BRITISH GEOLOGICAL SURVEY
Overseas Directorate

A regional drainage geochemical exploration survey of the Harare area, Zimbabwe

P. N. Dunkley

Natural Environment Research Council

Report MP/87/18
British Geological Survey
Keyworth, Notts, UK
November 1987

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Bibliographic reference
Dunkley, P. N. 1987. A regional drainage geochemical exploration survey of the Harare area, Zimbabwe. *Research report of the British Geological Survey*, No. MP/87/18.

Keyworth, Nottinghamshire British Geological Survey 1987

SUMMARY AND RECOMMENDATIONS

During the period 1982-86 a team of geologists from the British Geological Survey carried out a programme of regional geological mapping and geochemical exploration in collaboration with the Zimbabwe Geological Survey under a Technical Co-operation agreement. This report describes the working methods and results of a stream sediment geochemical exploration survey of the Harare area, which formed part of this programme. The results of the survey are presented in a series of geochemical maps which are held on open file at the offices of the Zimbabwe Geological Survey and the British Geological Survey, and which should be consulted in conjunction with this report.

The ground covers an area of 4 400 km^2 and is mostly underlain by volcano-sedimentary rocks of the Harare Greenstone Belt which are encircled and intruded by a variable suite of granitic rocks.

The Harare Greenstone Belt takes the form of a complex refolded synformal structure, which crops out in E-W and N-S trending limbs that converge within the vicinity of the city. Felsic volcanic and banded ironstones of the Iron Mask Formation are the oldest rocks of the belt, and these are overlain by a thick pile of tholeiitic metabasalts of the Arcturus Formation. In the central part of the belt the metabasalts are overlain by a thick sequence of graphitic and tuffaceous phyllites of the Mount Hampden Formation. The Passaford Formation is the uppermost unit of the belt and consists essentially of rhyolitic and dacitic volcanic and reworked volcaniclastic rocks. Felsic stocks and plugs of the Teviotdale Event intrude the greenstone belt and are believed to be coeval with the Passaford Formation, and metagabbros of the Selby Mafic Igneous Event cross-cut the greenstones but are folded with them.

Granitic rocks surrounding the greenstone belt are of two main types. Older gneissic and migmatitic tonalites and granodiorites intrude the greenstones but are also partly coeval with the youngest felsic volcanic rocks, and are correlated with Sesombi-type intrusions found elsewhere in the craton. Massive potassic granite, corresponding to Chilimanzi-type intrusions, post-date the greenstones and Sesombi-type intrusions. In addition certain migmatitic granitoids within the area may represent fragments of a basement to the greenstones.

Large dolerite sills and associated dykes intrude the greenstone belt and granitic terrain, and are ascribed to the Mashonaland and Manyika events.

Gold has been declared from more than 270 mines within the area, with total production exceeding 44 tonnes, most of which has been produced in the Enterprise belt. Numerous pegmatites occur throughout the granite-greenstone terrain and three areas have produced beryl and minor amounts of tin, tantalite and lepidolite.

A total of 1603 stream sediment samples was collected during the survey, giving an average density of 1 sample per 2.7 km^2. The -80 mesh fraction was analysed for Cu, Pb, Zn, Co, Ni, Mn and Li by atomic absorption spectrophotometry following digestion with hot concentrated hydrochloric acid, and approximately 40% of these samples were also analysed for As, Ba, Sn, Ta and W by X-ray fluorescence spectrometry. Analytical precision was monitored by the replicate analysis of samples, and by the regular analysis of standard samples.

Results were analysed statistically and geochemical maps were plotted by computer at a scale of 1:100 000 as transparent overlays complementary to the published geological map for Harare. The analytical data for each element is presented in a series of single element maps, which illustrate element concentration by means of proportional symbols, and provide a rapid and visual means of assessing concentration ranges and broad variations related to lithology.

Geochemical anomalies are portrayed on multi-element anomaly maps. Because of difficulties in portraying 12 elements on a single plot, the anomalies are split into two element associations, and each is presented separately. During interpretation the influences of lithology on stream sediment chemistry were accounted for by classifying the analytical results into groups according to the dominant drainage basin lithology at each sample site. For each element and lithological grouping, graphs of log-concentration plotted against cumulative frequency on a probability scale were used to determine threshold values (T), above which concentrations are considered to be anomalous. Anomalous values were then standardised to produced standard anomaly values (SAV) that are directly comparable regardless of the element, concentration range, background lithology and map sheet.

The formula used for standardisation is: SAV = ((Anomaly - T)/T)100.

A total of 28 geochemical anomalies are listed and briefly described at the end of the report, and recommendations are made for further investigation of these. All of the anomalies are considered to merit further investgation, particularly those upon the greenstone belt, and especially the anomalies at Selby (anomaly 1) and to the east of Ascot Vale (anomaly 2).

In view of the low sample density and broadly defined nature of many of the anomalies, it is recommended that anomalous areas are initially investigated by more detailed stream sediment surveys. For some anomalous areas where there is a paucity of drainage channels, low to moderate density soil geochemical surveys are recommended for initial investigations. Subsequently, anomalies of continued interest should be investigated by detailed soil geochemical surveys, and by geological mapping and rock sampling where exposure permits.

Of the elements determined in the survey, As, Pb, Cu, Co, Ni and Mn appear to be the most useful in greenstone areas, and should be included in follow-up surveys. It is recommended that As be determined by AAS, using hydride generation, rather than by XRF. Gold should also be determined routinely at the ppb level, and orientation work should be undertaken at an early stage to ascertain the best sample type for these determinations.

With respect to pegmatite mineralisation, Li, determined by AAS, has been found to give an effective geochemical response, and it should be included in future surveys. It is recommended that orientation work be undertaken to ascertain the best sample leaching technique for Li, and that consideration be given to total dissolution methods so that Be may be determined on the same solution by AAS.

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A REGIONAL DRAINAGE GEOCHEMICAL EXPLORATION SURVEY OF THE HARARE AREA, ZIMBABWE

INTRODUCTION

This report describes the working methods and results of a regional drainage geochemical survey of the country around Harare in Zimbabwe. The work was undertaken as part of a regional geological mapping and mineral reconnaissance project carried out during the period 1982-1986 by staff of the British Geological Survey (BGS) and the Zimbabwe Geological Survey under a technical co-operation agreement funded by the Overseas Development Administration of the United Kingdom and the Ministry of Mines of Zimbabwe. The report is complementary to a series of geochemical maps held on open-file at the offices of the British Geological Survey and the Zimbabwe Geological Survey.

THE AREA

The ground covered by the survey has an area of 4 400 km^2 and extends between latitudes $17^{\circ}30'$S and $18^{\circ}00'$S and longitudes $30^{\circ}45'$E and $31^{\circ}30'$E. The city of Harare occupies much of the southern central part of the area. The ground outside of the city and its industrial and suburban areas is occupied by privately owned commercial and small-scale farmland, and also by communal land in the north and east, particularly around Chinamora and the Chikwakwa-Goromonzi areas.

Access

The area is served by an excellent system of sealed roads radiating outwards from the city, and numerous minor roads and farm tracks provide easy access to most of the area.

Topography and drainage

The area straddles an important NW-trending watershed. Drainage in the southern and western parts of the area is westwards via the Hunyani and its tributary the Gwebi, whereas the northern and eastern parts are drained principally by the Mazowe and its tributaries the Pote, Inyauri, Umwindsi and Nora rivers.

The ground in the west and south of the area is relatively flat, but becomes more rugged and dissected in the north and north-east. Altitude varies from around 1500 m along the watershed, with hills locally rising to about 1600 m, to less than 1200 m in the north-east along the Umwindsi valley. The high ground, approximately above 1500 m, is relatively flat to gently undulating and represents a mid-Cretaceous to Lower Tertiary 'African' erosional surface. The hill of Mt Hampden rises almost 100 m above this 'African' surface and represents an isolated remnant of an earlier Lower Cretaceous 'Post-Gondwana' erosional surface. As a result of Tertiary uplift and tilting the African surface slopes gently westwards and is replaced in the west of the area by a 'Post-African' surface which formed during a Miocene erosional cycle. Uplift during the Plio-Pleistocene brought the various erosinal surfaces to their present level.

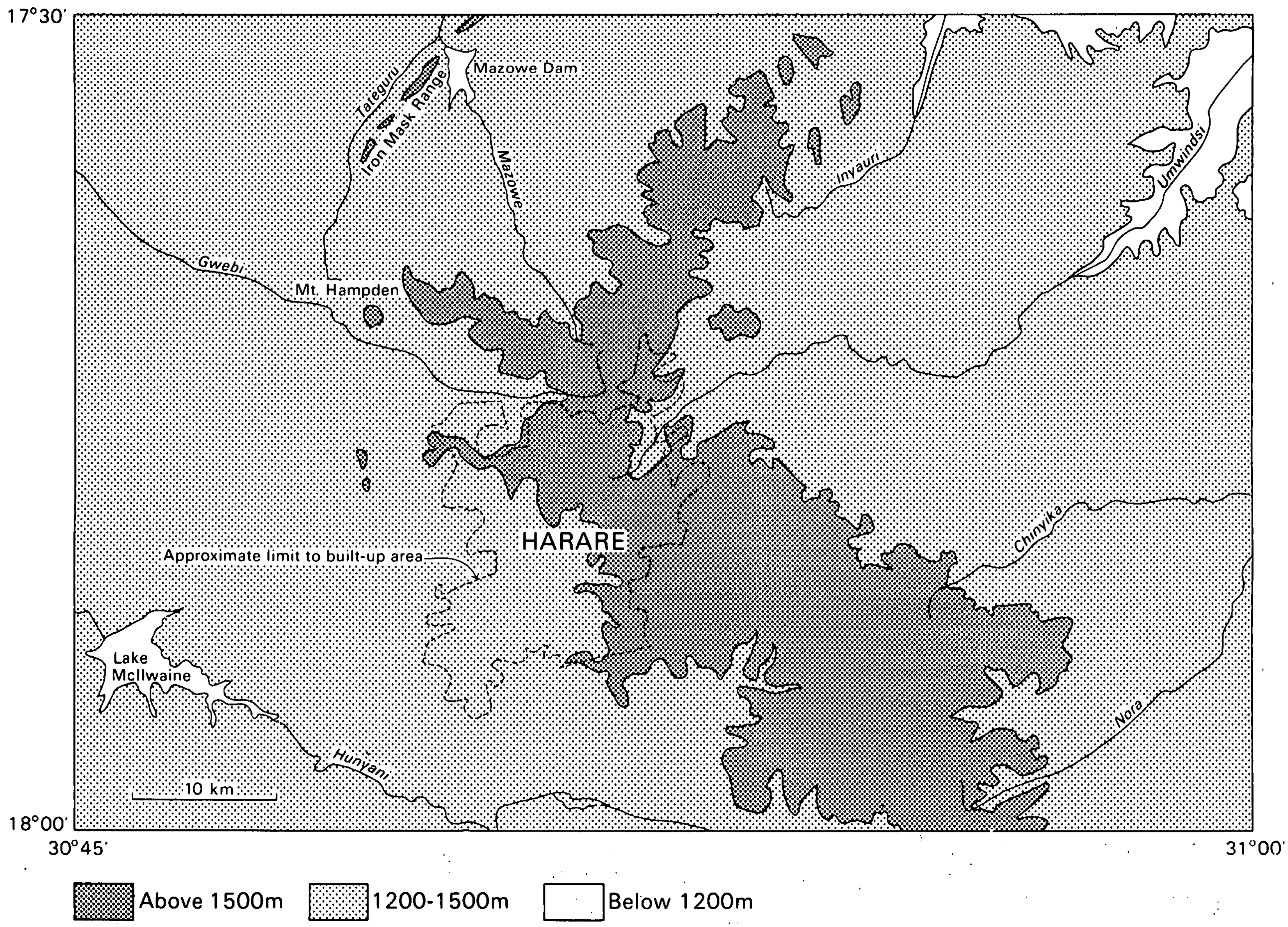


Figure 1: Relief and drainage of the area.

