibly anomalous levels of the chalcophile elements in this area (K4) it is considered that sulphide mineralisation may well be present. The high levels of lead observed in the Kambui Hills schist belts are not numerous and all occur in areas where acid pegmatites are known to occur. No anomalous copper levels were encountered in the North Kambui Hills but one sample (D4), in an area of chromitiferous ultrabasic schist, reveals an anomalous zinc content of 360 ppm. In the South Kambui Hills only one sample contains an anomalous level of copper, and that occurs with anomalous levels of As and Zn west of Serabu (H6). Several samples contain possibly anomalous levels of zinc and two of these (E4 & H4) both occur in granitic areas and contain 320 and 440 ppm respectively. Two more widespread patterns occur (D4 & H6)and in the latter (H6), which lies within the schist belt, levels rise to an average of 250 ppm and include the anomalous As, Cu, Zn sample. The former pattern (D4) is in the area of the chromium anomaly (D3) described previously and as the levels only rise to 170 ppm they may be associated with an ultrabasic body.

E. Molybdenum

Molybdenum, like arsenic, shows a partial relationship to bedrock geology in that the major zones of molybdenum occurrence are over granitic rocks or near the granite/schist contact. Detectable patterns ($>$ 2 ppm) of molybdenum occur in all the study areas and in the Nimini Hills it has been possible to establish threshold levels objectively. Of the two patterns present in basic and ultrabasic schist areas (H4 & G5) both are just above the threshold level, 5 ppm. The patterns are of interest as the presence of acid pegmatites has been postulated in the area and the molybdenum could well be derived from these. The threshold for metasedimentary areas is 7 ppm and a few scattered samples contain anomalous contents (L2, M5 & O4). The former of these areas (L2) is also known to contain molybdenite bearing pegmatites and the other areas may similarly contain such rocks. The threshold for granitic areas is 13 ppm and three areas of interest were found. The first is west of Njiama Nimi-Koro (H7) close to the granite schist contact where two weakly anomalous samples are found, but it is of interest that significant concentrations of Ag, As and Sn are also present. The second area is on the west flank of the hills (H3), again close to the granite schist contact, and is only weakly anomalous (15 ppm). The last area is near Bakuya (E4) and contains the molybdenum pattern of greatest significance found in the present study. A belt of anomalous levels trends east-west across the southern end of the schist belt (E2

& E3) Levels rise to 40 ppm at one locality and several samples contain 20 ppm. It is considered of significance that this anomalous zone lies in an area of considerable tectonic disturbance which cuts across the strike of the schist belt at its southern extremity.

Adopting the Nimini Hills threshold value of 13 ppm for molybdenum in granites several areas are of interest in the remaining field areas. In the Gori Hills three areas are of interest. The first, and most important, is a broad pattern on the granite/schist contact west of Duyamahun (J5); here levels rise to around 25 ppm. The second area is to the north (O6), where again a broad pattern of detectable levels are present, these rising to just above threshold. Lastly, an area is present in the main mass of the Gori Hills (G6) where levels rise to around 10 ppm, and which, on the basis of the Nimini Hills threshold value, are anomalous. In the North Kambui Hills a number of locations (C3, G6, H6, H7, I7 and N7) where values of the order of 20 ppm were found are of significance. The cause of these anomalous levels is unknown except for those at I7 where molybdeniferous acid pegmatites have been reported (Dunham et al, 1958). In the South Kambui Hills there are several anomalous samples (G5, Q7 and V5); the first and second of these localities contain acid pegmatites and the molybdenum levels may well be associated with these.

It is of interest that many of the detectable molybdenum patterns tend to be associated with the granite/schist contact and/or tectonic features. For instance, both the major patterns in the Nimini Hills (E3) and Gori Hills (J5) are located at flexure zones. In the Kambui and Gori Hills it is particularly noticeable that many of the patterns are linear in nature and can often be correlated to lineations in the basement, as exhibited by drainage patterns.

F. Tin

The distribution of tin is only of economic interest in the Nimini Hills, although several weak patterns (5 ppm) are present in the Kambui Hills (N. Kambui Hills I7 & S. Kambui Hills G4 & J8) none were observed in the Gori Hills. It may be of significance that one pattern in the South Kambui Hills (G4) is in an area where acid pegmatites have been found and alluvial gold was once mined. In the Nimini Hills two important patterns exist, one widespread and diffuse, the other small but of very high relief.

The first of these zones in which levels are on average 20 ppm, lies along the granite/schist contact on the east flank of the hills west of Njiama Nimi-Koro (H6) and also coincides with an area of high As and Mo levels coupled with known gold mineralisation. The second zone lies north of the Konkombadu and extends south to the village (R4 & Q4); the bedrock is granite and the levels are extremely anomalous (300 ppm).

A programme of detailed rock, soil and stream sediment sampling was carried out in the Konkombadu area and the results of the analysis of the soil and sediment samples for tin are shown in fig. 33.

The stream marked I on the figure was chosen as a background stream as no detectable level had been observed in it during the reconnaissance survey. The streams II and III which were known to contain anomalous levels were sampled in detail. A shallow pit was sunk in an alluvial flat close to the confluence of stream I with the main stream. Four feet of silty soil was removed and samples of it washed but no heavy minerals were observed. Beneath this cover lay a six inch thickness of gravel which in turn lay upon a white clayey material which was decomposed bedrock. The gravel was panned and several grains of cassiterite recovered indicating that, in part at least, the high tin levels were due to the presence of cassiterite. No cassiterite was observed in washings of the decomposed bedrock.

The results of the sampling indicate one major zone of tin accumulation in stream II and two lesser zones in stream III. During the survey several rock samples were collected; of these four were fine to medium grained granites of gneissic texture and a fifth was of an aplitic pegmatite. The granite samples did not contain any significant levels of tin, but the pegmatite sample contained 130 ppm Sn and flakes of muscovite associated with the pegmatite 350 ppm Sn.

In conclusion the tin values in both soils and stream

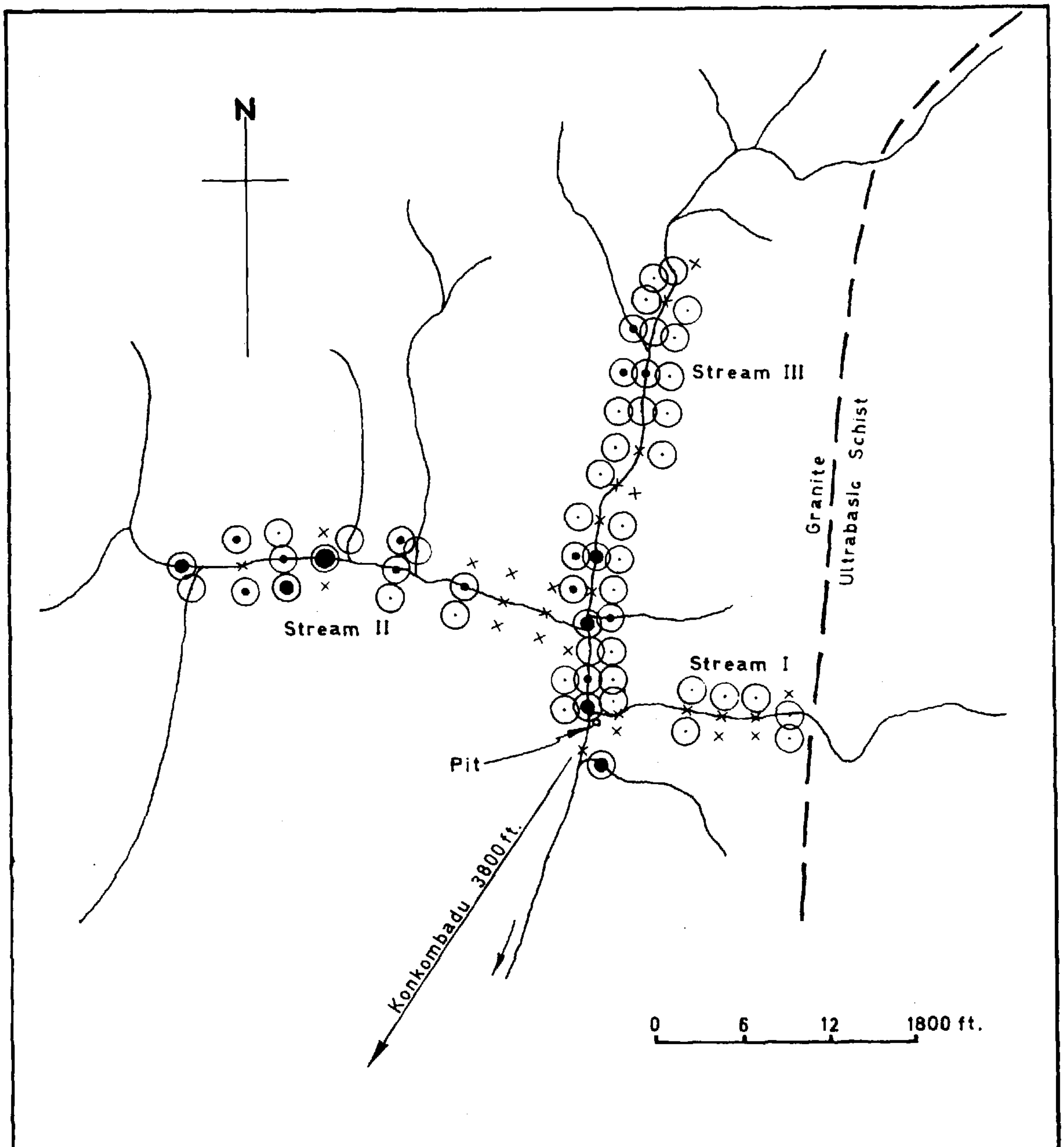
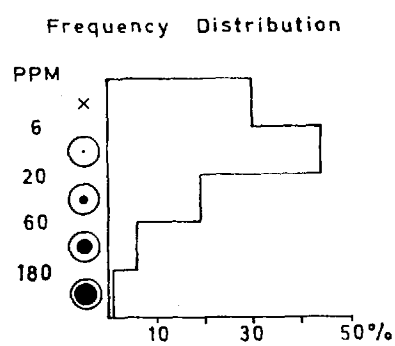


FIG. 32

KONKOMBADU AREA

Tin in Soils and Sediments



Topographic Detail by S. L. G. S.

sediments are erratic and not associated with the predominant rock type of the area, gneissic granite. The values do however appear to be related to aplitic pegmatites which are abnormally rich in tin and are the probable source of the cassiterite.

7.07. Summary

Following the regional geochemical surveys carried out over some 480 square miles of the Gori, Kambui and Nimini Hills areas, stream sediments were collected at a density of about 5 samples per square mile and the comprehensive analysis of the minus 80 mesh fraction of these samples has provided the data for the production of a series of regional geochemical maps.

The survey has demonstrated a number of features of both economic and fundamental interest in the distribution of some 15 elements (Ag, As, Bi, Co, Cr, Cu, Ga, Mn, Mo, Ni, Pb, Sn, Ti, V & Zn.)

Marked distribution patterns are exhibited in the stream sediments by many of the elements studied. The mafic elements (Co, Cr, Cu, Mn, Ni, T, V & Zn) all exhibit their highest levels over the schist belts. In particular, Co, Cr, Ni and V concentrations are highest over ultrabasic schists, Lower contents of the mafic elements are observed in metasedimentary areas and even lower levels over granites. Any features exhibited by the mafic elements in the surrounding granites tend to be parallel or sub-parallel to the schist belts, in addition it is in the granite areas that the highest lead levels are observed. The distribution of the remaining elements (Ag, As, Bi, Ga, Mo & Sn) appears to be basically unrelated to the bedrock type, though significant patterns of variation are present.

The major controlling factor in the distribution of the majority of the elements studied is the geochemistry of the underlying bedrock. The local soil type has a modifying influence on the geochemical patterns typical of any one bedrock, but this influence is not so extreme that it causes the pattern to resemble one derived from a different major bedrock unit.

A number of other factors may also influence the stream sediment patterns, e.g. complexity of the bedrock geology, size of stream and the nature of the banks. It has been shown that in areas of complex geology composite patterns are formed and that these often fail to yield information of specific interest relating to the bedrock geology. However, in such areas elements of economic interest whose distribution is unrelated to bedrock geology are still expected to form significant patterns. In some cases a particular pattern may persist for considerable distances downstream if the stream flows between alluvial banks.

Within each major bedrock unit minor differences of pattern may be found. In many cases these differences can be correlated to local or along strike facies variations, but at this scale of variations soil type and other factors have an increased importance in modifying the metal distribution pattern.

During the survey a number of areas were delineated as being of increased economic potential. All the known areas of gold mineralisation, known from alluvial diggings, were characterised by increased levels of arsenic, and, in addition, a number of areas which have not been mined in the past show increased arsenic levels. The known chromite occurrences in the Gori and Kambui Hills are reflected by anomalous chromium levels and several other possibly chromitiferous areas can be delineated on the basis of the chromium levels in stream sediments.

No significant molybdenite occurrences have been reported in the present field area. However, several localities are characterised by anomalous molybdenum levels which from experience in the Sula Mountains/Kangari Hills are known to indicate an increased molybdenite potential.

Within the field areas a number of localities have been outlined as being of increased base metal potential, however, no attempt has been made to relate these patterns to in situ base metal mineralisation. In the Nimini Hills a small zone of anomalous tin levels was discovered and follow-up work in that area showed the levels to be related to aplitic pegmatites which were the probable source of the cassiterite recovered from local alluvial gravels.

In conclusion, the survey has confirmed the applicability of regional geochemical reconnaissance and mapping programme to aiding mineral exploration by the delineation of areas of increased mineral potential and to providing information of fundamental interest on the distribution of elements within the mapped areas.

CHAPTER 8 - COMPARISON OF THE GEOCHEMISTRY OF THE KAMBUI SCHIST BELTS

8.01. Introduction

With the completion of the regional reconnaissance survey of the Gori, Kambui and Nimini Hills schist belts all the major Kambui Schist areas of Sierra Leone have been studied. In order to investigate the presence of any differences in the geochemistry of the different schist belts a comparative study has been made and special attention has been paid to three topics. Firstly, the data has been investigated to determine if there are any significant differences in bedrock geochemistry, secondly, to determine if the modifying effects of secondary environment differ between schist belts, and lastly, to review the data relating to elements of economic interest in terms of matallogenic provinces.

8.02. Fundamental Differences Related to Bedrock Geochemistry

In comparing the results of the present study with those of the Sula Mountains - Kangari Hills area (Viewing, 1963 & James, 1965) it is apparent that the major features of the geochemistry are very alike, with similar rock types in the different areas giving rise to fundamentally similar patterns. However, certain notable variations do occur; firstly, the levels of Cr and Ni in stream sediments from non-duricrusted ultrabasic areas tend to be higher in the Kambui and Nimini Hills than in the Sula Mountains and Kangari Hills. Secondly, in the Sula Mountains and Kangari Hills it was noted that the highest copper levels were observed in areas of basic schist, whilst in the Nimini and Kambui Hills it was seen that the copper levels were generally highest in ultrabasic schist areas.

In order to establish the significance of these variations samples from selected areas of basic and ultrabasic schist in the Kambui Schist belts were reanalysed (fig. 33). Representative suites of samples were selected using the established mean values reported previously (Viewing, 1963; James, 1965 & Nichol et al, 1966), the samples chosen laying above, below and at the respective means.

The Cr and Ni results for ultrabasic schist areas reveal slightly modified results on re-analysis (figs. 34 & 36). However, it is clear that Cr and Ni levels are significantly low in the central part of the Sula Mountains - Kangari Hills area and are significantly high in the North Kambui Hills relative to the other study areas. With regard to the areas of basic schist no conclusive results are observed except for a tendency for the North Sula Mountains to exhibit low levels of Cr and Ni.

The copper contents of stream sediments were plotted for study areas where both basic and ultrabasic schists were present (fig. 35). The results of re-analysis generally confirm the

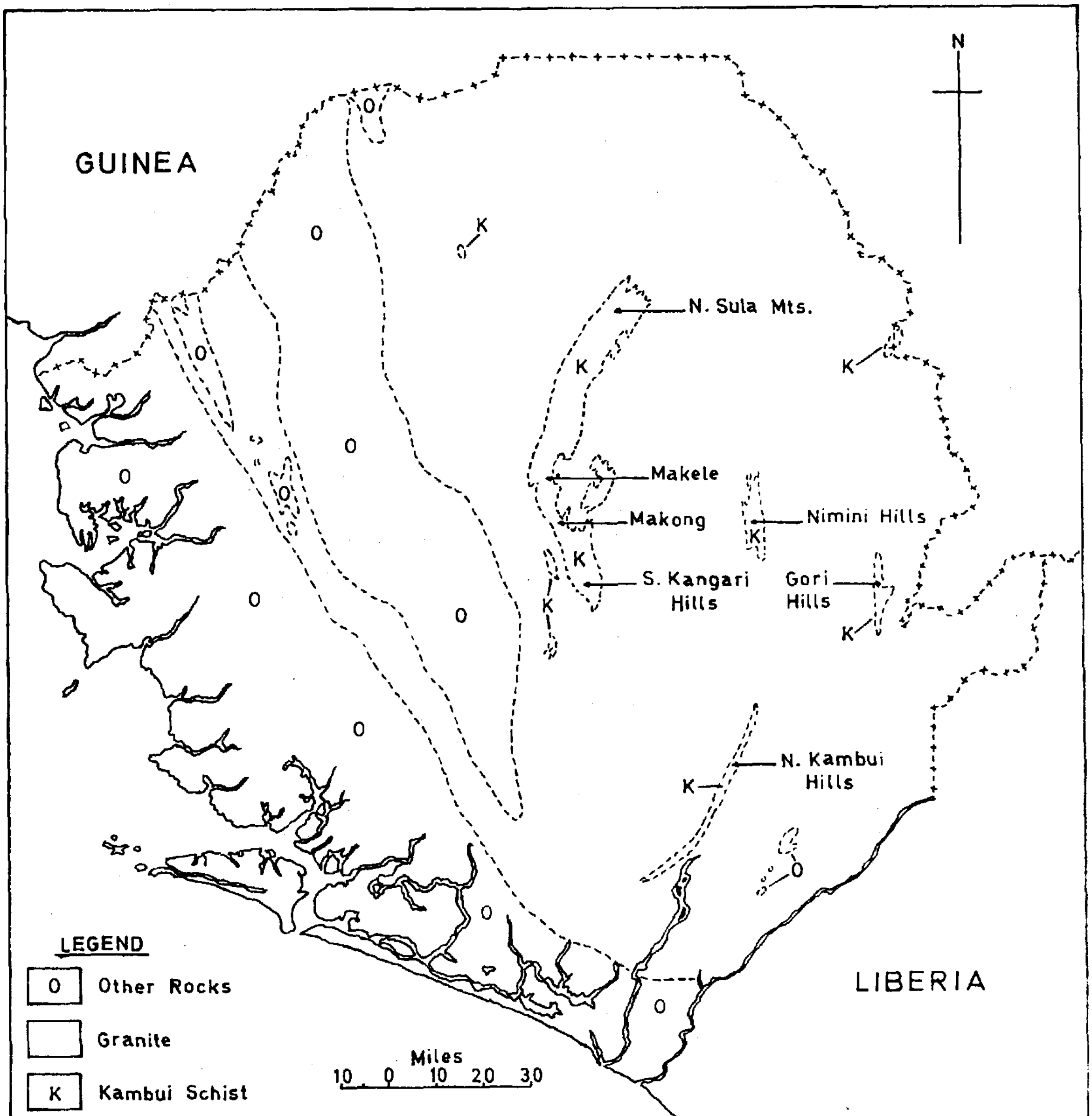


FIG. 33

LOCATION OF COMPARISON AREAS IN KAMBUI SCHISTS

Map reduced from Geological Map of Sierra Leone

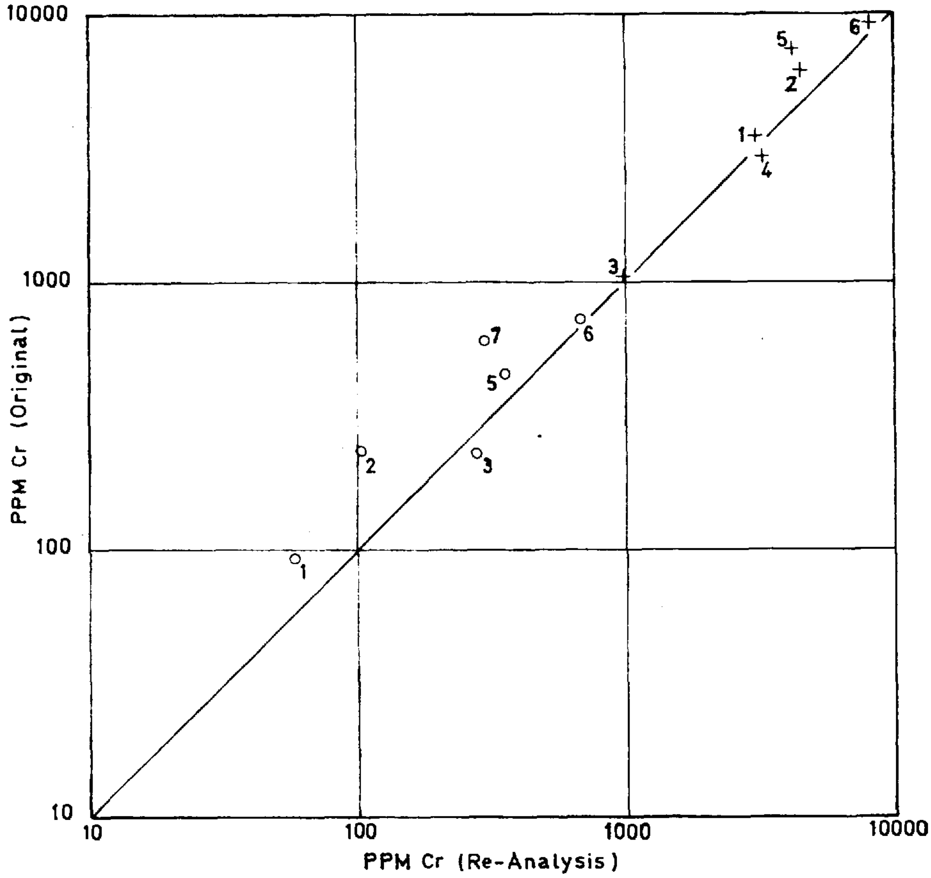


FIG. 34

PLOT OF
CHROMIUM VARIATIONS BETWEEN SCHIST BELTS
(Stream Sediments from Non-Duricrusted Areas)

Basic Schists - o **Ultrabasic Schists - +**

1 North Sula Mts.
2 South Kangari Hills
3 Makele
4 Makong
5 Nimini Hills
6 N. Kambui Hills
7 Gori Hills

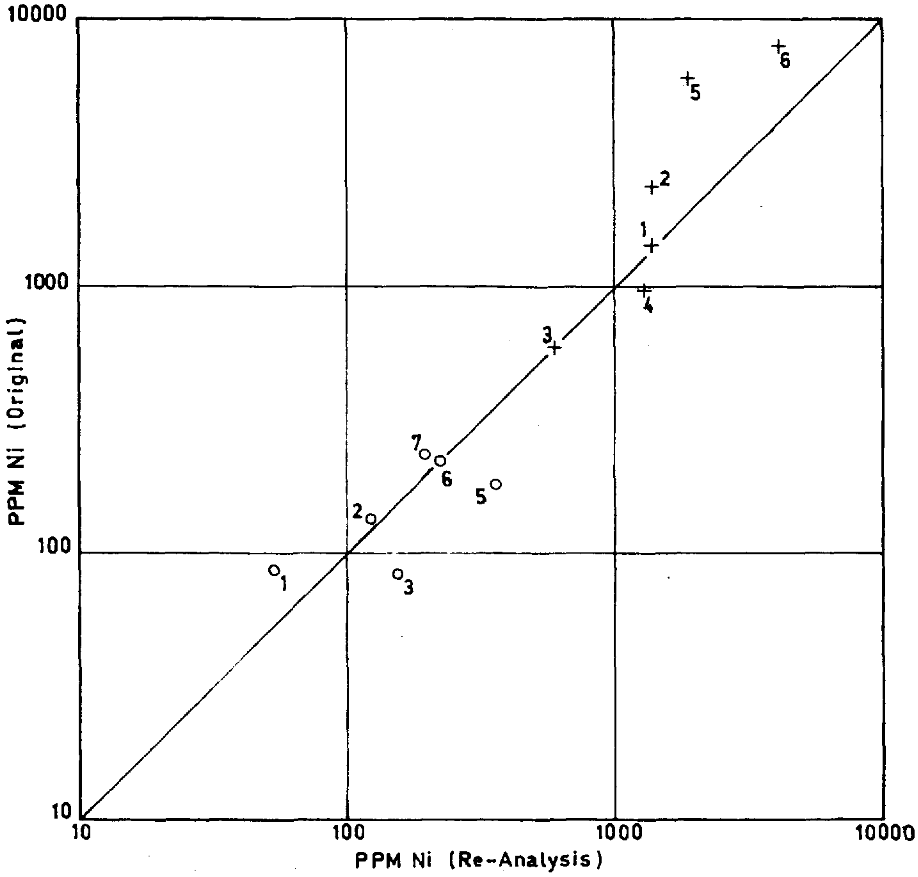


FIG. 35

PLOT OF
NICKEL VARIATIONS BETWEEN SCHIST BELTS
(Stream Sediments from Non-Duricrusted Areas)

Basic Schists - o   Ultrabasic Schists - +

1 North Sula Mts.
2 South Kangari Hills
3 Makele
4 Makong
5 Nimini Hills
6 N. Kambui Hills
7 Gori Hills

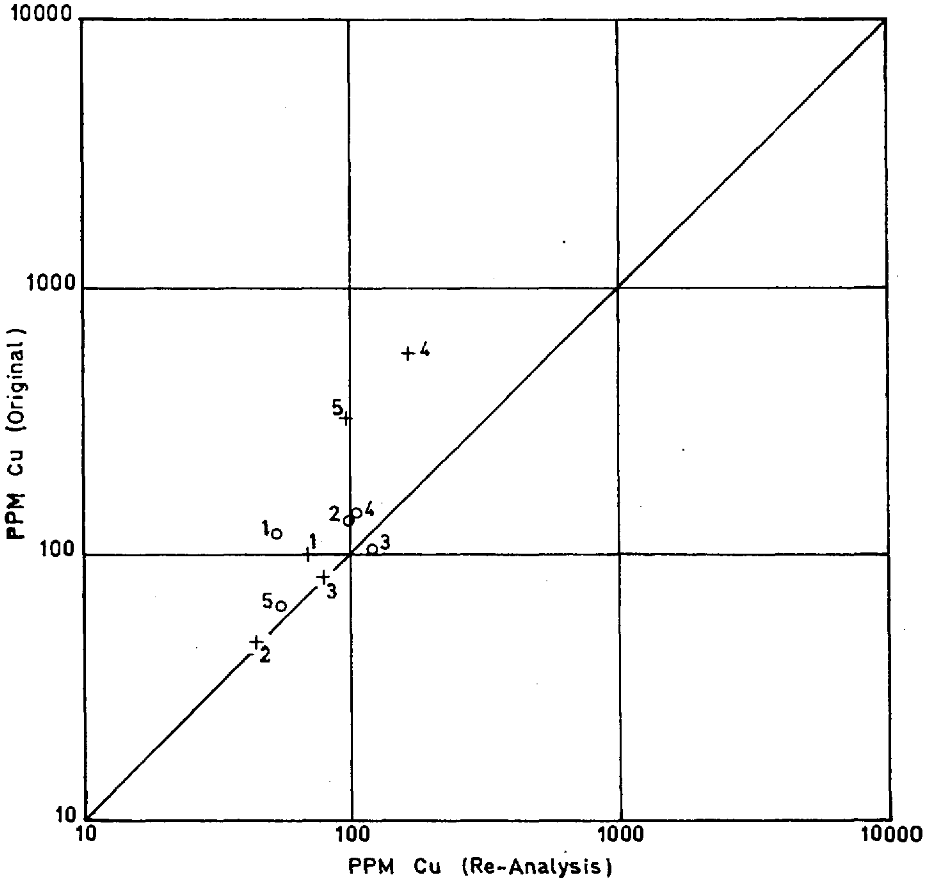


FIG. 36

PLOT OF
COPPER VARIATIONS BETWEEN SCHIST BELTS
(Stream Sediments from Non-Duricrusted Areas)

Basic Schists - o   Ultrabasic Schists - +

1 North Sula Mts.
2 South Kangari Hills
3 Makele
4 Nimini Hills
5 N. Kambui Hills

original observation that in the South Kangari Hills copper levels are significantly higher in basic schist than in ultrabasic schist areas and that in the Nimini and North Kambui Hills copper levels are highest over ultrabasic schists. In the North Sula Mountains and Makele Areas levels tend to be higher over basic schists.

The most significant variation observed, with respect to the fundamental aspects of the geochemistry, is the trend for Cr and Ni levels in stream sediments derived from ultrabasic schists to increase away from the central Sula Mountains - Kangari Hills area, and especially towards the southeast and the Kambui Hills. It is suggested that this trend may be related to variations in a petrographic province of ultrabasic intrusives.

The distribution of lead in the granites around the schist belts is of interest. Only to the south and west of the Kangari Hills are extensive areas of high lead ($>$70 ppm) observed. It is in this area that widespread occurrences of porphyroblastic granites have been found, these granites being considered to be the result of late metasomatic activity at the close of the period of granitisation (Eskola, 1954 & Marmo, 1956).

The overall relief of the data, regarding the schist belts as units, is highest in the Kambui Hills. It is believed that this feature is reflecting the increased geological complexity of the Kambui Hills schist belt as opposed to the relative simplicity to the remaining schist belts.

8:03. The Influences of Secondary Environment of Geochemical Patterns

The most important secondary environmental factor influencing the stream sediment patterns is soil type. In the extensive areas of duricrust and mature soil of the Sula Mountains it was noted that the levels of several elements were depressed or enhanced relative to non-duricrusted areas of similar bedrock. In the small area of duricrust in the Nimini Hills generally similar features were noted.

In all the duricrust areas, whether the bedrock be basic or ultrabasic schist, levels of lead tend to be enhanced. In areas underlain by basic schists levels of chromium are enhanced in all areas, however, in the Sula Mountains vanadium is increased and manganese depleted whilst in the Nimini Hills copper and nickel are enhanced and cobalt depressed. In areas underlain by ultrabasic schists cobalt and nickel are generally decreased, however, in the Sula Mountains area there is a depletion of manganese and in the Nimini Hills it is chromium and vanadium which are depleted.

The reasons for these differing patterns is not known, but it is suggested that the manner in which the elements are held in the bedrock may be a factor of considerable importance. The presence of an element in a resistate mineral in one area and incorporated into a silicate mineral in another would considerably affect its mode of behaviour in the secondary environment.

8.04. Differences of Economic Significance

The regional study of the Sula Mountains - Kangari Hills area revealed that distinct provincial distribution of certain elements exist and these are now described together with data obtained from the present study.

The South Kangari and Nimini Hills are both characterised by widespread areas of arsenic above 8 ppm. In the remaining areas of the Sula Mountains - Kangari Hills, Gori and Kambui Hills arsenic patterns are present to a lesser extent.

The North Sula Mountains are the only area of Kambui Schists which are characterised by widespread detectable molybdenum levels (> 3 ppm). Scattered occurrences of weak molybdenum patterns occur in the remaining field areas, and in the South Sula Mountains, Gori and Nimini Hills a few stronger patterns exist (>15 ppm).

The highest levels of chromium (> 7000 ppm) are observed in in the North Kambui and Gori Hills and appear, in some cases, to be associated with ultrabasic schists which contain disseminated chromite. The highest and most widespread areas of high chromium level are found in the North Kambui Hills wherein chromite has been mined.

Tin has only been detected in systematic patterns in the Nimini Hills area (> 5 ppm), though several weak features can be observed in the South Kambui Hills. The presence of anomalous (> 15 ppm) tin levels in the Nimini Hills, however, sets this area apart as a tin province.

The distribution of gold, as depicted by areas of alluvial gold digging, is also of interest. Outside the Sula Mountains - Kangari Hills the most gold has been produced from the Nimini Hills, where arsenical gold mineralisation has been found. A lesser amount has been won from the Gori Hills and only small quantities have been recovered from streams in the Kambui Hills. The correlation of these features with the abundance of arsenic in the field areas lends strength to the belief that arsenic can be used as a pathfinder element for gold.

The diamond deposits of Sierra Leone are not causally related to the Kambui Schists but are structurally controlled. However, the known kimberlite occurrences form a north-south trending belt which includes the Nimini and North Kambui Hills.

