British Geological Survey

TECHNICAL REPORT WC/94/55
Overseas Geology Series

A COMPARISON OF HIGH AND LOW DENSITY GEOCHEMICAL SAMPLING IN ZIMBABWE : APPLICATION TO ENVIRONMENTAL STUDIES

J RIDGWAY, R C JONES & K B GREALLY

Natural
Environment
Research
Council

International Division
British Geological Survey
Keyworth
Nottingham
United Kingdom NG12 5GG

British Geological Survey

TECHNICAL REPORT WC/94/55
Overseas Geology Series

A COMPARISON OF HIGH AND LOW DENSITY GEOCHEMICAL SAMPLING IN ZIMBABWE : APPLICATION TO ENVIRONMENTAL STUDIES

J RIDGWAY, R C JONES & K B GREALLY

A Report prepared for the Overseas Development Administration under the ODA/BGS Technology Development and Research Programme, Project 91/16

ODA classification :
Subsector: Geoscience
Theme: G2 - Identify and ameliorate mineral-related and other geochemical toxic hazards
Project title: Environmental geochemical mapping
Reference number: R5547

Bibliographic reference :
Ridgway J and others 1994. A comparison of high and low density geochemical sampling in Zimbabwe : application to environmental studies
BGS Technical Report WC/94/55

Keywords :
Zimbabwe; geochemistry; sampling density; stream sediments; soils; environment

Front cover illustration :
Soil sampling for soil/stream sediment comparison study

Keyworth, Nottingham, British Geological Survey, 1994

EXECUTIVE SUMMARY

Regional geochemical surveying based on the collection and analysis of sediment samples from streams with small drainage basins (<10 km^2) has been shown in several studies, largely in temperate regions, to provide valuable information for environmental purposes as well as being an important mineral exploration tool. In particular, geochemistry can help delineate regions where trace element excesses or deficiencies might have adverse effects on human, animal or crop health. This report describes two studies designed to examine specific aspects of environmental geochemistry in the seasonally wet/dry climate of the Harare region of Zimbabwe. The work was carried out as part of a wider study of the application of regional geochemical mapping to environmental problems (Project R5547, 91/16, Environmental Geochemical Mapping) funded by the Overseas Development Administration as part of the UK programme of aid to the developing countries and carried out under the ODA/BGS Technology Development and Research Programme.

The first study addressed the premise that the value of drainage geochemical data for environmental studies depends on there being a positive correlation between drainage and soil geochemistry. The relationship between soil and drainage geochemistry in areas with relatively high background levels of trace elements such as Cu, Pb, Zn, Ni and Co has been examined in other investigations forming part of Project R5547 and the work in Zimbabwe concentrated on this relationship in an area of low trace element levels. A drainage basin of 2-3 km^2 developed on granitic gneisses was chosen for the study. The subsistence farming in the basin meant that the chemistry of the soils was unlikely to have been affected by large scale additions of fertilisers or animal feed supplements.

The results showed that the correlation between soil and stream sediment geochemistry generally was good for the fine (<177 µm) fractions of the two media, but less satisfactory for the coarser (<2 mm) fraction, although the low trace element levels expected from the granite gneiss terrain were still evident in both soil and sediment. This feature is probably related to the winnowing of fine, trace element bearing particles from the stream sediment during periods when the normally dry streams are flowing. This leads to a dilution of the trace element content which can be reduced by the selection of a narrower particle size range. It is concluded that stream sediments are a suitable sampling medium for environmental studies because they provide a reliable indicator of trace element concentrations in soils, which are of particular interest to agronomists and others, while being quicker and cheaper to collect for any given area.

The second study examined whether the time and costs of regional geochemical surveying for environmental purposes can be reduced by sampling streams with large catchment areas. This has clear advantages for developing countries, especially for those where geological mapping is not well advanced. The Harare region was sampled at a relatively high density of 1 sample per 2.7 km^2 in a geochemical survey carried out between 1982 and 1986. Sixteen sites from this survey were resampled and the respective stored samples were retrieved and reanalysed with the new samples. Samples were also taken from larger, streams/rivers with drainage basins of between 45 and 135 km^2 to give low density coverage of the area.

Absolute concentration levels in original and new analyses on stored samples were substantially different. However, good correlation was shown between the two datasets

(Pearson correlation coefficients of >0.9 except for Pb, >0.8) and also between original analyses and analyses of new samples from resampled sites (all >0.8). Patterns of variation were thus similar and indicated that analytical differences arising from the analyses being carried out in different laboratories using slightly different methodologies, and sampling errors due, for instance, to temporal variation, were unlikely to have a large influence on any comparison based on correlation between the original high density and new low density surveys.

If low density sampling is to be of value, the results of low density geochemical surveys should display similar patterns of variation to those of high density surveys. For each large catchment basin represented by a drainage sample, estimates of the overall composition of the catchment were calculated by computing the arithmetic and geometric means and median value of the samples collected during the original high density survey. The absolute concentration levels in the original high and later low density survey were expected to be different because of the differences found between original analyses and new analyses from resampled sites. However, the correlation between estimates of the overall basin geochemistry and the geochemistry of the samples from high order drainage channels needs to be good if samples from high order streams are to be of use in regional geochemical surveys. Thus the drainage basins having the higher average composition, as calculated from low order stream samples, should also display the higher levels in the survey based on high order streams.

The results of the study demonstrate that the correlation between the geochemistry of high order stream samples and estimates of average concentrations for the large catchment basins is generally poor (Mn: 0.26-0.29, Zn: 0.43-0.60, Cu: 0.53-0.72, Pb: 0.85-0.88, Co: 0.59-0.61, Ni: 0.22-0.37). It is particularly bad for Mn and Ni, where the correlation coefficients are not significant at the 99% level. This poor level of correlation casts doubts on the usefulness of low density geochemical surveys based on the sampling of high order streams or rivers. The reasons for the poor correlation are not clear, but one important factor is undoubtably the inhomogeneity in the geology of the large drainage basins. Rock types which are present in only small quantities overall in a large basin can have a significant influence on the chemical composition of the representative stream sediment sample if they occur close to the sample site. Small drainage basins have more uniform geology and are thus less affected by such factors. Samples from the large (45 to 135 km^2) drainage basins used in this study did not yield data which matched the higher density survey results and so cannot be used to provide useful and reliable data for regional environmental geochemical surveys. Further work might reveal an optimum catchment size for low density geochemical reconnaissance programmes.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The investigation reported here is part of a wider study of the application of regional geochemical mapping to environmental problems (Project R5547, 91/16, Environmental Geochemical Mapping) funded by the Overseas Development Administration as part of the U.K. programme of aid to the developing countries and carried out under the ODA/BGS Technology Development and Research Programme. Field studies were conducted in Zimbabwe, where the work was supported by the Geological Survey Department of the Ministry of Mines.

Although geochemical mapping based on the collection and chemical analysis of drainage sediments (normally at relatively high densities of 1 sample per 1-5 km^2) was initially used for mineral exploration purposes, it is increasingly recognised that the techniques can be used to provide data that are valuable for environmental studies, with particular importance in the fields of human, animal and crop health (Aggett *et al.*, 1988; British Geological Survey, 1990. 1991, 1992; Plant and Moore, 1979; Plant, 1983; Plant and Stevenson, 1985; Thornton, 1983; Webb and Atkinson, 1965). The value of drainage geochemical data for many environmental studies depends on the relationship between drainage and soil geochemistry. Appleton and Greally (1992) discuss the stream sediment-soil relationship in a report describing work which also forms part of Project R5547 and conclude that there is a broad correlation between soil and stream sediment geochemistry and that regional drainage geochemical maps compare well with soil maps for identifying areas where trace element deficiencies or excesses may occur. Stream sediment-soil relationships have been investigated in the course of the present study to help confirm this correlation in the Zimbabwean environment.

Many parts of the earth's land surface, particularly in the developing countries, have not been covered by regional geochemical surveys and the cost-effective provision of the important data stemming from such surveys is seen as a high priority by geoscientists throughout the world. To this end, Project 259 of the International Geological Correlation Programme (IGCP 259, now continuing as IGCP 360, International Geochemical Mapping), has been concerned with promoting regional geochemical mapping and establishing guidelines for the surveying of unmapped regions. The costs and time necessary for geochemical surveying would be reduced if it could be demonstrated that low-density sampling was capable of producing data which were broadly compatible with those provided by the relatively high density surveys through which the links with environmental factors were established. Ridgway *et al.* (1991) and Fordyce *et al.* (1993) showed that the mathematical simulation of low density sampling by the reduction of data from high density drainage sediment surveys (based on collection from low order streams) could yield meaningful geochemical patterns at densities as low as 1 sample per 500 km^2. The major part of the present study is concerned with examining whether the collection and analysis of samples from high order streams/rivers, with drainage basins of between 50 and 150 km^2, would similarly give rise to geochemical results which were comparable with those from a previous high density survey. The findings have relevance for all developing countries where geochemical survey coverage is incomplete and also provide an input to IGCP 360.

PROJECT OBJECTIVES

The study reported here addressed two specific objectives of Project R5547:

1) The comparison of drainage sediment and soil as sampling media for environmental geochemical surveys.
2) Assessment of the relative usefulness of high and low density geochemical sampling for environmental geochemistry purposes.

Objective 1 had been largely met by the work reported in Appleton and Greally (1992) and the present study, designed to complement the earlier work, was confined to the examination of soil-stream sediment relationships in a small drainage basin where concentrations of Co, Cu, Mn, Ni, Pb and Zn were expected to be low because of the granitic gneiss bedrock.

Objective 2 was met by comparing the chemical composition of high order drainage samples from the Harare area of Zimbabwe, representing drainage basins of 50-150 km^2, with an average composition for each basin calculated from low order stream samples collected during an original high density geochemical survey. Because chemical analyses were to be performed in a different laboratory to that of the original survey and temporal variations in stream sediment geochemistry have been recorded in the study region (Ridgway and Dunkley, 1988), the investigation addressed three particular topics:

1) Comparison between original analyses and reanalysis of splits of original samples stored in the Geological Survey Department, Zimbabwe, to assess the compatibility of the original and new analytical results.
2) Comparison of both original and new analyses of stored sample splits with analyses of new samples collected from the original sample sites to assess the importance of temporal variations.
3) Comparison between analyses of samples from high order streams, representing large drainage basins, and calculated average values for the drainage basins based on the original sampling and analysis to assess the relationship between low and high density sampling programmes.

Field work in Zimbabwe took place in September and October 1992.

POTENTIAL BENEFITS

Mineral (trace element) deficiencies or imbalances in soils and forages are thought to be responsible for low production and reproduction problems among grazing livestock in many developing countries (McDowell *et al.*, 1983). Although extreme cases of trace element deficiency or toxicity are often easily diagnosed from clinical or pathological characteristics, the recognition of sub-clinical cases must rely on chemical and biological analyses. Similarly, humans living for long periods in one area with a diet based primarily on locally produced food and water, a situations which can be common in developing countries, may also suffer from trace element deficiencies or excesses with similar difficulties of diagnosis. Trace element related production problems are also recorded for crops (Thornton, 1983).

The identification of areas where trace element imbalances are a potential problem is clearly beneficial, allowing remedial or preventative measures to be taken as necessary, and permitting informed planning for development. Recognition of areas with sub-clinical mineral imbalance problems in grazing livestock has generally been carried out through mapping soil, forage, animal tissue or animal fluid compositions, techniques which are not only expensive, but also may be impractical for the mapping of large areas (Appleton and Greally, 1992). Appleton and Ridgway (1993) discuss the application of regional geochemical mapping in developing countries to environmental studies and the value of high density stream sediment survey data in the recognition of regions where trace element deficiencies might occur has been demonstrated by Fordyce and Appleton (1994). Stream sediment surveys are a cost-effective means of delineating geochemical patterns of environmental significance but their value would be enhanced if it could be shown that rapid, low density sampling programmes also produce useful information.

THE STUDY AREA

The Harare region of Zimbabwe, between latitudes 17°30'S and 18°00'S and longitudes 30°45'E and 31°30'E, was selected for the study. Covering 4400 km^2, the area had been previously sampled at an average density of 1 sample per 2.7 km^2 in a geochemical survey carried out between 1982 and 1986 (Dunkley, 1987). Access is good and there is strong geochemical contrast between the volcano-sedimentary rocks of the Harare Greenstone Belt and the surrounding granites and granitic gneisses (Fig 1). The earlier geochemical survey was based on the <177 µm fraction of stream sediments, analysed for Co, Cu, Li, Mn, Ni, Pb and Zn by atomic absorption spectrometry following digestion with hot concentrated hydrochloric acid for one hour. Approximately 40% of the samples were also analysed by XRF for As, Ba, Sn, Ta and W.

COMPARISON OF DRAINAGE SEDIMENT AND SOIL AS SAMPLING MEDIA FOR ENVIRONMENTAL GEOCHEMICAL SURVEYS.

Study area

A drainage basin having an area of 2-3 km^2, in an area underlain by granitic gneisses, was chosen for the investigation (Fig. 2). Farming in the basin is not intense and the soils are unlikely to have been affected by large scale additions of fertilisers or animal feed supplements.

Field methods

The basin contains two stream sediment sites sampled as part of the original high density survey. These sites were resampled, one additional site and a site representing the full 2-3 km^2 of the basin were also sampled. Soil samples were taken along the interfluves, a total

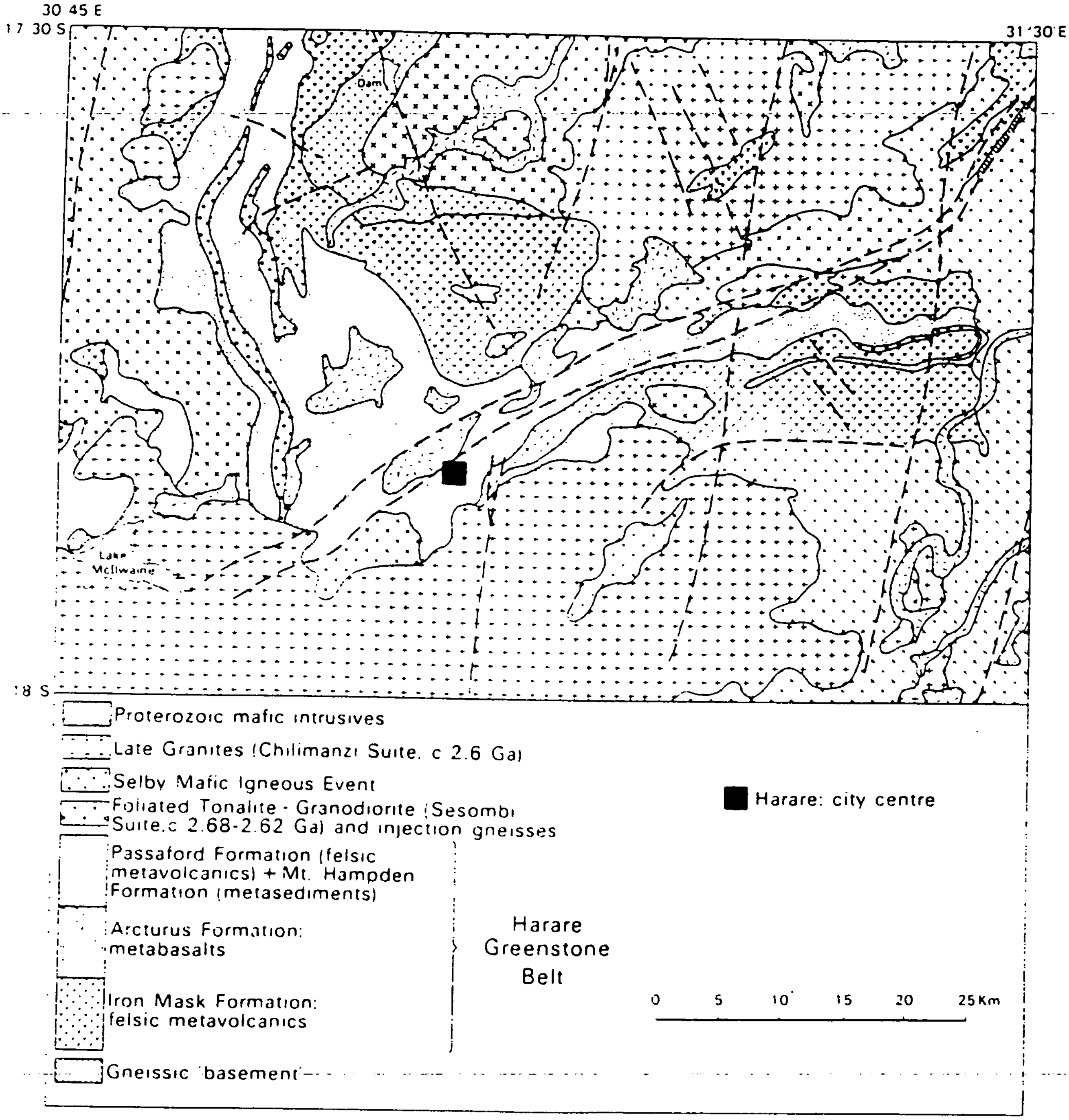

FIGURE 1: Simplified geology of the study area

of 24 sites being chosen to give a relatively even coverage of the flatter lying part of the catchment (Fig. 2). Hillslopes, where soils are very thin and the potential for agricultural use very limited, were not sampled. Soils are generally shallow with a poorly developed profile and over much of the area sampled had been tilled for subsistence agriculture.

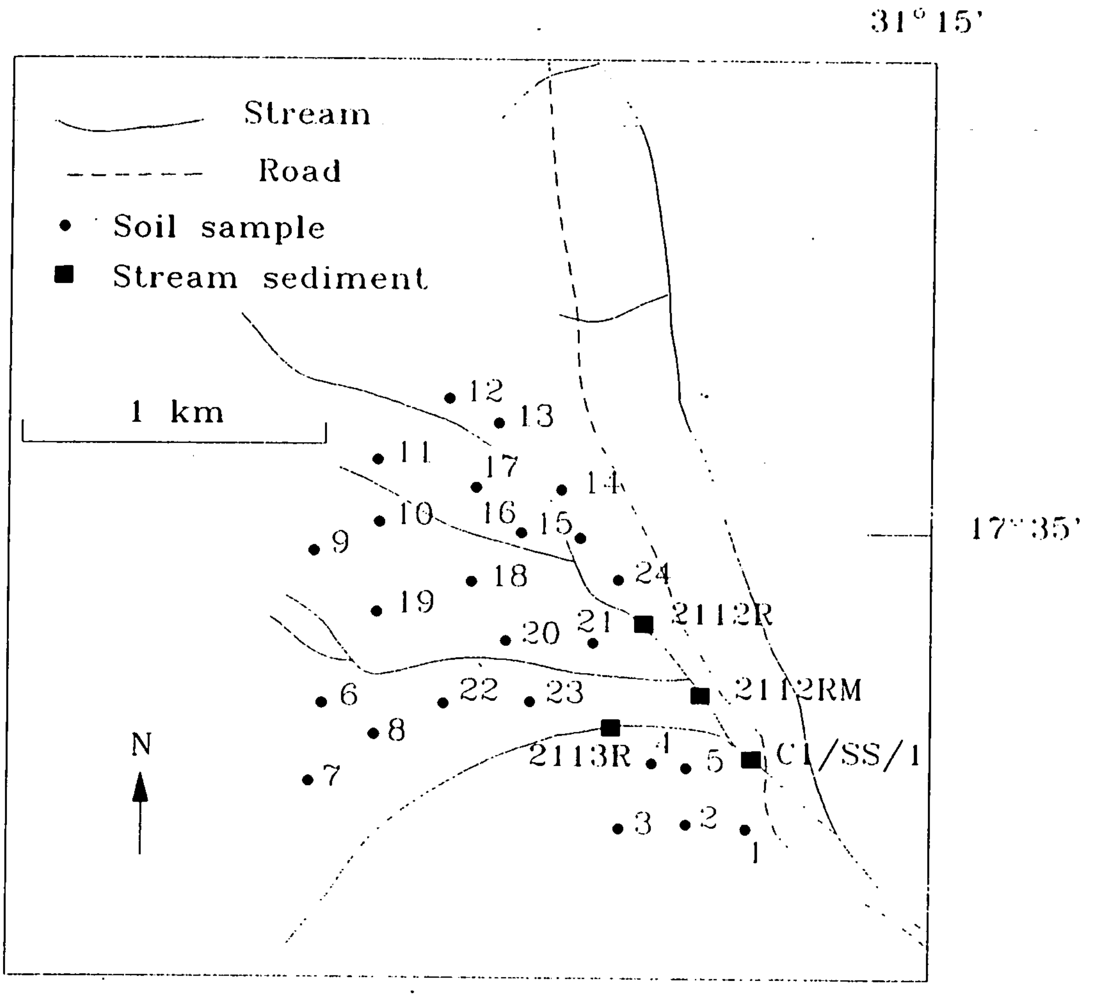

FIGURE 2: Sketch map of drainage basin used for the soil/stream sediment comparison, showing sample locations.

Stream sediments

Streams in the area were dry at the time of resampling and sieving was carried out in the field using nylon sieve cloth held in a wooden frame. Two types of sample were taken at each site, one of <2 mm material and the other of <177 μm sediment. At the site representing the whole drainage basin (C1/SS/1, Fig. 2), two samples of <177 μm sediment were collected as a check on reproducibility. Each sample was collected by making up a composite of sub-samples from 5-10 sites along a 10-20 m stretch of the stream bed centred on the nominal sample location.

Soils

Soils were also sieved in the field, two size fractions being collected using the same equipment as for stream sediments. At each sample location five sub-samples were taken and composited to make one full sample. The sub-samples were collected from a central site and four other sites, each at a distance of 5 m from the central site and forming the corners of a square. A small pit was dug at each site, 20-30 cm deep, and material collected from B horizon soil, although in most cases distinct horizons were difficult to recognise.

Analytical methods

Both soil and stream sediment samples were analysed in the BGS laboratories by ICP-AES for Co, Cu, Fe, Mn, Ni, Pb and Zn after digestion for one hour in hot concentrated hydrochloric acid. A comparison of analytical results and recommended values (RV) for three reference materials is given in Table 1 and shows the good agreement between the two sets of data. Detection limits for the analytical method also are shown in Table 1.

(ug/g)	Mn	Fe	Zn	Cu	Pb	Co	Ni
GXR 3	24366	20.05%	230	15	15	63	64
RV	22308	19.00%	207	18	15	43	60
GXR 5	247	3.24%	47	374	<10	27	66
RV	310	3.39%	49	354	21	30	75
GXR 6	1226	6.24%	145	78	111	18	28
RV	1007	5.58%	118	66	101	14	27
Det. Limit	1	0.0002%	5	2	10	3	3

TABLE 1: Comparison of determined and recommended values (RV) for international reference materials (Potts et al. 1992).

Results

In Table 2 element concentrations in stream sediments 2112R, 2112RM, 2113R and C1/SS/1 are compared with mean soil values for subsets of soils which are considered to lie within the respective catchment areas. The full dataset is tabulated in Appendix 1. In computing mean values, concentrations below the detection limit have been given a value of half the detection limit.

	Mn	Fe	Zn	Cu	Pb	Co	Ni	No.
<2mm soil mean for whole basin	291	0.81%	14	6	12	5	12	24
<2mm C1/SS/1	66	0.35%	5	3	<10	<3	4	1
<2mm soil mean for 2112R	276	0.72%	14	5	12	4	8	11
<2mm 2112R	63	0.23%	5	2	<10	<3	234	1
<2mm soil mean for 2113R	381	0.87%	15	5	14	6	39	3
<2mm 2113R	96	0.68%	17	6	14	2	9	1
<177 mic. soil mean for whole basin	554	1.33%	25	8	27	9	14	24
<177 mic. C1/SS/1A	271	1.88%	28	7	27	7	13	1
<177 mic. C1/SS/1B	311	1.85%	29	7	30	4	9	1
<177 mic. soil mean for 2112R	550	1.24%	25	8	29	8	15	11
<177 mic. 2112R	111	0.38%	11	3	21	<3	5	1
<177 mic. soil mean for 2112RM	596	1.39%	27	9	29	10	15	17
<177 mic. 2112RM	186	1.40%	23	6	31	4	9	1
<177 mic. soil mean for 2113R	830	1.55%	30	9	35	12	14	3
<177 mic. 2113R	155	1.52%	39	13	46	6	13	1

TABLE 2: Comparison of mean values for within-catchment soils with values for the equivalent stream sediment. Values in ppm except for Fe.

<2 mm material

Values for Mn and Fe are significantly lower in the stream sediments than in the soils for C1/SS/1 and 2112R. This is generally reflected in the other elements with the exception of Ni in 211R which is extremely high. Although Mn and Fe are also lower in stream sediment 2113R, the differences from the soil values for other elements are not pronounced. Again Ni is an exception, but in this case the soil value is higher. The explanation for these differences may be that the soils contain a higher proportion of very fine-grained material than the stream sediments. In the latter, fine material will have been washed out at times of stream flow. Coatings of Mn and Fe oxides on the surfaces of clay minerals and silt particles are known to scavenge other metals (Watters, 1983) and thus sediments with low fines contents will have correspondingly low metal values. The large variations in Ni content are more difficult to explain and require investigation beyond the scope of this study.

<177 μm material

The selection of a narrower size range through sieving eliminates most of the effects of natural processes and overall there is much closer agreement between the data for soils and stream sediments in this size fraction. Manganese concentrations are consistently lower in the stream sediments, but Fe values are variable. Given the degree of analytical variation to be expected at the relatively low concentrations recorded, it can reasonably be said that for Co, Cu, Ni, Pb and Zn there is close correspondence between the soil and stream sediment datasets.

Conclusions

In the <177 μm material the geochemistry of stream sediments compares well with that of soils and for this terrain type stream sediments could be used with confidence as a sampling medium for environmental studies. The correspondence between soil and stream sediment geochemistry is less good in the <2mm fraction but both reflect the low trace element concentrations to be expected from an area underlain by granitic gneisses.

ASSESSMENT OF THE RELATIVE USEFULNESS OF HIGH AND LOW DENSITY GEOCHEMICAL SAMPLING FOR THE PRODUCTION OF ENVIRONMENTAL GEOCHEMICAL MAPS.

For this part of the investigation, the Harare region was divided into drainage basins with catchment areas of 50 to 100 km^2 using 1:250 000 and 1:50 000 topographic maps. In practice the area of the basins varied between approximately 45 and 135 km^2 (Fig. 3) and because of the drainage pattern large tracts of the region were not included within basins of this size.

Field methods

Samples were collected from the major streams at the exit point from the selected catchment basins. The general techniques and equipment used were the same as described in the previous section. Stream conditions varied and some samples were wet sieved on site, some dry sieved, and some collected in bulk for later drying and sieving in the laboratory. No attempt was made in this investigation to determine the effects of different sample collection and sieving methods, but earlier work in NE Zimbabwe (Ridgway, 1983) showed that differences in chemistry between wet and dry sieved samples were minimal. Only <177 µm material was taken and each sample was collected by making up a composite from 10-15 sites along a 50 m reach of river bed spanning the nominal sample location. At 6 locations the samples were collected in triplicate and at a seventh location duplicate samples were taken.

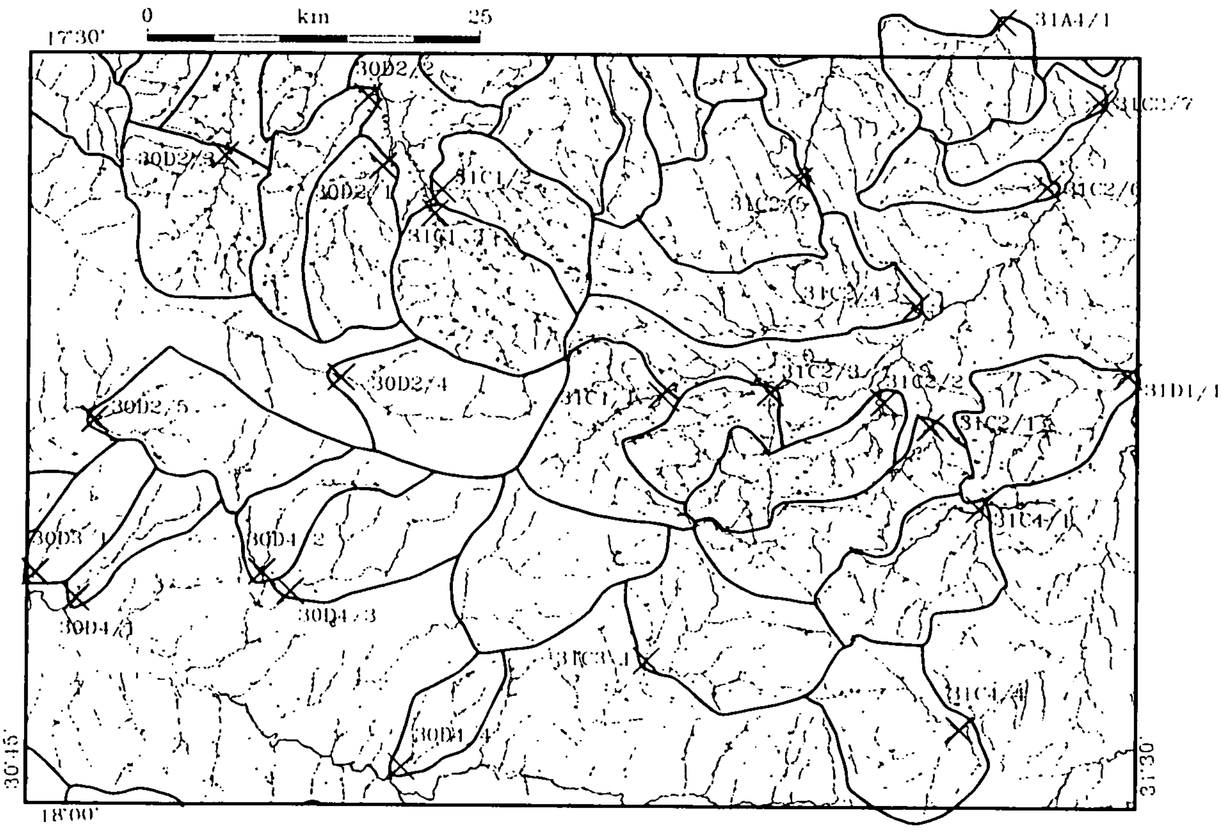

FIGURE 3: Drainage map of the Harare area showing major drainage basin sampled and sample numbers. Locations of original samples from low order streams are also shown. The area boundary is the same as for FIGURE 1.

Sixteen sites from the earlier high density survey were resampled and the corresponding stored sample splits retrieved from the sample archive in the Geological Survey Department, Harare.

Analytical methods

After drying and disaggregation as necessary, all samples and sub-samples were analysed using the same methodology as for the soil-stream sediment comparison study already described .

Results

For comparison purposes all concentrations below the detection limit have been assigned a nominal value of half the detection limit.

1) Test 1: Comparison between original analyses and reanalysis of splits of original samples

Table 3 shows the results analysis of original samples during the previous survey (o) and reanalysis of these samples in the present study (ra) along with Pearson product-moment correlation coefficients (o/ra). Although absolute values vary considerably the correlation is generally good, only Pb having a Pearson coefficient of less than 0.9. The lower correlation coefficient for Pb reflects the low concentration of this element which means that determinations must be carried out near the detection limit, thus leading to poor precision in the results (Thompson and Howarth, 1973). Having established that the agreement between the original and new analytical data is good, it is thus reasonable to examine how analysis of replicate samples from the original sites compares with the original data.

