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AN ORIENTATION GEOCHEMICAL SURVEY IN THE WESTMORELAND AREA, NORTHERN AUSTRALIA

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CONTENTS

TABLES

FIGURES

SUMMARY

This report presents the results of orientation geochemical sampling carried out during 1972 and 1973 as the forerunner to a proposed regional stream-sediment survey in the Westmoreland region.

Stream sediments sieved to minus 180 micrometres were collected in areas both remote from and adjacent to known mineral deposits. Heavy-mineral concentrates and soil samples were also taken in the mineralized areas. The sieved stream-sediment and soil samples were analysed for a large number of elements by atomic absorption spectrophotometry and X-ray fluorescence spectrometry. Heavy-mineral concentrates were examined under the microscope and analysed semi-quantitatively by optical emission spectrography. Simple univariate and more complex multivariate statistical procedures were used to assist in the interpretation of the data.

The main mineralization types of the area can all be detected by stream-sediment sampling. Sieved samples are adequate for locating uranium, tin, and lead deposits; heavy-mineral samples are superior during exploration for copper mineralization. The pathfinder elements found most useful in the area are arsenic, lithium, and tungsten. False zinc anomalies apparently caused by manganese 'scavenging' occur in places, and consequently manganese determinations are advantageous.

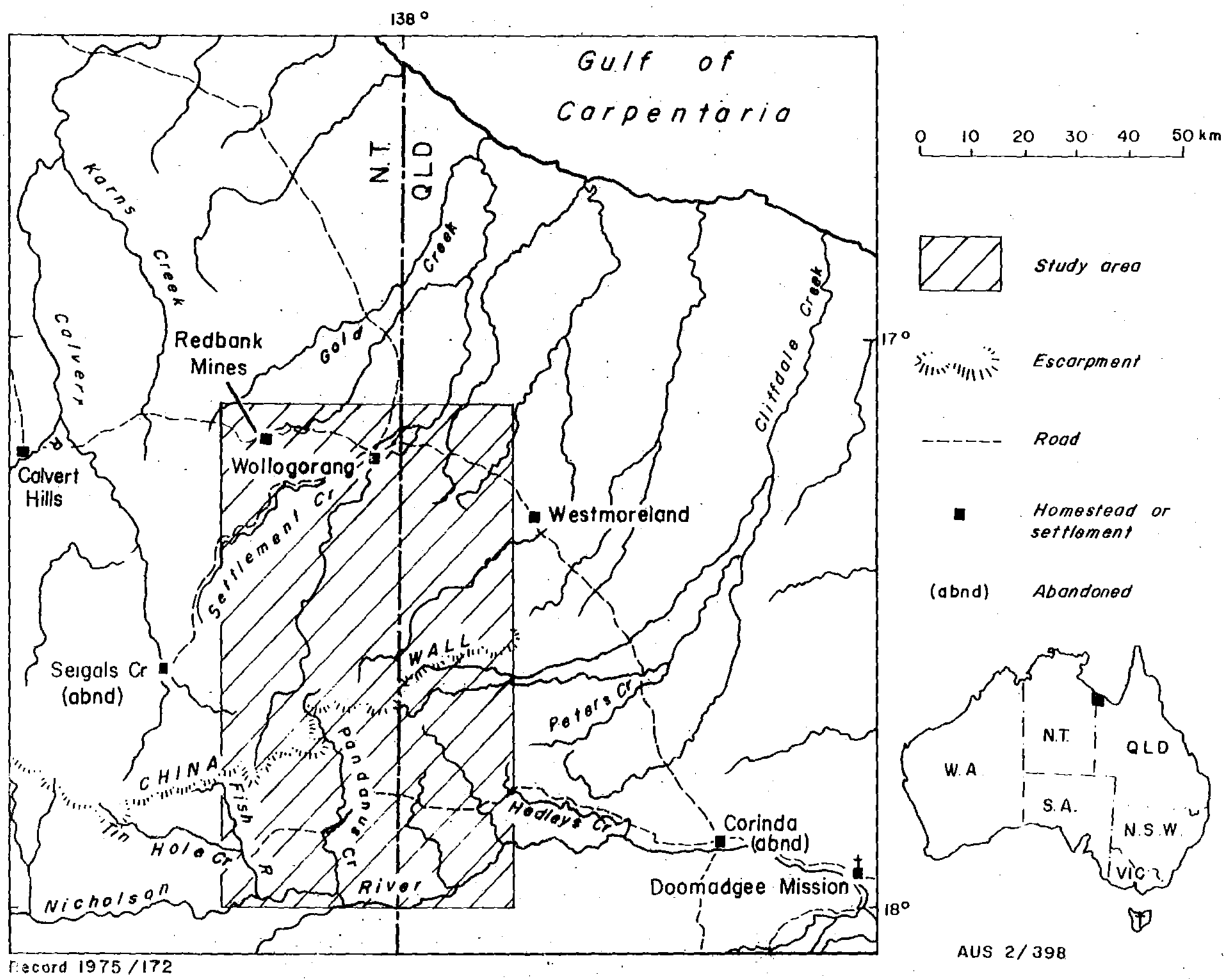

Fig. 1 Locality map

INTRODUCTION

Orientation studies were carried out during 1972 and 1973 as the forerunner to a regional stream-sediment sampling program scheduled to begin in the Westmoreland area during the 1975 field season. Initially the Hedleys Creek (Queensland) and Seigal (Northern Territory) 1:100 000 Sheet areas will be sampled at a density of about 1 sample/2.5 km^2.

Location

The study area comprises adjoining parts of the Calvert Hills and Westmoreland 1:250 000 Sheet areas. It occupies a band about 50 km wide straddling the Queensland/Northern Territory border and extending from the Nicholson River in the south to north of Wollogorang homestead (Fig. 1).

Climate and vegetation

The climate is semi-arid tropical with a well defined wet season. The average annual rainfall is about 700 mm. Rain is almost entirely confined to the period November to April, and consequently most streams are dry during the winter. Average maximum daily temperature throughout the year is about 32°C.

The region is covered by savannah woodland; small eucalypts dominate and large trees are generaly found only near stream channels.

Physiography

The elevation of the area ranges from about 60m to about 300 m above sea level. The physiography is controlled largely by the differential rates of erosion of the various rock types. The most prominent feature is the China Wall which consists of a series of strike ridges of resistant Precambrian conglomerate. The 'wall' extends from the headwaters of the Nicholson River for over 100 km in an east-northeast direction to near Westmoreland homestead. It varies from 3 to 10 km in width and in most parts is bounded to the south by a near-vertical escarpment about 130 m high. Flat-lying sandstone remnants of both Precambrian and Mesozoic age also form positive features. The topography is more subdued in areas underlain by Precambrian volcanic units, although rugged hills occur locally. Precambrian granite and pelitic and calcareous sedimentary/metamorphic rocks generally form lowlands. Towards the east the Cainozoic-Recent plains slope gently to the sea.

Drainage is well developed on all rock types. It is generally dendritic although in some areas pronounced trends parallel the regional east-northeast strike of the country rocks. In the higher areas streams are youthful, and gorges and waterfalls are common; on the lowlands drainage is more mature.

Geology

The geological features of the Westmoreland region have been discussed by Carter (1959), Carter et al. (1961), and Roberts et al. (1963). The results of more recent geological mapping are described by Sweet & Slater (in press), Mitchell (in prep.), and Gardner (in prep.).

The Precambrian rocks of the area form part of the Australian Shield. Four major tectonic units are represented - the Murphy Tectonic Ridge, the McArthur Basin, the Lawn Hill Platform, and the south Nicholson Basin.

The Murphy Tectonic Ridge is a narrow east-northeast-trending belt of Lower Proterozoic and Carpentarian igneous and metamorphic rocks. The oldest outcrops are schist and gneiss of the Murphy Metamorphics. Unconformably overlying them are the Cliffdale Volcanics consisting of rhyolitic to dacitic lavas and tuffs, some of which have ignimbritic textures. The earlier workers in the area distinguished the Nicholson Granite, which appears older than the Cliffdale Volcanics, from the Norris Granite which is younger. The two granites are very similar chemically and isotopic dating shows that their age difference is rather small. Consequently there has been a recent tendency (Gardner, in prep.) for the term Norris Granite to be abandoned and all granites to be described as phases of the 'Nicholson Granite Complex' (tentative name).

The Murphy Tectonic Ridge is flanked to the north by the McArthur Basin, which contains rocks of the Carpentarian Tawallah Group. The sequence begins with the Westmoreland Conglomerate resting unconformably on the older rocks. The conglomerate passes up into basic volcanics (Seigal Volcanics) which are in turn overlain by a number of dominantly sedimentary formations (McDermott Formation, Sly Creek Sandstone, Aquarium Formation, Settlement Creek Volcanics, Wollogorang Formation, and Masterton Formation).

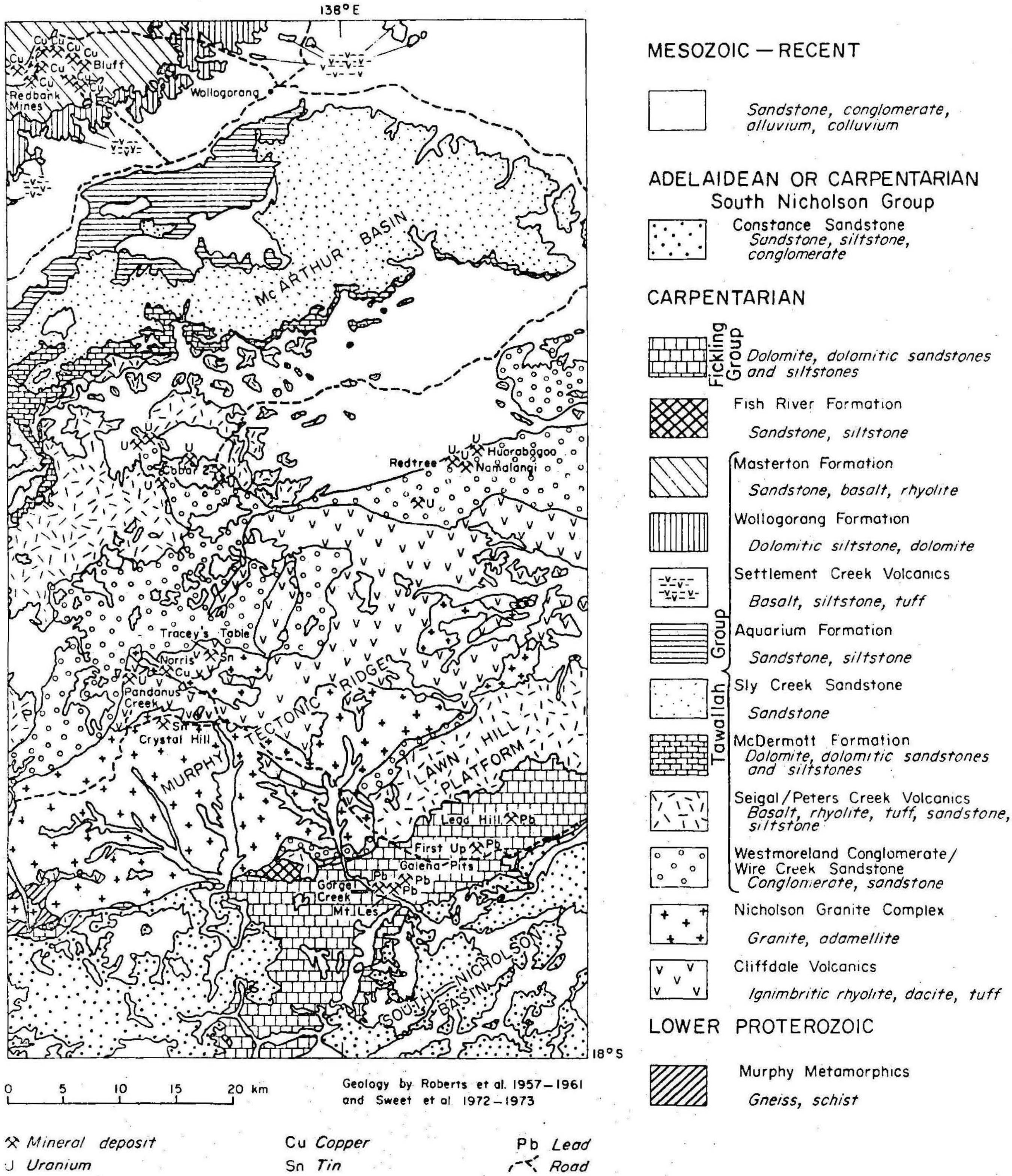

Fig 2 Geological map of the Westmoreland region showing the more important mineral deposits

To the south of the Murphy Tectonic Ridge on the Lawn Hill Platform the sequence is similar although basic volcanics are more abundant. Correlations have been made by Sweet & Slater (in press) between the Wire Creek Sandstone and the Westmoreland Conglomerate and between the Peters Creek Volcanics and the remainder of the Tawallah Group. The Peters Creek Volcanics are overlain unconformably by sandstone of the Fish River Formation which in turn passes up into the dolomitic Fickling Group.

In the south of the study area the rocks of the South Nicholson Basin unconformably overlie those of the Lawn Hill Platform. The South Nicholson Group may be Adelaidean and consists mainly of sandstone and siltstone; the most important unit is the Constance Sandstone.

Mineralization is widespread throughout the region. Uranium deposits occur within fractures in three lithological units - Westmoreland Conglomerate, Seigal Volcanics, and Cliffdale Volcanics. Copper, tin, and minor tungsten are found in Cliffdale Volcanics and the high-level phase* of the Nicholson Granite Complex. Copper is also associated with basic lavas of the Seigal/Peters Creek Volcanics and the Masterton Formation. Lead mineralization occurs in the dolomitic rocks of the Fickling Group. Small amounts of alluvial gold are reported from the Tin Hole Creek and Gold Creek areas (Roberts et al. 1963), and gold is associated with most uranium deposits.