8.05. Summary

In conclusion it may be stated that there are significant variations in geochemistry between the different Kambui Schist areas. The distribution of chromium and nickel in stream sediments from non-duricrusted ultrabasic areas reveals a trend of increasing levels away from the central part of the Sula Mountains - Kangari Hills area. The highest levels were noted in the North Kambui Hills in a south-easterly direction from the central low area. No distinct regional trend could be observed in the data relating to areas of non-duricrusted basic schist. However, there is a tendency for levels of chromium and nickel to increase in a southerly direction from the North Sula Mountains.

The effects of secondary environment are similar in all the field areas with soil type being the most important factor. The exact form of modification of the stream sediment patterns differs slightly from area to area but certain common features are persistently maintained.

With reference to patterns of economic interest a number of areas have been delineated where high metal values prevail relative to the surrounding areas. These areas are of considerable interest as it is in them that there is the greatest chance of discovering mineralisation of the element under consideration.

CHAPTER 9 - BASEMENT RECONNAISSANCE SURVEY

9.01. Introduction

As described in the previous section the regional geochemical reconnaissance surveys of the Kambui Schist areas in Sierra Leone have revealed the existence of significant variations in the geochemistry of stream sediments from similar bedrock types of the different schist belts. These differences are considered to reflect major variations in bedrock geochemistry.

As the granite basement is considered to be predominently of metamorphic origin (Marmo, 1955), it would seem possible that some record of the primary geochemistry of the pre-existing metamorphic rocks would be retained in the geochemistry of the present granites.

In order to test this hypothesis a reconnaissance stream sediment survey of the basement complex of central and eastern Sierra Leone was planned to investigate :-

1) The existence of relict geochemical patterns related to the petrology and metamorphic history of the basement rocks.

and 2) The existence of geochemical provinces which might be related to areas of mineralisation.

The sampling programme has been described in section 4.02 and the investigation into the representivity of this programme in section 8.02. This investigation showed that the programme adopted yielded adequate results in terms of local geochemistry.

9.02. Description of Results

The dominant feature of the results, as revealed by the analyses of the stream sediments, is a northeast-southwest trending trough passing through the Sula Mountains - Kangari Hills area and is best illustrated by the distribution of Cr and Mn (figs. 37 & 38). This trend is revealed, to varying extents, in the distribution of all elements plotted except Mo, Pb and Sn (figs. 98-108 filed in Vol. II). The trend is, however, most clearly seen in the distribution of Cr and Mn. The distributions of Ag, As, Bi and Ga show no regional patterns and the concentrations of these elements, except gallium, were mostly undetectable. The majority of the elements Cu, Mn, Ni, Ti, V and Zn reach equally high levels in both the northwest and southeast of the basement. However, cobalt is higher, by a factor of approximately 2, in the northwest than in the southeast whilst chromium contents are some 10 times higher in the southeast than the northwest. The differing extent to which the elements reflect the trough shaped distribution can be expressed in terms of contrast. The contrast of the high areas to the trough is around 20 for Cr and Mn, but for the remaining elements it is

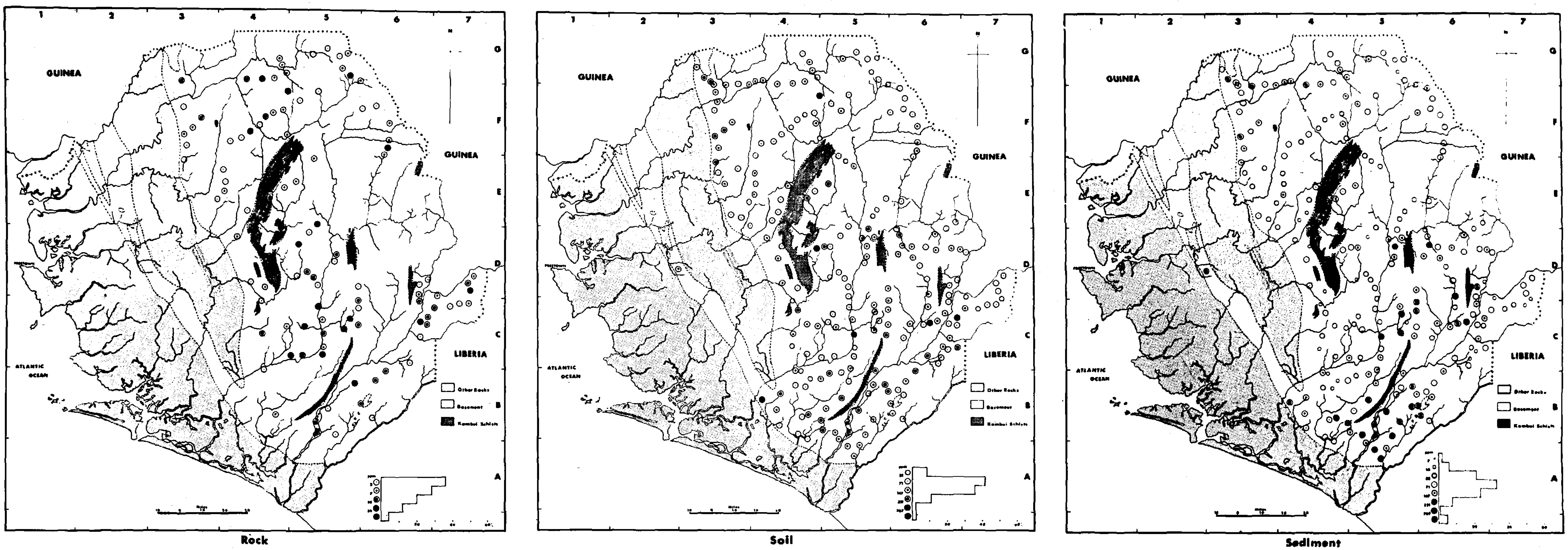
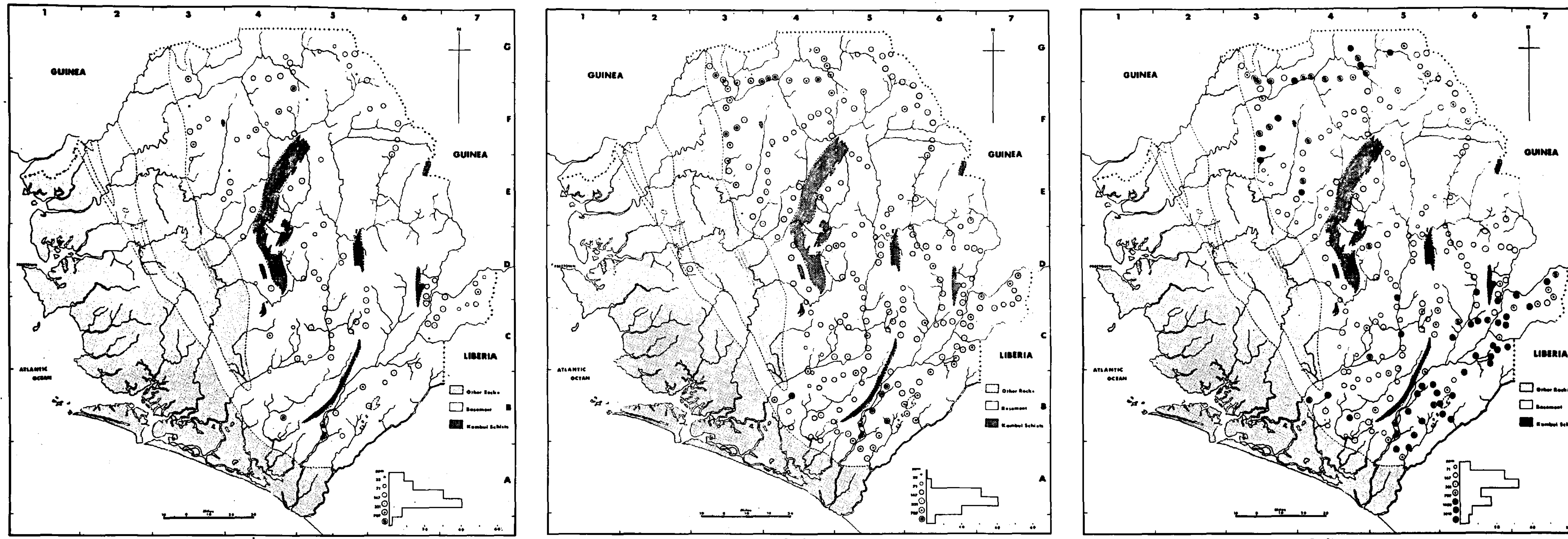


Fig. 37 – Basement Distribution of Chromium



Rock Soil Sediment

Fig. 38 – Basement Distribution of Manganese

far less, Cu, V and Zn are about 5, Ti is approximately 4, whilst Co and Ni are the weakest at 3 (figs. 98-108 filed in Vol. II).

The molybdenum results form no coherent pattern, but it may be of significance that the majority of the detectable values are near the Sula Mountains and Kangari Hills. Several erratically high levels of tin were detected, and of interest is a 30 mile zone of high values running parallel to and to the east of the South Kambui Hills (B5). The pattern of lead distribution is difficult to determine except for broad areas of higher values around the south of the Kangari Hills (C4) and northwest of the Sula Mountains (F3).

The distribution of the elements studied tends to be lognormal, with the exception of Cr and Mn which are bimodal (figs. 37 & 38). It is of interest that in manganese the two populations show quite distinct areal distributions, the lower of the two populations being mostly confined to the central trough area, and the higher value population being almost exclusive to the northwest and southeastern part of the basement. The second, higher value, population in the chromium data is confined to the southeast part of the basement.

Superimposed on the regional trends are a number of minor fluctuations, some of which may be of economic interest, and these are described together with variations in pattern of elements of economic significance in section 9.05.

9.03. The Relationship of Geochemical Patterns in Stream Sediments to the Geochemistry of rocks and soils

The patterns observed in the stream sediments could be due to one of two causes. Firstly they may reflect variations in the bedrock geochemistry, or secondly, features of the secondary environment, or a combination of these two.

Generally there are similar trends in the soil data as are revealed in the stream sediments (figs. 109-119 filed in Vol. II), however, this is best exhibited by manganese and to a lesser extent chromium (figs. 37 & 38). The rock results tend to reflect the major trend in the data but the correspondence to soils and stream sediments is by no means as good as that between the soils and sediments (figs. 120-130 filed in Vol. II). This may be for two reasons, firstly, the rock data is at a lower sample density so making data assimilation relatively more difficult, and secondly, as pointed out in section 2.01, there are severe limitations in the representivity of rock sampling in areas of such low exposure as the basement.

The general correspondence of the soil and stream sediment patterns indicates a positive correlation between the geochemistry of these two media. The weaker correspondence of the secondary environmental patterns with those of the bedrock is believed to be due to the sampling of atypical rocks. The agreement that is present is believed to indicate that the bedrock geochemistry is exercising a strong influence on the secondary environmental patterns.

It is of interest to note that the second population observed in the chromium distribution in stream sediments is not seen in the soil or rock data. The chromite, to which this second population is believed to be related, occurs only in the southeast of the country (fig. 6) where small discrete lenses of chromite are found in the basement granite. Unless one of these was sampled directly, a very improbable event, the second population would not be sampled in a rock or soil survey. The absence of the bimodal distribution in rocks and soils only goes to underline the superiority of stream sediment sampling in the present environment as it provides a composite sample from a finite area rather than a sample at a point.

9.04. Discussion of the Geological Significance of Major Variations in the Geochemistry of the Basement Complex

The regional trend with high levels of many elements concentrated in the northwest and southeast may be explained by one of three mechanisms. Firstly, if the granite is homogeneous the variations reflect pre-granitisation differences in the geochemistry of the original rocks. Secondly, the variations may have been superimposed on some original pattern by metasomatism during granitisation. Lastly, if the basement is inhomogeneous the variations could reflect varying densities of schist inclusions and assimilation within the basement.

If the geochemical patterns in the basement are reflecting varying densities of schist inclusions, rather than differences of geochemistry in the original Pre-Cambrian rocks, they would indicate that metasomatism had its greatest effect in the area of the trough of low values. Moreover, if this is the case, the problem arises to account for the existence of the largest single mass of Kambui Schist in the zone of maximum metasomatism. The knowledge gained of the schist belt geochemistry, and especially of ultrabasic rocks, indicates increases in level for nickel and chromium away from the central part of the Sula Mountains - Kangari Hills schist belt and it thus seems likely that the variations are due to pre-metamorphic effects. These variations could either be simple areal variations in metal distribution or could be related to the evolutionary changes of a petrographic province. Taking all the known facts into account it is most probable that the observed trends reflect the pre-metamorphic Pre-Cambrian distribution of elements in Sierra Leone.

9.05. Minor Variations Unrelated to the Major Trend of Variation within the Basement Complex

Several minor variations superimposed on the major regional trend of the mafic elements are of interest together with certain patterns exhibited by the distribution of Mo, Pb and Sn.

The presence of high chromium levels in the southeast of the country coincident with the occurrence of known chromite bodies is considered to be of significance. It is suggested that these high levels indicate the presence of a chromium geochemical province superimposed on the major regional trend across Sierra Leone, and that this province is related to a metallogenic province of chromite.

The southeast of Sierra Leone appears to be characterised by high tin values in stream sediments, in particular there is a linear zone 30 miles in length with tin levels in the order of 30 ppm. It is of interest that younger granite and alkaline intrusives have been found to the east of the zone, where regional geological mapping has been undertaken in the Gola Forest. At one location, Bagbe (B5), a syenite complex is known to contain pyrochlore, columbite and cassiterite (S.L.G.S. Ann. Rep. 1960/61). It is possible that the observed tin levels are in some way associated with a similar intrusive phase within the basement granites.

Two sites show anomalously high levels of Mo, Pb, Sn and Zn in stream sediments. One, 30 miles north of the Sula Mountains (G4) and the other, to the east of the South Kambui Hills (B5), the latter site falling into the 30 miles long linear zone of high tin levels. The high zinc levels are also reflected in the soils of both areas and the high lead levels by the soils in the area of the northern sample (G4). The combination of Pb, Sn and Zn is unusual in mineralisation, although it is known in Bolivia, Cornwall, Nigeria and Sullivan B.C. The Bolivian deposits are telethermal and associated with granodiorites, the Cornish and Nigerian deposits are veins and stockworks associated with granites, whilst the Sullivan ore-body may be of syngenetic origin.

Around and to the south of the Kangari Hills (C4)is an area of higher lead levels associated with low levels of Ti and V. It is of interest that this area, to the southwest of the Kangari Hills, is characterised by porphyritic granites known to be high in lead (Viewing, 1963) and this is thought to indicate areas of late metasomatic activity (Eskola, 1954 & Marmo, 1956).

An area of high lead occurs to the northwest of the Sula Mountains (E3), where slightly higher levels of Co, Cu, Mn, Sn, Ti, V and Zn than might be expected are also found. The cause of these patterns is not known but one site exhibits high levels of Co, Mn, Sn and Zn, which is an assemblage of economic interest.

Areas of particularly low metal content exist and two are of particular interest. Firstly, an area of low Co and Ni levels is present to the northeast of the Gola Forest (C6) and it is suggested that this feature might be related to areas of younger granite such as are found southeast along strike in the Gola Forest Area. Secondly, around the north of the Sula Mountains and extending southeastwards, towards the Nimini Hills (E5), is a zone of low manganese levels which is also characterized to varying extents by low levels of Cu, Ti and V. The cause of these patterns is not known, but as the low levels of some of the mafic elements are present it may be that granites poor in dark minerals are to be found in the area. It is not believed that the patterns are due to secondary environmental influences, as to cause the observed low levels in only those mafic elements mentioned would require geochemically unrealistic selective leaching and removal processes.

9.06. Summary

The existence of geochemical patterns in stream sediments has been demonstrated over 15,000 square miles of Pre-Cambrian basement rocks based on the collection of stream sediment samples from 215 sites and their analysis for 15 elements.

The mafic elements (Co, Cr, Cu, Mn, Ni, Ti, V & Zn) generally display a trough like distribution pattern with levels low in the area of the Sula Mountains and Kangari Hills and rising to the northwest and southeast. The remaining elements, Mo, Pb and Sn do not reveal any marked regional distribution but scattered areas of increased levels are present.

The patterns observed in soils are very similar to those revealed by the stream sediments, indicating a strong positive correlation between the geochemistry of the two media. The rock patterns are fundamentally similar which suggests that the bedrock geochemistry is the dominant factor controlling the patterns observed in the soils and stream sediments.

Variations in the bedrock geochemistry are considered to reflect differences in the geochemistry of the Pre-Cambrian rocks prior to granitisation, though certain patterns of high lead levels may, however, reflect areas of late metasomatic activity during granitisation.

The occurrence of high chromium levels in the stream sediments of southeastern Sierra Leone, associated with known chromitiferous intrusives, demonstrates the applicability of the method in delineating large areas of increased mineral potential. The areas of high Pb, Sn and Zn levels may therefore be worthy of further examination from the economic mineral potential point of view.

Although the basement survey has been successful in achieving its original aims and has added a new dimension to regional geochemical surveying it has also emphasized the need for more objective and less empirical methods of interpretation. Towards this end a number of mathematical and statistical data handling methods have been applied to the data.

CHAPTER 10 - MATHEMATICAL AIDS TO DATA ANALYSIS

10.01. Introduction

Two problems of interpretation are encountered in the present study and each requires a different technique for a satisfactory solution. The first, found in simple geological situations, such as the basement of Sierra Leone where the data is homogeneous and apparently, with the exception of Cr and Mn, drawn from a single population (section 9.02), is to establish if any major areal trends are present and then to identify any areas where the data differs significantly from the underlying trend. In cases where the trend is already obvious by presenting data with conventional methods little is to be gained by mathematics. However, in cases where the trend is not apparent when using conventional methods mathematical techniques have the greatest potential.

The second problem is encountered in complex geological environments, such as the schist belts; here the data is most probably drawn from several populations (section 7.02) and it is not feasible, due to the complexity of the data, to establish if any areal trends are present. The approach in complex areas is therefore to determine the cause of the major patterns of distribution observed, then attention can be focussed on minor patterns, some of which may be related to mineralisation. When the geological situation is not too complex and no great intermixing of patterns is present the task of interpretation can be carried out efficiently. However, in more complex areas and where the patterns are intermixed the efficiency of interpretation falls and becomes subjective. It is again in cases such as these that mathematics could assist interpretation.

10.02. Basement Area

To investigate the applicability of mathematical methods to aiding the interpretation of data from predominantly homogeneous areas the techniques of polynomial trend surface fitting and rolling mean analysis have been applied to the data of the basement survey, Polynomial surface fitting techniques require that the data should be normally distributed, in contrast, it is not necessary for the data for rolling mean analysis to be normally distributed. Both techniques set out to determine the underlying areal trends in the data, and achieve this task by different methods. Trend surface analysis fits a surface of pre-conceived form to the data by least squares, whereas the rolling mean surface is produced by a smoothing operation based on taking a large number of local means from over the entire map area. The trend surfaces do not fit the data exactly and differ from it by an amount known as the residual. The use of rolling means does not allow residuals to be computed as the surface generated has no simple mathematical expression.

However, in areas where large erratic residual values, not forming a minor trend, occur in trend surface analysis, the standard deviation of the rolling means will increase, thus areas of high geochemical relief will be reflected by high standard deviations.

The basement reconnaissance survey in Sierra Leone revealed a trough shaped areal distribution for the mafic elements. In order to elucidate the nature of this trend and aid the selection of samples and areas which differed significantly from it, trend surfaces, up to the third degree, and rolling means have been computed (for rocks, soils and stream sediments) for all elements, except As, Ag, Bi and Ga. The techniques of trend surface analysis and rolling mean analysis have been described in sections 5.03 and 5.04.

A. Reliability of Results

Prior to describing the results it is necessary to discuss their reliability in terms of the data from which they were produced. The degree of fit of the surfaces, produced by the two methods, to the data is expressed as the percentage of the variance of the computed surface present in the original data:-

$$\% \text{ fit} = \frac{\text{Variance of Computed Values}}{\text{Variance of Observations}} \times 100\%$$

The higher the percentage the better is the fit of the surface to the data and vice versa.

(a) Trend Surface Analysis

The fits obtained by the cubic trend surfaces are in the range 7-37%, but average 22% (Table X). This figure is low in comparison with many other trend surface analysis studies and does not take into account the analytical and sampling errors which are present in the observations. By definition the computed values contain only systematic components and no random errors (Grant, 1957), thus by removing the effect of the analytical and sampling errors a more realistic estimate of the fit to the underlying trend in the data could be made.

The fits for the rock surfaces are generally some 10% better than those for soils and stream sediments. This is due to only 101 points being used for the computation of the rock surfaces whilst 216 are used for other media. The increase in fit is to be expected and would reach 100% if only 10 points were being fitted. This is the minimum number of points a cubic surface can be fitted to, and is analogous to the minimum number of points, i.e. three, to which a plane can be perfectly fitted.

The analytical and sampling errors can be estimated from the triplicate sampling of each sample site, the combined error variance being equal to the mean of all the variances of the groups of three samples. For reasons of computation it is easier during trend surface analysis to use sums of squares rather than variances; the sum of squares being numerically equal to the variance times the number of samples involved. In the

TABLE X

Table of Original and Recomputed Percentage Fits for Cubic Trend Surfaces for Stream Sediments

	SSO	SSE	CSSO	SSC	% Fit	C % Fit	% Imp
Co	49.19	12.83	36.27	11.03	22.43	30.33	35.2
Cr	58.52	14.03	44.49	15.42	26.34	34.66	31.6
Mn	55.81	10.86	44.95	20.50	36.73	45.61	24.2
Ni	34.23	7.97	26.26	5.90	17.24	22.47	30.4
Pb	12.04	5.77	6.27	0.89	7.39	14.19	92.0

Note:- SSO = Sum of squares of observations
SSE = Sum of squares of errors
CSSO = Corrected sum of squares of observations
SSC = Sum of squares of computed values
C % Fit = Corrected % fit
% Imp. = % improvement in fit

$$CSSO = SSO - SSE$$

$$\% \text{ Fit} = \frac{SSC}{SSO} \times 100\%$$

$$C \% \text{ Fit} = \frac{SSC}{CSSO} \times 100\%$$

$$\% \text{ Imp.} = \frac{C \% \text{ Fit} - \% \text{ Fit}}{\% \text{ Fit}} \times 100\%$$

present case it is equal to the sum of all the variances of groups of three samples. This error sum of squares is then subtracted from the sum of squares of the observations and this new figure is used for re-computation of the % fit:-

$$\text{Re-computed \% fit} = \frac{\text{Variance of Computed Values x 100\%}}{\text{Variance of Observations - Error Variance}}$$

The various sums of squares (i.e. variances x number of samples) are given with the original and re-computed cubic fits in table X. There is on average a 40% improvement in the percentage fit.

The statistical significance of linear, quadratic and cubic trend surfaces of chromium and nickel was investigated and cubic trend surfaces found to have a significance of greater than 99.99% (Table XI) (Allen and Krumbein, 1962). This means that if groups of 216 random numbers were taken only once in 10,000 trials the observed trend surfaces would be formed. From this it is concluded that the distribution of the data and the trend surfaces are highly significant, and thus reliable measures of the regional trend.

The method used is really only applicable in cases where residual deviations from the trend surface are normally distributed errors. In cases where the trend surface fits are poor and the residual deviations contain geological information in addition to errors, such as in the present case, the method is not strictly

TABLE XI

Significance of Trend Surfaces

	Source of squares	Sums of squares	Degrees of Freedom	Mean Square	F	Confidence Level %
Cr	Linear	2.37	2	1.18	4.51	98.5
	Deviations	56.16	214	0.26		
	Quadratic	9.57	3	3.19	14.49	99.99+
	Deviations	46.59	211	0.22		
	Cubic	15.42	4	3.86	24.74	99.99+
	Deviations	31.17	207	0.15		
	Total	58.52				
Ni	Linear	0.61	2	0.31	1.94	80
	Deviations	33.62	214	0.16		
	Quadratic	3.61	3	1.20	8.57	99.99+
	Deviations	30.01	211	0.14		
	Cubic	5.90	4	1.48	12.34	99.99+
	Deviations	24.11	207	0.12		
	Total	34.34				

For method of calculation see:-

Allen and Krumbein (1962)

or Krumbein and Graybill (1965)

applicable (Allen and Krumbein, 1962). However the authors in discussing this problem believe their method still provides a most useful guide to the significance and reliability of the trend surfaces.

As the polynominal function used in trend surface analysis very probably has no geological meaning the test of significance carried out in Table XI does not relate to the geological significance of the fitted surface. The significance test carried out only tests the strength of the surfaces in demonstrating the underlying polynominal trend in the data. The percentage fit of the surface to the data is, in fact, a better measure of the achievement of the surface in describing the areal distribution of the data.

The setting up of limits about the trend surfaces, with which to gauge the significance and reliability of the residual deviations, has been achieved using the data on the combined analytical and sampling errors from the triplicate sampling of each site. The error standard deviations are used to set up two sigma limits about the trend surface. This band of values between the positive and negative limits is taken as background and samples falling outside this limit are regarded as anomalous. The thickness of the background band varies from area to area depending on the level of the trend surface; in areas of low level it is thin and in areas of high level it thickens. The two sigma limits about the trend surface, based on the estimate of analytical and sampling errors, give rise to a selection of samples as being anomalous only if there is less than a 1 in 20 chance of their values being due to errors.

Where rock, soil and stream sediment data are presented together (i.e. figs. 48 & 49) a different method of anomaly selection has been used as triplicate sampling of rocks was not possible and therefore the combined error variance could not be estimated. The contrast of observed to computed values has been used, a contrast of greater than 5 or less than 0.2 being taken arbitrarily as indicating an anomalous sample.

(b) Rolling Mean Analysis

The fit obtained in rolling mean studies is a function of the size of the search areas and the overlap between the search areas. The size of the search area and the overlap between the search areas are chosen for convenience in the problem, however in the present case the overlap is a function of the size of the search area and thus these two parameters are not independent. The size of the search area has to be chosen bearing in mind the following facts:-

(1) Too small a search area, and in the present case overlap, includes too few samples to make the calculated statistical parameters valid.

(2) Too small a search area results in little smoothing of the data, whilst a large overlap may result in oversimplification of the patterns present.

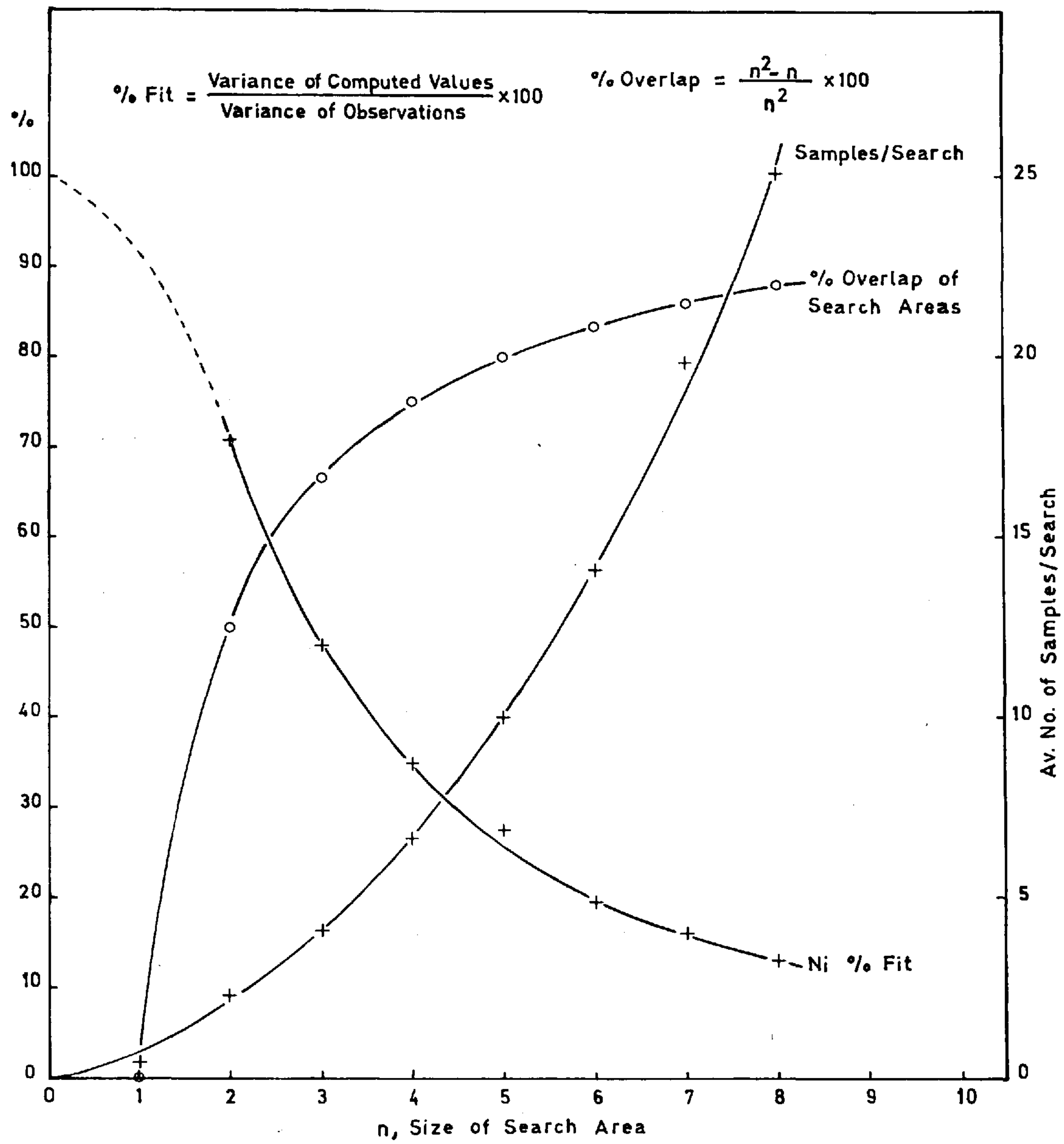


FIG. 39

PLOT OF EFFECT OF SEARCH AREA SIZE
ON
ROLLING MEAN PARAMETERS

In order that the most efficient search area and overlap could be chosen a series of trials were carried out varying the overlap in the range 50-83% (fig. 39). A search area with an 80% overlap was chosen as, on an average, the searches would include 10 samples so satisfying the statistical assumptions of the method. In addition an 80% overlap gave rise to rolling mean results which had a fit of 30%, a comparable figure to the recomputed fit obtained in the trend surface analysis so aiding comparison of the two techniques.

As the rolling mean process is one of smoothing, if there are sufficient samples within each search area, the effects of random analytical and sampling errors will be minimised. Thus in rolling mean analysis it is not necessary to recompute the percentage fits or to allow for random errors in the interpretation as has to be done in polynomial trend surface analysis.