Bedrock lithology and jointing influences the detailed geomorphology, although the main 'African' and 'Post-African' erosional surfaces cut, largely indiscriminantely, across both granite and greenstone terrain. Granitic terrain is characterised by rugged castelated kopjes and residual boulders in well jointed areas, by bornhardts or dwalas in more massive granites, and by low pavement outcrops in gneissic granites. In greenstone terrain, basaltic rocks are characterised by undulating ground with smooth slopes and sedimentary sequences produce flat subdued surfaces, whilst felsic volcanic rocks give rise to rugged ground and iron-formations to steep-sided hill-ranges.

Climate

The climate of the area is characterised by a dry season from May to October, during which little rain falls, and a wet season from November to April when rainfall is intermittant but heavy. The western half of the area has a mean annual rainfall of 600-800 mm and is generally slightly drier than the east, which averages 800-1000 mm with the Goromonzi area having 1000-1200 mm.

During the wet season mean monthly maximum temperatures range between 25 and 27^{o} C and mean monthly minimum temperatures between 12 and 14^{o} C. The early part of the dry season, from May to August, is cool with mean monthly maximum temperatures in the range 21 to 24^{o} C and mean monthly minimum temperatures between 6 and 9^{o} C. The hottest part of the year occurs at the end of the dry season, during September to November, when mean monthly maximum temperatures range between 27 and 29^{o} C, and mean monthly minimum temperatures range between 11 and 16^{o} C.

Vegetation

Farmland covers a large part of the area and indigenous vegetation is generally confined to the less easily cultivated ground, but has in places survived in grazing land. Commercial and small-scale farms produce maize, winter wheat, ground nuts, soya beans and vegetables, as well as beef and dairy products, from the fertile red soils of the greenstones. Maize is increasingly grown on sandy granite soils, although traditionally this is dominated by tobacco and ranching. Citrus fruit and cotton are grown in the lower lying areas.

The natural vegetation of both greenstone and granitic terrain is similar, although growth tends to be more prolific on the more fertile soils of the greenstones. Mixed woodland is widespread, particularly on well-drained hills and ridges of greenstone, and is dominated by Msasa (<u>Brachystegia</u> <u>spiciformis</u>) and Mnondo (<u>Julernardia</u> <u>globiflora</u>), with Mufuti (<u>Brachystegia</u> <u>boehmii</u>). More open Msasa-Mnondo tree savanna associated with <u>Hyparrhenia</u> grassland is common throughout granitic areas, although over the Chinamora granitic terrain woodland is more sparse, and where soils are thin various brushes and brooms are developed. Mixed Mukwa (<u>Pterocarpus</u> <u>angolensis</u>) - Combretum woodland with Acacia occurs in valley areas.

Soils

Residual soils cover most of the area and are mainly fersiallitic. Over basic greenstone lithologies and mafic intrusive rocks soils are moderately shallow to moderately deep, reddish brown to greyish brown, silty sandy clay loams and clay loams. Soils derived from felsic volcanic rocks are much lighter orange-brown and usually silty, and on the steep slopes of the Iron Mask Range, which is composed of felsic volcanic rocks and banded ironstones, lithosols are developed (Thompson and Purves, 1978).

Over granitic areas soils are mainly moderately shallow, greyish brown, coarse-grained sands and sandy loams, overlying sandy clay loams. Extensive rock pavements and bare hill slopes without soil are also common in granitic areas.

Near drainage channels dark grey 'vlei' soils are developed, sometimes with nodular calcrete beneath the surface, resulting from seasonal fluctuations in the level of the water table.

Fericrete and silcrete-calcrete also occur in small isolated patches on mature erosinal surfaces.

GEOLOGY

The geology of the area has recently been re-mapped and described by Baldock et al. (in press) whose work forms the basis of the following brief description. Most of the area is underlain by metavolcanosedimentary rocks of the Harare Greenstone Belt which are encircled and intruded by a variable suite of granitic rocks, the oldest of which may have been co-eval with the youngest felsic volcanic rocks of the belt. There is also some evidence for a small remnant area of gneissic basement to the greenstone belt.

The Harare Greenstone Belt

The Harare Greenstone Belt takes the form of a complex refolded synformal structure, which crops out in two major limbs. An E-W trending Arcturus Limb occupies a broad band across the centre of the area, and to the west of the city of Harare this passes via a fold closure into the N-S trending Passaford Limb which is contiguous northwards with the greenstones of the Bindura area.

The Iron Mask Formation is the oldest unit within the greenstone belt, and consists mainly of metamorphosed felsic volcanic rocks. The formation includes lavas and volcaniclastic rocks, including breccias, which are predominantly dacitic in composition with subordinate amounts of andesite and rhyolite. Associated metasediments include prominent bands of cherty sulphide-facies iron-formation which form the steep sided ridges of the Iron Mask Range, and subordinate phyllite, meta-arenite and quartzose schists. The basal part of the formation is missing as a result of intrusion of the Chinamora Igneous Complex, but the exposed thickness exceeds 2 500 m, although cannot be estimated with confidence because of isoclinal folding, shearing and possible thrusting.

The Arcturus Formation overlies the Iron Mask Formation and the contact between the two formations appears to be structural. The Arcturus Formation consists mainly of a thick sequence of tholeiitic metabasaltic rocks, including pillow basalts, with very minor meta-andesite and dacite, as well as bands of iron-formation and chert. At its maximum development the Arcturus Formation is probably about 3 000 to 4 000 m thick, but isoclinal folding, which is often only evident from the configuration of sporadic iron-formation bands, precludes an accurate estimation of true stratigraphic thickness.

The Mount Hampden Formation overlies the metabasalts of the Arcturus Formation in the central part of the greenstone belt, and is composed of graphitic and tuffaceous meta-argillites or phyllites of probable deep water origin. Thin bands of iron-formation and chert occur within the phyllites, and locally limestones are developed and possibly signify shallower water deposition. The phyllites are at least 2 000 m thick in the Harare - Mt Hampden area, but thin rapidly and die out in both the northern and eastern limbs of the greenstone belt, where felsic volcanic rocks of the suceeding Passaford Formation may come to rest directly upon basaltic rocks of the underlying Arcturus Formation.

The Passaford Formation is the uppermost and most complex unit of the greenstone belt, and is spatially divided into two slightly different lithological facies. In the Passaford limb of the belt the lower part of the formation is composed of dacitic and rhyolitic metavolcanics of the Murowodzi Member, which is overlain by the Gwebi Member consisting of reworked volcaniclastic and wacke metasediments. In the Arcturus limb of the belt the lower part of the formation is composed of dacitic metavolcanic rocks of the Manyonga Member, which is overlain by quartzose metasediments of the Mapfeni Member. Locally metasedimentary lithologies occur beneath the metavolcanic rocks at the base of the formation and are gradational into phyllite of the underlying Mt Hampden Formation. The rocks of the formation are highly sheared and in places the metamorphic grade is quite high. The thickness of the formation is uncertain, although the metavolcanic members locally exceed 3 000 m and the metasedimentary sequence is in places at least 2 000 m thick.

A number of felsitic stocks and plugs intrude the greenstone belt. These belong to the **Teviotdale Event** and are generally believed to represent subvolcanic intrusions that were coeval with volcanism of the Passaford Formation.

The succession of the greenstone belt is intruded by a suite of metagabbro and metadolerite bodies of the **Selby Mafic Igneous Event.** These bodies cross-cut the greenstones but are folded with them.

The Granitic Terrain

The Harare Greenstone Belt is circumscribed and intruded by various granitoid complexes which fall into two broad categories. Older gneissic and migmatitic tonalites and granodiorites are correlated with the Sesombi-type intrusions found elsewhere in the craton, and although they intrude the greenstone belt they also appear to be partly coeval with the youngest felsic volcanic rocks of the belt. The other category consists of massive potassic granite corresponding to the Chilimanzi-type intrusions which post-date the greenstones and Sesombi-type intrusions, and were intruded during a widespread 2 600 Ma old thermal event. In addition certain gneissic and migmatitic granitoids within the area may represent fragments of 'basement' to the greenstones.

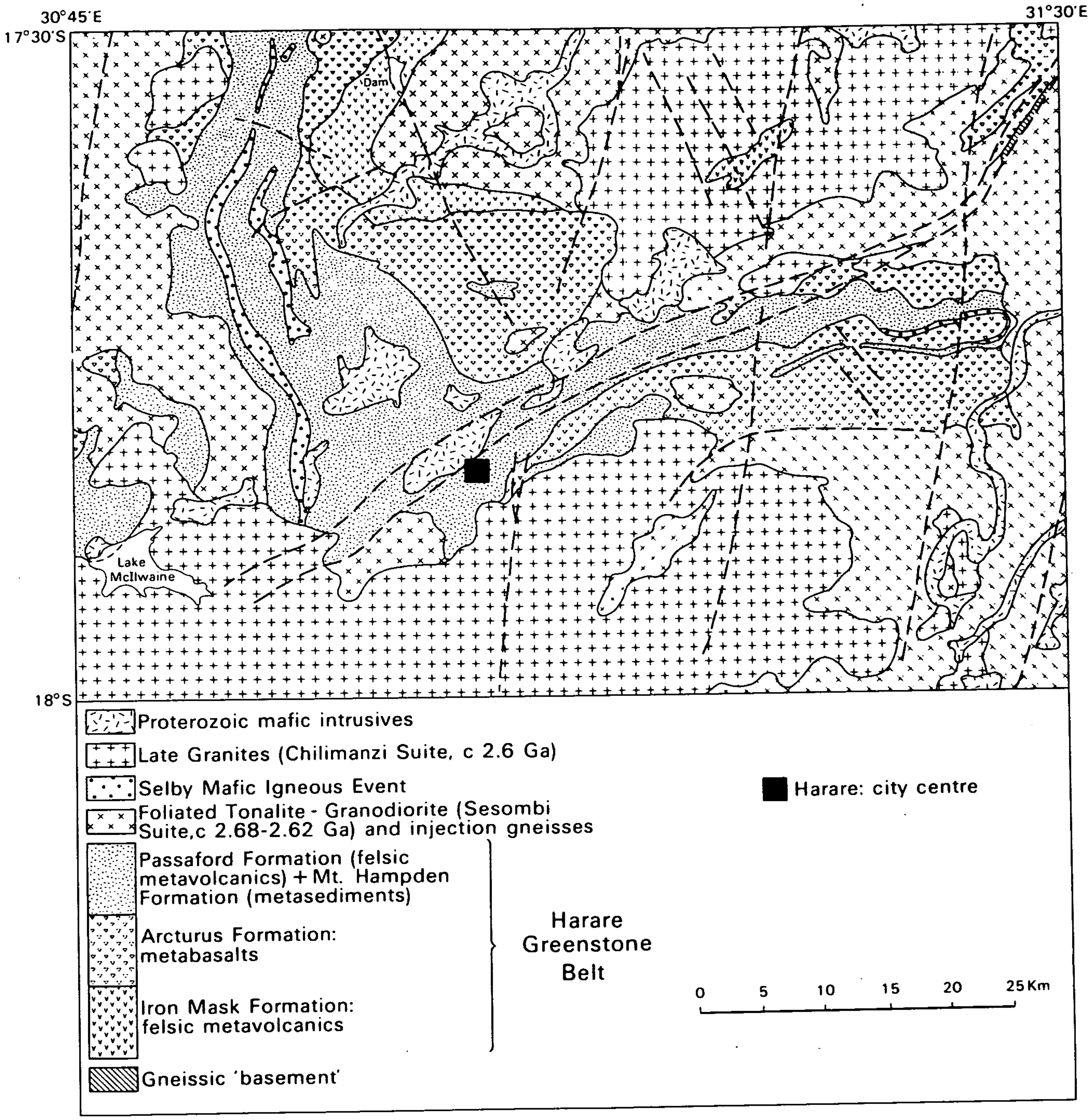


Figure 2: Simplified geological map of the area.