Company geochemical work

Nearly all exploration effort in the Westmoreland area has been aimed at locating uranium mineralization. Airborne and ground radiometric surveys have been used almost to the exclusion of other methods in the search for uranium. Companies known to have carried out radiometric survey work include Queensland Mines, BHP, Esso Minerals, International Nickel, Mineral Deposits, Nickel Mines, Sedimentary Uranium, United Uranium and Planet Mining. A few companies (e.g. Queensland Mines, BHP, Mineral Deposits) have used geochemical methods but none reports encouraging results.

Geochemical sampling has played a more important role in the small number of base-metal exploration programs carried out in the region. The most comprehensive stream-sediment and soil surveys for which details are available were made by Harbourside Oil and Triako Mines in the Redbank copper field and by Carpentaria Exploration and Westmoreland Minerals in the lead province towards the southeast of the study area.

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* That part known previously as Norris Granite.

SAMPLING AND ANALYTICAL PROCEDURES

The sampling and analytical procedures used during this survey have been discussed elsewhere (Rossiter et al. 1974) and only a brief account is given here.

Sieved stream-sediment samples

Stream-sediment samples were sieved on site using plastic sieves fitted with nylon bolting cloth. It was important during the initial stages of the program to decide what grainsize was the best to collect. Bulk stream-sediment samples weighing about 10 kg were collected for sieving into various grain sizes and chemical analysis. The distribution of zinc in various size fractions of a number of samples is shown in Figure 3. The general increase in the finer grainsizes indicated by the diagram has been verified for a wide range of elements. The geochemical contrast (the difference between anomalous and background samples) is greatest in the finer size fractions. It follows that for the purpose of delineating anomalies, the finer the material sampled the better. However, it was found that sieving time was excessive if a sieve finer than 180 μm (85 mesh BSS) was used because some samples contained as little as 0.2 percent of minus 180 μm material (Table 1). It was decided therefore that for all subsequent sampling 180 μm sieves would be employed. Sieved stream-sediment samples were analysed for silver, beryllium, cadmium, cobalt, chromium, copper, lithium, manganese, nickel, lead and zinc by atomic absorption and for arsenic, barium, cerium, nickel, lead, rubidium, sulphur, tin, thorium, uranium and tungsten by X-ray fluorescence in the BMR laboratories. Of these elements barium, cadmium, cerium, cobalt, chromium, nickel, rubidium, sulphur and thorium proved to be of little use.

Heavy-mineral concentrate samples

In the field heavy-mineral concentrates were extracted from stream sediments by panning. Back in the laboratory the roughly panned concentrates were passed through bromoform (S.G. = 2.89) to remove quartz and feldspar, and treated with a hand magnet to remove magnetite. They were then examined under a binocular microscope and analysed for silver, bismuth, cerium, cobalt, chromium, copper, lanthanum, molybdenum, niobium, nickel, lead, tin, tantalum, tungsten, yttrium, zinc and zirconium by optical emission spectrography. Chemical tests and X-ray diffraction patterns were sometimes needed to aid mineral identification.

Soil samples

Soil samples were collected from a depth of about 20 cm using a miner's pick. Many samples contained fairly large pebbles which were removed by sieving. As the soils contained a large proportion of very fine material the choice of size fraction sampled was not as critical as for stream sediments - 500 μm (30 mesh BSS) sieves were used. Soil samples were analysed for the same elements and by the same methods as stream sediments (page 4).

TABLE 1. AMOUNT OF MINUS 180 μm MATERIAL PRESENT IN SEVERAL STREAM-SEDIMENT SAMPLES FROM THE WESTMORELAND REGION

Sample No.	Percent - 180 μm fraction
72760092	0.75
72760192	4.57
72760259	0.19
72760354	3.73
72760452	0.86
72760521	0.31
72760825	0.38
72760876	0.46
72760989	0.95

DISCUSSION OF RESULTS

Sampling was carried out in two types of environment. In areas remote from mineralization the variation in metal contents of stream sediments associated with different rock types was assessed, and an attempt made to define threshold (upper limit of background) values for each rock type. In the vicinity of known mineralization the secondary dispersion of anomalous elements was investigated.

Results of sampling in areas remote from mineralization

It is important during geochemical surveys to establish the normal or background variation of elements considered significant in the detection of economic mineral deposits. Once the geochemical background has been investigated an attempt can be made to recognize anomalous values and thereby delineate exploration targets.

TABLE 2. GEOCHEMICAL VARIATION IN STREAM-SEDIMENT SAMPLES COLLECTED FROM CATCHMENTS DRAINING A SINGLE FORMATION OR ROCK TYPE. All values are in parts per million. Arithmetic means and the actual range of values observed are presented. Where no mean is given the element was not detected in some samples.

Formation	No. of Samples	Cu	Pb	Zn
High-level phase of Nicholson Granite Complex	58	10 5 - 22	- Less than 5 - 15	14 5 - 32
Cliffdale Volcanics	74	10 5 - 20	- Less than 5 - 15	24 10 - 60
Westmoreland Conglomerate/Wire Creek Sandstone	10	12 8 - 25	10 7 - 12	29 9 - 75
Seigal Volcanics/lower Peters Creek Volcanics	60	72 43 - 122	17 9 - 79	89 41 - 351
Fickling Group	13	16 11 - 21	30 11 - 39	23 5 - 38

A number of catchments draining a single formation or rock type were sampled in order to assess the variations in trace-metal contents of sediments derived from different rock types. Attention was focused on rock types known to be associated with mineralization in other parts of the region. Results for elements of economic interest are summarized in Table 2. Copper is fairly homogeneously distributed among sediments related to different rock types except for a pronounced enrichment near basic lavas of the Seigal and lower Peters Creek Volcanics. Lead contents are also similar on the different rock types although a slightly higher mean value is encountered in sediments derived from the dolomitic rocks of the Fickling Group. Zinc seems higher on the basic volcanics than other rock types but this is not necessarily the case as the average value is biased by occasional very high levels (up to 351 ppm) that appear to be the result of 'scavenging' by hydrated manganese oxides (page 12). In fact zinc is quite low on the basic volcanic rocks of the Redbank copper field (Fig. 10). Data for uranium and tin are very limited; no values are available for the Fickling Group and only a few for the other rock units. However, there are indications that uranium is low on Seigal/Peters Creek Volcanics and Westmoreland Conglomerate/Wire Creek Sandstone and that tin is enriched relative to other rock types on Cliffdale Volcanics and the high level phase of the Nicholson Granite Complex.

When metal contents vary considerably between stream sediments associated with different rock types, threshold values should be defined very carefully. For example, a copper value of 100 ppm on basic volcanics is probably not significant but in a granitic terrain this level would be anomalously high. The problem is not a major one when the highest background values occur on the rock types most likely to contain mineralization - this is the case for tin and lead.

Results of sampling in areas of known mineralization

To evaluate the geochemical expression of each type of deposit, sieved stream sediment, heavy-mineral concentrate and some soil samples were collected from around uranium, copper, tin, and lead mineralization. The four types of deposit are discussed in the following sections in approximate order of economic importance. Other elements particularly useful in prospecting for a certain metal are mentioned under the relevant heading. The secondary dispersion in a semi-arid tropical regime of the elements determined during this survey has been discussed in detail elsewhere (Rossiter, in prep.) and is treated only briefly here.

Uranium

Structurally-controlled uranium mineralization occurs in a number of rock units. The Pandanus Creek deposit is located within Cliffdale Volcanics, the Cobar 2 and related smaller occurrences in Seigal Volcanics, and the Westmoreland group of deposits in Westmoreland Conglomerate (Fig. 2). In most cases there is some evidence to suggest a genetic relationship between the uranium mineralization and basic igneous rocks. The ore minerals are mainly secondary, and pitchblende is relatively rare; minor chalcopyrite, galena and gold, are sometimes present.

The Westmoreland (Namalangi-Huarabagoo-Redtree) deposits discussed by Brooks (1972) are among the largest known in Queensland. Queensland Mines has announced reserves of 1.7 million tonnes of ore averaging 0.25 percent U_3O_8* but no figures are available for Mt Isa Mines' Redtree leases. The only production in the area has been from the Pandanus Creek and Cobar 2 mines. At Pandanus Creek 311 tonnes of ore containing 8.37 percent U_3O_8 were mined between 1960 and 1962 (Morgan, 1965). At Cobar 2, 73 tonnes of hand-picked ore averaging 10.5 percent U_3O_8 were mined.

Extensive anomalies occur downstream from the three areas of uranium mineralization sampled. Presumably uranium has first passed into solution in ionic form and then has been absorbed by clays, hydrated oxides, and organic matter in the stream sediments. Anomalous levels of arsenic (Fig. 4), copper and lead (Fig. 5), and lithium, tin, and tungsten (Fig. 6) also occur. Minor enrichment of silver and beryllium is observed on occasions. The abnormally strong correlation between uranium and lead values in samples collected from near uranium mineralization (Table 3) suggests that much of the lead is being produced by radiogenic decay and is not a primary variety. The high lithium, tin, and tungsten levels associated with the Pandanus Creek deposit may be coincidental as it is possible (although unlikely) that the stanniferous greisen occurring here (Fig. 6) is unrelated to the uranium ore body. It should be remembered that exploration and mining activity has probably exaggerated the anomalies in the three mineralized areas, but it is encouraging from an exploration viewpoint that uranium dispersion trains persist for greater distances downstream than those of the associated elements.

The distribution of uranium in the stream sediments and soils of the Westmoreland region is shown in Figure 7. Arithmetic and logarithmic probability cumulative frequency plots* for both media approach linearity for low uranium values, indicating that the background populations are closely approximated by the ideal normal and lognormal distributions. Above values of 8 ppm for stream sediments and 12 ppm for soils there is an abrupt change in slope of the logarithmic plots, implying a deviation from typical background values. In other words, a second (anomalous) population in both cases is beginning to make significant contributions to the total uranium distribution. Values of 8 ppm in stream sediments and 12 ppm in soils can be used therefore to distinguish anomalous from background samples. Arsenic levels of 15 ppm in stream sediments and 12 ppm in soils (Fig. 8) should also be regarded as significant during uranium exploration programs.

Heavy-mineral sampling appears to be of little use in detecting uranium deposits. Sometimes detrital gold is present in concentrates near mineralization but secondary uranium minerals are rare owing to their softness and solubility. Monazite does not seem to occur in significant quantities in the region and is unlikely to interfere with the interpretation of stream-sediment surveys for uranium as it does in the Georgetown area (Rossiter, in prep.).

Copper

There are basically two types of copper mineralization in the region.

Deposits of the first type occur in basic volcanic rocks. The best examples are the Redbank mines which are located within a basic volcanic member of the Masterton Formation (Fig. 2). The ore occurs in breccia pipes and in the old workings consists entirely of secondary minerals with malachite, chrysocolla, azurite, and chalcocite being the most abundant. Drilling in recent years, however, indicates chalcopyrite at depth. Total production from the Redbank field was about 1000 tonnes of ore ranging in grade from 25 to 52 percent copper. No other deposits in basic volcanics have been exploited commercially.

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* The use of these diagrams in geochemical prospecting has been discussed by Rossiter (in prep.).

Copper deposits also occupy faults and shears in the Cliffdale Volcanics and the high-level phase of the Nicholson Granite Complex. Of these the Norris mine (Fig. 2) has been the only significant producer. The orebody is associated with a small quartz-filled fracture related to the Calvert Fault, a major structure. Chalcopyrite altered, in places, to digenite constitutes the primary ore; malachite occurs in the oxidized zones. Minor uranium mineralization occurs nearby. Production has been quite small.

Copper dispersion trains in stream sediments are relatively short (Figs 9 and 10) and a very close sample spacing would be needed to reliably detect copper mineralization using sieved samples. Heavy-mineral sampling appears to have more potential as an exploration method. As detrital malachite grains are so conspicuous under the microscope, a few small fragments in an original bulk sample of 10 kg can be readily detected. Hence, although most of the copper is probably in absorbed form in the fine-grained fraction of the stream sediments (maximum copper value encountered in heavy-mineral concentrates is 100 ppm), the optical heavy-mineral technique is more sensitive than the chemical analysis of sieved material. No metal other than copper is significantly enriched in sediments or soils around the Norris and Bluff mines (Figs 9 and 10) and there appear to be no useful pathfinder elements in the search for copper deposits.

The definition of threshold copper values for stream sediments (and soils) is difficult because background levels differ greatly between basic igneous rocks and other rock types (Table 2). To overcome this problem data for samples from catchments draining only basic rocks and values from areas of other rock types have been plotted separately (Fig. 11). The two copper distributions show lognormal affinities and threshold values deduced from the logarithmic cumulative frequency diagrams are 120 ppm for basic rocks and 80 ppm for other rock types. Thresholds for soils are 150 ppm and 80 ppm respectively (Fig. 12).

Tin

Tin occurs at several localities within the Cliffdale Volcanics and the high-level phase of the Nicholson Granite Complex (Fig. 2). The largest deposit is at Crystal Hill where a greisenized vein contains cassiterite, wolframite, cuprite, fluorite, and manganese oxides. Small amounts of both lode and alluvial material have been won. Tin is also associated with the Pandanus Creek uranium deposit and occurs at Traceys Table.

Extensive dispersion trains occur downstream from tin mineralization (Figs. 6 and 13). Anomalous levels of copper, lithium, tungsten, and uranium also occur. Minor enrichment of beryllium is observed. The dispersion of tin in the secondary environment is dominated by mechanical processes because of the chemical stability of cassiterite. Heavy-mineral concentrates near mineralization are, as expected, extremely rich in detrital cassiterite. In addition, high tungsten (greater than 2000 ppm) and tantalum (to 200 ppm) in heavy-mineral samples suggest the presence of wolframite and tantalite, although these minerals were not positively identified. Topaz is also abundant.