B. Description of Polynomial Trend Surfaces for Stream Sediments

The linear, quadratic and cubic trend surfaces are presented for nickel in order that the development of the surfaces from the raw data can be traced (fig. 40). The linear surface indicates that levels are higher in the southeast than northwest. The quadratic surface shows the development of the central trough, which is deepest at the western end, also the most notable features of the symbol map (fig. 41). The cubic surface reveals a cross trend in the southeast which also deepens the central

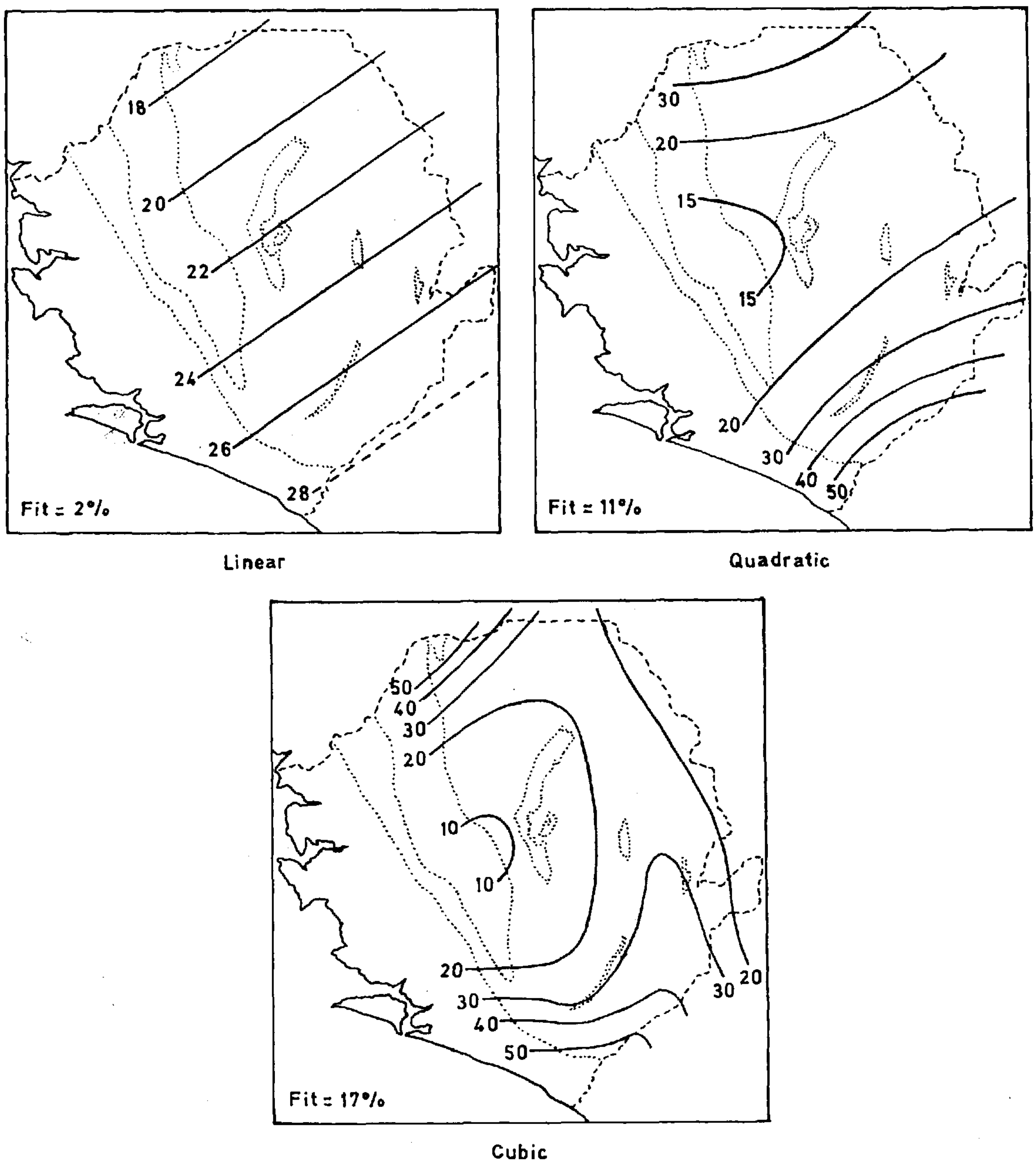


FIG. 40

1°, 2° and 3° TREND SURFACES
FOR
NICKEL IN STREAM SEDIMENTS
(levels are expressed in ppm.)

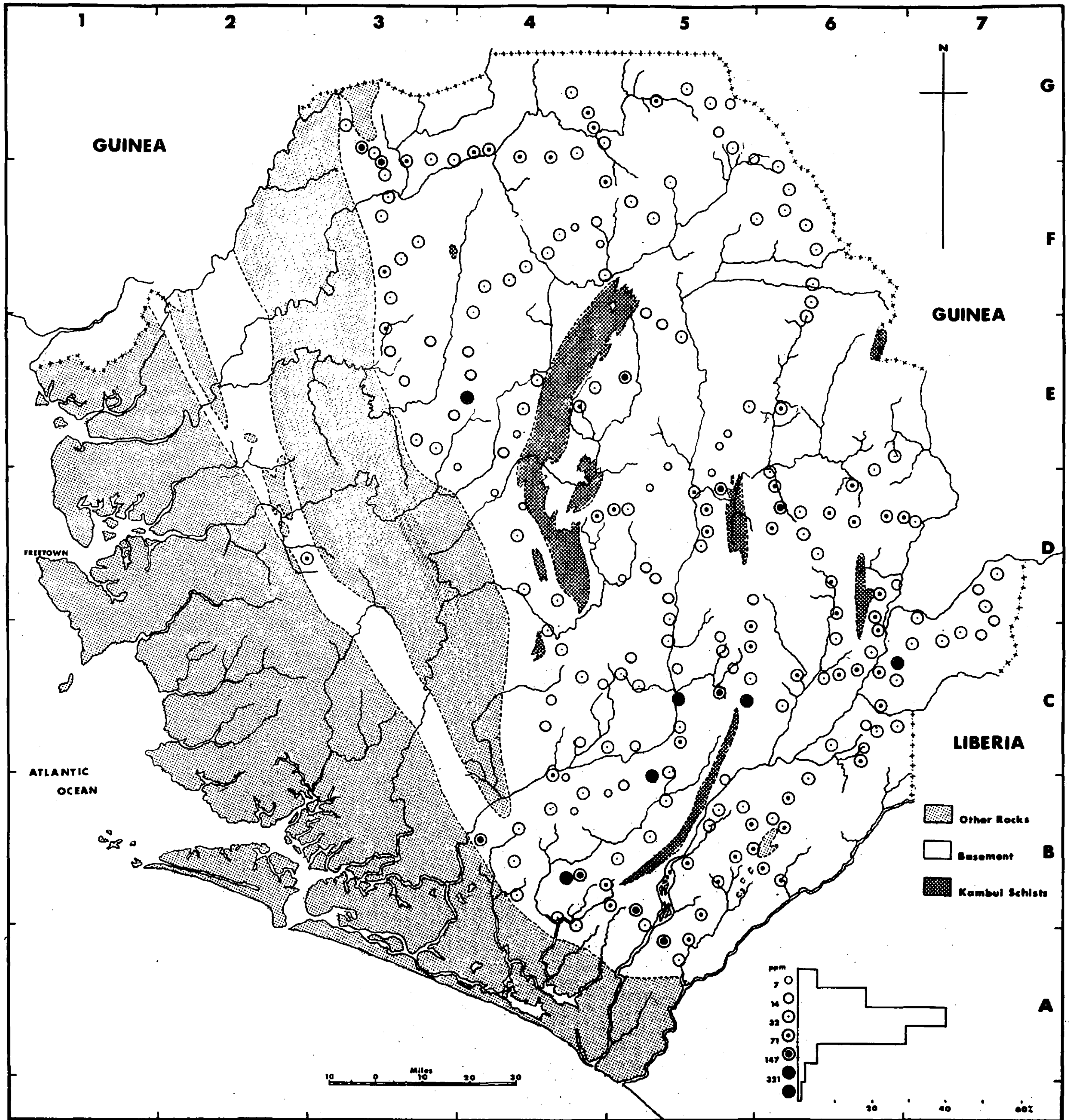


Fig. 41 — Nickel in Stream Sediments

trough to a basin around the Sula Mountains and Kangari Hills. These last features are not altogether apparent from the symbol map and thus the trend surfaces have considerably aided the appreciation of the data.

The cubic trend surfaces for Co, Cr, Mn, Ni and Pb in stream sediments are presented in figures 42 - 46. The sample sites characterised by anomalous residual deviations are marked as described on the figures.

The cubic trend surfaces of Co, Cr and Ni all display similar characteristics of a basin like structure around the Sula Mountains and Kangari Hills with higher levels to the northwest and southeast. To differing extents there is a ridge running north-south to the east of the central basin through the southeastern group of schist belts.

The cubic surface for manganese is simpler than those previously described and consists of a synclinal form plunging to the northeast with its axis running through the Kangari Hills.

The lead surface has none of the features revealed in the distribution of the mafic elements but forms a belt of higher levels swinging in an arc from the northwest to the east northeast of the basement. To the north and south of this arc levels fall off and are lowest just to the north of the Sula Mountains.

The significant residual deviations, indicating areas of significant local variation from regional background pattern,

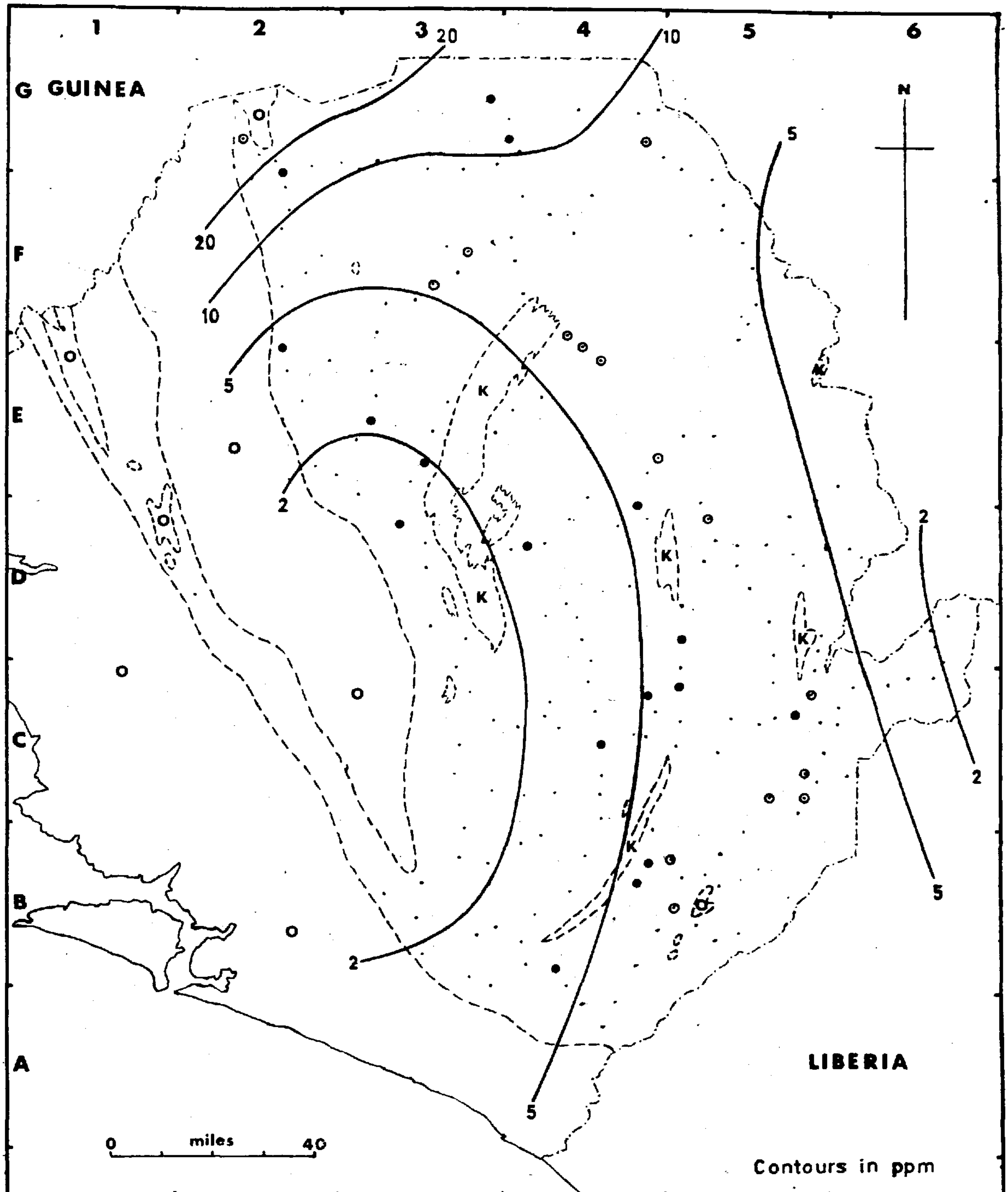


Fig 42

SIERRA LEONE BASEMENT COMPLEX
CUBIC TREND SURFACE

Cobalt in Stream Sediments

Sample Site ·
Anomaly Positive ● Negative ⊙

GEOLOGY

O	Other Rocks
	Granite
K	Kambui Schists

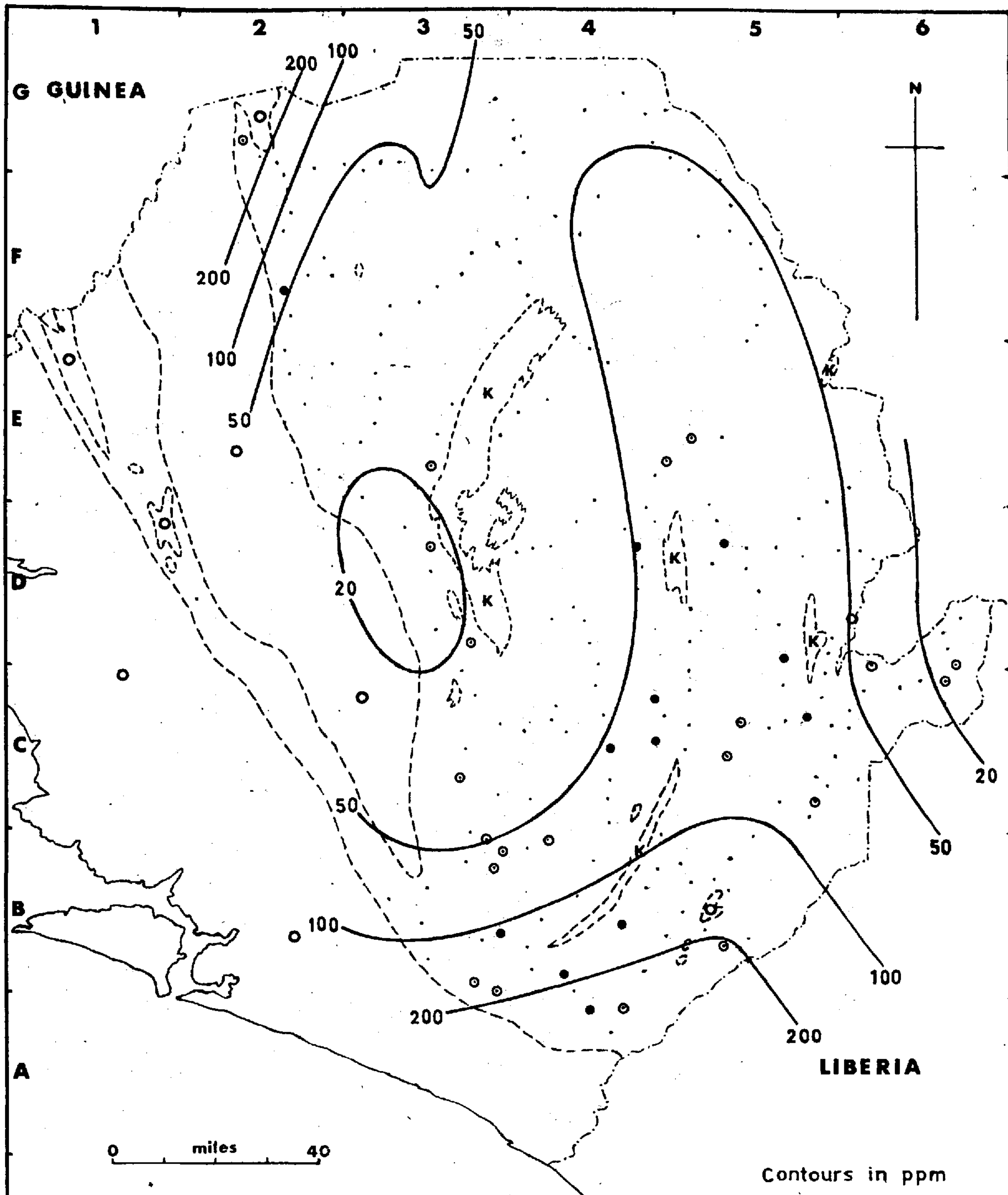


Fig 43

SIERRA LEONE BASEMENT COMPLEX

CUBIC TREND SURFACE

Chromium in Stream Sediments

Sample Site ·

Anomaly Positive ● Negative ⊙

GEOLOGY

O Other Rocks

Granite

K Kambui Schists

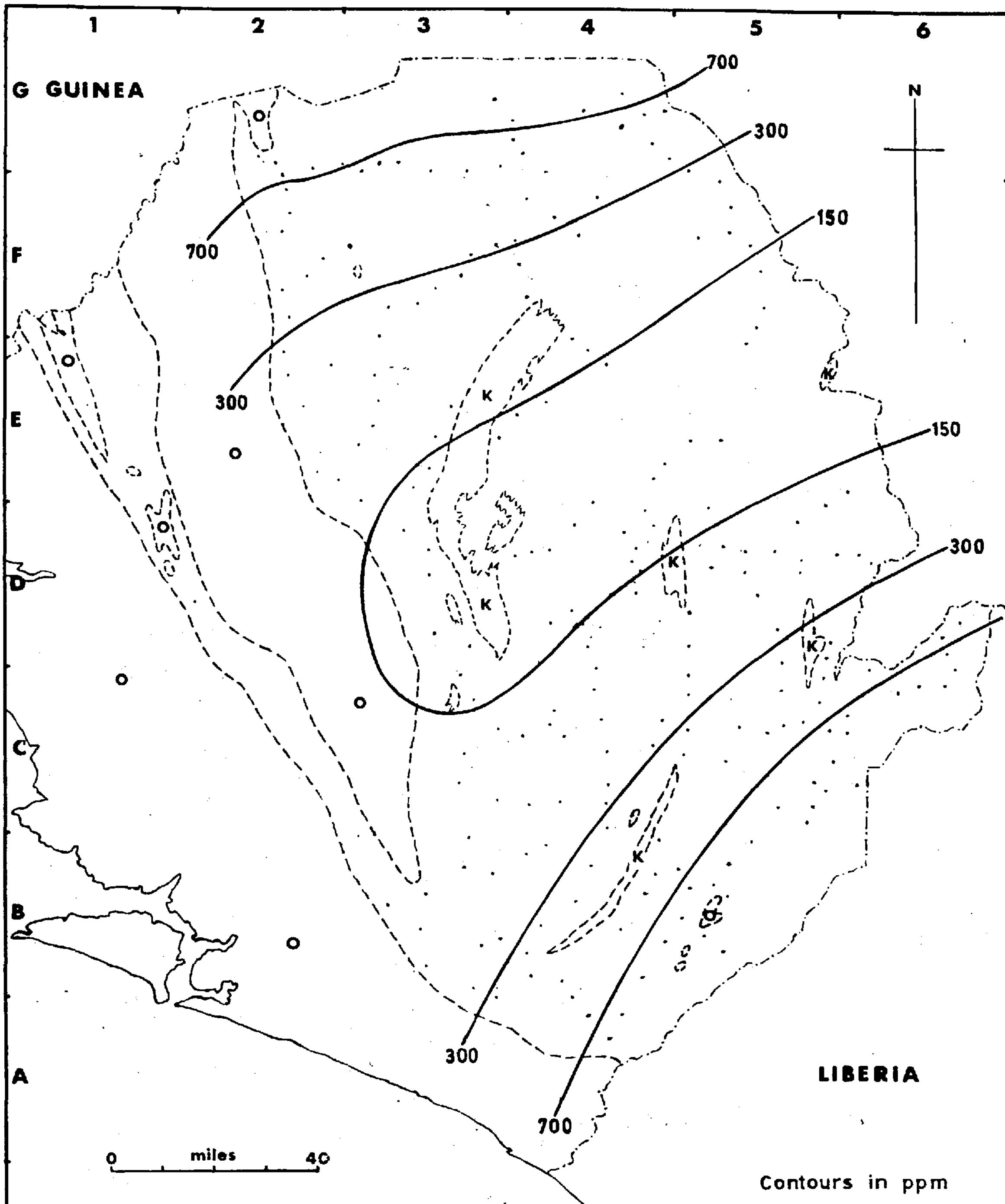


Fig 44

SIERRA LEONE BASEMENT COMPLEX
CUBIC TREND SURFACE

Manganese in Stream Sediments

Sample Site ·
Anomaly Positive ● Negative ⊙

GEOLOGY

O Other Rocks

Granite

K Kambui Schists

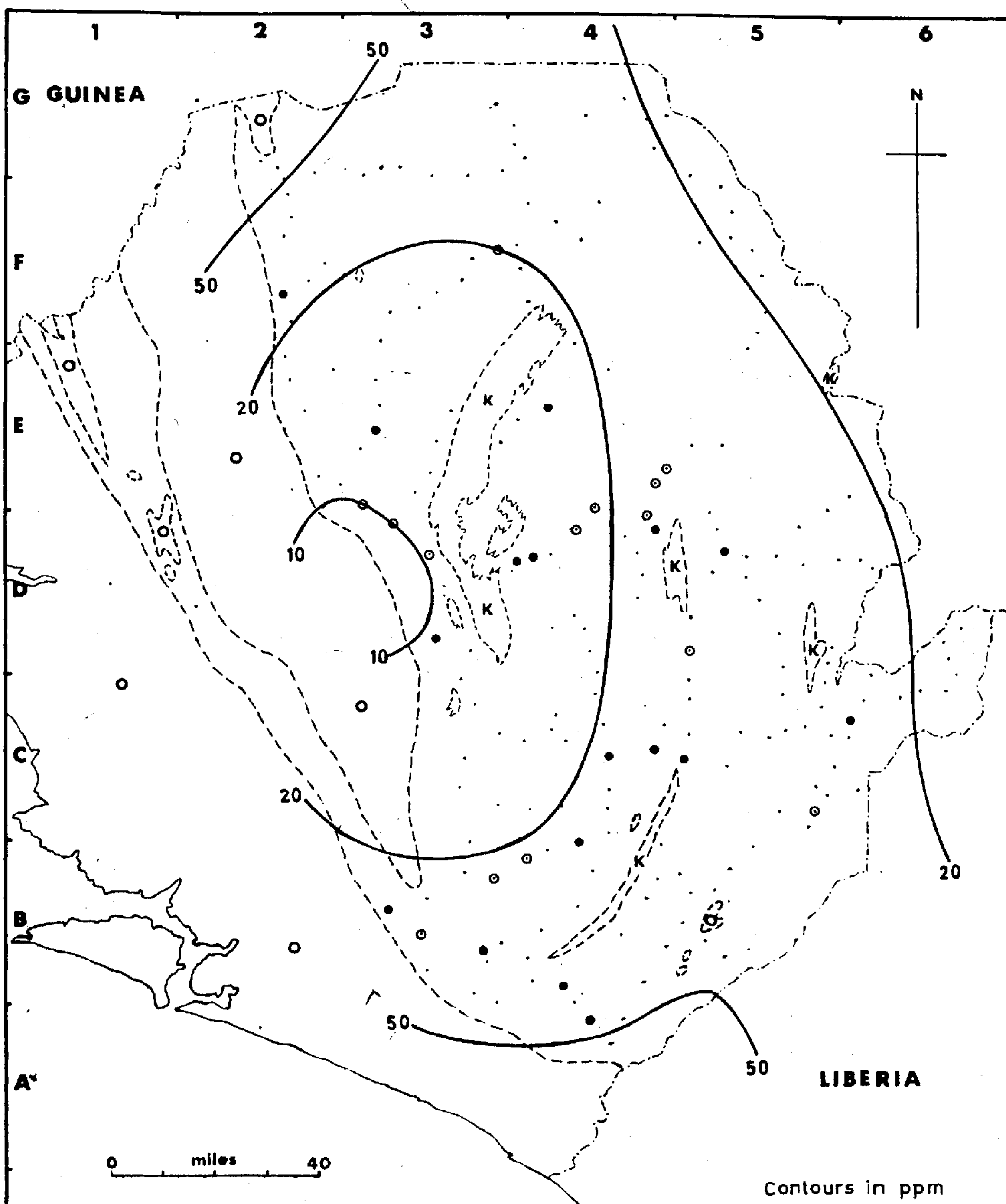


Fig 45

SIERRA LEONE BASEMENT COMPLEX
CUBIC TREND SURFACE

Nickel in Stream Sediments

Sample Site ·
Anomaly Positive ● Negative ⊙

GEOLOGY

O Other Rocks

Granite

K Kambui Schists

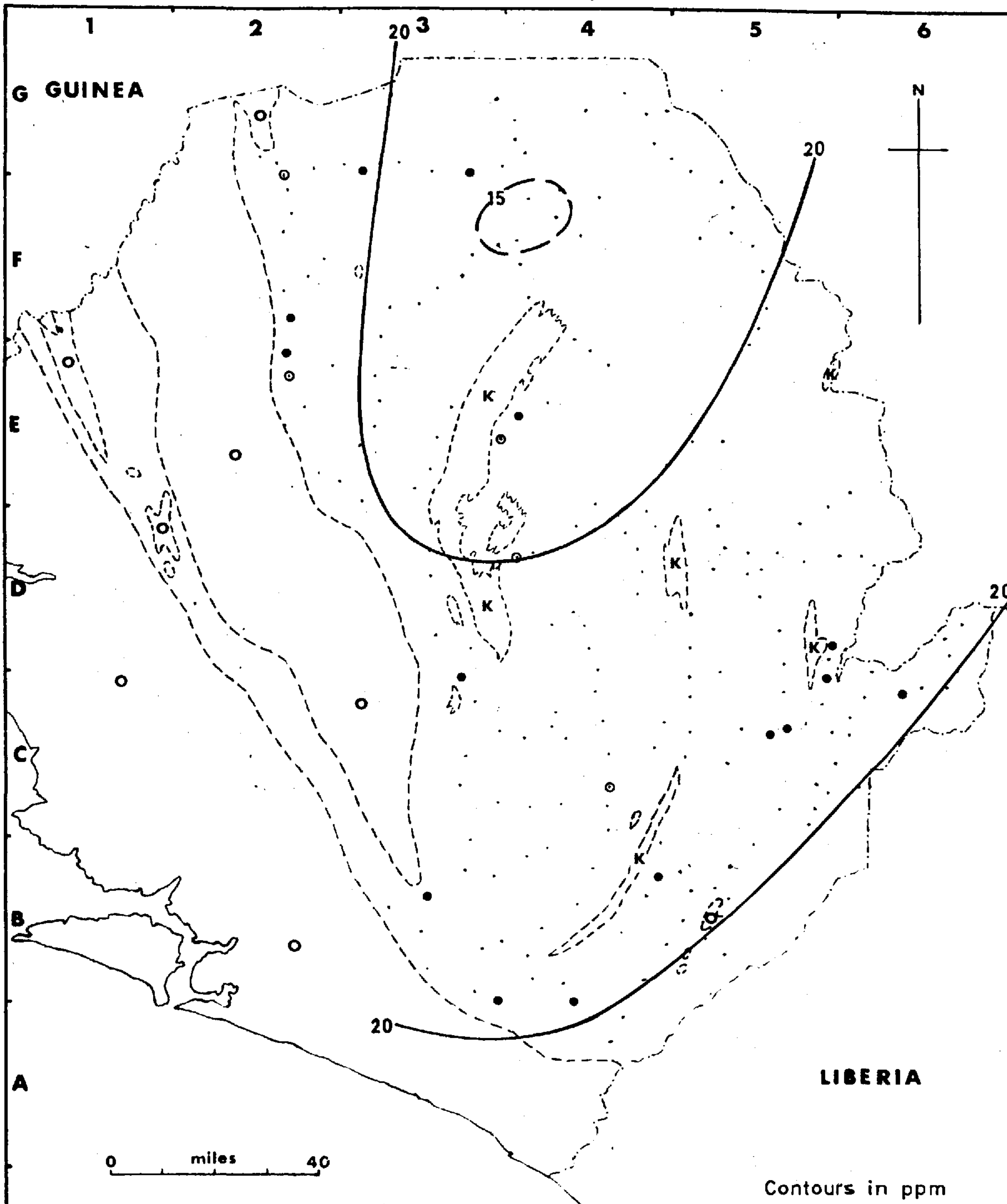


Fig 46

SIERRA LEONE BASEMENT COMPLEX
CUBIC TREND SURFACE

Lead in Stream Sediments

Sample Site ·
Anomaly Positive ● Negative ⊙

GEOLOGY

O	Other Rocks
	Granite
K	Kambui Schists

show several features of interest. The most important of these are those which involve more than one element. Two sample sites (B5 & C5) show positively anomalous contents of Cr and Ni and anomalous chromium levels are also noted in several areas (A5, B4, C5, D6 & F3). In contrast two sites (C6 & E5) show levels of Co, Cr and Ni below negative threshold. It is of interest that the combined error variance for manganese is so great that no samples are selected as anomalous.

C. Comparison of Trend Surface Analysis with Data Presentation by Symbol Maps

The trend surfaces based on the actual analytical values outline the major regional trends far more clearly than is achieved by conventional symbol maps. In cases, such as chromium, where the contrast of the trend is large the advantages are less than in cases e.g. nickel, where the contrast of the trend is low and it is difficult to ascertain the form of the trend. This lack of appreciation of the trend in cases of poor contrast could be due to one of two causes. Firstly the regional variations could be so small that they reach the scale of the group width used for data presentation on the symbol maps; or secondly, that, if the local relief of the data is approaching the magnitude of the overall relief of the mapped area it will become increasingly difficult to separate the two features one from another.

To investigate this problem a series of surface trend analyses have been carried out using grouped data. Any value between the group limits has been ascribed the value at the geometric midpoint of the limits. These points are of course the points at which the standards in use in the spectrographic laboratory are placed.

The results for the two computations for the cubic surface fitted to the nickel stream sediment data are presented in figure 47. As can be seen there is very little difference between the two surfaces, though there are differences between the patterns of the residuals produced by the two computations. Firstly there are differences between the samples selected as anomalous. The grouped data selects a sample east of the Sula Mountains as anomalous which is not selected using the raw data; the reverse is true with a sample in the northwestern extremity of the mapped area which is selected as anomalous using the raw data but not as anomalous by the grouped data. Secondly, there are differences in the general outline of the areas of positive and negative residuals, but the general pattern of the residuals is similar.

From this investigation two conclusions may be drawn. Firstly, as the two cubic trend surfaces are very similar it is concluded that the grouped data is efficiently reflecting the regional trends in the data. Thus the symbol maps are an efficient means of depicting the regional trends in the data and any failure in comprehension is due more to the human brain's inability to assess the patterns presented than to a failure

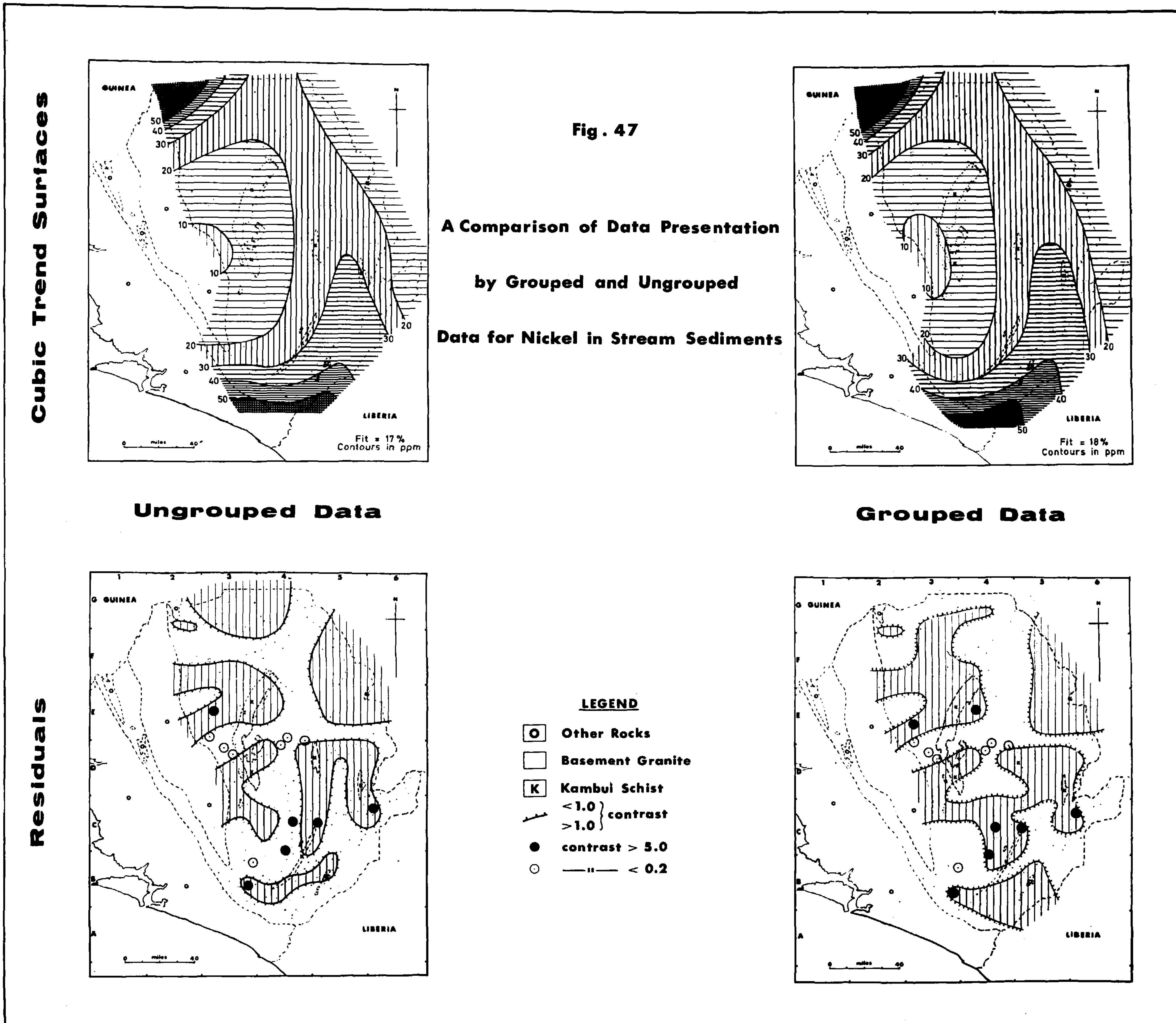


Fig. 47

A Comparison of Data Presentation by Grouped and Ungrouped Data for Nickel in Stream Sediments

in the method of presentation. Secondly, as the patterns of the residuals are not altogether similar it is clear that the grouping of the data is causing some distortion of the geochemical patterns. However, this distortion is unlikely to hinder interpretation when the residuals are large but may become more serious around the threshold levels which are often the areas of greatest interest when interpreting the finer points of geochemistry.

