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DEPARTMENT OF NATIONAL RESOURCES

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AN ORIENTATION GEOCHEMICAL SURVEY IN THE GEORGETOWN AREA, NORTH QUEENSLAND

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SUMMARY

This report presents the results of orientation geochemical sampling carried out during 1972 and 1973 as the forerunner to a regional stream-sediment survey in the Georgetown 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. Stream-sediment and soil samples were analysed by atomic absorption spectrophotometry and X-ray fluorescence spectrometry for a wide range of elements. 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 with interpretation of the data.

The main types of mineralization in the area can all be detected by stream-sediment sampling. Sieved samples are successful in the search for uranium, porphyry copper, and zinc deposits whereas heavy-mineral concentrates are more suitable for delineating lead and vein-type copper mineralization. Both methods may be used to locate gold and tin deposits. The most useful pathfinder elements are arsenic, beryllium, fluorine, lithium, molybdenum, silver, sulphur, and tungsten. Cerium and thorium values are helpful in the interpretation of geochemical surveys for uranium.

INTRODUCTION

The orientation geochemical studies described were carried out during 1972 and 1973 in preparation for a regional stream-sediment survey which began in the Georgetown area of north Queensland during the 1974 field season. The survey was designed to provide data for the production of geochemical maps which, in conjunction with the results of recent geological mapping, will facilitate future mineral exploration in the region. Both the geochemical and geological maps will be produced at a scale of 1:100 000.

Location

The study area lies entirely within a 150-km radius of the settlement of Georgetown which is situated 280 km southwest of Cairns. The work was confined largely to the Georgetown 1:250 000 Sheet area, but a few samples were collected from the adjoining edges of the Red River, Einasleigh, and Gilberton Sheet areas (Fig. 1).

Climate and vegetation

The climate is semi-arid with an average annual rainfall of about 640 mm and a well defined summer wet season. Apart from occasional waterholes the streams are dry during the winter months. The mean daily temperatures are high, ranging from about 15-20°C in the winter to 25-30°C in the summer.

Savannah woodland dominated by small eucalypts covers the region; large trees are generally found only in proximity to watercourses. Very little land has been cleared or cultivated.

Physiography

The three major physiographic divisions of the area are the Newcastle Range, flanked on the west by the Georgetown Upland and on the east by the Einasleigh-Copperfield Plain. The nomenclature used for these units is that suggested by Twidale (1956).

The Newcastle Range consists of resistant Upper Palaeozoic volcanics. It increases steadily in elevation towards the south reaching a maximum height of 900 m above sea level (Branch, 1966). The southern portion is bounded by steep escarpments.

The Georgetown Upland ranges in elevation from 200 m near Forest Home homestead to about 600 m in the southeast (White, 1965). In general the Precambrian sedimentary and metamorphic rocks, which constitute a large part of this unit, are deeply dissected; granitic rocks of Proterozoic to Palaeozoic age form many of the uplands and flat-lying Mesozoic sediments normally occur as plateaux.

The Einasleigh-Copperfield Plain, like the other two units, increases in elevation towards the south, reflecting widespread post-Mesozoic tilting of the area (Reynolds, 1960; White, 1965). The plain ranges in height from 330 m in the north to 600 m in the south.

Drainage, generally of dendritic pattern, is well developed on all three units. Most of the streams draining the Newcastle Range are youthful in aspect and degradation far outweighs deposition. Gorges and waterfalls are common where these streams leave the range and flow out onto the adjoining lowlands. The drainage on the Georgetown Uplands and the Einasleigh-Copperfield Plain is more mature and alluvial deposits are more common. Degradation still dominates, however.

Soils are generally thin and skeletal in areas of higher relief where erosion is considerable. Chemical weathering processes assume more importance on the lowlands and as a consequence soils are deeper here. Profile development seldom occurs even though most soils are residual. Gravel-size siliceous and ferruginous material is generally an abundant constituent.

Geology

The geological features of the Georgetown region have been discussed in detail by White (1965). More recent accounts have been provided by Bain (1973), Bain et al. (1974) and Bain et al. (in prep.). The terminology proposed by White (1965) is used here although the Etheridge Formation has been discarded. Later work suggests that rocks previously assigned to this formation should in fact be included in the Robertson River Metamorphics.

The Georgetown Inlier is about 300 km long by 250 km wide and consists of a great variety of rock types ranging in age from Precambrian

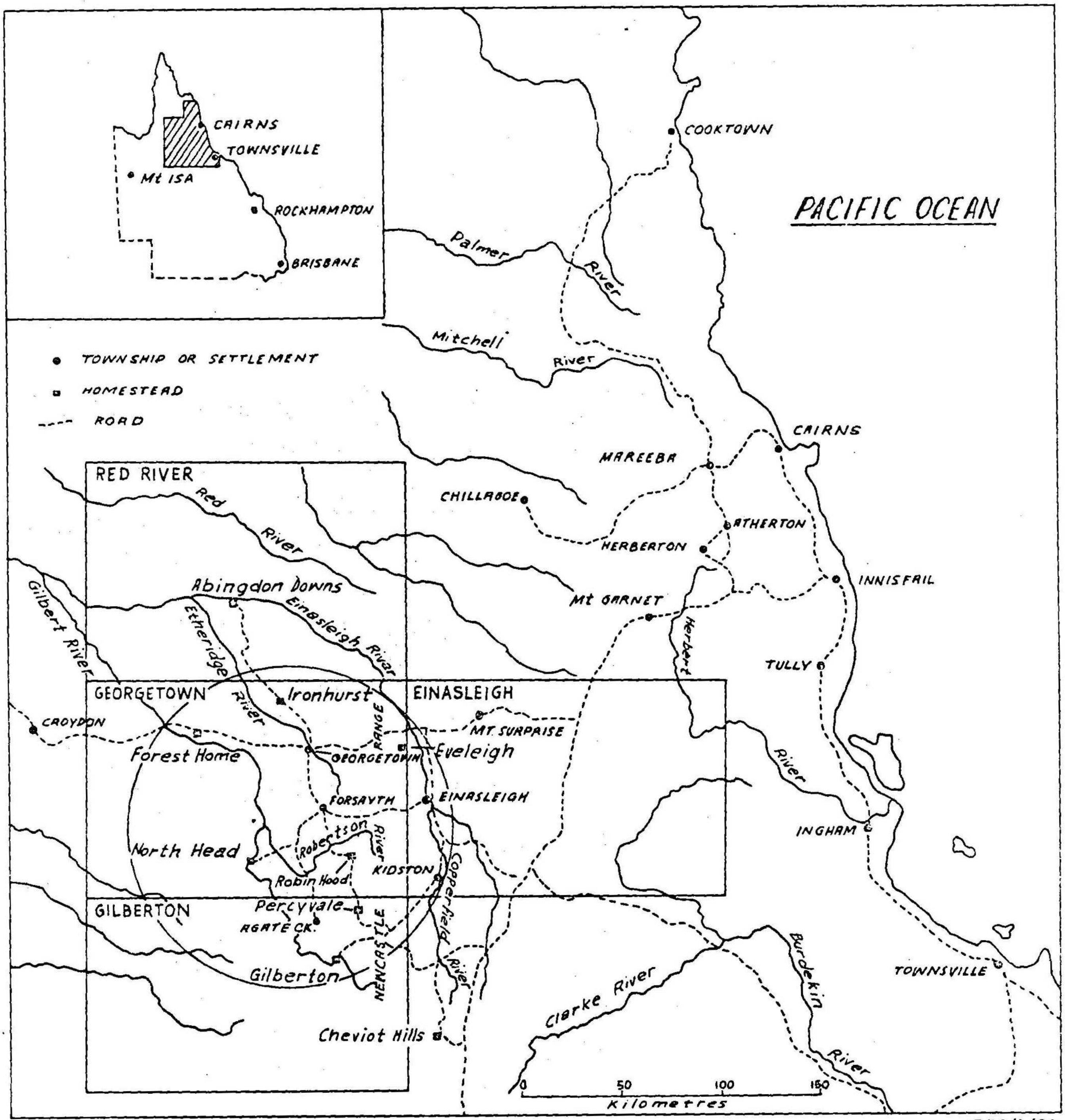

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Fig 1: Locality map showing the area covered by the survey (circled) and the boundaries of the Georgetown, Einasleigh, Gilberton and Red River 1: 250,000 Sheet areas to Recent (Fig. 2). The inlier is bounded on the east by Palaeozoic rocks of the Tasman Geosyncline. To the west Mesozoic and younger sediments of the Great Artesian and Carpentaria Basins obscure the relation of the Precambrian rocks of the inlier to those of the Australian Shield.

The Precambrian geology of the region is complex. The basement rocks range from the high-grade migmatitic gneisses of the Einasleigh Metamorphics to the almost unaltered sediments of the Langdon River Formation. White (1965) has suggested that the high-grade metamorphic rocks are older than the unmetamorphosed rocks. He assigned an Archaean age to the former and regarded the latter as Proterozoic, however this relation has not been firmly established. The Cobbold Dolerite intrudes these sedimentary and metamorphic rocks as dykes and sills. The intrusions of amphibolite and dolerite were folded at the same time as the sedimentary sequence and thus antedate a widespread episode of post-orogenic acid plutonism that began in the Late Precambrian and possibly extended into the Palaeozoic. Two major complexes that resulted from this second period of igneous activity crop out in the study area; these are the Forsayth Granite and the Robin Hood Granite.

During the Upper Palaeozoic there was a further episode of widespread igneous activity in the region. Numerous large cauldron subsidence structures were initiated and very thick rhyodacitic to rhyolitic ash-flow sequences accumulated in them. The Newcastle Range, Galloway, and Cumberland Range cauldrons occur within the area under consideration. The volcanism was accompanied by the emplacement of numerous high-level granitic stock and ring-dyke systems. The Elizabeth Creek Granite is an example.

During Mesozoic time sandstones continuous with those of the Great Artesian and Carpentaria Basins were deposited over large areas. As a result of erosion, however, such rocks today crop out only in isolated patches. Generally these erosion remnants form plateaux.

Basalts of Tertiary to Recent age were extruded over extensive areas of the eastern half of the Georgetown Inlier. These rocks occur only in the extreme east of the study area.

Mineral deposits

The mineral deposits of the Georgetown area have been described by White (1965) and Withnall (in press). These authors provide details of most of the mines in the region and only a short summary is given here.