The distribution of tin in the stream sediments and soils of the area is shown in Figure 14. The dispersed cassiterite is fine enough for substantial amounts to occur in some of the minus 180 µm samples. Threshold tin values of 50 ppm for stream sediments and 40 ppm for soils are obtained from the arithmetic cumulative frequency plots. Lithium values of greater than 20 ppm in both stream sediments and soils (Fig. 15) should be regarded as significant during exploration for tin as should tungsten levels exceeding 20 ppm in either medium (Fig. 16). The analysis of sieved samples and the examination by microscope of heavy-mineral concentrates are both equally effective for the detection of tin deposits.

Lead

Syngenetic galena and some pyrite, sphalerite, and minor chalcopyrite occur in silicified dolomitic rocks of the Fickling Group at several localities in the southeast of the study area (Fig. 2). Cerussite, pyromorphite, and some malachite are present in the near-surface parts of the deposits. The most significant occurrences are the Lead Hill, Mt Les, Gorge Creek, Galena Pits, and First Up prospects. The Lead Hill prospect is the only one with an economic grade, but the deposit is very small. The largest is Mt Les where Carpentaria Exploration has reported 4.5 million tonnes of 0.1 percent lead.

Substantial lead, zinc, and very weak copper anomalies occur in stream sediments associated with deposits of this type (Fig. 17). No lead data for heavy-mineral concentrates are available but, by analogy with the climatically and physiographically similar Georgetown area (Rossiter, in prep.), it is likely that lead is dispersed as anglesite ($PbSO_4$) and cerussite ($PbCO_3$) by mechanical processes. Hence heavy-mineral sampling* will probably prove a useful exploration tool for lead mineralization in the Westmoreland

* As anglesite and cerussite have rather undiagnostic optical properties, chemical analysis of the heavy-mineral samples is probably necessary to establish the presence of these minerals.

region - this possibility will be investigated by further sampling. In addition, the presence of the lead sulphate could lead to anomalous sulphur values in sieved samples but no data have been obtained as yet.

The distributions of lead and zinc in the stream sediments and soils of the area are shown in Figures 18 and 19 respectively. The lead distributions are complex with neither normal nor lognormal models fitting the data very well. Nevertheless well defined breaks in the cumulative frequency diagrams indicate that a threshold value of 120 ppm is appropriate in both media. Both zinc distributions are adequately described by combinations of lognormal populations - thresholds of 140 ppm in stream sediments and 100 ppm in soils are obtained from the logarithmic cumulative frequency plots. The zinc threshold value for stream sediments must be used with care, however, as there is evidence that this element is more susceptible to co-precipitation with and adsorption by manganese compounds such as $Mn(OH)_4$ and MnO_2 than other metals.

An apparent example of manganese 'scavenging' of zinc is shown in Figure 20. Several stream-sediment samples in catchments draining basic rocks contain anomalous zinc but normal amounts of copper and lead. The majority of these samples also have anomalous manganese contents - any value exceeding 1000 ppm can be considered abnormal (Fig. 21). If the high zinc and manganese levels were due to increased amounts of a rock-forming ferromagnesian mineral in the stream sediments, correspondingly high chromium and nickel values would be expected - these do not occur. The alternative explanation i.e. that zinc and manganese are associated in secondary oxidate compounds is more likely. Some enrichment of silver also appears to take place.

No rock type is associated with consistently high manganese values, rather very high levels are observed sporadically in areas of differing lithology - to date they are known to occur where Peters Creek Volcanics or Fickling Group rocks crop out. These high values are probably the result of precipitation. Conditions conducive to manganese precipitation are not commonly encountered in areas of seasonal rainfall (Horsnail, Nichol, & Webb, 1969; Rossiter, in prep.), and manganese 'scavenging' is not likely to occur on a wide scale in the Westmoreland region, however, occasional false zinc anomalies can result. The problem of deciding how significant is a high zinc value can be overcome by examining the abundances of other elements, especially copper, lead, and manganese. An elaborate way of doing this is by means of factor analysis (page 15).

More complex data evaluation techniques

As indicated in the preceding discussion the distributions of the various elements in the stream sediments of the Westmoreland region combine both normal and lognormal characteristics. Consequently statistical parameters are calculated for both raw and logarithmically transformed data in the following section.

Correlation coefficients

The interrelation between two or more elements determined during a geochemical survey may be quantified by the use of Pearson correlation coefficients. When these are calculated for the Westmoreland stream-sediment data most of the significant interelement relations already noted on an empirical basis reappear in mathematical terms (Table 3). There is strong correlation between uranium values and silver, beryllium, copper, and lead levels in sediments near uranium mineralization. Arsenic may be anomalous on the scale of a single deposit but its association with uranium is not sufficiently widespread for the total data correlation coefficient to be significant*. Covariation also occurs between copper and silver, beryllium, tin, and uranium values near mineralization in granitic rocks. It should be pointed out, however, that no tin and uranium data applying to copper deposits in basic volcanics are available for inclusion in the correlation coefficient calculations, and these two elements are not necessarily associated with copper in a basic environment. Concentrations of beryllium, copper, lithium, and tungsten occur in combination with tin. Lead is correlated with uranium and zinc. The mathematical relation between lead and uranium might at first glance be interpreted as indicating that high uranium values are to be expected near lead mineralization. This is not necessarily the case because the correlation coefficients between the two elements are calculated for a limited number of samples, all collected near uranium deposits and not near lead mineralization.

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* A correlation is not considered meaningful unless it is statistically significant for both raw and logarithmically transformed values.

TABLE 3: PEARSON CORRELATION COEFFICIENTS FOR THE WESTMORELAND STREAM-SEDIMENT DATA. Asterisks indicate positive correlations that are significant at the 99% confidence level for both raw and logarithmically transformed values.

Raw data

	Ag	Be	Cu	Li	Mn	Pb	Zn	As	Sn	U	W
Ag		0.30*	0.27*	0.09	0.46*	0.09	0.52*	-0.04	0.13	0.47*	0.02
Be	0.30*		0.25*	0.38*	0.09	0.06	0.02	-0.01	0.37*	0.65*	0.18
Cu	0.44*	0.62*		0.09	0.08	0.03	0.04	0.06	0.49*	0.77*	0.27
Li	0.18	0.54*	0.58		-0.01	-0.08	0.05	-0.11	0.54*	0.03	0.54
Mn	0.34*	0.36	0.53	0.29		0.14	0.55*	-0.27	0.01	0.17	-0.01
Pb	0.08	0.19	0.28	-0.01	0.30		0.38*	0.22	0.08	0.98*	0.01
Zn	0.42*	0.31	0.52	0.40	0.70*	0.41*		-0.12	-0.08	0.15	-0.02
As	0.20	-0.03	0.06	-0.09	-0.35	0.33	-0.20		-0.09	0.22	-0.04
Sn	-0.07	0.63*	0.37*	0.60*	0.11	0.27	-0.01	-0.08		0.05	0.46*
U	0.50*	0.49*	0.51*	0.28	-0.10	0.75*	0.03	0.54	0.31		-0.02
W	0.08	0.52	0.47	0.60*	0.17	0.38	0.13	0.14	0.68*	0.34	

Logarithmically transformed data

Coefficients above and to the left of the dashed line were calculated for 214 samples, the remainder were calculated for 84 samples.

R-mode factor analysis

The interrelation of the elements can be studied in additional depth by means of R-mode factor analysis. This technique generates a set of new variables (or factors). a few of which are usually sufficient to describe most of the variance in the original data. Generally any elements showing covariation (either sympathetic or antipathetic) are combined in the one factor. In this way a confusingly large array of data can be reduced to a small number of highly significant variables.

The mathematics involved in the extraction of R-mode factors are extremely complex and will not be gone into here. Initially the Pearson correlation coefficients are calculated and expressed as vectors in multi-dimensional space. The factors are actually a framework of co-ordinate axes superimposed on this vector array. The factor axes are rotated both orthogonally (Varimax rotation) and obliquely (Promax rotation) so that the correlation vectors have the simplest possible factor constitution (or factor loadings). All samples can be represented in terms of the factor model by the numeric values of their projections on the various factor axes - these values are termed factor scores.

A large number of factor analyses have been carried out using the Westmoreland stream-sediment data - only the two most successful are described here. The first (Table 4) is a four-factor raw data model constructed from 214 samples analyzed for silver, beryllium, copper, lithium, manganese, lead, and zinc. The matrix is interpreted as follows:

Factor 1: high negative loadings of silver, manganese, and zinc. This factor is probably a manifestation of the process of 'scavenging' of zinc and silver by hydrated manganese oxides (page).

Factor 2: high negative loadings of beryllium and lithium. This factor reflects fractionated or greisenous rocks - these are often associated with mineralization.

Factor 3: high positive loadings of lead and zinc. This is a lead mineralization factor.

Factor 4: high negative loadings of silver and copper. This factor reflects copper mineralization.

The four factors describe 80.1 percent of the total variance in the data set.

This model provides a solution to the problem noted earlier (page 12) of deciding whether a high zinc value is significant. Factor scores are calculated for all samples containing anomalous (greater than 140 ppm) zinc. High Factor 3 scores very successfully distinguish samples related to mineralization from those in which manganese 'scavenging' has occurred (Table 5). Factor 1 scores are also useful but are not as reliable. It could be argued that simple inspection of the contents of elements other than zinc would suffice and although this is often true, in borderline cases mathematical quantification is desirable or even necessary.

The second factor model (Table 6) is a five-factor raw data matrix constructed from 84 samples analyzed for silver, beryllium, copper, lithium, manganese, lead, zinc, arsenic, tin, uranium, and tungsten. The five-factor model is interpreted as follows:

Factor 1: high positive loadings of copper, lead, and uranium. This is a mineralization factor, high positive factor scores are found near uranium deposits.

Factor 2: high negative loadings of copper, lithium, and tin. This is also a mineralization factor, high negative scores occur near copper and tin deposits.

Factor 3: high positive loadings of silver, manganese, and zinc. This may be described as a manganese 'scavenging' factor and the process should be suspected in any sample with a high positive factor score.

Factor 4: high positive loading of arsenic. This is a mineralization factor; high positive scores are encountered near some uranium deposits.

Factor 5: high negative loadings of lithium and tungsten. Again this is a mineralization factor; high negative factor scores are found near tin-tungsten lodes.

These five factors describe 87.3 percent of the total variance in the data. The most striking feature of the matrix is the confirmation of the very strong uranium-copper and tin-copper associations noted in previous sections. Beryllium practically disappears from the factor model, suggesting that this element has less to offer than the others during future geochemical surveys in the region.

TABLE 4. FOUR-FACTOR RAW DATA MATRIX FOR THE WESTMORELAND STREAM SEDIMENTS.

Factor No.	1	2	3	4
Ag	-0.80	-0.09	-0.11	-0.29
Be	0.21	-0.64	0.06	-0.21
Cu	-0.06	0.03	0.05	-0.94
Li	-0.13	-0.91	-0.04	0.18
Mn	-0.86	0.08	0.11	0.05
Pb	0.02	0.00	0.99	-0.05
Zn	-0.78	0.00	0.28	0.13
Eigenvalues (cum %)	32.3	53.5	67.0	80.1
Principal loadings	-Ag -Mn -Zn	-Be -Li	Pb Zn	-Cu -Ag

TABLE 5. FACTOR SCORES (FOUR-FACTOR RAW DATA MODEL) FOR ALL STREAM SEDIMENT SAMPLES ANOMALOUS IN ZINC. All samples associated with mineralization have a Factor 3 score of 3.0 or greater, those in which manganese scavenging has presumably occurred have scores of 2.1 or less. There is also some tendency for greater negative Factor 1 scores in the latter group of samples.

	Factor 1 (Manganese 'scavenging')	Factor 3 (Mineralization)
Samples near mineralization	-3.6	8.4
	-3.9	4.0
	-2.0	4.0
	-2.3	8.3
	-3.6	4.5
	-7.0	3.0
Samples remote from mineralization in which high Zn values are probably due to manganese 'scavenging'	-2.9	0.6
	-2.4	0.6
	-12.9	2.1
	-4.2	0.9
	-4.6	1.0
	-2.8	0.6
	-2.9	0.5
	-5.0	1.7
	-3.6	0.5

TABLE 6. FIVE-FACTOR RAW DATA MATRIX FOR THE WESTMORELAND STREAM SEDIMENTS

Factor No.	1	2	3	4	5
Ag	0.26	-0.25	0.58	0.08	0.23
Be	0.14	-0.07	-0.28	-0.14	0.04
Cu	0.74	-0.39	0.01	-0.03	-0.06
Li	-0.07	-0.66	0.15	0.01	-0.33
Mn	-0.01	0.01	0.90	-0.15	0.03
Pb	1.05	0.14	-0.05	0.01	-0.02
Zn	-0.07	0.19	0.99	0.05	-0.10
As	0.02	-0.01	0.04	1.00	0.00
Sn	-0.11	-1.02	-0.22	0.01	0.08
U	1.05	0.18	-0.08	0.01	-0.02
W	0.06	-0.06	0.01	0.00	-0.94
Eigenvalues (cum %)	39.0	57.6	74.7	82.3	87.3
Principal loadings	Cu	-Cu	Ag	As	-Li
	Pb	-Li	Mn		-W
	U	-Sn	Zn		

CONCLUSIONS

The results of the survey are summarized in Table 7. The four main types of mineralization occurring in the Westmoreland region can all be detected by stream-sediment sampling.

Uranium deposits are associated with extensive uranium and in some instances arsenic, copper, lead, lithium, tin, and tungsten anomalies in minus 180 µm (85 mesh BSS) sediment. Heavy-mineral samples show little evidence of nearby mineralization - they contain only rare grains of gold and yellow secondary uranium minerals.

The best indicator of copper deposits is the presence of malachite in heavy-mineral samples. In sieved sediments copper anomalies normally do not persist for long distances downstream from the source.

Tin mineralization shows up equally well in sieved or heavy-mineral samples. If the analysis of sieved material is preferred copper, lithium, uranium, and tungsten values are useful additions to tin data.