D. Relationship of Surfaces for Rocks, Soils and Stream Sediments

To illustrate the relationship between the geochemistry of rocks, soils and stream sediments two contrasting elements, Cr and Ni, were chosen for investigation by both polynomial trend surface fitting and rolling mean techniques. Chromium exhibits a large contrast between the trough and peaks of the major trend and is of interest due to the relationship of the data to known mineralisation in the basement. In the case of nickel the contrast of the raw data is very much less, thus making interpretation and comparison of the patterns observed in the three media more difficult.

The cubic surfaces for chromium in soils and stream sediments are basically similar with a basin like feature around the Kangari Hils and higher values to the northwest and southeast, also with a ridge reaching northwards through the southeastern schist belts from the southeastern high area (fig. 48). The levels exhibited by the soil and sediment surfaces are

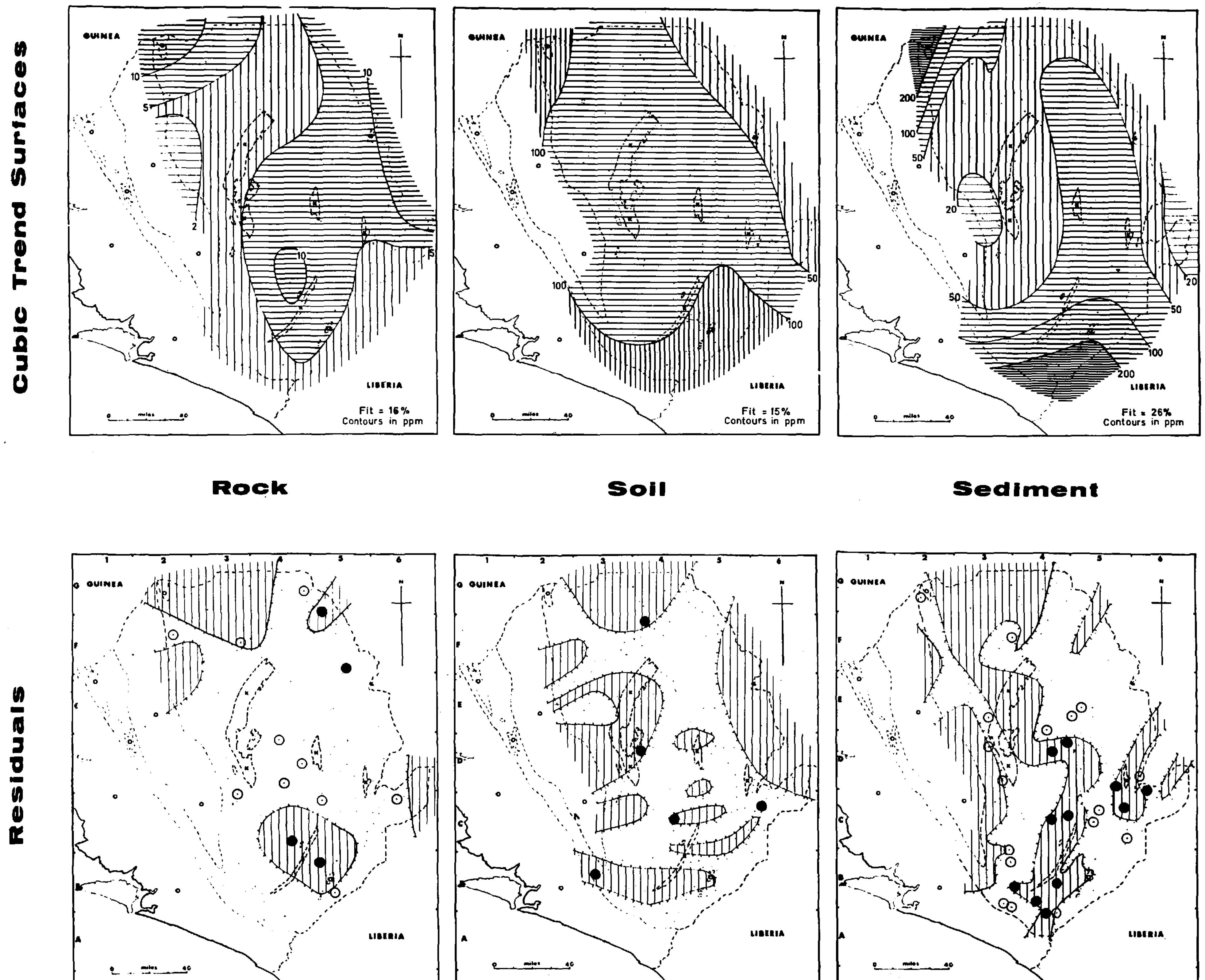


Fig. 48

Chromium

Trend Surface Analysis

for Rocks, Soils and Sediments

LEGEND

- O Other Rocks
- Basement Granite
- K Kambui Schist
- <1.0 / >1.0 contrast
- ● contrast > 5.0
- ○ —"— < 0.2

generally similar, although the overall range is a little higher in the stream sediment surface. The cubic trend surface for rocks differs somewhat in detail from those of soils and sediments. A high value area is still present in the northwest as is a basin of low values west of the Kangari Hills. However, the high value of the southeast is not present, but a ridge of high levels stretches down to the North Kambui Hills from the northeast. Generally it appears that the chromium contents of the rocks is some 10 times less than for soils and stream sediments. The generally similarity of level in the soils and sediments is taken as evidence for the very strong correlation between the major trends in these media.

The patterns of the residual deviations reveal the nature of the local variations from the trend surfaces and the large areas of positive or negative residuals indicate areas where the trend surface is systematically lower or higher than the observed values. No consistent features can be observed between the residuals of the three media.

The three cubic trend surfaces for nickel are basically similar to one another and to the soil and sediment surfaces described for chromium (fig. 49). However, minor discrepancies occur; the soil surface shows higher levels near the Nimini Hills than in the southeast and the rock surface is characterised by an extensive area of low values northeast of the Sula Mountains.

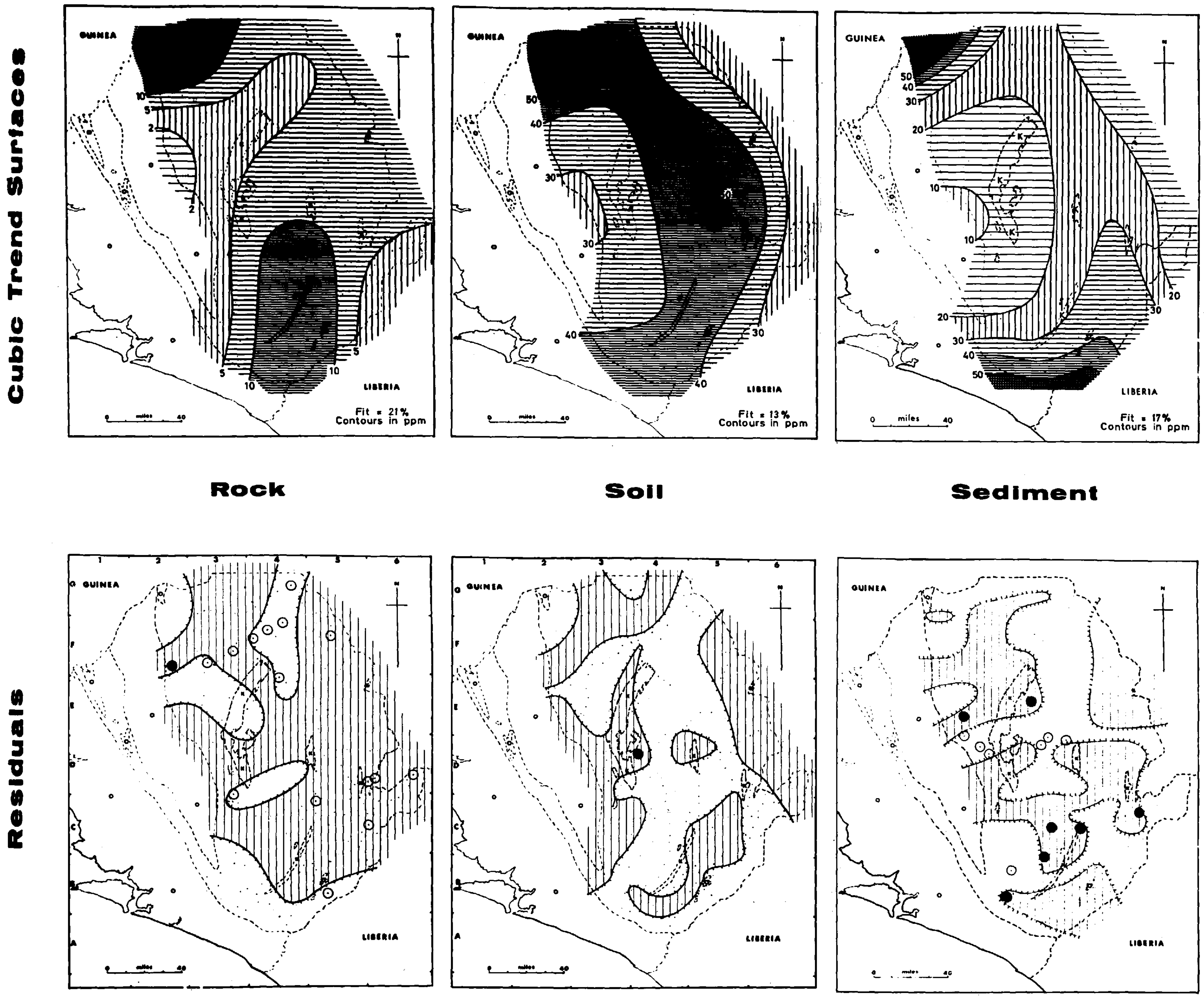


Fig. 49

Nickel

Trend Surface Analysis

for Rocks, Soils and Sediments

LEGEND

- O Other Rocks
- Basement Granite
- K Kambui Schist
- <1.0 / >1.0 } contrast
- ● contrast > 5.0
- ○ —"— < 0.2

In comparing the levels of the three nickel surfaces it is apparent that the levels in soils are only a little higher than in sediments. However, the rocks exhibit values some 5 times lower than the soils and stream sediments. The general similarity of level and shape of the soil and sediment surfaces is again evidence of the positive correlation of the geochemistry of these two media.

The residual deviations show some features common to the three media. Of note are areas of negative residuals stretching northeastwards from the Sula Mountains indicating that the trend surfaces are portraying values which are too high. In addition the areas either side of this belt, i.e. along the north and northeastern borders of Sierra Leone, are characterised by positive residuals. Also of interest is an area of positive residuals in the soil and sediment data around the South Kambui Hills, again indicating that the trend surface is portraying too high values for the area.

The rolling means for chromium in soils and stream sediments have some features in common (fig. 50). Most noticeable is the area of high levels in the southeast of the country, and to a lesser extent the areas of higher level in the northwest and lower levels in the northeast. The stream sediment rolling means also show a basin to the south of the Kangari Hills. The rock rolling means have little in common with those of the soils and

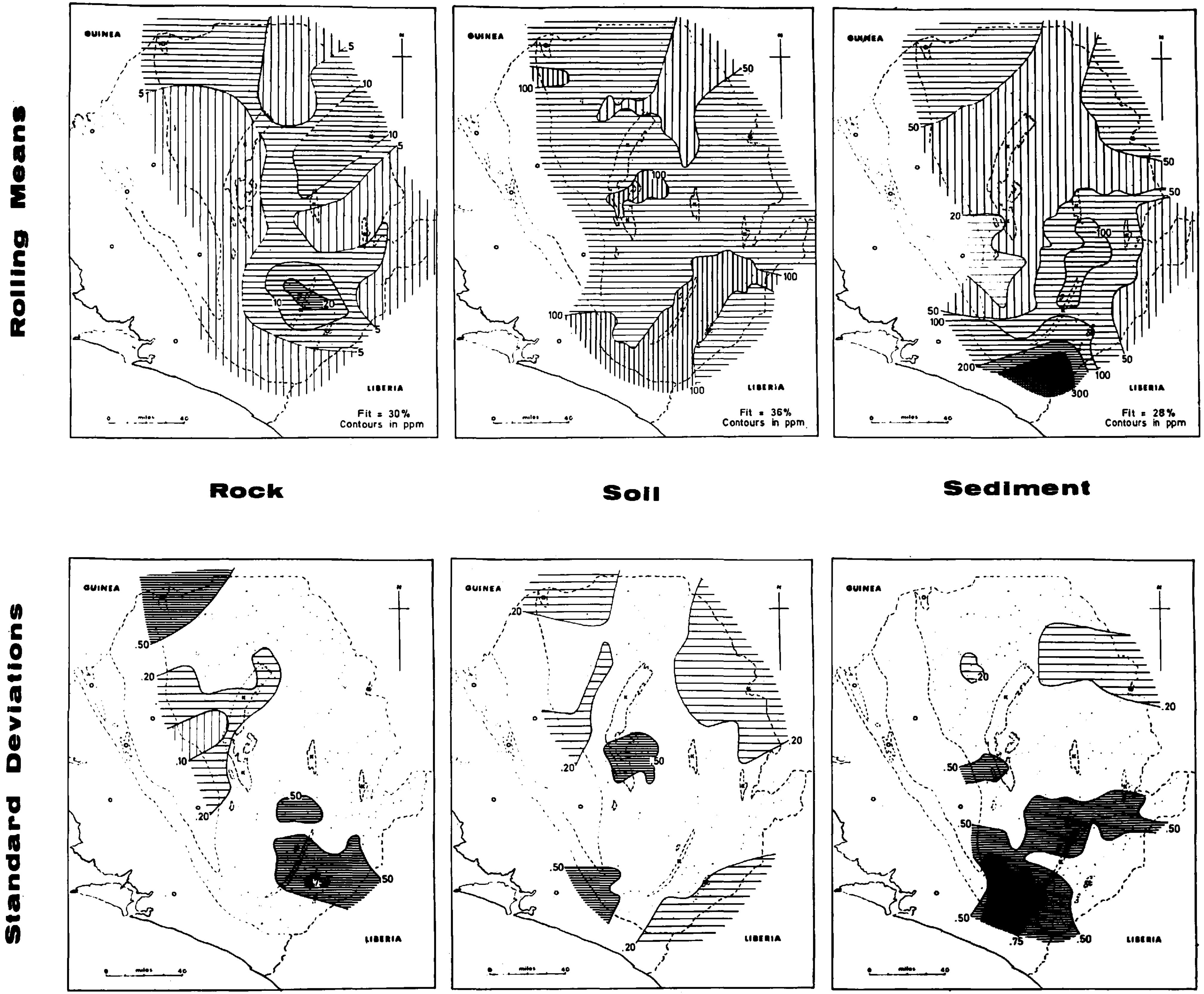


Fig. 50

Chromium

Rolling Mean Analysis

for Rocks, Soils and Sediments

LEGEND

- O Other Rocks
- Basement Granite
- K Kambui Schist

Standard deviations are expressed in $\log_{10}$ ppm.

stream sediments. An area of high levels is present around the North Kambui Hills and in the northeast of the country, a less well developed high is present in the northwest.

The maps of chromium standard deviation have little in common with each other except that high values tend to concentrate in the southeast. Very high standard deviations are observed in the stream sediments southwest of the Kambui Hills, indicating a complexity of the raw data; a similar area of very high relief is present in the soils east of the Kambui Hills. Very low standard deviations are to be seen in the soils west of the Kangari Hills, indicating a considerable homogeneity of pattern.

The rolling mean surfaces for nickel in rocks, soils and stream sediments (fig. 51) are basically similar having the following features. High level areas in the northwest and southeast, with a ridge of higher levels reaching northwards from the southeastern high area and an area of low levels to the west of the Kangari Hills and Sula Mountains. The soil surface is also characterised by high levels in the central part of the country in a belt between the Kangari and Nimini Hills. The rock surface shows a concentration of high levels around the North Kambui Hills which is weakly reflected by the soil and stream sediment patterns.

The local standard deviations show no significant features

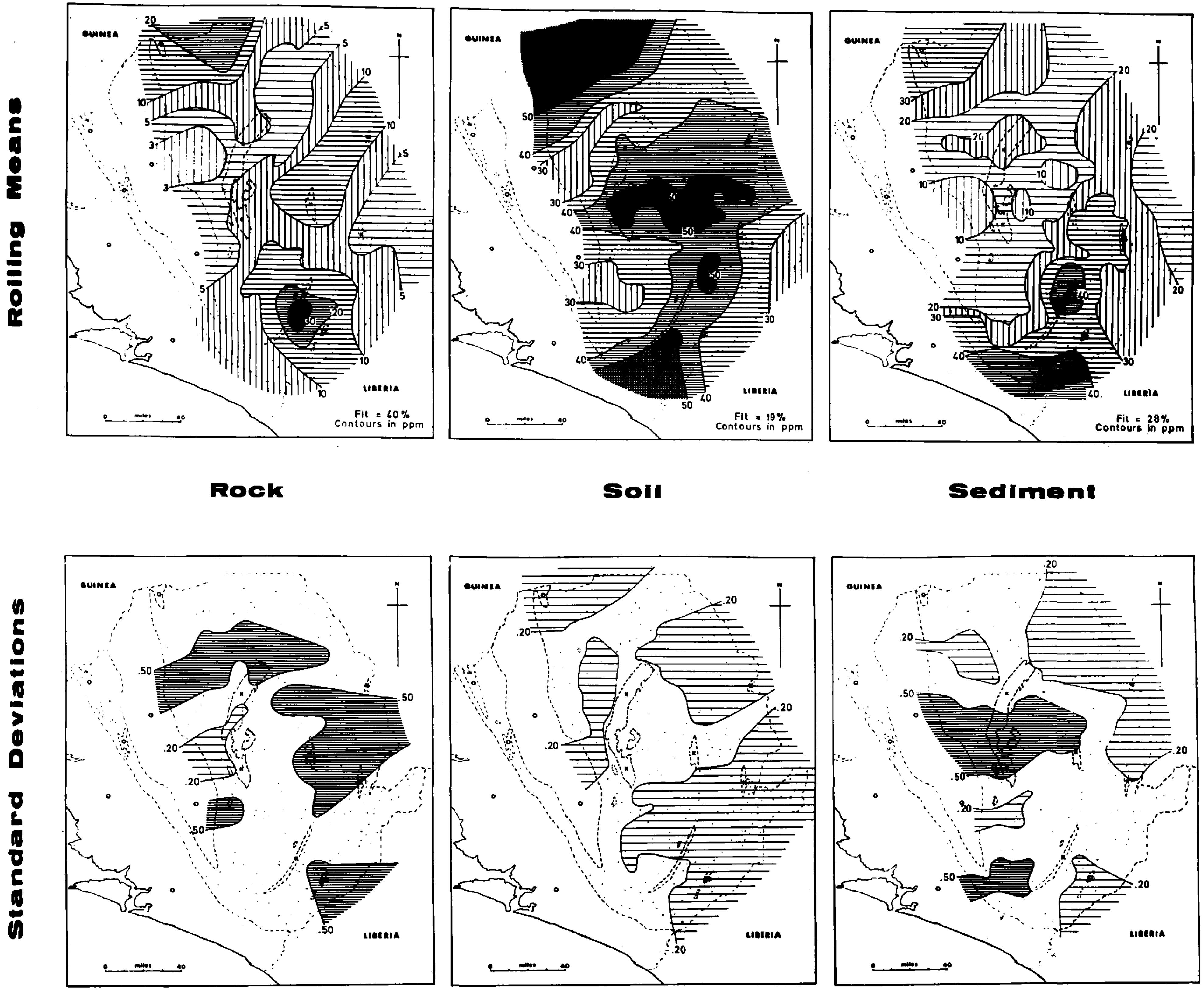


Fig. 51

Nickel

Rolling Mean Analysis

for Rocks, Soils and Sediments

LEGEND

- O Other Rocks
- Basement Granite
- K Kambui Schist

Standard deviations are expressed in $\log_{10}$ ppm.

in common between the three sampling media and no areas of excessively high or low standard deviation are present.

It is of note that the rolling means surfaces for Cr and Ni both appear to be more realistic in terms of the data plotted by conventional means than the corresponding cubic trend surfaces. Of particular interest in the present study is the realistic manner in which the nickel rolling means adjust to reflect the trough of low levels in the three sampling media stretching northeastwards from the Sula Mountains. This trough is not reflected by the trend surfaces, though the residuals for the three sampling media all reveal negative values in the area, indicating that the cubic trend surfaces are too high in level. Similarly, the area of positive residuals in soils and sediments near the South Kambui Hills, where the trend surface is too low, is marked by increased rolling mean levels in comparison with the trend surfaces so forming a more realistic model of the areal variability.

In conclusion it may be stated that the rolling mean and cubic trend surfaces for Cr and Ni in soils and stream sediments are basically similar in shape and level. However, although the cubic surface for nickel in rocks is very similar to the nickel surfaces of the other two media, the cubic surface for chromium in rocks does not show such a good agreement. In addition, both Cr and Ni in rocks are at lower absolute levels of concentration than in the respective soils and sediments.

E. Geological Significance of Patterns Revealed by Surface Analyses

The point of greatest significance geochemically is the striking similarity in the shapes and values of the surfaces for soils and stream sediments. This similarity indicates a strong positive correlation between the geochemistry of the soils and stream sediments. This fact lends weight to the suggestion that much of the stream sediment material in Sierra Leone is obtained by the mass wasting of stream banks and colluvial soils.

The similarity of shape between the rock surfaces on the one hand and soils and stream sediments on the other is not so marked. However, the agreement that is present is significant as it indicates that the same major trends in geochemistry are present in rocks, soils and stream sediments. This feature is of great importance as it strengthens the argument for the use of stream sediments as the major sampling media in regional reconnaissance mapping surveys. The poorer similarity of the rock surfaces to those of soils and stream sediments is probably due to the systematic sampling errors introduced by rock sampling in an area of very low exposure where any outcropping is almost certainly atypical. Of particular interest is the lack of correlation between chromium in rocks and chromium in soils and sediments. This is believed to be due to the presence of chromium as chromite in the stream sediments, and possibly in the soils. However, the rocks collected only contain chromium in silicate minerals, thus a population has been sampled by the stream sediments which is completely unsampled by the rocks.

The difference in absolute levels of the rock trend surfaces for Cr and Ni on one hand and the respective soil and stream sediment surfaces on the other can be interpreted in two ways. Firstly, that there has been a considerable accumulation of Cr and Ni in the soils during weathering of the bedrock, or secondly, that atypical rocks, in terms of the soils and stream sediments, have been sampled during the survey.

The regional trend across Sierra Leone for Co, Cr, Mn and Ni has been investigated by studying the linear, quadratic and cubic trend surfaces for nickel (fig. 40). The major component, which is the only component the distribution of manganese shows, is the northeast-southwest trending trough through the Kangari Hills and Sula Mountains. The second component is a ridge which runs northwards through the southeastern schist belts from the major area of high levels in the southeast. It is conjectured that the major component may be related to a Pre-Cambrian geosyncline whilst the second component may be related to a petrographic province of ultrabasic intrusives. It could be argued that the higher levels of the second component were due to a greater incidence of small schist remnants in the southeast. However, taking into account the known existence of a chromitiferous ultrabasic province in the area, this argument is not given great weight.

In terms of the present geology it is of note that the generally low level areas around the Kangari Hills and Sula Mountains coincides with large areas of porphyroblastic granites and quartz syenite. The high level areas in the northwest contain hornblende granite gneisses and grey hypersthene granites (S.L.G.S. Ann. Rep. 1929/30) and the high areas in the southeast coincide with large belts of granulites which are interspersed with biotite granites, some of which are very rich in biotite (Wilson, 1966).

Of fundamental interest is the distribution of Cr and Ni as depicted by the surfaces for stream sediments. The investigation into Cr and Ni levels in stream sediments from non-duricrusted ultrabasic areas within the Kambui Schists lead to the conclusion that the North Kambui Hills exhibit the highest levels which then decrease through the Nimini Hills to the lowest levels in the central part of the Sula Mountains - Kangari Hills schist belt. The Cr and Ni surfaces tend to exhibit these same variations, and this feature provides the strongest possible evidence substantiating Marmo's hypothesis that the basement granitic complex of Sierra Leone is predominantly of metamorphic origin.

The correct interpretation of the residual deviations requires more geological information than is available. However several points of geological interest are evident. The area of low Co, Cr and Ni northeast of the Gola Forest (C6) may contain outcrops of younger granite such as are found along strike to the southeast (Wilson, 1966). The Co and Cr positive anomaly south of the Gori Hills (C6) is near a reported gabbro containing pyrite, pyrrhotite and chalcopyrite (S.L.G.S. Ann. Rep. 1927/28) and may be related to gabbroic rocks. All the sites characterised by high chromium, which it is postulated are related to chromite occurrences, contain positively anomalous residuals, and two of these also contain anomalous contents of Co and Ni (B5 & C5). Of interest is one site (B5) which exhibits anomalously high Co and Pb levels and is in the tin zone of the southeast of the country. A similar pattern is observed in one sample from the northwest (F3) where tin was not detected.

The interpretation of the standard deviation maps is difficult due to the lack of geological knowledge of the field area. However, the standard deviation is a measure of local relief and provides information on the geochemical heterogeneity. Of note is the high Cr and Ni relief around the South Kambui Hills where it is possible that further chromitiferous ultrabasic remnants may be present in the basement granite. The high relief area for nickel in stream sediments between the Kangari and Nimini Hills may be due to the known heterogeneity of the area which contains many small schist inclusions, especially near the Kangari Hills.

F. Summary

The application of trend surface and rolling mean analysis to aiding the interpretation of regional geochemical data has revealed a number of points of interest.

The surfaces are efficient and objective methods for depicting regional trends, conveying the same information as conventional maps but in a more assimilatable form.

The surfaces provide a useful objective approach to the problem of the comparison of patterns observed in different sampling media and elements.

The technique of trend surface analysis removes the grouping effect of the symbols, which have been necessary for the visual presentation of data previously, and this is especially important when subtle features are being sought.

The correct interpretation of the residual deviations from the trend surfaces requires a knowledge of the errors incurred during sampling and analysis.

In rolling mean analysis the degree of smoothing of the data, and thus the fit, can be chosen to suit the problem. However, if the parameters calculated are to be statistically valid care should be taken to ensure sufficient samples are included in each search.

If the analytical and sampling errors are truly random, and sufficient samples are included in each rolling mean search, their influence is minimised by the computations of the individual means with the result that they need not be allowed for in interpretation.

In rolling mean analysis any areas characterised by increased heterogeneity of the primary or secondary environment will be marked by increased standard deviations.

The absolute shape of the trend surface may not be a faithful model of the areal variability of the data. However, when only low order surfaces are computed they are probably geologically valid.

Low order surfaces have the drawback that they sometimes fail to adjust sufficiently to the data and wide areas, where the trend surface is systematically too high, or too low in value, occur.

The shape of the rolling mean surface is more faithful to the original data than a cubic trend surface of similar percentage fit.

The interpretation of the results of rolling mean analysis is less difficult than for trend surface analysis as they are presented in a familiar form to the geochemist, i.e. level and relief.

10.03. Schist Belt Study.

The aim of interpretation in complex areas such as the schist belts is to ascribe all the distinctive geochemical patterns observed in the data to a causal factor or a mixture of factors which can be related to features of the primary and secondary environment. However, when the differences in the patterns are subtle it becomes increasingly difficult to carry out interpretation efficiently. In an attempt to increase the efficiency of interpretation by using the data itself to determine the causal structure of the geochemical patterns the application of factor/vector analysis has been investigated.

For this investigation an area of some 30 square miles was selected in the north of the Nimini Hills where ultrabasic schists, metasediments and granites are the major rock types. A minor intrusive phase of aplites containing cassiterite is also known to occur. The technique of factor/vector analysis has been described in section 5.05 and for this study 100 samples were used for which 13 variables had been determined, As, Co, Cr, Cu, Ga, Mn, Mo, Ni, Pb, Sn, Ti, V and Zn. A number of trial computations were carried out in which the data was expressed in terms of 2 to 5 factors.

A. Presentation of Results

The first three factors extracted account for a total of 89.3% of the variability of the data, 76.2%, 8.0% and 5.1% respectively. The following two factors accounted for 2.6% and 2.2% each. The fourth factor appeared to be closely related to the second factor and the fifth to the third so forming two sub-groups of the second and third factors. As one of the advantages gained by the use of factor/vector analysis is the reduction in the number of maps required to present the major features of the data, it was decided to use the three factor model in which the two sub-groups of factors two and three were incorporated rather than the five factor model.

As the three factor model accounts for only 89.3% of the total variability 10.7% of the information in the data is unaccounted for. Thus the actual fit of the data to the new model is of interest and this is expressed by the communality, which for a perfect fit equals 1.0 and decreases as the fit deteriorates. This fact is of the greatest significance during interpretation as samples with low communalities must contain information from some causal factor unaccounted for by the factors mapped. If all the mapped factors can be related to bedrock types the extra information could be due to a less important rock type, a particular secondary environment, or, and of the greatest importance in the present exercise, the presence of some discrete mineralisation.

To ease interpretation the factors, which are purely mathematical in nature, are resolved into vectors. The samples whose composition is nearest to that of the factors are chosen as vectors and the remaining samples are expressed as percentages of these. It then remains to relate the vector samples to features of the primary and secondary environment of the study area.

B. Description of Results

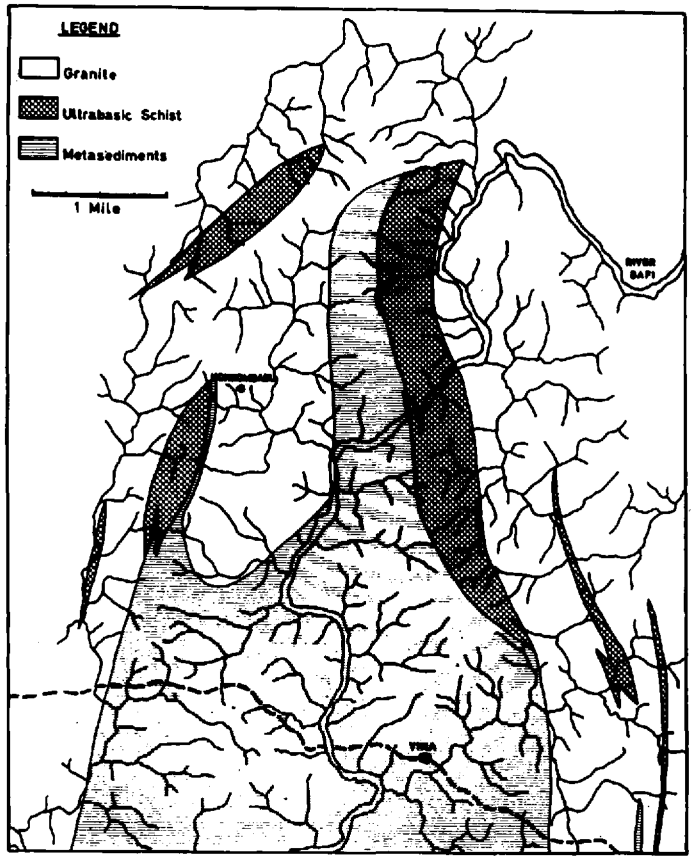
The three vector maps together with the communality map of the factors underlying the vectors are presented together with the geology in figure 52.

Areas high in vector 1 components are generally confined to the western parts of the study area. A marked north-south zone of low values occurs through the central part of the study area. In contrast, vector 2 is highest in the central part of the study area where vector 1 is low in value. Lastly, vector 3 is somewhat similar to vector 1 in that it exhibits the feature of a north-south zone of low levels. However the similarity ceases there, as the zones of high vector 3 are predominantly in the north and northeast of the study area.

The communality map indicates several areas of low fit of the data to the three factor model. The most significant of these are north of Konkombadu and to the north of Yima (fig. 52). Several other scattered cases are present but 80% of the data is within the 0.81-1.00 communality range.