White (1965) recognized three main epochs of metallogenesis. The first occurred in Precambrian time when gold, copper, lead, and silver were introduced by the Cobbold Dolerite. Later in the Precambrian and possibly in the Early Palaeozoic, gold and base-metal deposits accompanied the emplacement of the Forsayth and Robin Hood Granites. The third period of mineralization occurred in the Late Palaeozoic - tin, tungsten, copper, lead, and silver* are associated with the granites and volcanics of this age. Mitchell (1969) assigned little importance to the Cobbold Dolerite as a mineralizer and considered that most of the ore occurrences in the regionare genetically related to the Precambrian and Palaeozoic granites.

Gold Most of the gold deposits in the area form part of the Etheridge Goldfield which lies near the western margin of the Forsayth Granite (Fig. 2). The field consists of about 150 reefs that have produced nearly all of the 20 200 kg of gold mined in the Georgetown region since 1877 (White, 1965). With the exception of minor gouging, none of the deposits is currently being worked. The auriferous veins range in width from about 0.2 to 4 m, averaging about 1 m, and vary from nearly pure quartz to massive sulphides (galena, sphalerite, and pyrite with lesser chalcopyrite). Cameron (1900) noted that the lodes within the Forsayth Granite are generally sulphide-rich while those in the adjacent sediments usually contain only minor sulphide mineralization. White (1965) suggested that this difference might be the consequence of the introduction of the former lodes by the Forsayth Granite and the latter by the Cobbold Dolerite. However, Quennel (1962) put forward the opinion that the weakly mineralized veins are genetically related to the Forsayth Granite and the sulphide-rich types he attributed to an unexposed Late Palaeozoic granite.

Other smaller fields in the area are the Oaks, Percyville, and Gilbert Goldfields (Fig. 2). The deposits of the Oaks Goldfield near Kidston are associated with a breccia pipe of probable Late Palaeozoic age.

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* Recent discoveries indicate that uranium, molybdenum, gold, and fluorine are also related to Late Palaeozoic igneous rocks.

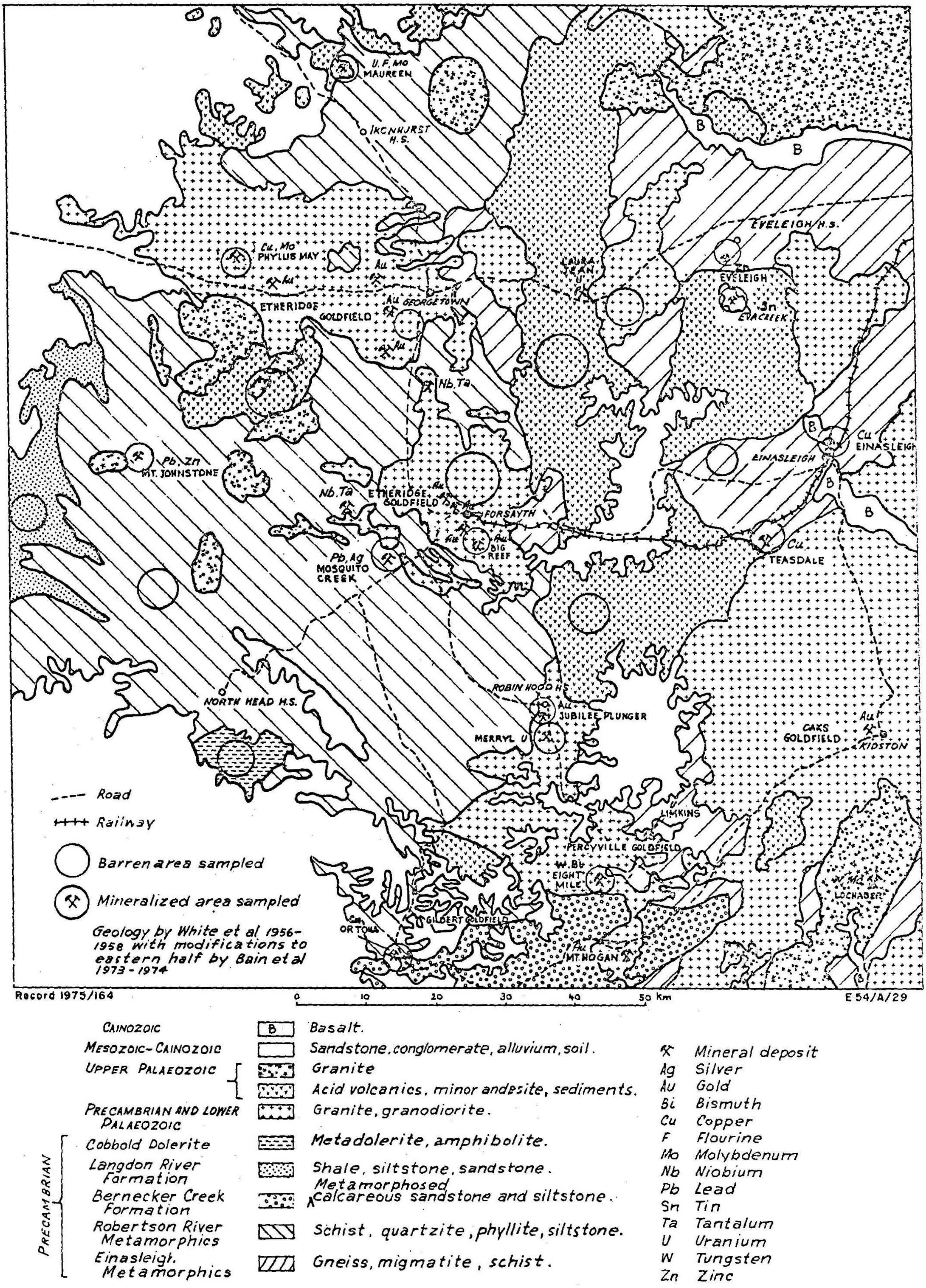

Fig 2 : Geological map of the Georgetown area showing the more important mineral deposits. Areas sampled during the survey are indicated

Most of the gold occurs in veinlets along joints and fractures around the margins of the pipe. Considerable disseminated sulphide mineralization accompanies the gold; pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite are the most common sulphides. The gold of the Percyville field occurs in complex copper, lead, zinc, and silver ores apparently introduced by the Robin Hood Granite. The Gilbert Goldfield is mainly a copper-bearing area but contains some gold veins that may be related to the Cobbold Dolerite (White, 1965). Ball (1915) recorded tellurides in these lodes.

Copper Most of the copper mineralization in the area occurs as narrow veins. The lodes may be as much as several hundred metres long but are almost invariably less than 10 m wide. In most cases these deposits appear to be associated with Cobbold Dolerite but some copper was undoubtedly introduced by both the Precambrian and Palaeozoic granites. The most important ore minerals are chalcopyrite, malachite, and azurite; associated sulphides include pyrite, pyrrhotite, sphalerite, galena, and molybdenite. Vein-type copper deposits are largely confined to three provinces - the Percyville Goldfield, the Gilbert Goldfield, and a large region extending from south of Einasleigh northwards to Eveleigh homestead (Fig. 2).

The largest copper producer in the area was the Einasleigh mine from which 8200 tonnes of copper, 71.2 kg of gold and 4083 kg of silver were won between 1900 and 1924 (White, 1965). Here the ore appears to replace calcareous beds in the Einasleigh Metamorphics. Simpson & Rawlins (1968) considered that the mineralization is genetically related to Upper Palaeozoic granite. Perkin (1971) claimed that ore reserves might be as high as 19 million tonnes containing an average of 1.5 percent copper but this estimate was based on very limited information. Nevertheless, there is a good chance of fairly large tonnages of unworked ore remaining in the mine.

Recently mineralization of the porphyry copper type (Phyllis May prospect) has been found west of Georgetown by Central Coast Exploration. Disseminated chalcopyrite and molybdenite are associated with a granodiorite body of probable Palaeozoic age that intrudes the Precambrian Forsayth Granite. This deposit may not be suitable for economic exploitation at present but its discovery indicates that exploration for large low-grade copper ore bodies in the region might be successful.

Lead-zinc-silver Mineralization of the lead-silver type occurs, like copper, mainly in narrow veins. The lead lodes do not attain the same dimensions as the copper lodes and seldom exceed 2 m in width; the average length is about 100 m. As is the case for copper, lead has been mined to depths of greater than 30 m only on rare occasions.

Most of the lead deposits cluster in the Mosquito Creek area (Fig. 2) where they are associated with intrusions of Cobbold Dolerite. Other veins that occur sporadically throughout the Georgetown region can usually be linked genetically with the Precambrian granites. According to White (1965) lodes introduced by the Cobbold Dolerite are generally high in lead (60 percent average) and silver (1600 g/tonne average) but poor in gold; those related to granite are usually poorer in lead (14 percent average) and silver (95 g/tonne average) but often contain appreciable gold (32 g/tonne average). Zinc and copper are present in variable amounts. The dominant ore mineral is galena, accompanied in places by sphalerite and chalcopyrite. Anglesite, cerussite, and pyromorphite occur in the oxidized parts of the ore bodies. The McGregor's Creek portion of the Mosquite Creek Field yielded about 2000 tonnes of ore averaging 60 percent lead and 1600 g/tonne silver (White, 1965). Total production from the study area was probably no more than twice this amount.

The only known zinc deposit of appreciable size in the Georgetown area is located near Eveleigh station. Here low-grade zinc mineralization replaces calc-silicate beds in the Einasleigh Metamorphics. The main ore mineral is an iron-rich sphalerite. Estimated reserves are 15.7 million tonnes but zinc values are generally less than 2 percent and the deposit is considered subeconomic.

Uranium Small uranium occurrences are scattered throughout the Georgetown region. Recently uranium-fluorite-molybdenite mineralization has been found by Central Coast Exploration in the basal conglomerates of the Galloway Volcanics near Ironhurst station (Maureen prospect). Minor mineralization of similar type, but occurring in a porphyritic rhyolite dyke of the Newcastle Range Volcanics, is exposed in a road cutting on Highway 1, 25 km east of Georgetown (Laura Jean prospect). The Bureau of Mineral Resources has recently located a geochemical anomaly in

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which the elemental association appears to indicate mineralization of similar nature although the host rock is Robin Hood Granite (Merryl prospect). The only other known significant uranium occurrence in the study area is Limkin's prospect. Here metatorbernite, galena, and pyrite occur along fracture planes in a quartz vein which intrudes the Robin Hood Granite. Some mineralization occurs in the surrounding granite as well. Wyatt (1957) recorded production of 10 tonnes of ore with a grade of 1.5 to 4 percent U_3O_8 equivalent.

Tin To the northeast of the study area lies the Herberton Mt Garnet tinfield where alluvial cassiterite derived from Upper Paleozoic granites is won by dredging. The field is one of Australia's largest producers. A small tin-bearing pluton, probably contemporaneous with the Herberton granites, occurs in the headwaters of the east branch of Eva Creek 45 km east of Georgetown (Fig. 2). Some of the streams draining the pluton (Elizabeth Creek Granite) have been worked for alluvial tin.