The Nyabira Complex crops out in the west of the area. It is poorly exposed but includes granitized hornblende granodiorite intrusive into older leucotonalite-trondhjemite gneiss which may or may not represent 'basement' to the greenstone belt.

The Harare Complex occurs to the south of the greenstone belt. The earliest phase of the complex is the Chinyika Tonalite, which was tectonically emplaced against the Arcturus limb, and this is intruded by the Harare Granite (formerly Salisbury Adamellite) which is also intrusive into the Nyabira Complex.

The Chikwakwa Injection Complex occurs in the east of the area and is composed of early tonalite and granodiorite phases which were intruded, injected and metasomatised by later leucogranite, resulting in migmatitic gneisses. The complex contains greenstone xenoliths, but parts may possibly be older than the greenstone belt and have acted as a 'basement' to it.

The Chinamora Igneous Complex occupies much of the north and northeastern part of the area and comprises a series of gneissic tonalitic and granodioritic plutons with associated migmatitic injection gneisses, and the immense, probably tabular body, of the later Chinamora Porphyritic Granite. relationships are complex, but the foliated tonalite-granodiorite intrusions are broadly correlated with the Sesombi-type intrusions found elesewhere in the craton, whilst the massive and potassic Chinamora Porphyritic Granite corresponds to the Chilimanzi-type.

Proterozoic Intrusions

Large dolerite sills and associated dykes are widespread and intrude the greenstone belt and the granitic terrain. They are tholeiitic and petrographically fresh, and are ascribed to the Mashonaland Event. Differentiated ultramafic-mafic sills ascribed to the Manyika Event are also preserved in the extreme south-east of the area. The Harare Gabbro may also belong to this event.

MINERALISATION

Gold is the most important mineral to have been produced from the area, and there has been relatively minor production of pegmatite minerals.

More than 270 gold mines have been active within the area, producing more than 44 tonnes in total. The gold mines occur in 5 main groups. These are the 'Enterprise belt', which is by far the most important, the 'Mazowe-South district', the 'Salisbury gold belt', the 'Alpes-Surtic area' and the 'Harare-West district'.

The Enterprise belt occurs in the east of the area and is underlain by the Arcturus Formation. The belt includes the Arcturus Ceylon and Gladstone mines and has produced more than 36 t of gold. Here the gold occurs predominantly in shears or mylonite zones containing disseminated pyrrhotite and arsenopyrite, and characterised by biotite-actinolite alteration. Quartz vein deposits containing disseminated pyrite and arsenopyrite also occur but are of less importance, having yielded about 1.5 t of gold.

The Mazowe-South district, which includes the Alice and Stori's Golden Shaft mines, is situated to the north-west and west of Mazowe Dam and has produced more than 4 t of gold. Mineralisation mostly takes the form of quartz veins hosted in basaltic greenstone. These trend E-W and NW-SE and contain pyrite, pyrrhotite, chalcopyrite, arsenopyrite and scheelite.

The Salisbury gold belt lies north of Harare, within an area defined by Mount Hampden in the west, the Chinamora batholith to the north, and the Glen Forest Estate on the eastern side. More than 65 mines are recorded in this area. Total production is less than 2.5 t, and apart from the Central and Puzzle mine groups, no properties declared more than 20 kg. The district is mostly underlain by the Arcturus Formation and mineralisation tends to occur in easterly trending shears and quartz veins frequently developed at the contacts of felsic porphyry bodies.

The Alpes-Surtic area is situated to the east and south-east of Mazowe Dam and has been of minor importance as a gold producer. Mineralisation takes the form of small quartz veins and shears hosted in Sesombi-type granodiorite and gneissic tonalite.

The Harare-West district is a large ill-defined area to south of the Chinhoyi railway line and west of the city. The district has been of minor importance as a gold producer. Mineralisation takes the form of quartz lenses and veins in the Passaford Formation and also occurs in iron-formations of the Mount Hampden Formation.

Numerous pegmatites occur throughout the granite-greenstone terrain of the Harare region although only 3 areas have been productive. The Dombashawa pegmatite zone, occuring to the north of the city, is the most important and includes the Mistress, Mauve and Hotspur mines. Here the pegmatites occur in close proximity to the contact between Sesombi-type granodiorite/tonalite and the Harare greenstone belt. The Chishawasha pegmatite zone which is situated to the east of Harare includes the Patronage and Pope claims and occurs at the margin of the Chishawasha Granodiorite (Sesombi-type). The Arcadia-Green Mamba pegmatite zone occurs to the east of Arcturus and is hosted in basaltic volcanics of the Arcturus Formation.

ORIENTATION SURVEY

Prior to commencing the survey, a geochemical orientation survey was conducted in late 1982 by J. Ridgway of the B.G.S. (Ridgway, 1983). The purpose of the orientation survey was to determine the best sediment size fraction to sample and the analytical methods most suitable for detecting known types of mineralisation.

The orientation survey indicated that the best anomaly to background contrast could be obtained by analysing the -100 mesh size fraction of the stream sediments. However, sieving to this size was found to be too time consuming and at many localities it was impossible to obtain a sufficient quantity of sample. The -80 mesh size fraction was found to give acceptable anomaly to background contrast and sieving was much faster, and this size fraction was therefore chosen for the main survey.

It was decided to analyse the samples for Cu, Pb, Zn, Co, Ni, Mn, and Li by atomic absorbtion spectrophotometry, following digestion by hot concentrated hydrochloric acid, and to determine As, Sn, Ba, Pb, Ta and Ni by X-ray fluorescence spectrometry.

SAMPLING

Sampling was mostly undertaken during the rainy season when most drainage channels were flowing. Samples were collected from pre-determined sites marked on 1:50 000 scale topographical maps.

Each sample was made up of sediment taken at several different spots in the stream bed within a radius of up to about 5 metres. Only the central or active parts of channels were sampled so as to avoid local material collapsed from banks. Samples were wet-sieved on site using plastic sieves and the -80 mesh fraction collected in paper (Kraft) sample envelopes. Samples were dried in their envelopes by air and sunlight over a period of days, and were then dissagregated by hand using a porcelain pestle and mortar, and re-sieved through an 80 mesh sieve and transferred to clean sample envelopes.

Information was recorded on sample registration forms at the site of collection. This included:

i) Sample number
ii) Map sheet number, e.g. 1732A1.
iii) Sample type (in this case drainage sample)
iv) Grid reference
v) Stream order
vi) Name of sampler
vii) Date
viii) Description of channel morphology, including depth, width, cross profile shape and description of sediment (ie. sandy or bouldery etc.)
ix) Description of unusual rock types found in float

CHEMICAL ANALYSIS OF SAMPLES

The chemical analysis of samples was undertaken at the Institute of Mining Research, University of Zimbabwe.

Samples were submitted to the laboratory in batches of about 150. They were analysed for Cu, Pb, Zn, Co, Ni, Mn and Li by atomic absorption spectrophotometry (AAS) following digestion with hot concentrated hydrochloric acid for a period of 1 hour, and for As, Ba, Pb, Ni, Sn, Ta and W by X-ray fluorescence spectrometry (XRF).

Precision of the AAS analytical method was monitored by the regular analysis of control samples. Three 'known' control samples, designated BGS1, BGS2 and BGS3 were inserted into each analytical batch by the laboratory, and another three 'hidden' controls, designated A, B and C, were submitted to the laboratory under the guise of routine samples. During the analysis of the first 10 batches of samples the control samples were analysed routinely and the mean, standard deviation and coefficient of variation was calculated for each element, the values of which are given in appendix 1. Precision was set at mean$\pm$2SD and for the remainder of the survey the control samples were analysed routinely and results were plotted on precision monitoring charts of the type presented in appendix 2. Using this method only 1 in 22 determinations should fall outside mean±2SD, and fewer than 1 in 370 outside mean±3SD. Departures from these limits would indicate the introduction of unacceptable errors or bias.

Precision of the AAS analytical programme was also monitored by the method of Thompson and Howarth (1973), which takes into account the variation of precision with concentration. In this method precision is defined as twice the coefficient of variation expressed as a percentage (SDx200/mean), and may be examined for conformity to an arbitrary level by use of a precision chart such as that shown in appendix 3. Throughout the course of the analytical programme samples were re-analysed routinely and replicate analyses plotted on such charts.

Precision for the AAS analysis was generally good, except for Pb at low concentrations (below 10 ppm). At higher concentrations however, the precision for Pb was acceptable.

Precision of the XRF analytical method was monitored by the regular analysis of international rock standards and of 'in house' control stream sediment samples, the results of which are summarised in appendix 1.

Detection limits for both the AAS and XRF analytical methods are presented in table 1. Detection limit is here defined as twice the standard deviation at zero concentration, and was calculated by regression of the means against the differences of duplicate analytical results (Thompson and Howarth, 1978).

Table 1: Analytical detection limits

Element	Det. Limit
Cu	1 ppm
Pb	9 ppm
Zn	3 ppm
Co	3 ppm
Ni	2 ppm
Mn	26 ppm
Li	1 ppm
Sn	4 ppm
W	4 ppm
Ta	5 ppm
Ba	54 ppm
As	10 ppm

ACQUISITION OF DATA

Four data subsets were compiled during the course of the survey, and these were eventually merged to form a single data set for interpretation and the generation of geochemical maps. A printed copy of the merged data set is held on open file at the Geological Survey offices in Harare, and copies can also be obtained on magnetic diskette from BGS headquarters on request.

The four data subsets are as follows:

1. AAS analytical results. These were entered into the project's Cifer 1880 microcomputer in Harare.

2. XRF analyses were recorded on the PDP11 computer at IMR and on completion of the analytical programme the results were forwarded on magnetic tape to BGS headquarters in the U.K. A large proportion of the samples, or their analytical results, were mislaid in the XRF laboratory, and absent data values (-1) were therefore assigned to these samples and were not taken into account during subsequent statistical analysis. The elements Ni and Pb were analysed by both the XRF and AAS methods, but because of the loss of so many XRF analyses and the general uncertainty over the quality of the XRF data, only the AAS analyses for these two elements were used in the interpretation.