Lead deposits are associated with lead, zinc, and weaker copper anomalies in sieved stream sediment. The possibility of false zinc anomalies caused by manganese 'scavenging' should be borne in mind and manganese data are helpful in assessing the significance of high zinc values. The presence of high sulphur levels near lead mineralization is likely, and the analysis of heavy-mineral samples for lead might prove a useful exploration technique.

TABLE 7. APPLICATION OF STREAM-SEDIMENT SURVEYS IN PROSPECTING FOR THE MAJOR MINERALIZATION TYPES OF THE WESTMORELAND REGION. The threshold values shown are relevant for programs using identical analytical techniques to those used in this survey; otherwise they should be taken as a guide only.

Element sought	Threshold (ppm) in minus 180 µm sediment	Useful pathfinders	Applicability of the heavy-mineral technique
Uranium	8	Arsenic (threshold 15 ppm) copper, lithium (threshold 20 ppm), lead, tin, tungsten (threshold 20ppm)	
Copper	Basic rocks 120 Other lithologies 80		Microscope examination of heavy-mineral samples for malachite
Tin	50	Copper, lithium, uranium, and tungsten	Microscope examination of heavy-mineral samples for cassiterite
Lead	120	Copper, zinc (threshold 140 ppm)	Chemical analysis of heavy-mineral samples?

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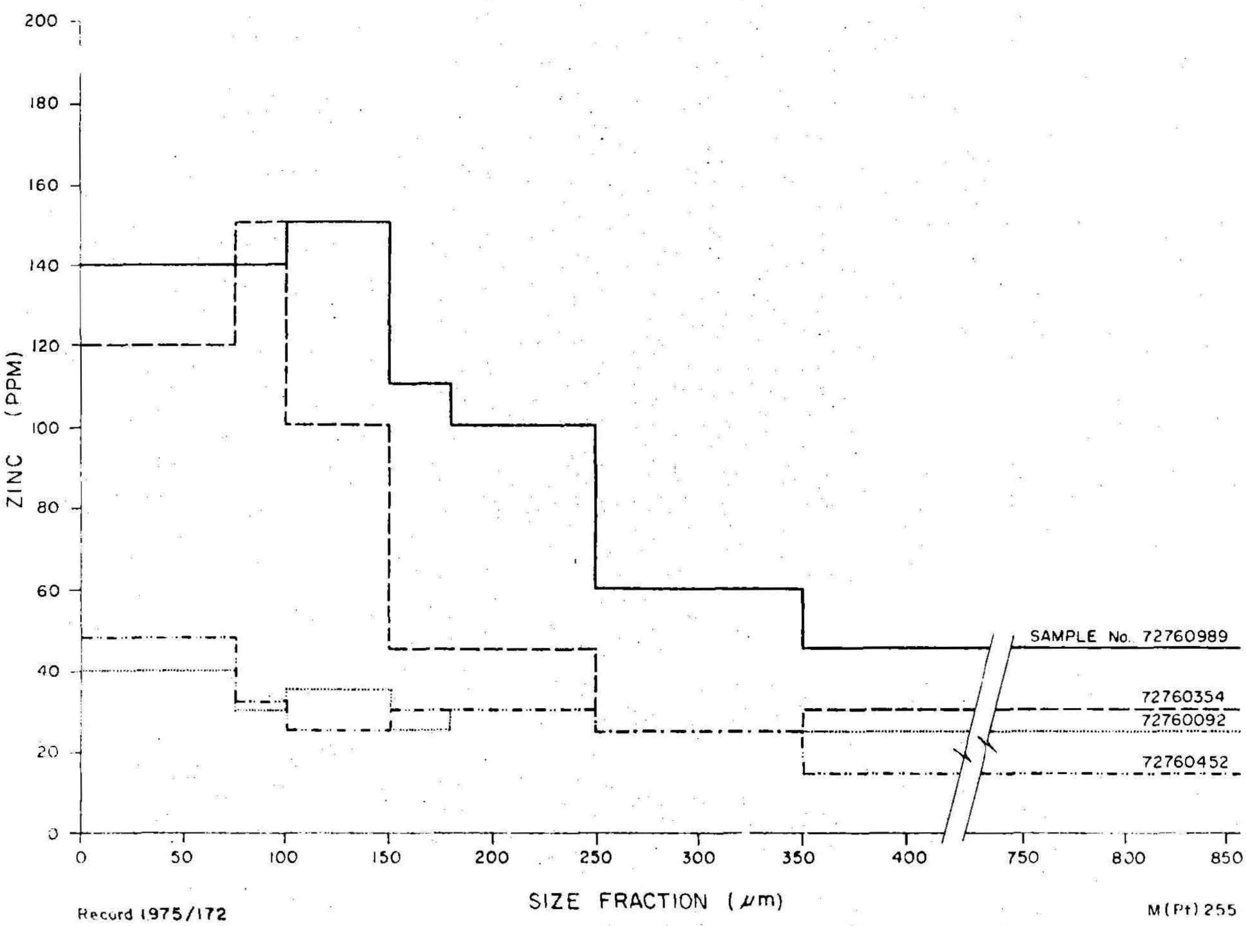


Fig. 3 Distribution of zinc in various size fractions of four stream – sediment samples

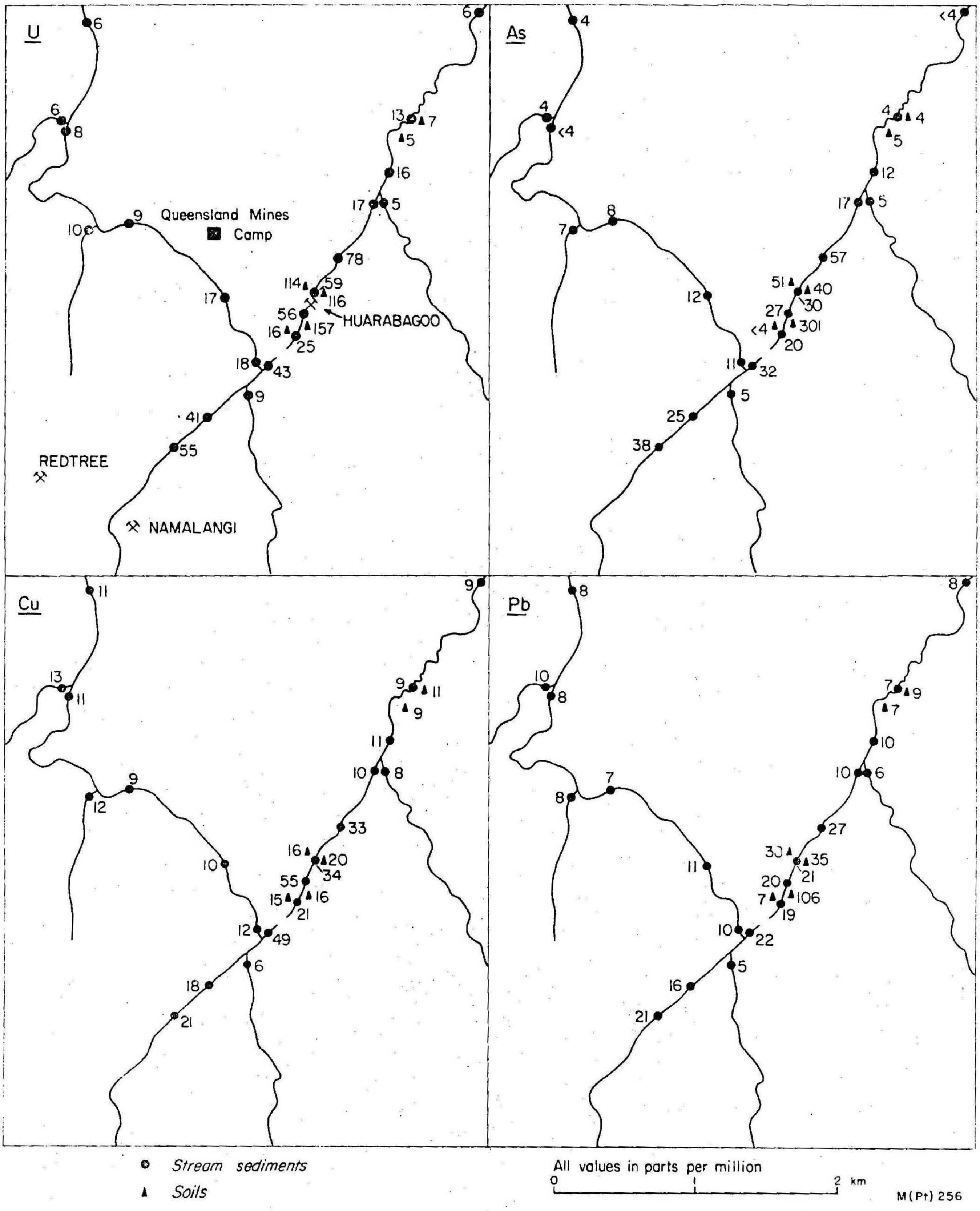


Fig. 4 Results of geochemical sampling near the Westmoreland uranium deposits

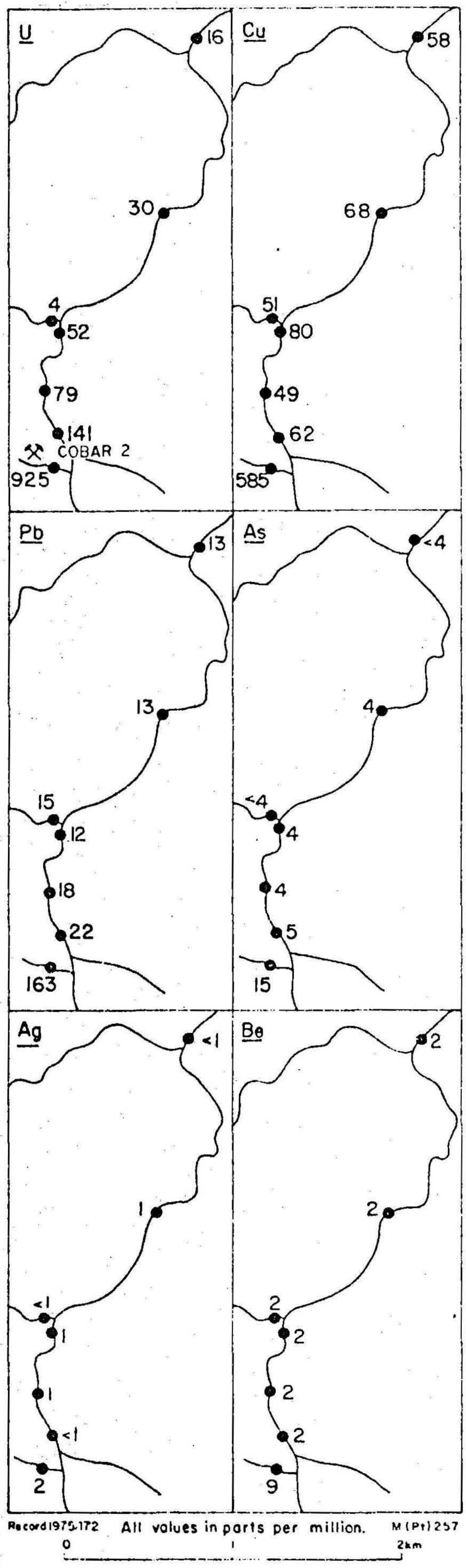
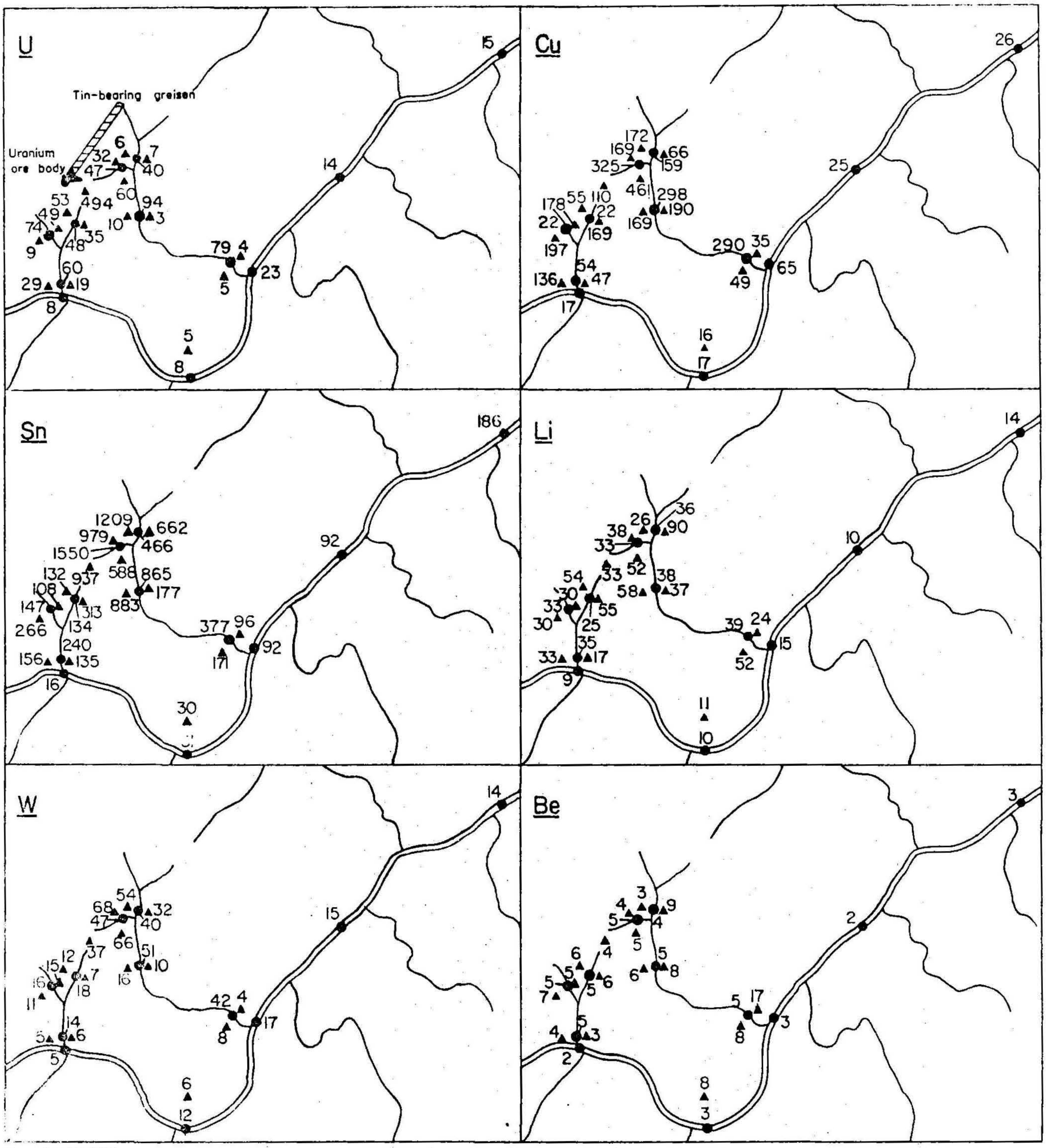


Fig. 5 Results of stream-sediment sampling near the Cobar 2 uranium deposit.