Other metals A few small deposits of tungsten (both wolframite and scheelite), bismuth, molybdenum, niobium, and tantalum occur in quartz and pegmatite veins associated with the granites of the study area. Although the limited number of occurrences makes generalization difficult, tungsten and bismuth appear to have been introduced by both Precambrian and Palaeozoic granites; niobium and tantalum by the former only and molybdenum solely by the latter.

Mineral potential There appear to be only four types of deposit occurring in the Georgetown region that have the potential size necessary for large-scale exploitation. These are:

1. porphyry copper mineralization (a known example is the Phyllis May prospect)
2. replacement copper and zinc deposits in the Einasleigh Metamorphics (e.g. Einasleigh mine and Eveleigh prospect)
3. hydrothermal uranium - fluorite - molybdenite mineralization (e.g. Maureen prospect)
4. disseminated gold deposits (e.g. Kidston prospect)

Company geochemical work

In Queensland mining companies may reserve ground for exploration work by obtaining either an Authority to Prospect, or a Mining Lease. Companies taking out an Authority to Prospect are required to submit a report to the Queensland Department of Mines; those preferring Mining Leases are not obliged to report on their findings. It is not always possible therefore to assess work done on leases. A detailed account of mineral exploration carried out on Authorities to Prospect in the Georgetown region up to December 1973 has been compiled by Withnall (1974). Only a brief summary of the geochemical aspects of this work is given here.

Several companies have undertaken stream-sediment sampling programs in the area (Fig. 3) but soil and rock sampling have been very limited. Very few orientation studies have been carried out and normally an arbitrary decision to collect 'minus 80 mesh' material has been made. Heavy-mineral sampling has received little consideration; Nickel Mines* and Urangesellschaft (Schindlemayr, pers. comm.) are the only companies known to have used this method.

Nearly all surveys have used copper, lead, and zinc analyses and frequent use has been made of molybdenum, nickel, silver, and cobalt values. In a limited number of programs gold has been determined along with arsenic and bismuth in the hope that these last two elements might prove useful pathfinders for gold mineralization. On rare occasions manganese and tin analyses have been used.

Most companies have used an empirical approach to the evaluation of data, although some have used simple statistical procedures. Of the latter the well-known definition of threshold value as the mean of the population plus twice the standard deviation (p.14) has been fairly widespread.

It is during the follow-up stage that company geochemistry has possibly been most lacking. Many anomalies have not been followed up at all and most of the remainder have been rejected after only a superficial visual examination for mineralization. The Eveleigh prospect (p. 6) examined by Mines Administration may be cited as one of the few examples where a stream-sediment survey has been followed up by detailed soil sampling, geophysics, costeaning, and exploratory drilling.

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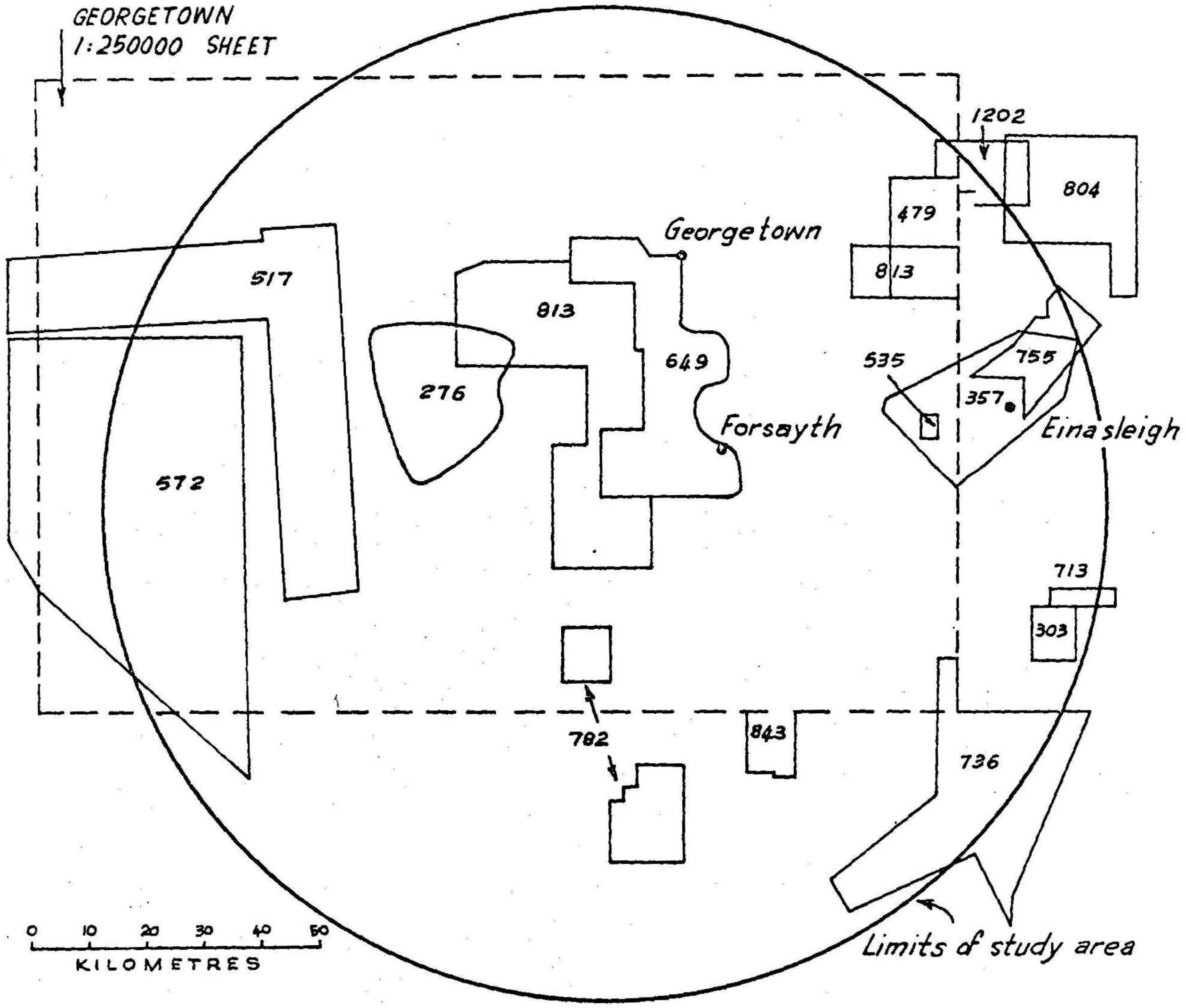
* A to P 731 (south of the study area), GSQ Open File Rep. 3724.



A to P		A to P	
276	Australian Geophysical (1908)	713	Nickel Mines (3661)
303	Anaconda (1852, 1999, 2146, 2255)	736	Lamadec-Laskan-Alkane (3524)
357	Carpentaria Exploration (2507)	755	Longreach Metals (3981)
479	Mines Admin. (3891, 3972)	782	Nickel Mines (confidential)
517	Pickands Mather (2737)	804	Tipperary Land and Expl. (3855)
535	Trans. Aust. Expl. (2831, 3183, 3593)	813	Bridge Minerals (3533, 4296)
572	Kennecott (3028, 3029)	843	Marumba Minerals (4331)
649	Forsayth Mineral Expl. (3843)	1202	Barrier Exploration (4678)

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Fig 3 : Areas covered by company stream sediment sampling to December 1973 (after Withnall, 1974). Geological Survey of Queensland library open file report numbers are shown in brackets.

SAMPLING AND ANALYTICAL METHODS

Design of the survey

The geochemical work carried out in the Georgetown area during 1972 and 1973 was intended to provide the basic information needed for the design of a regional stream-sediment survey in the region. The following questions were posed during planning of the orientation work:

1. Should sieved stream sediments or heavy-mineral concentrates or both be collected? Assuming that sieving proves useful, what grainsize is it best to select?

2. Does it matter from which part of the stream channel the samples are taken? How does alluvial bank material compare geochemically with the active sediment in the channel?

3. How does the variability of geochemical values among samples collected from the one locality (i.e. sampling + analytical fluctuations) compare with the variability observed on a regional scale?

4. What are the background geochemical values that should be assigned to sediments derived from the various rock types in those areas where mineralization is absent?

5. How does mineralization manifest itself in the surrounding sediments? What are the characteristics and dimensions of the geochemical anomalies in the area? What is the sampling density required to detect all the significant near-surface mineralization present?

6. How do stream-sediment and related soil anomalies compare?

The following sampling program was undertaken to answer these questions. Bulk stream-sediment samples weighing about 10 kg were collected and sieved into various grainsize fractions. These were chemically analysed to decide which fraction was the best to use for subsequent stream-sediment sampling. Several localities were sampled in detail (up to 10 samples spaced a few metres apart) to study the possible significance of sampling position in the stream, as well as the sampling and analytical fluctuations to be expected in element concentrations at a given site. Catchments draining a single rock type or formation were sampled to determine the value representative of the geochemical background for the major rock units of the region. Detailed stream-sediment, heavy-mineral, and soil sampling was carried out around known mineralization to investigate the characteristics of the anomalies present. In some areas (both mineralized and barren) bank and channel stream-sediment samples were collected for comparison.

Techniques

The sampling and analytical methods used during the survey have been discussed in detail elsewhere (Rossiter, Cruikshank, & Pyke, 1974) and only a brief account is given here. The greater part of the sampling was carried out by 2-man teams equipped with 4-wheel-drive vehicles although a helicopter was used for collecting a few samples in the more inaccessible areas. All stream sediments were passed through plastic sieves fitted with nylon bolting cloth; panning was used for the extraction of heavy-mineral concentrates. Soils were collected from a depth of approximately 20 cm with hand augers and miner's picks.

Stream-sediment and soil samples were analysed for beryllium, cadmium, chromium, cobalt, copper, lead, lithium, manganese, nickel, silver, and zinc by atomic absorption spectrophotometry (AAS) and for arsenic, barium, cerium, lead, nickel, rubidium, sulphur, thorium, tin, tungsten, and uranium by X-ray fluorescence (XRF) in the BMR laboratories. Selected samples were sent to AMDEL for gold and molybdenum determinations by AAS and for flourine analysis using a specific ion electrode method. 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 bismuth, cerium, chromium, cobalt, copper, lanthanum, lead, molybdenum, nickel, niobium, silver, tantalum, tin, tungsten, yttrium, zinc, and zirconium by optical emission spectrography.