3. Information on the geology of sample sites was taken from 1:50 000 manuscript geological maps, and each sample was given a two-tiered code denoting its underlying bedrock type and lithostratigraphic unit, as listed in appendix 4. This information, together with stream order at sample sites, was recorded on the project's microcomputer.

4. Grid references of sample sites were obtained by automated digitisation of sample locality maps at BGS headquarters. Important river courses and international boundaries were also digitised for automated plotting on the final geochemical maps.

INTERPRETATION AND PRESENTATION OF RESULTS

Each element is approximately log-normally distributed. This is borne out by the close similarity between the median and geometric mean values, as shown in the statistical summary presented in table 2, and by straight-line distributions produced in numerous log-probability plots during the interpretation, an example of which is shown in figure 3.

Table 2. Statistical summary of analytical results for the entire area

	Min Conc	Max Conc	Median	Arith Mean	Stand Dev	Geom Mean	Geom Mean (log)	Log Dev	N
Cu	*	290	22	33	34.1	18	1.260	0.528	1603
Pb	*	420	10	13	18.3	8	0.913	0.448	1603
Zn	4	850	33	46	51.7	34	1.535	0.320	1603
Co	*	300	12	19	20.4	11	1.040	0.487	1603
Ni	*	860	20	33	42.0	18	1.245	0.523	1603
Mn	40	40500	600	1087	2151.9	624	2.795	0.428	1603
Li	*	335	5	8	13.4	5	0.721	0.340	1603
Sn	*	239	4	12	18.1	6	0.776	0.519	680
W	*	156	13	18	18.7	10	0.989	0.534	680
Ta	*	237	16	24	25.9	12	1.062	0.572	680
Ba	*	1645	470	513	252.2	447	2.650	0.215	680
As	*	710	10	18	42.9	11	1.023	0.369	680

*Below detection limit. Values below detection limit were set to half the detection limit prior to statistical analysis.

The results of the survey are presented in a series of maps, which include:

a) Single element concentration maps at 1:100 000 scale.
b) Multi-element anomaly maps at 1:100 000 scale.

Single element concentration maps

Single element concentration maps were produced at a scale of 1:100 000 as transparent overlays complementary to the geological map sheet of the Harare area. These illustrate the level of a particular element at each sample site by means of a line, of length directly proportional to concentration, extending from the sample point. In addition to presenting the raw data in a visual form, these maps provide a rapid means of assessing the overall results for each element by indicating the concentration range and broad variations related to lithology, as well as drawing attention to some of the more prominent anomalies. Large gaps appear in the north-east and south-west quadrants of the maps for the elements As, Ba, Sn, Ta and W. This is because the samples collected from these areas were not analysed by XRF (see section on chemical analysis above).

In order to maintain general uniformity between the concentration maps for each element, the background (median) level for each element is assigned a standard symbol size of 5 mm. For elements such as Pb, Sn, W and Ta the true median values are well below detection limits, and therefore the symbol sizes were standardised using a median value calculated only from values above detection; without doing this the maps would have been confused by a proliferation of very large symbol sizes representing the higher concentrations. For the other elements almost all analytical results are above detection and the true median is practically the same as that calculated using only values above detection.

Multi-element anomaly maps

Multi-element anomaly maps were produced at a scale of 1:100 000 as transparent overlays complementary to the geological map for the Harare area. Because of difficulties in portraying 12 elements on a single plot, the anomalies are split into two element associations and presented separately.

The two multi-element anomaly maps are:

Anomaly map 7	Harare: Cu, Pb, Zn, Co, Ni, Mn, Ba, W and As.
Anomaly map 8	Harare: Sn, Ta, Li and W.

Lithological influences on stream sediment chemistry were accounted for by classifying the analytical results into groups according to the dominant drainage basin lithology at each sample site. The lithological classification used to subdivide the data was chosen in consultation with mapping geologists and is given in table 3, whilst sorting by computer was achieved using the codes listed in appendix 4.

Table 3. Classification used to group the data according to dominant lithological influence on sample sites.

LITHOLOGICAL UNIT	CODE
Mashonaland Dolerite	MD
Chilimanzi-Type Intrusions	CT
Sesombi-Type Intrusions	ST
Teviotdale Event Felsic Porphyries	TE
Selby Event Mafic Intrusions	SE
Passaford Formation	PF
Mt Hampden Formation	HF
Arcturus Formation	AF
Iron Mask Formation	IM

For each element and lithological grouping, graphs of log-concentration plotted against cumulative frequency on a probability scale were used to determine threshold values (Sinclair, 1976), above which concentrations are considered to be anomalous (e.g. Fig. 3). Threshold values were identified at inflexion points at high concentrations, and background concentration taken at the 50^{th} percentile (median) of the distribution. The practice, frequently adopted in the absence of well-defined inflexions in the log-concentration versus probability curves, of regarding the top 2.5% of high values as being anomalous was not followed; in the absence of such inflexions all values are considered to be sub-anomalous. Summary statistics for the data grouped according to influencing lithologies are given in appendix 5, and threshold and background values are presented in table 4.

Anomalous values, for each element and lithological group, were standardised by the method of Govett and Galanos (1974), thus resulting in anomaly magnitudes that are directly comparable regardless of element, concentration range, background lithology and map sheet.

The formula used for standardisation is:

$$\text{Standardised anomaly value} = \frac{(\text{Anomaly} - \text{Threshold})}{\text{Threshold}} * 100$$

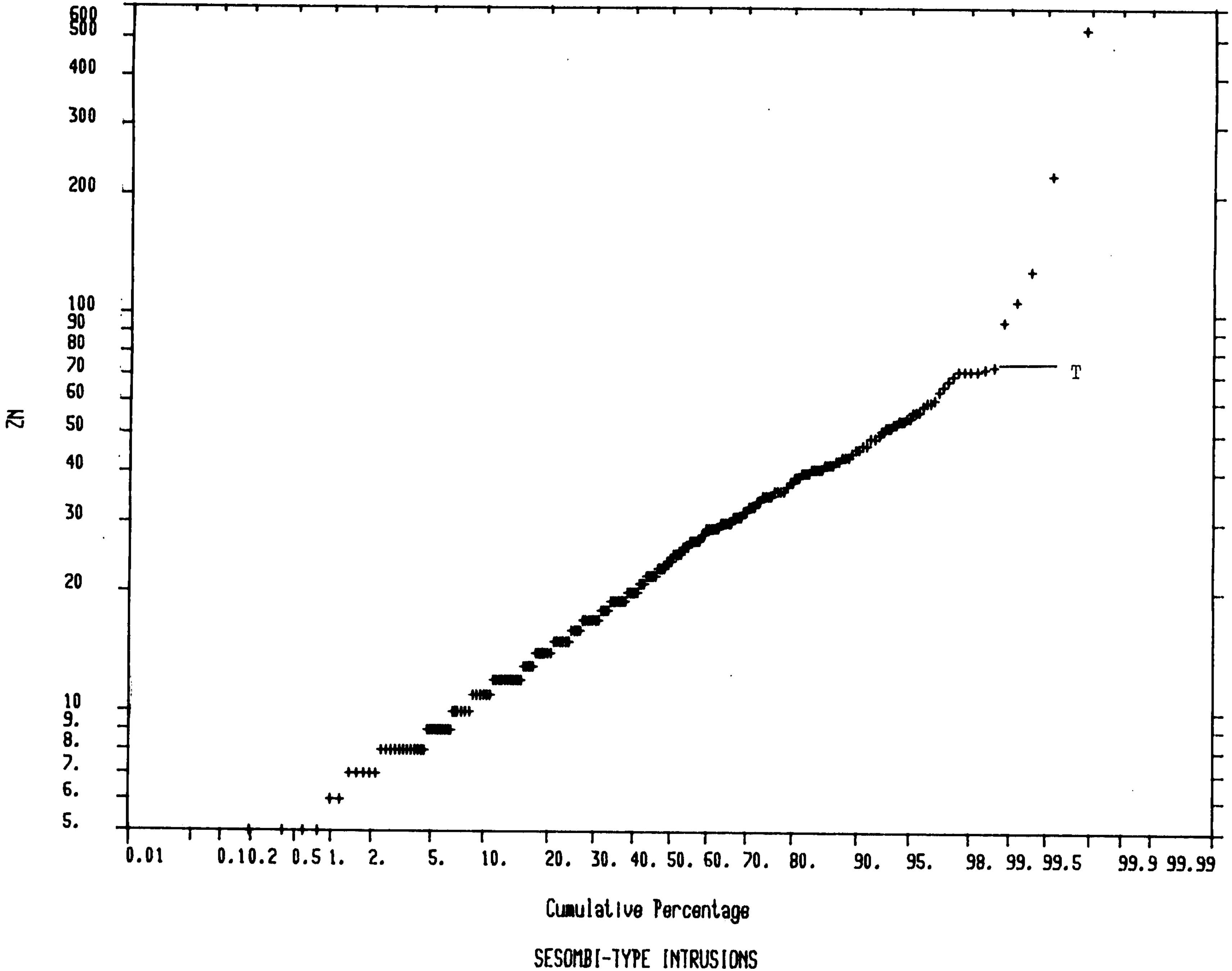


Figure 3: Example of a log probability plot. T = threshold (75 ppm).

Table 4. Threshold (upper) and background (lower) values in relation to lithological groups (see Table 3 for explanation of letter codes).

Rock Group	Cu	Pb	Zn	Ba	Mn	Co	Ni	As	W	Sn	Ta	Li
IM	94	48	144	-	3921	45	69	38	65	-	83	28
	24	*	42	354	800	18	37	13	23	*	26	5
AF	126	36	161	862	5160	78	201	70	67	61	82	36
	61	*	63	310	1650	36	67	18	23	5	24	6
HF	102	38	160	453	3840	101	-	23	-	-	-	38
	48	*	62	397	1070	22	37	19	16	*	14	5
PF + TE	116	19	139	1050	5610	90	94	43	41	-	66	29
	29	*	45	409	840	18	29	15	13	5	23	6
ST	78	45	75	1240	2910	46	103	29	57	56	80	30
	11	10	23	679	370	7	11	8	13	*	*	5
CT	71	81	74	966	1770	30	59	34	-	-	60	-
	6	20	21	466	300	4	6	*	*	5	8	5
MD + SE	-	41	225	1070	3210	53	94	28	54	53	69	-
	53	*	47	701	1140	21	23	*	14	11	12	5

* Below detection limit

GEOCHEMICAL ANOMALIES

Numerous anomalies occur throughout the area, although only the more important ones are described here, and the grading of these is somewhat subjective. In the following section the anomalies are listed approximately in order of importance, and include single sample anomalies as well as groups containing several anomalous sites scattered over a broad area. The locations of the anomalies described below are given in figue 4.

Anomaly 1

The most important anomaly discovered by the survey is a group of strong Cu, Pb, Zn, Co and Mn anomalies situated on the farms of Mayfield, Danbury Park and Sigaro about 7 km north-north-west of Mount Hampden. The anomalous samples were not analysed for As, although a follow-up soil survey indicated a strong anomaly for that element.

The anomaly is underlain by the Mount Hampden, Arcturus and Passaford formations, and occurs in streams draining a prominent hill composed of gossanous phyllite situated a short distance to the north of Selby railway siding.