2) Test 2: Comparison of original and new analyses of stored sample splits with analyses of new samples collected from the original sample sites

Table 3 again shows the Pearson coefficients for this comparison. Results for resampled sites are designated as rs. The level of correspondence is markedly lower than for Test 1, and is particularly poor for Zn. Pearson correlation coefficients (o/rs) are less than 0.9 for all elements except Mn and Pb. Results are very similar for the comparison between reanalysed splits and recollected samples (ra/rs). The discrepancy between the original data and those for the resampling exercise could be attributed to temporal variations. Ridgway and Dunkley

No	Mn o	Mn ra	Mn rs	Zn o	Zn ra	Zn rs	Cu o	Cu ra	Cu rs	Pb o	Pb ra	Pb rs	Co o	Co ra	Co rs	Ni o	Ni ra	Ni rs
1747	170	185	1262	3	13	78	3	3	60	15	13	19	4	2	41	4	2	58
2111	220	277	483	2	11	34	3	4	12	28	26	43	4	6	10	8	9	18
2112	140	161	111	2	11	11	2	1	3	10	13	21	2	2	2	2	4	5
2417	380	401	231	5	21	37	14	16	15	12	13	21	5	8	8	13	16	21
2543	1290	1369	1260	35	128	130	59	71	65	10	14	19	37	46	52	60	84	107
2556	1600	1756	1033	55	117	70	69	81	56	9	5	11	26	29	33	61	83	66
2557	9200	9943	7339	36	89	94	62	78	87	0	5	5	79	109	77	82	118	121
2568	4500	5137	1370	475	522	96	53	67	55	16	22	5	40	52	41	67	98	78
2631	760	761	401	10	37	31	6	7	7	25	30	31	10	10	6	6	9	5
2634	500	524	491	14	47	33	9	8	11	15	5	21	14	11	13	25	26	30
2815	90	125	190	4	9	14	1	3	6	10	5	5	1	2	2	5	5	5
2819	980	1099	1856	26	27	63	22	28	96	0	5	5	18	29	70	34	43	122
2823	1100	959	1754	20	18	55	25	28	76	10	5	12	22	29	55	24	28	74
2824	180	185	322	12	12	39	6	8	23	10	5	12	3	5	15	13	10	40
2935	1150	1163	1518	44	50	53	59	71	90	0	5	5	42	53	85	125	169	378
2954	1500	1629	2334	60	70	71	105	127	127	0	5	5	45	59	111	102	147	174
	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs
Pears.	0.9993	0.8922	0.9032	0.9783	0.5305	0.4146	0.9990	0.7935	0.7881	0.8160	0.7109	0.8398	0.9938	0.7711	0.7649	0.9975	0.8449	0.8684

99% significance value = 0.5742

TABLE 3: Values for original determinations (o), reanalysed splits of originals (ra) and resampled sites (rs). Pearson correlation coefficients are shown for paired sets of analyses (original and reanalysed splits = o/ra etc.).

No.	Zn o	Zn ra	Zn nrs	Cu o	Cu ra	Cu nrs	Pb o	Pb ra	Pb nrs	Co o	Co ra	Co nrs	Ni o	Ni ra	Ni nrs
1747	3	13	11	3	3	9	15	13	5	4	2	6	4	2	9
2111	2	11	20	3	4	7	28	26	25	4	6	6	8	9	10
2112	2	11	16	2	1	5	10	13	30	2	2	2	2	4	7
2417	5	21	64	14	16	26	12	13	36	5	8	13	13	16	36
2543	35	128	141	59	71	71	10	14	21	37	46	57	60	84	116
2556	55	117	118	69	81	95	9	5	19	26	29	56	61	83	111
2557	36	89	128	62	78	118	0	5	7	79	109	105	82	118	163
2568	475	522	360	53	67	205	16	22	19	40	52	153	67	98	293
2631	10	37	58	6	7	14	25	30	59	10	10	11	6	9	10
2634	14	47	35	9	8	12	15	5	22	14	11	14	25	26	32
2815	4	9	9	1	3	4	10	5	5	1	2	2	5	5	4
2819	26	27	38	22	28	57	0	5	5	18	29	42	34	43	72
2823	20	18	30	25	28	42	10	5	7	22	29	30	24	28	41
2824	12	12	22	6	8	13	10	5	7	3	5	8	13	10	23
2935	44	50	40	59	71	69	0	5	4	42	53	65	125	169	290
2954	60	70	50	105	127	89	0	5	5	45	59	78	102	147	122
	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs
Pears.	0.9783	0.9710	0.9145	0.9990	0.7470	0.7315	0.8160	0.7415	0.6604	0.9938	0.8327	0.8365	0.9975	0.8688	0.8667

99% significance value = 0.5742

TABLE 4: As for TABLE 3. except that values for resampled sites have been recalculated according to the formula: nrs = rs((reanalysed Fe+Mn)/(resampled Fe+Mn)).

(1988) suggest that seasonal variations may be compensated for by using correction factors based on element-Fe oxide ratios and an attempt to do this is shown in Table 4. In Table 4, combined totals of Fe and Mn in original samples and replicate samples recollected from the original sites have been used to adjust the concentration levels for the replicate samples. This results in an improvement in correlation coefficients between original and replicate values for Zn, in particular, and Co, but gives no improvement for Cu, and Ni, and much poorer correlation for Pb. The discrepancies, however, could also relate to difficulties in relocating the original sites. At several of the sites the stream channel was poorly defined and may have been disturbed by agricultural practices, while at one location a dam had been built upstream of the original sampling point. If only data for sites where there was a well defined stream channel are considered (Table 5), the correlation coefficients improve dramatically with only Zn having a Pearson coefficient (o/rs) of less than 0.9. This indicates that temporal variations are of lesser importance than accurate resampling in accounting for discrepancies between original and replicate sampling datasets and suggests that geochemical patterns arising from the original survey and a new survey would be very similar, even when absolute values differ.

3) Test 3: Comparison between analyses of samples from high order streams and computed values for the drainage basins based on the original sampling and analysis

Given that there is compatibility, at least in a relative sense, between the original survey results and those from the resampling exercise, the outcome of this third test can now be examined.

Data for replicate sampling on the same day in the major streams (Table 6) demonstrate that the sampling methodology is sound and provides reproduceable results. In Table 7, the analytical results from samples collected at the mouth of each large catchment basin are compared with the arithmetic mean, geometric mean and median of all the samples from low order streams within that basin. Pearson correlation coefficients show that the arithmetic mean performs as well as, or better than, the geometric mean or median as a measure of the overall composition of the drainage basin. The coefficients are, with the exception of that between major drainage sample and arithmetic mean Pb, lower than the correlation coefficients between original and recollected samples from low order streams shown in Table 5. In the cases of Mn and Ni the correlations are very poor, the recorded coefficients not being significant at the 99% level. The implication is that, in the Harare area, either samples from high order streams are not truly representative of the geochemistry of the upstream catchment area, or mean values of the low order stream samples are not representative of the drainage basin as a whole.

The reasons for the poor correlation between the chemistry of samples from high order streams and measures of the overall geochemistry of samples from low order streams are not clear. Plots of major stream sample against arithmetic mean for individual elements (Fig. 4 a and b) show that some major basins persistently plot off the main trend (e.g. 6, 7, 8, 10, 12, 16 and 18). Tables 8 and 9 summarise the geology of the 25 drainage basins studied in terms of major rock types and formations. There is no obvious common factor linking the most aberrant basins (6, 7, 8, 10, 12, 16 and 18). Basin 10, at 45 km ^{2}, is one of the smallest sampled, while basin 6 is the largest at approximately 135 km^2. Basins 7 and 8 have a relatively simple geological make-up, each containing only 2 rock types, whereas 6 and 18 are more complex with a variety of rock types and formations within their confines. Other basins of simple (e.g. 13 and 21) or complex (e.g. 1 and 5) geology lie on the general trend defined by scatter plots of, for instance, high order stream sample against mean value of low order stream samples from the same drainage basin (Fig. 4 a and b).

In the case of basins 7 and 10 an examination of the geological map of the region shows that the high order stream sample site lies on a rock type which is of relatively minor importance in the basin as a whole, but which probably makes a major contribution to the composition of the sediment at that site. The bedrock in both basins is predominantly of granitic composition, but the sample sites lie on more basic lithologies producing, for example, a Ni value for basin 10 of 248 ppm against mean, geometric mean and median values for the whole basin of 24, 10 and 8 ppm respectively (Table 7). This discrepancy is far higher than can be accounted for by differences in the analytical method and must arise from the local lithological influence. Such a simple explanation cannot be advanced for the other aberrant basins where a variety of factors may have influenced the situation (Hawkes, 1976; Rose *et al.*, 1979). Careful choice of sample site on the basis of geology might help overcome this type of problem, but would not help in areas of poor geological knowledge.

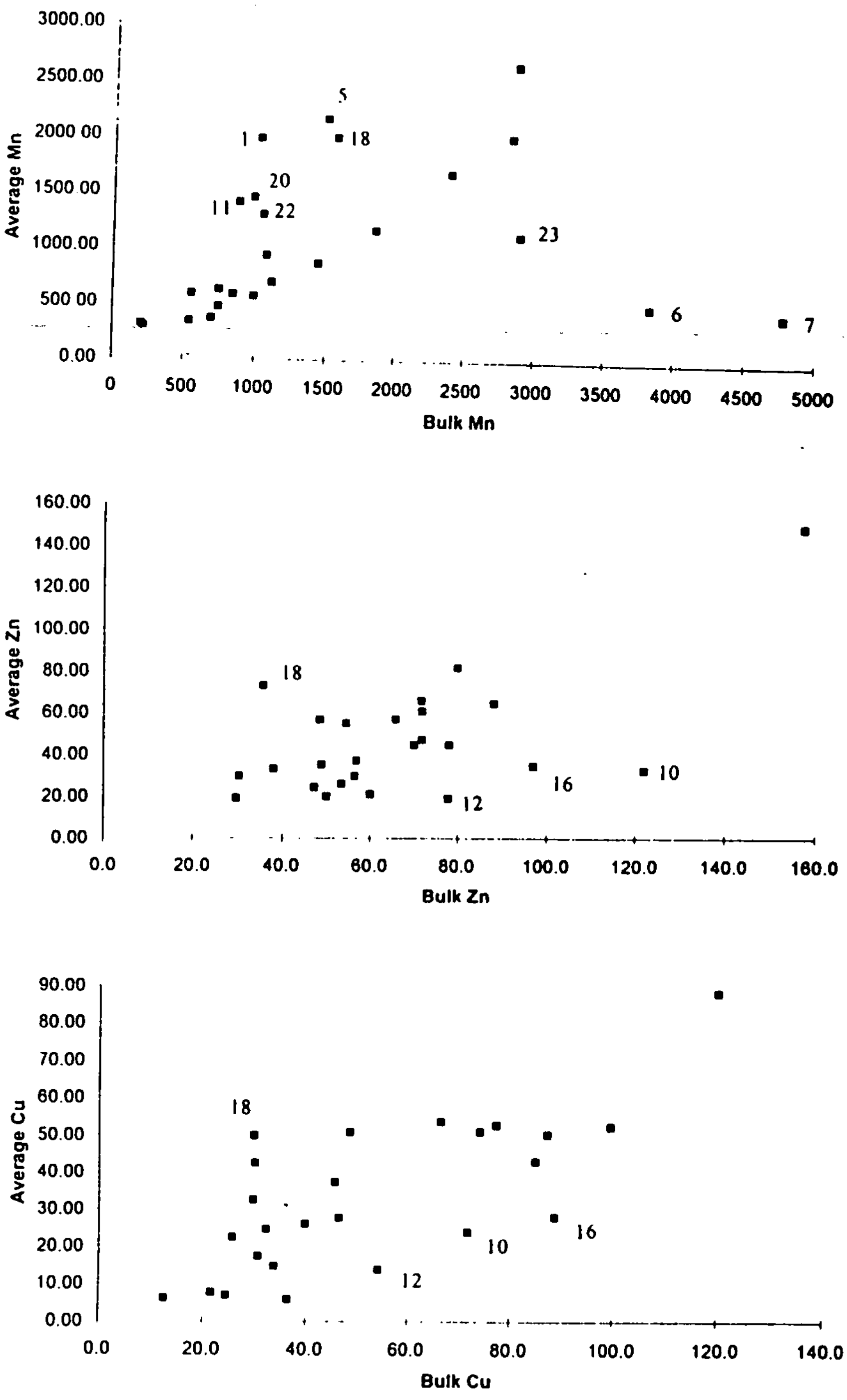

FIGURE 4a: Scatter plots of arithmetic mean (average) element values for low order stream samples against the high order stream sample representing the whole drainage basin; Mn, Zn and Cu. The tendancy for the bulk values to be higher than the average reflects the pattern seen in Table 3, where resampled low order streams yielded generally higher concentrations than the original sampling and analysis.

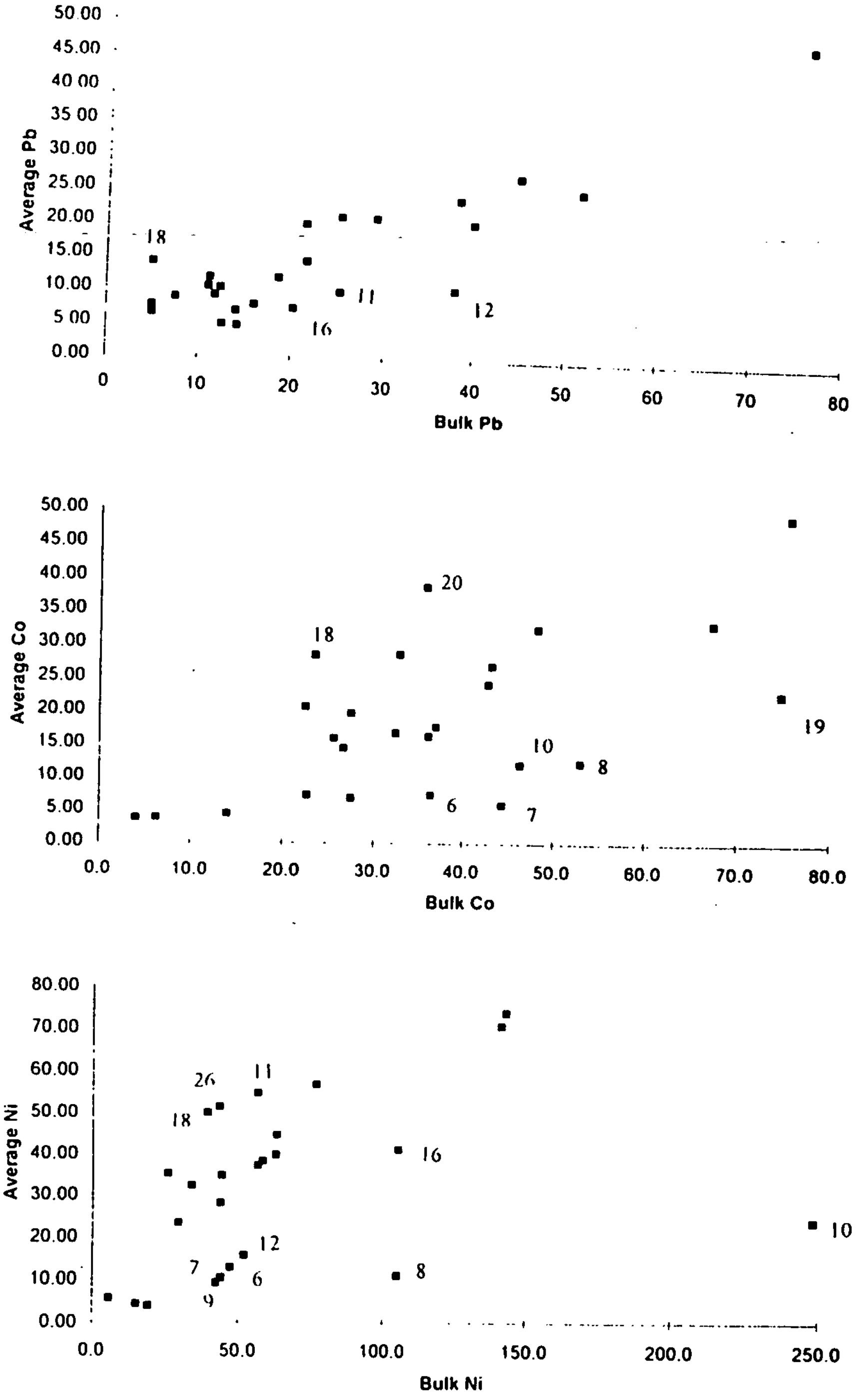

FIGURE 4b: Scatter plots of arithmetic mean (average) element values for low order stream samples against the high order stream sample representing the whole drainage basin: Pb, Co and Ni.

No.	Mn o	Mn ra	Mn rs	Zn o	Zn ra	Zn rs	Cu o	Cu ra	Cu rs	Pb o	Pb ra	Pb rs	Co o	Co ra	Co rs	Ni o	Ni ra	Ni rs
2111	220	277	483	9	11	34	3	4	12	28	26	43	4	6	10	8	9	18
2112	140	161	111	10	11	11	2	1	3	10	13	21	2	2	2	2	4	5
2417	380	401	231	20	21	37	14	16	15	12	13	21	5	8	8	13	16	21
2543	1290	1369	1260	114	128	130	59	71	65	10	14	19	37	46	52	60	84	107
2556	1600	1756	1033	106	117	70	69	81	56	9	5	11	26	29	33	61	83	66
2557	9200	9943	7339	75	89	94	62	78	87	0	5	5	79	109	77	82	118	121
2631	760	761	401	32	37	31	6	7	7	25	30	31	10	10	6	6	9	5
2634	500	524	491	41	47	33	9	8	11	15	5	21	14	11	13	25	26	30
2815	90	125	190	7	9	14	1	3	6	10	5	5	1	2	2	5	5	5
2824	180	185	322	12	12	39	6	8	23	10	5	12	3	5	15	13	10	40
	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs
Pears.	1.0000	0.9969	0.9967	0.9992	0.8920	0.8866	0.9987	0.9531	0.9390	0.8315	0.8634	0.9057	0.9947	0.9637	0.9679	0.9961	0.9493	0.9556

99% significance value = 0.7155

TABLE 5: As for TABLE 3, except that only samples from sites which could be accurately relocated are included.

	Mn			Zn			Cu			Pb			Co			Ni		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
30D2/2	2126	3154	3321	133	173	166	104	129	127	5	5	5	88	68	72	126	149	150
30D2/4	964	949	1048	65	63	69	64	63	72	14	14	5	37	33	37	63	60	66
30D3/1	623	801	819	31	28	31	28	24	25	5	12	5	24	27	26	46	43	41
30D4/4	176	232		25	35		30	43		27	31		4	8		11	19	
31C1/2	978	1274	990	60	62	49	46	53	40	25	12	5	38	41	29	33	32	24
31C3/1	229	186	259	44	36	70	11	11	16	22	17	26	6	2	5	5	5	8
31C4/4	568	521	552	58	57	65	21	21	23	41	38	36	16	13	13	21	18	19
	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C
Pears.	0.9866	0.9902	0.9821	0.9811	0.9530	0.9551	0.9835	0.9849	0.9860	0.8632	0.8775	0.8011	0.9737	0.9666	0.9874	0.9902	0.9959	0.9914

99% Significance value = 0.8329

TABLE 6: Comparison of replicate samples from large catchment areas and Pearson correlation coefficients.

	Sample	Mn	Mn m	Mn gm	Mn md	Zn	Zn m	Zn gm	Zn md	Cu	Cu m	Cu gm	Cu md
1	30D2/3	1030	1981	793	660	48	57	41	37	30	33	22	24
2	30D2/2	2867	2638	2126	2540	157	148	110	88	120	88	76	75
3	30D2/1	2401	1681	1003	930	54	55	48	47	49	51	33	32
4	31C1/2	1081	928	717	680	57	37	34	37	46	28	21	20
5	31C1/3	1501	2157	1513	1670	88	65	61	65	74	51	46	52
6	31C2/4	3837	496	382	345	53	26	23	21	34	15	8	7
7	31C2/5	4785	428	377	375	56	30	26	27	24	7	6	6
8	31A4/1	1447	860	755	810	78	45	41	40	85	43	18	8
9	31C2/6	700	364	333	310	47	25	22	23	31	17	13	12
10	31C2/7	1120	693	527	650	122	33	28	26	72	24	16	19
11	31D1/1	882	1404	949	950	72	66	50	44	87	50	35	46
12	31C4/1	846	582	367	290	78	19	17	17	54	14	5	3
13	31C4/4	547	337	273	295	60	21	18	17	22	8	4	3
14	31C3/1	224	290	224	210	50	20	17	18	13	6	5	4
15	31C2/1	752	624	371	260	97	35	21	18	89	28	11	9
16	31C2/2	1863	1161	888	940	70	45	37	43	100	52	36	45
17	31C2/3	1573	1988	1459	1520	36	73	62	69	30	50	38	56
18	31C1/1	2836	2003	1112	1040	80	82	63	62	30	42	33	38
19	30D2/4	987	1450	1018	970	66	57	52	48	66	54	50	48
20	30D4/4	204	309	251	240	30	19	17	15	37	6	4	5
21	30D4/3	1055	1295	1073	1090	72	61	52	45	46	37	33	35
22	30D4/2	2901	1118	874	810	72	47	45	43	77	53	47	49
23	30D2/5	558	586	462	395	49	35	33	33	40	26	24	24
24	30D4/1	992	568	523	560	38	33	32	34	32	25	24	27
25	30D3/1	748	469	412	380	30	30	29	30	26	22	22	21
Pearson			0.2639	0.2903	0.2849		0.6013	0.5428	0.4281		0.7234	0.6013	0.5341

99% significance value = 0.4686

	Sample	Pb	Pb m	Pb gm	Pb md	Co	Co m	Co gm	Co md	Ni	Ni m	Ni gm	Ni md
1	30D2/3	5	6	5	5	22	21	16	15	57	37	28	31
2	30D2/2	5	8	4	4	76	49	44	47	141	70	62	65
3	30D2/1	16	8	5	8	43	27	20	23	63	45	34	38
4	31C1/2	14	7	5	6	36	16	13	14	29	23	17	17
5	31C1/3	13	5	3	3	48	32	29	31	76	57	53	57
6	31C2/4	40	20	16	17	36	7	5	4	47	13	9	9
7	31C2/5	45	27	25	28	44	6	5	5	44	10	8	9
8	31A4/1	76	48	35	35	53	12	8	8	105	11	9	9
9	31C2/6	52	25	23	24	23	7	6	6	42	9	7	7
10	31C2/7	25	21	18	20	46	12	8	9	248	24	10	8
11	31D1/1	25	10	5	6	33	28	21	26	57	55	36	47
12	31C4/1	38	10	7	10	27	7	3	2	52	16	10	9
13	31C4/4	38	24	22	20	14	4	3	3	19	4	3	3
14	31C3/1	21	20	18	20	4	4	3	3	6	6	4	4
15	31C2/1	20	7	4	10	37	18	6	6	105	41	16	10
16	31C2/2	5	14	4	2	67	33	25	31	143	73	49	75
17	31C2/3	14	5	3	4	23	28	23	25	39	50	43	57
18	31C1/1	12	10	7	7	43	24	19	20	26	35	28	28
19	30D2/4	11	10	9	11	36	38	26	22	63	40	33	32
20	30D4/4	29	21	19	19	6	4	3	4	15	4	3	3
21	30D4/3	22	14	13	10	27	20	18	18	44	35	31	34
22	30D4/2	19	12	10	10	75	23	19	20	58	38	31	29
23	30D2/5	12	9	8	8	27	14	13	13	44	28	26	27
24	30D4/1	11	12	11	10	32	17	16	17	34	32	29	31
25	30D3/1	7	9	9	9	26	16	15	15	43	51	45	38
Pearson			0.8777	0.8525	0.8759		0.6085	0.5926	0.6147		0.3654	0.2219	0.2299

99% significance value = 0.4686

TABLE 7: Comparison of arithmetic mean (m), geometric mean (gm) and median values (md) for all original survey samples within a major catchment with values for the major drainage sample representing the total catchment. Pearson correlation coefficients between major drainage samples and computed values are also given.

Make-up of catchments by lithological unit

Catchment		AF	CT	HF	IM	PF	SE	ST	TE	Total
1	30D2/3	9	7	3	1	38	6	3	0	67
2	30D2/2	27	1	11	8	1	2	0	0	50
3	30D2/1	14	0	1	25	0	0	6	2	48
4	31C1/2	10	1	0	3	0	0	40	0	54
5	31C1/3	64	1	0	12	0	0	11	7	95
6	31C2/4	1	32	0	0	0	0	19	0	52
7	31C2/5	0	35	0	5	0	0	0	0	40
8	31A4/1	0	14	0	0	0	0	0	0	14
9	31C2/6	3	10	0	0	0	0	1	0	14
10	31C2/7	2	2	0	0	0	0	8	0	12
11	31D1/1	4	1	0	0	7	0	15	0	27
12	31C4/1	6	3	0	0	0	0	14	0	23
13	31C4/4	0	5	0	0	0	0	13	0	18
14	31C3/1	0	30	0	0	0	0	4	0	34
15	31C2/1	21	4	0	0	1	0	23	0	49
16	31C2/2	49	2	0	0	0	0	9	0	60
17	31C2/3	18	0	4	0	17	4	6	0	49
18	31C1/1	18	4	5	0	29	0	7	0	63
19	30D2/4	5	0	10	0	1	0	3	0	19
20	30D4/4	0	10	0	0	0	0	0	0	10
21	30D4/3	0	0	7	1	3	0	0	2	13
22	30D4/2	0	0	1	0	8	0	3	3	15
23	30D2/5	0	0	1	0	6	0	21	0	28
24	30D4/1	0	3	1	0	3	0	3	0	10
25	30D3/1	0	1	0	0	6	0	1	0	8
Total		251	166	44	55	120	12	210	14	872

Make-up of catchments by bedrock

Catchment		FP	FV	GN	GR	GT	MD	MI	MV	PH	Total
1	30D2/3	0	39	1	7	2	0	6	9	3	67
2	30D2/2	0	9	0	1	0	0	2	27	11	50
3	30D2/1	2	25	3	0	3	0	0	14	1	48
4	31C1/2	0	3	0	1	33	7	0	10	0	54
5	31C1/3	5	11	0	1	9	5	0	64	0	95
6	31C2/4	0	0	1	30	16	4	0	1	0	52
7	31C2/5	0	5	0	35	0	0	0	0	0	40
8	31A4/1	0	0	0	9	0	5	0	0	0	14
9	31C2/6	0	0	0	10	1	0	0	3	0	14
10	31C2/7	0	0	0	1	8	1	0	2	0	12
11	31D1/1	0	7	14	1	0	1	0	4	0	27
12	31C4/1	0	0	1	2	13	1	0	6	0	23
13	31C4/4	0	0	13	5	0	0	0	0	0	18
14	31C3/1	0	0	1	30	3	0	0	0	0	34
15	31C2/1	0	1	0	4	23	0	0	21	0	49
16	31C2/2	0	0	0	2	9	0	0	49	0	60
17	31C2/3	0	17	0	0	6	0	4	18	4	49
18	31C1/1	0	27	0	4	7	11	0	9	5	63
19	30D2/4	0	0	0	0	3	1	0	5	10	19
20	30D4/4	0	0	0	10	0	0	0	0	0	10
21	30D4/3	2	3	0	0	0	1	0	0	7	13
22	30D4/2	3	4	0	0	3	4	0	0	1	15
23	30D2/5	0	6	0	0	21	0	0	0	1	28
24	30D4/1	0	2	0	3	3	1	0	0	1	10
25	30D3/1	0	6	0	1	1	0	0	0	0	8
Total		12	165	34	157	164	42	12	242	44	872

TABLE 8: Numbers of samples in major drainage basins according to bedrock and lithological unit at the sample site. See TABLE 9 for lithological unit and bedrock codes.

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
1	PF	FV	2	IM	FV	3	IM	FV	4	ST	MD	5	AF	MV
	AF	MV		AF	MV		ST	GN		ST	GT		IM	FV
	HF	PH		HF	PH		TE	FP		IM	FV		ST	MD
	SE	MI		CT	GR		ST	GT		AF	MV		ST	GT
	CT	GR		SE	MI		AF	MV		CT	GR		CT	GR
	ST	GT		PF	FV		HF	PH					IM	MD
	ST	GN											TE	FP
	IM	FV											TE	MD

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
6	ST	MD	7	CT	GR	8	CT	GR	9	CT	GR	10	CT	MD
	CT	GR		IM	FV		CT	MD		ST	GT		ST	GT
	CT	MD								AF	MV		CT	GR
	AF	MV											AF	MV
	ST	GT												
	ST	GN												

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
11	CT	GR	12	ST	GT	13	ST	GN	14	CT	GR	15	CT	GR
	AF	MV		AF	MV		CT	GR		ST	GT		ST	GT
	PF	FV		ST	GN					ST	GN		PF	FV
	ST	GN		CT	GR								AF	MV
	ST	MD		CT	MD									

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
16	CT	GR	17	PF	FV	18	HF	PH	19	HF	PH	20	CT	GR
	AF	MV		SE	MI		PF	FV		PF	MD			
	ST	GT		AF	MV		PF	MD		AF	MV			
				ST	GT		AF	MV		ST	GT			
				HF	PH		CT	GR						
							AF	MD						
							ST	GT						

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
21	TE	FP	22	TE	FP	23	PF	FV	24	ST	GT	25	ST	GT
	HF	PH		PF	MD		ST	GT		HF	PH		HF	PH
	PF	FV		ST	GT		HF	PH		PF	MD		PF	MD
	IM	FV		HF	PH					PF	FV		PF	FV
	PF	MD		PF	FV					CT	GR		CT	GR

Lithological Unit	
Chilimazi-type Intrusions	CT
Sesombi-type intrusions	ST
Teviotdale Event	TE
Selby Event	SE
Passaford Formation	PF
Mt Hampden Formation	HF
Arcturus Formation	AF
Iron Mask Formation	IM

Rock Type	
Dolerite	MD
Granite	GR
Granodiorite-Tonalite	GT
Gneiss and Migmatite	GN
Felsic Porphyries	FP
Mafic Intrusives	MI
Felsic Volcanics	FV
Phyllites	PH
Mafic Volcanics	MV

TABLE 9: Breakdown of major drainage basins by lithological unit and rock type

SUMMARY AND DISCUSSION

From the foregoing, it can be concluded that:

1) For granitic terrains, stream sediments from low order streams are reasonably representative of the soils of their catchment basins, at least where the soils are relatively undisturbed by agricultural practices. There is reason to believe that the same will hold true for other bedrock lithologies as has been demonstrated by Appleton *et al.* (1992)

2) In the Harare area, the drainage pattern is such that the sampling of drainage basins with areas of 45-135 km^2 leads to an uneven distribution of sample sites and leaves large tracts of land not represented by a geochemical sample (Fig. 3). This situation will occur almost anywhere if samples from high order streams draining large catchments are used as the basis for a geochemical survey.

3) Within the drainage basin size range given under (2), the geochemistry of a sample from a high order stream is not always representative of the overall chemistry of the upstream catchment area as measured by the mean, geometric mean or median of samples from low order streams within the basin.

Although it was not possible in the course of this investigation to determine the optimum size of drainage basin for a meaningful low density survey, the results are similar to those of previous workers. Garrett and Nichol (1967) conducted a regional geochemical reconnaissance survey of eastern Sierra Leone at a mean density of 1 stream sediment sample per 180 km^2 but used catchment basins of only up to 40 km^2. They considered that samples from this size of basin "had a composition related to the material within the catchment area" and also found that there was marked similiarity between stream sediment and soil geochemistry. In Zambia, Armour-Brown and Nichol (1970) found that stream sediment samples from catchments of up to 26 km^2 displayed a more constant relationship to the geochemistry of the upstream catchment area than those from larger basins. Moreover, it was not possible to obtain an adequate sample density from drainages with large catchments. Similarly, Reedman and Gould (1970) were able to recognise meaningful geochemical patterns using a density of 1 sample per 195 km^2 based on sampling drainage basins of 26 km^2. They conclude by posing the question of how the results of taking samples from major rivers with upstream catchments of 195 km^2 would compare with their findings. The present study suggests that such sampling of major rivers would not give useful results. All the studies mentioned above refer to African terrains, but the findings are supported by the work of Baldock (1977), who successfully located porphyry copper deposits in the Peruvian Andes using a sample density of 1 per 25 km^2 and suggested that at least in areas of active erosion, reconnaissance geochemistry might rely on sampling medium sized (3rd and 4th order) streams.