Choice of stream-sediment size fraction to be used

It was obviously necessary in the initial stage of the program to decide what grainsize should be selected for the stream-sediment sampling. The distribution of copper, lead, and zinc in various size fractions of several samples collected in the Georgetown area was determined and the

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results are shown in Figure 4. As is usually the case in stream-sediment surveys, a general increase is found in the concentration of all three metals the finer the grainsize. The same general trend has been verified for beryllium, cadmium, chromium, cobalt, lithium, manganese, nickel, and silver although these elements are not shown in Figure 4 because the data available are less comprehensive. The increased lead content in the coarser portions of two samples (72300272 and 72300717) is possibly due to the presence of this element in coarse alkali feldspar grains. The geochemical contrast, i.e. the difference in metal content between anomalous and background samples, is greatest in the finer size fractions. It follows logically, that for the purpose of delineating anomalies, the finer the material sampled the better.

Another factor to be considered when selecting the size fraction to be used in stream-sediment sampling is the abundance of each grainsize. Table 1 shows the quantity of minus 180μm (85 mesh BSS) material present in a number of Georgetown samples. The amount falls to as low as 0.2 percent of the total weight of sediment. It was apparent early in the program that more than 10 kg of sediment would have to be sieved in some cases to obtain the 20 g of minus 180 μm sediment considered necessary for the intended analytical work. It was considered impracticable to spend the time required to sieve amounts larger than 10 kg and so the minus 180 μm fraction was used for all subsequent stream-sediment sampling. This grainsize proved sufficiently fine to enhance the geochemical contrast significantly but not so fine that excessive time was lost during sampling.

Geochemical variation in samples collected from the same site

A geochemical survey will fail if the fluctuation in metal values owing to sampling and analytical factors is greater than the variation attributable to natural causes. The analysis of replicate samples from one locality can give an estimate of the combined sampling and analytical variance. At a number of sites in the Georgetown region several samples were collected from various parts of the stream channel a few metres apart; the resultant analyses are summarized in Table 2. Overall there is close agreement between geochemical values in different minus 180 μm samples from the same locality - deviations are slightly greater for elements determined by XRF. Values are also more variable in mineralized samples. Manganese shows greater fluctuation than other elements; this may be the consequence of biological activity. Three conclusions may be drawn from these results:

1. The concordance of geochemical values among samples collected from different parts of the stream bed suggests that the position from which the sediment is taken is not significant.

2. The close agreement also indicates that sampling errors are small. This suggests that the size of the samples (always greater than 20 g, majority greater than 50 g) is adequate and grinding of the minus 180 μm material before analysis is not necessary.

3. The analytical techniques used, particularly AAS, are sufficiently precise.

The variability of the heavy-mineral fraction was studied in similar fashion at three localities near tin, lead, and gold base-metal mineralization respectively. As was expected the yield of heavy minerals varied greatly with position in the stream, but their trace element composition did not fluctuate to the same degree (Table 3). Heavy minerals from a stream draining a number of tin veins were characterized by high tin values (500 ppm to greater than 6000 ppm) in all samples, and high bismuth, molybdenum, tantalum, and tungsten in some. Concentrates from samples collected near lead mineralization showed high lead (500 ppm to 5000 ppm) in all except bank samples. Heavy minerals near a gold base-metal deposit were characterized by high lead (greater than 6000 ppm) and detrital gold in all channel samples, with sporadic high bismuth, gold, and silver values. Hence at the three sites, all concentrates taken from the stream channel indicated the proximity of mineralization; bank samples were less reliable.

In view of the relatively small variation observed at a particular site in both the sieved and heavy-mineral samples, the additional time and expense involved in duplicate sampling is considered unjustified during future BMR work in the region.

In both mineralized and barren areas, corresponding alluvial bank and channel samples compare quite closely (Table 4). It follows that, in the Georgetown area, during geochemical exploration utilizing sieved stream

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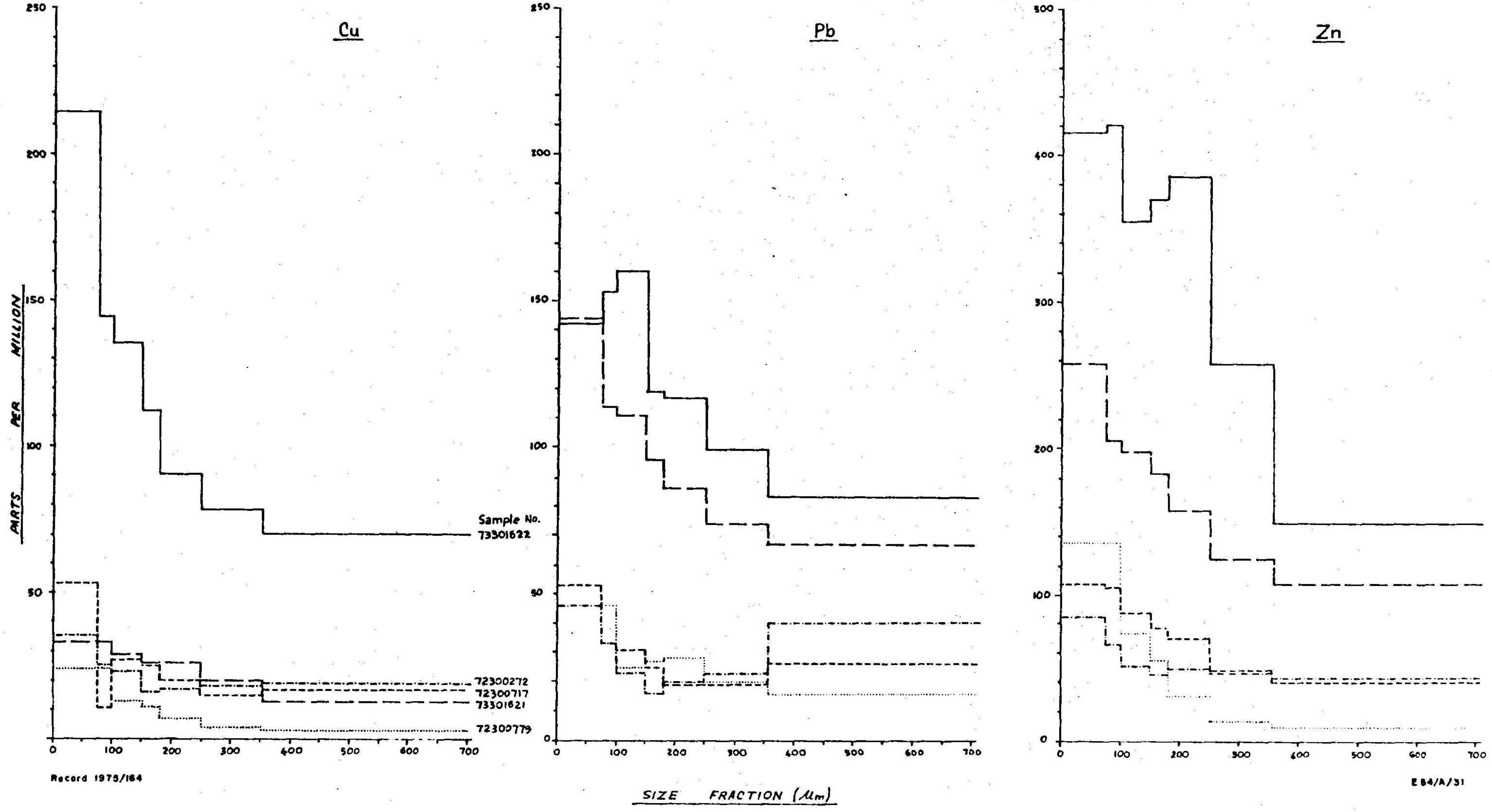

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Fig. 4 : Distribution of copper, lead and zinc in various size fractions of stream sediments

TABLE 1. AMOUNT OF MINUS 180 μm MATERIAL PRESENT IN SEVERAL SAMPLES FROM WIDELY SCATTERED PARTS OF THE GEORGETOWN REGION.

Sample No.	% - 180 μm fraction
72300062	1.6
72300102	1.3
72300197	3.6
72300272	2.4
72300340	3.8
72300480	1.5
72300511	0.3
72300537	1.1
72300562	2.8
72300673	1.8
72300686	2.5
72300717	4.2
72300735	11.3
72300773	0.2

TABLE 2. RESULTS OF REPLICATE STREAM SEDIMENT SAMPLING AT
are located near tin, lead, and gold base-metal mineralization respectively.
occasions when a particular element was below the detection limit in some of the
These cases are indicated by a dash.

	A		B		C		D	
No. of Samples	10		9		4		9	
	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
AAS								
Ag	1	0.5	5	1	-	-	1	0.5
Be	2	0.4	2	0.3	1	0.1	2	0.4
Cd	-	-	-	-	-	-	-	-
Co	10	3	13	1	11	0.5	8	0.9
Cr	49	4	70	19	91	2	48	5
Cu	13	3	24	3	16	0.8	11	1
Li	5	1	10	2	8	1	4	0.9
Mn	964	682	598	140	778	44	629	174
Ni	15	4	18	2	17	0.6	13	2
Pb	31	2	28	2	16	2	27	4
Zn	49	7	60	7	40	1	40	4
XRF								
As	-	-	-	-	-	-		
Ba	903	67	617	47	372	81		
Ce	57	11	122	47	44	8		
Rb	125	7	122	19	97	2		
S	410	52	372	42	352	46		
Sn	-	-	-	-	-	-		
Th	17	3	28	15	20	3		
U	-	-	5	2	5	0.5		
W	-	-	-	-	-	-		

SEVERAL LOCALITIES. A - F occur in barren areas; G, H, and I
X-ray fluorescence data are available for only three groups of samples. On those
samples at the site, the mean and standard deviations could not be calculated.

E		F		G		H		I	
7		29*		8		8		5	
Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
1	0.5	1	0.0	-	-	2	0.7	8	4
2	0.2	2	0.3	7	0.5	3	0.5	6	2
-	-	-	-	-	-	2	0.5	3	3
12	2	8	2	-	-	19	2	24	8
87	21	29	4	9	0.7	68	18	69	10
41	14	13	2	11	3	26	2	559	367
9	4	10	2			12	1	16	3
753	168	333	70	214	68	1441	218	993	603
18	4	6	2	3	0.4	22	3	17	5
32	4	33	5	50	5	226	122	347	163
60	15	51	5	49	6	259	66	497	385

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* Bank samples included.