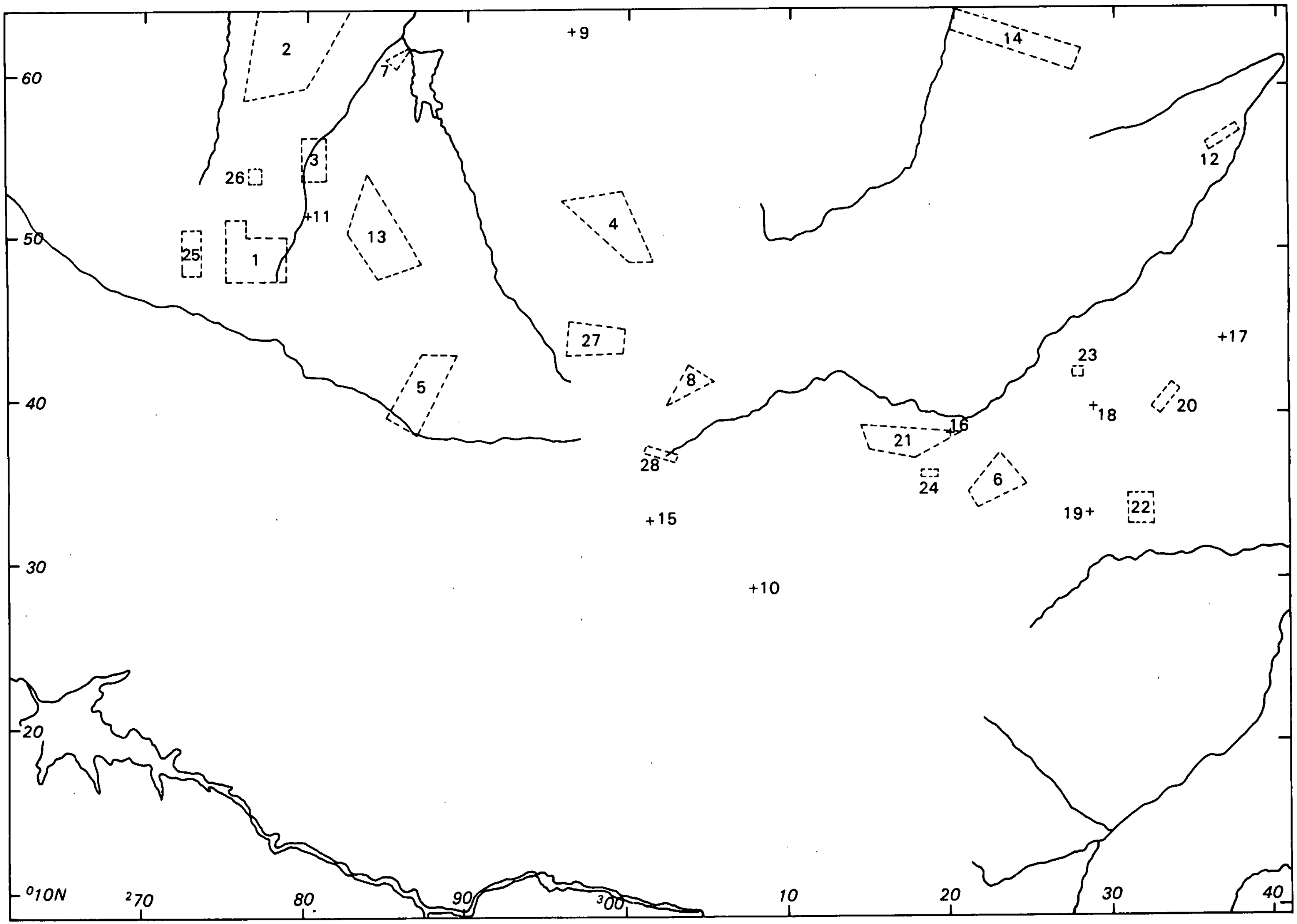


Figure 4: Distribution of geochemical anomalies.

Anomalous sites include:

On Arcturus Formation

Site	Grid Ref.	Cu	Pb	Zn	Co	Mn
1112	27830480	-	-	-	-	12300
1113	27810481	161	-	290	105	6100
1114	27820485	235	-	810	-	-
1346	27750478	290	45	850	85	-
	Threshold	126	36	161	78	5160
	Background	61	*	63	36	1650

*Below detection

On Mt Hampden Formation

Site	Grid Ref.	Cu	Pb	Zn
1349	27760484	210	57	265
1350	27780492	150	-	530
1351	27780493	-	-	210
	Threshold	102	38	160
	Background	48	*	62

On Passaford Formation

Site	Grid Ref.	Cu	Pb	Zn	Mn
1197	27530507	170	46	192	-
1208	27490474	-	-	220	-
1357	27560501	-	-	172	-
1358	27560491	-	-	236	18000
	Threshold	116	19	139	5610
	Background	29	*	45	840

A follow-up soil survey outlined a very strong Zn, Cu, Pb and As anomaly over 3000 km in strike-length and 800 m in width, and gossanous surface samples assayed up to 1.03% Zn and 0.23% Cu. Subsequent drilling proved difficult, but indicated a sequence of phyllites with interstratified massive and semi-massive beds of pyrite containing sub-economic Zn values over considerable intersections, and one hole was abandoned (due to drilling difficulties) in phyllite containing minor chalcopyrite. Details of the follow-up survey are held by the Geological Survey in Harare.

The follow-up soil survey did not extend any distance to the west and north-west of the gossanous hill. It is possible that the drainage anomalies upon the Passaford Formation in the lower ground to the west of the hill may be completely separate and related to a second zone of mineralisation.

Further investigation of the Selby anomaly is strongly recommended.

Anomaly 2

A group of scattered Pb, Zn, Cu and As anomalies occurs in the north-west of the area, within a piece of hilly ground extending eastwards from the Shamva railway line, in the vicinity of Ascot Vale, to the Nemhara River. Most of this ground is underlain by felsic volcanics of the Passaford Formation and lesser amounts of Chilimanzi-type granite and phyllites of the Mount Hampden Formation.

Anomalous sites include:

On Passaford Formation

Site	Grid Ref.	Pb	Zn	Cu	As
1082	27971597	-	200	140	-
1084	28010607	-	-	-	70
1085	28000609	-	-	-	67
1086	28060613	-	-	190	-
1100	27920620	-	-	-	74
1121	27760625	35	-	-	-
1136	27670591	150	400	144	62
	Threshold	19	139	116	43
	Background	*	45	29	15

On Chilimanzi-type granite

Site	Grid Ref.	Zn	As
1095	28130637	-	54
1097	28080639	90	-
	Threshold	74	34
	Background	21	*

This group of anomalies occurs well to the west of the Mazowe South gold mining district and does not appear to result from contamination or to be related to known mineralisation. The area should therefore be given high priority for follow-up investigations, particularly the very strong anomally associated with site 1136.

Anomaly 3

A group of strong As anomalies and associated weak Zn, Co, Mn and Ni anomalies occurs a short distance to the west of the Iron Cap Mine, at the southwestern end of the Iron Mask Range. The anomalies occur within tributaries of the Tateguru River and are underlain by basic volcanics of the Arcturus Formation and felsic volcanics of the Iron Mask Formation. The largest anomalies occur in streams draining off the Iron Mask Range, although several of the smaller anomalies are situated upon tributaries draining the ground to the west of the Tateguru.

Anomalous samples include:

On Arcturus Formation

Site	Grid Ref.	As	Ni
1070	28040560	145	280
1072	28020553	645	-
1073	28010554	84	-
	Threshold	70	201
	Background	18	67

On Iron Mask Formation.

Site	Grid Ref.	As	Zn	Co	Mn
1071	28030550	-	-	65	4400
1105	28020539	710	245	-	5200
	Threshold	38	144	45	3921
	Background	13	42	18	800

Anomaly 4

A prominent group of strong Li, Sn and Ta anomalies is associated with the Domboshawa pegmatite zone, which occurs in proximity to the contact between Sesombi-type granodiorite/tonalite and volcanics of the Harare Greenstone Belt. The two most anomalous sites (2292 and 2294) occur on streams draining the area of the Mauve, Hotspur, Mops and Elizabeth mines. However, several other prominent Li-Sn anomalies (sites 2286, 2287 and 2288) occur in small streams draining the north-east flanks of the ridge extending between the Mauve and Mistress mines, which is an area that does not appear to have been worked for pegmatites, and therefore merits further exploration. Similarly a strong Sn anomaly occurs at site 2271 which is well to the north of the area previously worked for pegmatites.

Anomalous sites include:

On Sesombi-type granodiorite/tonalite

Site	Grid Ref.	Li	Sn	Ta
2271	29890525	-	239	-
2274	29670524	-	-	87
2275	29670523	38	-	-
2286	29890506	75	114	-
2287	29860509	50	-	-
2288	29920502	69	-	-
	Threshold	30	56	80
	Background	5	*	*

On Arcturus Formation

Site	Grid Ref.	Li	Sn	Ta
2292	30060492	322	142	203
2294	30050492	335	88	237
	Threshold	36	61	82
	Background	6	5	24

On Iron Mask Formation

Site	Grid Ref.	Li
2291	29990497	36
	Threshold	28
	Background	5

Anomaly 5

A broadly scattered group of strong As and moderate Co, Ba and Mn anomalies occurs approximately 5-6 km south-east of Mount Hampden and a short distance to the north of Marlborough, within the Gwebi River and its tributaries. The anomalous area is generally featurless and poorly exposed, and is underlain by phyllites of the Mount Hampden Formation and basic volcanics of the Arcturus Formation.

Anomalous sites include:

On Mount Hampden Formation

Site	Grid Ref.	As	Ba	Co	Mn
1183	28540396	65	-	-	-
1184	28680385	130	1096	168	8400
1188	28640415	-	-	165	-
1189	28780425	128	-	-	-
	Threshold	23	453	101	3840
	Background	19	397	22	1070

On Arcturus Formation

Site	Grid Ref.	As
2364	28890428	142
	Threshold	70
	Background	18

Anomaly 6

A group of strong Pb and weak Cu and Zn anomalies is situated between 1 and 3 km north of Arcturus Mine. The anomalies occur within a tributary system of the Mutenje River and are underlain by basic volcanics of the Arcturus Formation. The Pb anomalies are most probably a result of contamination from mining, although one site (2928) does not appear to be on a stream draining a mined area.

Anomalous samples include:

Site	Grid Ref.	Pb	Zn	Cu
2571	32290373	107	-	-
2926	32330362	130	195	-
2928	32300351	70	-	-
2929	32190349	260	-	-
2930	32140348	-	-	139
	Threshold	36	161	126
	Background	*	63	61

Anomaly 7

A small group of moderate Cu, Zn, Co, Ni and As anomalies occurs immediately to the west of the Mazowe Dam, within streams draining felsic volcanics and ironstones of the Iron Mask Formation.

Anomalous sites include:

Site	Grid Ref.	Cu	Zn	Co	Ni	As
1004	28620619	-	-	-	-	68
1038	28560617	170	380	88	89	-
1039	28520611	134	-	69	141	-
	Threshold	94	144	45	69	38
	Background	24	42	22	37	13

Anomaly 8

A small group of widely scattered, moderate to strong Zn and As, and weak Cu anomalies occurs in the vicinity of Borrowdale Brook. The anomalies are underlain by Sesombi-type granodiorite/tonalite.