Record 1975/172

● *Stream sediments*
▲ *Soils*

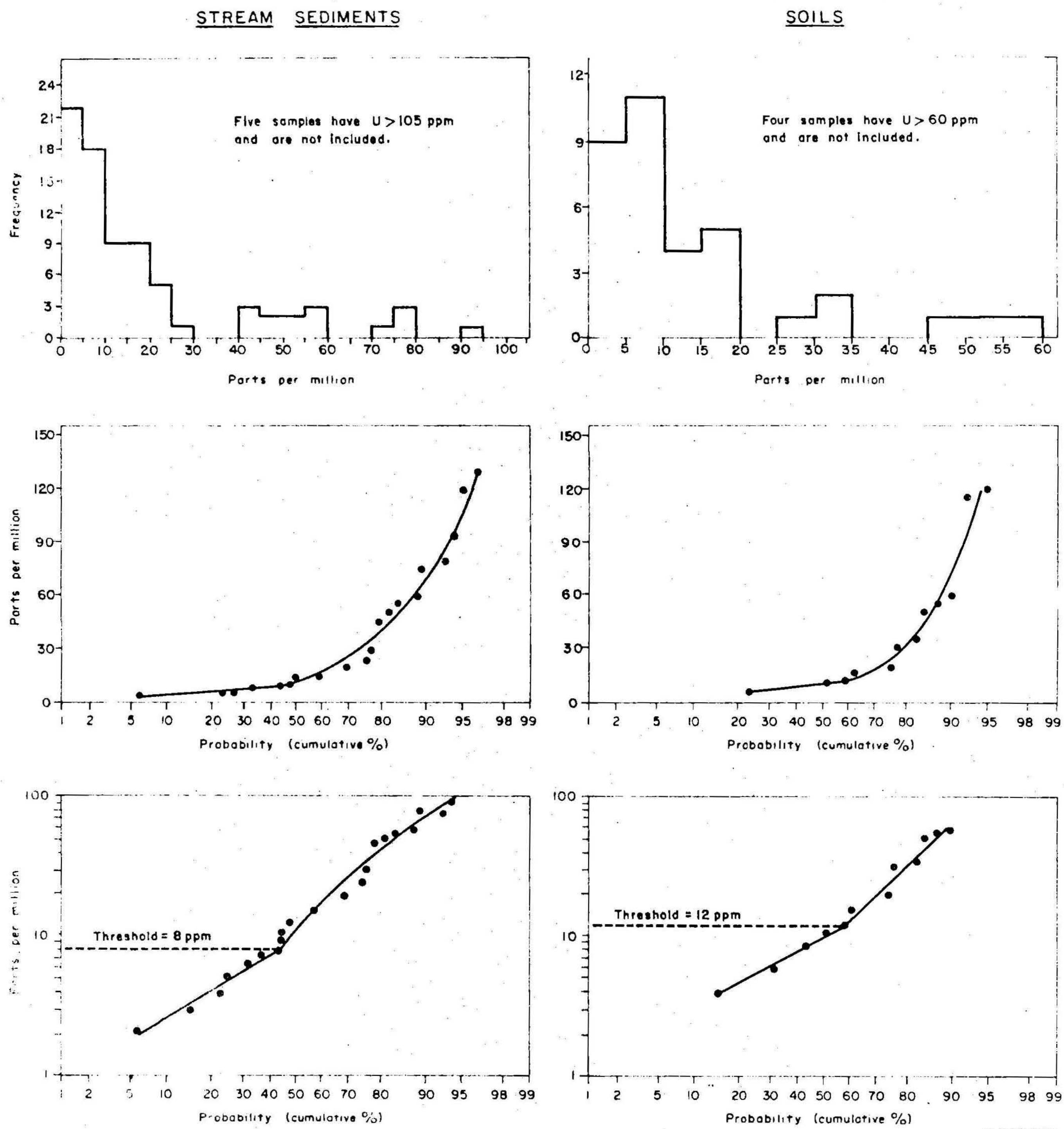
All values in parts per million

0 1 km

M(Pt) 258

Position of orebody and greisen after United Uranium NL

Fig 6. Results of geochemical sampling near the Pandanus Creek uranium deposit



Record 1975/172

M(Pt) 259

Fig. 7 Uranium distributions in histogram and cumulative frequency form.

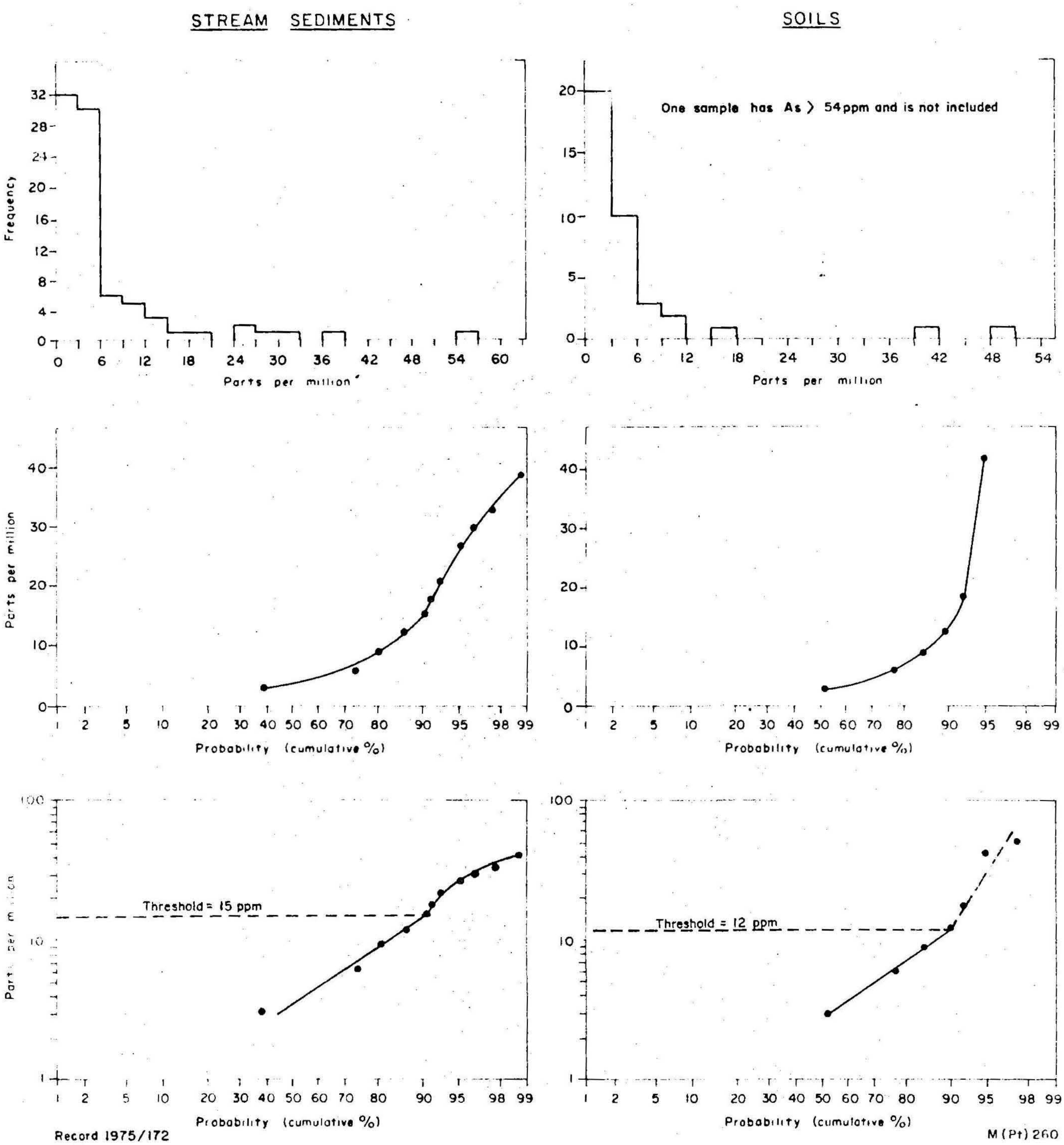


Fig. 8 Arsenic distributions in histogram and cumulative frequency form.

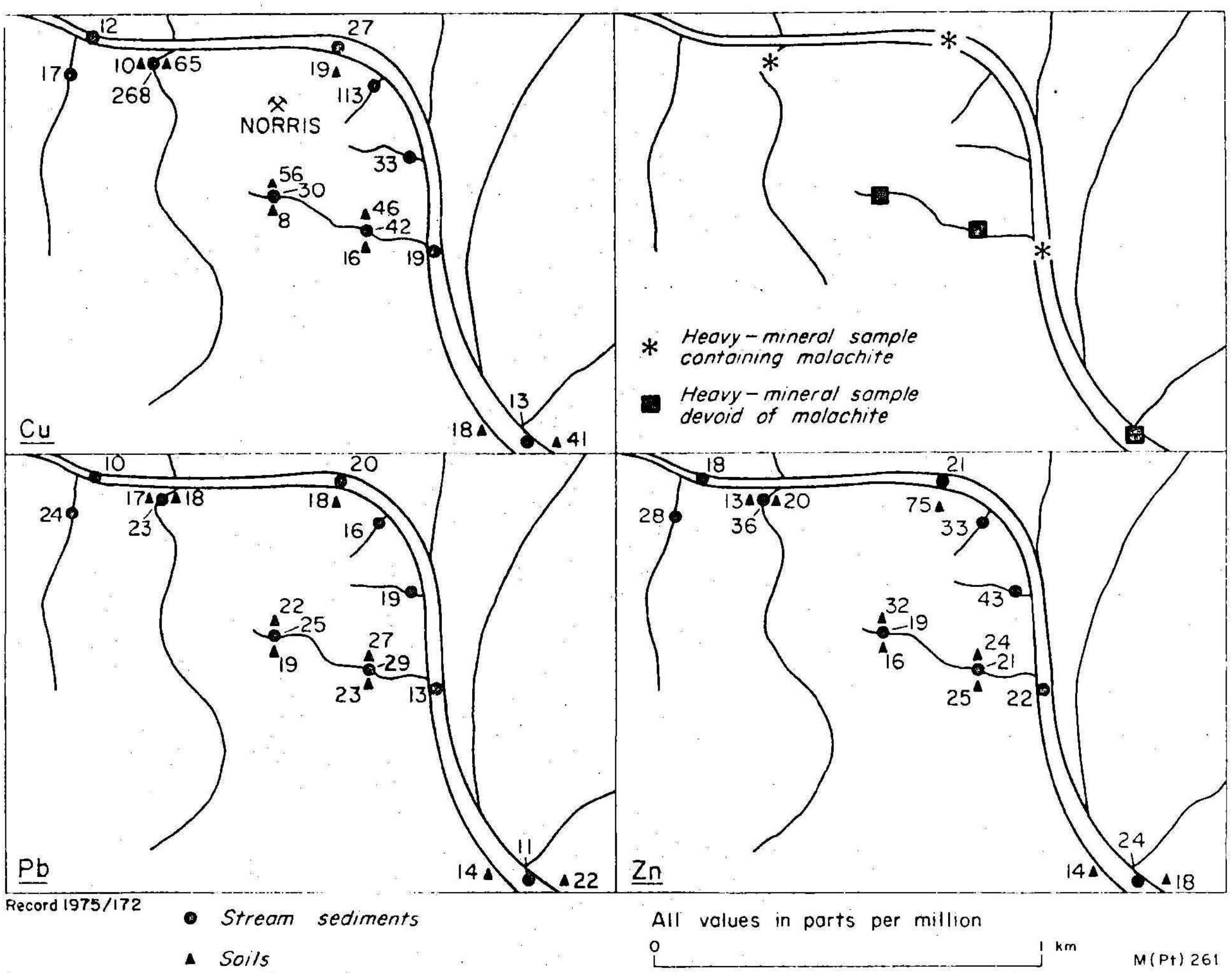


Fig. 9 Results of geochemical sampling near the Norris copper deposit

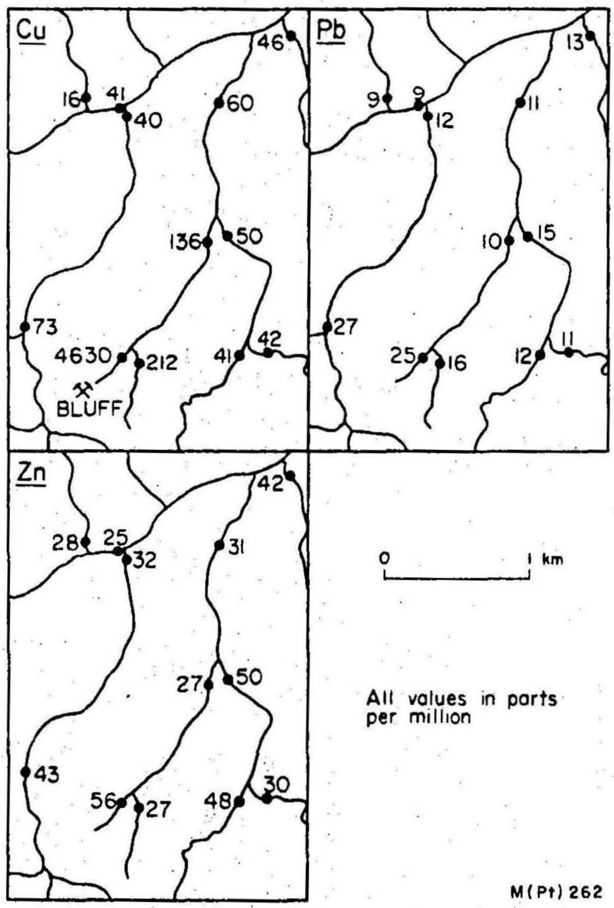


Fig 10 Results of stream-sediment sampling near the Bluff deposit — Redbank copper field