TABLE 3. SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSES OF REPLICATE HEAVY-MINERAL SAMPLES FR
through bromoform. Where possible estimates in ppm appear in brackets, but thes

Sample No.	Heavy mineral yield (g)	Ag	Au	Ba	Bi	Co	Cr
Tin mineralization							
74304142*	0.571	–	–	Tr	–	L(LT100)	L
74304143*	0.874	–	–	"	–	"	"
74304144	0.400	–	–	–	M(100)	"	"
74304145	0.198	–	–	Tr	L(LT100)	"	"
74304146	0.133	–	–	"	Tr	"	"
74304147	0.180	–	–	"	–	"	–
74304149	0.979	–	–	–	–	"	L
74304150	4.975	–	–	–	L(LT100)	"	"
74304151	1.515	–	–	–	"	"	"
Lead mineralization							
74304152*	17.012	–	–	L	–	"	"
74304153	12.460	–	–	"	–	"	"
74304154	12.315	–	–	"	–	"	"
74304155	7.520	–	–	"	–	"	"
74304156	6.075	–	–	"	–	"	"
74304157*	8.907	–	–	"	–	"	"
74304158	10.761	–	–	"	–	"	"
74304161	8.681	–	–	"	–	"	"
Gold base-metal mineralization							
74304162*	4.767	–	–	L	–	"	"
74304163*	5.810	–	–	"	–	"	"
74304164	4.600	Tr	L(30)	Tr	Tr	"	"
74304165	5.280	L(LT10)	M(100)	"	"	"	"
74304166	1.561	"	–	L	L(LT100)	"	"
74304167	3.817	"	M(100)	"	Tr	"	"
74304168	2.897	"	L(30)	"	"	"	"
74304169	3.248	–	–	"	–	"	"

* Bank sample

Dash – not detected, Tr – trace, L – low, M – moderate, H – high, V – very hig

THREE MINERALIZED LOCALITIES. Samples originally weighing 5 kg were panned and passed should be used as a guide only.

Cu	Li	Mo	Ni	Pb	Sb	Sn	Ta	W	Zr	Zn	Detrital gold
Tr	-	-	L(LT100)	L(LT100)	Tr	H(1000)	-	-	M	-	-
LT100)	Tr	-	"	M(300)	L(LT100)	"	Tr	-	"	-	-
"	L	Tr	Tr	"	Tr	H(2000)	"	-	L	M(600)	-
"	Tr	"	"	"	"	V(GT6000)	"	Tr	M	-	-
Tr	"	"	"	M(100)	"	H(1000)	-	-	"	-	-
"	"	-	L(LT100)	M(300)	"	M(500)	-	Tr	"	-	-
L(LT100)	"	-	"	"	"	V(GT6000)	-	-	"	-	-
"	-	Tr	-	H(1000)	"	"	L	H(1000)	L	M(600)	-
Tr	-	-	Tr	M(300)	"	"	Tr	Tr	M	-	-
L(LT100)	M	-	"	L(LT100)	"	-	-	-	L	-	-
"	M	-	L(LT100)	H(2000)	"	-	-	-	"	Tr	-
"	L	-	"	M(800)	-	-	-	-	Tr	-	-
"	M	-	"	M(500)	Tr	-	-	-	"	-	-
"	M	-	"	"	L(LT100)	-	-	-	L	-	-
"	L	-	"	H(1000)	"	-	-	-	"	-	-
"	L	-	"	V(5000)	M (100)	Tr	-	-	"	Tr	-
"	L	-	"	V(4000)	"	M(100)	-	-	"	-	-
"	M	-	Tr	M(300)	L(LT100)	Tr	-	-	L	-	-
"	L	-	"	"	Tr	L(LT100)	-	-	"	-	Tr
"	M	-	"	V(GT6000)	-	M(200)	-	-	Tr	-	Tr
"	L	-	"	"	-	"	-	-	L	-	Tr
"	"	-	L(LT100)	"	Tr	Tr	-	-	"	-	Tr
"	"	-	Tr	"	"	M(100)	-	-	Tr	-	Tr
Tr	"	-	"	"	-	"	-	-	"	-	Tr
"	M	-	"	"	-	"	-	-	"	-	Tr

LT - less than, GT - greater than

TABLE 4. GEOCHEMICAL COMPARISON OF CHANNEL AND ADJACENT ALLUVIAL BANK SAMPLES. Bank figures are the average of analyses of alluvium from both sides of the stream.

Cu (ppm)		Pb (ppm)		Zn (ppm)	
Channel	Bank	Channel	Bank	Channel	Bank
23	26	43	42	78	79
93	67	151	131	138	95
268	107	556	351	222	108
33	31	101	94	32	42
60	67	118	163	48	54
36	41	97	87	110	126
28	34	92	90	107	119
29	33	120	113	135	138
46	37	148	105	155	135
37	44	175	139	130	150
32	25	358	209	250	182
18	19	131	128	115	124
16	15	115	115	84	92
338	284	35	44	86	107
200	314	20	23	59	82
58	90	28	37	64	102
64	102	34	35	115	103
83	124	40	47	110	152
124	216	46	66	110	165
69	101	32	35	81	90
75	103	32	37	73	86
40	68	50	54	53	81

sediments, bank alluvium (which contains more fine material and is therefore easier to sieve) could be collected with little risk of overlooking important anomalies. In fact, bank samples might be more meaningful than the channel type in areas contaminated by mining activity.

DISCUSSION OF RESULTS.

Statistical methods

During a geochemical survey an extremely large volume of data may be accumulated. These data can be reduced to a less cumbersome and more easily interpretable form by the use of descriptive statistics. The application of parametric statistical parameters such as the mean, standard deviation, Pearson correlation coefficient, and R-mode factor score has been widespread in the interpretation of geochemical surveys. Regrettably few workers, however, have considered the basic assumption made by the parametric methods viz. that the data follow a normal distribution or can be normalized by some mathematical (e.g. logarithmic) transformation. Whether this assumption can be safely made for a particular data set is seldom assessed.

Ahrens (1954a, 1954b, 1957, 1963a, 1963b, 1966) claimed that all elements closely approximate lognormality in their geochemical distribution. However, objections to his conclusions have been numerous (e.g. Aubrey, 1955; Miller & Goldberg, 1955; Vistelius, 1960; Butler, 1964). Rodoniov (1961) argued that an element will be normally distributed if it is evenly dispersed among the minerals which make up a rock (soil, stream sediment, etc.) and lognormally distributed if it is confined to a single mineral phase. He suggested that between the two extremes of normality and lognormality lie an infinite number of intermediate distribution types determined by the number of minerals containing a given element and by their proportion in the sample. Tolstoy et al. (1965) considered that geochemical data follow Pearson (beta) curves more closely than normal or lognormal in many cases, and Oertel (1969) claimed wide applicability for gamma distributions.

The foregoing should indicate that it can be by no means assumed that a particular set of geochemical data is either normally or lognormally distributed. It is very convenient if the data show such behaviour, as the

Gaussian distribution has been emphasized in the development and application of mathematical statistics. In all cases, however, the data should be tested to see how closely they fit a normal or lognormal form before parametric statistical tests are used.

Univariate techniques

The main objective of exploration geochemistry 'is the discovery of abnormal chemical patterns, or geochemical anomalies, related to mineralization' (Hawkes & Webb, 1962). It is important, therefore, to establish the normal or background variation of any element considered significant in the detection of economic mineral deposits. Once the background has been determined it is then possible to recognize anomalous values. Several methods have been proposed for estimating the upper limit of background variation, or threshold, as it is commonly known.

According to Hawkes & Webb (1962) the threshold for a single population of values that are normally distributed may be conventionally taken as the arithmetic mean plus twice the standard deviation. This is equivalent to saying that only 1 in about 40 background samples is likely to exceed the threshold content. For a single lognormal population the equivalent equation is that the threshold equals the geometric mean multiplied by the square of the geometric deviation (Lepeltier, 1969). The limited suitability of the common single population statistics for the interpretation of a regional stream-sediment survey in the Georgetown area can be assessed by examining Table 5. Of the elements of economic interest there is relatively minor variation of zinc in sediments derived from different rock types; therefore for this metal one threshold value can be safely assigned to all rock types. However, the average copper varies from 74 ppm on dolerite to 10 ppm on acid volcanics, and lead from 50 ppm on sediments to 19 ppm on dolerite. The background copper and lead distributions appear, then, at least bimodal and care must be taken in the estimation of threshold values for these elements (see pp. 19, 21). When a polymodal distribution is suspected, the constituent populations can be recognized and isolated by the use of histograms and cumulative frequency diagrams.

Histograms may be misleading as a slight change in the arbitrarily selected class intervals can give an entirely different shape to the

TABLE 5. GEOCHEMICAL VARIATION IN STREAM-SEDIMENT SAMPLES COLLECTED IN CATCHMENTS DRAINING A SINGLE FORMATION OR ROCK TYPE.

Arithmetic means and the actual range of values observed are presented. The mean is used purely for purposes of comparison and not in a strict statistical sense (see discussion p. 14). Where no mean is given the element was not detected in the majority of samples; where no range is given all samples showed identical content of that particular element.

Formation	No. of drainage basins sampled	No. of samples	Ag	Be	Cd	Co	Cr	Cu	Li	Mn	Ni	Pb	Zn
Cobbold	1	12	1	1	-	24	66	74	11	880	33	19	69
Dolerite			0-2	1-2	-	14-36	35-127	40-119	8-15	405-1400	18-66	9-27	38-86
Forsayth	3	63	1	3	-	11	54	17	9	563	14	40	47
Granite			0-2	1-6	0-1	5-27	14-171	5-39	3-18	200-2270	0-33	10-82	18-126
Robin Hood	1	20	1	3	-	14	56	23	16	870	19	34	72
Granite			0-1	2-4	0-1	4-22	7-131	6-46	9-31	288-2000	1-30	26-60	51-134
Newcastle Range	2	32	1	3	1	6	17	10	8	345	5	45	64
Volcanics			0-1	1-5	0-1	3-12	7-63	6-22	5-10	115-850	2-20	25-83	25-145
Einasleigh	1	7	1	2	-	18	85	41	11	1219	29	32	123
Metamorphics			1-2	2-3	0-1	12-24	58-113	29-52	9-17	875-1830	18-35	28-41	105-151
Robertson River	2	14	1	2	1	13	41	24	14	669	16	30	56
Metamorphics			1-2	2-3	0-1	6-33	17-75	8-42	9-21	195-1650	6-25	24-51	31-103
Langdon River	1	6	2	3	1	23	57	29	23	531	26	50	76
Formation			-	3-4	-	20-28	53-65	24-39	22-26	400-745	25-30	25-30	60-103

histogram; the individual populations of polymodal distributions are also difficult to distinguish. Nevertheless, histograms have proved very useful for the population analysis of geochemical data. The cumulative form of the frequency distribution has the advantage of being independent of the choice of class interval. When cumulative frequency values are plotted on probability paper the different populations present in the data can be more readily separated. The interpretation of such plots is at times somewhat subjective, but their use has been widespread in the geochemical literature e.g. Tennant & White (1959), Williams (1967), Lepeltier (1969), Sinclair (1974), and Parslow (1974).