C. Interpretation of Results

The vector 1 sample is from the granitic area surrounding



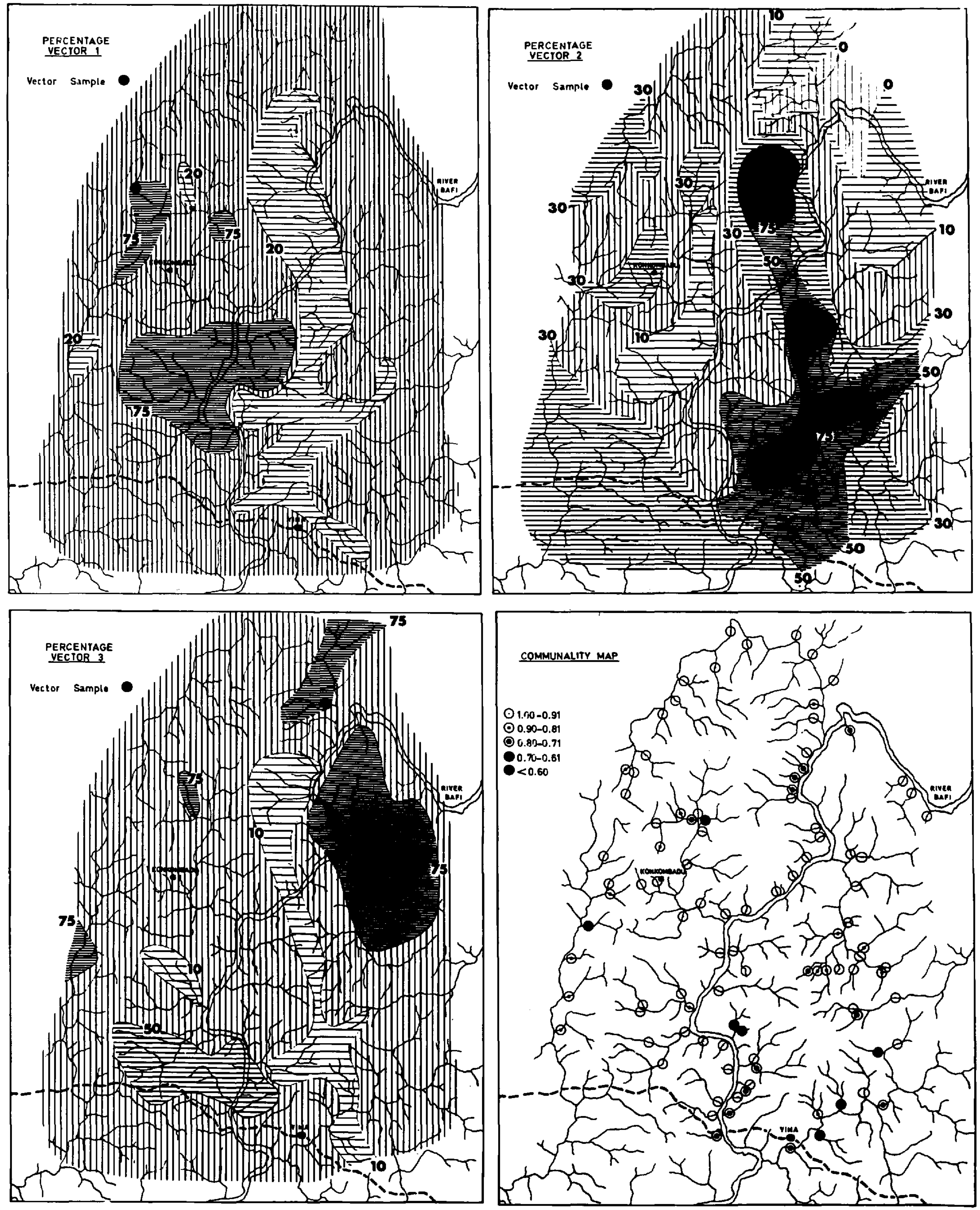


Fig. 52

Nimini Hills Factor Analysis

the schist belt and it is of considerable interest that it comes from an area where many aplitic intrusives have been noted. Vector 2 is associated with the major belt of ultrabasic schists in the study area. Lastly, vector 3 appears to be related to low level patterns of the mafic elements within the surrounding granites. These low values could either be a feature of the primary geochemistry or a pattern superimposed by a secondary environment. The former view is believed to be true as the physical environment is different in the various areas of high vector 3. Concluding, it appears that vector 1 may be associated with intrusive granitic phases, that vector 2 is almost certainly associated with ultrabasic schists and that vector 3 is associated with a bedrock containing low levels of mafic elements and it is suggested that this could be granite gneiss.

Samples with a high communality are those whose variability can be explained by the mixing of information, and therefore sediment, from the vector types. However, of interest are samples characterised by a low communality as these must contain information from some other source than the three vectors.

In interpreting the communalities the effect of analytical and sampling errors should be allowed for. A limit is required by which it can be decided, at some probability level, if the low communality is due to the accumulation of analytical and sampling errors or is due to some unaccounted for source of information. At present no such limit can be calculated due to the lack of development of factor/vector techniques in the present field of study. However, a subjective appraisal of the communalities has been made in order to select anomalous samples.

By selecting the 0.80 communality as threshold level some 20% of data becomes possibly anomalous on the basis of the three factor model. By using the conventional method of anomaly selection where the data is split into three groups, ultrabasic, metasedimentary and granitic, and the threshold (mean $\pm$ 2 sigma) determined for each element, 33% of the data is possibly anomalous, 5% negative, probably anomalous (-3 sigma limit), and 4% positive, probably anomalous.

In comparing the results of the two anomaly selection techniques it is apparent that both techniques select anomalous samples which the other does not. Of the four positive, probably anomalous samples only three have communalities less than 0.80; the fourth which reveals high arsenic levels has a communality of 0.97. Of the five negative probably anomalous samples two show communalities less than 0.80 and the remaining three greater than 0.80. Viewed in terms of communality of the 20 samples which exhibit values less than 0.80 ten can be related to samples selected by conventional means and ten cannot.

Without being able to carry out further detailed survey work it is difficult to critically assess the relative merits of the two anomaly selection techniques in highlighting potentially mineralised areas. However, the area of high tin levels discovered by the reconnaissance survey has been shown to contain cassiterite and both methods indicate the area of mineralisation as anomalous. The area of low communalities around Yima is also considered to be of particular interest as the conventional data interpretation indicates that the contents of As, Cu and Mo are all above positive threshold.

For the following reasons the communality map is believed to be presenting a more realistic analysis of the data. Firstly, as the conventional method relies on grouping the data under bedrock, or environmental, types misposting into the wrong pigeonhole is likely in areas of poor exposure. Secondly, as the conventional method relies on pigeonholing the samples this precludes all possibility of acknowledging samples to be composed of mixtures of sediment from two or more sources. It is suggested that the samples selected as anomalous by the conventional method and not by factor analysis have been misposted into wrong rock type groups. Where samples are selected by factor analysis, and not by the conventional method, may be due to the misgrouping but it may also be due to factor analysis recognising subtle patterns which before had been hidden within the background of the conventional method.

D. Summary

The application of factor/vector analysis to the problem of interpreting geochemical reconnaissance data from areas of complex geology has revealed several important points.

Factor analytical techniques can successfully reduce the number of maps required to present the most significant features of the data, thus easing assimilation of the data.

To a very large extent the success of the interpretation of the results of factor/vector analysis is dependent on finding the relationship of the hypothetical factors to features of the primary and secondary environment of the field area.

The communalities can be used as a method for selecting anomalous samples in terms of the extracted factors and their associated vectors.

The objectivity of the selection of anomalous samples could be much improved by computing a communality threshold level on the basis of analytical and sampling errors.

10.04. Summary and Conclusions

The methods of trend surfaces, rolling mean and factor analysis have been applied to differing problems of interpretation in Sierra Leone.

Both trend surface and rolling mean analysis have been applied to the basement data and a requirement of these methods is that the data used be normally distributed. However, this constraint is far more serious in trend surface analysis than in rolling mean analysis. The trend surface is fitted to the whole area, thus the whole of the data should be normally distributed, but in rolling mean analysis this need not be the case under certain circumstances. If the size of the search area is small in comparison with the size of areas of different population, sufficient searches will fall into each differing area and the results will be statistically valid. In areas near the junction of two populations the surface will be in transition between two levels and the relief of the data will be seen to be high due to the inclusion of data from both populations. Thus as long as there is sufficient data in each search area, and this is normally distributed, except in contact areas, and enough searches are present in each different population area to sufficiently elucidate the underlying trends, rolling means can be used in areas where several populations are present.

The greatest contribution of these two methods has been with elements where the trends were not clear using the conventional means of data presentation. Both techniques fulfilled this task well but during the studies observations were made on the applicability of the techniques and a comparison between conventional data presentation and the mathematical techniques can now be made.

Firstly, it has been shown using surface trend analysis that the lack of appreciation of the regional trends in the conventional symbol maps is due to an inability to extract the underlying trend from the local variability rather than any failure in the symbol system used.

A careful comparison of the cubic trend surfaces with rolling means surfaces indicates that where there are areas of persistently positive or negative residuals associated with the trend surfaces, indicating an inability of the trend surface to adjust sufficiently to the data, the rolling mean surface is adjusted to the data and therefore gives a more realistic surface.

A theoretical objection to the method of surface fitting used is that a polynomial function is employed. The use of a function of this type is probably quite unrealistic as the basement is a metamorphic area and has suffered considerable chemical and physical changes. These changes will have been controlled by the laws of thermodynamics, and these generally follow exponential, and not polynomial, laws. However, if only low order surfaces are used to determine the regional trend the polynominal model is probably valid. But a drawback of low order surfaces is that they often suffer severe distortions around the edge of the mapped area where they start to rise or fall to exceptionally high or low values.

The residual deviations from the trend surfaces can be interpreted objectively, taking account of the analytical and sampling errors, and can be used for identifying anomalous samples and areas. In contrast, rolling mean analysis is more suited to outlining areas of high relief than to identifying single anomalous samples.

Thus the technique of trend surface analysis seems suited to problems of mineral reconnaissance as, during the interpretation of residuals, attention is focussed on single, or groups of, samples. In contrast, rolling means, with standard deviation maps offering maps of geochemical relief, are more suited to problems in regional reconnaissance mapping, where the more realistic nature of the rolling mean surface would also be an advantage over trend surface techniques.

As no further survey work on detailed areas has been carried out in the basement area it has not been possible to assess the significance of the results in terms of aiding mineral exploration. However, on the basis of previous knowledge on the distribution of chromite in Sierra Leone it is very probable that the areas of high chromium level and relief in the southeast of the basement are delineating a chromium distribution which is related to a metallogenic province.

As has been pointed out contouring methods such as trend surface and rolling mean analysis are not applicable in areas of complex geology and in such cases it is necessary to relate geochemical patterns to their causes rather than to an areal trend in distribution. The multivariate technique of factor analysis has been applied to interpreting data from an area in the Nimini Hills in order to assess the techniques potential as an interpretating aid in complex geological environments.

Factor analysis enables a large proportion of the variability of a set of data to be presented on a few maps by re-expressing the data as proportions of a number of causal factors determined by a mathematical appraisal of the variability of the data. Clearly, as the majority of information is presented on fewer maps than there are variables, factor maps considerably aid data assimilation. As all the variability is not accounted for it is of considerable interest to know which samples contain the unaccounted for information. Communality maps offer to be a most powerful interpretive tool once the geological significance of the factors has been determined as it is the samples with low communalities that hold the information derived from some source other than the determined factors.

In the study of the Nimini Hills area the vector maps considerably helped the understanding of the data as the vectors and their underlying factors could be related to different bedrock types. The communality map delineated a number of areas as of interest, and some of these may be associated with mineralisation. Some of these areas were already believed to be of interest;

however, the technique has outlined a further number of areas where subtle variations do occur but were undetected by conventional means of interpretation.

The main criticism of the factor technique is that the factors are entirely mathematical, and thus hypothetical in geological terms. Thus care must be exercised in choosing only significant factors to be represented in the maps used for interpretation. Having selected these factors the greatest attention must be paid to interpreting them, and their associated vectors, in terms of geology. This link is the weakest in the logical chain underlying factor/vector techniques.

In conclusion the advantages and disadvantages of the three methods may now be bo briefly stated. Of the two methods available for elucidating trends, polynomial trend surface analysis is only applicable to single populations and the residuals offer an objective anomaly selection method so suiting the method to problem of mineral reconnaissance. Rolling mean analysis, however, provides a more realistic model of the areal variability and may be applied, under certain circumstances, in areas containing more than one population. Local standard deviations are not well suited to outlining single anomalous samples but do provide useful information on the geochemical relief, thus this model is best suited to regional mapping problems. Factor analysis has the greatest potential as an anomaly selection device as it can be used in the most complex areas where, instead of approaching the interpretation element by element, it is carried out in terms of the factors affecting the observed patterns.

It is suggested that the combination of rolling mean analysis for elucidating regional trends and studying local relief in individual elements coupled with factor analytical techniques for selecting anomalous samples, in terms of the major geological and environmental factors, would provide a most powerful and objective interpretive tool.

CHAPTER 11 - SUMMARY OF CONCLUSIONS

11.01. Introduction

The present research study set out to investigate by means of regional geochemical surveying:-

(a) The identification of areas of economic mineral potential.

(b) The comparison between the primary geochemistry and weathering products of various lithological units in the field area and with similar rock types in the Sula Mountain - Kangari Hills.

(c) To determine whether the variations observed in the schist belts were also reflected in the basement, and in addition, to delineate any further metallogenic or geochemical provinces and to obtain any information of fundamental importance on the distribution of minor elements within the basement.

11.02. Summary

The following section consists of the main conclusions of the research study itemised in the order of this thesis:-

A. Schist Belt Sampling Programme

1) The sampling density used in the study of Kambui schist areas has proved high enough to delineate all known

mineral occurrences of significance.

2) The sampling density could be reduced by as much as 50% and the major patterns, related to bedrock geochemistry, would still be clearly defined.

B. Basement Sampling

3) Stream sediments were chosen as the main sampling media as they represent a composite sample over a small finite area. Supporting collections were made of rocks and soils. The stream sediment sampling at one site per 75 square miles has proved to be representative of this large area and sufficient to demonstrate the major features of the basement geochemistry.

C. Sample Analysis

4) The minus 80 mesh size fraction used for analysis has proved satisfactory in providing data for the preparation of regional geochemical maps.

5) The spectrochemical technique used for sample analysis has proved to be a rapid and efficient method in terms of the objectives of the study. The methods of chemical analysis have proved satisfactory in providing the required information.

D. Analytical Accuracy

6) Due to the use of direct comparison with standard plates for the estimation of metal contents in spectro-

chemical analysis some operator bias is introduced into the method.

7) The operator bias introduced in estimation can be reduced by the use of a photodensitometer for making objective measurements of line intensity.

8) Matrix effects are present in the analytical data due to the wide range of matrix composition of the stream sediments. However, these influences on the data are small in relation to the overall magnitude of the data and do not influence interpretation.

E. Analytical Precision

9) The precision of the spectrochemical analyses has proved sufficient for the problem.

10) An alternate method for the computation of analytical precision has been investigated, this is capable of giving equal weight to all determinations, and gives a truer estimate of the precision than the previously used method.

11) The precision of the chemical analyses has proved to be comparable with those of the spectrochemical determinations, and thus the analyses are compatable.

F. Geochemistry of the Schist Belts

12) The majority of the minor elements investigated show distribution patterns which can be broadly related to

the major bedrock units. Levels of Co, Cr, Cu, Mn, Ni, Ti, V and Zn are highest over schistose rocks and generally lowest in granitic areas where lead levels are often highest.

13) Within each major bedrock unit minor differences of geochemical pattern are present, the major factor controlling these minor variations is the bedrock geochemistry.

14) Soil type is the most important modifying influence on the patterns produced by the weathering bedrock. However, the modifications are not so severe that they cause the patterns derived from major bedrock unit to resemble those from a different unit. In areas of basic schist covered by mature soils and duricrust, Cr, Cu, Ni and Pb tend to be enhanced and Co depleted relative to areas of immature soil. In ultrabasic schist areas covered by mature soils only Pb appears to be enhanced and Co, Cr, Ni and V are depleted relative to areas of immature soil.

15) The survey successfully delineated a number of areas as being of increased mineral potential. Patterns were detected which were presumably related to zones of gold/ arsenic, molybdenum, base metal and tin mineralisation. The Nimini Hills is, in particular, characterised by widespread anomalous arsenic levels, whilst only scattered significant arsenic concentrations are present in the remaining areas. Molybdenum concentrations are

found in all the field areas but the most widespread patterns are found in the Nimini Hills. Several localities are characterised by high Cu, Pb and Zn levels which cannot be reconciled to levels of these elements expected in silicate minerals; the most important of these are in the Gori and Nimini Hills. Last, significant tin patterns are only found in the Nimini Hills where a bedrock source of cassiterite has been indicated.

16) A study of the regional distributions of molybdenum offers strong evidence for some tectonic control of molybdenum patterns. Of particular interest is an east-west trending zone of high molybdenum levels in the granites to the south-west of the Nimini Hills.

G. Comparison of the Geochemistry of the Kambui Schist Belts

17) A comparison of the chromium and nickel contents of stream sediments, derived from non-duricrusted ultrabasic rocks throughout the Kambui Schist areas of Sierra Leone, indicate a general increase in level of these elements in a southeasterly direction across central and southern Sierra Leone.

18) Several distinct metallogenic provinces are present in Sierra Leone and these can be related to geochemical variations in the reconnaissance data.

H. Geochemistry of the Basement

19) The patterns of metal distribution in rock, soils and stream sediments from the basement are basically similar so indicating the bedrock geochemistry to be the major controlling factor in the soil and stream sediment patterns. The dominant pattern of the results is the trough shaped feature with high levels of Co, Cr, Cu, Mn, Ni, Ti, V and Zn in the northwest and southeast of the basement area and low levels around the Sula Mountains - Kangari Hills area.

20) Variations in bedrock geochemistry, as demonstrated by the stream sediment survey, are considered predominantly to reflect variations in the Pre-Cambrian geochemistry prior to granitisation.

21) The fact that the patterns of chromium and nickel distribution reveal the same trend as results obtained in comparing the geochemistry of the schist belts is considered to be of the greatest significance and to indicate that the basement is predominantly of metamorphic origin.

22) The occurrence of high chromium contents in the stream sediments of the southeast of Sierra Leone associated with known chromitiferous intrusives demonstrates the applicability of the method to delineating areas of increased mineral potential.

23) Areas of high Mo, Pb, Sn and Zn levels are worthy of further examination as areas of increased mineral potential.

I. Mathematical Aids to Data Analysis

24) Trend surface analysis has been investigated and provides an objective means of depicting regional trends.

25) The absolute shape of the trend surfaces may not be faithful models of the variability, however, if only low order surfaces are computed they are probably geologically valid.

26) The trend surfaces provide a useful objective approach to the comparison of patterns observed in different elements and sampling media.

27) The correct interpretation of the residuals requires a knowledge of the sampling and analytical errors.

28) The residuals reveal patterns which have been superimposed on the dominant regional trend. It has, however, not been possible to investigate the geological significance of these areas.

29) The surface trend technique removes the grouping effects of the symbols used in the initial metal maps and presents the data relating to the regional trends in a more assimilatable form. The technique also aids the detection of significant minor variations which may be

masked by the grouping effect of the symbols.

30) The rolling mean surfaces are an objective method for depicting regional trends in a more assimilatable form than symbol maps.

31) The shape of the surface produced is more faithful to the original data than a cubic trend surface of similar percentage fit.

32) If the sampling and analytical errors are truly random and contain no systematic component these need not be allowed for during interpretation, as their influence is minimised by the computation of the rolling means.

33) Any areas characterised by increased heterogeneity of the primary and secondary environment will be marked by increased standard deviations of the means.

34) The interpretation of the results of rolling means analysis is simpler than that of trend surface analysis as the results are presented in a form familiar to the geochemist.

35) Factor analytical techniques have been investigated successfully as an aid to improving interpretation in areas of complex geology by presenting a large mass of data in terms of the causal factors controlling the distribution of the data.

36) The communalities of the factor model can be used as a method for selecting anomalous samples in terms of extracted factors and this offers a most useful tool

for identifying mineralised areas.

37) To a very large extent the success of the interpretation is dependent on finding the correct relationship of the hypothetical factors to the primary and secondary environment of the field area.

CHAPTER 12 - RECOMMENDATIONS FOR FUTURE RESEARCH

12.01. General Recommendations.

The present research study has indicated several areas where further research would possibly provide information of fundamental interest:-

1) The extension of the basement survey technique to other large areas of metamorphic basement rocks could provide information of both fundamental and economic importance. Of particular interest would be the extension of the Sierra Leone Survey to cover the whole of the West African basement shield. The further extension of this work to basement areas in South America could provide information on the likelihood of continental drift. Other areas where the basement technique might be applied are in the Shield areas of Canada and Scandinavia.
2) The technique of Discriminant Analysis should be investigated as a method for classifying sediments into provenance groups on the basis of all the measured variables. This method allows established information to be introduced into the problem and the decision as to the probability of a sample coming from one or other of the established types is made on the basis of prior information.

3) A new form of factor analysis should be developed where any number of established causal factors could be introduced and the data screened in terms of these factors with the communality of each sample being computed in terms of the a priori model. By this method successively more of the variability of the data could be apportioned to known causal factors and herein lies a potentially powerful technique for the interpretation of geochemical data by multivariate methods. In addition, it will be necessary to determine objectively a communality threshold on the basis of which it can be decided whether a sample does not fit into the prescribed model due to an accumulation of analytical and sampling errors or, and more importantly, due to information being present from some unaccounted for causal factor.

4) The application of Information Theory to aiding the mapping and interpretation of multivariate systems should be investigated. For instance, in areas where several causal factors are known to be operating a map of the entropy of the area would indicate where particular patterns were dominant and where the maximum mixing of the patterns was taking place.

5) The application of Filter Theory developed in electrical engineering for problems involving the isolation of significant signals from a background of noise should be

investigated as a method for detecting anomalous levels of elements in sets of data.

12.02. Recommendations for Future Research on Problems Particular to Sierra Leone

The research programme carried out in Sierra Leone has indicated a number of problems where further work would reveal information of both economic and fundamental interest.

1) The most important factor affecting the formation of the stream sediment patterns from the original bedrock patterns is the nature of the secondary environment. The exact mode of formation of the stream sediment patterns is still not fully understood. Investigations into the soil and rock weathering processes and how the behaviour of elements is affected by their being held in different primary minerals should be made.
2) A number of areas were delimited as of being of increased economic potential in the schist belt study areas. These areas should be further investigated in order to establish their true potential. Of particular interest in this field are the arsenic anomalies of the Nimini Hills areas, some of which are associated with high Cu, Pb and Zn levels and which may be related to bedrock sources of gold. Also of interest are the arsenic anomalies in the north of the Gori Hills and the area

in the South Kambui Hills which is characterised by a stream sediment pattern similar to that at Yirisen where a bedrock source of gold has been found. The molybdenum anomaly found in the south of the Nimini Hills should be investigated in order to ascertain the cause of the zone of high levels which might be related to a widespread area of disseminated molybdenite. The tin occurrence at Konkombadu in the Nimini Hills should be further investigated by pitting and banka drilling to determine if any alluvial concentrations of cassiterite worthy of exploitation are present.

3) Should economic conditions change and nickel become of economic interest, the lateritic soils overlying the nickel rich ultrabasic schists of the Kambui and Nimini Hills could be of considerable potential as nickeliferous lateritic ores.

4) The basement survey of the metamorphic granites has revealed regional variations in the metal distribution. As there is complete aerial photographic cover of Sierra Leone a photogeological and structural map of the basement area should be prepared for simultaneous study and interpretation with the geochemical data.

5) The basement survey indicates a number of areas as being of increased economic potential. The most important of these is the zone of increased tin levels to the east of the South Kambui Hills where alkaline intrusive may be

present. Also of interest are the increased lead levels northwest of the Sula Mountains and the site reflecting anomalous levels of Mo, Pb, Sn and Zn north o of the Sula Mountains.

6) Should economic interest be revived in chromium, the search for further chromitiferous bodies should be concentrated in the country around the southern end of the Kambui Hills where the highest chromium levels and relief are observed.

7) Should methods be developed such as recommended in paragraph 3 of section 12.01 the entire schist belt data collected to date should be re-interpreted using this technique in an attempt to carry out a realistic and objective interpretation of the data in order to to discover significant anomalies possibly associated with mineralisation.

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APPENDIX I

Computation of Analytical Precision

The program described has been written in Fortran IV to carry out the calculation of analytical precision after the method of Stern (1959) where the data has been derived from the technique described by Craven (1954).

The card arrangement necessary for running the program at Imperial College is shown in figure 1. The arrangement of the first four cards, the program, the $DATA and $EOF cards is common to all the programs described and is laid out in Appendix IV. Following the $DATA card are M sets of data, where M is the total number of problems to be processed. Each set of data consists of eight cards which must be punched as follows:-

Card 1

columns	1	Punch 1, for printer carriage control.
	2-78	Punch any title information.

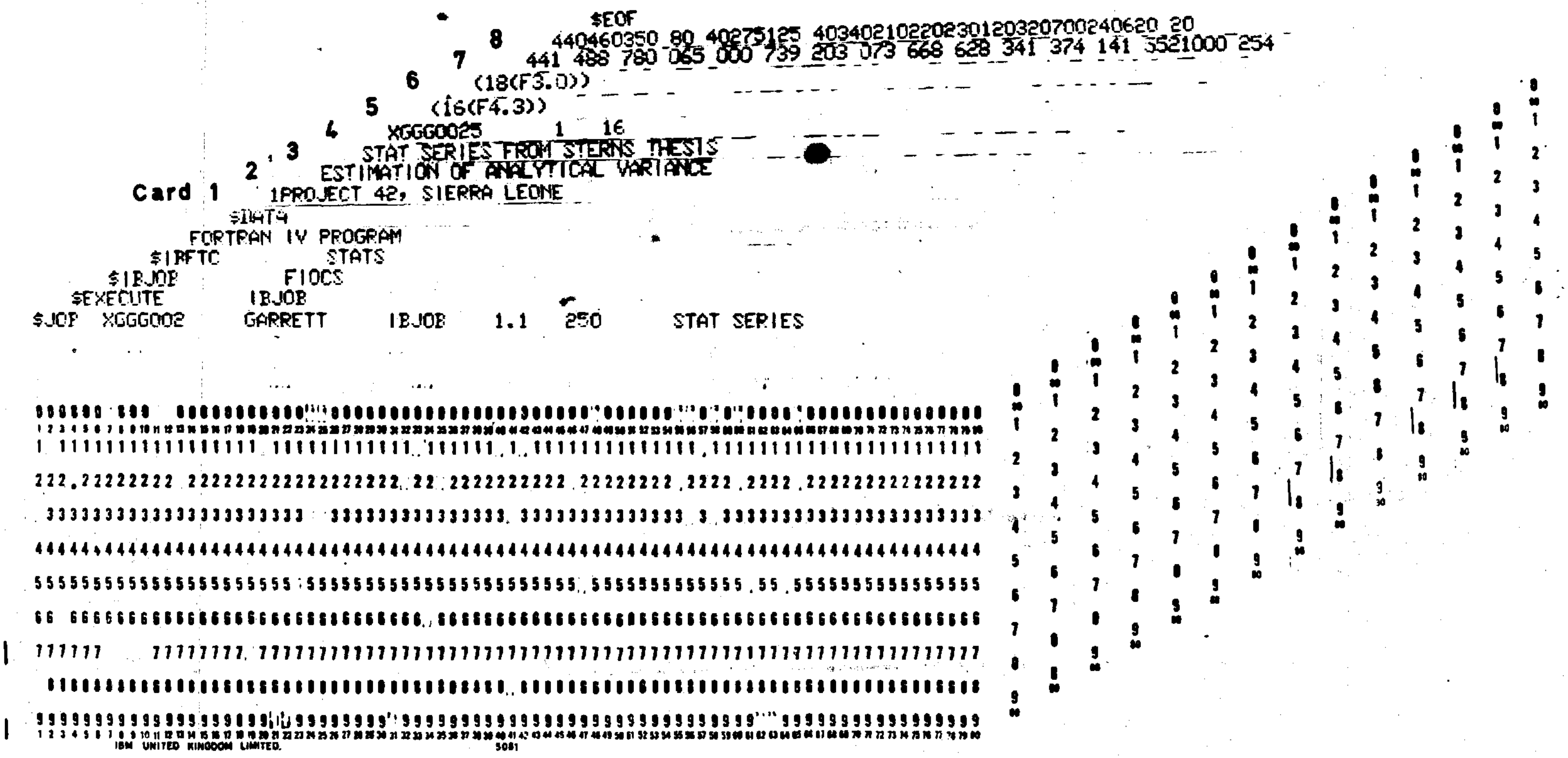
Cards 2 & 3

	1	Leave blank.
	2-78	Punch any title information.

Card 4

	14-15	Punch, M, the total number of problems (max 99).

FIG. 1— PROGAM SET-UP FOR STATISTICAL SERIES DATA



19-20 Punch, NX, the number of analytical determinations in the current problem (max 20).

Card 5

Columns 1-78 Punch the format of theta value card (7).

Card 6

1-78 Punch the format of the analytical values and estimated high and low values of the statistical series which are punched on card 8.

Card 7

1-80 Punch the theta values of the samples being analysed according to the format punched on card 5.

Card 8

1-80 Punch the analytical values, NX in numbers, and the estimated high and low values of the statistical series according to the format punched on card 6.

The format statements are both of similar form. The statements start and close with brackets, between the brackets is punched the number of fields to be read from the cards (7 & 8) and the way these are to be read. In the present case the theta format consists of 14 fields to be read in blocks of 4 with only three numbers to the right of the decimal point. The format card for the analytical values requires two extra fields to allow for the estimated high and low values, i.e. 16, and these fields are read in blocks of three with no decimal places.

As an indication of the time required for computation, and the number of lines of output, the following rules should be followed:-

$$\text{Time in minutes} = 1.0 + M \times 0.1$$

$$\text{Lines output} = 150 + M \times 90$$

The program (Table I), after allocating the necessary storage for numbers used and calculated in the program, sets the count of the number of problems processed (MM) to zero, following this eight cards are read. The first three are title cards (TIT1, TIT2, & TIT3), the contents of which are printed out prior to the results. The second card informs the program of the total number of problems to be processed (M) and the number of analytical determinations (NX). The four remaining cards inform the computer of how it is to read the data for the computation and the data itself. The first and third cards relate to the theta (THETA) values of the statistical series, and the second and fourth to the analytical values (X) together with the estimated values of the high (HICOMP) and low (LOCOMP) end-members of the statistical series. If the value of LOCOMP is zero it is set to 0.1 as at a later stage the logarithm of LOCOMP is taken. The initialisation phase of the program is completed by the calculation of the lambda values (LAMBDA) of the statistical series from THETA and setting the count of the number of times the computation (iterations) has been carried out (N) to one.

The computation is now started, first the calculated values for the statistical series samples (CALC) are computed from HICOMP, THETA, LOCOMP and LAMBDA. Two parameters termed 'theta dash' and 'lambda dash' by Stern (1959) are then computed (CICOMP & COCOMP). A further parameter, DIFF, the difference of the logarithms of the analytical value, X, from the calculated value, CALC, is then computed.

The standard deviation of the analytical errors SIGMA is calculated from the sum of all the DIFFs, the number of samples involved (NX) and the conversion factor for logarithm to base 10 to natural logarithms. The analytical precision is then calculated for the two sigma (95%) level.

The values of CICOMP, COCOMP and DIFF are used for the formation of two matrices, A and R. Matrix A is then inverted, AINV, and a correction to the high and low values of the statistical series calculated, CORR. A full explanation of the theory of this least squares operation is given by Stern (1959). If the logarithms of these corrections exceeds 1% they are applied to the estimated values and the program loops to carry out the second iteration; this process continues until the corrections are within the 1% limits.

On completing the computation all the revelant information on the problem and computation are printed out (Table II). Finally, using a standard package program available at Imperial

College the analytical and calculated values are plotted together on a graph against the theta values.

This printing completed, the count of the problems processed (MM) is incremented by one and compared with the total number of problems to be processed (M). If these numbers are equal the program stops and the job is completed; however, if these numbers are not equal the program loops back to read the next set of data cards and so on until the job is finally completed.