Anomalous sites include:

Site	Grid Ref.	Zn	As	Cu
2074	30470419	530	189	-
2077	30240404	225	-	-
2084	30360424	108	-	113
	Threshold	75	29	78
	Background	23	*	11

Anomaly 9

A large single-site As anomaly occurs at grid reference 29630620, approximately 10 km east of Mazowe Dam. The site (2386) is underlain by Sesombi-type granodiorite/tonalite and gave an analytical result of 343 ppm As over a threshold of 29 ppm and background of less than 10 ppm.

Anomaly 10

A single-site Pb anomaly occurs at grid reference 30750290 in the headwaters of the Makabusi River, approximately 3.5 km upstream from the Cleveland Dam. The site is underlain by Chilimanzi-type granite and gave an analytical result of 420 ppm Pb over a threshold of 81 ppm and a background of 20 ppm.

Anomaly 11

A moderate single-site As anomaly occurs on the Tateguru River at grid reference 27980513, immediately west of Pearson Settlement. The site (1102) is underlain by the Arcturus Formation and gave an analytical result of 239 ppm As over a threshold of 70 ppm and background of 18 ppm.

Anomaly 12

Two strong Ni anomalies occur within tributaries of the Nora and Umwindsi rivers, approximately 2-3 km south of Rutope Township in the north-east of the area. The anomalies are underlain by Sesombi-type granodiorite, although occur a short distance downstream from an ultramafic body which forms the prominent hill of Rutope.

Anomalous sites are:

Site	Grid Ref.	Ni
2466	33580563	860
2468	33740574	540
	Threshold	103
	Background	11

Anomaly 13

A broadly scattered group of moderate to weak Cu, Pb, Zn, W, As and Mn anomalies is situated in the Dasura drainage system, approximately midway between Mazowe Dam and Mount Hampden. The anomalies are underlain by an assortment of lithologies.

Anomalous sites include:

Site	Grid Ref.	Anomaly	Lithology
1002	28360537	As	Iron Mask Formation.
1011	28540493	Cu	- - -
1012	28470504	W	Sesombi-type granodiorite
1014	28420519	Pb	Teviotdale Porhyry
1033	28340488	W	Iron Mask Formation
1035	28420480	Mn	Arcturus Formation
1047	28420495	Cu	- -
1052	28260510	As, Zn, Cu	Sesombi-type granodiorite

Anomaly 14

A widely scattered group of moderate to weak Pb anomalies occurs in the north-east of the area upon Sesombi and Chilimanzi type granitic rocks and Mashonaland Dolerite.

Anomalous sites include:

On Sesombi-type granodiorite

Site	Grid Ref.	Pb
2656	32020642	50
2657	32020639	80
2661	32270627	54
	Threshold	45
	Background	10

On Chilimanzi-type granite

Site	Grid Ref.	Pb
2654	32700617	230
	Threshold	81
	Background	20

On Mashonaland Dolerite

Site	Grid Ref.	Pb
2655	32470626	74
	Threshold	41
	Background	*

Anomaly 15

A strong Mn and weak Pb and Zn anomaly occurs 1.5 km west of Chispite shopping centre. The anomaly is underlain by phyllites of the Mount Hampden Formation, although felsic and basic volcanics outcrop a short distance upstream.

Details of the anomaly are:

Site	Grid Ref.	Mn	Pb	Zn
1704	30120331	35000	84	200
	Threshold	3840	38	160
	Background	1070	*	62

Anomaly 16

A moderately high single-site Zn anomaly occurs at grid reference 31990387, on the south side of the Harare-Mrewa road approximately 5 km south-west of Ewanrigg National Park. The anomaly is situated on a tributary of the Umwindsi River and is underlain by felsic volcanics of the Passaford Formation, although a short distance upstream phyllites and basaltic volcanics crop out. The site (2568) retuned an analytical value of 475 ppm Zn over a threshold of 139 ppm and a background of 45 ppm.

Anomaly 17

A moderately strong single-site Co anomaly occurs at grid reference 33650445, approximately 1 km north-west of Juru Township on the Harare-Mrewa road. the anomaly is underlain by Sesombi-type granodiorite close to a contact with basic volcanics of the Arcturus Formation. The site (2489) gave an analytical result of 163 ppm Co over a threshold of 46 ppm and background of 7 ppm.

Anomaly 18

A strong Mn-Co and weak Ni anomaly occurs on the southern side of the Harare-Mrewa road approximately 1-2 km west-south-west of Devonia, at grid reference 32860403. The anomaly is underlain by felsic volcanics of the Passaford Formation.

Details of the anomaly are:

Site	Mn	Co	Ni
2527	40500	300	180
Threshold	5610	90	94
Background	840	18	29

Anomaly 19

A single-site Zn anomaly occurs at grid reference 32840338, approximately 800 m downstream from the Ceylon Mine. The site (2918) is underlain by basaltic volcanics of the Arcturus Formation and gave an analytical result of 354 ppm Zn over a threshold of 161 ppm and background of 63 ppm.

Anomaly 20

A small group of weak Zn and minor Cu and Ni anomalies occurs in a northeasterly flowing tributary of the Kowoyo River approximately 2.5 km north-west of Mpitazebi beacon (33470389). The anomalies are underlain by felsic volcanics of the Passaford Formation.

Anomalous sites include:

Site	Grid Ref.	Zn	Cu	Ni
2588	33260403	247	139	160
2589	33290402	163	-	-
2603	33380413	175	-	-
	Threshold	139	116	94
	Background	45	29	29

Anomaly 21

A group of Li anomalies occurs upon the Passaford, Arcturus and Mount Hampden formations in the vicinity of the Pig Board Research Station close to the Harare-Mrewa road. These anomalies are not associated with known pegmatite workings and are situated several kilometres north-east of the Chishawasha pegmatite zone.

Anomalous sites are:

On Passaford Formation

Site	Grid Ref.	Li
2556	31530389	55
2557	31570389	36
2568	31990387	36
	Threshold	29
	Background	6

On Arcturus Formation.

Site	Grid Ref.	Li
2561	31720373	49
	Threshold	36
	Background	6

On Mount Hampden Formation

Site	Grid Ref.	Li
2559	31500378	67
	Threshold	38
	background	5

Anomaly 22

A small group of Li, Sn and W anomalies is associated with the Arcadia-Green Mamba pegmatite workings approximately 9 km east of Arcturus. The anomalies are underlain by basic volcanics of the Arcturus Formation.

Anomalous sites are:

Site	Grid Ref.	Li	Sn	W
2897	33160334	51	-	-
2898	33180337	76	-	83
2900	33130347	62	114	-
	Threshold	36	61	67
	background	6	5	23

Anomaly 23

A weak Zn anomaly occurs 4.5 km east-south-east of Ewanrigg National Park and is underlain by a Selby-event mafic intrusion.

Anomalous sites are:

Site	Grid Ref.	Zn
2531	32770422	300
2532	32750423	340
	Threshold	225
	Background	47

Anomaly 24

A weak Cu anomaly occurs at two sites underlain by felsic volcanics of the Passaford Formation, approximately 5 km north-west of Arcturus. The anomaly does not appear to be related to known mineralisation.

Anomalous sites are:

Site	Grid Ref.	Cu
2974	31840361	136
2975	31870361	193
	Threshold	116
	Background	29

Anomaly 25

A group of moderately strong Mn anomalies and a weak Co anomaly occurs in the headwaters of the Murowodzi River, approximately 5 km west of anomaly 1 near Selby Siding. The anomalies are underlain by a mafic intrusion of the Selby event and felsic volcanics of the Passaford Formation.

Anomalous sites are:

On Selby-event mafic intrusion

Site	Grid Ref.	Mn
1204	27250497	8100
1210	27240480	27300
	Threshold	3210
	Background	1140

On Passaford Formation

Site	Grid Ref.	Mn	Co
1205	27240501	13400	81
	Threshold	5610	53
	Background	840	21

Anomaly 26

Two weak Zn anomalies occur on separate tributaries of the Madzegetu River approximately 1-1.5 km south-south-east of Passaford Siding. The anomalies are underlain by felsic volcanics of the Passaford Formation and phyllites of the Mount Hampden Formation.

The anomalous sites are:

On Mount Hampden Formation

Site	Grid Ref.	Zn
1341	27610539	235
	Threshold	160
	Background	62

On Passaford Formation

Site	Grid Ref.	Zn
1342	27640534	173
	Threshold	139
	background	45

Anomaly 27

A group of Mn, Ba, As, Co and W anomalies occurs 3-4 km south-west of the Glen Forest area. The anomalies are underlain by basic volcanics of the Arcturus Formation and Teviotdale Felsic Porphyry.

Anomalous sites are:

On Arcturus Formation

Site	Grid Ref.	Ba	Mn	As	Co	W
2315	29950444	-	-	104	-	-
2317	29890435	1565	37500	-	86	-
2323	29630447	-	-	-	-	79
2324	29650449	-	-	-	-	136
	Threshold	862	5160	70	78	67
	Background	310	1650	18	36	23

On Teviotdale Felsic Porphyry

Site	Grid Ref.	Ba	Mn
2322	29650433	1238	8700
	Threshold	1050	5610
	Background	409	840

Anomaly 28

A group of Mn, Ba, Co and W anomalies occurs in the headwaters of the Umwindsi River between Glen Lorne and Borrowdale, and are underlain by Mashonaland Dolerite.

Anomalous sites are:

Site	Grid Ref.	Mn	Ba	Co	W
2003	30110374	-	6500	90	-
2006	30240370	1463	13000	-	-
2007	30260368	-	-	-	101
	Threshold	1070	3210	53	54
	Background	701	1140	21	14

RECOMMENDATIONS

All of the anomalies described in the previous section are considered to merit further investigation, particularly those occurring upon the Harare Greenstone Belt. In view of the low density of sampling in the present survey, and the broadly defined nature of many of the anomalies, it is recommended that anomalous areas are initially investigated by more detailed stream sediment surveys. For some anomalous areas this may not be feasible because of a sparsity of drainage channels, in which case low to moderate-density soil geochemical surveys are recommended for initial investigations. Subsequently, areas of continued interest should be investigated by detailed soil geochemical surveys, and by geological mapping and rock sampling where exposure permits.

Of the elements determined in the present survey, As, Pb, Cu, Zn, Co, Ni and Mn appear to be the most useful in the greenstone areas, and should be included in follow-up surveys. It is recommended that As be determined by atomic absorption spectrophotometry (AAS), using the hydride vapour generation technique, rather than by XRF as in the present survey. In follow-up surveys it is recommended that Au be determined routinely to the ppb level, and orientation work should be undertaken at an early stage to ascertain the best sample type for these determinations. The collection of heavy mineral concentrates, from both stream sediments and soils, for the visible and chemical determination of Au should be considered. If concentrates are collected they should also be analysed for W, since scheelite frequently occurs as an accessory in Au-bearing shears and veins within the region. Visible estimates of scheelite in heavy mineral concentrates, with the aid of a UV lamp, might also prove to be a useful and rapid guide during field work. It is recommended that heavy mineral concentrates be obtained by automative separation techniques, rather than traditional panning methods, in order to optomise precision.