In the following sections each of the elements studied during the survey is discussed. A short summary of the theoretical geochemistry of each element in both the primary and secondary* environments is followed by an account of its observed geochemical behaviour in the stream sediments and soils of the Georgetown region. Histograms and probability cumulative frequency plots are presented and threshold values estimated. Manganese is considered first owing to its important role in secondary processes affecting all the other elements; the remaining metals are discussed in approximate order of decreasing economic significance.

Manganese Magmatic concentrations of manganese are rare and the element is normally fairly evenly distributed throughout the iron and magnesium silicate minerals of igneous rocks. Occasionally, however, manganese may be enriched in hydrothermal veins especially those containing tin, tungsten, niobium, and tantalum (Rankama & Sahama, 1950).

During weathering, manganese is released from its host minerals in the manganous (Mn^{2+}) state as bicarbonate, chloride, and sulphate (Boyle, 1972). In environments which are oxygen-deficient and acidic in character Mn^{2+} is stable in solution but if Eh and pH* are raised, precipitation as Mn^{4+} compounds occurs. Horsnail, Nichol & Webb (1969) have discussed the behaviour of manganese under supergene influences. They noted that in areas

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* The secondary (or supergene) environment is defined as the zone influenced by circulating meteoric waters; the primary environment includes more deep-seated processes such as igneous differentiation and metamorphism.

* Eh is a measure of the oxidizing or reducing properties of a system (high Eh indicates strongly oxidizing conditions); pH is a measure of acidity (low pH is indicative of a highly acid environment).

of high rainfall and poor drainage where soil Eh and pH are both low, manganese readily passes into the groundwater solution. When the metal-bearing groundwaters enter a drainage channel there is an abrupt rise in the Eh and pH, and manganese oxides and hydroxides are precipitated. The negatively-charged sols of $Mn(OH)_4$ and MnO_2 readily adsorb metal cations, which are then coprecipitated with the oxides and hydroxides. This effect is well known, and the literature describes many examples of false anomalies caused by so-called manganese 'scavenging'.

In well drained areas, especially those like the Georgetown region with a well defined wet season, the soils remain wet and waterlogged for only short periods of time. Under these conditions there is an insignificant difference between the Eh and pH of the soil environment and those of the drainage channels; consequently there is little manganese precipitation in the stream sediments. That this argument is valid for the Georgetown area is demonstrated by the fact that a hot hydrochloric and nitric acids digestion extracts only 39 percent of total manganese from some stream sediments (Rossiter, Cruikshank, & Pyke, 1974). This indicates that much manganese occurs in the form of detrital minerals rather than in readily soluble oxides and hydroxides. Hence it is unlikely that the manganese 'scavenging' process operates on a large enough scale in the Georgetown region to produce false anomalies and interfere with the interpretation of stream-sediment surveys.

The distribution of manganese in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 5. For both stream sediments and soils the histograms are positively skewed suggesting that the background manganese populations may have lognormal affinities. This is confirmed by the observation that the arithmetic probability plots follow a curved path for low manganese values while the equivalent parts of the logarithmic diagrams are straight lines. At higher manganese levels the log-probability plots for both soils and stream sediments show changes in slope above which second (anomalous) populations contribute significantly to the total manganese distributions. It is reasonable, then, to define the manganese contents at the breaks in slope as distinguishing anomalous from background samples*. Manganese contents

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* Several alternative methods for defining threshold values using probability cumulative frequency plots have been suggested (e.g. Sinclair, 1974; Parslow, 1974), but the simple procedure used here has in the past given equally satisfactory results (Rossiter, 1974).

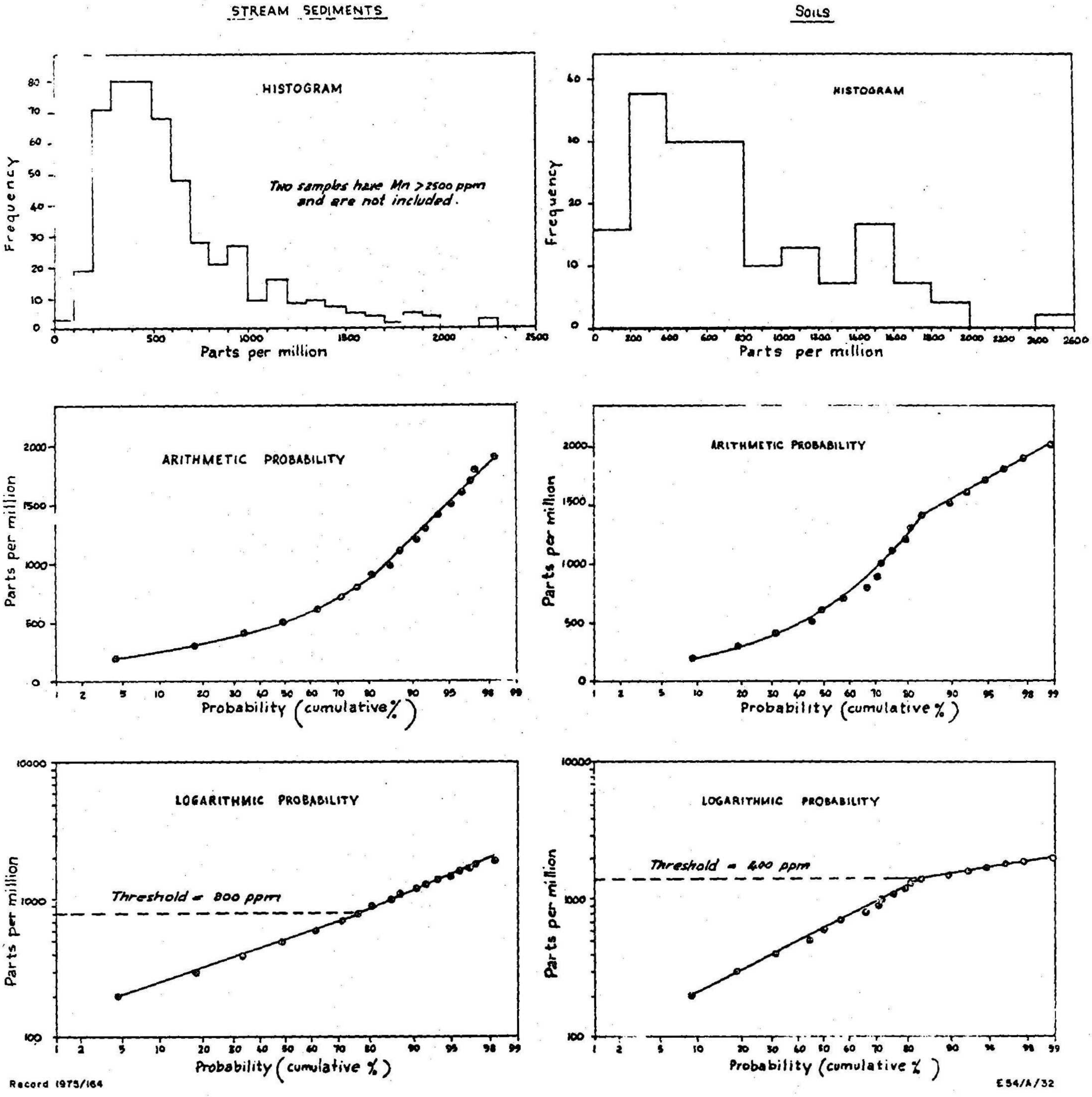

Fig. 5 : Distribution of manganese in stream sediments and soils

of greater than 800 ppm in stream sediments and greater than 1400 ppm in soils are therefore regarded as anomalous. Difficulty would be encountered in applying these or any other threshold figures, however, as large sampling errors are associated with manganese analyses (p. 11). High values appear associated with basic igneous rocks rather than with mineralization – manganese is strongly correlated with cobalt, chromium, nickel, and zinc (Table 7, following p. 32), all characteristically high in basic rocks. Manganese, therefore, appears to be of little value for geochemical exploration in the Georgetown area.

Uranium Uranium is concentrated late in the igneous differentiation process as the large size of the U^{4+} ion prevents its entry into the lattices of early-crystallizing silicate minerals. It is not surprising therefore to find the late-stage elements arsenic, (Fig. 6) flourine and molybdenum (p.6) associated with uranium mineralization in the Georgetown area. Uranium also shows positive correlation with beryllium, cerium, lithium, rubidium, thorium, and tin in stream sediments (Table 7.).

Uranium minerals are readily oxidized under aerated near-surface conditions. As the resultant UO_2^{2+} ion (Rogers & Adams, 1969) and related $UO_2(CO_3)_3^{4-}$ and $UO_2(CO_3)_2^{2-}$ ions (Hostetler & Garrels, 1962) are highly soluble, uranium is very mobile in the supergene environment. It can also be transported as a uranyl sulphate complex (Miller, 1958) when associated with oxidizing sulphides. In view of this mobility it is not surprising that yellow secondary uranium minerals are only rarely observed in the Georgetown heavy-mineral concentrates even immediately adjacent to mineralization. The element occurs instead in the fine-grained fraction of the stream sediments where it has presumably been adsorbed from solution by organic matter (Swanson, 1961), various oxides and hydroxides, or clays (Goldsztaub & Wey, 1955).

The distribution of uranium in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 7. In both cases lognormal models appear to fit the data quite closely. There is a hint of two background populations in the stream-sediment distribution – perhaps lower uranium values are associated with basic igneous rocks than with siliceous rock types. Lower thresholds might, therefore, apply in areas of basic rocks, but the possibility of uranium deposits related to such rock types in the Georgetown region is so remote that the question does not warrant further investigation. Anomalous values are defined as greater than 12 ppm in stream sediments and greater than 8 ppm in soils. These thresholds, however, must be used with extreme care as heavy-mineral studies show some of the stream-sediment samples to be very rich in monazite ((Ce, La, Th) PO_4), a resistant mineral containing appreciable amounts of uranium. Uranium as high as 81 ppm is found in the minus 180 μm fraction in streams draining monazite-bearing granitic terrains. To distinguish high uranium values caused by monazite from those related to mineralization, there are two alternatives:

(a) Consideration of the other elements present -
Arsenic occurs in all samples showing high uranium values associated with mineralization but has not been detected in any of the samples collected near monazite granites. In addition, cerium and thorium contents can be used as an index of the amount of monazite present in a sample. A plot of cerium + thorium vs arsenic (Fig. 8) would appear to have great potential for deciding the significance of a high uranium value. At this stage, however, only one uranium deposit in the area has been sampled and more data are needed.