Table I

```
C       APPLIED GEOCHEMISTRY• GEOLOGY DEPARTMENT• IMPERIAL COLLEGE
C
C       1965 GARRETT• PROGRAM WRITTEN TO COMPUTE ANALYTICAL VARIANCE AND
C            PRECISION LOGARITHMICALLY• AFTER STERN(1959)•
C
C            TIT1• TIT2 AND TIT3 ARE TITLE CARDS•  VFT1 IS THE THETA CARD
C            FORMAT AND VFT2 IS THE DATA CARD FORMAT•
C
C            M IS THE TOTAL NUMBER OF PROBLEMS TO BE PROCESSED (MAX 99)•
C            NX IS THE NUMBER OF ANALYTICAL VALUES (MAX 20) TO BE
C            PROCESSED• READ IN AS X(I)•  HICOMP IS THE ESTIMATED HIGH
C            VALUE AND LOCOMP THE ESTIMATED LOW VALUE OF THE STAT SERIES•
C
      DIMENSION X(20)•THETA(20)•LAMBDA(20)•CALC(20)•DIFF(20)
      DIMENSION CICOMP(20)•COCOMP(20)•A(2•2)•AINV(2•2)•R(2)•CORR(2)
      DIMENSION VFT1(13)•VFT2(13)•TIT1(13)•TIT2(13)•TIT3(13)
      DIMENSION D(2•40)
      REAL LAMBDA•LOCOMP•LMEAN
C
C     INITIALISE AND READ MASTER CARDS ETC•
      MM=0
    1 READ (5•102) TIT1•TIT2•TIT3
      READ (5•101) M•NX
      READ (5•102) VFT1•VFT2
      READ (5•VFT1) (THETA(I)•I=1•NX)
      READ (5•VFT2) (X(I)•I=1•NX)•HICOMP•LOCOMP
      IF(LOCOMP•LE•0•0)LOCOMP=0•1
      DO 2 I=1•NX
    2 LAMBDA(I)=1•-THETA(I)
      B=NX
      N=1
C
C     COMPUTE CALCULATED VALUES
    7 SUM=0•
      DO 8 I=1•NX
      CALC(I)=HICOMP*THETA(I)+LOCOMP*LAMBDA(I)
      CICOMP(I)=THETA(I)/CALC(I)
      COCOMP(I)=LAMBDA(I)/CALC(I)
      DIFF(I)=ALOG10(X(I)/CALC(I))
    8 SUM=SUM+DIFF(I)**2
      SIGMA=SQRT((SUM/(B-2•0))/(0•4342945**2))
      VAR=SIGMA**2
C
C     COMPUTE PRECISION
      LMEAN=ALOG10((HICOMP+LOCOMP)/2•0)
      PREC=(SIGMA*200•0)/LMEAN
C
C     FORM MATRICES
      DO 9 J=1•2
      R(J)=0•
      DO 9 I=1•2
    9 A(I•J)=0•
      DO 10 I=1•NX
      A(1•1)=A(1•1)+CICOMP(I)**2
      A(2•2)=A(2•2)+COCOMP(I)**2
      A(1•2)=A(1•2)+CICOMP(I)*COCOMP(I)
      A(2•1)=A(1•2)
      R(1)=R(1)+CICOMP(I)*DIFF(I)/0•4342945
   10 R(2)=R(2)+COCOMP(I)*DIFF(I)/0•4342945
C
C     INVERT MATRIX A
      DET=A(1•1)*A(2•2)-A(1•2)**2
      AINV(1•1)=A(2•2)/DET
      AINV(2•2)=A(1•1)/DET
      AINV(1•2)=-A(1•2)/DET
      AINV(2•1)=AINV(1•2)
C
C     COMPUTE CORRECTION
      CORR(1)=AINV(1•1)*R(1)+AINV(1•2)*R(2)
      CORR(2)=AINV(2•1)*R(1)+AINV(2•2)*R(2)
C
C     TEST FOR FURTHER ITERATION
      CIRLIM=(ALOG10(HICOMP))/100•0
      CORLIM=(ALOG10(LOCOMP))/100•0
      CORR(1)=ALOG10(ABS(CORR(1)))
      CORR(2)=ALOG10(ABS(CORR(2)))
      IF((CORR(1)•LT•CIRLIM)•AND•(CORR(2)•LT•CORLIM)) GO TO 12
      N=N+1
      HICOMP=HICOMP+CORR(1)
      LOCOMP=LOCOMP+CORR(2)
      GO TO 7
C
C     WRITE OUTPUT
   12 WRITE (6•102) TIT1•TIT2•TIT3
      WRITE (6•103) N
      WRITE (6•104) HICOMP
      WRITE (6•105) LOCOMP
      WRITE (6•106)
      DO 13 I=1•NX
   13 WRITE (6•107) THETA(I)•LAMBDA(I)•X(I)•CALC(I)•DIFF(I)•CICOMP(I)•CO
     1COMP(I)
      WRITE (6•108) VAR
      WRITE (6•109) SIGMA
      WRITE (6•112) PREC
      WRITE (6•113) ((A(I•J)•J=1•2)•I=1•2)
      WRITE (6•114) ((AINV(I•J)•J=1•2)•I=1•2)
      WRITE (6•115) (R(J)•J=1•2)
      WRITE (6•110) CORR(1)
      WRITE (6•111) CORR(2)
C
C     PLOT THE ANALYTICAL AND CALCULATED RESULTS
      DO 201 I=1•NX
      J=I
      JJ=NX+J
      D(1•J)=THETA(I)
      D(1•JJ)=THETA(I)
      D(2•J)=X(I)
  201 D(2•JJ)=CALC(I)
      [illegible]=2*NX
```

```
      A(1,2)=A(1,2)+C1COMP(I)*COCOMP(I)
      A(2,1)=A(1,2)
      R(1)=R(1)+C1COMP(I)*DIFF(I)/0.4342945
   10 R(2)=R(2)+COCOMP(I)*DIFF(I)/0.4342945
C
C     INVERT MATRIX A
      DET=A(1,1)*A(2,2)-A(1,2)**2
      AINV(1,1)=A(2,2)/DET
      AINV(2,2)=A(1,1)/DET
      AINV(1,2)=-A(1,2)/DET
      AINV(2,1)=AINV(1,2)
C
C     COMPUTE CORRECTION
      CORR(1)=AINV(1,1)*R(1)+AINV(1,2)*R(2)
      CORR(2)=AINV(2,1)*R(1)+AINV(2,2)*R(2)
C
C     TEST FOR FURTHER ITERATION
      CIRLIM=(ALOG10(HICOMP))/100.0
      CORLIM=(ALOG10(LOCOMP))/100.0
      CORR(1)=ALOG10(ABS(CORR(1)))
      CORR(2)=ALOG10(ABS(CORR(2)))
      IF((CORR(1).LT.CIRLIM).AND.(CORR(2).LT.CORLIM)) GO TO 12
      N=N+1
      HICOMP=HICOMP+CORR(1)
      LOCOMP=LOCOMP+CORR(2)
      GO TO 7
C
C     WRITE OUTPUT
   12 WRITE (6,102) TIT1,TIT2,TIT3
      WRITE (6,103) N
      WRITE (6,104) HICOMP
      WRITE (6,105) LOCOMP
      WRITE (6,106)
      DO 13 I=1,NX
   13 WRITE (6,107) THETA(I),LAMBDA(I),X(I),CALC(I),DIFF(I),C1COMP(I),CO
     1COMP(I)
      WRITE (6,108) VAR
      WRITE (6,109) SIGMA
      WRITE (6,112) PREC
      WRITE (6,113) ((A(I,J),J=1,2),I=1,2)
      WRITE (6,114) ((AINV(I,J),J=1,2),I=1,2)
      WRITE (6,115) (R(J),J=1,2)
      WRITE (6,110) CORR(1)
      WRITE (6,111) CORR(2)
C
C     PLOT THE ANALYTICAL AND CALCULATED RESULTS
      DO 201 I=1,NX
      J=I
      JJ=NX+J
      D(1,J)=THETA(I)
      D(1,JJ)=THETA(I)
      D(2,J)=W(I)
  201 D(2,JJ)=CALC(I)
      NXT=2*NX
      CALL XYPLOT(D,NXT,NX)
C
C     TEST FOR FURTHER PROBLEM
      MM=MM+1
      IF(MM.EQ.M)STOP
      GO TO 1
C
  101 FORMAT (13X,2(I2,3X))
  102 FORMAT (13A6)
  103 FORMAT (///17H ITERATION NUMBER,I3)
  104 FORMAT (/21H ESTIMATED HIGH VALUE,F7.1)
  105 FORMAT (20H ESTIMATED LOW VALUE,F8.1)
  106 FORMAT (///6H THETA,5X,6HLAMBDA,4X,8HANALYSIS,10X,16HCALCULATED VA
     1LUE,5X,14HLOG DIFFERENCE,7X,11H THETA DASH,10X,12H LAMBDA DASH//)
  107 FORMAT (F5.2,7X,F4.2,6X,F6.1,15X,F6.1,14X,F7.4,2(12X,F10.7))
  108 FORMAT (//15H LOG10 VARIANCE,2X,F7.4)
  109 FORMAT (16H LOG10 STD. DEV.,2X,F6.4)
  110 FORMAT (//25H CORRECTION TO HIGH VALUE,F7.1)
  111 FORMAT (24H CORRECTION TO LOW VALUE,F8.1)
  112 FORMAT (/48H PERCENTAGE PRECISION AT THE 95 PERCENT LEVEL  =,F6.2)
  113 FORMAT (//9H MATRIX A,4X,2(2X,F19.8)/13X,2(2X,F19.8))
  114 FORMAT (/13H INVERSE OF A,2(6X,F15.4)/13X,2(6X,F15.4))
  115 FORMAT (/9H MATRIX R,4X,2(2X,F19.8))
C
      END
```

Table II

PROJECT 42, SIERRA LEONE
ESTIMATION OF ANALYTICAL VARIANCE
STAT SERIES FROM BASEMENT ANALYSES, CHROMIUM

ITERATION NUMBER 4

ESTIMATED HIGH VALUE 361.2
ESTIMATED LOW VALUE 8.0

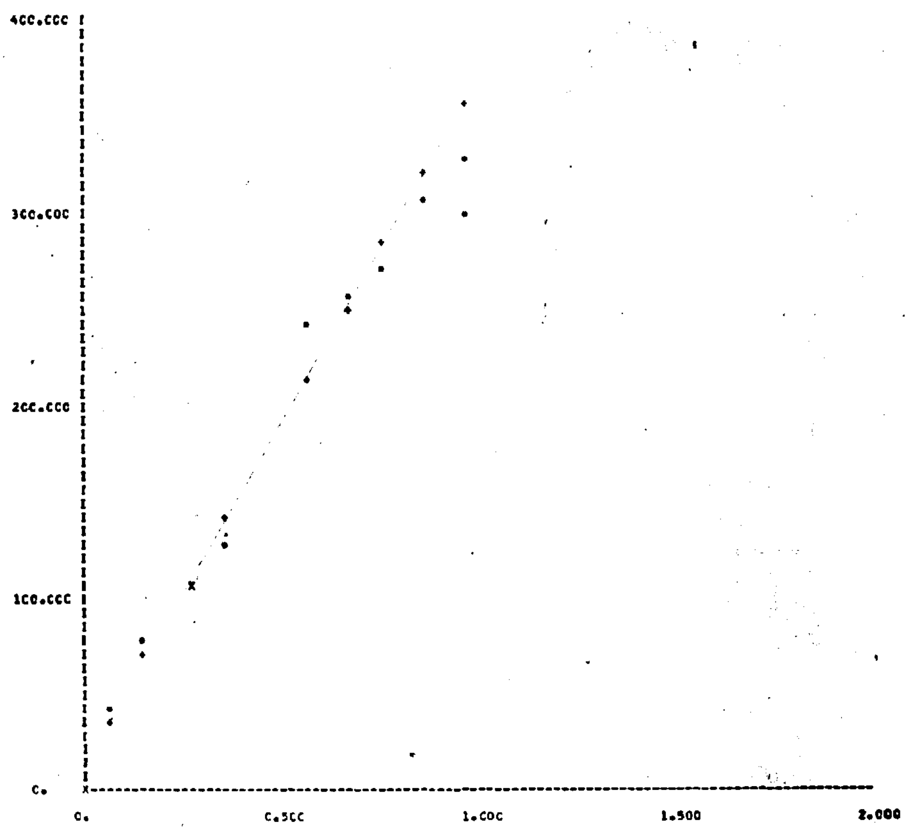
THETA	LAMBDA	ANALYSIS	CALCULATED VALUE	LOG DIFFERENCE	THETA DASH	LAMBDA DASH
0.90	0.10	310.	326.	-0.0217	0.0027618	0.0003069
0.70	0.30	260.	255.	0.0080	0.0027426	0.0011754
1.00	0.	330.	361.	-0.0392	0.0027666	0.
0.30	0.70	115.	114.	0.0040	0.0026329	0.0061435
0.	1.00	8.	8.	0.0013	0.	0.1253719
0.10	0.90	53.	43.	0.0878	0.0023056	0.0207862
0.40	0.60	139.	149.	-0.0309	0.0026758	0.0040197
0.80	0.20	280.	291.	-0.0161	0.0027534	0.0006883
0.	1.00	8.	8.	0.0013	0.	0.1253719
1.00	0.	303.	361.	-0.0763	0.0027686	0.
0.60	0.40	250.	220.	0.0557	0.0027284	0.0018189
0.20	0.80	87.	79.	0.0440	0.0025439	0.0101795

LOGIC VARIANCE 0.0116
LOGIC STD. DEV. 0.1077

PERCENTAGE PRECISION AT THE 95 PERCENT LEVEL = 9.50

MATRIX A	0.0007142	0.0011177
	0.0011177	0.0323099
INVERSE OF A	14077.6353	-49.1228
	-49.1228	31.3912
MATRIX B	-0.0001742	0.00596289

CORRECTION TO HIGH VALUE -0.5
CORRECTION TO LOW VALUE 0.2



APPENDIX II

Computation of Frequency Distributions

The program has been written in Fortran IV, up to twenty variables can be processed simultaneously in up to 9998 samples. One or more cards, depending on the number of variables, are used for each sample and the variables are punched across the card(s) (fig.1).

Various features incorporated in the program for flexibility of usage are as follows.

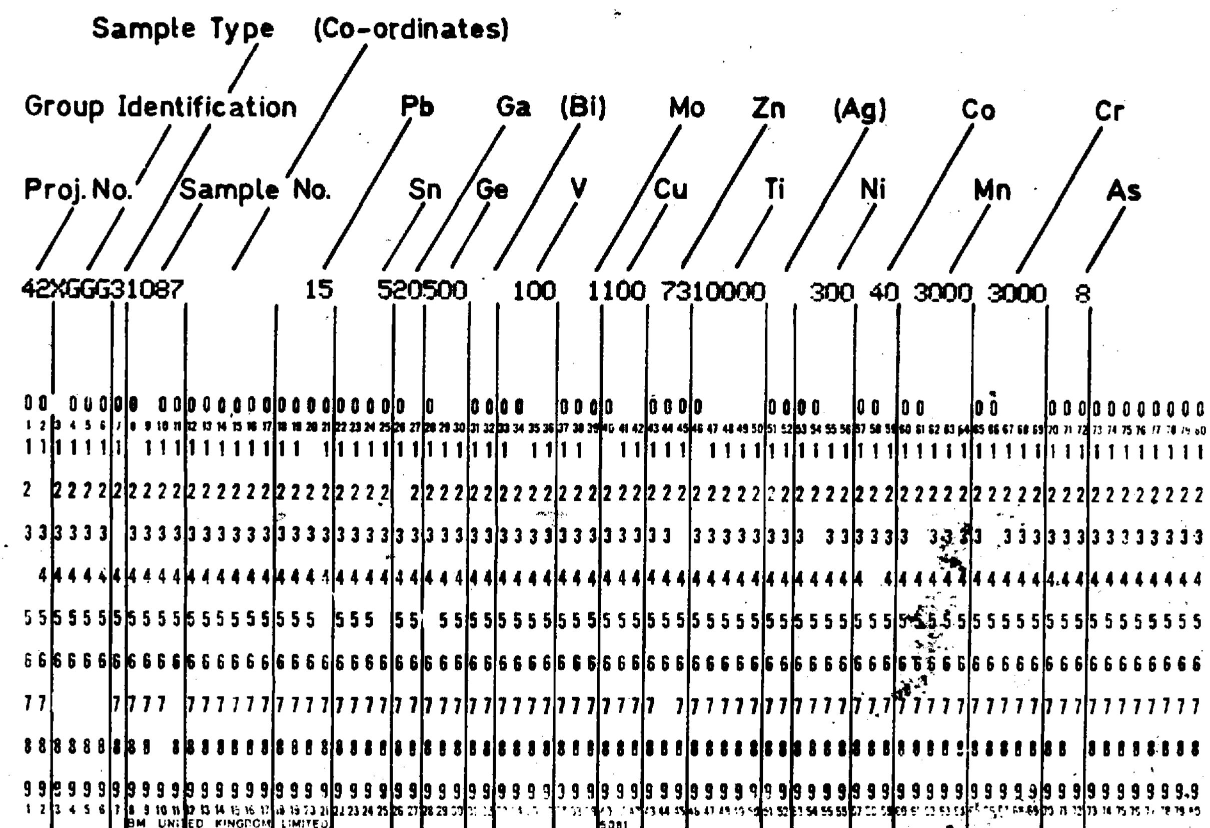
(a) The computations can be carried out in one of two modes according to whether the data is normally or lognormally distributed.

(b) Variable format input allows the punching arrangement of the data cards to be adjusted to the requirements of the specific problem. The format is read from a master card (the variable format card) prior to the processing of a particular set of data.

(c) A units card is punched with the name of the units of measurement of the data, which may be up to twelve characters long.

(d) Name cards are punched according to the identity of

FIG. 1 — DATA CARD FORMAT



the variables for a set of data; the names may be up to six characters long.

(e) Three title cards containing information identifying the problem are printed out prior to the computed output.

(f) Options are available to carry out a number of further tasks. The histograms may be plotted; ± 2 and 3 sigma limits may be set up about the means and samples falling outside these limits selected. A chi square test for normality may be made and a matrix of correlation coefficients between all the variables, together with the corresponding t values for assessing the coefficient's significance, may be computed.

Two systems of histograms are available for use. The first is the standard system used at the A.G.R.G. and described in the text. The second histogram system is formed by the computer itself from the lowest value of the histogram (A(1)) and increment equivalent to the group width (AINC) both of which are read from a master card. If the logarithmic option is not exercised these will be distributed arithmetically, i.e. with an initial value, A(1), of 100 ppm and an increment, AINC, of 50 ppm intervals will be formed at 100, 150, 200, 250 ppm etc. If the logarithmic option is exercised the distribution will be logarithmic; however, A(1) and AINC must be expressed in logarithms. Thus with an initial value, A(1), of log 2 ppm and AINC equal to log 0.5 ppm the intervals will be formed at 100, 316, 1000, 3162 ppm etc. Although A(1) and AINC must be punched on the master card in logarithmic form the values of the histogram intervals are antilogged prior to printing out as tabulation headings.

The arrangement of cards necessary for running the program at Imperial College is shown in figure 2. The description of the set up of the systems control cards is given in Appendix IV. Following the ØDATA card are stacked M sets of data, where M is the total number of problems to be processed. Each set of data is made up as follows:-

Card 1

Column	1	Punch 1, for printer carriage control.
	2-78	Punch any title information

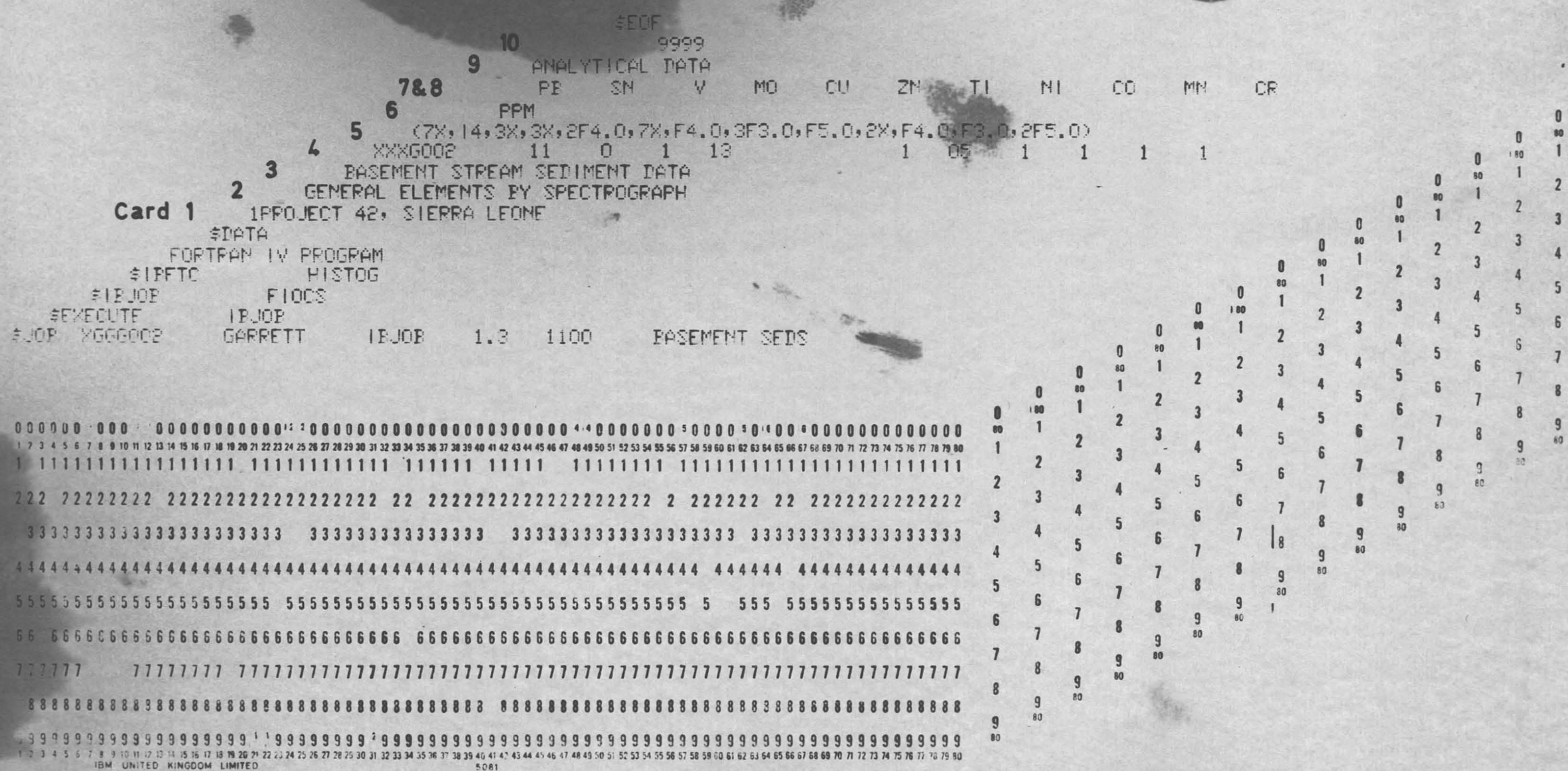
Cards 2 & 3

1	Leave blank
2-78	Punch any title information .

Card 4

1-10	Project identification number
14-15	NX, the number of variables, from 1 to 20
20	IFVH controls the histogram system used, punch 0 for the standard A.G.R.G. histogram or 1 for a user specified histogram, the specifications for which are punched columns 31 - 40.

FIG. 2 — PROGRAM SET-UP FOR FREQUENCY DISTRIBUTIONS



Columns 25 If IFVH is punched 1 this option, IFLH, controls whether the user specified histograms are arithmetic or logarithmic. Punch 0 for arithmetic or 1 for logarithmic.

29-30 NG, the number of histogram groups required; which may be between 1 and 13. These columns must be punched 13 if column 20 is punched 0.

The columns 31 - 35 and 36 - 40 contain the basic information needed by the computer for the histograms opted for by a 1 punched in column 20.

31-35 A(1), the lowest group boundary of the histogram to 2 decimal places punched without the decimal point.

36-40 AINC, the histogram interval width to 2 decimal places punched without the decimal point.

44-45 M, the total number of problems being processed, up to a maximum of 99.

49-50 K, the index number of the tape unit the data is stored on, punch 05.

55 IFPLOT, the histogram plot option, punch with a 1 to exercise.

60 IFANOM, the anomaly selection option, punch with a 1 to exercise.

65 IFCORR, the correlation coefficient option, punch with a 1 to exercise.

70 IFCHI, the chi square for normality option, punch with a 1 to exercise.

Card 5

Columns 1-78 Punch the format of the data cards.

Card 6

1-12 Punch the name of the units of measurement of the data. For clarity of output the name should be centred on column 6.

Cards 7 & 8

1-78 Punch the names of the variables, which may be up to six characters long, across the card(s). For clarity of output these should be punched right justified within the fields of six. If thirteen or less variables are under study only one card is necessary.

Card 9

1-80 Punch the data as described by the format card (5) Up to 9998 cards may be stacked in any order desired.

Card 10

1-80 Punch 9999 in the columns reserved for the sample number on the data card.

As an indication of the time required for computation and the number of lines of output, the following rules should be observed if all the options are exercised:-

Time in minutes = 1.2 + M x 0.1

Lines output = 600 + 40 x NX + N/4

where N is the number of samples processed.

If the anomaly selection routine is not used the N/4 term for lines output need not be allowed for. In addition, if the histograms are not plotted a further reduction of 40 x NX lines may be made, and if the correlation coefficients are not computed a further saving of 80 lines is made.

The program computes so rapidly that no noticeable saving in time is made by not exercising the options.

The program, after allocating the necessary core storage for the variables and setting up the standard A.G.R.G. histogram intervals (A) and their logarithmic mid points (C, used in the chi square routine), sets the count of problems processed (MM), together with a count of the number of times the anomaly selection routine has been used (MC), to zero (Table I).

The ~~nine~~ eight master cards are then read. The first three are title cards (TIT1, TIT2 & TIT3) containing information which is printed out as a page heading prior to the results. The following card is the master control card which is punched according to the number of variables to be processed (NX) and the options which are to be exercised. The variable format card (VFT) follows with instructions to the computer as to how it is to read the data cards. Lastly three name cards are read, the first contains the name of the units (UNITS) of measurement and the second and third the names of the variables (ANAME), up to NX in number.

Prior to reading in the data cards a number of summation arrays are set to zero and the histogram intervals generated from A(1) and AINC if they are required. Also if the anomaly selection option is to be exercised the value of MC is incremented by one and a message is printed for the computer operator to ensure that a spare reel of magnetic tape is mounted for temporary data storage.

The program now proceeds to read the data cards, making a copy of each one on magnetic tape if the anomaly selection routine is opted for. As each card is read it is checked to see if it is the last card, which is punched 9999 in the columns for sample number. If the card is not the last the data is sorted into the respective histogram groups (HIST) and a number of summations, including a count of the samples processed (B), carried out. This completed, the program loops back to read the next data card, and so on until the nines card is reached. On reaching this card the mean (AVE), sum of squares (SSX), variance (VAR), standard deviation (SDV), skew (SKEW), kurtosis (KURT) and percentage histograms (PERC) are computed using the following formulae:-

$$AVE = (\Sigma X)/N$$

$$SSX = (\Sigma X^2)/N - AVE^2$$

$$VAR = (\Sigma X^2 - (\Sigma X)^2/N)/(N-1)$$

$$SDV = VAR^{\frac{1}{2}}$$

$$SKEW = \left[\left(\Sigma X^3 - \frac{3\Sigma X^2 \Sigma X}{N} + \frac{2(\Sigma X)^3}{N^2} \right) / N \right] / \sigma^3$$

$$KURT = \left[\left(\Sigma X^4 - \frac{4\Sigma X^3 \Sigma X}{N} + \frac{\Sigma X^2 (\Sigma X)^2}{N^2} - \frac{3(\Sigma X)^4}{N^3}\right)/N\right]/\sigma^4 - 3$$

$$PERC = HIST \times 100 / N$$

where N is the number of samples.

Following these calculations three operations are carried out according to the options exercised. Firstly, the 2 and 3 standard deviations (SDV) levels are set up about the means (AVE) for the anomaly selection routine. Secondly, the correlation (CORR) and Student's t (T) matrices are computed after the following formulae:-

$$CORR = \left[(\Sigma X.Y/N) - \frac{\Sigma X \Sigma Y}{N^2}\right] / (SSX,X \times SSX,Y)^{\frac{1}{2}}$$

$$T = \frac{CORR \times (N-2)^{\frac{1}{2}}}{(1 - CORR^2)^{\frac{1}{2}}}$$

Lastly the chi square for normality is computed. The expected number of samples (EXV) falling into each histogram group is computed using the formula for the normal distribution:-

$$EXV = \frac{N}{SDV \times (2\pi)^{\frac{1}{2}}} e^{-(C - AVE)^2/2 \times SDV}$$

The value of chi square is then calculated as the sum of the difference of the expected value from the observed value squared divided by the expected value for each group i.e.

$$CHI = \sum \frac{(HIST - EXV)^2}{EXV}$$

These three tasks carried out, the first part of the output (Table II) is printed out, this consists of the percentage histograms and a table of the means, variances, etc. for each variable. Following this the histograms are plotted for each variable together with the data already outputputed in Table II (Table III). The results of the chi square test are printed out together with the number of degrees of freedom with which to enter the chi square tables (Table III).

If the anomaly selection routine has been opted for, the program next prints out the 2 and 3 sigma levels for each variable. The magnetic tape with the copy of the data written on it is rewound and read. As each sample is read again the levels are checked to see if they fall outside the computed limits, if this is so the sample number is printed out together with details of the anomalous elements (Table IV). Lastly, the correlation and Student's t matrices are printed out (Table V). In the t matrix those correlations which have a greater than 99% significance are underlined.

The computation and printing having been completed, the value of MM is incremented by one and compared with the value of M; the total number of problems to be processed. If these numbers are equal the program stops, if they are not the program loops back to read a further set of data. The second problem is computed in a similar manner as the first except for one point. If the anomaly selection routine has already been used, ascertained by checking the value of MC, the message to the operator to load a spare magnetic tape is not printed out as the tape used in the previous problems will still be in position.