The results of this study suggest that there are no short cuts to the provision of reliable regional geochemical data. Sampling of low order streams with small catchment areas will provide a more even distribution of sample sites and more complete coverage than sampling high order channels. Small basins are more likely to be lithologically homogeneous than large basins and the geochemical samples are thus more likely to be truly representative of the upstream catchment. As far as possible the size of catchment and sampling density should be chosen to reflect the scale of lithological change. Large areas of homogeneous geology can be sampled at a lower density than more complex regions. Collecting from smaller basins will lead to larger numbers of samples and the effects of aberrant results on the dataset, whether through sampling or analytical error, are therefore diminished. Small streams also are physically easier to sample than large ones, particularly in regions where flow is perennial.

CONCLUSIONS AND RECOMMENDATIONS

1) The sampling of low order streams provides geochemical data which are closely related to the geochemistry of undisturbed soils in the catchment basement.

2) The geochemistry of sediment samples from high order streams with drainage basins of over 45 km^2 may not be representative of the overall chemistry of the upstream catchment area.

3) Regional geochemical surveys for environmental or exploration purposes should be based on as low an order of stream as possible. It is recommended that, unless further studies

establish the validity of sampling larger catchments, the drainage basin size should not exceed 25 km^2.

4) Wide-spaced sampling for international geochemical mapping should not be based on high order streams with large drainage basins. More reliable results will be obtained from evenly distributed samples from basins of less than 25 km^2.

ACKNOWLEDGEMENTS

The cooperation and assistance of Dr J.L. Orpen, then Director of the Geological Survey Department, Harare, and his Deputy Director, Mr S. Ncube, are gratefully acknowledged. Assistance in Zimbabwe was also received from Drs P. Lowenstein, M. Armstrong, P. Frey and P. Pitfield. Mr O. Chihotu was an invaluable help in the field along with Mr B. Dick. Comment and criticism from Drs J.D Appleton and J.W. Baldock helped improve the text of the report. Funding for the investigation came from the Overseas Development Administration of the Britsh Foreign and Commonwealth Office.

REFERENCES

AGGETT P.J., MILLS C.F, PLANT J.A., SIMPSON P.R., STEVENSON A., DINGWALL-FORDYCE I. and HALLIDAY C.F. 1988. A study of environmental geochemistry and health in north east Scotland. In *Geochemistry and Health. Proceedings of the Second International Symposium* (ed. I.Thornton), pp. 81-91, Science Reviews Ltd., Northwood, England.

APPLETON J.D. and GREALLY K.B. 1992. Environmental Geochemistry R&D Project: a comparison of the trace element geochemistry of drainage sediments and soils in eastern Bolivia. *British Geological Survey Technical Report* WC/92/67.

APPLETON J.D. and RIDGWAY J. 1993. Regional geochemical mapping in developing countries and its application to environmental studies. *Appl. Geochem.* Suppl. Issue No. 2, 103-110.

ARMOUR-BROWN A. and NICHOL I. 1970. Regional geochemical reconnaissance and the location of metallogenic provinces. *Econ. Geol.*, **65**, 312-330.

BALDOCK J.W. 1977. Low-density geochemical reconnaissance in Peru to delineate individual mineral deposits. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **86**, B63-72.

BRITISH GEOLOGICAL SURVEY 1990. *Regional Geochemical Atlas: Argyll.* Keyworth, Nottingham: British Geological Survey.

BRITISH GEOLOGICAL SURVEY 1991. *Regional Geochemistry of the East Grampian Area.* Keyworth, Nottingham: British Geological Survey.

BRITISH GEOLOGICAL SURVEY 1992. *Regional Geochemistry of the Lake District and adjacent areas.* Keyworth, Nottingham: British Geological Survey.

DUNKLEY P.N. 1987. A regional drainage geochemical exploration survey of the Harare area, Zimbabwe. *British Geological Survey Technical Report* MP/87/18.

FORDYCE F.M. and APPLETON J.D. 1994. Draft report on stream sediment, soil and forage chemistry as indicators of cattle mineral status in north-east Zimbabwe. *British Geological Survey Technical Report* WC/94/3R.

FORDYCE F.M., GREEN P.M. and SIMPSON P.R. 1993. Simulation of regional geochemical survey maps at variable sample density. *J. Geochem. Explor.*, **49**, 161-175.

GARRETT R.G. and NICHOL I. 1967. Regional geochemical reconnaissance in eastern Sierra Leone. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **76**, B97-112.

HAWKES. H.E. 1976. The downstream dilution of stream sediment anomalies. *J. Geochem. Explor.* **6**, 345-358.

MCDOWELL L.R., CONRAD J.H., ELLIS G.L. and LOOSLI J.K. (1983) *Minerals for* *grazing ruminants in tropical regions*. Bulletin Dept. Animal Science, University of Florida; Gainesville, Florida.

PLANT J.A. (1983) Regional geochemical maps of the United Kingdom; environmental and economic applications. *The Mercian Geologist (Nottingham)*, **9**, 75-87.

PLANT J.A. and MOORE P.J. (1979) Regional geochemical mapping and interpretation in Britain. *Phil. Trans. Roy. Soc. Lond.* **B288**, 95-112.

PLANT J.A. and STEVENSON, A.G. (1985) Regional geochemistry and its role in epidemiological studies. In: *Trace Elements in Man and Animals TEMA 5* (eds C.F.Mills, I. Bremner and J.K. Chesters), pp. 900-906. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

POTTS P.J., TINDLE A.G. and WEBB P.C. 1992. *Geochemical Reference Material Compositions*. CRC Press: London.

REEDMAN A.J. and GOULD D. 1970. Low sample-density stream sediment surveys in geochemical propspecting: an example from northeast Uganda. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **79**, B246-248.

RIDGWAY J. 1983. IGS Zimbabwe project. Geochemical exploration - results of an orientation survey and organisation of the sampling programme. IGS Overseas Division report 83/14, 68p.

RIDGWAY J. and DUNKLEY P.N. 1988. Temporal variations in the trace element content of stream sediments: examples from Zimbabwe. *Appl. Geochem.*, **3**, 609-621.

RIDGWAY J., APPLETON J.D. and GREALLY K.B. 1991. Variations in regional geochemical patterns - effects of site selection and data-processing algorithms. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **100**, B122-129.

ROSE A.W., HAWKES H.E. and WEBB J.S. 1979. *Geochemistry in Mineral Exploration*. Academic Press: London.

THOMPSON M. and HOWARTH R.J. 1973. The rapid estimation and control of precision by duplicate determinations. *Analyst*, **98**, 153-160.

THORNTON I. (1983). Geochemistry applied to agriculture. In Thornton, I. (Ed.), *Applied Environmental Geochemistry*. (p. 231-266). London: Academic Press.

WATTERS R.A. 1983. Geochemical exploration for uranium and other metals in tropical and subtropical environments using heavy mineral concentrates. *J. Geochem. Explor.*, **19**, 103-124.

WEBB J.S., & ATKINSON W. J. (1965). Regional geochemical reconnaissance applied to some agricultural problems. *Nature (London)*, **208**, 1056.

APPENDIX 1: Tabulated data for the soil/stream sediment comparison

Element values are in ppm except for Fe, which is in weight %

Appendix 1

Sample	Mn	Fe	Zn	Cu	Pb	Co	Ni
<2mm 1	207	0.63%	9	4	5	2	4
<2mm 2	169	0.60%	12	4	5	2	4
<2mm 3	345	0.98%	19	5	12	6	9
<2mm 4	191	0.69%	12	4	5	2	5
<2mm 5	172	0.56%	8	4	5	2	4
<2mm 6	230	1.73%	27	11	14	9	19
<2mm 7	346	0.85%	14	5	14	5	100
<2mm 8	453	0.79%	11	6	16	7	9
<2mm 9	491	1.59%	23	11	23	6	7
<2mm 10	544	0.86%	14	5	18	5	6
<2mm 11	398	1.06%	15	6	5	7	8
<2mm 12	350	0.80%	15	4	23	5	5
<2mm 13	383	0.62%	10	5	12	6	7
<2mm 14	230	0.54%	8	4	10	2	10
<2mm 15	209	0.79%	19	5	15	2	7
<2mm 16	126	0.50%	15	5	15	5	8
<2mm 17	173	0.40%	8	3	5	5	6
<2mm 18	239	0.74%	14	3	5	4	7
<2mm 19	513	0.86%	16	7	26	7	12
<2mm 20	229	0.51%	10	3	5	2	6
<2mm 21	158	1.08%	25	10	22	4	17
<2mm 22	388	1.02%	19	11	13	10	12
<2mm 23	221	0.67%	9	5	10	4	5
<2mm 24	225	0.55%	6	3	5	3	2
<177mic. 1	325	0.96%	16	4	15	6	6
<177mic. 2	339	1.06%	23	5	19	5	7
<177mic. 3	578	1.37%	28	7	28	9	9
<177mic. 4	388	1.16%	21	6	20	8	6
<177mic. 5	351	0.92%	15	6	19	6	9
<177mic. 6	384	2.92%	50	18	32	14	33
<177mic. 7	729	1.52%	27	8	29	10	10
<177mic. 8	1182	1.76%	35	12	47	18	23
<177mic. 9	799	2.24%	43	18	42	14	18
<177mic. 10	1069	1.62%	32	11	48	12	17
<177mic. 11	821	1.73%	24	10	37	13	15
<177mic. 12	734	1.43%	33	8	44	8	11
<177mic. 13	722	1.01%	20	7	22	12	13
<177mic. 14	523	1.07%	15	5	19	9	10
<177mic. 15	397	1.36%	33	8	36	5	12
<177mic. 16	237	0.75%	22	5	17	4	8
<177mic. 17	445	0.90%	18	5	17	11	13
<177mic. 18	515	1.43%	29	11	22	7	46
<177mic. 19.	956	1.47%	26	11	43	18	18
<177mic. 20	386	0.79%	11	4	11	4	7
<177mic. 21	262	1.59%	37	13	38	7	17
<177mic. 22	516	1.22%	20	7	23	12	11
<177mic. 23	322	0.87%	14	3	16	7	6
<177mic. 24	326	0.78%	15	3	13	2	7
<2mm C1/SS/1	66	0.35%	5	3	<10	<3	4
<2mm 2112R	63	0.23%	5	2	<10	<3	234
<2mm 2113R	96	0.68%	17	6	14	2	9
<177 mic C1/SS/1A	271	1.88%	28	7	27	7	13
<177 mic C1/SS/1B	311	1.85%	29	7	30	4	9
<177 mic 2112R	111	0.38%	11	3	21	<3	5
<177 mic 2112RM	186	1.40%	23	6	31	4	9
<177 mic 2113R	155	1.52%	39	13	46	6	13

APPENDIX 2: Tabulated data for the original geochemical survey using low order streams

See TABLE 9 for key to codes for FORM = Lithological Unit and ROCK = Rock Type.
Catchmt = catchment number shown in TABLE 7. Element values are in ppm.

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1141	PF	FV	1	1	17	13	52	8	11	270
1156	AF	MV	2	1	3	6	15	3	7	120
1157	AF	MV	3	1	19	2	20	15	16	630
1158	PF	FV	4	1	11	3	23	10	18	710
1159	PF	FV	5	1	14	3	14	13	20	800
1160	PF	FV	6	1	29	5	77	20	35	1110
1162	HF	PH	7	1	23	3	52	22	45	2200
1163	PF	FV	8	1	31	11	46	25	102	1100
1164	PF	FV	9	1	23	4	32	21	72	1000
1196	PF	FV	10	1	70	0	81	59	100	1630
1197	PF	FV	11	1	170	46	192	14	14	730
1198	PF	FV	12	1	7	4	41	6	6	610
1199	PF	FV	13	1	66	10	110	27	36	1550
1200	PF	FV	14	1	46	7	63	37	40	4500
1201	PF	FV	15	1	22	8	36	9	21	410
1202	HF	PH	16	1	75	3	70	34	88	2900
1203	SE	MI	17	1	71	2	72	41	85	1140
1204	SE	MI	18	1	48	0	48	38	57	8100
1205	PF	FV	19	1	19	5	29	32	34	13400
1206	PF	FV	20	1	14	13	25	18	32	1400
1207	PF	FV	21	1	25	8	124	17	21	440
1208	PF	FV	22	1	23	8	220	12	24	470
1209	PF	FV	23	1	31	10	70	22	50	360
1210	SE	MI	24	1	60	0	62	81	81	27300
1214	CT	GR	25	1	19	12	21	10	20	500
1215	CT	GR	26	1	9	12	18	9	17	380
1216	PF	FV	27	1	105	5	35	27	93	880
1217	PF	FV	28	1	25	4	32	15	19	700
1218	PF	FV	29	1	115	0	39	52	174	1380
1219	PF	FV	30	1	18	4	30	11	28	440
1220	AF	MV	31	1	29	0	27	18	45	460
1221	AF	MV	32	1	36	0	34	54	43	9100
1222	CT	GR	33	1	10	0	21	9	14	320
1223	CT	GR	34	1	24	3	36	12	32	410
1224	AF	MV	35	1	70	11	54	40	75	1580
1225	AF	MV	36	1	25	8	25	8	16	340
1226	AF	MV	37	1	5	3	19	4	9	220
1227	AF	MV	38	1	12	0	18	7	11	300
1228	AF	MV	39	1	38	0	44	20	38	210
1229	CT	GR	40	1	6	13	23	7	11	240
1230	CT	GR	41	1	12	7	15	5	8	140
1246	PF	FV	42	1	30	18	45	48	37	1750
1247	PF	FV	43	1	22	9	37	40	45	1830
1248	PF	FV	44	1	30	3	43	24	32	1340
1249	PF	FV	45	1	12	6	29	9	18	870
1250	PF	FV	46	1	5	5	19	6	12	450
1251	PF	FV	47	1	28	10	43	21	42	1620
1252	PF	FV	48	1	4	6	16	4	9	250
1253	PF	FV	49	1	8	9	19	6	12	430
1254	PF	FV	50	1	8	8	17	7	6	290
1255	CT	GR	51	1	4	5	14	4	8	140
1263	ST	GT	52	1	14	10	36	9	35	340
1265	ST	GT	53	1	3	3	13	5	12	140
1266	ST	GN	54	1	11	6	24	14	35	900
1267	PF	FV	55	1	5	3	16	7	12	280

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1268	PF	FV	56	1	13	4	29	9	25	560
1339	SE	MI	57	1	61	0	91	34	80	1200
1340	SE	MI	58	1	56	0	65	33	86	1230
1341	HF	PH	59	1	66	14	235	12	28	360
1342	PF	FV	60	1	41	10	173	12	31	320
1343	PF	FV	61	1	33	10	100	15	50	270
1344	PF	FV	62	1	22	6	74	17	20	800
1345	PF	FV	63	1	35	7	64	14	29	620
1356	SE	MI	64	1	51	4	69	42	54	5300
1357	PF	FV	65	1	58	5	172	39	46	2320
1358	PF	FV	66	1	61	5	236	45	34	18000
1370	IM	FV	67	1	25	6	50	15	20	660
1038	IM	FV	68	2	170	32	380	88	89	3920
1039	IM	FV	69	2	134	3	124	69	141	3300
1045	AF	MV	70	2	107	2	82	57	89	2530
1046	AF	MV	71	2	111	0	77	55	94	2670
1068	AF	MV	72	2	110	0	70	70	100	2550
1069	AF	MV	73	2	63	0	72	47	77	1100
1070	AF	MV	74	2	53	0	74	54	280	4250
1071	IM	FV	75	2	76	4	143	65	49	4400
1072	AF	MV	76	2	57	0	108	34	82	3650
1073	AF	MV	77	2	48	3	63	42	47	910
1074	AF	MV	78	2	33	4	47	20	26	770
1075	HF	PH	79	2	97	0	71	65	29	1630
1076	AF	MV	80	2	32	12	57	39	80	2800
1077	IM	FV	81	2	70	0	90	30	59	870
1078	IM	FV	82	2	68	6	106	44	36	3150
1080	AF	MV	83	2	98	0	68	44	65	1980
1081	AF	MV	84	2	120	0	85	66	78	3150
1087	AF	MV	85	2	108	0	72	55	100	2360
1088	AF	MV	86	2	92	0	79	32	79	1120
1089	HF	PH	87	2	42	7	65	23	35	1430
1090	AF	MV	88	2	60	3	121	30	71	2800
1102	AF	MV	89	2	57	0	81	34	64	2900
1104	IM	FV	90	2	57	3	75	35	58	2800
1105	IM	FV	91	2	58	29	245	24	46	5200
1106	HF	PH	92	2	43	9	103	24	29	1480
1107	HF	PH	93	2	75	12	168	37	95	1660
1109	CT	GR	94	2	56	5	73	46	58	3100
1110	HF	PH	95	2	55	9	75	20	35	620
1111	SE	MI	96	2	75	4	142	47	60	1750
1112	AF	MV	97	2	67	0	112	67	56	12300
1113	AF	MV	98	2	161	15	290	105	89	6100
1114	AF	MV	99	2	235	35	810	67	83	2150
1115	AF	MV	100	2	95	0	70	25	75	820
1116	AF	MV	101	2	100	0	116	54	81	4710
1140	PF	FV	102	2	30	16	92	12	15	310
1194	HF	PH	103	2	60	0	62	100	59	1080
1195	SE	MI	104	2	62	8	142	72	42	3200
1346	AF	MV	105	2	290	45	850	85	97	3110
1347	AF	MV	106	2	113	0	125	63	110	3170
1348	AF	MV	107	2	105	0	91	68	111	3150
1349	HF	PH	108	2	210	57	265	50	57	1390
1350	HF	PH	109	2	150	13	530	51	57	2820
1351	HF	PH	110	2	81	5	210	65	64	3830

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1352	AF	MV	111	2	90	7	150	45	67	2100
1353	AF	MV	112	2	62	7	106	37	57	2380
1354	AF	MV	113	2	84	0	77	60	77	2800
1355	AF	MV	114	2	101	0	84	53	82	2390
1368	HF	PH	115	2	36	7	57	26	37	1070
1369	HF	PH	116	2	34	8	56	23	36	1820
1374	IM	FV	117	2	21	8	80	10	14	350
1001	IM	FV	118	3	24	10	34	17	32	460
1002	IM	FV	119	3	56	8	52	41	55	3710
1003	IM	FV	120	3	56	0	67	36	68	1980
1011	IM	FV	121	3	205	0	82	39	65	1470
1012	ST	GN	122	3	34	7	42	22	37	1140
1013	TE	FP	123	3	26	15	42	14	24	710
1014	TE	FP	124	3	29	30	44	9	23	310
1015	IM	FV	125	3	23	21	44	18	39	580
1016	IM	FV	126	3	17	10	32	23	29	830
1017	ST	GN	127	3	13	21	28	7	13	320
1018	ST	GT	128	3	7	10	15	3	8	110
1019	ST	GT	129	3	5	13	23	4	3	430
1020	IM	FV	130	3	93	3	54	24	36	1070
1021	IM	FV	131	3	24	6	54	25	47	1350
1022	ST	GT	132	3	6	16	27	6	7	690
1023	IM	FV	133	3	11	7	22	14	22	830
1024	IM	FV	134	3	18	9	40	16	42	810
1025	IM	FV	135	3	7	8	18	3	8	340
1026	IM	FV	136	3	17	9	34	8	27	200
1027	IM	FV	137	3	14	8	36	8	21	200
1028	IM	FV	138	3	13	9	33	7	19	420
1029	IM	FV	139	3	11	9	30	7	15	400
1034	AF	MV	140	3	64	0	67	57	54	5150
1035	AF	MV	141	3	50	0	67	66	65	15100
1036	AF	MV	142	3	19	30	48	23	28	1030
1037	HF	PH	143	3	90	0	79	45	41	2490
1047	AF	MV	144	3	183	0	75	36	68	4900
1048	IM	FV	145	3	45	15	54	25	35	640
1049	IM	FV	146	3	50	6	51	26	43	2550
1050	AF	MV	147	3	90	8	61	48	62	2070
1051	AF	MV	148	3	125	0	66	44	81	2200
1052	ST	GN	149	3	100	0	96	41	74	1800
1053	AF	MV	150	3	85	0	87	71	200	2450
1054	AF	MV	151	3	80	0	92	40	57	2520
1055	AF	MV	152	3	85	3	110	42	71	2000
1056	AF	MV	153	3	95	4	130	61	161	2450
1057	AF	MV	154	3	100	0	95	52	82	3400
1058	AF	MV	155	3	92	19	145	40	54	1880
1059	AF	MV	156	3	71	0	75	46	58	3050
1060	AF	MV	157	3	100	0	84	53	67	2100
1061	IM	FV	158	3	35	13	45	22	38	750
1062	IM	FV	159	3	20	9	41	11	28	620
1063	IM	FV	160	3	9	5	20	7	10	390
1064	IM	FV	161	3	13	7	32	9	16	270
1065	IM	FV	162	3	16	5	33	10	19	440
1066	IM	FV	163	3	14	7	36	11	21	410
1337	IM	FV	164	3	83	8	60	39	41	1150
1338	IM	FV	165	3	19	10	38	10	22	500

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2218	ST	MD	166	4	92	0	55	17	38	650
2219	ST	GT	167	4	53	10	51	20	23	1180
2220	ST	MD	168	4	105	8	61	32	33	1710
2221	ST	GT	169	4	19	4	31	12	11	700
2222	ST	GT	170	4	22	8	49	16	17	1210
2223	ST	GT	171	4	18	12	45	15	21	950
2224	ST	GT	172	4	12	10	29	7	15	350
2225	ST	GT	173	4	26	20	46	11	16	700
2226	ST	GT	174	4	28	17	57	21	25	1310
2257	ST	MD	175	4	20	5	35	9	6	1000
2258	ST	MD	176	4	17	3	26	11	11	810
2260	ST	GT	177	4	56	3	53	40	16	1760
2261	ST	GT	178	4	14	3	23	7	3	550
2262	ST	GT	179	4	30	3	30	13	8	700
2263	ST	GT	180	4	12	0	23	6	5	430
2264	ST	GT	181	4	18	4	30	9	6	550
2265	ST	GT	182	4	5	4	20	4	3	390
2266	ST	GT	183	4	32	3	41	15	10	1050
2267	ST	GT	184	4	49	6	41	17	11	1140
2268	ST	GT	185	4	53	4	41	16	11	820
2269	ST	MD	186	4	60	4	42	16	14	1110
2270	ST	GT	187	4	11	14	41	9	11	730
2271	ST	GT	188	4	14	15	27	3	5	330
2272	ST	MD	189	4	9	16	21	8	12	650
2273	ST	MD	190	4	11	7	21	4	7	330
2274	ST	GT	191	4	20	8	40	15	25	580
2275	ST	GT	192	4	38	7	47	20	50	650
2276	ST	GT	193	4	32	6	34	18	46	450
2277	ST	GT	194	4	36	7	46	20	53	660
2278	ST	GT	195	4	23	4	29	16	34	730
2279	ST	GT	196	4	23	24	41	19	31	860
2280	ST	GT	197	4	7	12	26	4	5	360
2281	ST	GT	198	4	6	15	27	5	5	380
2282	ST	GT	199	4	5	13	27	4	4	400
2283	ST	GT	200	4	11	21	40	5	5	420
2284	ST	GT	201	4	7	16	30	6	8	400
2285	ST	GT	202	4	6	10	20	7	9	350
2286	ST	GT	203	4	18	10	33	13	32	420
2287	ST	GT	204	4	15	10	31	11	27	390
2288	ST	GT	205	4	20	6	36	15	45	500
2289	IM	FV	206	4	50	4	44	25	62	930
2290	IM	FV	207	4	49	7	50	41	51	3300
2291	IM	FV	208	4	36	8	64	43	55	4500
2292	AF	MV	209	4	15	0	20	7	19	260
2293	AF	MV	210	4	54	3	60	41	53	2120
2294	AF	MV	211	4	17	0	20	7	19	220
2295	AF	MV	212	4	24	0	37	23	36	1660
2296	CT	GR	213	4	11	0	18	9	30	300
2297	AF	MV	214	4	4	0	8	4	12	180
2298	AF	MV	215	4	11	0	22	9	14	580
2299	AF	MV	216	4	28	0	43	23	33	1460
2300	AF	MV	217	4	55	0	61	32	49	1900
2301	AF	MV	218	4	37	0	47	46	49	2650
2302	AF	MV	219	4	58	0	61	50	61	1410
1030	AF	MV	220	5	53	0	110	52	50	1960

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1031	AF	MV	221	5	56	0	93	45	56	2120
1032	AF	MV	222	5	62	0	85	30	56	630
1033	IM	FV	223	5	19	29	44	22	26	1020
2216	ST	MD	224	5	97	8	38	25	34	860
2217	ST	GT	225	5	29	5	33	16	36	870
2227	IM	FV	226	5	38	5	50	35	60	2060
2228	ST	GT	227	5	18	14	42	5	14	420
2229	ST	GT	228	5	34	7	46	17	44	780
2230	ST	GT	229	5	27	7	43	18	35	930
2231	CT	GR	230	5	16	5	36	11	33	420
2232	IM	FV	231	5	20	3	46	19	51	670
2233	ST	MD	232	5	58	6	68	27	50	1960
2234	ST	GT	233	5	9	0	21	8	26	260
2235	ST	GT	234	5	26	0	49	27	82	860
2236	IM	FV	235	5	26	0	43	28	51	1000
2237	ST	GT	236	5	41	0	26	17	64	550
2238	ST	GT	237	5	26	0	37	17	50	630
2239	ST	GT	238	5	28	0	30	15	62	630
2240	IM	FV	239	5	29	0	39	22	65	890
2241	IM	FV	240	5	54	15	58	42	66	3470
2242	IM	FV	241	5	54	3	69	33	42	1830
2243	IM	FV	242	5	25	0	39	18	29	680
2244	IM	FV	243	5	57	3	70	29	40	1850
2245	AF	MV	244	5	42	3	53	33	42	1920
2246	AF	MV	245	5	54	0	94	43	56	2360
2247	AF	MV	246	5	54	6	90	37	54	1950
2248	AF	MV	247	5	59	0	96	44	55	3300
2249	IM	MD	248	5	37	0	74	20	21	1640
2250	AF	MV	249	5	83	0	90	41	80	2130
2251	AF	MV	250	5	76	3	86	49	78	2200
2252	AF	MV	251	5	75	11	102	44	79	2650
2253	AF	MV	252	5	34	4	58	23	39	970
2254	AF	MV	253	5	44	5	96	25	47	470
2255	AF	MV	254	5	61	0	74	32	63	1740
2256	AF	MV	255	5	54	0	73	30	57	1820
2303	IM	FV	256	5	21	3	32	20	43	890
2304	AF	MV	257	5	61	7	52	35	69	1370
2305	AF	MV	258	5	43	26	58	61	66	1280
2306	AF	MV	259	5	80	16	81	55	91	3710
2307	AF	MV	260	5	71	16	126	39	66	2710
2308	AF	MV	261	5	68	6	88	45	75	2580
2309	AF	MV	262	5	30	0	63	33	34	4420
2310	AF	MV	263	5	43	9	77	40	52	4750
2311	AF	MV	264	5	60	0	88	31	55	1930
2312	AF	MV	265	5	37	7	59	29	32	3850
2313	AF	MV	266	5	44	0	61	21	63	750
2314	AF	MV	267	5	39	0	92	33	38	1660
2315	AF	MV	268	5	52	0	76	37	90	890
2316	AF	MV	269	5	69	3	76	57	65	3920
2317	AF	MV	270	5	33	0	45	86	58	37500
2322	TE	FP	271	5	50	9	60	54	39	8700
2323	AF	MV	272	5	56	3	78	40	84	2100
2324	AF	MV	273	5	35	5	75	29	81	1660
2325	AF	MV	274	5	82	7	57	54	105	3470
2326	AF	MV	275	5	24	0	49	44	35	4290

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2327	AF	MV	276	5	77	0	96	46	73	2480
2328	AF	MV	277	5	62	4	96	36	47	2180
2329	AF	MV	278	5	40	52	102	23	43	1540
2330	TE	FP	279	5	63	6	47	23	30	1030
2331	TE	MD	280	5	88	5	68	29	57	920
2332	AF	MV	281	5	105	5	76	37	61	1180
2333	TE	FP	282	5	42	8	27	15	28	490
2334	TE	FP	283	5	52	12	40	15	24	470
2335	TE	FP	284	5	13	10	33	13	29	500
2336	TE	MD	285	5	11	10	24	10	19	360
2337	AF	MV	286	5	51	4	68	28	60	3850
2338	AF	MV	287	5	70	3	65	36	62	1920
2339	IM	FV	288	5	21	0	33	22	47	1080
2340	AF	MV	289	5	83	22	82	32	63	1650
2341	AF	MV	290	5	52	20	82	31	70	1640
2342	AF	MV	291	5	59	9	51	36	65	1770
2343	AF	MV	292	5	50	3	78	39	53	2040
2344	AF	MV	293	5	51	5	79	31	47	1340
2345	AF	MV	294	5	67	0	71	37	72	1970
2346	AF	MV	295	5	37	0	71	31	106	2000
2347	AF	MV	296	5	45	3	119	33	91	1750
2348	AF	MV	297	5	50	0	73	31	67	1600
2349	AF	MV	298	5	38	3	58	25	43	1360
2350	AF	MV	299	5	61	4	65	31	57	1760
2351	AF	MV	300	5	37	0	67	31	67	1670
2352	AF	MV	301	5	85	4	85	37	74	2150
2353	AF	MV	302	5	58	4	53	32	58	1390
2354	AF	MV	303	5	41	9	36	20	28	680
2355	AF	MV	304	5	75	0	88	32	71	1740
2356	AF	MV	305	5	80	0	71	33	81	1660
2357	AF	MV	306	5	83	0	75	36	82	1980
2358	AF	MV	307	5	75	0	60	38	78	1650
2359	AF	MV	308	5	62	0	58	29	63	980
2360	AF	MV	309	5	65	0	64	44	75	2000
2361	AF	MV	310	5	85	0	61	51	92	2150
2362	AF	MV	311	5	81	0	66	49	84	2050
2363	AF	MV	312	5	78	0	60	46	85	1900
2365	AF	MV	313	5	60	0	65	31	73	1810
2366	AF	MV	314	5	22	8	40	18	19	1270
2053	ST	MD	315	6	59	23	45	21	15	1250
2054	ST	MD	316	6	61	17	43	17	20	450
2055	CT	GR	317	6	105	6	57	29	32	1550
2056	CT	GR	318	6	25	9	29	11	12	610
2057	CT	GR	319	6	6	30	15	3	7	330
2058	CT	GR	320	6	2	8	11	1	4	120
2059	CT	GR	321	6	4	20	28	1	5	230
2060	CT	GR	322	6	1	13	11	1	2	220
2061	CT	GR	323	6	2	8	12	1	2	140
2062	CT	GR	324	6	3	15	14	2	5	170
2063	CT	MD	325	6	13	0	20	7	12	580
2064	CT	GR	326	6	4	8	14	3	4	180
2065	CT	MD	327	6	31	15	34	9	10	510
2098	CT	GR	328	6	3	8	9	3	3	150
2099	CT	GR	329	6	3	47	21	3	5	400
2100	CT	GR	330	6	3	17	13	2	3	210