(b) Examination of a heavy-mineral concentrate -
This technique is of limited use unless a heavy-mineral sample has been taken at each collection point. The procedure is more tedious than the one described above but is probably more reliable.

Copper Copper has a great affinity for sulphur and where both elements are present in sufficient quantities chalcopyrite is readily formed. In ultrabasic rocks this occurs at an early stage in the crystallization sequence, whereas in granitic magmas it is not until differentiation is well advanced that copper and sulphur are sufficiently enriched for copper sulphides to separate. Copper is associated with cadmium, lead, silver, sulphur, zinc (Table 7), and molybdenum (Fig. 9) in the mineral deposits of the Georgetown area.

Under the acid oxidizing conditions prevailing in the near-surface parts of sulphide deposits, copper goes readily into solution as the sulphate. On theoretical grounds therefore heavy-mineral concentrates, even those collected near copper mineralization, might be expected to be poor in copper. This is in fact the case with a maximum copper content of approximately 200 ppm (semiquantitative spectrographic analysis) being observed in the

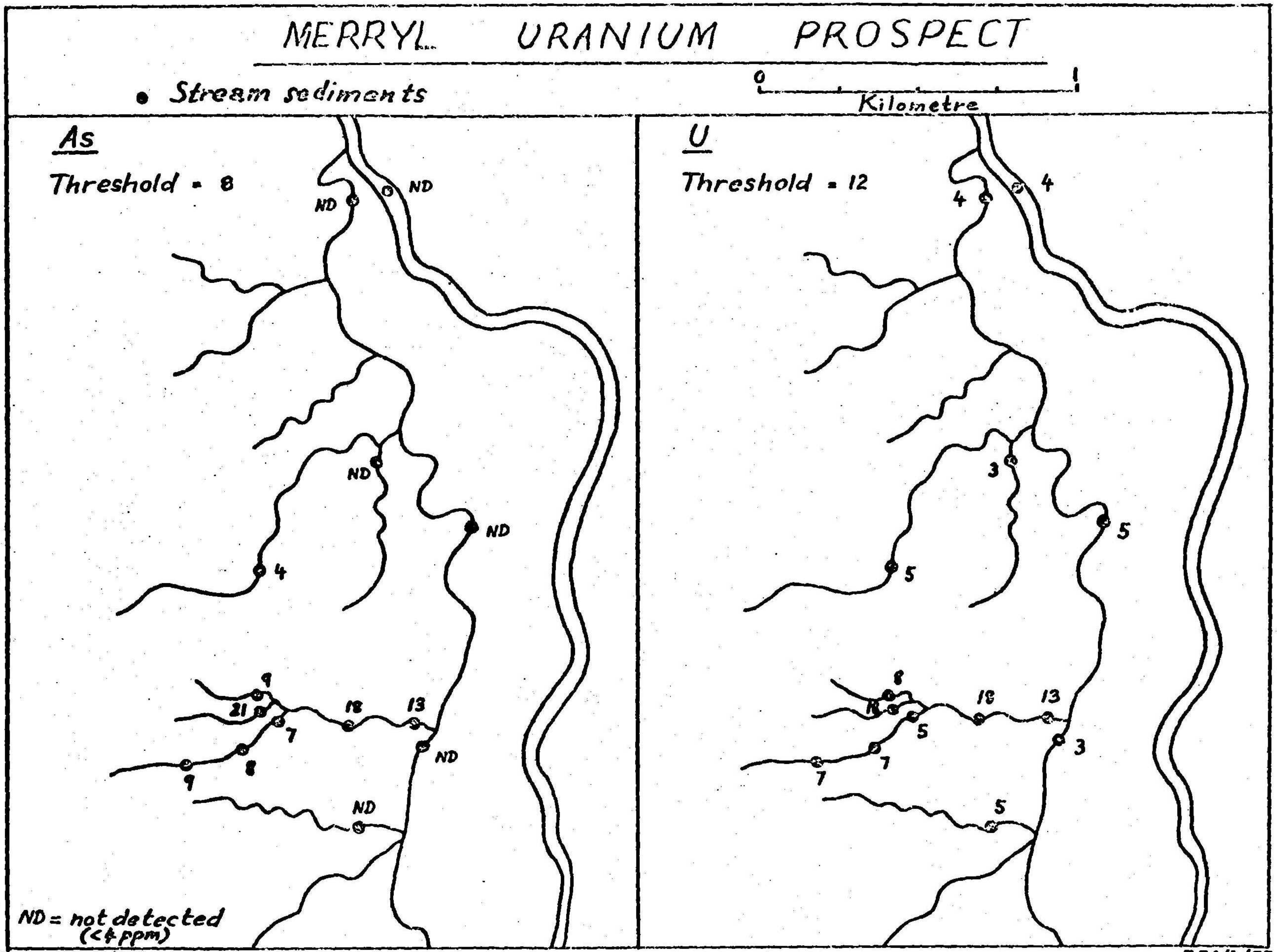

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Fig 6 : Results of stream-sediment sampling near the Merryl uranium prospect
Values are in ppm

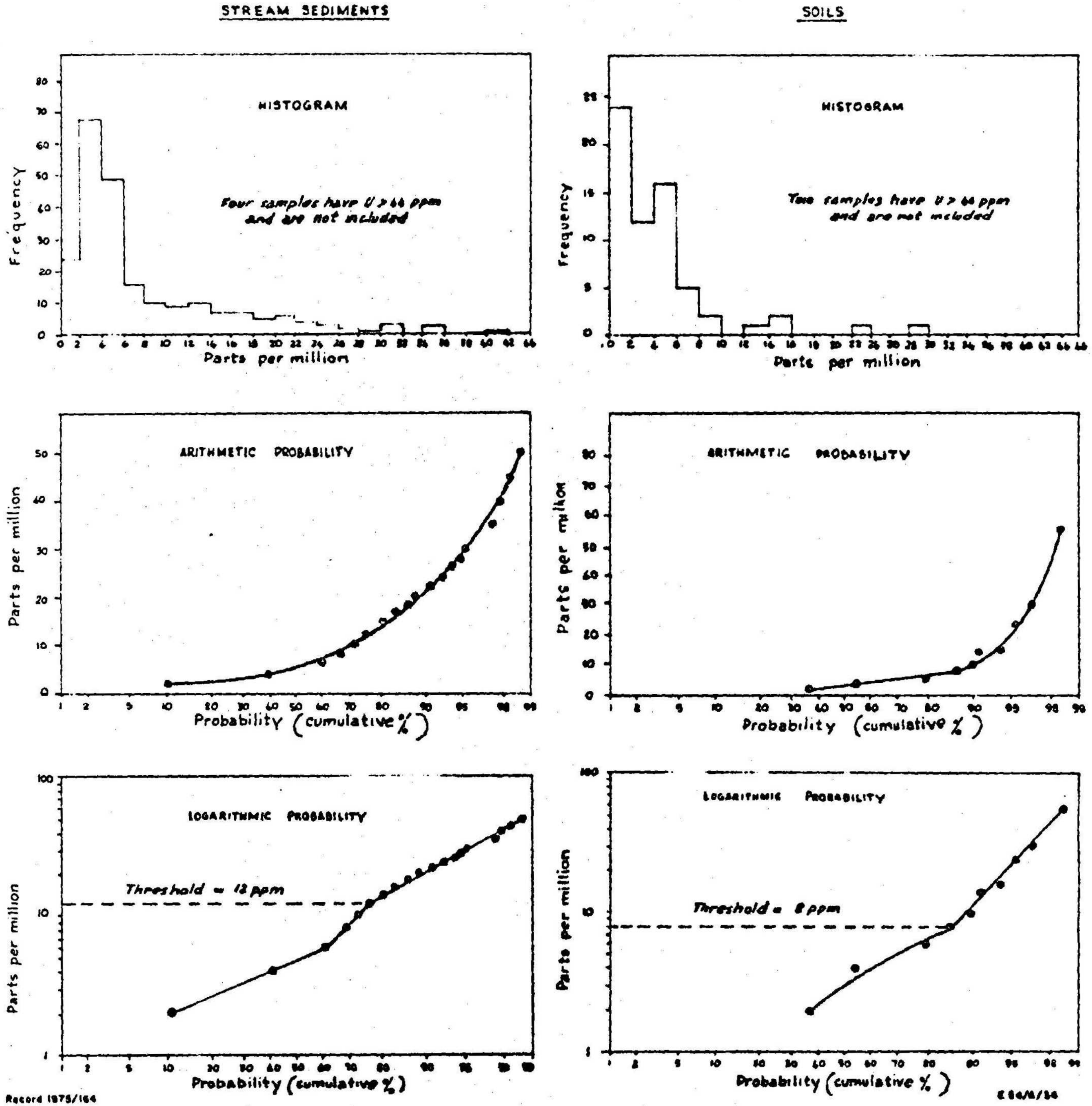

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Fig. 7 : Distribution of uranium in stream sediments and soils