Table I

```
C     APPLIED GEOCHEMISTRY, GEOLOGY DEPARTMENT, IMPERIAL COLLEGE
C
C     1965 GARRETT, PROGRAM TO COMPUTE PERCENTAGE HISTOGRAMS, MEANS,
C           STANDARD DEVIATION, SKEW AND KURTOSIS FOR UP TO TWENTY
C           VARIABLES WITH AN OPTIONAL LOGARITHMIC TRANSFORMATION AND
C           VARIABLE HISTOGRAM INTERVAL FOR IBM 7090 IN FORTRAN IV.
C           THE PROGRAM ALSO INCLUDES OPTIONAL HISTOGRAM PLOTS, ANOMALY
C           SELECTION AT THE 2 AND 3 SIGMA LEVELS, THE FORMATION OF A
C           SIMPLE CORRELATION MATRIX AND A CHI SQUARE TEST FOR
C           NORMALITY.  IF THE ANOMALY SELECTION ROUTINE IS TO BE USED
C           A SCRATCH TAPE MUST BE MOUNTED ON UNIT 1 (A3,SYSUT1).
C
C           TIT1, TIT2, AND TIT3 ARE TITLE CARDS.  VFT IS THE DATA CARD
C           FORMAT, UNITS ARE THE UNITS OF DATA MEASUREMENT AND ANAME IS
C           THE NAMES OF THE VARIABLES.
C
C           NX=NO. OF VARIABLES.  IFVH IS THE HISTOGRAM OPTION, PUNCH 0
C           FOR BUILT IN RUN OR 1 FOR USER SPECIFIED RUN.  IFLH IS THE
C           LOG OPTION, PUNCH 0 TO SUPPRESS OR 1 TO EXCERCISE.  NG=NO. OF
C           DATA GROUPS (MAX 13).  A(1)=FIRST INTERVAL OF USER SPECIFIED
C           HISTOGRAM AND AINC=THE GROUP WIDTH.  M=TOTAL NO. OF PROBLEMS
C           TO BE PROCESSED (MAX 99).  K IS THE FORTRAN NO. OF THE TAPE
C           UNIT ON WHICH THE DATA IS STORED.  IFPLOT IS THE PLOT OPTION,
C           IFANOM THE ANOMALY SELECTION OPTION, IFCORR THE CORRELATION
C           MATRIX OPTION AND IFCHI THE CHI SQUARE TEST OPTION.  PUNCH
C           1 TO EXCERCISE ANY OF THESE OPTIONS, OR 0 TO SUPPRESS.
C           UP TO 9998 SAMPLES CAN BE PROCESSED.  THE PROGRAM TERMINATES
C           ON READING 9999 (INTEGER) IN THE COLUMNS FOR SAMPLE ID.
C
C           THE OBJECT PROGRAM OCCUPIES APPROXIMATELY 12K OF STORAGE.
C           ALTERATIONS TO THE NUMBER OF VARIABLES OR HISTOGRAM
C           INTERVALS CAN BE MADE BY ALTERING THE APPROPRIATE DIMENSION,
C           DATA AND FORMAT STATEMENTS.  HOWEVER, IF MORE THAN 20
C           VARIABLES ARE TO BE PROCESSED RADICAL CHANGES WILL HAVE TO BE
C           MADE TO THE OUTPUT STATEMENTS FOR THE ANOMALY SELECTION
C           AND CORRELATION COEFFICIENT ROUTINES.
C
      DIMENSION TIT1(13),TIT2(13),TIT3(13),VFT(13),UNITS(2),ANAME(20)
      DIMENSION A(12),C(13),X(20),HIST(20,13),PERC(20,13),SPERC(20)
      DIMENSION IPERC(20,13),DRAW(13,50),APOSS(20),APROB(20)
      DIMENSION APOMI(20),APRMI(20),LINE(20),APOSW(20),APROW(20)
      DIMENSION SUMX(20),SUMSX(20),SUMCX(20),SUMQX(20),SSUMX(20)
      DIMENSION CSUMX(20),QSUMX(20),AVE(20),SSX(20),VAR(20),SDV(20)
      DIMENSION SKEW(20),KURT(20),SUM(20,20),CORR(20,20),T(20,20)
      DIMENSION EXV(20,13),CHI(20)
      REAL KURT
      INTEGER DRAW,BLANK,PLOT,CROSS,TWOAST,THRAST,TOP
      DATA BLANK,TWOAST,THRAST/1H ,6H    **,6H   ***/
      DATA CROSS,MINTWO,MINTHR/1HX,6H    --,6H   ---/
C
C     INSERT BUILT IN HISTOGRAM INTERVALS ETC.
      DATA (A(I),I=1,12)/1.47,3.21,7.07,14.7,32.1,70.7,147.0,321.0,707.0
     1,1470.0,3210.0,7070.0/
      DATA (C(I),I=1,13)/0.0,0.301,0.699,1.0,1.301,1.699,2.0,2.301,2.699
     1,3.0,3.301,3.699,4.0/
```

```
C
C     INITIALISE MM AND READ TITLE, MASTER APD NAME CARDS
      MM=0
      MC=0
    1 READ (5,101) TIT1,TIT2,TIT3
      READ (5,102) NX,IFVH,IFLH,NG,A(1),AINC,M,K,IFPLOT,IFANOM,IFCORR,IF
     1CHI
      READ (5,101) VFT
      READ (5,116) UNITS
      READ (5,101) (ANAME(I),I=1,NX)
C
C     INITIALISE REMAINING ARRAYS ETC.
      DO 3 I=1,NX
      CHI(I)=0.
      SUMX(I)=0.
      SUMSX(I)=0.
      SUMCX(I)=0.
      SUMQX(I)=0.
      SPERC(I)=0.
      DO 2 J=1,NG
    2 HIST(I,J)=0.
      DO 3 J=1,NX
    3 SUM(I,J)=0.
      B=0.
      NI=NG-1
      IF(IFVH.EQ.0)GO TO 6
      DO 4 J=2,NI
    4 A(J)=A(J-1)+AINC
      IF(IFCHI.EQ.0)GO TO 7
      C(1)=A(1)-AINC/2.0
      DO 5 J=1,NI
    5 C(J+1)=C(J)+AINC
      GO TO 7
    6 IFLH=1
      A(1)=1.47
    7 IF(IFANOM.EQ.0)GO TO 9
      MC=MC+1
      IF(MC.GT.1)GO TO 8
      PRINT 103
      CALL PAUSE
    8 REWIND 1
C
C     READ DATA CARDS
    9 READ (K,VFT) ID,(X(I),I=1,NX)
      IF(IFANOM.EQ.1)WRITE (1) ID,(X(I),I=1,NX)
      IF(ID.EQ.9999)GO TO 603
C
C     FORM HISTOGRAMS
      IF(IFVH.EQ.0)GO TO 300
      IF(IFLH.EQ.1)CALL TRANS(X,NX)
  300 DO 302 I=1,NX
      DO 301 J=1,NI
      IF(X(I).GT.A(J))GO TO 301
      HIST(I,J)=HIST(I,J)+1.
```

Table I cont.

```
      GO TO 302
  301 IF(J.EQ.N)CONTINUE
      HIST(I,NG)=HIST(I,NG)+1.
  302 CONTINUE
C
C     CARRY OUT SUMMATIONS
      IF(IFVH.EQ.0)CALL TRANS(X,NX)
      B=B+1.
      DO 600 I=1,NX
      SUMX(I)=SUMX(I)+X(I)
      SUMSX(I)=SUMSX(I)+X(I)**2
      SUMCX(I)=SUMCX(I)+X(I)**3
  600 SUMQX(I)=SUMQX(I)+X(I)**4
      IF(IFCORR.EQ.0)GO TO 9
      JJ=1
      DO 602 I=1,NX
      DO 601 J=1,JJ
  601 SUM(I,J)=SUM(I,J)+X(I)*X(J)
      JJ=JJ+1
  602 IF(JJ.GT.NX)GO TO 9
  603 DO 604 I=1,NX
      SSUMX(I)=SUMX(I)**2
      CSUMX(I)=SUMX(I)**3
  604 QSUMX(I)=SUMX(I)**4
C
C     CALCULATE MEAN, VARIANCE, STANDARD DEVIATION, SKEW AND KURTOSIS
      N=B
      BSQ=B**2
      BCU=B**3
      DO 400 I=1,NX
      AVE(I)=SUMX(I)/B
      SSX(I)=SUMSX(I)/B-AVE(I)**2
      VAR(I)=(SUMSX(I)-SSUMX(I)/B)/(B-1.0)
      SDV(I)=SQRT(VAR(I))
      SKEW(I)=((SUMCX(I)-3.*SUMSX(I)*SUMX(I)/B+2.*CSUMX(I)/BSQ)/B)/SDV(I
     1)**3
      KURT(I)=((((SUMQX(I)-4.*SUMCX(I)*SUMX(I)/B+6.*SUMSX(I)*SSUMX(I)/BS
     1Q-3.*QSUMX(I)/BCU)/B)/VAR(I)**2)-3.0)
C
C     CALCULATE PERCENTAGE HISTOGRAMS
      DO 400 J=1,NG
      PERC(I,J)=HIST(I,J)*100./B
  400 SPERC(I)=SPERC(I)+PERC(I,J)
C
C     TEST FOR ANOMALY SELECTION AND SET UP ANOMALY LIMITS
 2000 IF(IFANOM.EQ.0)GO TO 3000
      DO 2001 I=1,NX
      APROB(I)=AVE(I)+3.*SDV(I)
      APOSS(I)=AVE(I)+2.*SDV(I)
      APOM(I)=AVE(I)-2.*SDV(I)
 2001 APRM(I)=AVE(I)-3.*SDV(I)
C
C     COMPUTE CORRELATION AND STUDENT'S T MATRICES
 3000 IF(IFCORR.EQ.0)GO TO 4000
      JJ=1
```

```
      DO 3002 I=1,NX
      DO 3001 J=1,JJ
      CORR(I,J)=(SUM(I,J)/B-AVE(I)*AVE(J))/SQRT(SSX(I)*SSX(J))
      CORR(J,I)=CORR(I,J)
      T(I,J)=(CORR(I,J)*SQRT(B-2.0))/SQRT(1.0-CORR(I,J)**2)
 3001 T(J,I)=T(I,J)
      JJ=JJ+1
 3002 IF(JJ.GT.NX)CONTINUE
C
C     COMPUTE CHI SQUARE FOR NORMALITY
 4000 IF(IFCHI.EQ.0)GO TO 401
      DO 4001 I=1,NX
      COE1=B/(SDV(I)*2.50661)
      COE2=-0.5/VAR(I)
      DO 4001 J=1,NG
      COE3=(C(J)-AVE(I))**2
      EXV(I,J)=COE1*EXP(COE2*COE3)
 4001 CHI(I)=CHI(I)+((HIST(I,J)-EXV(I,J))**2)/EXV(I,J)
      IDOF=N-1
C
C     WRITE OUTPUT
  401 WRITE (6,101) TIT1,TIT2,TIT3
      WRITE (6,104) UNITS
      IF(IFVH.EQ.0)GO TO 404
      IF(IFLH.EQ.0)GO TO 403
      DO 402 J=1,N1
  402 A(J)=EXP(2.302582*A(J))
  403 WRITE (6,113) (A(J),J=1,N1)
      GO TO 405
  404 WRITE (6,105)
  405 DO 406 I=1,NX
  406 WRITE (6,106) ANAME(I),(PERC(I,J),J=1,NG)
      WRITE (6,107) N
      DO 407 I=1,NX
  407 IF(SPERC(I).GT.100.1.OR.SPERC(I).LT.99.9)WRITE (6,112) ANAME(I)
      WRITE (6,117) UNITS
      IF(IFLH.EQ.1)GO TO 408
      WRITE (6,114)
      WRITE (6,110) (ANAME(I),AVE(I),VAR(I),SDV(I),SKEW(I),KURT(I),I=1,N
     1X)
      GO TO 410
  408 WRITE (6,108)
      WRITE (6,109)
      DO 409 I=1,NX
      AVE(I)=EXP(2.302582*AVE(I))
  409 WRITE (6,115) ANAME(I),AVE(I),VAR(I),SDV(I),SKEW(I),KURT(I)
  410 WRITE (6,111) N
C
C     PREPARE HISTOGRAMS FOR PLOTTING
 1000 IF(IFPLOT.EQ.0)GO TO 4002
      DO 1001 I=1,NX
      DO 1001 J=1,NG
 1001 IPERC(I,J)=(PERC(I,J)/2.0)+0.5
      DO 1006 I=1,NX
```

Table I cont.

```
      DO 1004 J=1,NG
      DO 1004 PLOT=1,50
      IF(IPERC(I,J))1002,1002,1003
 1002 DRAW(J,PLOT)=BLANK
      GO TO 1004
 1003 DRAW(J,PLOT)=CROSS
      IPERC(I,J)=IPERC(I,J)-1
 1004 CONTINUE
C
C     PLOT HISTOGRAMS
      WRITE (6,802) ANAME(I),UNITS
      IF(IFLH.EQ.1)WRITE (6,803)
      WRITE (6,804)
      DO 1005 J=1,NI
      WRITE (6,806) (DRAW(J,PLOT),PLOT=1,50),PERC(I,J)
 1005 WRITE (6,805) A(J)
      J=NG
      WRITE (6,806) (DRAW(J,PLOT),PLOT=1,50),PERC(I,J)
      WRITE (6,807)
      WRITE (6,808) N,AVE(I),VAR(I),SDV(I),SKEW(I),KURT(I)
      IF(IFCHI.EQ.1)WRITE (6,809) CHI(I),IDOF
 1006 CONTINUE
C
C     WRITE OUT CHI SQUARE FOR NORMALITY
 4002 IF(IFCHI.EQ.0)GO TO 2002
      WRITE (6,810)
      IF(IFLH.EQ.1)WRITE (6,702)
      WRITE (6,811)
      WRITE (6,812) (ANAME(I),CHI(I),IDOF,I=1,NX)
C
C     WRITE OUT ANOMALOUS LEVELS
 2002 IF(IFANOM.EQ.0)GO TO 3003
      IF(IFLH.EQ.0)GO TO 2004
      DO 2003 I=1,NX
      APROB(I)=EXP(2.302582*APROB(I))
      APOSS(I)=EXP(2.302582*APOSS(I))
      APOMI(I)=EXP(2.302582*APOMI(I))
 2003 APRMI(I)=EXP(2.302582*APRMI(I))
 2004 DO 2005 I=1,NX
      APROW(I)=APROB(I)
      APOSW(I)=APOSS(I)
      IF(APROB(I).GE.10000.)APROW(I)=9999.
 2005 IF(APOSS(I).GE.10000.)APOSW(I)=9999.
      WRITE (6,902) UNITS
      WRITE (6,903) (ANAME(I),I=1,NX)
      WRITE (6,911)
      WRITE (6,905) (APROW(I),I=1,NX)
      WRITE (6,904) (APOSW(I),I=1,NX)
      WRITE (6,906) (APOMI(I),I=1,NX)
      WRITE (6,909) (APRMI(I),I=1,NX)
      WRITE (6,906) (ANAME(I),I=1,NX)
      WRITE (6,911)
C
C     READ IN STORED COPY OF DATA FROM TAPE 1 AND CHECK FOR ANOMALIES
      KP=0
      KL=0
      REWIND 1
 2006 READ (1) ID,(X(I),I=1,NX)
      IF(ID.EQ.9999)GO TO 3003
      L=0
      DO 2007 I=1,NX
      LINE(I)=BLANK
      IF(X(I).GE.APROB(I))LINE(I)=THRAST
      IF((X(I).GE.APOSS(I)).AND.(X(I).LT.APROB(I)))LINE(I)=TWOAST
      IF((X(I).LT.APOSS(I)).AND.(X(I).GT.APOMI(I)))L=L+1
      IF((X(I).LE.APOMI(I)).AND.(X(I).GT.APRMI(I)))LINE(I)=MINTWO
 2007 IF(X(I).LE.APRMI(I))LINE(I)=MINTHR
C
C     WRITE OUT RESULTS
      IF(L.EQ.NX)GO TO 2006
      WRITE (6,907) ID,(LINE(I),I=1,NX)
      KL=KL+1
      IF(KP.EQ.0.AND.KL.LT.25)GO TO 2006
      IF(KP.NE.0.AND.KL.LT.50)GO TO 2006
      KP=KP+1
      KL=0
      WRITE (6,910) (ANAME(I),I=1,NX)
      WRITE (6,911)
      GO TO 2006
C
C     WRITE OUT CORRELATION AND STUDENT'S T MATRICES
 3003 IF(IFCORR.EQ.0)GO TO 5000
      WRITE (6,701)
      IF(IFLM.EQ.1)WRITE (6,702)
      WRITE (6,903) (ANAME(I),I=1,NX)
      SERR=0.00
      DO 3004 I=1,NX
      J=I
      SERR=SERR+CORR(I,J)-1.00
      CORR(I,J)=1.00
 3004 WRITE (6,703) ANAME(I),(CORR(I,J),J=1,NX)
      ERR=SERR/FLOAT(NX)
      WRITE (6,704) N,ERR
      WRITE (6,705)
      WRITE (6,903) (ANAME(I),I=1,NX)
      DO 3005 I=1,NX
 3005 WRITE (6,703) ANAME(I),(T(I,J),J=1,NX)
      IDOF=N-2
      WRITE (6,706) IDOF
C
C     TEST FOR FURTHER PROBLEM
 5000 MM=MM+1
      IF(MM.LT.M)GO TO 1
      WRITE (6,118)
      STOP
C
  [illegible] FORMAT (13A6)
  [illegible] FORMAT (13X,[illegible],2(4X,I1),3X,I2,2F5.2,6(3X,I2))
  [illegible] FORMAT (33H [illegible]SE READY SCRATCH TAPE ON A3.)
```

Table I cont.

```
104 FORMAT (1H1//49X,21HPERCENTAGE HISTOGRAMS//42X36HHISTOGRAM INTERVA
   1LS ARE EXPRESSED IN/54X,2A6///)
105 FORMAT (15X,4H1.47,4X,4H3.21,4X,4H7.07,4X,4H14.7,4X,4H32.1,4X,4H70
   1.7,4X,4H 147,4X,4H 321,4X,4H 707,4X,4H1470,4X,4H3210,4X,4H7070)
106 FORMAT (1H0,A6,3X,13(F5.1,3X))
107 FORMAT (1H0,6X,2HN=,I4//)
108 FORMAT (1H //28X,74HVARIANCE, STANDARD DEVIATION, SKEW AND KURTOSI
   1S ARE EXPRESSED IN LOG UNITS///)
109 FORMAT (26X,4HMEAN,17X,8HVARIANCE,15X,8HSTD DEV.,17X,4HSKEW,17X,8H
   1KURTOSIS)
110 FORMAT (1H0,4X,A6,10X,F9.3,17X,F7.1,16X,F7.3,F22.3,F23.3)
111 FORMAT (1H0,10X,2HN=,I4)
112 FORMAT (1H ,8X,A6,42HPERCENTAGES DO NOT SUM TO WITHIN .1 OF 100)
113 FORMAT (1H ,13X,12(F6.1,2X)//)
114 FORMAT (1H //25X,4HMEAN,17X,8HVARIANCE,15X,8HSTD DEV.,17X,4HSKEW,1
   17X,8HKURTOSIS)
115 FORMAT (1H0,4X,A6,12X,F9.3,2(15X,F7.3),1X,2F23.3)
116 FORMAT (2A6)
117 FORMAT (1H1,55X,10HVALUES IN ,2A6///)
118 FORMAT (1H1,25HTHE PROBLEM IS COMPLETED.)
C
701 FORMAT (1H1//56X,18HCORRELATION MATRIX//)
702 FORMAT (1H ,43X,45HTHE DATA HAS BEEN TRANSFORMED INTO LOGARITHMS//
   1/)
703 FORMAT (1H0,2X,A6,1X,20(1X,F5.2))
704 FORMAT (1H ///12X,19HNUMBER OF SAMPLES =,I4//12X,19HERROR IN DIAGO
   1NAL =,F7.2)
705 FORMAT (1H1//43X,43HSTUDENTS T TEST OF CORRELATION COEFFICIENTS///
   1)
706 FORMAT (1H ///12X,20HDEGREES OF FREEDOM =,I4)
C
802 FORMAT (1H1,13X,13HHISTOGRAM OF ,A6,11X,10HVALUES IN ,2A6//)
803 FORMAT (1H ,21X,35HHISTOGRAM INTERVALS ARE LOGARITHMIC////)
804 FORMAT (1H ,4X,6(9X,1H*)/12X,1H*)
805 FORMAT (1H ,F10.1,2H *)
806 FORMAT (1H ,13X,50A1,3H  *,F6.2)
807 FORMAT (1H ,11X,1H*/5X,6(9X,1H*)/14X,1H0,8X,2H20,8X,2H40,8X,2H60,8
   1X,2H80,8X,3H100/36X,7HPERCENT/////)
808 FORMAT (13X,18H NUMBER OF SAMPLES,5X,2H= ,I5/13X,5H MEAN,18X,2H= ,
   1F9.3/13X,9H VARIANCE,14X,2H= ,F9.3/13X,24H STANDARD DEVIATION    =
   2,F10.3/13X,5H SKEW,18X,2H= ,F9.3/13X,9H KURTOSIS,14X,2H= ,F9.3)
809 FORMAT (1H0,13X,10HCHI SQUARE,12X,2H= ,F8.2/14X,18HDEGREES OF FREE
   1DOM,4X,2H= ,I5)
810 FORMAT (1H1//52X,29HCHI SQUARE TEST FOR NORMALITY///)
811 FORMAT (9H VARIABLE,6X,22H CUMULATIVE CHI SQUARE,6X,18HDEGREES OF
   1FREEDOM)
812 FORMAT (1H0,1X,A6,12X,F9.2,21X,I4)
C
902 FORMAT (1H1////47X,28HTABLE OF ANOMALOUS LEVELS IN/55X,2A6//39X,44
   1H9999. DENOTES A VALUE OF GREATER THAN 10000.///)
903 FORMAT (1H ,9X,20A6)
904 FORMAT (9H +2 SIGMA,2X,20F6.0)
905 FORMAT (9H +3 SIGMA,2X,20F6.0)
906 FORMAT (1H //////49X,27H TABLE OF ANOMALOUS SAMPLES/33X,62H ** DEN
   1OTES ABOVE THRESHOLD AND *** PROBABLY ANOMALOUS SAMPLES/27X,74H *H
   21LST -- DENOTES LESS THAN MEAN -2 SIGMA AND --- LESS THAN MEAN -3
   3SIGMA///7H SAMPLE,3X,20A6)
907 FORMAT (1H ,1X,I4,4X,20A6)
908 FORMAT (9H -2 SIGMA,2X,20F6.0)
909 FORMAT (9H -3 SIGMA,2X,20F6.0)
910 FORMAT (1H1,49X,27H TABLE OF ANOMALOUS SAMPLES/33X,62H ** DENOTES
   1ABOVE THRESHOLD AND *** PROBABLY ANOMALOUS SAMPLES/27X,74H *HILST
   2-- DENOTES LESS THAN MEAN -2 SIGMA AND --- LESS THAN MEAN -3 SIGMA
   3///7H SAMPLE,3X,20A6)
911 FORMAT (1H )
C
      END
      SUBROUTINE TRANS(X,NX)
C
      DIMENSION X(20)
C
      DO 1 I=1,NX
      IF(X(I).EQ.0.)GO TO 1
      X(I)=ALOG10(X(I))
    1 CONTINUE
      RETURN
C
      END
```

Table II

PROJECT 42, SIERRA LEONE
GENERAL ELEMENTS BY SPECTROGRAPH
BASEMENT STREAM SEDIMENT DATA

PERCENTAGE HISTOGRAMS

HISTOGRAM INTERVALS ARE EXPRESSED IN PPM

		1.47	3.21	7.07	14.7	32.1	70.7	147	321	707	1470	3210	7070
PB	0.5	0.5	0.	16.7	69.3	10.7	1.4	0.9	0.	0.	0.	0.	0.
SN	54.1	0.	30.7	7.9	1.9	1.4	0.	0.	0.	0.	0.	0.	0.
V	0.5	0.	0.5	2.8	18.1	37.2	31.6	9.3	0.	0.	0.	0.	0.
MO	54.4	39.5	6.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
CU	3.7	4.7	21.9	28.4	34.9	6.5	0.	0.	0.	0.	0.	0.	0.
ZN	0.	0.	0.	0.5	10.7	54.4	28.8	5.6	0.	0.	0.	0.	0.
TI	0.	0.	0.	0.	0.	0.5	0.	0.	0.5	13.0	36.7	36.7	12.6
NI	3.3	0.	3.7	16.7	42.8	26.0	4.7	2.3	0.5	0.	0.	0.	0.
CO	27.4	0.	34.4	25.1	9.8	2.8	0.5	0.	0.	0.	0.	0.	0.
MN	0.	0.	0.	0.	0.5	5.6	26.0	27.9	12.1	16.3	7.4	3.7	0.5
CR	0.	0.5	2.3	5.6	22.8	35.8	20.0	7.9	0.5	1.4	1.9	0.9	0.5

N= 215

VALUES IN PPM

VARIANCE, STANDARD DEVIATION, SKEW AND KURTOSIS ARE EXPRESSED IN LOG UNITS

	MEAN	VARIANCE	STD DEV.	SKEW	KURTOSIS
PB	21.015	0.056	0.237	0.209	7.159
SN	2.275	0.194	0.441	0.657	-0.924
V	56.084	0.107	0.327	-0.915	2.789
MO	1.530	0.049	0.222	0.752	-0.629
CU	11.004	0.136	0.369	-0.796	0.681
ZN	59.544	0.048	0.219	0.283	0.121
TI	3108.257	0.091	0.301	-0.801	3.50[illegible]
NI	23.122	0.160	0.399	-0.782	3.[illegible]45
CO	4.970	0.229	0.479	-0.279	-0.863
MN	315.792	0.261	0.510	0.550	-0.57[illegible]
CR	55.013	0.273	0.522	1.242	3.735

N= 215

Table III

```
HISTOGRAM OF     CR           VALUES IN     PPM
          HISTOGRAM INTERVALS ARE LOGARITHMIC

           .         .         .         .         .         .
         .
  1.5  .                                                          .  0.
  3.2  .                                                          .  0.47
           X                                                      .  2.33
  7.1  .
           XXX                                                    .  5.58
  14.7 .
           XXXXXXXXXXX                                            .  22.79
  32.1 .
           XXXXXXXXXXXXXXXXXX                                     .  35.81
  70.7 .
           XXXXXXXXXX                                             .  20.00
 147.0 .
           XXXX                                                   .  7.91
 321.0 .                                                          .  0.47
 707.0 .
           X                                                      .  1.40
1470.0 .
           X                                                      .  1.86
3210.0 .                                                          .  0.93
7070.0 .                                                          .  0.47
         .
           .         .         .         .         .         .
           0         20        40        60        80        100
                                PERCENT
```

```
NUMBER OF SAMPLES        =   215
MEAN                     =    55.013
VARIANCE                 =     0.273
STANDARD DEVIATION       =     0.522
SKEW                     =     1.242
KURTOSIS                 =     3.735

CHI SQUARE               =   399.79
DEGREES OF FREEDOM       =   214
```

CHI SQUARE TEST FOR NORMALITY

THE DATA HAS BEEN TRANSFORMED INTO LOGARITHMS

VARIABLE	CUMULATIVE CHI SQUARE	DEGREES OF FREEDOM
PB	15849.26	214
SN	287.64	214
V	6511.32	214
MO	284.91	214
CU	308.82	214
ZN	306.10	214
TI	180272.27	214
NI	364.05	214
CO	304.97	214
MN	297.81	214
CR	399.79	214

Table IV

TABLE OF ANOMALOUS LEVELS IN
PPM

9999. DENOTES A VALUE OF GREATER THAN 10000.

	PB	SN	V	MO	CU	ZN	TI	NI	CO	MN	CR
+3 SIGMA	108.	48.	537.	7.	141.	269.	9999.	365.	136.	9999.	2027.
+2 SIGMA	63.	17.	253.	4.	60.	163.	9999.	145.	45.	3313.	609.
-2 SIGMA	7.	0.	12.	1.	2.	22.	777.	4.	1.	30.	5.
-3 SIGMA	4.	0.	6.	0.	1.	13.	389.	1.	0.	9.	1.

TABLE OF ANOMALOUS SAMPLES
** DENOTES ABOVE THRESHOLD AND *** PROBABLY ANOMALOUS SAMPLES
WHILST -- DENOTES LESS THAN MEAN -2 SIGMA AND --- LESS THAN MEAN -3 SIGMA

SAMPLE	PB	SN	V	MO	CU	ZN	TI	NI	CO	MN	CR
128				**							
29	---										
129				**							
31			--	**							
32								---			
135								---			
136			--					---			--
27				**							
151					--			---			
152								---			
134	---										
138				**							
23				**							
152			---		--	**					--
12			--								
15		**									
157											***
160								**		**	
125											***
115	**	**		**		**				**	
161						**					
121		**									***
13											**
163		**									***
165								**			

TABLE OF ANOMALOUS SAMPLES
** DENOTES ABOVE THRESHOLD AND *** PROBABLY ANOMALOUS SAMPLES
WHILST -- DENOTES LESS THAN MEAN -2 SIGMA AND --- LESS THAN MEAN -3 SIGMA

SAMPLE	PB	SN	V	MO	CU	ZN	TI	NI	CO	MN	CR
233											**
145											**
166									**		
173						**					
175		**						---			
176					--						
181											**
184							---				
185	***									**	
186											***
193										**	
195					--						
103						**					
102								**			
90					--						
207					--						
92					--						
144				**				**			***
235								**			
209						---					
113					--	--		---			
236					--						
237			--				--				
35								**			
212					--						
49					--						
51					--						
216					**						
72					--						
217					--						
218					--						
28										**	
127							--				
57							--				
46	***	**				**				**	
221						**					
222									**		
47										**	
41	***										
225	***					**					

Table V

CORRELATION MATRIX

THE DATA HAS BEEN TRANSFORMED INTO LOGARITHMS

	PB	SN	V	MO	CU	ZN	TI	NI	CO	MN	CR
PB	1.00	0.30	0.18	0.29	0.15	0.35	0.26	0.17	0.19	0.26	0.11
SN	0.30	1.00	0.26	0.22	0.21	0.40	0.33	0.25	0.21	0.33	0.34
V	0.18	0.26	1.00	0.33	0.68	0.44	0.50	0.50	0.54	0.50	0.55
MO	0.29	0.22	0.33	1.00	0.28	0.19	0.26	0.18	0.12	0.11	0.15
CU	0.15	0.21	0.68	0.28	1.00	0.33	0.40	0.52	0.53	0.33	0.50
ZN	0.35	0.40	0.44	0.19	0.33	1.00	0.44	0.37	0.46	0.56	0.27
TI	0.26	0.33	0.50	0.26	0.40	0.44	1.00	0.27	0.32	0.62	0.26
NI	0.17	0.25	0.50	0.18	0.52	0.37	0.27	1.00	0.47	0.38	0.67
CO	0.19	0.21	0.54	0.12	0.53	0.46	0.32	0.47	1.00	0.44	0.49
MN	0.26	0.33	0.50	0.11	0.33	0.56	0.62	0.38	0.44	1.00	0.36
CR	0.11	0.34	0.55	0.15	0.50	0.27	0.26	0.67	0.49	0.36	1.00

NUMBER OF SAMPLES = 215

ERROR IN DIAGONAL = 0.

STUDENTS T TEST OF CORRELATION COEFFICIENTS

	PB	SN	V	MO	CU	ZN	TI	NI	CO	MN	CR
PB	-0.	4.60	2.73	4.40	2.18	5.44	3.88	2.45	2.79	3.98	1.68
SN	4.60	-0.	4.01	3.33	3.14	6.40	5.08	3.82	3.20	5.04	5.25
V	2.73	4.01	-0.	5.08	13.56	7.15	8.33	8.40	9.34	8.49	9.49
MO	4.40	3.33	5.08	-0.	4.26	2.87	3.99	2.73	1.80	1.55	2.22
CU	2.18	3.14	13.56	4.26	-0.	5.10	6.33	8.95	9.17	5.14	8.41
ZN	5.44	6.40	7.15	2.87	5.10	-0.	7.14	5.83	7.48	9.89	4.13
TI	3.88	5.08	8.33	3.99	6.33	7.14	-0.	4.10	4.96	11.56	3.92
NI	2.45	3.82	8.40	2.73	8.95	5.83	4.10	-0.	7.67	6.00	13.29
CO	2.79	3.20	9.34	1.80	9.17	7.48	4.96	7.67	-0.	7.15	8.24
MN	3.98	5.04	8.49	1.55	5.14	9.89	11.56	6.00	7.15	-0.	5.54
CR	1.68	5.25	9.49	2.22	8.41	4.13	3.92	13.29	8.24	5.54	-0.

DEGREES OF FREEDOM = 213

$t(213, 0.99) \simeq 2.34$

APPENDIX III

Computation of Rolling Means

The following program has been written in Fortran IV and is based on a program developed by Mr R. Leigh and Dr T. Thomas both of the Mining Department of the Royal School of Mines. The program is capable of processing up to twenty variables simultaneously and not more than 4800 samples should be used. Facilities have been provided in the program for storing a complete set of results on a magnetic tape. This tape can be processed in order to provide instructions for automatic plotting equipment such as the Calcomp Plotter or the Stromberg-Carlsan 4020. The necessary program for automatically plotting the results has yet to be developed.

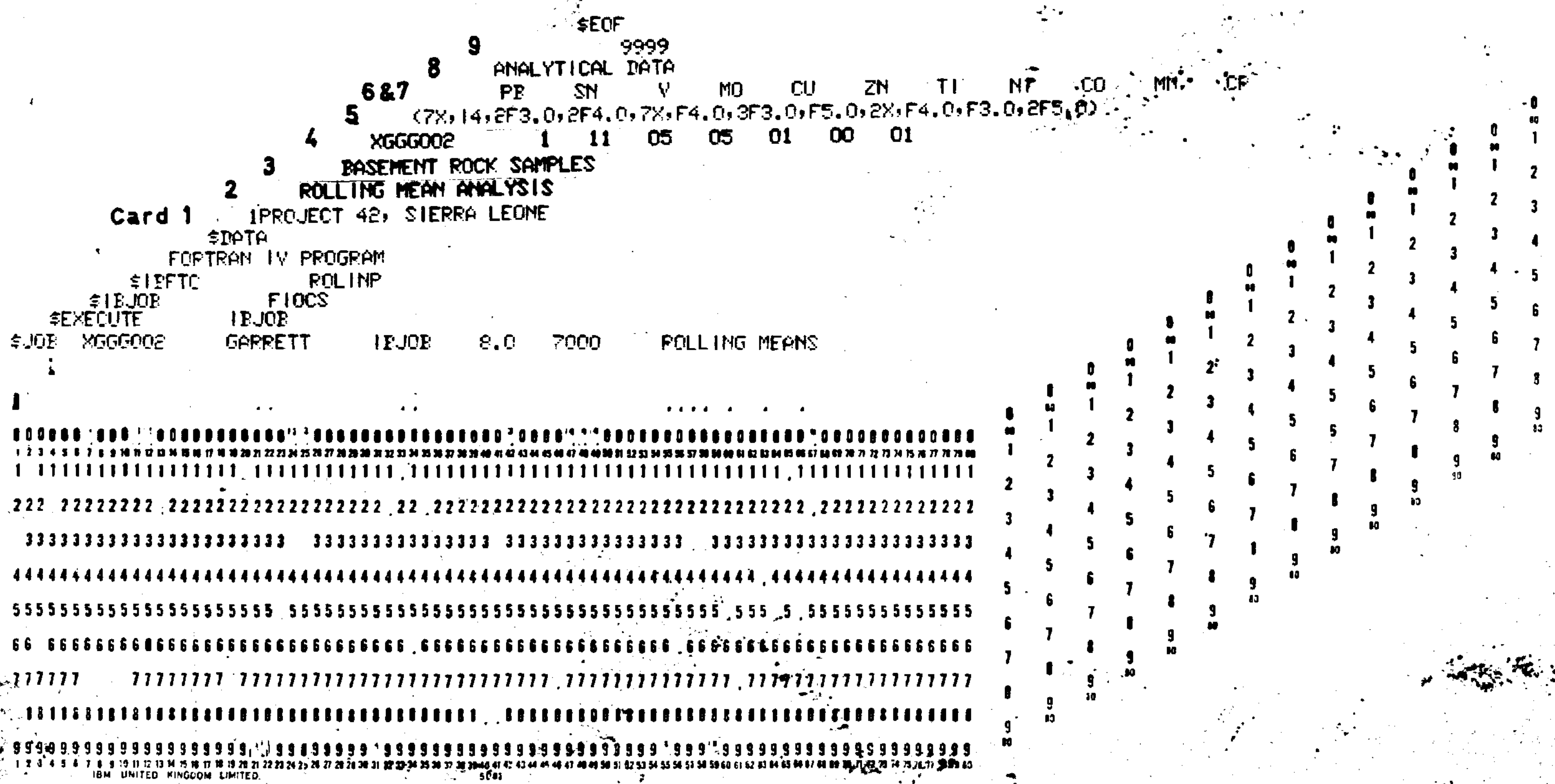
The card arrangement for running the program at Imperial College is shown in figure 1. The set up of the systems control cards and program is described in Appendix IV, the program is followed by the ØDATA card, the data deck and terminated by a ØEOF card. The data deck must be punched as follows:%

Card 1

Columns 1 Punch 1, for printer carriage control.