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2101	CT	GR	331	6	5	60	21	2	4	380
2102	AF	MV	332	6	61	3	51	28	55	920
2103	CT	GR	333	6	46	22	61	39	43	2210
2105	CT	GR	334	6	6	35	34	3	9	280
2401	ST	GT	335	6	5	16	31	4	6	380
2402	ST	GT	336	6	8	15	40	4	6	380
2403	ST	GT	337	6	17	16	43	7	9	530
2404	ST	GT	338	6	19	11	16	4	15	230
2405	CT	GR	339	6	20	8	14	8	19	230
2406	CT	GR	340	6	5	20	19	4	6	260
2407	CT	GR	341	6	6	16	20	3	6	280
2408	CT	GR	342	6	6	16	22	4	7	370
2409	CT	GR	343	6	6	15	17	4	10	310
2410	ST	GT	344	6	4	14	14	2	6	210
2411	ST	GT	345	6	18	21	32	15	19	680
2412	CT	GR	346	6	5	12	16	3	5	240
2413	CT	GR	347	6	4	12	15	4	4	270
2414	CT	GR	348	6	2	12	13	2	2	360
2415	CT	GR	349	6	6	20	21	6	6	1080
2416	CT	GR	350	6	5	25	19	3	5	370
2418	CT	GR	351	6	4	28	21	2	7	270
2419	ST	GT	352	6	9	23	44	7	30	420
2420	ST	GT	353	6	9	27	30	9	23	540
2421	ST	GT	354	6	9	10	14	3	9	210
2422	CT	GR	355	6	13	24	19	7	16	320
2423	ST	GT	356	6	10	13	15	5	13	230
2424	ST	GT	357	6	7	18	22	5	14	250
2425	ST	GN	358	6	10	19	12	4	10	230
2426	ST	GT	359	6	9	20	34	8	23	470
2427	ST	GT	360	6	7	20	39	10	16	1480
2428	ST	GT	361	6	4	13	19	3	9	320
2429	ST	GT	362	6	28	17	34	15	39	420
2430	ST	GT	363	6	35	20	60	26	41	2000
2438	CT	GR	364	6	8	80	44	4	7	810
2439	CT	GR	365	6	12	40	25	7	10	310
2440	CT	GR	366	6	10	71	30	8	10	420
2106	CT	GR	367	7	14	29	37	8	22	410
2107	CT	GR	368	7	7	31	33	5	10	330
2108	CT	GR	369	7	8	32	24	4	4	320
2109	CT	GR	370	7	1	9	8	2	2	130
2110	CT	GR	371	7	3	17	16	3	5	250
2111	CT	GR	372	7	3	28	9	4	8	220
2112	CT	GR	373	7	2	10	10	2	2	140
2113	CT	GR	374	7	4	10	26	4	13	210
2114	CT	GR	375	7	4	23	133	2	3	300
2115	IM	FV	376	7	7	37	38	5	7	450
2116	CT	GR	377	7	2	47	23	2	3	510
2117	CT	GR	378	7	2	19	19	3	4	230
2118	CT	GR	379	7	7	26	24	5	9	320
2119	CT	GR	380	7	6	39	24	3	6	420
2120	CT	GR	381	7	3	33	23	3	5	330
2121	CT	GR	382	7	6	36	39	10	11	1040
2122	CT	GR	383	7	9	33	51	7	11	940
2123	CT	GR	384	7	2	14	14	2	5	160
2124	CT	GR	385	7	9	53	41	4	12	380

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2125	CT	GR	386	7	16	31	27	6	15	290
2126	CT	GR	387	7	6	15	19	4	12	220
2127	CT	GR	388	7	9	35	30	7	13	550
2128	CT	GR	389	7	3	21	17	2	6	150
2417	CT	GR	390	7	14	12	20	5	13	380
2628	CT	GR	391	7	12	46	41	7	12	860
2629	CT	GR	392	7	14	17	29	13	22	750
2630	CT	GR	393	7	6	18	24	6	11	530
2631	CT	GR	394	7	6	25	32	10	6	760
2632	CT	GR	395	7	14	28	29	16	13	850
2633	CT	GR	396	7	6	10	14	9	13	330
2634	IM	FV	397	7	9	15	41	14	25	500
2635	IM	FV	398	7	6	28	23	6	8	360
2636	IM	FV	399	7	5	47	30	6	7	370
2637	IM	FV	400	7	4	45	31	5	6	390
2638	CT	GR	401	7	5	38	31	6	5	610
2639	CT	GR	402	7	5	28	20	5	8	360
2640	CT	GR	403	7	5	36	28	5	6	520
2641	CT	GR	404	7	8	25	27	8	11	310
2642	CT	GR	405	7	17	16	50	15	52	460
2643	CT	GR	406	7	8	31	34	6	10	480
2622	CT	GR	407	8	5	40	26	6	6	530
2623	CT	GR	408	8	9	50	37	10	7	820
2649	CT	MD	409	8	147	9	70	32	28	1330
2650	CT	MD	410	8	66	29	47	24	12	1250
2651	CT	GR	411	8	61	26	88	22	13	880
2652	CT	MD	412	8	121	22	60	25	22	1130
2653	CT	GR	413	8	6	65	29	3	6	420
2654	CT	GR	414	8	6	230	43	3	4	800
2691	CT	GR	415	8	6	35	29	5	14	680
2692	CT	GR	416	8	4	23	23	1	6	220
2693	CT	GR	417	8	7	40	33	4	6	730
2694	CT	MD	418	8	90	38	62	19	14	1500
2695	CT	MD	419	8	70	23	54	17	11	1400
2696	CT	GR	420	8	4	35	24	2	4	350
2442	CT	GR	421	9	5	13	14	1	2	210
2452	ST	GT	422	9	66	10	46	21	16	950
2453	AF	MV	423	9	11	15	17	7	11	280
2454	AF	MV	424	9	5	26	7	8	2	420
2455	AF	MV	425	9	24	14	24	11	31	310
2614	CT	GR	426	9	15	19	21	6	5	240
2615	CT	GR	427	9	23	17	20	6	5	260
2616	CT	GR	428	9	13	23	21	6	4	280
2617	CT	GR	429	9	9	25	24	4	6	210
2618	CT	GR	430	9	5	26	20	4	4	360
2619	CT	GR	431	9	14	37	26	7	8	310
2620	CT	GR	432	9	6	27	24	6	7	530
2621	CT	GR	433	9	10	50	35	6	12	340
2670	CT	GR	434	9	36	51	44	9	15	390
2678	CT	MD	435	10	72	12	75	24	10	1140
2679	ST	GT	436	10	33	18	35	13	10	840
2680	ST	GT	437	10	37	33	41	10	4	990
2681	ST	GT	438	10	31	25	32	8	5	540
2682	ST	GT	439	10	11	44	27	3	6	260
2683	ST	GT	440	10	5	12	14	2	4	250

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2684	CT	GR	441	10	4	30	23	2	3	350
2685	ST	GT	442	10	3	10	9	3	3	150
2686	ST	GT	443	10	12	20	19	5	24	170
2688	AF	MV	444	10	25	6	24	31	100	1500
2689	AF	MV	445	10	45	19	69	33	97	1360
2690	ST	GT	446	10	9	24	23	11	17	760
2582	CT	GR	447	11	46	17	40	47	90	1650
2583	AF	MV	448	11	46	0	44	44	106	2600
2584	AF	MV	449	11	79	0	88	47	91	1810
2587	PF	FV	450	11	112	0	138	50	84	4540
2588	PF	FV	451	11	139	0	247	73	160	3800
2589	PF	FV	452	11	105	0	163	56	76	2100
2590	AF	MV	453	11	120	0	93	60	92	2100
2591	ST	GN	454	11	34	0	40	26	47	950
2592	ST	GN	455	11	53	6	40	30	61	1260
2593	ST	GN	456	11	16	8	18	12	22	430
2594	PF	FV	457	11	66	0	69	52	130	3550
2595	ST	GN	458	11	46	6	53	32	55	2100
2596	AF	MV	459	11	37	6	83	12	34	500
2597	PF	FV	460	11	48	5	71	26	47	920
2598	ST	GN	461	11	45	18	64	20	42	420
2599	ST	GN	462	11	13	29	23	7	11	270
2600	ST	GN	463	11	34	12	35	13	39	280
2601	ST	GN	464	11	61	14	44	30	50	920
2602	PF	FV	465	11	41	6	66	24	60	880
2603	PF	FV	466	11	81	15	175	43	91	2850
2607	ST	GN	467	11	5	20	19	4	6	230
2608	ST	MD	468	11	76	0	43	27	30	1330
2609	ST	GN	469	11	12	22	24	9	9	560
2610	ST	GN	470	11	5	14	22	4	5	230
2611	ST	GN	471	11	8	22	17	6	25	280
2612	ST	GN	472	11	24	26	26	8	8	260
2613	ST	GN	473	11	5	22	34	7	3	1100
2811	ST	GT	474	12	2	10	12	2	12	440
2812	ST	GT	475	12	2	10	12	2	11	190
2813	ST	GT	476	12	2	20	18	2	6	230
2814	ST	GT	477	12	1	10	8	1	5	70
2815	ST	GT	478	12	1	10	7	1	5	90
2816	ST	GT	479	12	4	10	13	0	6	160
2817	ST	GT	480	12	2	10	11	1	5	180
2818	AF	MV	481	12	35	0	28	24	51	1100
2819	AF	MV	482	12	22	0	26	18	34	980
2820	AF	MV	483	12	56	0	33	19	41	1150
2821	AF	MV	484	12	30	0	30	11	32	930
2822	AF	MV	485	12	41	0	25	21	50	2020
2823	AF	MV	486	12	25	10	20	22	24	1100
2824	ST	GT	487	12	6	10	12	3	13	180
2829	ST	GN	488	12	3	10	11	1	3	150
2830	CT	GR	489	12	70	0	63	16	6	2100
2831	CT	MD	490	12	3	20	20	1	4	650
2832	ST	GT	491	12	2	20	8	2	9	130
2833	ST	GT	492	12	5	20	19	3	14	430
2834	ST	GT	493	12	1	20	16	2	7	330
2835	ST	GT	494	12	1	20	17	2	8	270
2836	CT	GR	495	12	2	20	21	3	12	290

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2843	ST	GT	496	12	3	10	11	1	2	210
2710	ST	GN	497	13	4	20	10	2	1	80
2711	ST	GN	498	13	2	20	10	2	0	100
2712	ST	GN	499	13	3	30	19	2	2	300
2713	ST	GN	500	13	8	30	43	5	5	800
2714	ST	GN	501	13	2	50	18	2	0	300
2715	CT	GR	502	13	31	20	41	9	10	670
2716	CT	GR	503	13	6	20	21	3	2	320
2717	CT	GR	504	13	3	40	33	3	2	400
2718	CT	GR	505	13	48	30	52	19	11	730
2724	ST	GN	506	13	2	10	8	4	2	120
2725	ST	GN	507	13	6	20	15	6	13	190
2729	ST	GN	508	13	3	20	14	4	3	130
2730	ST	GN	509	13	3	20	12	5	2	210
2731	CT	GR	510	13	11	20	20	7	0	510
2765	ST	GN	511	13	3	20	16	3	4	290
2766	ST	GN	512	13	1	20	15	1	3	210
2767	ST	GN	513	13	0	10	12	1	4	210
2768	ST	GN	514	13	2	30	21	1	4	500
1780	CT	GR	516	15	11	30	17	5	6	300
1781	CT	GR	517	15	24	11	31	8	16	380
1782	ST	GT	518	15	4	25	14	1	4	200
1783	CT	GR	519	15	11	24	21	6	8	330
1784	ST	GT	520	15	4	7	18	3	8	160
1785	CT	GR	521	15	16	22	24	7	11	520
1786	CT	GR	522	15	5	13	67	3	4	2080
1787	CT	GR	523	15	2	14	18	1	1	280
1788	CT	GR	524	15	4	12	25	3	4	230
1789	ST	GT	525	15	4	11	9	2	2	160
1790	CT	GR	526	15	4	12	19	2	3	210
1791	CT	GR	527	15	4	21	12	6	3	270
1800	CT	GR	528	15	4	24	17	4	5	130
1801	CT	GR	529	15	16	21	25	9	22	240
1802	CT	GR	530	15	11	30	25	6	8	210
1803	CT	GR	531	15	5	28	15	5	8	170
1804	CT	GR	532	15	5	23	22	4	6	310
1805	CT	GR	533	15	11	12	29	8	6	340
1806	CT	GR	534	15	2	11	14	2	2	310
1807	CT	GR	535	15	7	30	19	4	2	350
1808	CT	GR	536	15	4	14	13	6	6	200
1809	CT	GR	537	15	4	17	26	6	4	330
1810	CT	GR	538	15	11	15	47	2	3	190
1811	CT	GR	539	15	4	20	18	2	4	190
1812	CT	GR	540	15	2	17	11	1	2	60
1813	CT	GR	541	15	6	20	17	3	11	80
1828	CT	GR	542	15	2	24	15	1	2	120
1829	CT	GR	543	15	4	15	17	1	2	160
1830	CT	GR	544	15	3	20	19	5	7	360
1831	CT	GR	545	15	4	45	34	3	3	480
2837	CT	GR	546	15	1	30	7	1	2	200
2838	CT	GR	547	15	1	10	4	0	3	100
2839	ST	GN	548	15	6	20	7	2	6	90
2840	CT	GR	549	15	2	30	8	0	3	130
1775	CT	GR	550	16	10	33	26	6	9	310
1776	CT	GR	551	16	4	28	13	1	5	180

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1777	CT	GR	552	16	4	12	15	1	3	250
1778	CT	GR	553	16	8	19	14	2	4	160
1779	ST	GT	554	16	3	12	12	2	4	260
2578	AF	MV	555	16	20	9	30	15	38	820
2579	PF	FV	556	16	26	0	39	67	54	1640
2580	AF	MV	557	16	11	0	22	10	24	570
2581	AF	MV	558	16	61	0	44	38	96	910
2844	ST	GT	559	16	2	10	11	1	2	210
2845	ST	GT	560	16	3	10	13	1	7	180
2846	ST	GT	561	16	2	10	9	0	4	160
2847	ST	GT	562	16	5	10	15	2	7	100
2848	ST	GT	563	16	3	10	14	1	5	230
2849	ST	GT	564	16	9	10	12	1	11	80
2850	ST	GT	565	16	4	10	5	0	6	80
2851	AF	MV	566	16	42	0	21	9	45	310
2852	ST	GT	567	16	3	10	10	0	2	200
2853	ST	GT	568	16	2	10	6	1	3	100
2859	ST	GT	569	16	3	10	5	1	3	70
2860	ST	GT	570	16	4	20	23	2	4	260
2861	ST	GT	571	16	1	10	11	0	3	240
2862	ST	GT	572	16	4	20	21	1	12	210
2863	ST	GT	573	16	2	20	8	1	7	150
2864	ST	GT	574	16	3	10	8	1	4	110
2865	ST	GT	575	16	2	10	7	2	2	210
2912	AF	MV	576	16	93	0	71	32	75	1290
2913	AF	MV	577	16	73	0	60	51	93	1840
2916	AF	MV	578	16	96	0	74	68	106	2400
2917	AF	MV	579	16	26	0	37	26	57	720
2918	AF	MV	580	16	70	10	354	45	128	1500
2919	AF	MV	581	16	68	0	58	36	80	1160
2920	AF	MV	582	16	74	0	53	37	174	1330
2921	AF	MV	583	16	76	0	47	66	104	2050
2922	AF	MV	584	16	81	0	28	50	88	1540
2923	AF	MV	585	16	26	0	27	34	93	1150
2924	AF	MV	586	16	53	0	44	70	130	2000
2931	AF	MV	587	16	154	0	177	53	150	1300
2938	AF	MV	588	16	9	0	13	7	10	310
2939	ST	GT	589	16	12	0	14	5	3	240
2940	ST	GT	590	16	8	10	16	6	8	200
2941	ST	GT	591	16	10	0	17	7	11	200
2942	ST	GT	592	16	2	10	10	4	4	170
2943	AF	MV	593	16	24	10	27	18	34	670
2944	AF	MV	594	16	73	0	53	40	100	1000
2976	AF	MV	595	16	86	0	49	32	103	940
2977	AF	MV	596	16	16	0	18	11	88	330
2978	ST	GT	597	16	2	10	19	0	4	180
2979	ST	GT	598	16	0	10	11	0	3	70
1741	CT	GR	599	17	21	7	41	11	20	600
1742	CT	GR	600	17	13	13	32	5	3	450
1743	AF	MV	601	17	13	12	29	6	10	340
1744	AF	MV	602	17	12	11	28	7	8	500
1745	AF	MV	603	17	28	23	75	25	30	1610
1746	AF	MV	604	17	86	4	54	35	88	1310
1747	ST	GT	605	17	3	15	15	4	4	170
1758	ST	GT	606	17	14	9	17	22	18	800

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1759	AF	MV	607	17	58	0	49	35	61	2150
1761	ST	GT	608	17	7	4	19	11	12	370
1762	ST	GT	609	17	15	8	12	10	17	300
1763	ST	GT	610	17	22	16	25	14	27	400
1764	ST	GT	611	17	9	7	23	13	8	860
1765	ST	GT	612	17	9	8	15	7	17	310
1766	ST	GT	613	17	12	7	19	12	14	710
1767	ST	GT	614	17	16	5	17	13	22	420
1768	AF	MV	615	17	110	3	55	42	97	1830
1769	AF	MV	616	17	83	3	45	58	173	1710
1770	AF	MV	617	17	115	5	60	31	149	880
1771	AF	MV	618	17	26	13	20	17	41	620
1772	AF	MV	619	17	12	17	12	10	23	380
1773	AF	MV	620	17	19	18	19	18	33	800
1774	AF	MV	621	17	23	8	22	13	33	470
2570	AF	MV	622	17	47	0	33	33	63	1400
2571	AF	MV	623	17	63	107	64	39	84	2900
2925	AF	MV	624	17	27	0	23	23	51	1080
2926	AF	MV	625	17	75	130	195	88	183	1840
2927	AF	MV	626	17	43	20	58	35	68	1300
2928	AF	MV	627	17	42	70	74	41	94	520
2929	AF	MV	628	17	54	260	102	18	120	240
2930	AF	MV	629	17	139	0	82	75	85	2900
2932	AF	MV	630	17	57	0	37	26	110	560
2933	AF	MV	631	17	41	0	28	37	250	800
2934	AF	MV	632	17	52	10	49	30	97	1430
2935	AF	MV	633	17	59	0	44	42	125	1150
2936	AF	MV	634	17	88	0	54	50	100	1620
2937	AF	MV	635	17	21	0	23	21	68	650
2945	AF	MV	636	17	36	0	26	15	95	320
2946	AF	MV	637	17	40	0	30	36	188	1000
2947	AF	MV	638	17	102	0	84	43	96	1000
2948	AF	MV	639	17	20	0	19	22	49	500
2949	AF	MV	640	17	115	0	78	43	96	1170
2950	AF	MV	641	17	74	0	61	90	110	3020
2951	AF	MV	642	17	102	0	65	89	127	2900
2952	AF	MV	643	17	63	0	48	63	95	2050
2953	AF	MV	644	17	50	0	46	36	82	830
2954	AF	MV	645	17	105	0	60	45	102	1500
2955	AF	MV	646	17	77	0	54	31	91	1320
2956	AF	MV	647	17	123	0	63	58	136	2300
2957	AF	MV	648	17	110	0	57	61	104	2400
2958	AF	MV	649	17	107	0	62	60	81	2150
2959	AF	MV	650	17	102	0	49	57	100	2110
2960	AF	MV	651	17	41	0	37	40	60	680
2961	AF	MV	652	17	12	10	25	12	13	300
2962	AF	MV	653	17	57	0	36	31	65	1040
2963	AF	MV	654	17	112	0	54	73	127	2400
2964	AF	MV	655	17	7	10	25	4	6	690
2965	AF	MV	656	17	2	0	11	4	4	90
2966	AF	MV	657	17	47	0	63	23	38	1050
2967	AF	MV	658	17	98	0	55	65	134	2450
1717	PF	FV	659	18	42	6	100	39	62	1850
1718	SE	MI	660	18	65	7	168	29	45	1750
1719	PF	FV	661	18	31	0	88	89	62	5200

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1720	SE	MI	662	18	75	7	196	27	60	1070
1721	AF	MV	663	18	84	0	105	20	59	1240
1722	AF	MV	664	18	37	0	100	21	38	1160
1730	PF	FV	665	18	12	7	31	6	15	5600
1731	PF	FV	666	18	15	9	56	10	23	2750
1732	PF	FV	667	18	25	7	53	13	30	1410
1733	PF	FV	668	18	14	2	32	11	14	1320
1734	PF	FV	669	18	7	15	28	9	18	1220
1735	PF	FV	670	18	11	26	25	4	23	150
1736	AF	MV	671	18	14	0	21	8	18	250
1737	AF	MV	672	18	15	6	19	10	18	310
1749	ST	GT	673	18	2	7	31	30	25	1650
1750	ST	GT	674	18	25	12	46	20	30	1000
1751	ST	GT	675	18	13	8	31	11	18	520
1752	ST	GT	676	18	14	18	72	20	31	1150
1753	ST	GT	677	18	15	6	37	14	21	920
1754	ST	GT	678	18	17	8	21	10	18	230
1755	AF	MV	679	18	82	0	110	38	67	2500
1756	AF	MV	680	18	47	4	62	20	44	1220
1757	AF	MV	681	18	80	0	89	31	69	2900
1760	AF	MV	682	18	68	0	35	24	60	950
2018	HF	PH	683	18	17	7	42	14	23	530
2019	SE	MI	684	18	49	5	146	25	60	1040
2020	PF	FV	685	18	31	11	83	17	56	1380
2021	PF	FV	686	18	29	12	78	14	34	1110
2022	SE	MI	687	18	68	5	115	26	51	1290
2023	AF	MV	688	18	68	0	76	30	64	2600
2024	AF	MV	689	18	71	0	85	29	58	1960
2025	AF	MV	690	18	120	0	142	35	73	2200
2026	AF	MV	691	18	65	0	69	28	63	1840
2027	AF	MV	692	18	56	0	61	27	67	2020
2028	AF	MV	693	18	90	8	160	27	58	1620
2029	HF	PH	694	18	78	0	93	21	61	1640
2030	PF	FV	695	18	67	4	84	14	55	840
2031	PF	FV	696	18	73	8	108	22	57	1810
2032	PF	FV	697	18	29	0	42	19	25	1790
2555	PF	FV	698	18	36	10	31	26	34	1520
2556	PF	FV	699	18	69	9	106	26	61	1600
2557	PF	FV	700	18	62	0	75	79	82	9200
2558	PF	FV	701	18	62	0	56	32	68	1500
2559	HF	PH	702	18	75	0	76	43	76	2300
2560	HF	PH	703	18	68	0	56	44	76	1510
2968	AF	MV	704	18	95	0	54	58	95	2400
2969	AF	MV	705	18	71	0	55	39	69	2300
2970	AF	MV	706	18	99	0	54	60	117	2700
2971	AF	MV	707	18	85	0	74	120	92	10400
1704	HF	PH	708	19	44	84	200	77	76	35000
1705	PF	FV	709	19	43	11	81	24	30	1100
1706	PF	MD	710	19	53	7	125	33	26	2040
1707	PF	FV	711	19	11	5	28	7	10	490
1708	PF	FV	712	19	22	9	64	29	27	1570
1709	PF	FV	713	19	29	5	106	38	25	1530
1710	PF	MD	714	19	54	10	57	25	23	1620
1711	PF	FV	715	19	17	8	38	10	15	480
1712	PF	FV	716	19	30	10	62	17	22	790

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1713	PF	FV	717	19	35	4	71	20	32	690
1714	HF	PH	718	19	90	10	206	44	68	3100
1715	PF	FV	719	19	45	8	95	35	48	2950
1716	PF	FV	720	19	42	5	96	52	69	870
1723	PF	FV	721	19	20	14	37	15	28	1440
1724	PF	FV	722	19	17	7	51	34	28	2950
1725	AF	MV	723	19	48	7	196	31	39	2350
1726	AF	MV	724	19	38	22	95	17	42	1970
1727	PF	FV	725	19	21	15	31	13	14	680
1728	CT	GR	726	19	12	23	32	6	10	1760
1729	PF	FV	727	19	12	16	38	8	11	570
1738	CT	GR	728	19	9	24	30	8	6	740
1739	CT	GR	729	19	60	21	30	15	19	350
1740	CT	GR	730	19	9	19	25	5	9	340
2001	AF	MV	731	19	71	6	91	25	32	440
2002	AF	MD	732	19	33	6	74	27	26	920
2003	AF	MD	733	19	81	0	65	90	36	6500
2004	AF	MD	734	19	52	4	219	18	26	1200
2005	AF	MD	735	19	23	6	47	13	27	1270
2006	AF	MD	736	19	49	0	57	52	24	13000
2007	AF	MD	737	19	30	0	56	19	14	1980
2008	HF	PH	738	19	18	6	39	8	13	530
2009	HF	PH	739	19	14	5	30	5	6	380
2010	PF	FV	740	19	9	4	20	9	7	1100
2011	PF	FV	741	19	35	0	75	20	63	1580
2012	PF	FV	742	19	20	10	45	14	28	1490
2013	PF	FV	743	19	11	3	30	9	25	440
2014	PF	FV	744	19	10	4	21	5	7	320
2015	PF	FV	745	19	12	4	33	14	30	640
2016	PF	FV	746	19	12	4	36	8	13	920
2017	PF	FV	747	19	23	8	45	10	42	590
2066	PF	FV	748	19	24	7	60	10	39	530
2067	PF	FV	749	19	17	0	43	15	22	1020
2068	PF	FV	750	19	59	2	46	27	28	1180
2069	PF	FV	751	19	41	4	34	13	17	590
2070	PF	FV	752	19	11	4	21	8	10	420
2071	HF	PH	753	19	55	10	146	15	31	360
2072	PF	FV	754	19	115	16	173	30	60	820
2073	ST	GT	755	19	53	7	42	21	16	600
2074	ST	GT	756	19	46	22	530	20	34	1120
2075	ST	GT	757	19	24	15	36	6	6	390
2076	ST	GT	758	19	52	10	68	20	49	770
2077	ST	GT	759	19	41	8	225	30	46	2700
2078	AF	MD	760	19	49	9	65	19	48	1120
2079	AF	MD	761	19	57	7	84	34	44	1640
2080	AF	MD	762	19	73	12	85	38	61	1940
2081	AF	MV	763	19	95	18	102	33	79	1400
2082	AF	MV	764	19	81	8	82	36	78	1820
2083	AF	MV	765	19	81	18	85	25	57	620
2084	ST	GT	766	19	113	36	108	37	65	1040
2085	ST	GT	767	19	26	3	44	15	69	770
2086	AF	MV	768	19	92	10	77	45	71	2600
2087	AF	MV	769	19	97	6	114	72	100	3200
2088	AF	MV	770	19	110	5	92	41	87	860
1183	HF	PH	771	20	39	7	37	19	31	970

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1184	HF	PH	772	20	69	24	70	168	105	8400
1185	PF	MD	773	20	45	11	58	45	49	1440
1186	HF	PH	774	20	26	11	31	13	21	520
1187	HF	PH	775	20	70	4	48	18	35	450
1188	HF	PH	776	20	37	0	62	165	50	3700
1189	HF	PH	777	20	90	18	116	41	69	820
1335	HF	PH	778	20	48	4	41	21	23	1060
1336	HF	PH	779	20	101	13	114	26	67	310
2318	AF	MV	780	20	64	9	41	29	19	1300
2319	ST	GT	781	20	48	8	39	22	25	930
2320	ST	GT	782	20	22	13	23	9	12	630
2321	ST	GT	783	20	36	12	34	14	16	640
2364	AF	MV	784	20	62	14	60	33	71	1450
2367	AF	MV	785	20	50	9	43	17	28	980
2368	AF	MV	786	20	41	5	34	18	14	1210
2369	AF	MV	787	20	47	14	83	11	32	660
2370	HF	PH	788	20	58	10	82	24	35	640
2371	HF	PH	789	20	66	12	66	36	53	1440
1866	CT	GR	790	21	7	25	31	6	5	800
1867	CT	GR	791	21	4	19	13	1	1	210
1868	CT	GR	792	21	2	12	10	2	2	120
1870	CT	GR	793	21	5	18	13	3	3	110
1872	CT	GR	794	21	1	6	9	1	2	110
1873	CT	GR	795	21	3	17	17	5	3	390
1874	CT	GR	796	21	13	35	35	5	7	230
1875	CT	GR	797	21	11	30	32	6	10	510
1876	CT	GR	798	21	11	32	21	5	7	360
1877	CT	GR	799	21	2	15	11	3	3	250
1502	TE	FP	800	22	51	8	44	27	41	2200
1521	HF	PH	801	22	36	37	159	28	40	2200
1522	HF	PH	802	22	23	23	76	18	28	1600
1523	PF	FV	803	22	30	13	59	21	84	670
1524	PF	FV	804	22	61	22	75	40	53	1400
1525	IM	FV	805	22	71	9	43	20	20	930
1526	TE	FP	806	22	51	10	45	22	40	890
1527	HF	PH	807	22	23	9	26	13	28	640
1528	HF	PH	808	22	26	12	118	18	34	2200
1552	PF	MD	809	22	35	7	26	15	12	1090
1701	HF	PH	810	22	52	8	40	10	36	340
1702	HF	PH	811	22	14	18	53	16	18	2340
1703	HF	PH	812	22	13	10	25	8	17	340
1503	TE	FP	813	23	69	9	43	22	31	940
1504	PF	MD	814	23	38	21	52	45	150	1780
1505	PF	MD	815	23	71	7	42	41	34	2760
1506	PF	MD	816	23	107	11	73	20	56	420
1546	ST	GT	817	23	16	27	30	7	15	680
1547	ST	GT	818	23	77	27	31	5	23	100
1548	ST	GT	819	23	38	11	52	17	31	810
1549	HF	PH	820	23	28	6	34	11	25	460
1550	PF	FV	821	23	49	10	55	30	28	1830
1551	PF	FV	822	23	46	9	39	25	46	1680
1554	PF	FV	823	23	22	4	40	16	14	810
1555	PF	FV	824	23	29	8	71	18	22	670
1635	PF	MD	825	23	50	6	38	21	23	1140
1636	TE	FP	826	23	59	11	48	16	29	720

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1637	TE	FP	827	23	93	11	59	45	46	1970
1310	PF	FV	828	24	24	0	33	12	23	520
1311	ST	GT	829	24	20	11	24	13	24	410
1312	ST	GT	830	24	25	10	34	12	34	360
1313	ST	GT	831	24	25	8	31	11	31	520
1314	ST	GT	832	24	40	9	59	27	60	1110
1315	ST	GT	833	24	13	5	27	10	17	320
1316	PF	FV	834	24	15	6	30	15	26	840
1317	ST	GT	835	24	23	7	47	11	29	420
1318	ST	GT	836	24	31	9	50	15	29	360
1319	ST	GT	837	24	18	8	36	10	20	320
1320	ST	GT	838	24	26	7	30	12	43	350
1321	PF	FV	839	24	17	7	35	10	29	360
1322	ST	GT	840	24	15	8	25	10	22	200
1323	PF	FV	841	24	16	7	30	10	20	230
1324	ST	GT	842	24	24	5	33	13	22	380
1325	ST	GT	843	24	17	6	29	20	22	830
1327	ST	GT	844	24	14	8	28	8	16	290
1328	ST	GT	845	24	21	16	35	10	24	300
1329	ST	GT	846	24	20	38	26	28	25	1630
1507	PF	FV	847	24	60	6	66	40	40	2480
1508	HF	PH	848	24	56	8	44	17	37	710
1509	ST	GT	849	24	28	14	40	19	27	960
1510	ST	GT	850	24	31	15	40	13	27	410
1511	ST	GT	851	24	33	9	36	14	36	320
1515	ST	GT	852	24	30	8	29	16	29	630
1516	ST	GT	853	24	12	7	17	7	14	210
1517	ST	GT	854	24	24	7	19	4	13	110
1519	PF	FV	855	24	51	7	49	17	45	840
1512	ST	GT	856	25	28	17	38	11	20	610
1513	ST	GT	857	25	16	15	22	16	21	510
1514	HF	PH	858	25	31	9	44	26	56	920
1518	ST	GT	859	25	26	17	29	11	37	360
1537	PF	MD	860	25	22	6	31	18	23	830
1538	PF	FV	861	25	29	6	26	13	32	510
1539	PF	FV	862	25	28	9	37	20	29	630
1540	CT	GR	863	25	14	21	25	8	9	270
1541	CT	GR	864	25	24	8	37	26	47	770
1542	CT	GR	865	25	28	10	43	18	48	270
1529	PF	FV	866	26	28	8	27	15	73	430
1530	PF	FV	867	26	14	9	24	14	31	350
1531	ST	GT	868	26	18	8	25	14	45	350
1532	CT	GR	869	26	21	10	29	10	27	220
1533	PF	FV	870	26	19	9	31	17	30	410
1534	PF	FV	871	26	20	5	33	18	30	490
1535	PF	FV	872	26	30	11	31	14	65	300
1536	PF	FV	873	26	29	10	38	25	110	1200

British Geological Survey

TECHNICAL REPORT WC/94/55
Overseas Geology Series

A COMPARISON OF HIGH AND LOW DENSITY GEOCHEMICAL SAMPLING IN ZIMBABWE : APPLICATION TO ENVIRONMENTAL STUDIES

J RIDGWAY, R C JONES & K B GREALLY

A Report prepared for the Overseas Development Administration under the ODA/BGS Technology Development and Research Programme, Project 91/16

ODA classification :
Subsector: Geoscience
Theme: G2 - Identify and ameliorate mineral-related and other geochemical toxic hazards
Project title: Environmental geochemical mapping
Reference number: R5547

Bibliographic reference :
Ridgway J and others 1994. A comparison of high and low density geochemical sampling in Zimbabwe : application to environmental studies
BGS Technical Report WC/94/55

Keywords :
Zimbabwe; geochemistry; sampling density; stream sediments; soils; environment

Front cover illustration :
Soil sampling for soil/stream sediment comparison study

Keyworth, Nottingham, British Geological Survey, 1994

EXECUTIVE SUMMARY

Regional geochemical surveying based on the collection and analysis of sediment samples from streams with small drainage basins (<10 km^2) has been shown in several studies, largely in temperate regions, to provide valuable information for environmental purposes as well as being an important mineral exploration tool. In particular, geochemistry can help delineate regions where trace element excesses or deficiencies might have adverse effects on human, animal or crop health. This report describes two studies designed to examine specific aspects of environmental geochemistry in the seasonally wet/dry climate of the Harare region of Zimbabwe. The work was carried out as part of a wider study of the application of regional geochemical mapping to environmental problems (Project R5547, 91/16, Environmental Geochemical Mapping) funded by the Overseas Development Administration as part of the UK programme of aid to the developing countries and carried out under the ODA/BGS Technology Development and Research Programme.