Record 1975/172

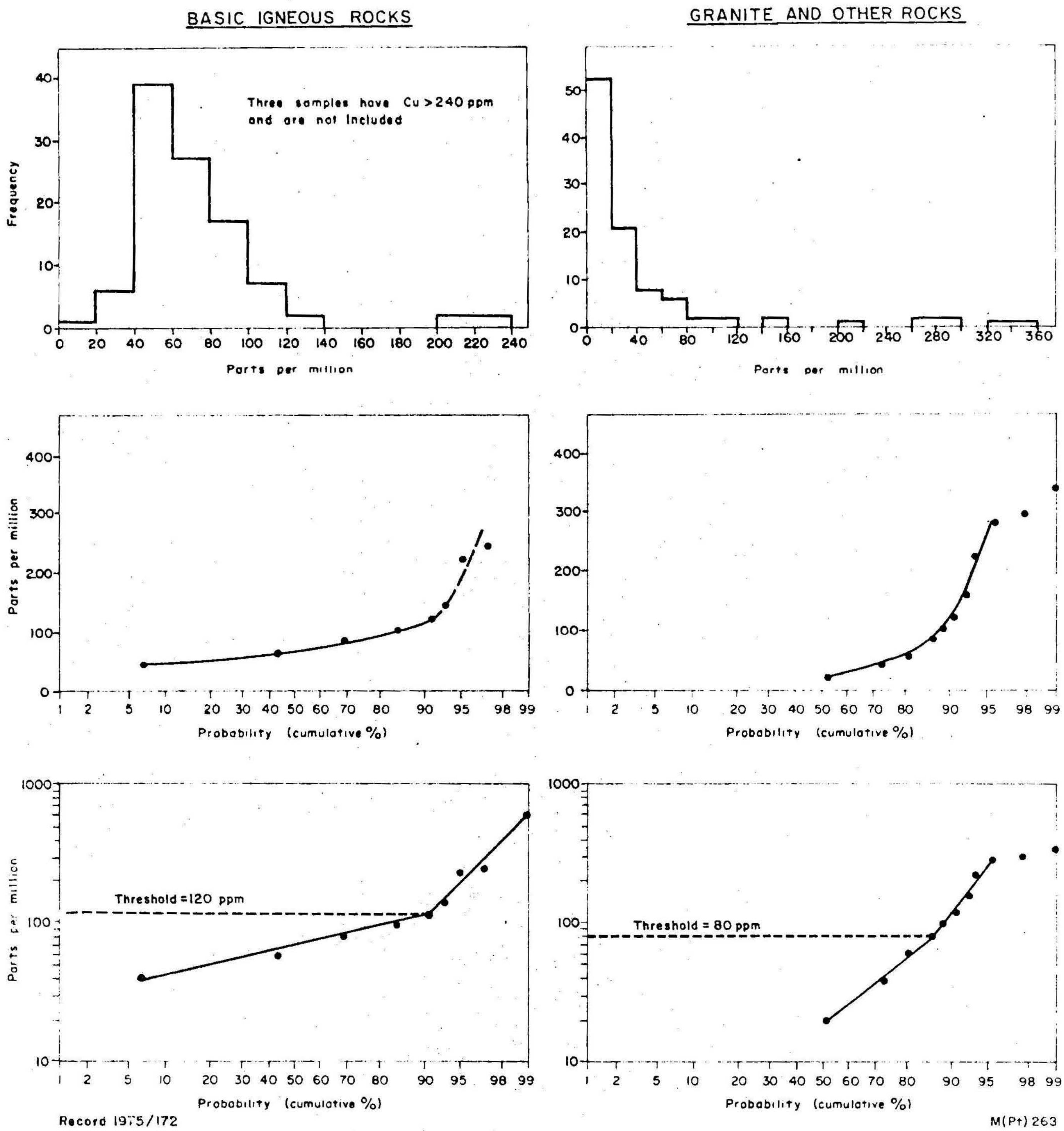


Fig. 11 Copper distributions in stream sediments from catchments draining different rock types.

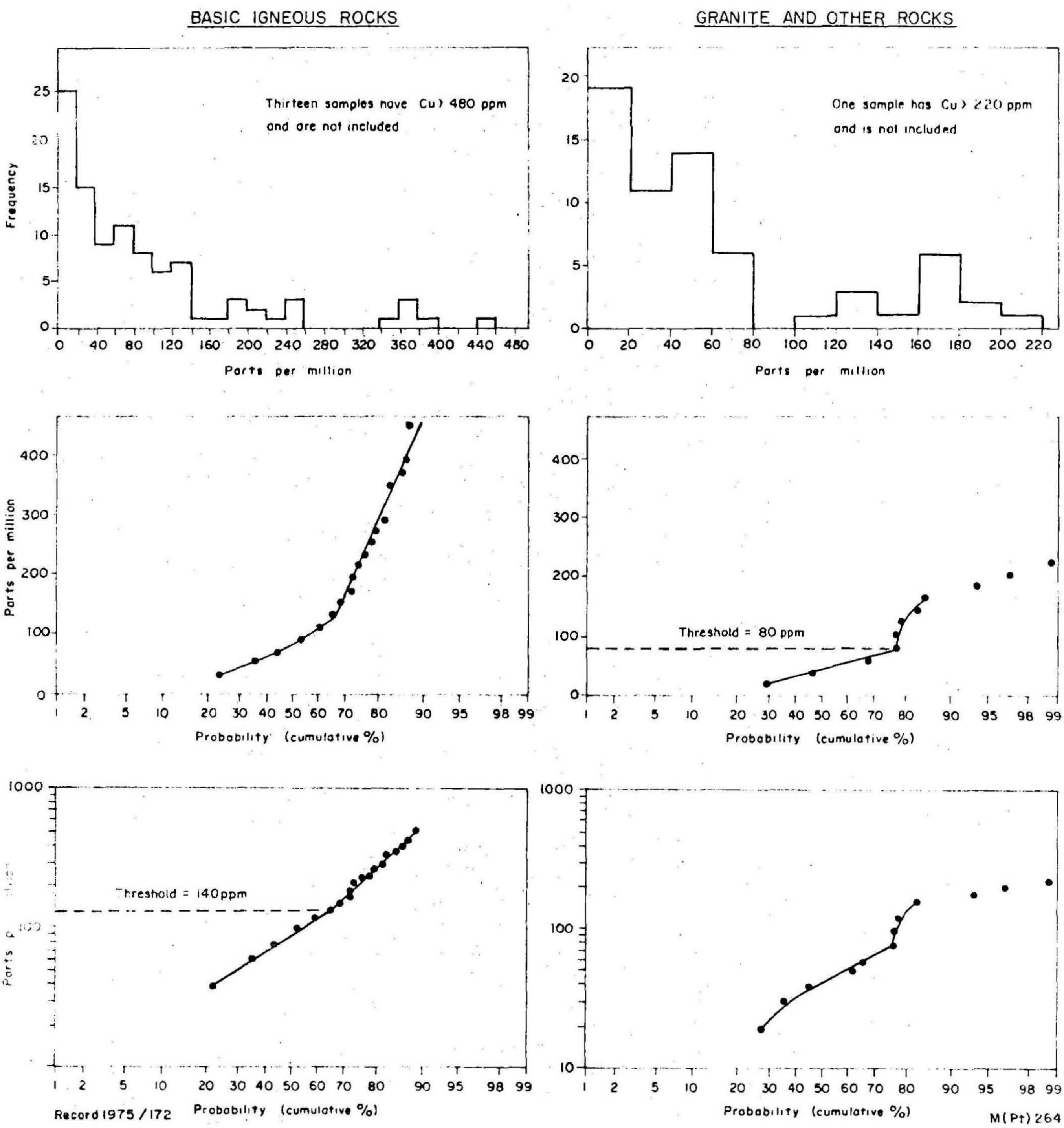


Fig. 12 Copper distributions in soils overlying different rock types

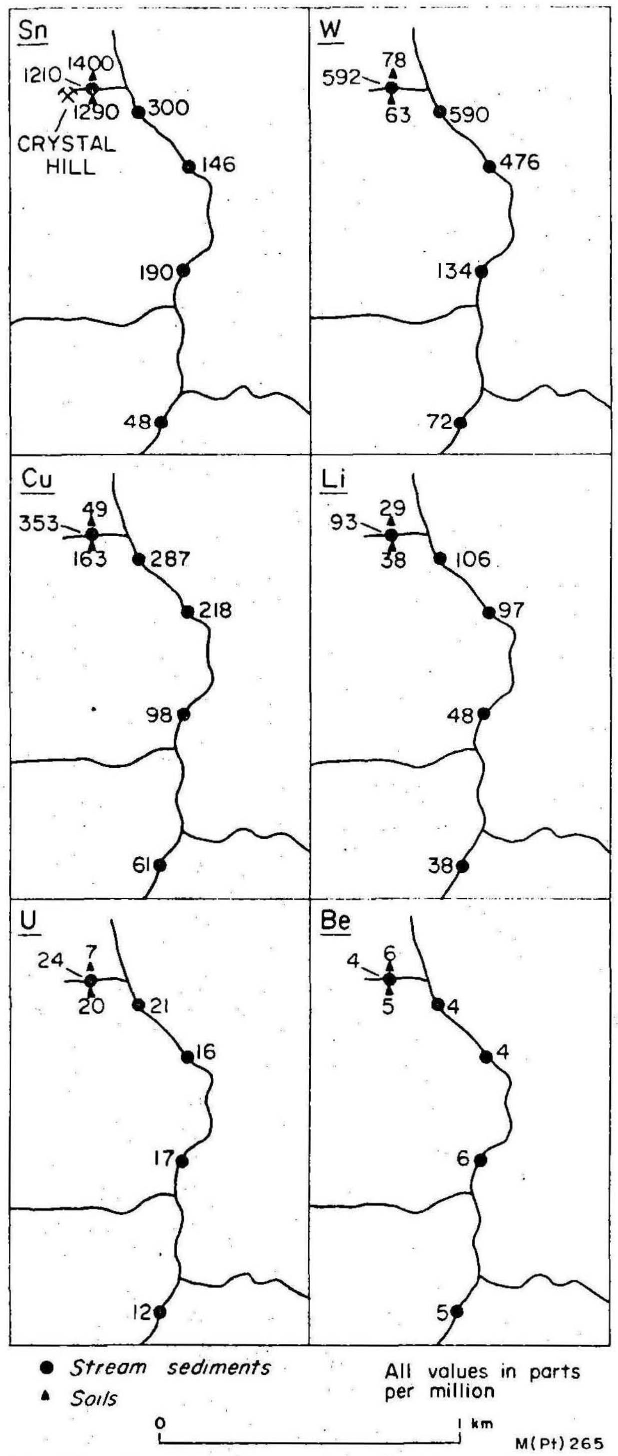


Fig. 13 Results of geochemical sampling near the Crystal Hill tin deposit

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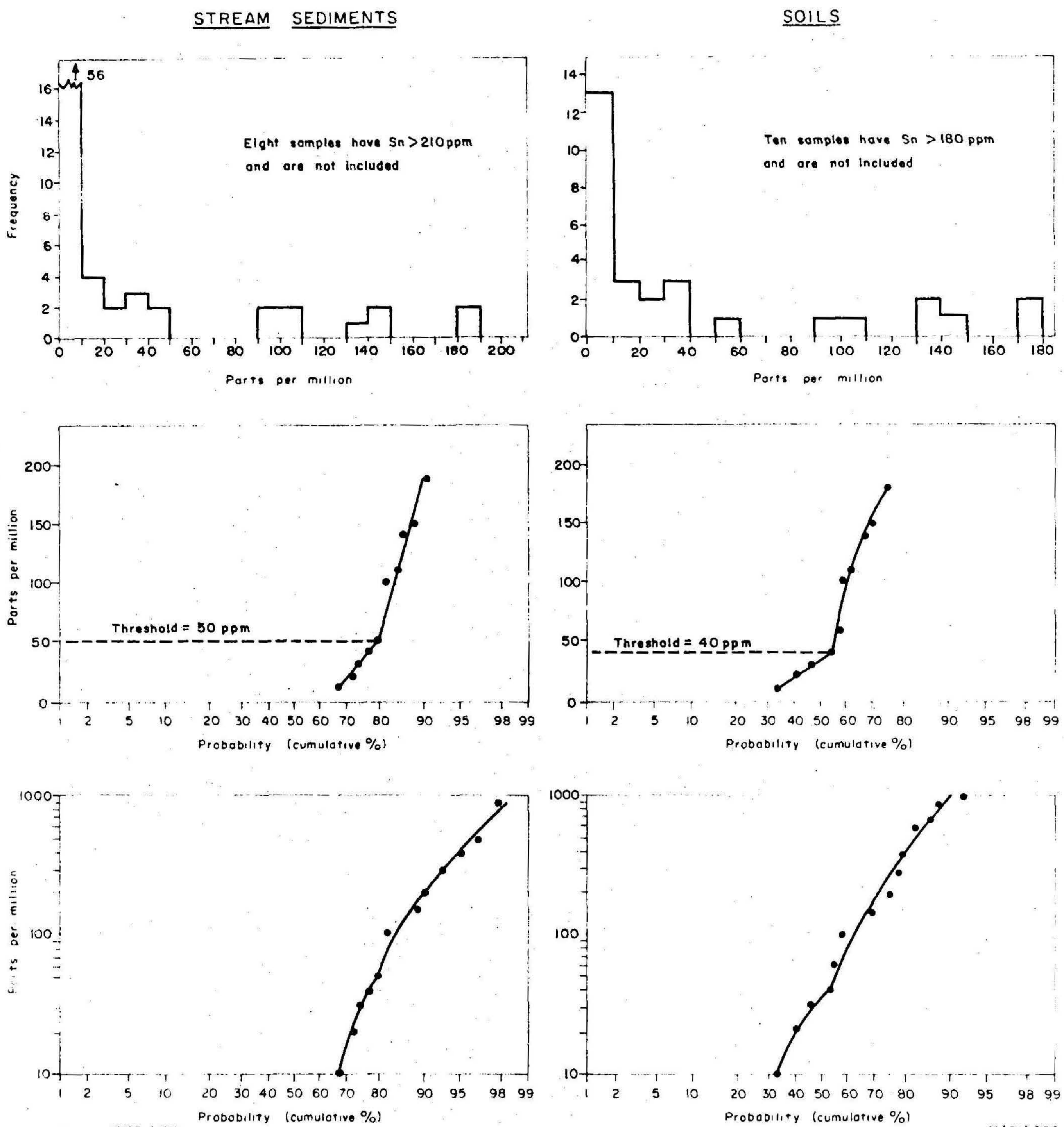

Record 1975/172

M(Pt)266

Fig. 14 Tin distributions in histogram and cumulative frequency form.