With respect to the known pegmatite mineralisation of the area, Li has been found to give a good geochemical response, exceeding that shown by Sn and Ta. However, it is likely that a more effective response for Sn and Ta could have been attained by the analysis of heavy mineral concentrates, although the collection of such concentrates is time consuming and logistically difficult in the absence of surface water. It is therefore concluded from the present survey that Li, determined by AAS on the fine fraction of normal stream sediments, provides a cheap and effective means of locating pegmatite mineralisation, and that it should be used in future geochemical surveys in Zimbabwe. It is also recommended that orientation work be undertaken to ascertain the best method of sample digestion for Li analysis. For example, if Li in stream sediments mainly resides in the lattice of silicate minerals, then a more vigorous acid digestion (eg. perchloric/hydrofluoric acid) may provide a better anomaly to background contrast. Furthermore, if a total dissolution method were to be employed, the feasibility of determining Be by AAS on the same solution should also be considered.

ACKNOWLEDGMENTS

The writer wishes to thank the Director of the Zimbabwe Geological Suvey, Mr E.R. Morrison, and Mr T.J. Broderick for their considerable assistance and support throughout the project.

Thanks are also given to the numerous field and office assistants without whose help this project would not have been possible. In particular, to M. Mashita, N. Chino, M. Chidhuru, G. Mapendere, P. Maxwell, S. Mashita, M. Ndemera and M. Nhamburo.

The chemical analysis of samples was performed at the Institute of Mining Research of the University of Zimbabwe, and with respect to this the project is indebted to Professor K.A. Viewing and to various analysts, notably B. Witkin, H. Ansari, D. Katsande, D. Mzengeza, M. Keough, I. Mazaiwana, J. Mzezwa, W. Mtasa and P. Hunda.

K. Becken, I.L. Cooke, K.B. Greally, R.C. Jones and A.H. Myers of the British Geological Survey are gratefully acknowledged for their assistance with computing and digital cartography. Thanks are also given to Mrs L. Baldock for typing the AAS analytical data into the computer.

REFERENCES

Baldock, J.W., Kalbskopf, S. & Machemwa, E. In press. The geology of the Harare greenstone belt and surrounding granitic terrain. Zimbabwe Geological Survey Bulletin.

Govett, G.J.S. & Galanos, D.A. 1974. Drainage and soil geochemical surveys in Greece: use of standardized data as an interpretative procedure. Transactions of the Institute of Mining and Metallurgy. 83, B99-111.

Govindaraju, K. (Editor). 1984. Compilation of working values and sample description for 170 international reference samples of mainly silicate rocks and minerals. Special Issue Geostandards Newsletter. 8.

Ridgway, J. 1983. I.G.S. Zimbabwe Project. Geochemical exploration - results of an orientation survey and the organisation of the sampling programme. Unpublished Report 83/14. Overseas Directorate, British Geological Survey.

Sinclair, A.J. 1976. Probability graphs. Association of Exploration Geochemists Special Volume. 4.

Thompson, M. & Howarth R.J. 1973. The rapid estimation and control of precision by duplicate determinations. Analyst. 98, 153-60.

Thompson, M. & Howarth R.J. 1978. A new approach to the estimation of analytical precision. Journal of Geochemical Exploration. 9, 23-30.

Thompson, J.G. & Purves, W.D. 1978. A guide to the soils of Zimbabwe. Zimbabwe Agricultural Handbook. 3.

APPENDIX 1: ANALYTICAL PRECISION OF CONTROL SAMPLES

Values in ppm

COPPER (AAS)

Sample	Mean	SD	CV	N
BGS-1	74.2	1.46	1.97	40
BGS-2	13.5	1.73	12.85	41
BGS-3	44.0	1.19	2.70	39
A	66.1	2.17	3.28	30
B	13.7	1.56	11.36	30
C	42.9	1.27	2.95	30

LEAD (AAS)

Sample	Mean	SD	CV	N
BGS-1	8.9	0.83	9.28	40
BGS-2	20.0	1.55	7.72	41
BGS-3	14.0	0.93	6.60	39
A	0.2	0.68	290.96	30
B	20.2	2.14	10.59	30
C	6.4	1.83	28.48	30

ZINC (AAS)

Sample	Mean	SD	CV	N
BGS-1	126.1	2.87	2.28	40
BGS-2	23.4	1.61	6.88	41
BGS-3	73.8	2.06	2.79	39
A	54.5	2.14	3.94	30
B	23.3	1.37	5.87	30
C	107.2	6.22	5.80	30

COBALT (AAS)

Sample	Mean	SD	CV	N
BGS-1	31.1	1.41	4.53	40
BGS-2	12.4	0.62	5.04	41
BGS-3	22.2	0.81	3.64	39
A	48.1	3.49	7.25	30
B	12.5	1.28	10.21	30
C	31.5	1.92	6.10	30

NICKEL (AAS)

Sample	Mean	SD	CV	N
BGS-1	75.1	2.95	3.92	40
BGS-2	12.4	1.16	9.35	41
BGS-3	43.9	2.67	6.08	39
A	61.1	4.08	6.68	30
B	12.1	1.45	12.00	30
C	37.9	2.30	6.07	30

MANGANESE (AAS)

Sample	Mean	SD	CV	N
BGS-1	1334.8	15.19	1.38	40
BGS-2	649.0	14.28	2.20	41
BGS-3	992.0	17.84	1.80	39
A	2096.0	71.65	3.42	30
B	679.3	25.99	3.82	30
C	1573.7	43.35	2.75	30

LITHIUM (AAS)

Sample	Mean	SD	CV	N
BGS-1	6.4	0.66	10.47	40
BGS-2	5.6	0.63	11.19	41
BGS-3	6.0	0.63	10.51	39
A	4.5	0.97	21.47	30
B	5.8	0.95	16.28	30
C	3.7	0.58	15.62	30

ARSENIC (XRF)

Sample	Mean		SD	CV	N
AGV-1	1.5	(0.8)	1.24	83.22	37
MA-N	13.4	(13)	1.48	11.08	37
ST-5	34.4		1.57	4.56	36
SV-6	3.7		2.08	56.68	36

BARIUM (XRF)

Sample	Mean		SD	CV	N
AGV-1	1274.5	(1200)	13.47	1.06	35
MA-N	63.6	(42)	7.97	12.53	35
ST-4	731.2		22.55	3.08	35
SV-6	789.2		9.05	1.15	35

TANTALUM (XRF)

Sample	Mean		SD	CV	N
AGV-1	2.6	(1.4)	4.50	172.40	35
MA-N	304.8	(306)	2.46	0.81	35
ST-4	252.9		8.41	3.33	35
SV-6	26.8		3.24	12.09	35

TIN (XRF)

Sample	Mean		SD	CV	N
AGV-1	6.1	(3.6)	3.00	49.10	35
MA-N	921.4	(1050)	0.65	0.07	35
ST-4	244.5		2.73	1.17	35
SV-6	71.1		2.93	4.12	35

TUNGSTEN (XRF)

Sample	Mean		SD	CV	N
AGV-1	4.5	(0.53)	2.43	5.90	35
MA-N	71.9	(70)	2.98	4.14	35
ST-4	22.3		2.23	9.99	35
SV-6	89.7		15.47	17.24	35

* Values in parenthesis for the international rock standards AGV-1 and MA-N are working values proposed or recommended by Govindaraju (1984).

List of AAS control samples:

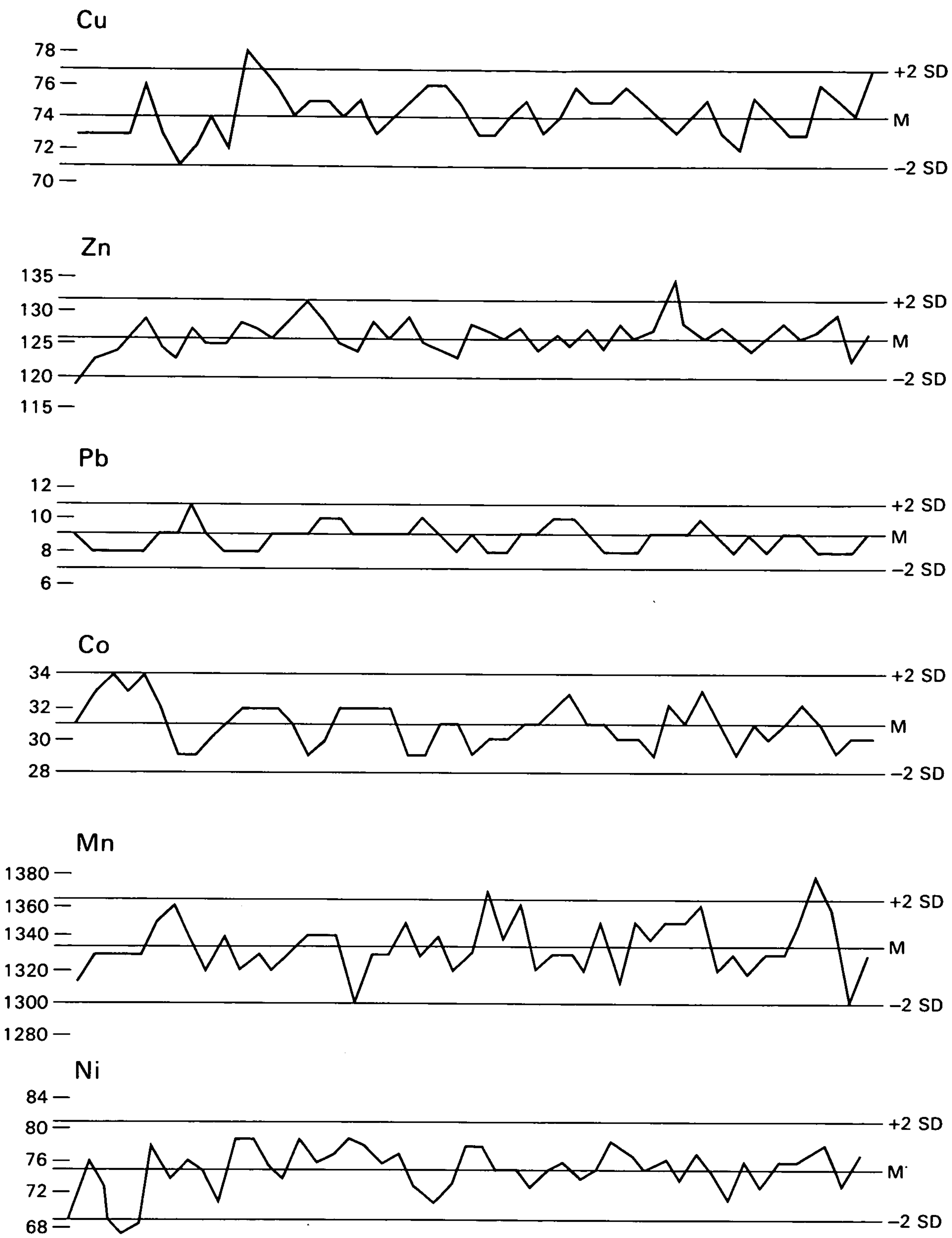
BGS-1, BGS-2, BGS-3: Stream sediment samples (BGS Zimbabwe Project). Inserted routinely into each analytical batch by laboratory.