The first study addressed the premise that the value of drainage geochemical data for environmental studies depends on there being a positive correlation between drainage and soil geochemistry. The relationship between soil and drainage geochemistry in areas with relatively high background levels of trace elements such as Cu, Pb, Zn, Ni and Co has been examined in other investigations forming part of Project R5547 and the work in Zimbabwe concentrated on this relationship in an area of low trace element levels. A drainage basin of 2-3 km^2 developed on granitic gneisses was chosen for the study. The subsistence farming in the basin meant that the chemistry of the soils was unlikely to have been affected by large scale additions of fertilisers or animal feed supplements.

The results showed that the correlation between soil and stream sediment geochemistry generally was good for the fine (<177 µm) fractions of the two media, but less satisfactory for the coarser (<2 mm) fraction, although the low trace element levels expected from the granite gneiss terrain were still evident in both soil and sediment. This feature is probably related to the winnowing of fine, trace element bearing particles from the stream sediment during periods when the normally dry streams are flowing. This leads to a dilution of the trace element content which can be reduced by the selection of a narrower particle size range. It is concluded that stream sediments are a suitable sampling medium for environmental studies because they provide a reliable indicator of trace element concentrations in soils, which are of particular interest to agronomists and others, while being quicker and cheaper to collect for any given area.

The second study examined whether the time and costs of regional geochemical surveying for environmental purposes can be reduced by sampling streams with large catchment areas. This has clear advantages for developing countries, especially for those where geological mapping is not well advanced. The Harare region was sampled at a relatively high density of 1 sample per 2.7 km^2 in a geochemical survey carried out between 1982 and 1986. Sixteen sites from this survey were resampled and the respective stored samples were retrieved and reanalysed with the new samples. Samples were also taken from larger, streams/rivers with drainage basins of between 45 and 135 km^2 to give low density coverage of the area.

Absolute concentration levels in original and new analyses on stored samples were substantially different. However, good correlation was shown between the two datasets

(Pearson correlation coefficients of >0.9 except for Pb, >0.8) and also between original analyses and analyses of new samples from resampled sites (all >0.8). Patterns of variation were thus similar and indicated that analytical differences arising from the analyses being carried out in different laboratories using slightly different methodologies, and sampling errors due, for instance, to temporal variation, were unlikely to have a large influence on any comparison based on correlation between the original high density and new low density surveys.

If low density sampling is to be of value, the results of low density geochemical surveys should display similar patterns of variation to those of high density surveys. For each large catchment basin represented by a drainage sample, estimates of the overall composition of the catchment were calculated by computing the arithmetic and geometric means and median value of the samples collected during the original high density survey. The absolute concentration levels in the original high and later low density survey were expected to be different because of the differences found between original analyses and new analyses from resampled sites. However, the correlation between estimates of the overall basin geochemistry and the geochemistry of the samples from high order drainage channels needs to be good if samples from high order streams are to be of use in regional geochemical surveys. Thus the drainage basins having the higher average composition, as calculated from low order stream samples, should also display the higher levels in the survey based on high order streams.

The results of the study demonstrate that the correlation between the geochemistry of high order stream samples and estimates of average concentrations for the large catchment basins is generally poor (Mn: 0.26-0.29, Zn: 0.43-0.60, Cu: 0.53-0.72, Pb: 0.85-0.88, Co: 0.59-0.61, Ni: 0.22-0.37). It is particularly bad for Mn and Ni, where the correlation coefficients are not significant at the 99% level. This poor level of correlation casts doubts on the usefulness of low density geochemical surveys based on the sampling of high order streams or rivers. The reasons for the poor correlation are not clear, but one important factor is undoubtably the inhomogeneity in the geology of the large drainage basins. Rock types which are present in only small quantities overall in a large basin can have a significant influence on the chemical composition of the representative stream sediment sample if they occur close to the sample site. Small drainage basins have more uniform geology and are thus less affected by such factors. Samples from the large (45 to 135 km^2) drainage basins used in this study did not yield data which matched the higher density survey results and so cannot be used to provide useful and reliable data for regional environmental geochemical surveys. Further work might reveal an optimum catchment size for low density geochemical reconnaissance programmes.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The investigation reported here is part of a wider study of the application of regional geochemical mapping to environmental problems (Project R5547, 91/16, Environmental Geochemical Mapping) funded by the Overseas Development Administration as part of the U.K. programme of aid to the developing countries and carried out under the ODA/BGS Technology Development and Research Programme. Field studies were conducted in Zimbabwe, where the work was supported by the Geological Survey Department of the Ministry of Mines.

Although geochemical mapping based on the collection and chemical analysis of drainage sediments (normally at relatively high densities of 1 sample per 1-5 km^2) was initially used for mineral exploration purposes, it is increasingly recognised that the techniques can be used to provide data that are valuable for environmental studies, with particular importance in the fields of human, animal and crop health (Aggett *et al.*, 1988; British Geological Survey, 1990. 1991, 1992; Plant and Moore, 1979; Plant, 1983; Plant and Stevenson, 1985; Thornton, 1983; Webb and Atkinson, 1965). The value of drainage geochemical data for many environmental studies depends on the relationship between drainage and soil geochemistry. Appleton and Greally (1992) discuss the stream sediment-soil relationship in a report describing work which also forms part of Project R5547 and conclude that there is a broad correlation between soil and stream sediment geochemistry and that regional drainage geochemical maps compare well with soil maps for identifying areas where trace element deficiencies or excesses may occur. Stream sediment-soil relationships have been investigated in the course of the present study to help confirm this correlation in the Zimbabwean environment.

Many parts of the earth's land surface, particularly in the developing countries, have not been covered by regional geochemical surveys and the cost-effective provision of the important data stemming from such surveys is seen as a high priority by geoscientists throughout the world. To this end, Project 259 of the International Geological Correlation Programme (IGCP 259, now continuing as IGCP 360, International Geochemical Mapping), has been concerned with promoting regional geochemical mapping and establishing guidelines for the surveying of unmapped regions. The costs and time necessary for geochemical surveying would be reduced if it could be demonstrated that low-density sampling was capable of producing data which were broadly compatible with those provided by the relatively high density surveys through which the links with environmental factors were established. Ridgway *et al.* (1991) and Fordyce *et al.* (1993) showed that the mathematical simulation of low density sampling by the reduction of data from high density drainage sediment surveys (based on collection from low order streams) could yield meaningful geochemical patterns at densities as low as 1 sample per 500 km^2. The major part of the present study is concerned with examining whether the collection and analysis of samples from high order streams/rivers, with drainage basins of between 50 and 150 km^2, would similarly give rise to geochemical results which were comparable with those from a previous high density survey. The findings have relevance for all developing countries where geochemical survey coverage is incomplete and also provide an input to IGCP 360.

PROJECT OBJECTIVES

The study reported here addressed two specific objectives of Project R5547:

1) The comparison of drainage sediment and soil as sampling media for environmental geochemical surveys.
2) Assessment of the relative usefulness of high and low density geochemical sampling for environmental geochemistry purposes.

Objective 1 had been largely met by the work reported in Appleton and Greally (1992) and the present study, designed to complement the earlier work, was confined to the examination of soil-stream sediment relationships in a small drainage basin where concentrations of Co, Cu, Mn, Ni, Pb and Zn were expected to be low because of the granitic gneiss bedrock.

Objective 2 was met by comparing the chemical composition of high order drainage samples from the Harare area of Zimbabwe, representing drainage basins of 50-150 km^2, with an average composition for each basin calculated from low order stream samples collected during an original high density geochemical survey. Because chemical analyses were to be performed in a different laboratory to that of the original survey and temporal variations in stream sediment geochemistry have been recorded in the study region (Ridgway and Dunkley, 1988), the investigation addressed three particular topics:

1) Comparison between original analyses and reanalysis of splits of original samples stored in the Geological Survey Department, Zimbabwe, to assess the compatibility of the original and new analytical results.
2) Comparison of both original and new analyses of stored sample splits with analyses of new samples collected from the original sample sites to assess the importance of temporal variations.
3) Comparison between analyses of samples from high order streams, representing large drainage basins, and calculated average values for the drainage basins based on the original sampling and analysis to assess the relationship between low and high density sampling programmes.

Field work in Zimbabwe took place in September and October 1992.

POTENTIAL BENEFITS

Mineral (trace element) deficiencies or imbalances in soils and forages are thought to be responsible for low production and reproduction problems among grazing livestock in many developing countries (McDowell *et al.*, 1983). Although extreme cases of trace element deficiency or toxicity are often easily diagnosed from clinical or pathological characteristics, the recognition of sub-clinical cases must rely on chemical and biological analyses. Similarly, humans living for long periods in one area with a diet based primarily on locally produced food and water, a situations which can be common in developing countries, may also suffer from trace element deficiencies or excesses with similar difficulties of diagnosis. Trace element related production problems are also recorded for crops (Thornton, 1983).

The identification of areas where trace element imbalances are a potential problem is clearly beneficial, allowing remedial or preventative measures to be taken as necessary, and permitting informed planning for development. Recognition of areas with sub-clinical mineral imbalance problems in grazing livestock has generally been carried out through mapping soil, forage, animal tissue or animal fluid compositions, techniques which are not only expensive, but also may be impractical for the mapping of large areas (Appleton and Greally, 1992). Appleton and Ridgway (1993) discuss the application of regional geochemical mapping in developing countries to environmental studies and the value of high density stream sediment survey data in the recognition of regions where trace element deficiencies might occur has been demonstrated by Fordyce and Appleton (1994). Stream sediment surveys are a cost-effective means of delineating geochemical patterns of environmental significance but their value would be enhanced if it could be shown that rapid, low density sampling programmes also produce useful information.

THE STUDY AREA

The Harare region of Zimbabwe, between latitudes 17°30′S and 18°00′S and longitudes 30°45′E and 31°30′E, was selected for the study. Covering 4400 km^2, the area had been previously sampled at an average density of 1 sample per 2.7 km^2 in a geochemical survey carried out between 1982 and 1986 (Dunkley, 1987). Access is good and there is strong geochemical contrast between the volcano-sedimentary rocks of the Harare Greenstone Belt and the surrounding granites and granitic gneisses (Fig 1). The earlier geochemical survey was based on the <177 µm fraction of stream sediments, analysed for Co, Cu, Li, Mn, Ni, Pb and Zn by atomic absorption spectrometry following digestion with hot concentrated hydrochloric acid for one hour. Approximately 40% of the samples were also analysed by XRF for As, Ba, Sn, Ta and W.

COMPARISON OF DRAINAGE SEDIMENT AND SOIL AS SAMPLING MEDIA FOR ENVIRONMENTAL GEOCHEMICAL SURVEYS.

Study area

A drainage basin having an area of 2-3 km^2, in an area underlain by granitic gneisses, was chosen for the investigation (Fig. 2). Farming in the basin is not intense and the soils are unlikely to have been affected by large scale additions of fertilisers or animal feed supplements.

Field methods

The basin contains two stream sediment sites sampled as part of the original high density survey. These sites were resampled, one additional site and a site representing the full 2-3 km^2 of the basin were also sampled. Soil samples were taken along the interfluves, a total

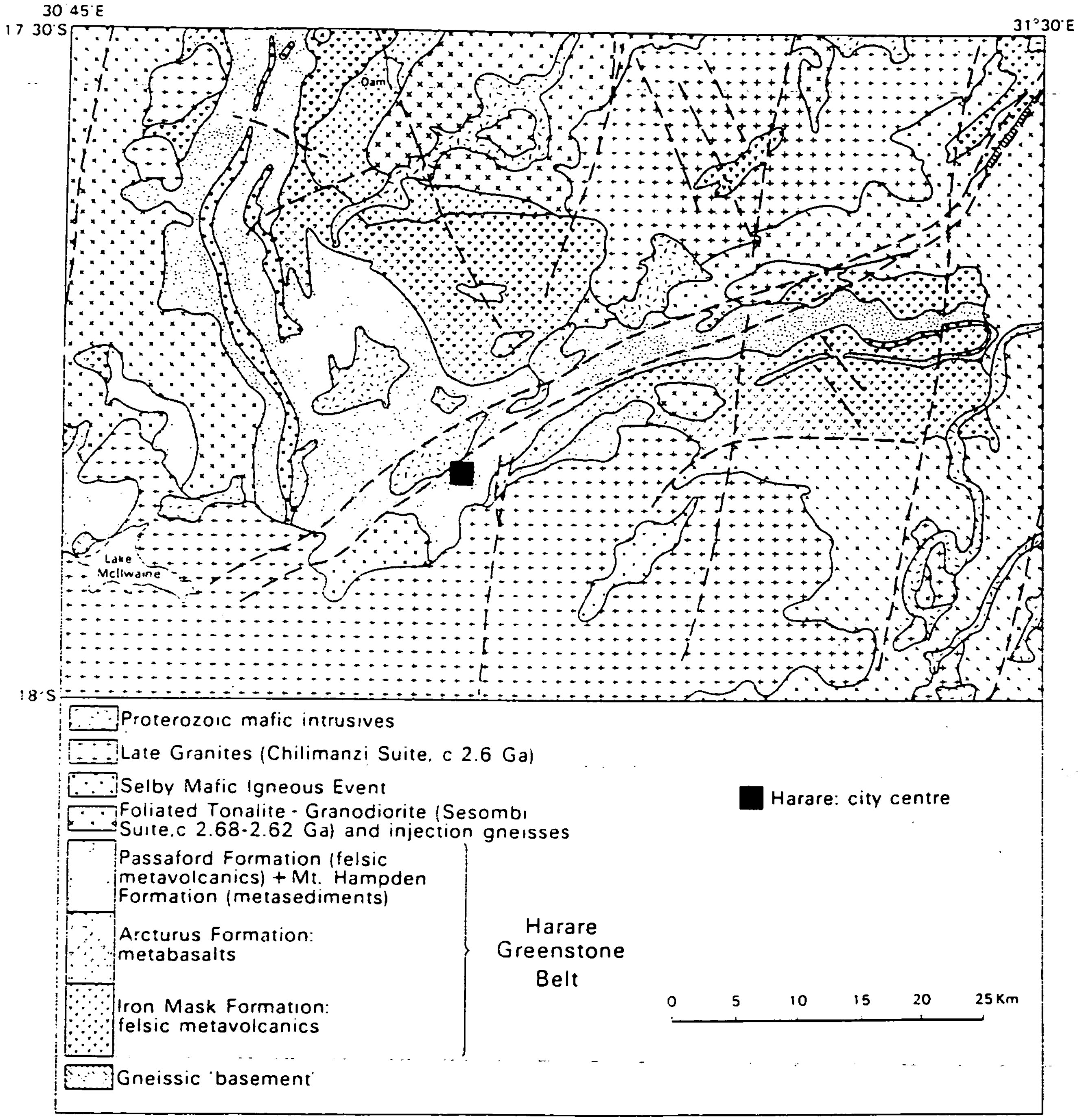

FIGURE 1: Simplified geology of the study area

of 24 sites being chosen to give a relatively even coverage of the flatter lying part of the catchment (Fig. 2). Hillslopes, where soils are very thin and the potential for agricultural use very limited, were not sampled. Soils are generally shallow with a poorly developed profile and over much of the area sampled had been tilled for subsistence agriculture.

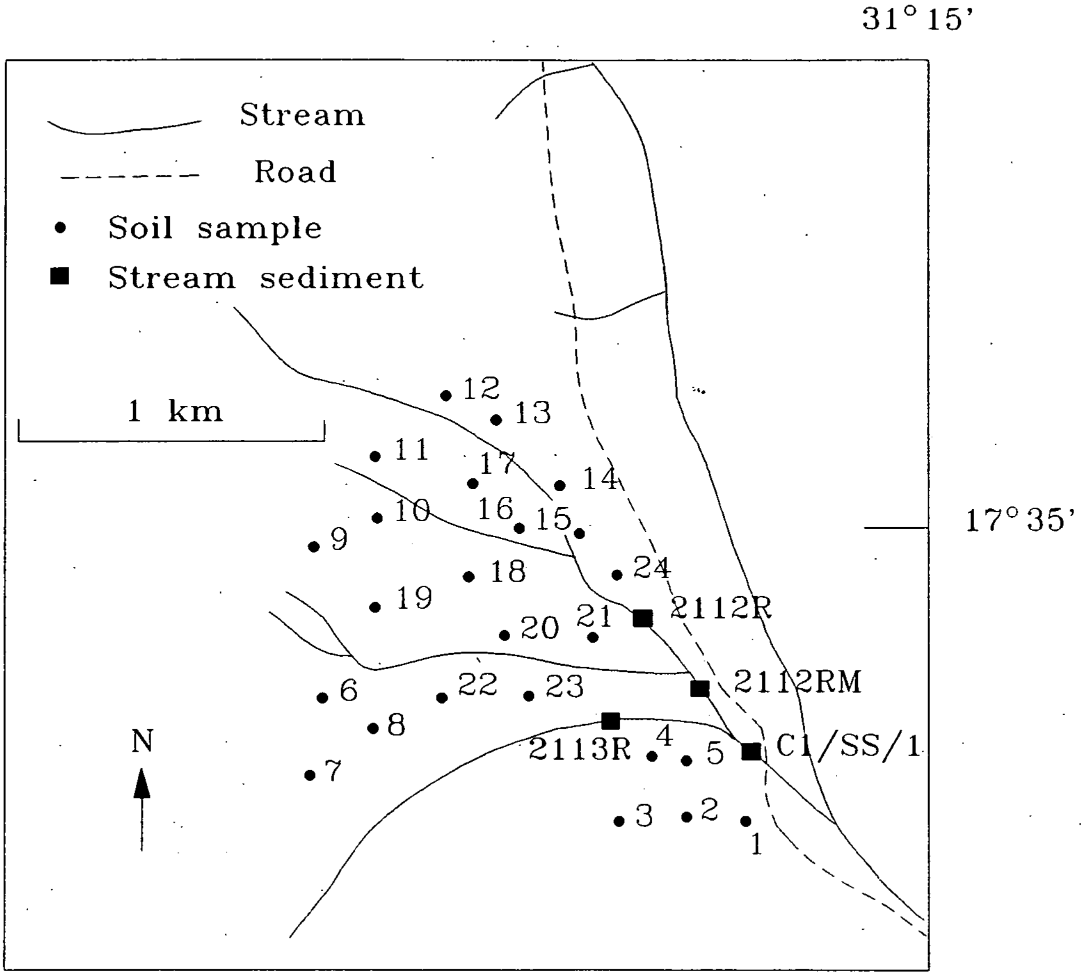

FIGURE 2: Sketch map of drainage basin used for the soil/stream sediment comparison, showing sample locations.

Stream sediments

Streams in the area were dry at the time of resampling and sieving was carried out in the field using nylon sieve cloth held in a wooden frame. Two types of sample were taken at each site, one of <2 mm material and the other of <177 μm sediment. At the site representing the whole drainage basin (C1/SS/1, Fig. 2), two samples of <177 μm sediment were collected as a check on reproducibility. Each sample was collected by making up a composite of sub-samples from 5-10 sites along a 10-20 m stretch of the stream bed centred on the nominal sample location.

Soils

Soils were also sieved in the field, two size fractions being collected using the same equipment as for stream sediments. At each sample location five sub-samples were taken and composited to make one full sample. The sub-samples were collected from a central site and four other sites, each at a distance of 5 m from the central site and forming the corners of a square. A small pit was dug at each site, 20-30 cm deep, and material collected from B horizon soil, although in most cases distinct horizons were difficult to recognise.

Analytical methods

Both soil and stream sediment samples were analysed in the BGS laboratories by ICP-AES for Co, Cu, Fe, Mn, Ni, Pb and Zn after digestion for one hour in hot concentrated hydrochloric acid. A comparison of analytical results and recommended values (RV) for three reference materials is given in Table 1 and shows the good agreement between the two sets of data. Detection limits for the analytical method also are shown in Table 1.

(ug/g)	Mn	Fe	Zn	Cu	Pb	Co	Ni
GXR 3	24366	20.05%	230	15	15	63	64
RV	22308	19.00%	207	18	15	43	60
GXR 5	247	3.24%	47	374	<10	27	66
RV	310	3.39%	49	354	21	30	75
GXR 6	1226	6.24%	145	78	111	18	28
RV	1007	5.58%	118	66	101	14	27
Det. Limit	1	0.0002%	5	2	10	3	3

TABLE 1: Comparison of determined and recommended values (RV) for international reference materials (Potts et al. 1992).

Results

In Table 2 element concentrations in stream sediments 2112R, 2112RM, 2113R and C1/SS/1 are compared with mean soil values for subsets of soils which are considered to lie within the respective catchment areas. The full dataset is tabulated in Appendix 1. In computing mean values, concentrations below the detection limit have been given a value of half the detection limit.

	Mn	Fe	Zn	Cu	Pb	Co	Ni	No.
<2mm soil mean for whole basin	291	0.81%	14	6	12	5	12	24
<2mm C1/SS/1	66	0.35%	5	3	<10	<3	4	1
<2mm soil mean for 2112R	276	0.72%	14	5	12	4	8	11
<2mm 2112R	63	0.23%	5	2	<10	<3	234	1
<2mm soil mean for 2113R	381	0.87%	15	5	14	6	39	3
<2mm 2113R	96	0.68%	17	6	14	2	9	1
<177 mic. soil mean for whole basin	554	1.33%	25	8	27	9	14	24
<177 mic. C1/SS/1A	271	1.88%	28	7	27	7	13	1
<177 mic. C1/SS/1B	311	1.85%	29	7	30	4	9	1
<177 mic. soil mean for 2112R	550	1.24%	25	8	29	8	15	11
<177 mic. 2112R	111	0.38%	11	3	21	<3	5	1
<177 mic. soil mean for 2112RM	596	1.39%	27	9	29	10	15	17
<177 mic. 2112RM	186	1.40%	23	6	31	4	9	1
<177 mic. soil mean for 2113R	830	1.55%	30	9	35	12	14	3
<177 mic. 2113R	155	1.52%	39	13	46	6	13	1

TABLE 2: Comparison of mean values for within-catchment soils with values for the equivalent stream sediment. Values in ppm except for Fe.

<2 mm material

Values for Mn and Fe are significantly lower in the stream sediments than in the soils for C1/SS/1 and 2112R. This is generally reflected in the other elements with the exception of Ni in 211R which is extremely high. Although Mn and Fe are also lower in stream sediment 2113R, the differences from the soil values for other elements are not pronounced. Again Ni is an exception, but in this case the soil value is higher. The explanation for these differences may be that the soils contain a higher proportion of very fine-grained material than the stream sediments. In the latter, fine material will have been washed out at times of stream flow. Coatings of Mn and Fe oxides on the surfaces of clay minerals and silt particles are known to scavenge other metals (Watters, 1983) and thus sediments with low fines contents will have correspondingly low metal values. The large variations in Ni content are more difficult to explain and require investigation beyond the scope of this study.

<177 µm material

The selection of a narrower size range through sieving eliminates most of the effects of natural processes and overall there is much closer agreement between the data for soils and stream sediments in this size fraction. Manganese concentrations are consistently lower in the stream sediments, but Fe values are variable. Given the degree of analytical variation to be expected at the relatively low concentrations recorded, it can reasonably be said that for Co, Cu, Ni, Pb and Zn there is close correspondence between the soil and stream sediment datasets.

Conclusions

In the <177 µm material the geochemistry of stream sediments compares well with that of soils and for this terrain type stream sediments could be used with confidence as a sampling medium for environmental studies. The correspondence between soil and stream sediment geochemistry is less good in the <2mm fraction but both reflect the low trace element concentrations to be expected from an area underlain by granitic gneisses.

ASSESSMENT OF THE RELATIVE USEFULNESS OF HIGH AND LOW DENSITY GEOCHEMICAL SAMPLING FOR THE PRODUCTION OF ENVIRONMENTAL GEOCHEMICAL MAPS.

For this part of the investigation, the Harare region was divided into drainage basins with catchment areas of 50 to 100 km^2 using 1:250 000 and 1:50 000 topographic maps. In practice the area of the basins varied between approximately 45 and 135 km^2 (Fig. 3) and because of the drainage pattern large tracts of the region were not included within basins of this size.

Field methods

Samples were collected from the major streams at the exit point from the selected catchment basins. The general techniques and equipment used were the same as described in the previous section. Stream conditions varied and some samples were wet sieved on site, some dry sieved, and some collected in bulk for later drying and sieving in the laboratory. No attempt was made in this investigation to determine the effects of different sample collection and sieving methods, but earlier work in NE Zimbabwe (Ridgway, 1983) showed that differences in chemistry between wet and dry sieved samples were minimal. Only <177 µm material was taken and each sample was collected by making up a composite from 10-15 sites along a 50 m reach of river bed spanning the nominal sample location. At 6 locations the samples were collected in triplicate and at a seventh location duplicate samples were taken.

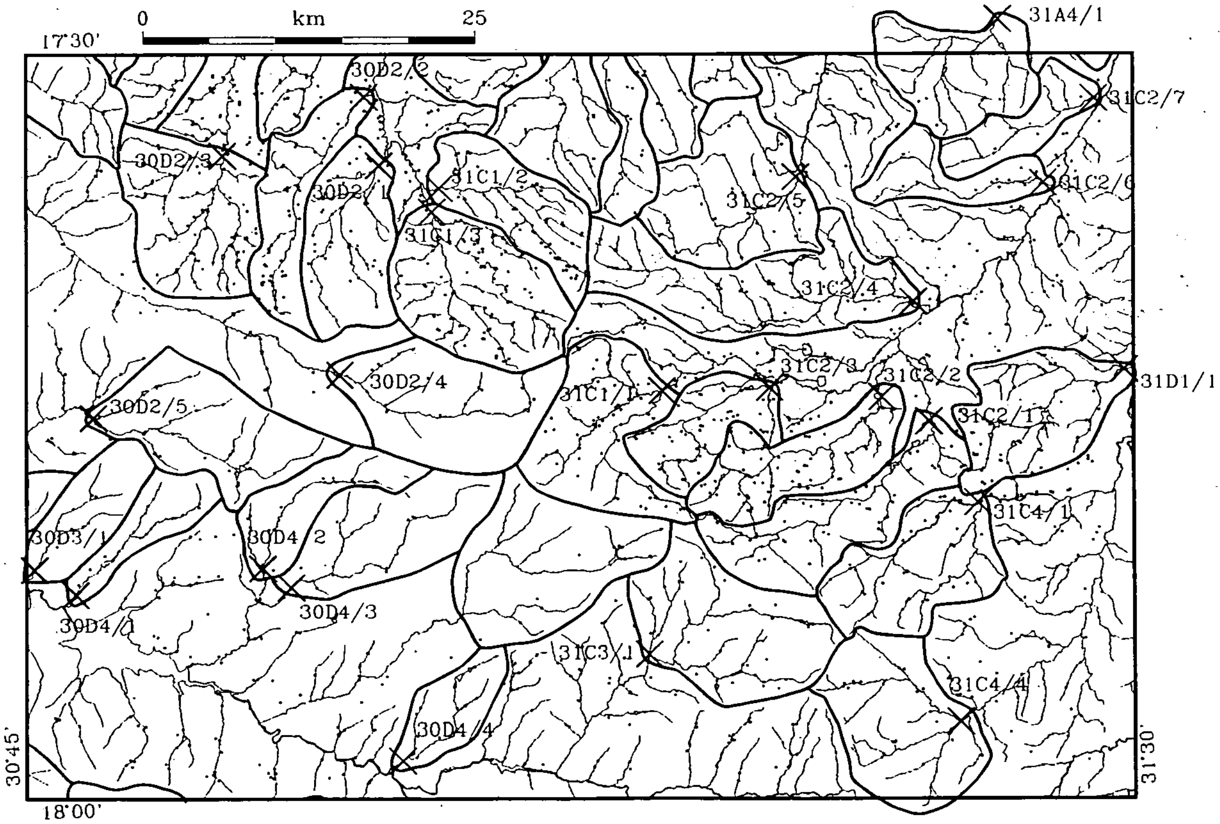

FIGURE 3: Drainage map of the Harare area showing major drainage basin sampled and sample numbers. Locations of original samples from low order streams are also shown. The area boundary is the same as for FIGURE 1.

Sixteen sites from the earlier high density survey were resampled and the corresponding stored sample splits retrieved from the sample archive in the Geological Survey Department, Harare.

Analytical methods

After drying and disaggregation as necessary, all samples and sub-samples were analysed using the same methodology as for the soil-stream sediment comparison study already described .

Results

For comparison purposes all concentrations below the detection limit have been assigned a nominal value of half the detection limit.

1) Test 1: Comparison between original analyses and reanalysis of splits of original samples

Table 3 shows the results analysis of original samples during the previous survey (o) and reanalysis of these samples in the present study (ra) along with Pearson product-moment correlation coefficients (o/ra). Although absolute values vary considerably the correlation is generally good, only Pb having a Pearson coefficient of less than 0.9. The lower correlation coefficient for Pb reflects the low concentration of this element which means that determinations must be carried out near the detection limit, thus leading to poor precision in the results (Thompson and Howarth, 1973). Having established that the agreement between the original and new analytical data is good, it is thus reasonable to examine how analysis of replicate samples from the original sites compares with the original data.