2-78 Punch any title information

FIG. 1 — PROGRAM SET-UP FOR ROLLING MEAN ANALYSES



Cards 2 & 3

Columns	1	Leave blank
	2-78	Punch any title information

Card 4

15	IFL, the logarithmic option, punch 1 to exercise or 0 for arithmetic values.
19-20	NX, the number of variables per sample which cannot be more than 20.
24-25	NT, the number of the tape unit the data is stored upon for input, punch 05.
29-30	IN, the initial size of the search area.
34-35	N, the number of trials by which IN is increased by one for each trial.
40	IFPLOT, the option for a magnetic tape containing the results, punch 1 to exercise.
45	IFPRNT, the print option, punch 1 for the complete data or 0 for only the efficiency details.

Card 5

1-78	The format of the data cards.

Cards 6 & 7

1-78	Punch the names of the variables, which may be up to six characters long, across the card(s). For clarity of output these chould be punched right justified within the fields of six. If

thirteen or less variables are under study only one card is necessary.

Card 8

Columns 1-80 Punch the data as described by the format card (5). Up to 4800 samples can be used, more samples will be accepted by the program but only 4800 samples will be processed.

Card 9

1-80 Punch 9999 in the columns reserved for the sample number on the number card.

As an indication of the time required for computation and the number of lines of output, the following rules should be followed if all the output is to be printed.

$$\text{Time in minutes} = 1.2 + N/10$$

$$\text{Lines output} = 250 + \frac{U \times V}{100S}$$

Where N is the number of samples, U and V the respective differences between the maximum and minimum U and V co-ordinate values and S the size of the search area.

The program (Table I) is split into two halves, the first part of which prepares a 'map' of the data relating to a particular element in the computer's memory. This 'map' is then passed to the second part of the program where the rolling means and other parameters are computed for that particular element.

The program first allocates the required core storage for the variables used for the computation and following this the program reads six or seven master cards. The first three cards (TIT1, TIT2 & TIT3) are title cards containing page heading information. The fourth card is the master control card which informs the computer of the number of variables to be processed (NX) and the magnetic tape unit on which the data is stored (NT). A number of options are also available; the data may be transformed into logarithms prior to computation (IFL), and after selecting the size of the search area (IN) a number of trials (N) may be carried out, with the search area being increased by one unit in each direction for each trial. The option IFPLOT controls the preparation of the copy of the results for processing for automatic data plotting. Lastly, the option IFPRNT controls whether the whole of the results are printed out or only a synopsis which includes the percentage fit of the new surface and the average number of samples in each search. This last option is of use when the date is to be automatically plotted or when a number of trials are being carried out in order to ascertain the best search area size and the full output is not required. Following the master control card the fifth card (VFT) contains information telling the computer how it is to read the data cards. The sixth and seventh cards are name cards which contain the names of the variables being processed; these names may be up to six characters long and are NX in number.

After reading the master cards the magnetic tapes for temporary data storage are prepared for use. The computer then reads the data cards and immediately makes a copy of them on magnetic tape. The end of the data is marked by a card punched 9999 in the columns reserved for the sample number and on reading this card the program sets the area of the core storage to be used for the 'map' of the data to zero and rewinds the temporary data storage tape.

The data is then read from the rewound tape and the co-ordinates and values relating to the first variable loaded into the 'map'. If the logarithmic option has been exercised it is the logarithm of the value which is loaded into the 'map'; however, if this value is zero for computational reasons it is set to 0.1. As the data is read in, the co-ordinates are constantly checked in order to find the highest and lowest values of each co-ordinate direction (U & V). On reading the nines card a second time the 'map' is completed and is passed, together with the maximum and minimum U and V co-ordinates, to the second part of the program.

The first operation carried out by the second part of the program (SUBROUTINE ROLLER) is to compute the overall mean and variance of the values in the 'map'. The results of this computation are then printed out with the title cards and the name of the variable under study as a heading page (Table II). The rolling mean computation is now started; first a series of initialisations are carried out and the limits of the first search area are set up using the minimum values of U and V (MINU & MINV) and the size of the search area (NN). The first search area is then placed on the 'map' and the mean of the co-ordinates (AVCOU & AVCOV) and the mean (RMEAN) and variance (VA) of the samples (S in number) falling inside the search area are computed. Two other parameters are also computed for each search. Firstly, the rolling mean (RMEAN) is expressed as a standard normal deviate (ZZ) of the overall mean (TMEAN) and standard deviation (TSD). Thus:-

ZZ = (RMEAN - TMEAN) / TSD

If the rolling mean is less than the overall mean this value will be negative, and vice versa; the magnitude of ZZ will be a measure of the number of standard deviations by which the rolling mean differs from the overall mean, thus high positive or negative values of ZZ indicate areas where there are significant departures of the local mean from the overall mean. The second parameter is the variance ratio (FRAT) of the local variance to the overall variance. To obtain this value the mean variance of the complete data (MV), i.e. the overall variance divided by the total number of samples minus one, is divided by the mean variance of the rolling mean. Thus:

FRAT = MV/(VA/(S - 1))

The results of this test have to be interpreted using tables of Snedecor's F (see Krumbein and Graybill, 1965, pp 422 - 440). Generally however, as the local variance gets significantly low relative to the overall variance the F value will increase, and vice versa.

The computations completed the results are printed out; each page contains 50 results also a heading giving details of the variable being processed, the size of the search area and whether the logarithmic transformation has been used (Table II).

The first search completed the search area is moved on one unit in the U direction and checked to see that it hasn't reached the value of MAXU, the maximum U value. If MAXU is reached the value of the U search co-ordinates is set to start again from MINU and the search area is moved one unit in the V direction. This operation continues until the last search when both MAXU and MAXV have been reached and the whole 'map' has been systematically searched.

On completing the searches the title cards are printed again together with the data printed out on the heading page. In addition, a count of the total number of searches made, the number of searches which included data, the average number of samples per search, the variance of the total data, the variance of the rolling means and the percentage fit of the new surface are also printed out (Table III). This completed, a test is made to see if a further trial is to be made with an increased search area size. If a further trial is not required the first variable is processed and control is returned to the first part of the program.

The program now begins to process the second variable by rewinding the magnetic tape containing the data and forming a 'map' of the second variable. It then continues as before and this series of operations is continued until all the variables have been processed.

Table I

```
C       APPLIED GEOCHEMISTRY. GEOLOGY DEPARTMENT. IMPERIAL COLLEGE
C
C       1969 GARRETT. INPUT PROGRAM TO SUBROUTINE ROLLER WHICH PERFORMS
C            ROLLING MEAN ANALYSES.  THIS PROGRAM REQUIRES A SCRATCH TAPE
C            ON UNIT10 (B6.SYSLB3) FOR OUTPUT OF PLOTTING DATA AND
C            STANDARD SYSTEMS SCRATCH TAPES ON UNITS 1 (A3.SYSUT1) AND
C            9 (B5.SYSCK2) FOR INTERMEDIATE DATA STORAGE.
C            IF ANALYTICAL RESULTS OF THE VALUE ZERO ARE ENCOUNTERED
C            EITHER AS LOGS OR NATURAL NUMBERS THE RESULT IS SET TO 0.1.
C
C            TIT1. TIT2.AND TIT3 ARE TITLE CARDS.  VFT IS THE DATA CARD
C            FORMAT AND ANAME IS THE NAME OF THE VARIABLES.
C
C            IFL IS THE LOG OPTION. PUNCH 0 TO SUPRESS OR 1 TO EXCERCISE.
C            NX=NO. OF VARIABLES (MAX 20).  NT IS THE FORTRAN NUMBER OF
C            THE TAPE UNIT ON WHICH THE DATA IS STORED.  IN IS THE INITIAL
C            SIZE OF THE SEARCH AREA AND N THE NUMBER OF TRIALS. THE
C            SEARCH AREA BEING INCLASED BY ONE UNIT IN EACH DIRECTION
C            FOR EACH TRIAL.  IFPLOT IS THE S-C 4020 PLOT OPTION. PUNCH
C            0 TO SUPRESS OR 1 TO EXCERCISE.  IFPRNT IS THE OFF-LINE
C            PRINT OPTION. PUNCH 1 FOR FULL DATA OUTPUT OR 0 FOR
C            EFFICIENCY DETAILS ONLY (FOR USE WITH THE PLOT OPTION).
C
C            IF THE PLOT OPTION IS EXCERCISED A SECOND EXECUTEABLE
C            PROGRAM. DECK SCPLOT. READS THE DATA FROM UNIT 9 (B5.SYSCK2)
C            AND WITH THE AID OF THE UAIDE SUBROUTINE PACKAGE. LOADED
C            WITH SCPLOT. GENERATES A SERIES OF S-C 4020 INSTRUCTIONS
C            ON UNIT10 (B6.SYSLB3).
C
C            THE DATA IS STORED IN A 40*40*3 MATRIX WITH UP TO THREE
C            SAMPLES IN EACH MATRIX MAP UNIT.  THE DATA INPUT TERMINATES
C            ON READING 9999 (INTEGER) IN THE COLUMNS FOR SAMPLE ID.
C
      DIMENSION X(20).ANAME(20).TIT1(13).TIT2(13).TIT3(13).VFT(13)
      DIMENSION XX(40.40.3).UU(40.40.3).VV(40.40.3)
      COMMON XX.UU.VV.MAXU.MINU.MAXV.MINV.NN.N.IFL.ANAME.II.IFPLOT
      COMMON TIT1.TIT2.TIT3.IFPRNT
C
C     READ MASTER CARDS
      READ (5.102) TIT1.TIT2.TIT3
      READ (5.101) IFL.NX.NT.IN.N.IFPLOT.IFPRNT
      READ (5.102) VFT
      READ (5.102) (ANAME(I).I=1.NX)
C
C     TRANSFER DATA TO SCRATCH TAPE
      IF(IFPLOT.EQ.0) GO TO 9
      PRINT 103
      CALL PAUSE
      REWIND 9
      REWIND 10
      WRITE (9) NX
    9 REWIND 1
    6 READ (NT.VFT) ID.U.V.(X(I).I=1.NX)
      WRITE (1) ID.U.V.(X(I).I=1.NX)
      IF(ID.EQ.9999) GO TO 5
      GO TO 6
C
C     INITIALISE INPUT PROGRAM
    5 DO 2 II=1.NX
      NN=IN
      REWIND 1
      DO 4 I=1.40
      OD A J=1.40
      DO 4 K=1.3
      UU(I.J.K)=0.0
      VV(I.J.K)=0.0
    4 XX(I.J.K)=0.0
      MAXU=0
      MAXV=0
      MINU=999
      MINV=999
C
C     READ IN DATA
    1 READ (1) ID.U.V.(X(I).I=1.NX)
      IF(ID.EQ.9999) GO TO 3
      IF(IFL.EQ.1) X(II)=ALOG10(X(II))
      IF(X(II).EQ.0.) X(II)=0.1
C
C     FORM DATA MATRIX
      IU=U/10.
      IV=V/10.
      DO 7 K=1.3
      IF(XX(IU.IV.K).GT.0.) GO TO 7
      UU(IU.IV.K)=U
      VV(IU.IV.K)=V
      XX(IU.IV.K)=X(II)
      GO TO 8
    7 CONTINUE
C
C     DETERMINE THE LIMITS OF THE MAPPED AREA
    8 IF(IU.GE.MAXU) MAXU=IU
      IF(IV.GE.MAXV) MAXV=IV
      IF(IU.LE.MINU) MINU=IU
      IF(IV.LE.MINV) MINV=IV
      GO TO 1
    3 CALL ROLLER
    2 CONTINUE
      IF(IFPLOT.EQ.1) END FILE 9
      IF(IFPLOT.EQ.1) PRINT 104
      STOP
C
  101 FORMAT (14X.I1.6(3X.I2))
  102 FORMAT (13A6)
  103 FORMAT (41H PLEASE MOUNT SCRATCH TAPES ON B5 AND B6.)
  104 FORMAT (106H THE COMPUTATION IS COMPLETED.  A SECOND EXECUTEABLE P
     1ROGRAM IS NOW TO BE CARRIED OUT UNDER THIS JOB CARD.)
C
      END
      SUBROUTINE ROLLER
```

Table I cont.

```
C
      DIMENSION ANAME(20),TIT1(13),TIT2(13),TIT3(13)
      DIMENSION XX(40,40,3),UU(40,40,3),VV(40,40,3)
      COMMON XX,UU,VV,MAXU,MINU,MAXV,MINV,NN,N,IFL,ANAME,II,IFPLOT
      COMMON TIT1,TIT2,TIT3,IFPRNT
      INTEGER SUS,SUE,SVS,SVE
      REAL MV
C
C     SET SUMMATIONS TO ZERO
      NNN=NN+N
      IS=0
      TSUM=0.
      TSUMSQ=0.
C
C     CALCULATE OVERALL MEAN AND VARIANCE
      DO 10 I=MINU,MAXU
      DO 10 J=MINV,MAXV
      DO 10 K=1,3
      IF(XX(I,J,K).EQ.0.) GO TO 10
      IS=IS+1
      TSUM=TSUM+XX(I,J,K)
      TSUMSQ=TSUMSQ+XX(I,J,K)**2
   10 CONTINUE
      SS=IS
      TMEAN=TSUM/SS
      TV=(TSUMSQ-(TSUM**2)/SS)/(SS-1.0)
      TSD=SQRT(TV)
      MV=TV/(SS-1.0)
      IF(IFL) 11,11,12
   11 TTMEAN=TMEAN
      GO TO 8
   12 TTMEAN=EXP(2.302582*TMEAN)
C
C     WRITE OUT OVERALL MEAN AND VARIANCE
    8 IF(IFPRNT.EQ.0) GO TO 9
      WRITE (6,40) TIT1,TIT2,TIT3
      IF(IFL.EQ.1) WRITE (6,41)
      WRITE (6,42) ANAME(II),TTMEAN,TV,TSD
    9 IF(IFPLOT.EQ.1) WRITE (9) ANAME(II),NN
C
C     INITIALISE FOR ROLLING MEAN SEARCH AND SET COUNT OF MEANS TO ZERO
      L=50
      KR=0
      KS=0
      SUMZ=0.
      NNUM=0
      CRMEAN=0.
      SRMEAN=0.
      SVS=MINV
      SVE=SVS+NN-1
    7 SUS=MINU
      SUE=SUS+NN-1
C
C     INITIALISE SUMMATIONS FOR EACH ROLLING MEAN
    6 NUM=0




      SUM=0.
      SUMSQ=0.
      SUMCOU=0.
      SUMCOV=0.
C
C     CARRY OUT SEARCH
      DO 5 I=SUS,SUE
      DO 5 J=SVS,SVE
      DO 5 K=1,3
      IF(XX(I,J,K).EQ.0.) GO TO 5
      NUM=NUM+1
      SUM=SUM+XX(I,J,K)
      SUMSQ=SUMSQ+XX(I,J,K)**2
      SUMCOU=SUMCOU+UU(I,J,K)
      SUMCOV=SUMCOV+VV(I,J,K)
    5 CONTINUE
      KS=KS+1
      S=NUM
      IF(S.EQ.0.) GO TO 14
      RMEAN=SUM/S
      VA=(SUMSQ-(SUM**2)/S)/(S-1.0)
      SD=SQRT(VA)
      ZZ=(RMEAN-TMEAN)/TSD
      FRAT=MV/(VA/(S-1.0))
      AVCOU=SUMCOU/S
      AVCOV=SUMCOV/S
      CRMEAN=CRMEAN+RMEAN
      SRMEAN=SRMEAN+RMEAN**2
      IF(IFL.EQ.1) RMEAN=EXP(2.302582*RMEAN)
      KR=KR+1
      GO TO 15
   14 RMEAN=0.
      SD=0.
      ZZ=0.
      FRAT=0.
      AVCOU=0.
      AVCOV=0.
C
C     WRITE PAGE HEADINGS
   15 IF(IFPRNT.EQ.0) GO TO 19
      IF(L.LE.49) GO TO 18
      L=0
      IF(IFL) 16,16,17
   16 WRITE (6,43) ANAME(II),NN
      GO TO 18
   17 WRITE (6,44) ANAME(II),NN
C
C     WRITE OUTPUT FOR THIS SEARCH AREA
   18 WRITE (6,45) KS,AVCOU,AVCOV,RMEAN,SD,ZZ,NUM,FRAT,SUS,SVS
   19 IF(IFPLOT.EQ.1) WRITE (9) KS,AVCOU,AVCOV,RMEAN,SD,ZZ,FRAT
      SUMZ=SUMZ+ZZ
      NNUM=NNUM+NUM
      L=L+1
C
```

Table I cont.

```
C     MOVE ON THE SEARCH AREA BY ONE UNIT
      SUS=SUS+1
      SUE=SUE+1
      IF(SUE.LE.MAXU) GO TO 6
      SVS=SVS+1
      SVE=SVE+1
      IF(SVE.LE.MAXV) GO TO 7
C
C     CALCULATE SEARCH EFFICIENCY FIGURES ETC.
      WRITE (6,40) TIT1,TIT2,TIT3
      WRITE (6,47) ANAME(II),NN
      ROLS=KR
      PS=100.0*ROLS/(FLOAT(KS))
      DEN=(FLOAT(NNUM))/ROLS
      CV=(SRMEAN-(CRMEAN**2)/ROLS)/(ROLS-1.0)
      RSS=TV-CV
      PRSS=100.0*RSS/TV
      FIT=100.0*CV/TV
      WRITE (6,46) IS,KS,KR,PS,DEN,SUMZ,TV,CV,RSS,PRSS,FIT
      KS=9999
      IF(IFPLOT.EQ.1) WRITE (9) KS,AVCOU,AVCOV,RMEAN,SD,ZZ,FRAT
C
C     TEST FOR FURTHER ROLLING MEAN SEARCH
      NN=NN+1
      IF(NN.EQ.NNN) RETURN
      GO TO 8
C
   40 FORMAT (13A6)
   41 FORMAT (1H ////,11X,39H THE VARIANCE IS EXPRESSED IN LOG UNITS///)
   42 FORMAT (1H0,10X,21HTHE OVERALL MEAN FOR ,1A6,2H =,F9.1//19X,13HTHE
     1 VARIANCE ,6X,2H =,F11.3//14X,18HAND THE STD. DEV. ,6X,2H =,F11.3)
   43 FORMAT (1H1,32X,28HTHE VARIABLE UNDER STUDY IS 1A6,20H AND THE SEA
     1RCH AREA,1A3,13H UNITS SQUARE///1X,5H  NO.,3X,8H U COORD,3X,8H V C
     2OORD,3X,13H ROLLING MEAN,3X,10H STD. DEV.,3X,8H Z SCORE,3X,14H NO.
     3 OF POINTS,3X,8H F RATIO,3X,24H COORDS OF SEARCH ORIGIN//)
   44 FORMAT (1H1,28X,28HTHE VARIABLE UNDER STUDY IS 1A6,20H AND THE SEA
     1RCH AREA,1I3,13H UNITS SQUARE/35X,57H THE LOG OPTION ON THE ANALYT
     2ICAL DATA HAS BEEN EXERCISED//1X,5H  NO.,3X,8H U COORD,3X,8H V COO
     3RD,3X,13H ROLLING MEAN,3X,10H STD. DEV.,3X,8H Z SCORE,3X,14H NO. O
     4F POINTS,3X,8H F RATIO,3X,24H COORDS OF SEARCH ORIGIN//)
   45 FORMAT (1H ,I4,2(7X,F4.0),7X,F6.1,8X,F7.3,4X,F8.3,10X,I2,9X,F7.3,2
     1X,2(8X,I2,1H0))
   46 FORMAT (1H //////24H TOTAL NUMBER OF SAMPLES,8X,1H=,I5////25H TOTA
     1L NUMBER OF SEARCHES,7X,1H=,I5//33H NUMBER OF SUCCESSFUL SEARCHES
     2 =,I5//33H PERCENTAGE SUCCESSFUL SEARCHES =,F8.2//33H MEAN NO. OF
     3SAMPLES PER SEARCH =,F8.2////27H CUMULATIVE SUM OF Z SCORES,5X,1H=
     4,F9.3////29H TOTAL VARIANCE OF DATA      ,3X,1H=,F9.3//30H VARIANC
     5E OF ROLLING MEANS     ,2X,1H=,F9.3//29H REDUCTION IN VARIANCE
     6  ,3X,1H=,F9.3//26H REDUCTION AS A PERCENTAGE,6X,1H=,F8.2//30H PER
     7CENTAGE FIT OF NEW SURFACE,2X,1H=,F8.2)
   47 FORMAT (1H ////29H THE VARIABLE UNDER STUDY IS 1A6,20H AND THE SEA
     1RCH AREA,1I3,13H UNITS SQUARE)
C
      END
```

Table II

PROJECT 42, SIERRA LEONE
ROLLING MEAN ANALYSIS
BASEMENT ROCK SAMPLES

THE VARIANCE IS EXPRESSED IN LOG UNITS

THE OVERALL MEAN FOR CR = 5.3
THE VARIANCE = 0.187
AND THE STD. DEV. = 0.432

THE VARIABLE UNDER STUDY IS CR AND THE SEARCH AREA 5 UNITS SQUARE
THE LOG OPTION ON THE ANALYTICAL DATA HAS BEEN EXERCISED

NO.	U COORD	V COORD	ROLLING MEAN	STD. DEV.	Z SCORE	NO. OF POINTS	F RATIO	COORDS OF SEARCH ORIGIN	
1	41.	98.	5.0	0.539	-0.072	3	0.013	10	80
2	50.	96.	5.2	0.397	-0.021	5	0.047	20	80
3	60.	101.	4.5	0.320	-0.167	8	0.128	30	80
4	70.	97.	3.4	0.247	-0.451	7	0.183	40	80
5	75.	98.	3.0	0.237	-0.570	9	0.265	50	80
6	81.	101.	3.3	0.190	-0.473	9	0.414	60	80
7	93.	105.	3.0	0.126	-0.583	9	0.941	70	80
8	105.	106.	2.8	0.108	-0.657	7	0.956	80	80
9	109.	110.	2.7	0.117	-0.669	6	0.676	90	80
10	122.	116.	3.4	0.068	-0.466	5	1.593	100	80
11	126.	117.	3.5	0.072	-0.437	4	1.075	110	80
12	136.	125.	3.5	0.088	-0.437	2	0.239	120	80
13	145.	121.	4.0	-0.	-0.292	1	-0.	130	80
14	145.	121.	4.0	-0.	-0.292	1	-0.	140	80
15	0.	0.	0.	0.	0.	0	0.	150	80
16	0.	0.	0.	0.	0.	0	0.	160	80
17	0.	0.	0.	0.	0.	0	0.	170	80
18	0.	0.	0.	0.	0.	0	0.	180	80
19	0.	0.	0.	0.	0.	0	0.	190	80
20	0.	0.	0.	0.	0.	0	0.	200	80
21	0.	0.	0.	0.	0.	0	0.	210	80
22	0.	0.	0.	0.	0.	0	0.	220	80
23	0.	0.	0.	0.	0.	0	0.	230	80
24	0.	0.	0.	0.	0.	0	0.	240	80
25	35.	129.	7.0	-0.	0.270	1	-0.	10	90
26	58.	113.	4.1	0.366	-0.268	4	0.042	20	90
27	65.	118.	4.5	0.352	-0.171	7	0.090	30	90
28	70.	116.	4.2	0.374	-0.245	6	0.067	40	90
29	74.	116.	3.8	0.363	-0.351	7	0.085	50	90
30	78.	115.	3.7	0.338	-0.380	8	0.115	60	90
31	94.	117.	3.7	0.281	-0.367	7	0.141	70	90
32	113.	115.	2.9	0.107	-0.605	5	0.647	80	90
33	113.	115.	2.9	0.107	-0.605	5	0.647	90	90
34	122.	116.	3.4	0.068	-0.466	5	1.593	100	90
35	126.	117.	3.5	0.072	-0.437	4	1.075	110	90
36	136.	125.	3.5	0.088	-0.437	2	0.239	120	90
37	167.	127.	2.9	0.151	-0.621	3	0.163	130	90
38	167.	127.	2.9	0.151	-0.621	3	0.163	140	90
39	182.	133.	2.0	0.189	-1.009	3	0.105	150	90
40	182.	133.	2.0	0.189	-1.009	3	0.105	160	90
41	182.	133.	2.0	0.189	-1.009	3	0.105	170	90
42	191.	138.	1.3	-0.	-1.455	1	-0.	180	90
43	191.	138.	1.3	-0.	-1.455	1	-0.	190	90
44	240.	139.	3.0	-0.	-0.582	1	-0.	200	90
45	240.	139.	3.0	-0.	-0.582	1	-0.	210	90
46	240.	139.	3.0	-0.	-0.582	1	-0.	220	90
47	240.	139.	3.0	-0.	-0.582	1	-0.	230	90
48	240.	139.	3.0	-0.	-0.582	1	-0.	240	90
49	40.	142.	7.8	0.295	0.377	4	0.064	10	100
50	48.	141.	5.9	0.401	0.096	6	0.058	20	100

Table III

PROJECT 42, SIERRA LEONE
ROLLING MEAN ANALYSIS
BASEMENT ROCK SAMPLES

THE VARIABLE UNDER STUDY IS CR AND THE SEARCH AREA 5 UNITS SQUARE

TOTAL NUMBER OF SAMPLES	=	101
TOTAL NUMBER OF SEARCHES	=	432
NUMBER OF SUCCESSFUL SEARCHES	=	369
PERCENTAGE SUCCESSFUL SEARCHES	=	85.42
MEAN NO. OF SAMPLES PER SEARCH	=	5.39
CUMULATIVE SUM OF Z SCORES	=	-1.773
TOTAL SUM OF SQUARES OF DATA	=	0.187
TOTAL SUM OF SQUARES OF MEANS	=	0.057
REDUCTION IN SUMS OF SQUARES	=	0.130
REDUCTION AS A PERCENTAGE	=	69.60
PERCENTAGE FIT OF NEW SURFACE	=	30.40

For Sum of Squares read Variance

5865 LINES OUTPUT.

APPENDIX IV

Systems Control Cards for Programs

When running the programs described (Appendices I, II & III) on the IBM 7090/1401 installation at Imperial College a number of systems control cards are required in addition to the program, the program control cards and data.

The set up of the cards is shown in figure 1, and the cards must be punched as follows:-

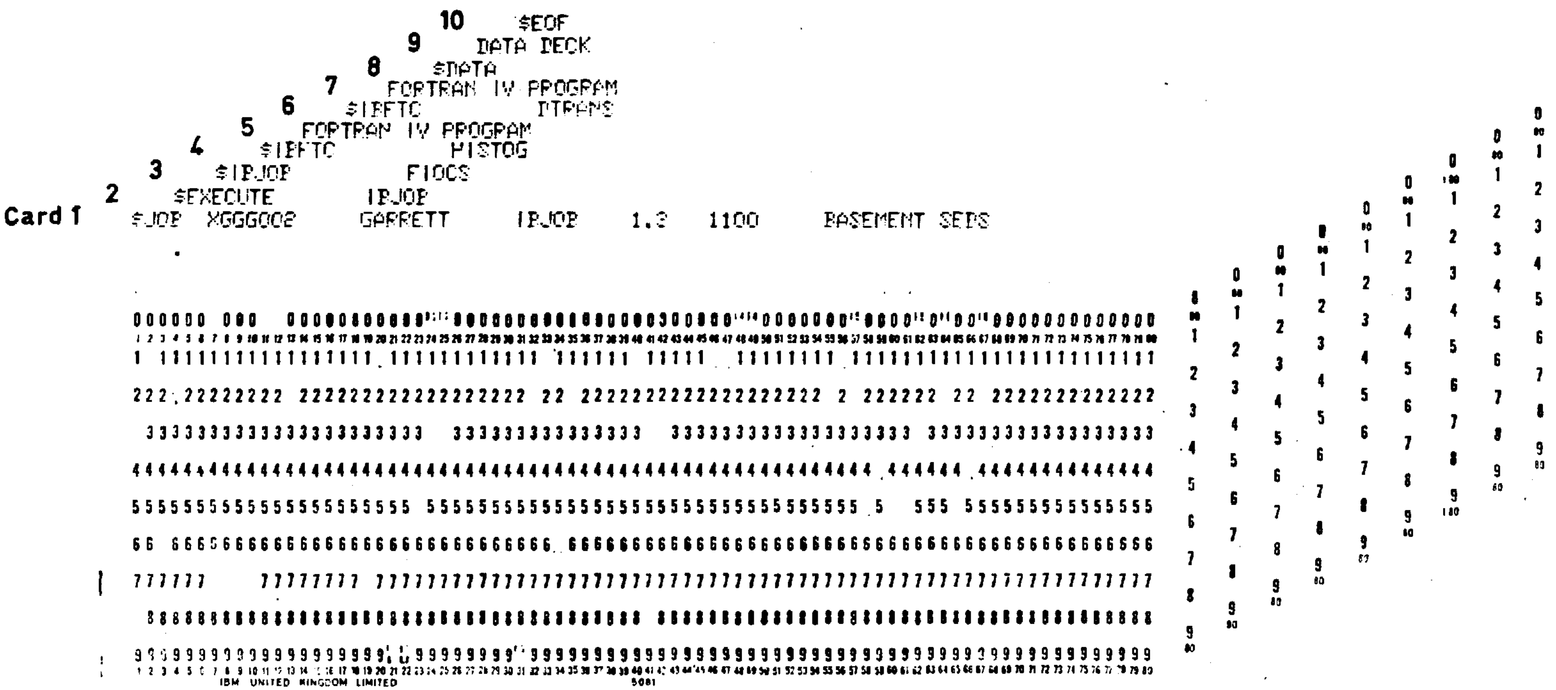
Card 1

Columns	1- 4	$JOB.
	7-14	Job number.
	19-30	User's name, starting in column 19.
	31-35	IBJOB.
	40-45	Maximum running time in minutes punched with decimal point, starting in column 40.
	46-51	Maximum lines output, starting in column 46.
	55-72	Any heading information.

Card 2

	1- 8	$EXECUTE
	16-20	IBJOB

FIG. 1 — SYSTEMS CONTROL CARDS



<u>Card 3</u>

Columns 1-6 ∅IBJOB

 16-20 **FIOCS**

<u>Card 4</u>

 1- 6 ∅IBFTC

 8-16 Deckname, starting in column 8

The following decknames have been used for the different programs :-

STATS Analytical precision main program

HISTOG Frequency distribution main program

ROLINP Rolling means main program

<u>Card 5</u> This card represents the main Fortran IV program.

<u>Card 6</u> This is a second ∅IBFTC card and contains the deckname of the subprograms required by the main programs. The following decknames have been used:-

XYPLOT The standard Imperial College graph plotting package for the analytical precision program.

DTRANS The logarithmic transformation routine for the frequency distribution program.

DROLL The routine for computing the rolling mean values, etc. from the 'map' prepared by the main rolling mean program.

<u>Card 7</u> This card represents the Fortran IV subprograms.

<u>Card 8</u> Columns 1-5, ∅DATA

<u>Card 9</u> This card represents the data deck, each data deck set

-up has been described in Appendices I - III.

Card 10 Columns 1-4, ØEOF

The systems control cards are standard to most IBM installations, however, these cards are likely to be changed at any time as the computer systems are being constantly developed. Therefore, any user of these programs is urged to consult with a member of their computer unit staff prior to submitting any program, and so ensure that the correct systems control cards are used.