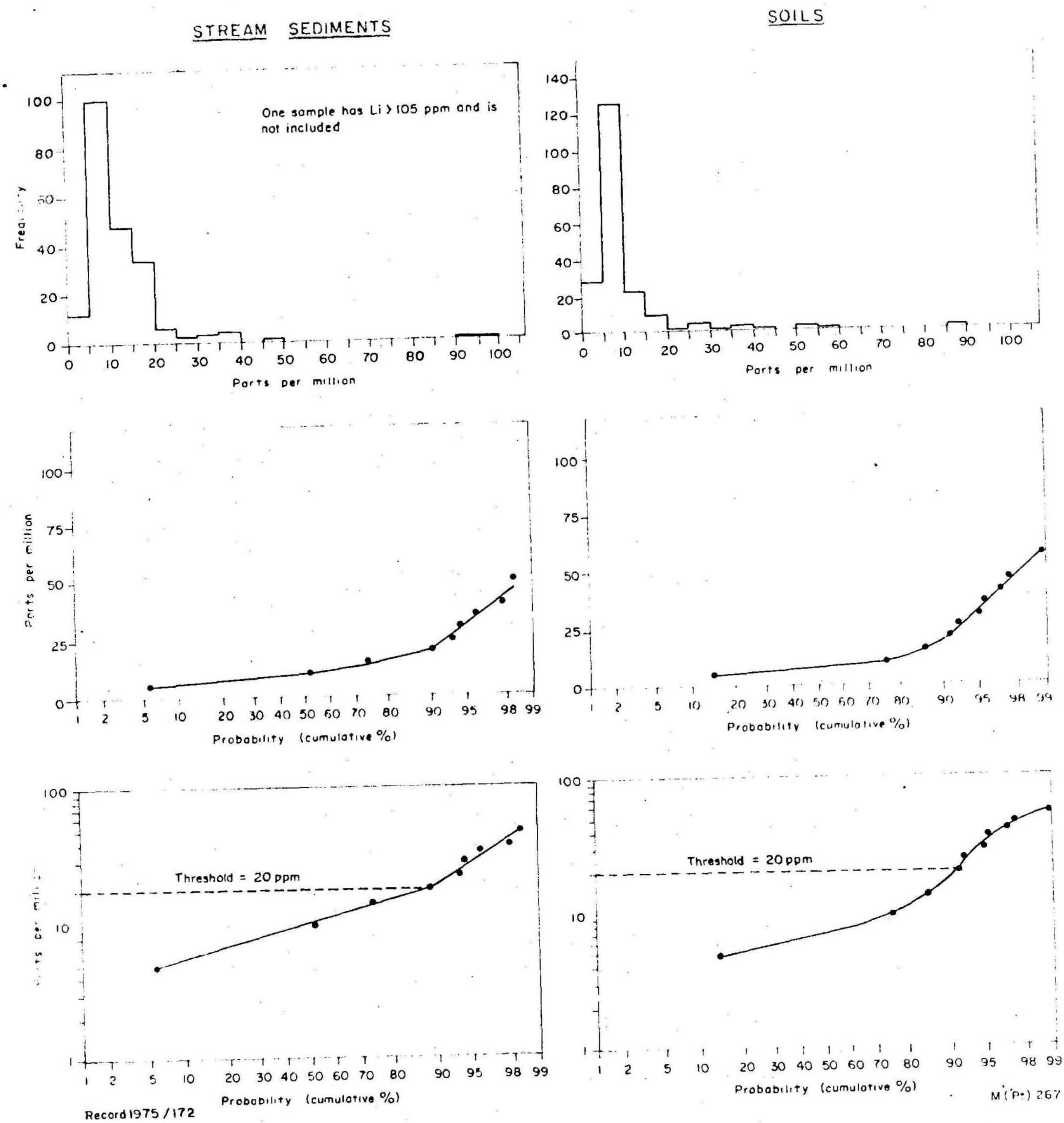

Fig. 15 Lithium distributions in histogram and cumulative frequency form.

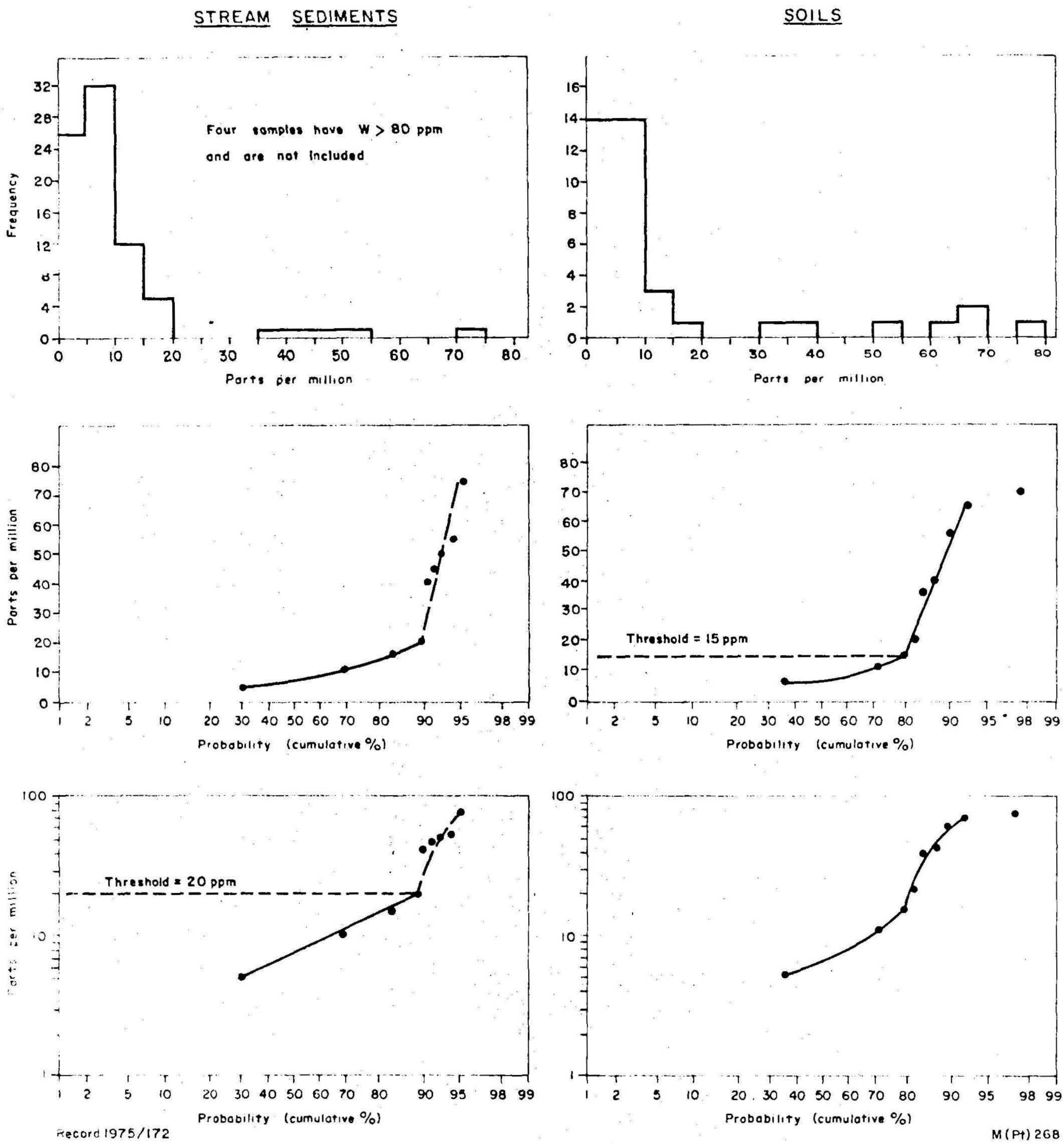

Fig. 16 Tungsten distributions in histogram and cumulative frequency form.