2) Test 2: Comparison of original and new analyses of stored sample splits with analyses of new samples collected from the original sample sites

Table 3 again shows the Pearson coefficients for this comparison. Results for resampled sites are designated as rs. The level of correspondence is markedly lower than for Test 1, and is particularly poor for Zn. Pearson correlation coefficients (o/rs) are less than 0.9 for all elements except Mn and Pb. Results are very similar for the comparison between reanalysed splits and recollected samples (ra/rs). The discrepancy between the original data and those for the resampling exercise could be attributed to temporal variations. Ridgway and Dunkley

No	Mn o	Mn ra	Mn rs	Zn o	Zn ra	Zn rs	Cu o	Cu ra	Cu rs	Pb o	Pb ra	Pb rs	Co o	Co ra	Co rs	Ni o	Ni ra	Ni rs
1747	170	185	1262	3	13	78	3	3	60	15	13	19	4	2	41	4	2	58
2111	220	277	483	2	11	34	3	4	12	28	26	43	4	6	10	8	9	18
2112	140	161	111	2	11	11	2	1	3	10	13	21	2	2	2	2	4	5
2417	380	401	231	5	21	37	14	16	15	12	13	21	5	8	8	13	16	21
2543	1290	1369	1260	35	128	130	59	71	65	10	14	19	37	46	52	60	84	107
2556	1600	1756	1033	55	117	70	69	81	56	9	5	11	26	29	33	61	83	66
2557	9200	9943	7339	36	89	94	62	78	87	0	5	5	79	109	77	82	118	121
2568	4500	5137	1370	475	522	96	53	67	55	16	22	5	40	52	41	67	98	78
2631	760	761	401	10	37	31	6	7	7	25	30	31	10	10	6	6	9	5
2634	500	524	491	14	47	33	9	8	11	15	5	21	14	11	13	25	26	30
2815	90	125	190	4	9	14	1	3	6	10	5	5	1	2	2	5	5	5
2819	980	1099	1856	26	27	63	22	28	96	0	5	5	18	29	70	34	43	122
2823	1100	959	1754	20	18	55	25	28	76	10	5	12	22	29	55	24	28	74
2824	180	185	322	12	12	39	6	8	23	10	5	12	3	5	15	13	10	40
2935	1150	1163	1518	44	50	53	59	71	90	0	5	5	42	53	85	125	169	378
2954	1500	1629	2334	60	70	71	105	127	127	0	5	5	45	59	111	102	147	174
	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs
Pears.	0.9993	0.8922	0.9032	0.9783	0.5305	0.4146	0.9990	0.7935	0.7881	0.8160	0.7109	0.8398	0.9938	0.7711	0.7649	0.9975	0.8449	0.8684

99% significance value = 0.5742

TABLE 3: Values for original determinations (o), reanalysed splits of originals (ra) and resampled sites (rs). Pearson correlation coefficients are shown for paired sets of analyses (original and reanalysed splits = o/ra etc.).

No.	Zn o	Zn ra	Zn nrs	Cu o	Cu ra	Cu nrs	Pb o	Pb ra	Pb nrs	Co o	Co ra	Co nrs	Ni o	Ni ra	Ni nrs
1747	3	13	11	3	3	9	15	13	5	4	2	6	4	2	9
2111	2	11	20	3	4	7	28	26	25	4	6	6	8	9	10
2112	2	11	16	2	1	5	10	13	30	2	2	2	2	4	7
2417	5	21	64	14	16	26	12	13	36	5	8	13	13	16	36
2543	35	128	141	59	71	71	10	14	21	37	46	57	60	84	116
2556	55	117	118	69	81	95	9	5	19	26	29	56	61	83	111
2557	36	89	128	62	78	118	0	5	7	79	109	105	82	118	163
2568	475	522	360	53	67	205	16	22	19	40	52	153	67	98	293
2631	10	37	58	6	7	14	25	30	59	10	10	11	6	9	10
2634	14	47	35	9	8	12	15	5	22	14	11	14	25	26	32
2815	4	9	9	1	3	4	10	5	5	1	2	2	5	5	4
2819	26	27	38	22	28	57	0	5	5	18	29	42	34	43	72
2823	20	18	30	25	28	42	10	5	7	22	29	30	24	28	41
2824	12	12	22	6	8	13	10	5	7	3	5	8	13	10	23
2935	44	50	40	59	71	69	0	5	4	42	53	65	125	169	290
2954	60	70	50	105	127	89	0	5	5	45	59	78	102	147	122
	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs
Pears.	0.9783	0.9710	0.9145	0.9990	0.7470	0.7315	0.8160	0.7415	0.6604	0.9938	0.8327	0.8365	0.9975	0.8688	0.8667

99% significance value = 0.5742

TABLE 4: As for TABLE 3, except that values for resampled sites have been recalculated according to the formula: nrs = rs((reanalysed Fe+Mn)/(resampled Fe+Mn)).

(1988) suggest that seasonal variations may be compensated for by using correction factors based on element-Fe oxide ratios and an attempt to do this is shown in Table 4. In Table 4, combined totals of Fe and Mn in original samples and replicate samples recollected from the original sites have been used to adjust the concentration levels for the replicate samples. This results in an improvement in correlation coefficients between original and replicate values for Zn, in particular, and Co, but gives no improvement for Cu, and Ni, and much poorer correlation for Pb. The discrepancies, however, could also relate to difficulties in relocating the original sites. At several of the sites the stream channel was poorly defined and may have been disturbed by agricultural practices, while at one location a dam had been built upstream of the original sampling point. If only data for sites where there was a well defined stream channel are considered (Table 5), the correlation coefficients improve dramatically with only Zn having a Pearson coefficient (o/rs) of less than 0.9. This indicates that temporal variations are of lesser importance than accurate resampling in accounting for discrepancies between original and replicate sampling datasets and suggests that geochemical patterns arising from the original survey and a new survey would be very similar, even when absolute values differ.

3) Test 3: Comparison between analyses of samples from high order streams and computed values for the drainage basins based on the original sampling and analysis

Given that there is compatibility, at least in a relative sense, between the original survey results and those from the resampling exercise, the outcome of this third test can now be examined.

Data for replicate sampling on the same day in the major streams (Table 6) demonstrate that the sampling methodology is sound and provides reproduceable results. In Table 7, the analytical results from samples collected at the mouth of each large catchment basin are compared with the arithmetic mean, geometric mean and median of all the samples from low order streams within that basin. Pearson correlation coefficients show that the arithmetic mean performs as well as, or better than, the geometric mean or median as a measure of the overall composition of the drainage basin. The coefficients are, with the exception of that between major drainage sample and arithmetic mean Pb, lower than the correlation coefficients between original and recollected samples from low order streams shown in Table 5. In the cases of Mn and Ni the correlations are very poor, the recorded coefficients not being significant at the 99% level. The implication is that, in the Harare area, either samples from high order streams are not truly representative of the geochemistry of the upstream catchment area, or mean values of the low order stream samples are not representative of the drainage basin as a whole.

The reasons for the poor correlation between the chemistry of samples from high order streams and measures of the overall geochemistry of samples from low order streams are not clear. Plots of major stream sample against arithmetic mean for individual elements (Fig. 4 a and b) show that some major basins persistently plot off the main trend (e.g. 6, 7, 8, 10, 12, 16 and 18). Tables 8 and 9 summarise the geology of the 25 drainage basins studied in terms of major rock types and formations. There is no obvious common factor linking the most aberrant basins (6, 7, 8, 10, 12, 16 and 18). Basin 10, at 45 km ^{2}, is one of the smallest sampled, while basin 6 is the largest at approximately 135 km^2. Basins 7 and 8 have a relatively simple geological make-up, each containing only 2 rock types, whereas 6 and 18 are more complex with a variety of rock types and formations within their confines. Other basins of simple (e.g. 13 and 21) or complex (e.g. 1 and 5) geology lie on the general trend defined by scatter plots of, for instance, high order stream sample against mean value of low order stream samples from the same drainage basin (Fig. 4 a and b).

In the case of basins 7 and 10 an examination of the geological map of the region shows that the high order stream sample site lies on a rock type which is of relatively minor importance in the basin as a whole, but which probably makes a major contribution to the composition of the sediment at that site. The bedrock in both basins is predominantly of granitic composition, but the sample sites lie on more basic lithologies producing, for example, a Ni value for basin 10 of 248 ppm against mean, geometric mean and median values for the whole basin of 24, 10 and 8 ppm respectively (Table 7). This discrepancy is far higher than can be accounted for by differences in the analytical method and must arise from the local lithological influence. Such a simple explanation cannot be advanced for the other aberrant basins where a variety of factors may have influenced the situation (Hawkes, 1976; Rose *et al.*, 1979). Careful choice of sample site on the basis of geology might help overcome this type of problem, but would not help in areas of poor geological knowledge.

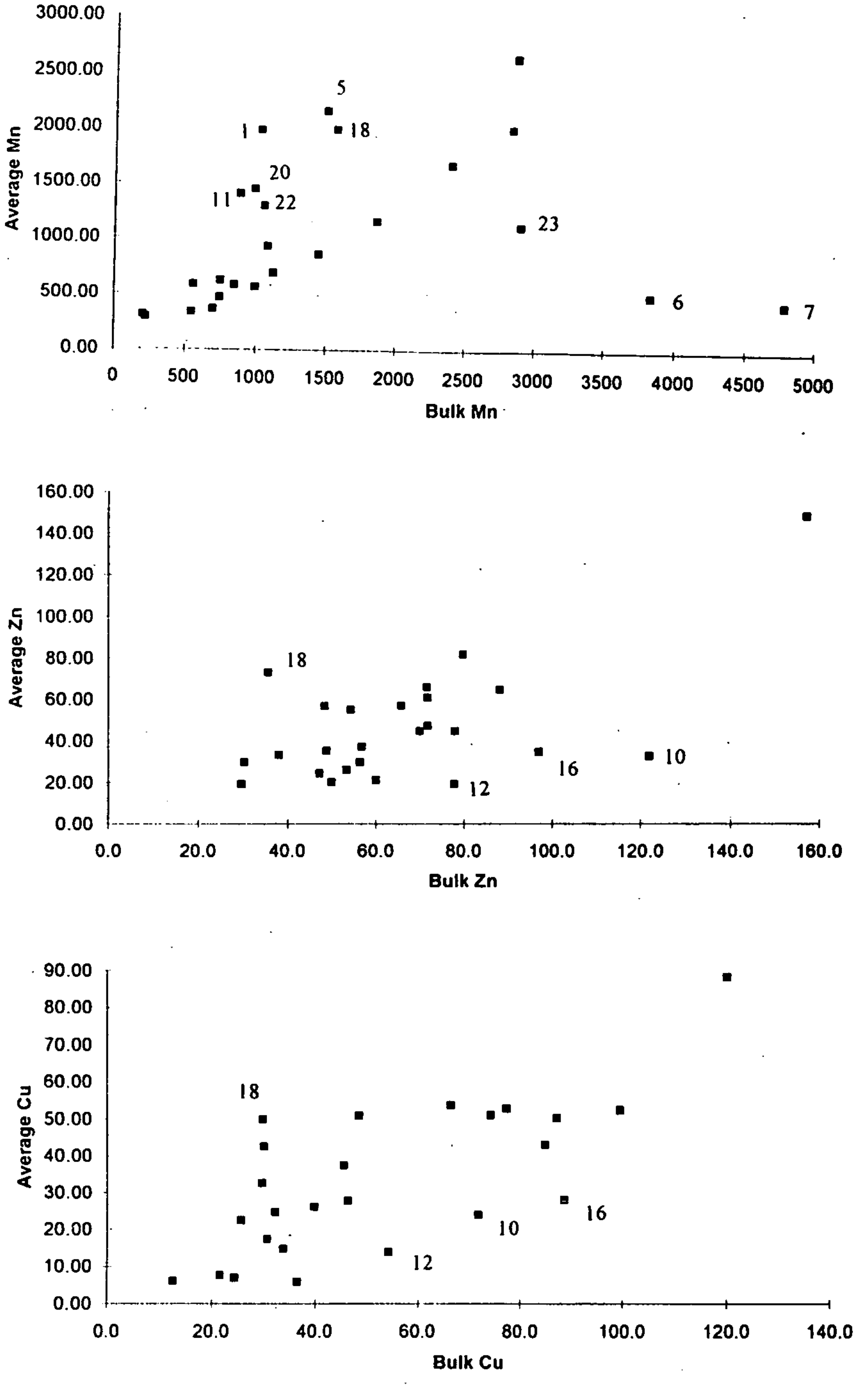

FIGURE 4a: Scatter plots of arithmetic mean (average) element values for low order stream samples against the high order stream sample representing the whole drainage basin; Mn, Zn and Cu. The tendancy for the bulk values to be higher than the average reflects the pattern seen in Table 3, where resampled low order streams yielded generally higher concentrations than the original sampling and analysis.

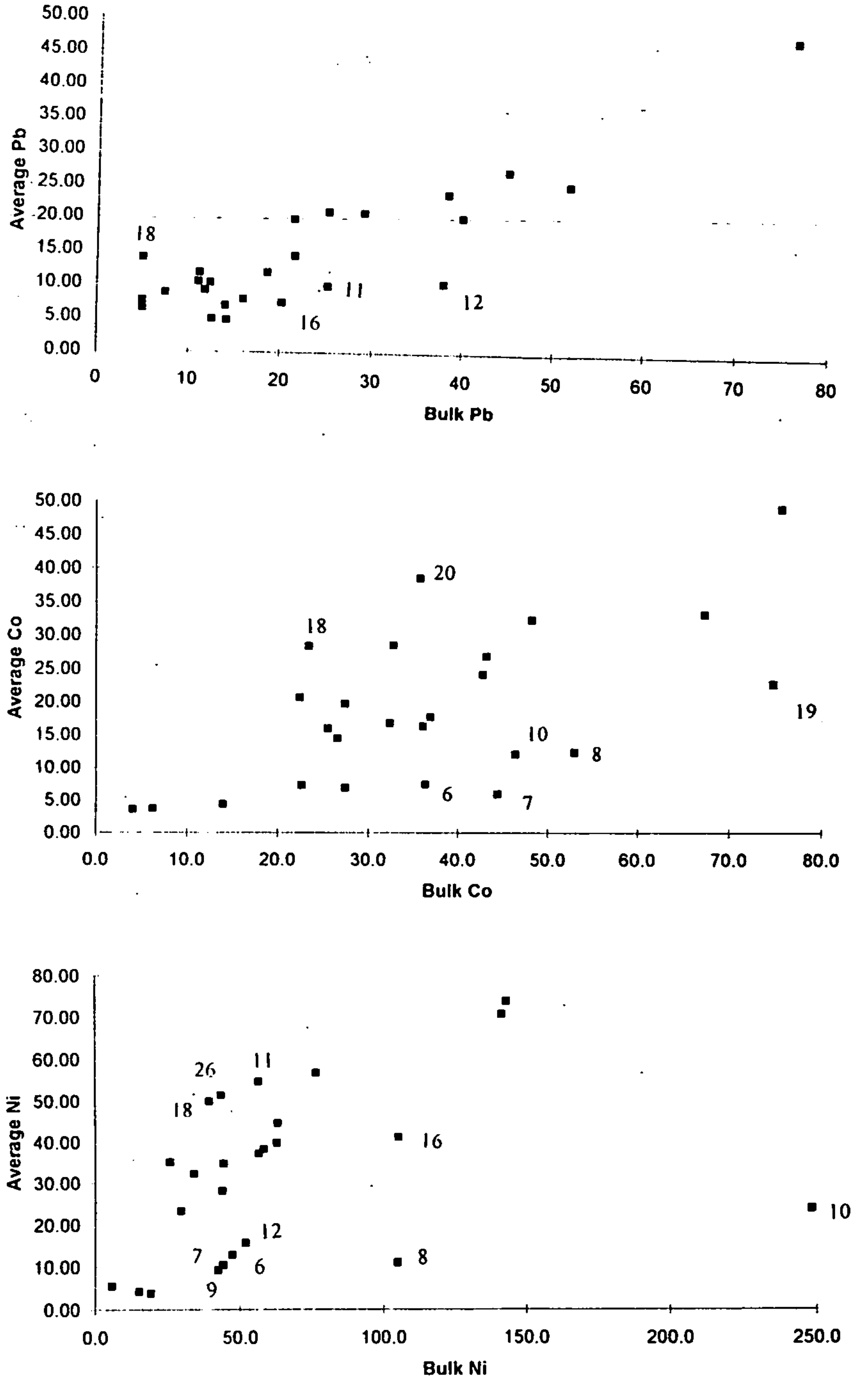

FIGURE 4b: Scatter plots of arithmetic mean (average) element values for low order stream samples against the high order stream sample representing the whole drainage basin; Pb, Co and Ni.

No.	Mn o	Mn ra	Mn rs	Zn o	Zn ra	Zn rs	Cu o	Cu ra	Cu rs	Pb o	Pb ra	Pb rs	Co o	Co ra	Co rs	Ni o	Ni ra	Ni rs
2111	220	277	483	9	11	34	3	4	12	28	26	43	4	6	10	8	9	18
2112	140	161	111	10	11	11	2	1	3	10	13	21	2	2	2	2	4	5
2417	380	401	231	20	21	37	14	16	15	12	13	21	5	8	8	13	16	21
2543	1290	1369	1260	114	128	130	59	71	65	10	14	19	37	46	52	60	84	107
2556	1600	1756	1033	106	117	70	69	81	56	9	5	11	26	29	33	61	83	66
2557	9200	9943	7339	75	89	94	62	78	87	0	5	5	79	109	77	82	118	121
2631	760	761	401	32	37	31	6	7	7	25	30	31	10	10	6	6	9	5
2634	500	524	491	41	47	33	9	8	11	15	5	21	14	11	13	25	26	30
2815	90	125	190	7	9	14	1	3	6	10	5	5	1	2	2	5	5	5
2824	180	185	322	12	12	39	6	8	23	10	5	12	3	5	15	13	10	40
	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs	o/ra	ra/rs	o/rs
Pears.	1.0000	0.9969	0.9967	0.9992	0.8920	0.8866	0.9987	0.9531	0.9390	0.8315	0.8634	0.9057	0.9947	0.9637	0.9679	0.9961	0.9493	0.9556

99% significance value = 0.7155

TABLE 5: As for TABLE 3, except that only samples from sites which could be accurately relocated are included.

	Mn			Zn			Cu			Pb			Co			Ni		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
30D2/2	2126	3154	3321	133	173	166	104	129	127	5	5	5	88	68	72	126	149	150
30D2/4	964	949	1048	65	63	69	64	63	72	14	14	5	37	33	37	63	60	66
30D3/1	623	801	819	31	28	31	28	24	25	5	12	5	24	27	26	46	43	41
30D4/4	176	232		25	35		30	43		27	31		4	8		11	19	
31C1/2	978	1274	990	60	62	49	46	53	40	25	12	5	38	41	29	33	32	24
31C3/1	229	186	259	44	36	70	11	11	16	22	17	26	6	2	5	5	5	8
31C4/4	568	521	552	58	57	65	21	21	23	41	38	36	16	13	13	21	18	19
	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C	A/B	B/C	A/C
Pears.	0.9866	0.9902	0.9821	0.9811	0.9530	0.9551	0.9835	0.9849	0.9860	0.8632	0.8775	0.8011	0.9737	0.9666	0.9874	0.9902	0.9959	0.9914

99% Significance value = 0.8329

TABLE 6: Comparison of replicate samples from large catchment areas and Pearson correlation coefficients.

	Sample	Mn	Mn m	Mn gm	Mn md	Zn	Zn m	Zn gm	Zn md	Cu	Cu m	Cu gm	Cu md
1	30D2/3	1030	1981	793	660	48	57	41	37	30	33	22	24
2	30D2/2	2867	2638	2126	2540	157	148	110	88	120	88	76	75
3	30D2/1	2401	1681	1003	930	54	55	48	47	49	51	33	32
4	31C1/2	1081	928	717	680	57	37	34	37	46	28	21	20
5	31C1/3	1501	2157	1513	1670	88	65	61	65	74	51	46	52
6	31C2/4	3837	496	382	345	53	26	23	21	34	15	8	7
7	31C2/5	4785	428	377	375	56	30	26	27	24	7	6	6
8	31A4/1	1447	860	755	810	78	45	41	40	85	43	18	8
9	31C2/6	700	364	333	310	47	25	22	23	31	17	13	12
10	31C2/7	1120	693	527	650	122	33	28	26	72	24	16	19
11	31D1/1	882	1404	949	950	72	66	50	44	87	50	35	46
12	31C4/1	846	582	367	290	78	19	17	17	54	14	5	3
13	31C4/4	547	337	273	295	60	21	18	17	22	8	4	3
14	31C3/1	224	290	224	210	50	20	17	18	13	6	5	4
15	31C2/1	752	624	371	260	97	35	21	18	89	28	11	9
16	31C2/2	1863	1161	888	940	70	45	37	43	100	52	36	45
17	31C2/3	1573	1988	1459	1520	36	73	62	69	30	50	38	56
18	31C1/1	2836	2003	1112	1040	80	82	63	62	30	42	33	38
19	30D2/4	987	1450	1018	970	66	57	52	48	66	54	50	48
20	30D4/4	204	309	251	240	30	19	17	15	37	6	4	5
21	30D4/3	1055	1295	1073	1090	72	61	52	45	46	37	33	35
22	30D4/2	2901	1118	874	810	72	47	45	43	77	53	47	49
23	30D2/5	558	586	462	395	49	35	33	33	40	26	24	24
24	30D4/1	992	568	523	560	38	33	32	34	32	25	24	27
25	30D3/1	748	469	412	380	30	30	29	30	26	22	22	21
Pearson			0.2639	0.2903	0.2849		0.6013	0.5428	0.4281		0.7234	0.6013	0.5341

99% significance value = 0.4686

	Sample	Pb	Pb m	Pb gm	Pb md	Co	Co m	Co gm	Co md	Ni	Ni m	Ni gm	Ni md
1	30D2/3	5	6	5	5	22	21	16	15	57	37	28	31
2	30D2/2	5	8	4	4	76	49	44	47	141	70	62	65
3	30D2/1	16	8	5	8	43	27	20	23	63	45	34	38
4	31C1/2	14	7	5	6	36	16	13	14	29	23	17	17
5	31C1/3	13	5	3	3	48	32	29	31	76	57	53	57
6	31C2/4	40	20	16	17	36	7	5	4	47	13	9	9
7	31C2/5	45	27	25	28	44	6	5	5	44	10	8	9
8	31A4/1	76	48	35	35	53	12	8	8	105	11	9	9
9	31C2/6	52	25	23	24	23	7	6	6	42	9	7	7
10	31C2/7	25	21	18	20	46	12	8	9	248	24	10	8
11	31D1/1	25	10	5	6	33	28	21	26	57	55	36	47
12	31C4/1	38	10	7	10	27	7	3	2	52	16	10	9
13	31C4/4	38	24	22	20	14	4	3	3	19	4	3	3
14	31C3/1	21	20	18	20	4	4	3	3	6	6	4	4
15	31C2/1	20	7	4	10	37	18	6	6	105	41	16	10
16	31C2/2	5	14	4	2	67	33	25	31	143	73	49	75
17	31C2/3	14	5	3	4	23	28	23	25	39	50	43	57
18	31C1/1	12	10	7	7	43	24	19	20	26	35	28	28
19	30D2/4	11	10	9	11	36	38	26	22	63	40	33	32
20	30D4/4	29	21	19	19	6	4	3	4	15	4	3	3
21	30D4/3	22	14	13	10	27	20	18	18	44	35	31	34
22	30D4/2	19	12	10	10	75	23	19	20	58	38	31	29
23	30D2/5	12	9	8	8	27	14	13	13	44	28	26	27
24	30D4/1	11	12	11	10	32	17	16	17	34	32	29	31
25	30D3/1	7	9	9	9	26	16	15	15	43	51	45	38
Pearson			0.8777	0.8525	0.8759		0.6085	0.5926	0.6147		0.3654	0.2219	0.2299

99% significance value = 0.4686

TABLE 7: Comparison of arithmetic mean (m), geometric mean (gm) and median values (md) for all original survey samples within a major catchment with values for the major drainage sample representing the total catchment. Pearson correlation coefficients between major drainage samples and computed values are also given.

Make-up of catchments by lithological unit

Catchment	AF	CT	HF	IM	PF	SE	ST	TE	Total
1 30D2/3	9	7	3	1	38	6	3	0	67
2 30D2/2	27	1	11	8	1	2	0	0	50
3 30D2/1	14	0	1	25	0	0	6	2	48
4 31C1/2	10	1	0	3	0	0	40	0	54
5 31C1/3	64	1	0	12	0	0	11	7	95
6 31C2/4	1	32	0	0	0	0	19	0	52
7 31C2/5	0	35	0	5	0	0	0	0	40
8 31A4/1	0	14	0	0	0	0	0	0	14
9 31C2/6	3	10	0	0	0	0	1	0	14
10 31C2/7	2	2	0	0	0	0	8	0	12
11 31D1/1	4	1	0	0	7	0	15	0	27
12 31C4/1	6	3	0	0	0	0	14	0	23
13 31C4/4	0	5	0	0	0	0	13	0	18
14 31C3/1	0	30	0	0	0	0	4	0	34
15 31C2/1	21	4	0	0	1	0	23	0	49
16 31C2/2	49	2	0	0	0	0	9	0	60
17 31C2/3	18	0	4	0	17	4	6	0	49
18 31C1/1	18	4	5	0	29	0	7	0	63
19 30D2/4	5	0	10	0	1	0	3	0	19
20 30D4/4	0	10	0	0	0	0	0	0	10
21 30D4/3	0	0	7	1	3	0	0	2	13
22 30D4/2	0	0	1	0	8	0	3	3	15
23 30D2/5	0	0	1	0	6	0	21	0	28
24 30D4/1	0	3	1	0	3	0	3	0	10
25 30D3/1	0	1	0	0	6	0	1	0	8
Total	251	166	44	55	120	12	210	14	872

Make-up of catchments by bedrock

Catchment	FP	FV	GN	GR	GT	MD	MI	MV	PH	Total
1 30D2/3	0	39	1	7	2	0	6	9	3	67
2 30D2/2	0	9	0	1	0	0	2	27	11	50
3 30D2/1	2	25	3	0	3	0	0	14	1	48
4 31C1/2	0	3	0	1	33	7	0	10	0	54
5 31C1/3	5	11	0	1	9	5	0	64	0	95
6 31C2/4	0	0	1	30	16	4	0	1	0	52
7 31C2/5	0	5	0	35	0	0	0	0	0	40
8 31A4/1	0	0	0	9	0	5	0	0	0	14
9 31C2/6	0	0	0	10	1	0	0	3	0	14
10 31C2/7	0	0	0	1	8	1	0	2	0	12
11 31D1/1	0	7	14	1	0	1	0	4	0	27
12 31C4/1	0	0	1	2	13	1	0	6	0	23
13 31C4/4	0	0	13	5	0	0	0	0	0	18
14 31C3/1	0	0	1	30	3	0	0	0	0	34
15 31C2/1	0	1	0	4	23	0	0	21	0	49
16 31C2/2	0	0	0	2	9	0	0	49	0	60
17 31C2/3	0	17	0	0	6	0	4	18	4	49
18 31C1/1	0	27	0	4	7	11	0	9	5	63
19 30D2/4	0	0	0	0	3	1	0	5	10	19
20 30D4/4	0	0	0	10	0	0	0	0	0	10
21 30D4/3	2	3	0	0	0	1	0	0	7	13
22 30D4/2	3	4	0	0	3	4	0	0	1	15
23 30D2/5	0	6	0	0	21	0	0	0	1	28
24 30D4/1	0	2	0	3	3	1	0	0	1	10
25 30D3/1	0	6	0	1	1	0	0	0	0	8
Total	12	165	34	157	164	42	12	242	44	872

TABLE 8: Numbers of samples in major drainage basins according to bedrock and lithological unit at the sample site. See TABLE 9 for lithological unit and bedrock codes.

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
1	PF	FV	2	IM	FV	3	IM	FV	4	ST	MD	5	AF	MV
	AF	MV		AF	MV		ST	GN		ST	GT		IM	FV
	HF	PH		HF	PH		TE	FP		IM	FV		ST	MD
	SE	MI		CT	GR		ST	GT		AF	MV		ST	GT
	CT	GR		SE	MI		AF	MV		CT	GR		CT	GR
	ST	GT		PF	FV		HF	PH					IM	MD
	ST	GN											TE	FP
	IM	FV											TE	MD

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
6	ST	MD	7	CT	GR	8	CT	GR	9	CT	GR	10	CT	MD
	CT	GR		IM	FV		CT	MD		ST	GT		ST	GT
	CT	MD								AF	MV		CT	GR
	AF	MV											AF	MV
	ST	GT												
	ST	GN												

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
11	CT	GR	12	ST	GT	13	ST	GN	14	CT	GR	15	CT	GR
	AF	MV		AF	MV		CT	GR		ST	GT		ST	GT
	PF	FV		ST	GN					ST	GN		PF	FV
	ST	GN		CT	GR								AF	MV
	ST	MD		CT	MD									

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
16	CT	GR	17	PF	FV	18	HF	PH	19	HF	PH	20	CT	GR
	AF	MV		SE	MI		PF	FV		PF	MD			
	ST	GT		AF	MV		PF	MD		AF	MV			
				ST	GT		AF	MV		ST	GT			
				HF	PH		CT	GR						
							AF	MD						
							ST	GT						

Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock	Basin	Unit	Rock
21	TE	FP	22	TE	FP	23	PF	FV	24	ST	GT	25	ST	GT
	HF	PH		PF	MD		ST	GT		HF	PH		HF	PH
	PF	FV		ST	GT		HF	PH		PF	MD		PF	MD
	IM	FV		HF	PH					PF	FV		PF	FV
	PF	MD		PF	FV					CT	GR		CT	GR

Lithological Unit	
Chilimazi-type Intrusions	CT
Sesombi-type intrusions	ST
Teviotdale Event	TE
Selby Event	SE
Passaford Formation	PF
Mt Hampden Formation	HF
Arcturus Formation	AF
Iron Mask Formation	IM

Rock Type	
Dolerite	MD
Granite	GR
Granodiorite-Tonalite	GT
Gneiss and Migmatite	GN
Felsic Porphyries	FP
Mafic Intrusives	MI
Felsic Volcanics	FV
Phyllites	PH
Mafic Volcanics	MV

TABLE 9: Breakdown of major drainage basins by lithological unit and rock type

SUMMARY AND DISCUSSION

From the foregoing, it can be concluded that:

1) For granitic terrains, stream sediments from low order streams are reasonably representative of the soils of their catchment basins, at least where the soils are relatively undisturbed by agricultural practices. There is reason to believe that the same will hold true for other bedrock lithologies as has been demonstrated by Appleton *et al.* (1992)

2) In the Harare area, the drainage pattern is such that the sampling of drainage basins with areas of 45-135 km^2 leads to an uneven distribution of sample sites and leaves large tracts of land not represented by a geochemical sample (Fig. 3). This situation will occur almost anywhere if samples from high order streams draining large catchments are used as the basis for a geochemical survey.

3) Within the drainage basin size range given under (2), the geochemistry of a sample from a high order stream is not always representative of the overall chemistry of the upstream catchment area as measured by the mean, geometric mean or median of samples from low order streams within the basin.

Although it was not possible in the course of this investigation to determine the optimum size of drainage basin for a meaningful low density survey, the results are similar to those of previous workers. Garrett and Nichol (1967) conducted a regional geochemical reconnaissance survey of eastern Sierra Leone at a mean density of 1 stream sediment sample per 180 km^2 but used catchment basins of only up to 40 km^2. They considered that samples from this size of basin "had a composition related to the material within the catchment area" and also found that there was marked similiarity between stream sediment and soil geochemistry. In Zambia, Armour-Brown and Nichol (1970) found that stream sediment samples from catchments of up to 26 km^2 displayed a more constant relationship to the geochemistry of the upstream catchment area than those from larger basins. Moreover, it was not possible to obtain an adequate sample density from drainages with large catchments. Similarly, Reedman and Gould (1970) were able to recognise meaningful geochemical patterns using a density of 1 sample per 195 km^2 based on sampling drainage basins of 26 km^2. They conclude by posing the question of how the results of taking samples from major rivers with upstream catchments of 195 km^2 would compare with their findings. The present study suggests that such sampling of major rivers would not give useful results. All the studies mentioned above refer to African terrains, but the findings are supported by the work of Baldock (1977), who successfully located porphyry copper deposits in the Peruvian Andes using a sample density of 1 per 25 km^2 and suggested that at least in areas of active erosion, reconnaissance geochemistry might rely on sampling medium sized (3rd and 4th order) streams.

The results of this study suggest that there are no short cuts to the provision of reliable regional geochemical data. Sampling of low order streams with small catchment areas will provide a more even distribution of sample sites and more complete coverage than sampling high order channels. Small basins are more likely to be lithologically homogeneous than large basins and the geochemical samples are thus more likely to be truly representative of the upstream catchment. As far as possible the size of catchment and sampling density should be chosen to reflect the scale of lithological change. Large areas of homogeneous geology can be sampled at a lower density than more complex regions. Collecting from smaller basins will lead to larger numbers of samples and the effects of aberrant results on the dataset, whether through sampling or analytical error, are therefore diminished. Small streams also are physically easier to sample than large ones, particularly in regions where flow is perennial.