A, B, C: Stream sediment samples (BGS Zimbabwe Project). 'Hidden controls' submitted to the laboratory under the guise of routinely collected samples. Controls BGS2 and B are splits of the same sample.

List of XRF control samples:

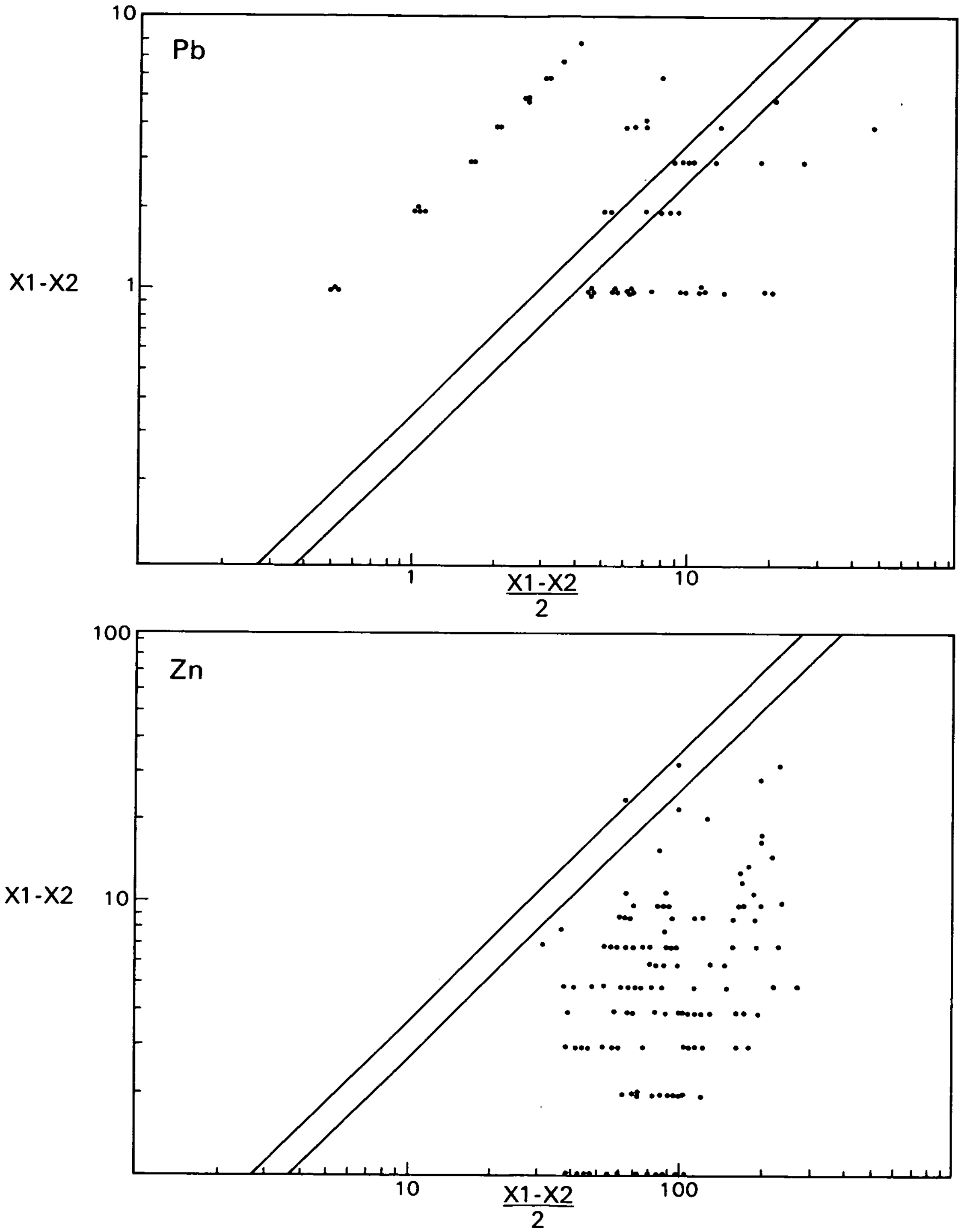
AGV-1: Andesite (USGS International rock standard).
MA-N: Granite (ARNT (France) International rock standard).
ST-5: Granite (Nottingham University standard).
ST-4: Stream sediment sample (BGS Zimbabwe Project).
ST-5: Stream sediment sample (BGS Zimbabwe Project).

APPENDIX 2:



Example of control charts, for control sample BGS-1, analytical batches 14-26.
SD = Standard deviation, M = Mean, calculated from 40 replicate analyses.

APPENDIX 3:



Examples of precision monitoring charts, for replicate determinations (X1 and X2) showing the 90th and 99th percentiles as a function of concentration for an arbitrary precision of 20%. In these examples the precision for Pb is unacceptable (i.e. greater than 20%), whilst that for Zn is acceptable.

APPENDIX 4: LITHOLOGICAL CODES FOR BEDROCK TYPE AT SAMPLE SITES

LITHOLOGICAL UNIT	CODE	ROCK TYPE	CODE
Mashonaland Dolerite	(Code as for host unit)		MD
Chilimanzi-Type Intrusions	CT	Granite	GR
Sesombi-Type Intrusions	ST	Granodiorite-Tonalite Gneiss + Migmatite	GT GN
Teviotdale Event	TE	Felsic Porphyries	FP
Selby Event	SE	Mafic Intrusives	MI
Passaford Formation	PF	Felsic Volcanics	FV
Mt Hampden Formation	HF	Phyllites	PH
Arcturus Formation	AF	Mafic Volcanics	MV
Iron Mask Formation	IM	Felsic Volcanics	FV

APPENDIX 5: STATISTICAL SUMMARY AND THRESHOLD VALUES FOR SAMPLES GROUPED ACCORDING TO DOMINANT LITHOLOGICAL INFLUENCE

IRON MASK FORMATION

Number of samples = 75

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	4	205	24	36	34.9	25	0.353	94
Pb	*	84	7	11	13.1	6	0.545	48
Zn	17	380	42	54	50.1	45	0.237	144
Co	3	88	18	22	15.3	18	0.294	45
Ni	6	141	37	39	21.5	33	0.271	69
Mn	190	5200	800	1217	1171.0	844	0.359	3921
Li	1	36	5	7	6.9	5	0.314	28
Sn	*	37	*	8	10.1	3	0.706	-
W	*	156	23	30	28.4	15	0.652	65
Ta	*	131	26	34	29.5	15	0.765	83
Ba	*	932	354	395	207.1	315	0.448	-
As	*	710	13	30	98.3	10	0.624	38

ARCTURUS FORMATION

Number of samples = 336

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	2	290	61	64	36.0	52	0.321	126
Pb	*	260	*	6	18.1	2	0.635	36
Zn	7	850	63	70	69.5	57	0.267	161
Co	*	120	36	38	20.0	31	0.297	78
Ni	2	310	67	71	40.5	58	0.314	201
Mn	90	37500	1650	1962	2484.2	1442	0.340	5160
Li	*	335	6	10	26.0	6	0.337	36
Sn	*	142	5	13	20.3	3	0.796	61
W	*	136	23	25	21.7	12	0.721	67
Ta	*	237	24	31	32.9	12	0.802	82
Ba	*	1565	310	359	206.7	287	0.426	862
As	*	645	18	28	57.1	14	0.562	70

*Below detection limit (see Table 1. for list of detection limits).

MOUNT HAMPDEN FORMATION

Number of samples = 53

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	11	210	48	54	36.2	44	0.282	102
Pb	*	84	*	12	14.6	6	0.543	38
Zn	17	530	62	90	86.1	68	0.298	160
Co	5	168	22	34	33.6	25	0.324	101
Ni	6	105	37	44	21.4	38	0.240	-
Mn	310	35000	1070	2181	4976.2	1164	0.399	3840
Li	2	67	5	9	10.9	6	0.306	38
Sn	*	44	*	13	15.4	3	0.815	-
W	*	44	16	17	11.9	10	0.578	-
Ta	*	107	14	19	26.6	5	0.823	-
Ba	61	1096	397	379	222.4	323	0.261	453
As	*	130	19	34	39.8	18	0.553	23

PASSAFORD FORMATION + TEVIOTDALE PORPHYRIES

Number of samples = 204

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	1	193	29	38	32.3	29	0.344	116
Pb	*	150	*	8	11.5	6	0.459	19
Zn	5	475	45	61	54.5	48	0.279	139
Co	*	300	18	23	25.1	18	0.320	90
Ni	2	180	29	38	28.6	30	0.308	94
Mn	*	40500	840	1480	3193.3	904	0.374	5610
Li	*	55	6	8	7.3	6	0.311	29
Sn	*	52	5	11	13.2	3	0.749	-
W	*	50	13	15	13.9	6	0.738	41
Ta	*	92	23	25	22.7	9	0.828	66
Ba	*	1238	409	455	216.5	401	0.250	1050
As	*	74	15	17	15.0	10	0.564	43

SESOMBI-TYPE INTRUSIONS

Number of samples = 483

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	*	129	11	17	18.0	10	0.461	78
Pb	*	80	10	13	9	10	0.370	45
Zn	5	530	23	28	29.1	23	0.256	75
Co	*	163	7	10	11.1	6	0.459	46
Ni	*	860	11	20	49.4	11	0.470	103
Mn	70	18000	370	558	922.2	395	0.331	2910
Li	*	75	5	7	7.5	5	0.371	30
Sn	*	239	*	11	22.0	3	0.768	56
W	*	91	13	17	15.9	8	0.691	57
Ta	*	107	*	17	23.1	4	0.894	80
Ba	*	1405	679	662	236.5	589	0.305	1240
As	*	343	*	11	27.5	5	0.572	29

CHILIMANZI-TYPE INTRUSIONS

Number of samples = 347

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	*	110	6	12	15.7	7	0.438	71
Pb	*	420	20	24	27.9	19	0.313	81
Zn	4	147	21	25	15.7	22	0.224	74
Co	*	47	4	6	6.2	4	0.375	30
Ni	*	90	6	9	9.5	6	0.372	59
Mn	60	3100	300	389	341.3	305	0.291	1770
Li	*	26	5	6	4.2	5	0.323	-
Sn	*	52	5	11	12.9	4	0.773	-
W	*	34	*	6	8.7	2	0.672	-
Ta	*	79	8	17	18.4	5	0.840	60
Ba	225	1199	466	491	180.0	462	0.149	966
As	*	69	*	8	10.3	3	0.645	34

MASHONALAND DOLERITES AND SELBY-EVENT INTRUSIONS

Number of samples = 105

Element	Min Conc	Max Conc	Median	Mean (Arith)	Stand Dev	Geom Mean	Log Dev	Threshold
Cu	2	148	53	55	35.2	41	0.389	-
Pb	*	74	*	11	11.3	6	0.581	41
Zn	15	340	47	62	53.3	49	0.272	225
Co	*	90	21	25	16.4	19	0.338	53
Ni	2	150	23	31	26.1	22	0.393	94
Mn	140	27300	1140	1701	2983.4	2000	0.354	3210
Li	2	26	5	6	4.5	5	0.265	-
Sn	*	111	11	18	21.4	6	0.824	53
W	*	101	14	20	21.2	9	0.717	54
Ta	*	94	12	23	25.4	8	0.827	69
Ba	314	1645	701	728	257.9	689	0.142	1070
As	*	48	*	10	11.6	5	0.644	28