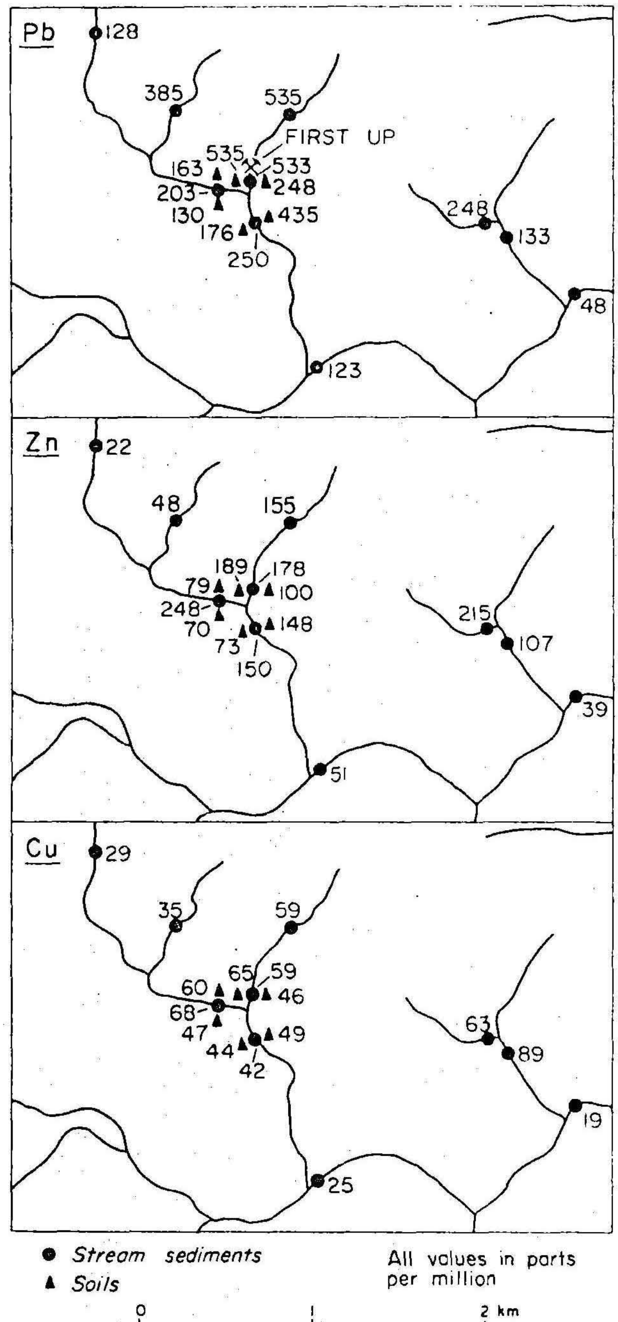

Fig. 17 Results of geochemical sampling near the First Up lead deposit

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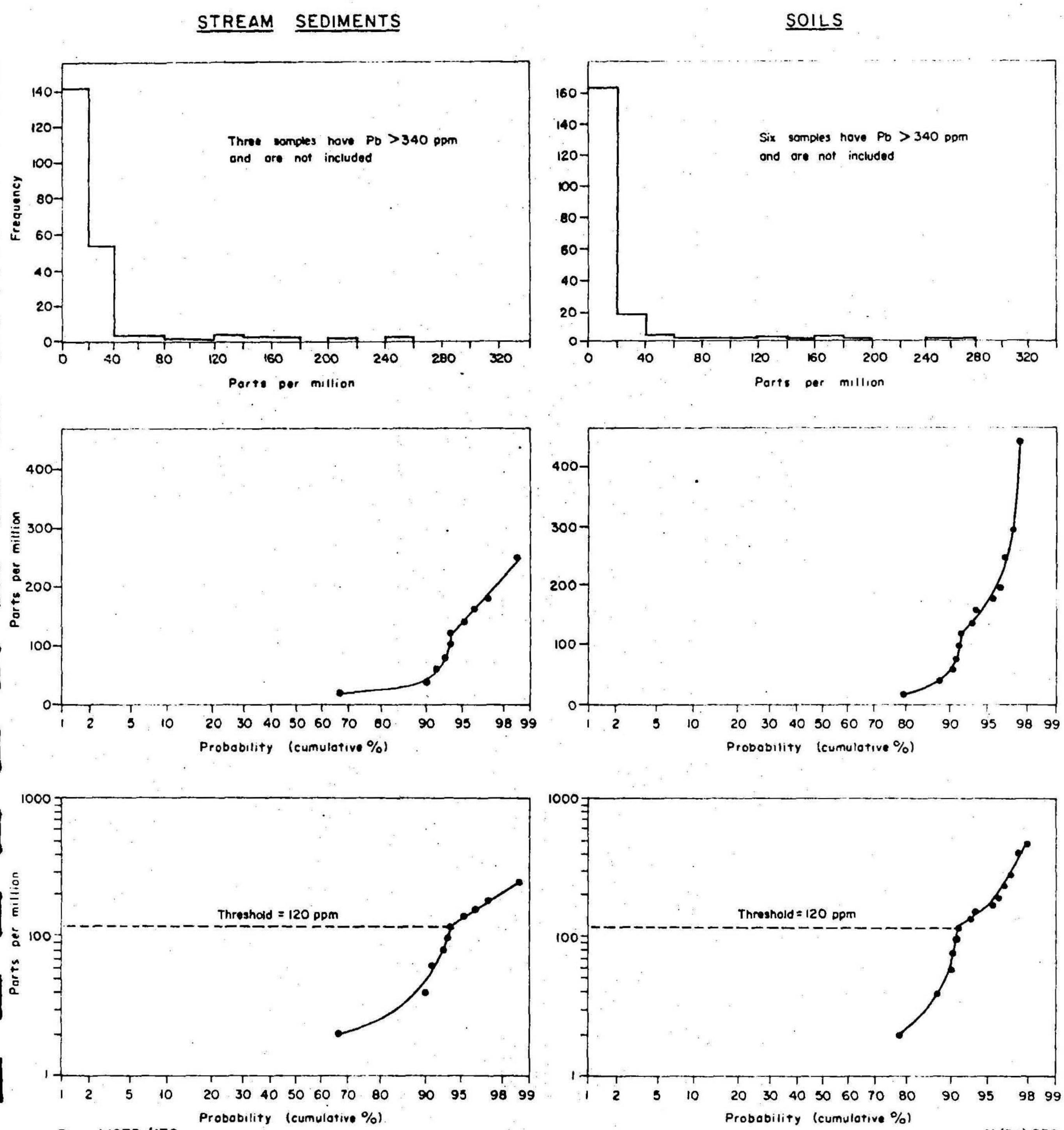


Record 1975/172

M (Pt) 270

Fig. 18 Lead distributions in histogram and cumulative frequency form.

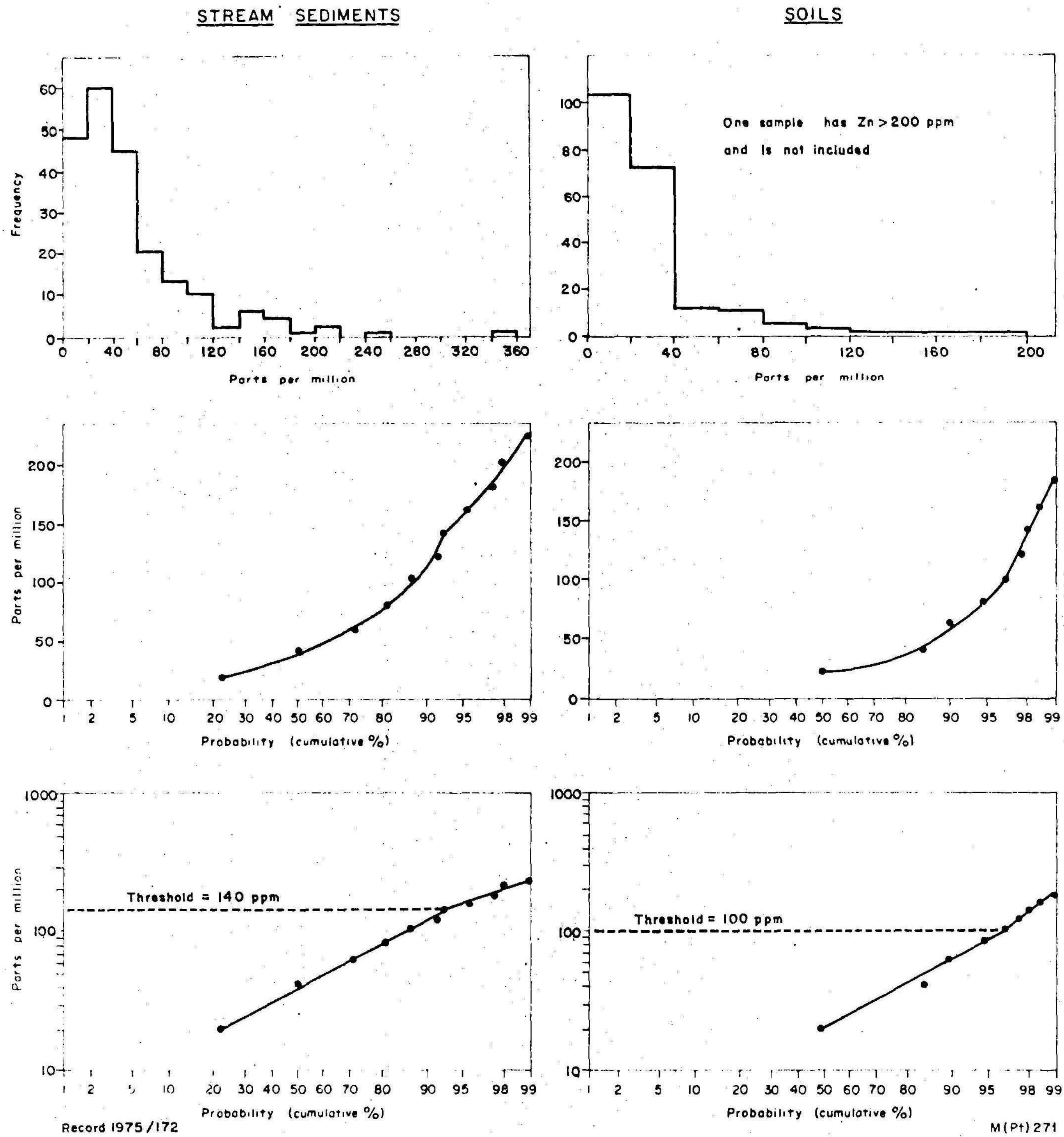


Fig. 19 Zinc distributions in histogram and cumulative frequency form.

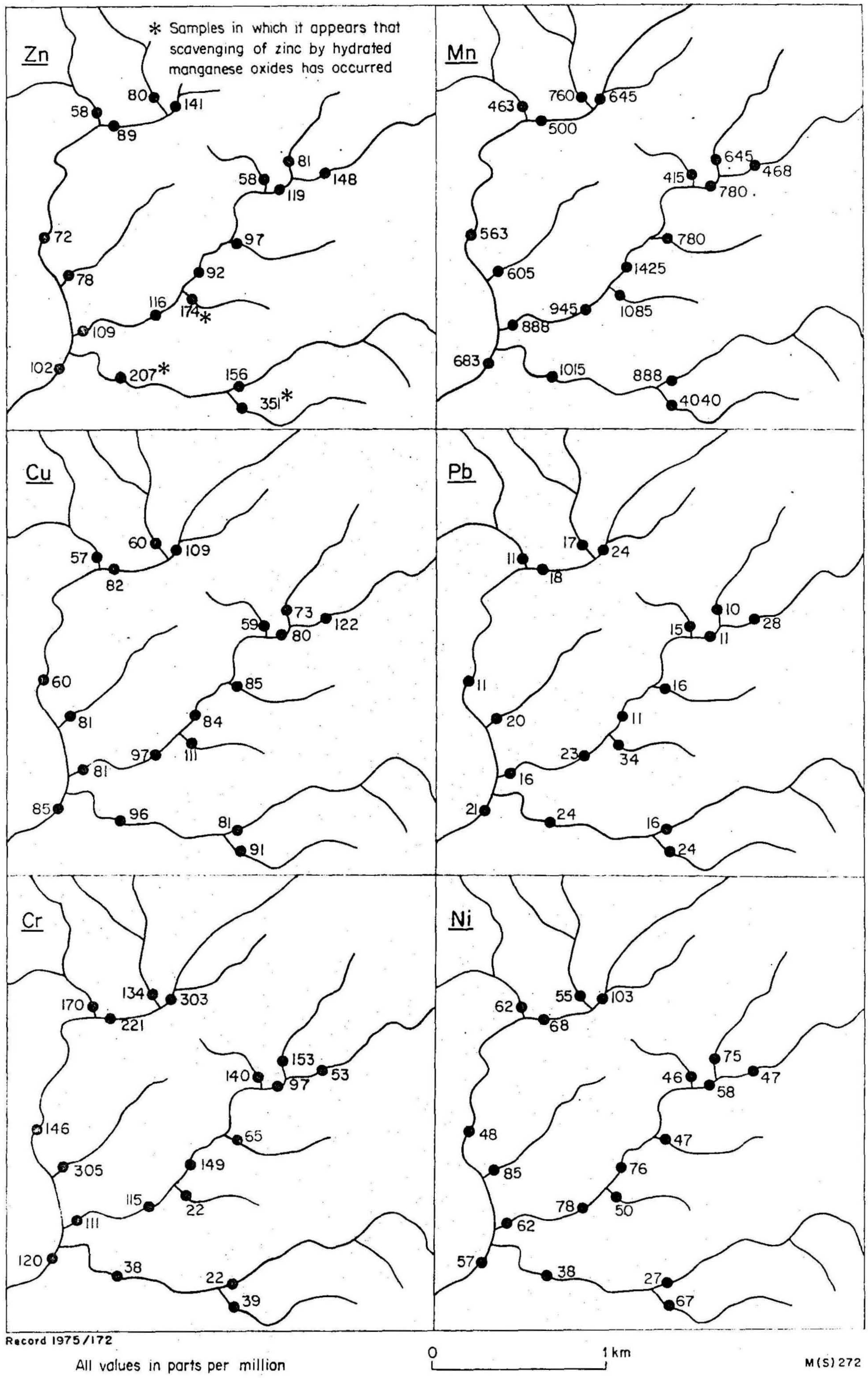
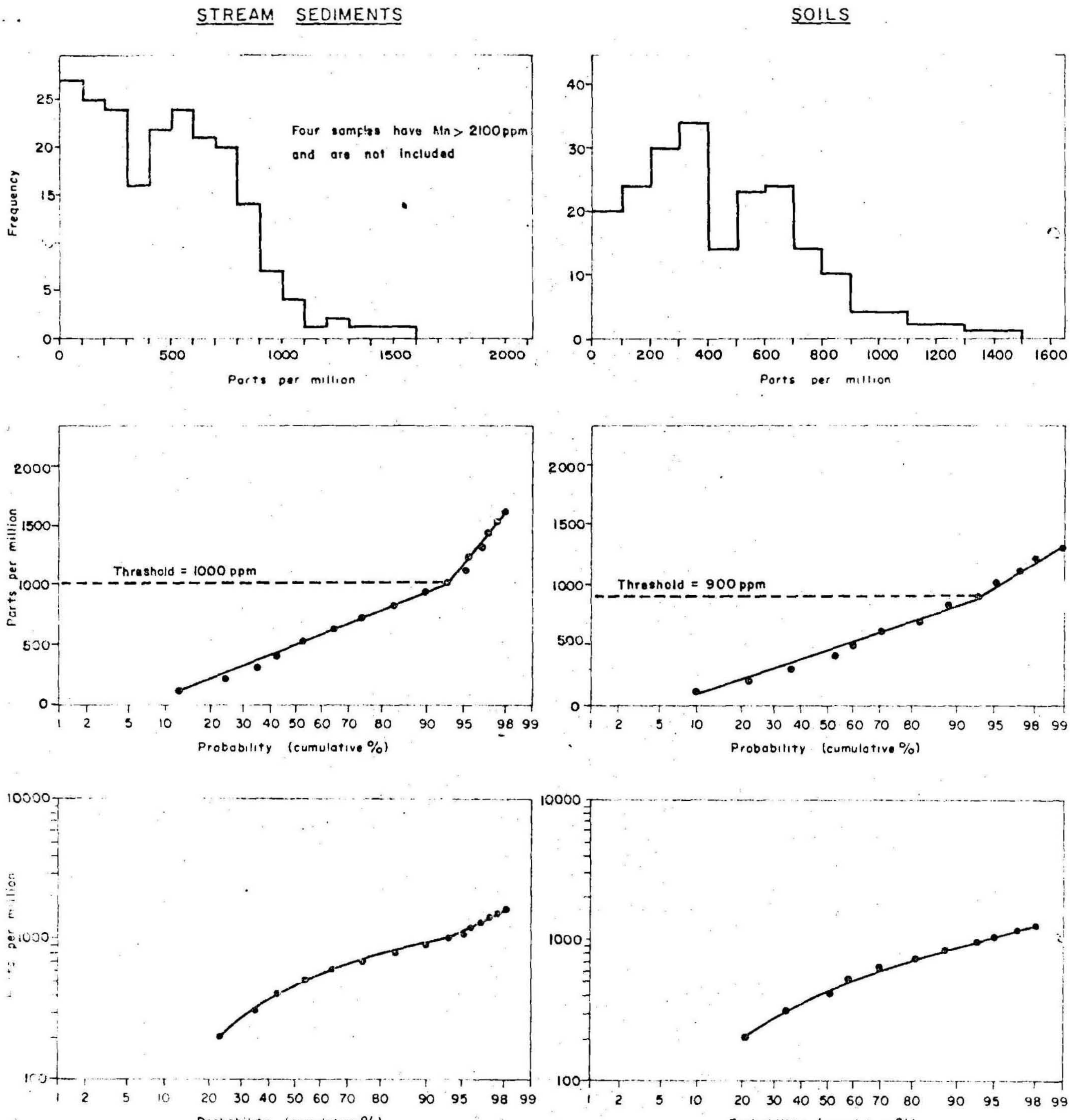


Fig. 20 An example of apparent manganese scavenging of zinc in stream sediments



Record 1975/172

M(Pt) 273

Fig. 21 Manganese distributions in histogram and cumulative frequency form.

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