CONCLUSIONS AND RECOMMENDATIONS

1) The sampling of low order streams provides geochemical data which are closely related to the geochemistry of undisturbed soils in the catchment basement.

2) The geochemistry of sediment samples from high order streams with drainage basins of over 45 km^2 may not be representative of the overall chemistry of the upstream catchment area.

3) Regional geochemical surveys for environmental or exploration purposes should be based on as low an order of stream as possible. It is recommended that, unless further studies

establish the validity of sampling larger catchments, the drainage basin size should not exceed 25 km^2.

4) Wide-spaced sampling for international geochemical mapping should not be based on high order streams with large drainage basins. More reliable results will be obtained from evenly distributed samples from basins of less than 25 km^2.

ACKNOWLEDGEMENTS

The cooperation and assistance of Dr J.L. Orpen, then Director of the Geological Survey Department, Harare, and his Deputy Director, Mr S. Ncube, are gratefully acknowledged. Assistance in Zimbabwe was also received from Drs P. Lowenstein, M. Armstrong, P. Frey and P. Pitfield. Mr O. Chihotu was an invaluable help in the field along with Mr B. Dick. Comment and criticism from Drs J.D Appleton and J.W. Baldock helped improve the text of the report. Funding for the investigation came from the Overseas Development Administration of the Britsh Foreign and Commonwealth Office.

REFERENCES

AGGETT P.J., MILLS C.F, PLANT J.A., SIMPSON P.R., STEVENSON A., DINGWALL-FORDYCE I. and HALLIDAY C.F. 1988. A study of environmental geochemistry and health in north east Scotland. In *Geochemistry and Health. Proceedings of the Second International Symposium* (ed. I.Thornton), pp. 81-91, Science Reviews Ltd., Northwood, England.

APPLETON J.D. and GREALLY K.B. 1992. Environmental Geochemistry R&D Project: a comparison of the trace element geochemistry of drainage sediments and soils in eastern Bolivia. *British Geological Survey Technical Report* WC/92/67.

APPLETON J.D. and RIDGWAY J. 1993. Regional geochemical mapping in developing countries and its application to environmental studies. *Appl. Geochem.* Suppl. Issue No. 2, 103-110.

ARMOUR-BROWN A. and NICHOL I. 1970. Regional geochemical reconnaissance and the location of metallogenic provinces. *Econ. Geol.*, **65**, 312-330.

BALDOCK J.W. 1977. Low-density geochemical reconnaissance in Peru to delineate individual mineral deposits. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **86**, B63-72.

BRITISH GEOLOGICAL SURVEY 1990. *Regional Geochemical Atlas: Argyll.* Keyworth, Nottingham: British Geological Survey.

BRITISH GEOLOGICAL SURVEY 1991. *Regional Geochemistry of the East Grampian Area.* Keyworth, Nottingham: British Geological Survey.

BRITISH GEOLOGICAL SURVEY 1992. *Regional Geochemistry of the Lake District and adjacent areas.* Keyworth, Nottingham: British Geological Survey.

DUNKLEY P.N. 1987. A regional drainage geochemical exploration survey of the Harare area, Zimbabwe. *British Geological Survey Technical Report* MP/87/18.

FORDYCE F.M. and APPLETON J.D. 1994. Draft report on stream sediment, soil and forage chemistry as indicators of cattle mineral status in north-east Zimbabwe. *British Geological Survey Technical Report* WC/94/3R.

FORDYCE F.M., GREEN P.M. and SIMPSON P.R. 1993. Simulation of regional geochemical survey maps at variable sample density. *J. Geochem. Explor.*, **49**, 161-175.

GARRETT R.G. and NICHOL I. 1967. Regional geochemical reconnaissance in eastern Sierra Leone. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **76**, B97-112.

HAWKES. H.E. 1976. The downstream dilution of stream sediment anomalies. *J. Geochem. Explor.* **6**, 345-358.

MCDOWELL L.R., CONRAD J.H., ELLIS G.L. and LOOSLI J.K. (1983) *Minerals for* *grazing ruminants in tropical regions*. Bulletin Dept. Animal Science, University of Florida; Gainesville, Florida.

PLANT J.A. (1983) Regional geochemical maps of the United Kingdom; environmental and economic applications. *The Mercian Geologist (Nottingham)*, **9**, 75-87.

PLANT J.A. and MOORE P.J. (1979) Regional geochemical mapping and interpretation in Britain. *Phil. Trans. Roy. Soc. Lond.* **B288**, 95-112.

PLANT J.A. and STEVENSON, A.G. (1985) Regional geochemistry and its role in epidemiological studies. In: *Trace Elements in Man and Animals TEMA 5* (eds C.F.Mills, I. Bremner and J.K. Chesters), pp. 900-906. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

POTTS P.J., TINDLE A.G. and WEBB P.C. 1992. *Geochemical Reference Material Compositions*. CRC Press: London.

REEDMAN A.J. and GOULD D. 1970. Low sample-density stream sediment surveys in geochemical propspecting: an example from northeast Uganda. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **79**, B246-248.

RIDGWAY J. 1983. IGS Zimbabwe project. Geochemical exploration - results of an orientation survey and organisation of the sampling programme. IGS Overseas Division report 83/14, 68p.

RIDGWAY J. and DUNKLEY P.N. 1988. Temporal variations in the trace element content of stream sediments: examples from Zimbabwe. *Appl. Geochem.*, **3**, 609-621.

RIDGWAY J., APPLETON J.D. and GREALLY K.B. 1991. Variations in regional geochemical patterns - effects of site selection and data-processing algorithms. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **100**, B122-129.

ROSE A.W., HAWKES H.E. and WEBB J.S. 1979. *Geochemistry in Mineral Exploration*. Academic Press: London.

THOMPSON M. and HOWARTH R.J. 1973. The rapid estimation and control of precision by duplicate determinations. *Analyst*, **98**, 153-160.

THORNTON I. (1983). Geochemistry applied to agriculture. In Thornton, I. (Ed.), *Applied Environmental Geochemistry*. (p. 231-266). London: Academic Press.

WATTERS R.A. 1983. Geochemical exploration for uranium and other metals in tropical and subtropical environments using heavy mineral concentrates. *J. Geochem. Explor.*, **19**, 103-124.

WEBB J.S., & ATKINSON W. J. (1965). Regional geochemical reconnaissance applied to some agricultural problems. *Nature (London)*, **208**, 1056.

APPENDIX 1: Tabulated data for the soil/stream sediment comparison

Element values are in ppm except for Fe, which is in weight %

Appendix 1

Sample	Mn	Fe	Zn	Cu	Pb	Co	Ni
<2mm 1	207	0.63%	9	4	5	2	4
<2mm 2	169	0.60%	12	4	5	2	4
<2mm 3	345	0.98%	19	5	12	6	9
<2mm 4	191	0.69%	12	4	5	2	5
<2mm 5	172	0.56%	8	4	5	2	4
<2mm 6	230	1.73%	27	11	14	9	19
<2mm 7	346	0.85%	14	5	14	5	100
<2mm 8	453	0.79%	11	6	16	7	9
<2mm 9	491	1.59%	23	11	23	6	7
<2mm 10	544	0.86%	14	5	18	5	6
<2mm 11	398	1.06%	15	6	5	7	8
<2mm 12	350	0.80%	15	4	23	5	5
<2mm 13	383	0.62%	10	5	12	6	7
<2mm 14	230	0.54%	8	4	10	2	10
<2mm 15	209	0.79%	19	5	15	2	7
<2mm 16	126	0.50%	15	5	15	5	8
<2mm 17	173	0.40%	8	3	5	5	6
<2mm 18	239	0.74%	14	3	5	4	7
<2mm 19	513	0.86%	16	7	26	7	12
<2mm 20	229	0.51%	10	3	5	2	6
<2mm 21	158	1.08%	25	10	22	4	17
<2mm 22	388	1.02%	19	11	13	10	12
<2mm 23	221	0.67%	9	5	10	4	5
<2mm 24	225	0.55%	6	3	5	3	2
<177mic. 1	325	0.96%	16	4	15	6	6
<177mic. 2	339	1.06%	23	5	19	5	7
<177mic. 3	578	1.37%	28	7	28	9	9
<177mic. 4	388	1.16%	21	6	20	8	6
<177mic. 5	351	0.92%	15	6	19	6	9
<177mic. 6	384	2.92%	50	18	32	14	33
<177mic. 7	729	1.52%	27	8	29	10	10
<177mic. 8	1182	1.76%	35	12	47	18	23
<177mic. 9	799	2.24%	43	18	42	14	18
<177mic. 10	1069	1.62%	32	11	48	12	17
<177mic. 11	821	1.73%	24	10	37	13	15
<177mic. 12	734	1.43%	33	8	44	8	11
<177mic. 13	722	1.01%	20	7	22	12	13
<177mic. 14	523	1.07%	15	5	19	9	10
<177mic. 15	397	1.36%	33	8	36	5	12
<177mic. 16	237	0.75%	22	5	17	4	8
<177mic. 17	445	0.90%	18	5	17	11	13
<177mic. 18	515	1.43%	29	11	22	7	46
<177mic. 19	956	1.47%	26	11	43	18	18
<177mic. 20	386	0.79%	11	4	11	4	7
<177mic. 21	262	1.59%	37	13	38	7	17
<177mic. 22	516	1.22%	20	7	23	12	11
<177mic. 23	322	0.87%	14	3	16	7	6
<177mic. 24	326	0.78%	15	3	13	2	7
<2mm C1/SS/1	66	0.35%	5	3	<10	<3	4
<2mm 2112R	63	0.23%	5	2	<10	<3	234
<2mm 2113R	96	0.68%	17	6	14	2	9
<177 mic C1/SS/1A	271	1.88%	28	7	27	7	13
<177 mic C1/SS/1B	311	1.85%	29	7	30	4	9
<177 mic 2112R	111	0.38%	11	3	21	<3	5
<177 mic 2112RM	186	1.40%	23	6	31	4	9
<177 mic 2113R	155	1.52%	39	13	46	6	13

APPENDIX 2: Tabulated data for the original geochemical survey using low order streams

See TABLE 9 for key to codes for FORM = Lithological Unit and ROCK = Rock Type.
Catchmt = catchment number shown in TABLE 7. Element values are in ppm.

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1141	PF	FV	1	1	17	13	52	8	11	270
1156	AF	MV	2	1	3	6	15	3	7	120
1157	AF	MV	3	1	19	2	20	15	16	630
1158	PF	FV	4	1	11	3	23	10	18	710
1159	PF	FV	5	1	14	3	14	13	20	800
1160	PF	FV	6	1	29	5	77	20	35	1110
1162	HF	PH	7	1	23	3	52	22	45	2200
1163	PF	FV	8	1	31	11	46	25	102	1100
1164	PF	FV	9	1	23	4	32	21	72	1000
1196	PF	FV	10	1	70	0	81	59	100	1630
1197	PF	FV	11	1	170	46	192	14	14	730
1198	PF	FV	12	1	7	4	41	6	6	610
1199	PF	FV	13	1	66	10	110	27	36	1550
1200	PF	FV	14	1	46	7	63	37	40	4500
1201	PF	FV	15	1	22	8	36	9	21	410
1202	HF	PH	16	1	75	3	70	34	88	2900
1203	SE	MI	17	1	71	2	72	41	85	1140
1204	SE	MI	18	1	48	0	48	38	57	8100
1205	PF	FV	19	1	19	5	29	32	34	13400
1206	PF	FV	20	1	14	13	25	18	32	1400
1207	PF	FV	21	1	25	8	124	17	21	440
1208	PF	FV	22	1	23	8	220	12	24	470
1209	PF	FV	23	1	31	10	70	22	50	360
1210	SE	MI	24	1	60	0	62	81	81	27300
1214	CT	GR	25	1	19	12	21	10	20	500
1215	CT	GR	26	1	9	12	18	9	17	380
1216	PF	FV	27	1	105	5	35	27	93	880
1217	PF	FV	28	1	25	4	32	15	19	700
1218	PF	FV	29	1	115	0	39	52	174	1380
1219	PF	FV	30	1	18	4	30	11	28	440
1220	AF	MV	31	1	29	0	27	18	45	460
1221	AF	MV	32	1	36	0	34	54	43	9100
1222	CT	GR	33	1	10	0	21	9	14	320
1223	CT	GR	34	1	24	3	36	12	32	410
1224	AF	MV	35	1	70	11	54	40	75	1580
1225	AF	MV	36	1	25	8	25	8	16	340
1226	AF	MV	37	1	5	3	19	4	9	220
1227	AF	MV	38	1	12	0	18	7	11	300
1228	AF	MV	39	1	38	0	44	20	38	210
1229	CT	GR	40	1	6	13	23	7	11	240
1230	CT	GR	41	1	12	7	15	5	8	140
1246	PF	FV	42	1	30	18	45	48	37	1750
1247	PF	FV	43	1	22	9	37	40	45	1830
1248	PF	FV	44	1	30	3	43	24	32	1340
1249	PF	FV	45	1	12	6	29	9	18	870
1250	PF	FV	46	1	5	5	19	6	12	450
1251	PF	FV	47	1	28	10	43	21	42	1620
1252	PF	FV	48	1	4	6	16	4	9	250
1253	PF	FV	49	1	8	9	19	6	12	430
1254	PF	FV	50	1	8	8	17	7	6	290
1255	CT	GR	51	1	4	5	14	4	8	140
1263	ST	GT	52	1	14	10	36	9	35	340
1265	ST	GT	53	1	3	3	13	5	12	140
1266	ST	GN	54	1	11	6	24	14	35	900
1267	PF	FV	55	1	5	3	16	7	12	280

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1268	PF	FV	56	1	13	4	29	9	25	560
1339	SE	MI	57	1	61	0	91	34	80	1200
1340	SE	MI	58	1	56	0	65	33	86	1230
1341	HF	PH	59	1	66	14	235	12	28	360
1342	PF	FV	60	1	41	10	173	12	31	320
1343	PF	FV	61	1	33	10	100	15	50	270
1344	PF	FV	62	1	22	6	74	17	20	800
1345	PF	FV	63	1	35	7	64	14	29	620
1356	SE	MI	64	1	51	4	69	42	54	5300
1357	PF	FV	65	1	58	5	172	39	46	2320
1358	PF	FV	66	1	61	5	236	45	34	18000
1370	IM	FV	67	1	25	6	50	15	20	660
1038	IM	FV	68	2	170	32	380	88	89	3920
1039	IM	FV	69	2	134	3	124	69	141	3300
1045	AF	MV	70	2	107	2	82	57	89	2530
1046	AF	MV	71	2	111	0	77	55	94	2670
1068	AF	MV	72	2	110	0	70	70	100	2550
1069	AF	MV	73	2	63	0	72	47	77	1100
1070	AF	MV	74	2	53	0	74	54	280	4250
1071	IM	FV	75	2	76	4	143	65	49	4400
1072	AF	MV	76	2	57	0	108	34	82	3650
1073	AF	MV	77	2	48	3	63	42	47	910
1074	AF	MV	78	2	33	4	47	20	26	770
1075	HF	PH	79	2	97	0	71	65	29	1630
1076	AF	MV	80	2	32	12	57	39	80	2800
1077	IM	FV	81	2	70	0	90	30	59	870
1078	IM	FV	82	2	68	6	106	44	36	3150
1080	AF	MV	83	2	98	0	68	44	65	1980
1081	AF	MV	84	2	120	0	85	66	78	3150
1087	AF	MV	85	2	108	0	72	55	100	2360
1088	AF	MV	86	2	92	0	79	32	79	1120
1089	HF	PH	87	2	42	7	65	23	35	1430
1090	AF	MV	88	2	60	3	121	30	71	2800
1102	AF	MV	89	2	57	0	81	34	64	2900
1104	IM	FV	90	2	57	3	75	35	58	2800
1105	IM	FV	91	2	58	29	245	24	46	5200
1106	HF	PH	92	2	43	9	103	24	29	1480
1107	HF	PH	93	2	75	12	168	37	95	1660
1109	CT	GR	94	2	56	5	73	46	58	3100
1110	HF	PH	95	2	55	9	75	20	35	620
1111	SE	MI	96	2	75	4	142	47	60	1750
1112	AF	MV	97	2	67	0	112	67	56	12300
1113	AF	MV	98	2	161	15	290	105	89	6100
1114	AF	MV	99	2	235	35	810	67	83	2150
1115	AF	MV	100	2	95	0	70	25	75	820
1116	AF	MV	101	2	100	0	116	54	81	4710
1140	PF	FV	102	2	30	16	92	12	15	310
1194	HF	PH	103	2	60	0	62	100	59	1080
1195	SE	MI	104	2	62	8	142	72	42	3200
1346	AF	MV	105	2	290	45	850	85	97	3110
1347	AF	MV	106	2	113	0	125	63	110	3170
1348	AF	MV	107	2	105	0	91	68	111	3150
1349	HF	PH	108	2	210	57	265	50	57	1390
1350	HF	PH	109	2	150	13	530	51	57	2820
1351	HF	PH	110	2	81	5	210	65	64	3830

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1352	AF	MV	111	2	90	7	150	45	67	2100
1353	AF	MV	112	2	62	7	106	37	57	2380
1354	AF	MV	113	2	84	0	77	60	77	2800
1355	AF	MV	114	2	101	0	84	53	82	2390
1368	HF	PH	115	2	36	7	57	26	37	1070
1369	HF	PH	116	2	34	8	56	23	36	1820
1374	IM	FV	117	2	21	8	80	10	14	350
1001	IM	FV	118	3	24	10	34	17	32	460
1002	IM	FV	119	3	56	8	52	41	55	3710
1003	IM	FV	120	3	56	0	67	36	68	1980
1011	IM	FV	121	3	205	0	82	39	65	1470
1012	ST	GN	122	3	34	7	42	22	37	1140
1013	TE	FP	123	3	26	15	42	14	24	710
1014	TE	FP	124	3	29	30	44	9	23	310
1015	IM	FV	125	3	23	21	44	18	39	580
1016	IM	FV	126	3	17	10	32	23	29	830
1017	ST	GN	127	3	13	21	28	7	13	320
1018	ST	GT	128	3	7	10	15	3	8	110
1019	ST	GT	129	3	5	13	23	4	3	430
1020	IM	FV	130	3	93	3	54	24	36	1070
1021	IM	FV	131	3	24	6	54	25	47	1350
1022	ST	GT	132	3	6	16	27	6	7	690
1023	IM	FV	133	3	11	7	22	14	22	830
1024	IM	FV	134	3	18	9	40	16	42	810
1025	IM	FV	135	3	7	8	18	3	8	340
1026	IM	FV	136	3	17	9	34	8	27	200
1027	IM	FV	137	3	14	8	36	8	21	200
1028	IM	FV	138	3	13	9	33	7	19	420
1029	IM	FV	139	3	11	9	30	7	15	400
1034	AF	MV	140	3	64	0	67	57	54	5150
1035	AF	MV	141	3	50	0	67	66	65	15100
1036	AF	MV	142	3	19	30	48	23	28	1030
1037	HF	PH	143	3	90	0	79	45	41	2490
1047	AF	MV	144	3	183	0	75	36	68	4900
1048	IM	FV	145	3	45	15	54	25	35	640
1049	IM	FV	146	3	50	6	51	26	43	2550
1050	AF	MV	147	3	90	8	61	48	62	2070
1051	AF	MV	148	3	125	0	66	44	81	2200
1052	ST	GN	149	3	100	0	96	41	74	1800
1053	AF	MV	150	3	85	0	87	71	200	2450
1054	AF	MV	151	3	80	0	92	40	57	2520
1055	AF	MV	152	3	85	3	110	42	71	2000
1056	AF	MV	153	3	95	4	130	61	161	2450
1057	AF	MV	154	3	100	0	95	52	82	3400
1058	AF	MV	155	3	92	19	145	40	54	1880
1059	AF	MV	156	3	71	0	75	46	58	3050
1060	AF	MV	157	3	100	0	84	53	67	2100
1061	IM	FV	158	3	35	13	45	22	38	750
1062	IM	FV	159	3	20	9	41	11	28	620
1063	IM	FV	160	3	9	5	20	7	10	390
1064	IM	FV	161	3	13	7	32	9	16	270
1065	IM	FV	162	3	16	5	33	10	19	440
1066	IM	FV	163	3	14	7	36	11	21	410
1337	IM	FV	164	3	83	8	60	39	41	1150
1338	IM	FV	165	3	19	10	38	10	22	500

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2218	ST	MD	166	4	92	0	55	17	38	650
2219	ST	GT	167	4	53	10	51	20	23	1180
2220	ST	MD	168	4	105	8	61	32	33	1710
2221	ST	GT	169	4	19	4	31	12	11	700
2222	ST	GT	170	4	22	8	49	16	17	1210
2223	ST	GT	171	4	18	12	45	15	21	950
2224	ST	GT	172	4	12	10	29	7	15	350
2225	ST	GT	173	4	26	20	46	11	16	700
2226	ST	GT	174	4	28	17	57	21	25	1310
2257	ST	MD	175	4	20	5	35	9	6	1000
2258	ST	MD	176	4	17	3	26	11	11	810
2260	ST	GT	177	4	56	3	53	40	16	1760
2261	ST	GT	178	4	14	3	23	7	3	550
2262	ST	GT	179	4	30	3	30	13	8	700
2263	ST	GT	180	4	12	0	23	6	5	430
2264	ST	GT	181	4	18	4	30	9	6	550
2265	ST	GT	182	4	5	4	20	4	3	390
2266	ST	GT	183	4	32	3	41	15	10	1050
2267	ST	GT	184	4	49	6	41	17	11	1140
2268	ST	GT	185	4	53	4	41	16	11	820
2269	ST	MD	186	4	60	4	42	16	14	1110
2270	ST	GT	187	4	11	14	41	9	11	730
2271	ST	GT	188	4	14	15	27	3	5	330
2272	ST	MD	189	4	9	16	21	8	12	650
2273	ST	MD	190	4	11	7	21	4	7	330
2274	ST	GT	191	4	20	8	40	15	25	580
2275	ST	GT	192	4	38	7	47	20	50	650
2276	ST	GT	193	4	32	6	34	18	46	450
2277	ST	GT	194	4	36	7	46	20	53	660
2278	ST	GT	195	4	23	4	29	16	34	730
2279	ST	GT	196	4	23	24	41	19	31	860
2280	ST	GT	197	4	7	12	26	4	5	360
2281	ST	GT	198	4	6	15	27	5	5	380
2282	ST	GT	199	4	5	13	27	4	4	400
2283	ST	GT	200	4	11	21	40	5	5	420
2284	ST	GT	201	4	7	16	30	6	8	400
2285	ST	GT	202	4	6	10	20	7	9	350
2286	ST	GT	203	4	18	10	33	13	32	420
2287	ST	GT	204	4	15	10	31	11	27	390
2288	ST	GT	205	4	20	6	36	15	45	500
2289	IM	FV	206	4	50	4	44	25	62	930
2290	IM	FV	207	4	49	7	50	41	51	3300
2291	IM	FV	208	4	36	8	64	43	55	4500
2292	AF	MV	209	4	15	0	20	7	19	260
2293	AF	MV	210	4	54	3	60	41	53	2120
2294	AF	MV	211	4	17	0	20	7	19	220
2295	AF	MV	212	4	24	0	37	23	36	1660
2296	CT	GR	213	4	11	0	18	9	30	300
2297	AF	MV	214	4	4	0	8	4	12	180
2298	AF	MV	215	4	11	0	22	9	14	580
2299	AF	MV	216	4	28	0	43	23	33	1460
2300	AF	MV	217	4	55	0	61	32	49	1900
2301	AF	MV	218	4	37	0	47	46	49	2650
2302	AF	MV	219	4	58	0	61	50	61	1410
1030	AF	MV	220	5	53	0	110	52	50	1960

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1031	AF	MV	221	5	56	0	93	45	56	2120
1032	AF	MV	222	5	62	0	85	30	56	630
1033	IM	FV	223	5	19	29	44	22	26	1020
2216	ST	MD	224	5	97	8	38	25	34	860
2217	ST	GT	225	5	29	5	33	16	36	870
2227	IM	FV	226	5	38	5	50	35	60	2060
2228	ST	GT	227	5	18	14	42	5	14	420
2229	ST	GT	228	5	34	7	46	17	44	780
2230	ST	GT	229	5	27	7	43	18	35	930
2231	CT	GR	230	5	16	5	36	11	33	420
2232	IM	FV	231	5	20	3	46	19	51	670
2233	ST	MD	232	5	58	6	68	27	50	1960
2234	ST	GT	233	5	9	0	21	8	26	260
2235	ST	GT	234	5	26	0	49	27	82	860
2236	IM	FV	235	5	26	0	43	28	51	1000
2237	ST	GT	236	5	41	0	26	17	64	550
2238	ST	GT	237	5	26	0	37	17	50	630
2239	ST	GT	238	5	28	0	30	15	62	630
2240	IM	FV	239	5	29	0	39	22	65	890
2241	IM	FV	240	5	54	15	58	42	66	3470
2242	IM	FV	241	5	54	3	69	33	42	1830
2243	IM	FV	242	5	25	0	39	18	29	680
2244	IM	FV	243	5	57	3	70	29	40	1850
2245	AF	MV	244	5	42	3	53	33	42	1920
2246	AF	MV	245	5	54	0	94	43	56	2360
2247	AF	MV	246	5	54	6	90	37	54	1950
2248	AF	MV	247	5	59	0	96	44	55	3300
2249	IM	MD	248	5	37	0	74	20	21	1640
2250	AF	MV	249	5	83	0	90	41	80	2130
2251	AF	MV	250	5	76	3	86	49	78	2200
2252	AF	MV	251	5	75	11	102	44	79	2650
2253	AF	MV	252	5	34	4	58	23	39	970
2254	AF	MV	253	5	44	5	96	25	47	470
2255	AF	MV	254	5	61	0	74	32	63	1740
2256	AF	MV	255	5	54	0	73	30	57	1820
2303	IM	FV	256	5	21	3	32	20	43	890
2304	AF	MV	257	5	61	7	52	35	69	1370
2305	AF	MV	258	5	43	26	58	61	66	1280
2306	AF	MV	259	5	80	16	81	55	91	3710
2307	AF	MV	260	5	71	16	126	39	66	2710
2308	AF	MV	261	5	68	6	88	45	75	2580
2309	AF	MV	262	5	30	0	63	33	34	4420
2310	AF	MV	263	5	43	9	77	40	52	4750
2311	AF	MV	264	5	60	0	88	31	55	1930
2312	AF	MV	265	5	37	7	59	29	32	3850
2313	AF	MV	266	5	44	0	61	21	63	750
2314	AF	MV	267	5	39	0	92	33	38	1660
2315	AF	MV	268	5	52	0	76	37	90	890
2316	AF	MV	269	5	69	3	76	57	65	3920
2317	AF	MV	270	5	33	0	45	86	58	37500
2322	TE	FP	271	5	50	9	60	54	39	8700
2323	AF	MV	272	5	56	3	78	40	84	2100
2324	AF	MV	273	5	35	5	75	29	81	1660
2325	AF	MV	274	5	82	7	57	54	105	3470
2326	AF	MV	275	5	24	0	49	44	35	4290

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2327	AF	MV	276	5	77	0	96	46	73	2480
2328	AF	MV	277	5	62	4	96	36	47	2180
2329	AF	MV	278	5	40	52	102	23	43	1540
2330	TE	FP	279	5	63	6	47	23	30	1030
2331	TE	MD	280	5	88	5	68	29	57	920
2332	AF	MV	281	5	105	5	76	37	61	1180
2333	TE	FP	282	5	42	8	27	15	28	490
2334	TE	FP	283	5	52	12	40	15	24	470
2335	TE	FP	284	5	13	10	33	13	29	500
2336	TE	MD	285	5	11	10	24	10	19	360
2337	AF	MV	286	5	51	4	68	28	60	3850
2338	AF	MV	287	5	70	3	65	36	62	1920
2339	IM	FV	288	5	21	0	33	22	47	1080
2340	AF	MV	289	5	83	22	82	32	63	1650
2341	AF	MV	290	5	52	20	82	31	70	1640
2342	AF	MV	291	5	59	9	51	36	65	1770
2343	AF	MV	292	5	50	3	78	39	53	2040
2344	AF	MV	293	5	51	5	79	31	47	1340
2345	AF	MV	294	5	67	0	71	37	72	1970
2346	AF	MV	295	5	37	0	71	31	106	2000
2347	AF	MV	296	5	45	3	119	33	91	1750
2348	AF	MV	297	5	50	0	73	31	67	1600
2349	AF	MV	298	5	38	3	58	25	43	1360
2350	AF	MV	299	5	61	4	65	31	57	1760
2351	AF	MV	300	5	37	0	67	31	67	1670
2352	AF	MV	301	5	85	4	85	37	74	2150
2353	AF	MV	302	5	58	4	53	32	58	1390
2354	AF	MV	303	5	41	9	36	20	28	680
2355	AF	MV	304	5	75	0	88	32	71	1740
2356	AF	MV	305	5	80	0	71	33	81	1660
2357	AF	MV	306	5	83	0	75	36	82	1980
2358	AF	MV	307	5	75	0	60	38	78	1650
2359	AF	MV	308	5	62	0	58	29	63	980
2360	AF	MV	309	5	65	0	64	44	75	2000
2361	AF	MV	310	5	85	0	61	51	92	2150
2362	AF	MV	311	5	81	0	66	49	84	2050
2363	AF	MV	312	5	78	0	60	46	85	1900
2365	AF	MV	313	5	60	0	65	31	73	1810
2366	AF	MV	314	5	22	8	40	18	19	1270
2053	ST	MD	315	6	59	23	45	21	15	1250
2054	ST	MD	316	6	61	17	43	17	20	450
2055	CT	GR	317	6	105	6	57	29	32	1550
2056	CT	GR	318	6	25	9	29	11	12	610
2057	CT	GR	319	6	6	30	15	3	7	330
2058	CT	GR	320	6	2	8	11	1	4	120
2059	CT	GR	321	6	4	20	28	1	5	230
2060	CT	GR	322	6	1	13	11	1	2	220
2061	CT	GR	323	6	2	8	12	1	2	140
2062	CT	GR	324	6	3	15	14	2	5	170
2063	CT	MD	325	6	13	0	20	7	12	580
2064	CT	GR	326	6	4	8	14	3	4	180
2065	CT	MD	327	6	31	15	34	9	10	510
2098	CT	GR	328	6	3	8	9	3	3	150
2099	CT	GR	329	6	3	47	21	3	5	400
2100	CT	GR	330	6	3	17	13	2	3	210

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2101	CT	GR	331	6	5	60	21	2	4	380
2102	AF	MV	332	6	61	3	51	28	55	920
2103	CT	GR	333	6	46	22	61	39	43	2210
2105	CT	GR	334	6	6	35	34	3	9	280
2401	ST	GT	335	6	5	16	31	4	6	380
2402	ST	GT	336	6	8	15	40	4	6	380
2403	ST	GT	337	6	17	16	43	7	9	530
2404	ST	GT	338	6	19	11	16	4	15	230
2405	CT	GR	339	6	20	8	14	8	19	230
2406	CT	GR	340	6	5	20	19	4	6	260
2407	CT	GR	341	6	6	16	20	3	6	280
2408	CT	GR	342	6	6	16	22	4	7	370
2409	CT	GR	343	6	6	15	17	4	10	310
2410	ST	GT	344	6	4	14	14	2	6	210
2411	ST	GT	345	6	18	21	32	15	19	680
2412	CT	GR	346	6	5	12	16	3	5	240
2413	CT	GR	347	6	4	12	15	4	4	270
2414	CT	GR	348	6	2	12	13	2	2	360
2415	CT	GR	349	6	6	20	21	6	6	1080
2416	CT	GR	350	6	5	25	19	3	5	370
2418	CT	GR	351	6	4	28	21	2	7	270
2419	ST	GT	352	6	9	23	44	7	30	420
2420	ST	GT	353	6	9	27	30	9	23	540
2421	ST	GT	354	6	9	10	14	3	9	210
2422	CT	GR	355	6	13	24	19	7	16	320
2423	ST	GT	356	6	10	13	15	5	13	230
2424	ST	GT	357	6	7	18	22	5	14	250
2425	ST	GN	358	6	10	19	12	4	10	230
2426	ST	GT	359	6	9	20	34	8	23	470
2427	ST	GT	360	6	7	20	39	10	16	1480
2428	ST	GT	361	6	4	13	19	3	9	320
2429	ST	GT	362	6	28	17	34	15	39	420
2430	ST	GT	363	6	35	20	60	26	41	2000
2438	CT	GR	364	6	8	80	44	4	7	810
2439	CT	GR	365	6	12	40	25	7	10	310
2440	CT	GR	366	6	10	71	30	8	10	420
2106	CT	GR	367	7	14	29	37	8	22	410
2107	CT	GR	368	7	7	31	33	5	10	330
2108	CT	GR	369	7	8	32	24	4	4	320
2109	CT	GR	370	7	1	9	8	2	2	130
2110	CT	GR	371	7	3	17	16	3	5	250
2111	CT	GR	372	7	3	28	9	4	8	220
2112	CT	GR	373	7	2	10	10	2	2	140
2113	CT	GR	374	7	4	10	26	4	13	210
2114	CT	GR	375	7	4	23	133	2	3	300
2115	IM	FV	376	7	7	37	38	5	7	450
2116	CT	GR	377	7	2	47	23	2	3	510
2117	CT	GR	378	7	2	19	19	3	4	230
2118	CT	GR	379	7	7	26	24	5	9	320
2119	CT	GR	380	7	6	39	24	3	6	420
2120	CT	GR	381	7	3	33	23	3	5	330
2121	CT	GR	382	7	6	36	39	10	11	1040
2122	CT	GR	383	7	9	33	51	7	11	940
2123	CT	GR	384	7	2	14	14	2	5	160
2124	CT	GR	385	7	9	53	41	4	12	380

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2125	CT	GR	386	7	16	31	27	6	15	290
2126	CT	GR	387	7	6	15	19	4	12	220
2127	CT	GR	388	7	9	35	30	7	13	550
2128	CT	GR	389	7	3	21	17	2	6	150
2417	CT	GR	390	7	14	12	20	5	13	380
2628	CT	GR	391	7	12	46	41	7	12	860
2629	CT	GR	392	7	14	17	29	13	22	750
2630	CT	GR	393	7	6	18	24	6	11	530
2631	CT	GR	394	7	6	25	32	10	6	760
2632	CT	GR	395	7	14	28	29	16	13	850
2633	CT	GR	396	7	6	10	14	9	13	330
2634	IM	FV	397	7	9	15	41	14	25	500
2635	IM	FV	398	7	6	28	23	6	8	360
2636	IM	FV	399	7	5	47	30	6	7	370
2637	IM	FV	400	7	4	45	31	5	6	390
2638	CT	GR	401	7	5	38	31	6	5	610
2639	CT	GR	402	7	5	28	20	5	8	360
2640	CT	GR	403	7	5	36	28	5	6	520
2641	CT	GR	404	7	8	25	27	8	11	310
2642	CT	GR	405	7	17	16	50	15	52	460
2643	CT	GR	406	7	8	31	34	6	10	480
2622	CT	GR	407	8	5	40	26	6	6	530
2623	CT	GR	408	8	9	50	37	10	7	820
2649	CT	MD	409	8	147	9	70	32	28	1330
2650	CT	MD	410	8	66	29	47	24	12	1250
2651	CT	GR	411	8	61	26	88	22	13	880
2652	CT	MD	412	8	121	22	60	25	22	1130
2653	CT	GR	413	8	6	65	29	3	6	420
2654	CT	GR	414	8	6	230	43	3	4	800
2691	CT	GR	415	8	6	35	29	5	14	680
2692	CT	GR	416	8	4	23	23	1	6	220
2693	CT	GR	417	8	7	40	33	4	6	730
2694	CT	MD	418	8	90	38	62	19	14	1500
2695	CT	MD	419	8	70	23	54	17	11	1400
2696	CT	GR	420	8	4	35	24	2	4	350
2442	CT	GR	421	9	5	13	14	1	2	210
2452	ST	GT	422	9	66	10	46	21	16	950
2453	AF	MV	423	9	11	15	17	7	11	280
2454	AF	MV	424	9	5	26	7	8	2	420
2455	AF	MV	425	9	24	14	24	11	31	310
2614	CT	GR	426	9	15	19	21	6	5	240
2615	CT	GR	427	9	23	17	20	6	5	260
2616	CT	GR	428	9	13	23	21	6	4	280
2617	CT	GR	429	9	9	25	24	4	6	210
2618	CT	GR	430	9	5	26	20	4	4	360
2619	CT	GR	431	9	14	37	26	7	8	310
2620	CT	GR	432	9	6	27	24	6	7	530
2621	CT	GR	433	9	10	50	35	6	12	340
2670	CT	GR	434	9	36	51	44	9	15	390
2678	CT	MD	435	10	72	12	75	24	10	1140
2679	ST	GT	436	10	33	18	35	13	10	840
2680	ST	GT	437	10	37	33	41	10	4	990
2681	ST	GT	438	10	31	25	32	8	5	540
2682	ST	GT	439	10	11	44	27	3	6	260
2683	ST	GT	440	10	5	12	14	2	4	250

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2684	CT	GR	441	10	4	30	23	2	3	350
2685	ST	GT	442	10	3	10	9	3	3	150
2686	ST	GT	443	10	12	20	19	5	24	170
2688	AF	MV	444	10	25	6	24	31	100	1500
2689	AF	MV	445	10	45	19	69	33	97	1360
2690	ST	GT	446	10	9	24	23	11	17	760
2582	CT	GR	447	11	46	17	40	47	90	1650
2583	AF	MV	448	11	46	0	44	44	106	2600
2584	AF	MV	449	11	79	0	88	47	91	1810
2587	PF	FV	450	11	112	0	138	50	84	4540
2588	PF	FV	451	11	139	0	247	73	160	3800
2589	PF	FV	452	11	105	0	163	56	76	2100
2590	AF	MV	453	11	120	0	93	60	92	2100
2591	ST	GN	454	11	34	0	40	26	47	950
2592	ST	GN	455	11	53	6	40	30	61	1260
2593	ST	GN	456	11	16	8	18	12	22	430
2594	PF	FV	457	11	66	0	69	52	130	3550
2595	ST	GN	458	11	46	6	53	32	55	2100
2596	AF	MV	459	11	37	6	83	12	34	500
2597	PF	FV	460	11	48	5	71	26	47	920
2598	ST	GN	461	11	45	18	64	20	42	420
2599	ST	GN	462	11	13	29	23	7	11	270
2600	ST	GN	463	11	34	12	35	13	39	280
2601	ST	GN	464	11	61	14	44	30	50	920
2602	PF	FV	465	11	41	6	66	24	60	880
2603	PF	FV	466	11	81	15	175	43	91	2850
2607	ST	GN	467	11	5	20	19	4	6	230
2608	ST	MD	468	11	76	0	43	27	30	1330
2609	ST	GN	469	11	12	22	24	9	9	560
2610	ST	GN	470	11	5	14	22	4	5	230
2611	ST	GN	471	11	8	22	17	6	25	280
2612	ST	GN	472	11	24	26	26	8	8	260
2613	ST	GN	473	11	5	22	34	7	3	1100
2811	ST	GT	474	12	2	10	12	2	12	440
2812	ST	GT	475	12	2	10	12	2	11	190
2813	ST	GT	476	12	2	20	18	2	6	230
2814	ST	GT	477	12	1	10	8	1	5	70
2815	ST	GT	478	12	1	10	7	1	5	90
2816	ST	GT	479	12	4	10	13	0	6	160
2817	ST	GT	480	12	2	10	11	1	5	180
2818	AF	MV	481	12	35	0	28	24	51	1100
2819	AF	MV	482	12	22	0	26	18	34	980
2820	AF	MV	483	12	56	0	33	19	41	1150
2821	AF	MV	484	12	30	0	30	11	32	930
2822	AF	MV	485	12	41	0	25	21	50	2020
2823	AF	MV	486	12	25	10	20	22	24	1100
2824	ST	GT	487	12	6	10	12	3	13	180
2829	ST	GN	488	12	3	10	11	1	3	150
2830	CT	GR	489	12	70	0	63	16	6	2100
2831	CT	MD	490	12	3	20	20	1	4	650
2832	ST	GT	491	12	2	20	8	2	9	130
2833	ST	GT	492	12	5	20	19	3	14	430
2834	ST	GT	493	12	1	20	16	2	7	330
2835	ST	GT	494	12	1	20	17	2	8	270
2836	CT	GR	495	12	2	20	21	3	12	290

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
2843	ST	GT	496	12	3	10	11	1	2	210
2710	ST	GN	497	13	4	20	10	2	1	80
2711	ST	GN	498	13	2	20	10	2	0	100
2712	ST	GN	499	13	3	30	19	2	2	300
2713	ST	GN	500	13	8	30	43	5	5	800
2714	ST	GN	501	13	2	50	18	2	0	300
2715	CT	GR	502	13	31	20	41	9	10	670
2716	CT	GR	503	13	6	20	21	3	2	320
2717	CT	GR	504	13	3	40	33	3	2	400
2718	CT	GR	505	13	48	30	52	19	11	730
2724	ST	GN	506	13	2	10	8	4	2	120
2725	ST	GN	507	13	6	20	15	6	13	190
2729	ST	GN	508	13	3	20	14	4	3	130
2730	ST	GN	509	13	3	20	12	5	2	210
2731	CT	GR	510	13	11	20	20	7	0	510
2765	ST	GN	511	13	3	20	16	3	4	290
2766	ST	GN	512	13	1	20	15	1	3	210
2767	ST	GN	513	13	0	10	12	1	4	210
2768	ST	GN	514	13	2	30	21	1	4	500
1780	CT	GR	516	15	11	30	17	5	6	300
1781	CT	GR	517	15	24	11	31	8	16	380
1782	ST	GT	518	15	4	25	14	1	4	200
1783	CT	GR	519	15	11	24	21	6	8	330
1784	ST	GT	520	15	4	7	18	3	8	160
1785	CT	GR	521	15	16	22	24	7	11	520
1786	CT	GR	522	15	5	13	67	3	4	2080
1787	CT	GR	523	15	2	14	18	1	1	280
1788	CT	GR	524	15	4	12	25	3	4	230
1789	ST	GT	525	15	4	11	9	2	2	160
1790	CT	GR	526	15	4	12	19	2	3	210
1791	CT	GR	527	15	4	21	12	6	3	270
1800	CT	GR	528	15	4	24	17	4	5	130
1801	CT	GR	529	15	16	21	25	9	22	240
1802	CT	GR	530	15	11	30	25	6	8	210
1803	CT	GR	531	15	5	28	15	5	8	170
1804	CT	GR	532	15	5	23	22	4	6	310
1805	CT	GR	533	15	11	12	29	8	6	340
1806	CT	GR	534	15	2	11	14	2	2	310
1807	CT	GR	535	15	7	30	19	4	2	350
1808	CT	GR	536	15	4	14	13	6	6	200
1809	CT	GR	537	15	4	17	26	6	4	330
1810	CT	GR	538	15	11	15	47	2	3	190
1811	CT	GR	539	15	4	20	18	2	4	190
1812	CT	GR	540	15	2	17	11	1	2	60
1813	CT	GR	541	15	6	20	17	3	11	80
1828	CT	GR	542	15	2	24	15	1	2	120
1829	CT	GR	543	15	4	15	17	1	2	160
1830	CT	GR	544	15	3	20	19	5	7	360
1831	CT	GR	545	15	4	45	34	3	3	480
2837	CT	GR	546	15	1	30	7	1	2	200
2838	CT	GR	547	15	1	10	4	0	3	100
2839	ST	GN	548	15	6	20	7	2	6	90
2840	CT	GR	549	15	2	30	8	0	3	130
1775	CT	GR	550	16	10	33	26	6	9	310
1776	CT	GR	551	16	4	28	13	1	5	180

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1777	CT	GR	552	16	4	12	15	1	3	250
1778	CT	GR	553	16	8	19	14	2	4	160
1779	ST	GT	554	16	3	12	12	2	4	260
2578	AF	MV	555	16	20	9	30	15	38	820
2579	PF	FV	556	16	26	0	39	67	54	1640
2580	AF	MV	557	16	11	0	22	10	24	570
2581	AF	MV	558	16	61	0	44	38	96	910
2844	ST	GT	559	16	2	10	11	1	2	210
2845	ST	GT	560	16	3	10	13	1	7	180
2846	ST	GT	561	16	2	10	9	0	4	160
2847	ST	GT	562	16	5	10	15	2	7	100
2848	ST	GT	563	16	3	10	14	1	5	230
2849	ST	GT	564	16	9	10	12	1	11	80
2850	ST	GT	565	16	4	10	5	0	6	80
2851	AF	MV	566	16	42	0	21	9	45	310
2852	ST	GT	567	16	3	10	10	0	2	200
2853	ST	GT	568	16	2	10	6	1	3	100
2859	ST	GT	569	16	3	10	5	1	3	70
2860	ST	GT	570	16	4	20	23	2	4	260
2861	ST	GT	571	16	1	10	11	0	3	240
2862	ST	GT	572	16	4	20	21	1	12	210
2863	ST	GT	573	16	2	20	8	1	7	150
2864	ST	GT	574	16	3	10	8	1	4	110
2865	ST	GT	575	16	2	10	7	2	2	210
2912	AF	MV	576	16	93	0	71	32	75	1290
2913	AF	MV	577	16	73	0	60	51	93	1840
2916	AF	MV	578	16	96	0	74	68	106	2400
2917	AF	MV	579	16	26	0	37	26	57	720
2918	AF	MV	580	16	70	10	354	45	128	1500
2919	AF	MV	581	16	68	0	58	36	80	1160
2920	AF	MV	582	16	74	0	53	37	174	1330
2921	AF	MV	583	16	76	0	47	66	104	2050
2922	AF	MV	584	16	81	0	28	50	88	1540
2923	AF	MV	585	16	26	0	27	34	93	1150
2924	AF	MV	586	16	53	0	44	70	130	2000
2931	AF	MV	587	16	154	0	177	53	150	1300
2938	AF	MV	588	16	9	0	13	7	10	310
2939	ST	GT	589	16	12	0	14	5	3	240
2940	ST	GT	590	16	8	10	16	6	8	200
2941	ST	GT	591	16	10	0	17	7	11	200
2942	ST	GT	592	16	2	10	10	4	4	170
2943	AF	MV	593	16	24	10	27	18	34	670
2944	AF	MV	594	16	73	0	53	40	100	1000
2976	AF	MV	595	16	86	0	49	32	103	940
2977	AF	MV	596	16	16	0	18	11	88	330
2978	ST	GT	597	16	2	10	19	0	4	180
2979	ST	GT	598	16	0	10	11	0	3	70
1741	CT	GR	599	17	21	7	41	11	20	600
1742	CT	GR	600	17	13	13	32	5	3	450
1743	AF	MV	601	17	13	12	29	6	10	340
1744	AF	MV	602	17	12	11	28	7	8	500
1745	AF	MV	603	17	28	23	75	25	30	1610
1746	AF	MV	604	17	86	4	54	35	88	1310
1747	ST	GT	605	17	3	15	15	4	4	170
1758	ST	GT	606	17	14	9	17	22	18	800

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1759	AF	MV	607	17	58	0	49	35	61	2150
1761	ST	GT	608	17	7	4	19	11	12	370
1762	ST	GT	609	17	15	8	12	10	17	300
1763	ST	GT	610	17	22	16	25	14	27	400
1764	ST	GT	611	17	9	7	23	13	8	860
1765	ST	GT	612	17	9	8	15	7	17	310
1766	ST	GT	613	17	12	7	19	12	14	710
1767	ST	GT	614	17	16	5	17	13	22	420
1768	AF	MV	615	17	110	3	55	42	97	1830
1769	AF	MV	616	17	83	3	45	58	173	1710
1770	AF	MV	617	17	115	5	60	31	149	880
1771	AF	MV	618	17	26	13	20	17	41	620
1772	AF	MV	619	17	12	17	12	10	23	380
1773	AF	MV	620	17	19	18	19	18	33	800
1774	AF	MV	621	17	23	8	22	13	33	470
2570	AF	MV	622	17	47	0	33	33	63	1400
2571	AF	MV	623	17	63	107	64	39	84	2900
2925	AF	MV	624	17	27	0	23	23	51	1080
2926	AF	MV	625	17	75	130	195	88	183	1840
2927	AF	MV	626	17	43	20	58	35	68	1300
2928	AF	MV	627	17	42	70	74	41	94	520
2929	AF	MV	628	17	54	260	102	18	120	240
2930	AF	MV	629	17	139	0	82	75	85	2900
2932	AF	MV	630	17	57	0	37	26	110	560
2933	AF	MV	631	17	41	0	28	37	250	800
2934	AF	MV	632	17	52	10	49	30	97	1430
2935	AF	MV	633	17	59	0	44	42	125	1150
2936	AF	MV	634	17	88	0	54	50	100	1620
2937	AF	MV	635	17	21	0	23	21	68	650
2945	AF	MV	636	17	36	0	26	15	95	320
2946	AF	MV	637	17	40	0	30	36	188	1000
2947	AF	MV	638	17	102	0	84	43	96	1000
2948	AF	MV	639	17	20	0	19	22	49	500
2949	AF	MV	640	17	115	0	78	43	96	1170
2950	AF	MV	641	17	74	0	61	90	110	3020
2951	AF	MV	642	17	102	0	65	89	127	2900
2952	AF	MV	643	17	63	0	48	63	95	2050
2953	AF	MV	644	17	50	0	46	36	82	830
2954	AF	MV	645	17	105	0	60	45	102	1500
2955	AF	MV	646	17	77	0	54	31	91	1320
2956	AF	MV	647	17	123	0	63	58	136	2300
2957	AF	MV	648	17	110	0	57	61	104	2400
2958	AF	MV	649	17	107	0	62	60	81	2150
2959	AF	MV	650	17	102	0	49	57	100	2110
2960	AF	MV	651	17	41	0	37	40	60	680
2961	AF	MV	652	17	12	10	25	12	13	300
2962	AF	MV	653	17	57	0	36	31	65	1040
2963	AF	MV	654	17	112	0	54	73	127	2400
2964	AF	MV	655	17	7	10	25	4	6	690
2965	AF	MV	656	17	2	0	11	4	4	90
2966	AF	MV	657	17	47	0	63	23	38	1050
2967	AF	MV	658	17	98	0	55	65	134	2450
1717	PF	FV	659	18	42	6	100	39	62	1850
1718	SE	MI	660	18	65	7	168	29	45	1750
1719	PF	FV	661	18	31	0	88	89	62	5200

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1720	SE	MI	662	18	75	7	196	27	60	1070
1721	AF	MV	663	18	84	0	105	20	59	1240
1722	AF	MV	664	18	37	0	100	21	38	1160
1730	PF	FV	665	18	12	7	31	6	15	5600
1731	PF	FV	666	18	15	9	56	10	23	2750
1732	PF	FV	667	18	25	7	53	13	30	1410
1733	PF	FV	668	18	14	2	32	11	14	1320
1734	PF	FV	669	18	7	15	28	9	18	1220
1735	PF	FV	670	18	11	26	25	4	23	150
1736	AF	MV	671	18	14	0	21	8	18	250
1737	AF	MV	672	18	15	6	19	10	18	310
1749	ST	GT	673	18	2	7	31	30	25	1650
1750	ST	GT	674	18	25	12	46	20	30	1000
1751	ST	GT	675	18	13	8	31	11	18	520
1752	ST	GT	676	18	14	18	72	20	31	1150
1753	ST	GT	677	18	15	6	37	14	21	920
1754	ST	GT	678	18	17	8	21	10	18	230
1755	AF	MV	679	18	82	0	110	38	67	2500
1756	AF	MV	680	18	47	4	62	20	44	1220
1757	AF	MV	681	18	80	0	89	31	69	2900
1760	AF	MV	682	18	68	0	35	24	60	950
2018	HF	PH	683	18	17	7	42	14	23	530
2019	SE	MI	684	18	49	5	146	25	60	1040
2020	PF	FV	685	18	31	11	83	17	56	1380
2021	PF	FV	686	18	29	12	78	14	34	1110
2022	SE	MI	687	18	68	5	115	26	51	1290
2023	AF	MV	688	18	68	0	76	30	64	2600
2024	AF	MV	689	18	71	0	85	29	58	1960
2025	AF	MV	690	18	120	0	142	35	73	2200
2026	AF	MV	691	18	65	0	69	28	63	1840
2027	AF	MV	692	18	56	0	61	27	67	2020
2028	AF	MV	693	18	90	8	160	27	58	1620
2029	HF	PH	694	18	78	0	93	21	61	1640
2030	PF	FV	695	18	67	4	84	14	55	840
2031	PF	FV	696	18	73	8	108	22	57	1810
2032	PF	FV	697	18	29	0	42	19	25	1790
2555	PF	FV	698	18	36	10	31	26	34	1520
2556	PF	FV	699	18	69	9	106	26	61	1600
2557	PF	FV	700	18	62	0	75	79	82	9200
2558	PF	FV	701	18	62	0	56	32	68	1500
2559	HF	PH	702	18	75	0	76	43	76	2300
2560	HF	PH	703	18	68	0	56	44	76	1510
2968	AF	MV	704	18	95	0	54	58	95	2400
2969	AF	MV	705	18	71	0	55	39	69	2300
2970	AF	MV	706	18	99	0	54	60	117	2700
2971	AF	MV	707	18	85	0	74	120	92	10400
1704	HF	PH	708	19	44	84	200	77	76	35000
1705	PF	FV	709	19	43	11	81	24	30	1100
1706	PF	MD	710	19	53	7	125	33	26	2040
1707	PF	FV	711	19	11	5	28	7	10	490
1708	PF	FV	712	19	22	9	64	29	27	1570
1709	PF	FV	713	19	29	5	106	38	25	1530
1710	PF	MD	714	19	54	10	57	25	23	1620
1711	PF	FV	715	19	17	8	38	10	15	480
1712	PF	FV	716	19	30	10	62	17	22	790

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1713	PF	FV	717	19	35	4	71	20	32	690
1714	HF	PH	718	19	90	10	206	44	68	3100
1715	PF	FV	719	19	45	8	95	35	48	2950
1716	PF	FV	720	19	42	5	96	52	69	870
1723	PF	FV	721	19	20	14	37	15	28	1440
1724	PF	FV	722	19	17	7	51	34	28	2950
1725	AF	MV	723	19	48	7	196	31	39	2350
1726	AF	MV	724	19	38	22	95	17	42	1970
1727	PF	FV	725	19	21	15	31	13	14	680
1728	CT	GR	726	19	12	23	32	6	10	1760
1729	PF	FV	727	19	12	16	38	8	11	570
1738	CT	GR	728	19	9	24	30	8	6	740
1739	CT	GR	729	19	60	21	30	15	19	350
1740	CT	GR	730	19	9	19	25	5	9	340
2001	AF	MV	731	19	71	6	91	25	32	440
2002	AF	MD	732	19	33	6	74	27	26	920
2003	AF	MD	733	19	81	0	65	90	36	6500
2004	AF	MD	734	19	52	4	219	18	26	1200
2005	AF	MD	735	19	23	6	47	13	27	1270
2006	AF	MD	736	19	49	0	57	52	24	13000
2007	AF	MD	737	19	30	0	56	19	14	1980
2008	HF	PH	738	19	18	6	39	8	13	530
2009	HF	PH	739	19	14	5	30	5	6	380
2010	PF	FV	740	19	9	4	20	9	7	1100
2011	PF	FV	741	19	35	0	75	20	63	1580
2012	PF	FV	742	19	20	10	45	14	28	1490
2013	PF	FV	743	19	11	3	30	9	25	440
2014	PF	FV	744	19	10	4	21	5	7	320
2015	PF	FV	745	19	12	4	33	14	30	640
2016	PF	FV	746	19	12	4	36	8	13	920
2017	PF	FV	747	19	23	8	45	10	42	590
2066	PF	FV	748	19	24	7	60	10	39	530
2067	PF	FV	749	19	17	0	43	15	22	1020
2068	PF	FV	750	19	59	2	46	27	28	1180
2069	PF	FV	751	19	41	4	34	13	17	590
2070	PF	FV	752	19	11	4	21	8	10	420
2071	HF	PH	753	19	55	10	146	15	31	360
2072	PF	FV	754	19	115	16	173	30	60	820
2073	ST	GT	755	19	53	7	42	21	16	600
2074	ST	GT	756	19	46	22	530	20	34	1120
2075	ST	GT	757	19	24	15	36	6	6	390
2076	ST	GT	758	19	52	10	68	20	49	770
2077	ST	GT	759	19	41	8	225	30	46	2700
2078	AF	MD	760	19	49	9	65	19	48	1120
2079	AF	MD	761	19	57	7	84	34	44	1640
2080	AF	MD	762	19	73	12	85	38	61	1940
2081	AF	MV	763	19	95	18	102	33	79	1400
2082	AF	MV	764	19	81	8	82	36	78	1820
2083	AF	MV	765	19	81	18	85	25	57	620
2084	ST	GT	766	19	113	36	108	37	65	1040
2085	ST	GT	767	19	26	3	44	15	69	770
2086	AF	MV	768	19	92	10	77	45	71	2600
2087	AF	MV	769	19	97	6	114	72	100	3200
2088	AF	MV	770	19	110	5	92	41	87	860
1183	HF	PH	771	20	39	7	37	19	31	970

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1184	HF	PH	772	20	69	24	70	168	105	8400
1185	PF	MD	773	20	45	11	58	45	49	1440
1186	HF	PH	774	20	26	11	31	13	21	520
1187	HF	PH	775	20	70	4	48	18	35	450
1188	HF	PH	776	20	37	0	62	165	50	3700
1189	HF	PH	777	20	90	18	116	41	69	820
1335	HF	PH	778	20	48	4	41	21	23	1060
1336	HF	PH	779	20	101	13	114	26	67	310
2318	AF	MV	780	20	64	9	41	29	19	1300
2319	ST	GT	781	20	48	8	39	22	25	930
2320	ST	GT	782	20	22	13	23	9	12	630
2321	ST	GT	783	20	36	12	34	14	16	640
2364	AF	MV	784	20	62	14	60	33	71	1450
2367	AF	MV	785	20	50	9	43	17	28	980
2368	AF	MV	786	20	41	5	34	18	14	1210
2369	AF	MV	787	20	47	14	83	11	32	660
2370	HF	PH	788	20	58	10	82	24	35	640
2371	HF	PH	789	20	66	12	66	36	53	1440
1866	CT	GR	790	21	7	25	31	6	5	800
1867	CT	GR	791	21	4	19	13	1	1	210
1868	CT	GR	792	21	2	12	10	2	2	120
1870	CT	GR	793	21	5	18	13	3	3	110
1872	CT	GR	794	21	1	6	9	1	2	110
1873	CT	GR	795	21	3	17	17	5	3	390
1874	CT	GR	796	21	13	35	35	5	7	230
1875	CT	GR	797	21	11	30	32	6	10	510
1876	CT	GR	798	21	11	32	21	5	7	360
1877	CT	GR	799	21	2	15	11	3	3	250
1502	TE	FP	800	22	51	8	44	27	41	2200
1521	HF	PH	801	22	36	37	159	28	40	2200
1522	HF	PH	802	22	23	23	76	18	28	1600
1523	PF	FV	803	22	30	13	59	21	84	670
1524	PF	FV	804	22	61	22	75	40	53	1400
1525	IM	FV	805	22	71	9	43	20	20	930
1526	TE	FP	806	22	51	10	45	22	40	890
1527	HF	PH	807	22	23	9	26	13	28	640
1528	HF	PH	808	22	26	12	118	18	34	2200
1552	PF	MD	809	22	35	7	26	15	12	1090
1701	HF	PH	810	22	52	8	40	10	36	340
1702	HF	PH	811	22	14	18	53	16	18	2340
1703	HF	PH	812	22	13	10	25	8	17	340
1503	TE	FP	813	23	69	9	43	22	31	940
1504	PF	MD	814	23	38	21	52	45	150	1780
1505	PF	MD	815	23	71	7	42	41	34	2760
1506	PF	MD	816	23	107	11	73	20	56	420
1546	ST	GT	817	23	16	27	30	7	15	680
1547	ST	GT	818	23	77	27	31	5	23	100
1548	ST	GT	819	23	38	11	52	17	31	810
1549	HF	PH	820	23	28	6	34	11	25	460
1550	PF	FV	821	23	49	10	55	30	28	1830
1551	PF	FV	822	23	46	9	39	25	46	1680
1554	PF	FV	823	23	22	4	40	16	14	810
1555	PF	FV	824	23	29	8	71	18	22	670
1635	PF	MD	825	23	50	6	38	21	23	1140
1636	TE	FP	826	23	59	11	48	16	29	720

Appendix 2

Sample	Form	Rock	Number	Catchmt	Cu	Pb	Zn	Co	Ni	Mn
1637	TE	FP	827	23	93	11	59	45	46	1970
1310	PF	FV	828	24	24	0	33	12	23	520
1311	ST	GT	829	24	20	11	24	13	24	410
1312	ST	GT	830	24	25	10	34	12	34	360
1313	ST	GT	831	24	25	8	31	11	31	520
1314	ST	GT	832	24	40	9	59	27	60	1110
1315	ST	GT	833	24	13	5	27	10	17	320
1316	PF	FV	834	24	15	6	30	15	26	840
1317	ST	GT	835	24	23	7	47	11	29	420
1318	ST	GT	836	24	31	9	50	15	29	360
1319	ST	GT	837	24	18	8	36	10	20	320
1320	ST	GT	838	24	26	7	30	12	43	350
1321	PF	FV	839	24	17	7	35	10	29	360
1322	ST	GT	840	24	15	8	25	10	22	200
1323	PF	FV	841	24	16	7	30	10	20	230
1324	ST	GT	842	24	24	5	33	13	22	380
1325	ST	GT	843	24	17	6	29	20	22	830
1327	ST	GT	844	24	14	8	28	8	16	290
1328	ST	GT	845	24	21	16	35	10	24	300
1329	ST	GT	846	24	20	38	26	28	25	1630
1507	PF	FV	847	24	60	6	66	40	40	2480
1508	HF	PH	848	24	56	8	44	17	37	710
1509	ST	GT	849	24	28	14	40	19	27	960
1510	ST	GT	850	24	31	15	40	13	27	410
1511	ST	GT	851	24	33	9	36	14	36	320
1515	ST	GT	852	24	30	8	29	16	29	630
1516	ST	GT	853	24	12	7	17	7	14	210
1517	ST	GT	854	24	24	7	19	4	13	110
1519	PF	FV	855	24	51	7	49	17	45	840
1512	ST	GT	856	25	28	17	38	11	20	610
1513	ST	GT	857	25	16	15	22	16	21	510
1514	HF	PH	858	25	31	9	44	26	56	920
1518	ST	GT	859	25	26	17	29	11	37	360
1537	PF	MD	860	25	22	6	31	18	23	830
1538	PF	FV	861	25	29	6	26	13	32	510
1539	PF	FV	862	25	28	9	37	20	29	630
1540	CT	GR	863	25	14	21	25	8	9	270
1541	CT	GR	864	25	24	8	37	26	47	770
1542	CT	GR	865	25	28	10	43	18	48	270
1529	PF	FV	866	26	28	8	27	15	73	430
1530	PF	FV	867	26	14	9	24	14	31	350
1531	ST	GT	868	26	18	8	25	14	45	350
1532	CT	GR	869	26	21	10	29	10	27	220
1533	PF	FV	870	26	19	9	31	17	30	410
1534	PF	FV	871	26	20	5	33	18	30	490
1535	PF	FV	872	26	30	11	31	14	65	300
1536	PF	FV	873	26	29	10	38	25	110	1200