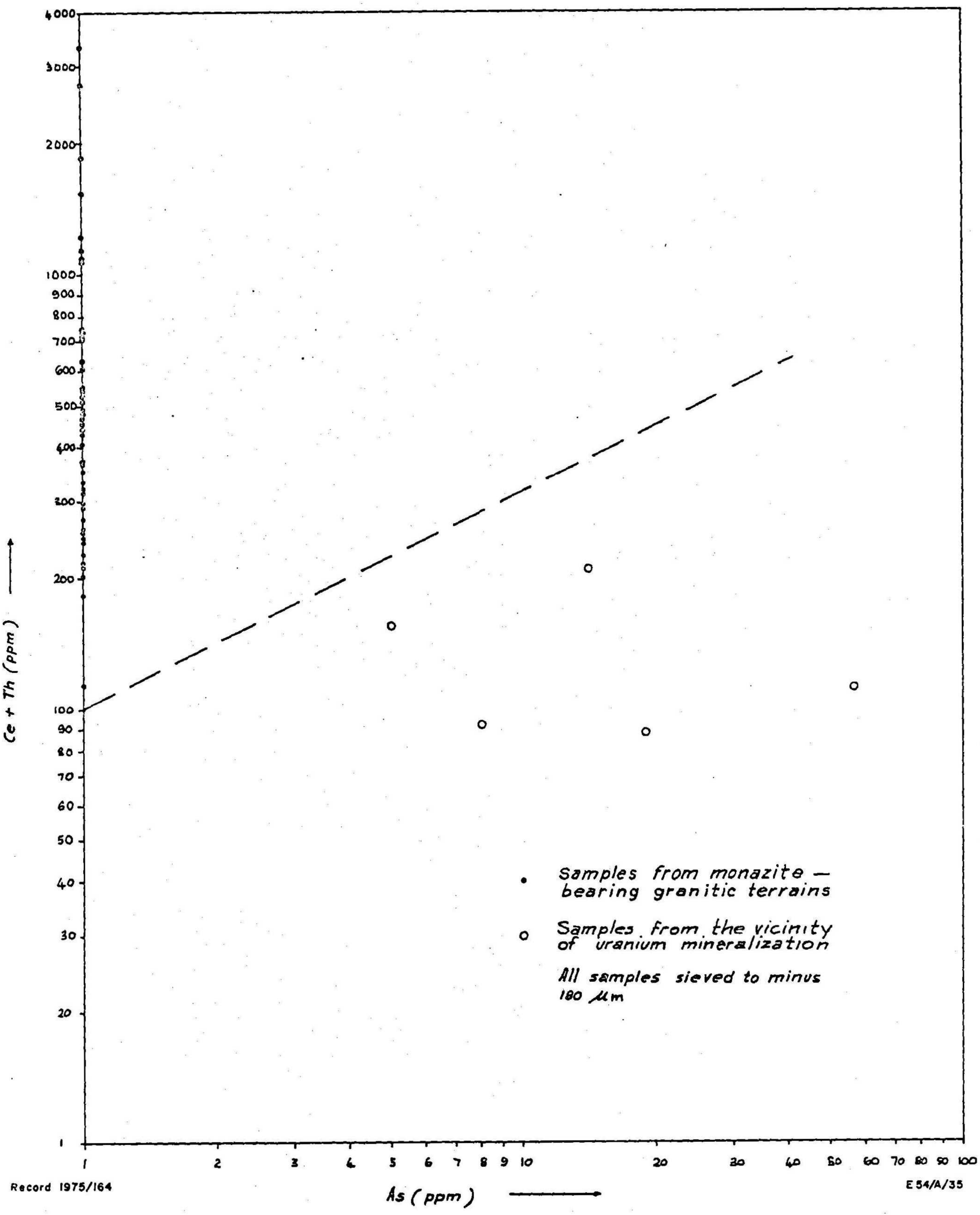

Fig 8: Plot of Ce + Th vs As for deciding whether anomalous uranium in stream sediments is due to mineralization or monazite. All samples plotted have U > 12 ppm. Samples in which As could not be detected (detection limit 4 ppm – XRF) have been arbitrarily assigned a value of 1 ppm

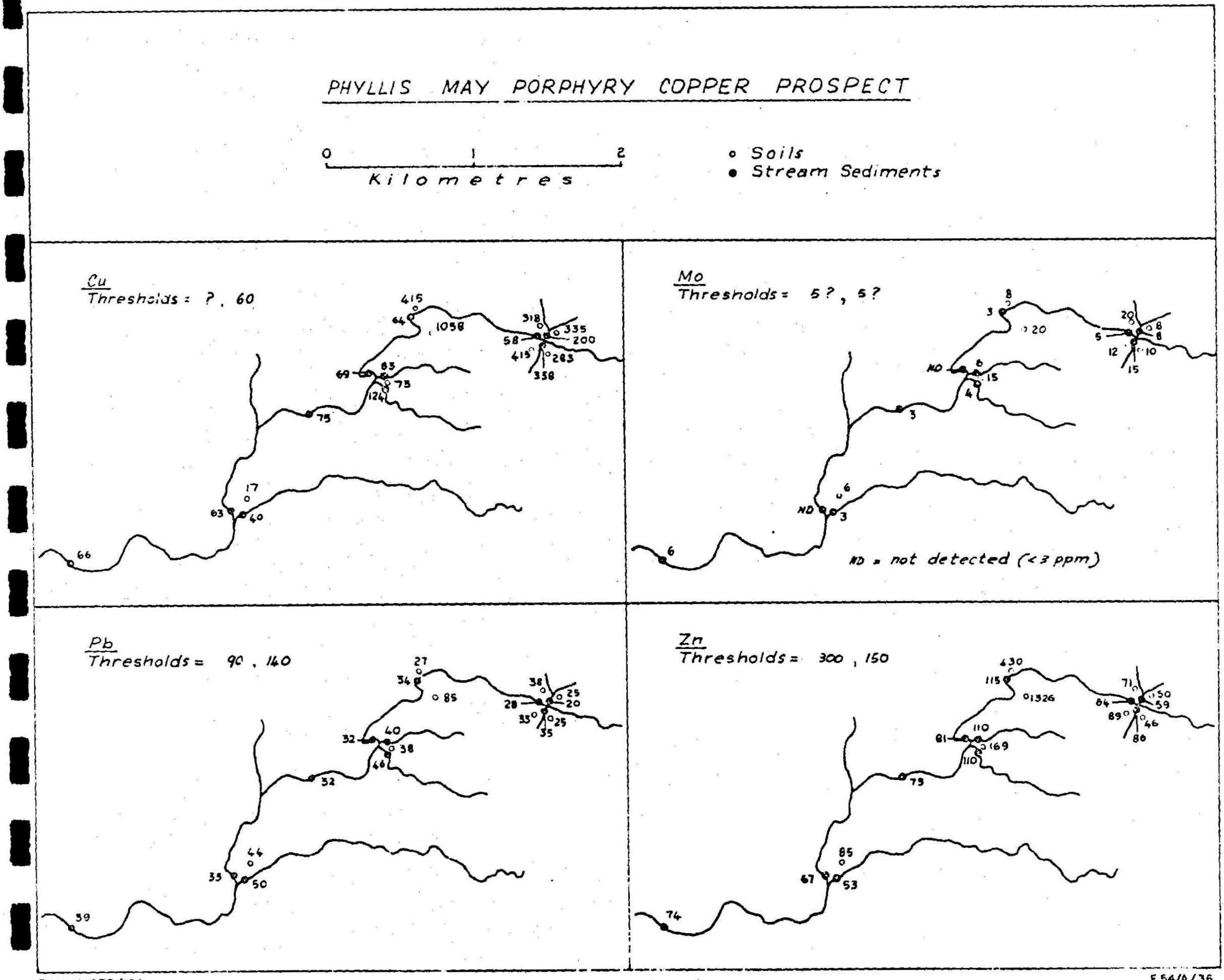

Fig. 9 : Results of geochemical sampling in the vicinity of the Phyllis May porphyry copper prospect. Values are in ppm. The first threshold given refers to soils, the second to stream sediments. Local high Zn values in soils are interesting

Georgetown concentrates. Copper occurs mainly in the fine fraction of the stream sediments where presumably it has been precipitated as malachite and azurite (Boyle, 1972) or adsorbed onto organic matter (Fraser, 1962), clays (Heydemann, 1959) and, to a limited degree, iron and manganese oxides and hydroxides (Collins, 1973; Jenne, 1968). In the last case adsorption compounds such as $Cu\,Mn_2\,O_5$ may form (Rankama & Sahama, 1950).

Despite the fact that the copper content of the heavy-mineral concentrates is low, this type of sample appears to have much potential in prospecting for higher-grade copper deposits. As detrital malachite grains are so conspicuous under the microscope a few small fragments in an original stream-sediment sample of 10 kg can be easily detected. Hence although most of the copper is contained in the fine-grained fraction the optical heavy-mineral technique is more sensitive than the chemical analysis of sieved material. In fact several instances can be cited (e.g. Ortona Copper Mine) where no anomaly is found in the sieved samples but the presence of mineralization is indicated by malachite in the heavy-mineral fraction.

The distribution of copper in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 10. The estimation of threshold copper values is difficult because background levels differ greatly between basic igneous rocks on the one hand and granitic, sedimentary, and metamorphic rocks on the other (p. 14). The probability plots for stream sediments suggest that the observed copper distribution contains three populations. The first consists mainly of background values from areas of siliceous rocks, the second of a mixture of background readings associated with basic rocks and both background and anomalous levels associated with siliceous lithologies, and the third of anomalous values from both basic and siliceous terrains. The uppermost break in slope of the log-probability curve for stream sediments indicates that samples containing more than 150 ppm copper warrant further inspection irrespective of the surrounding rock type. A value slightly less than this is considered insignificant near basic rocks but may be anomalous in a granitic area. As there is a possibility of locating porphyry copper deposits in the Georgetown region it is important to determine a threshold for sediments derived from granite. Consequently a log-probability cumulative frequency plot was constructed for all copper values pertaining to catchments draining only granite (Fig. 11). From this a threshold of 60 ppm copper would appear suitable for delineating stream-sediment anomalies in granitic terrains. The data for soils are more limited and although copper values greater than 250 ppm can be designated anomalous (Fig. 10), a lower threshold value for soils in granitic areas cannot be estimated at this stage.

Zinc and cadmium The geochemistry of zinc is similar in a number of ways to that of copper. Zinc, however, has a lower affinity for sulphur, and sphalerite does not separate early in the crystallization of some igneous rocks in the way chalcopyrite does (p. 18). Most of the zinc concentrates in the late-stage differentiates, although appreciable amounts may be incorporated in iron and magnesium minerals (notably biotites) earlier in the crystallization sequence. The correlation of zinc with cadmium, copper, and lead observed in the stream sediments of the Georgetown region is not surprising but the relation between zinc and cobalt, chromium, and nickel (Table 7) is interesting. Probably a large part of this correlation is due to the association of these elements with ferromagnesian minerals in the stream sediments, although one zinc deposit is known where the ore-forming fluids apparently carried high chromium and nickel (Fig. 12). The correlation between zinc and manganese is also probably due to both elements occurring in the same detrital minerals; major 'scavenging' of zinc by oxidate manganese is unlikely (p. 16).

In the vicinity of oxidizing sulphide bodies zinc is highly mobile owing to the solubility of the sulphate (Wedepohl, 1972) and the chloride (Rankama & Sahama, 1950). It is not surprising, then, that low zinc values are found in the Georgetown heavy-mineral concentrates even in close proximity to mineralization (Table 3). In addition, sphalerite is observed only rarely among the heavy minerals. It seems likely, therefore, that zinc occurs mainly in the fine fraction of the stream sediments where it has probably been adsorbed by clays (White, 1957), organic matter (Swanson et al., 1966) and perhaps to some extent iron and manganese oxides and hydroxides (Jenne, 1968).

The distribution of zinc in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 13. In both cases the log-probability plots are appropriate for estimating threshold values. Levels in excess of 150 ppm in stream sediments and 300 ppm in soils may be considered anomalous.

Cadmium shows very strong correlation with zinc and it seems

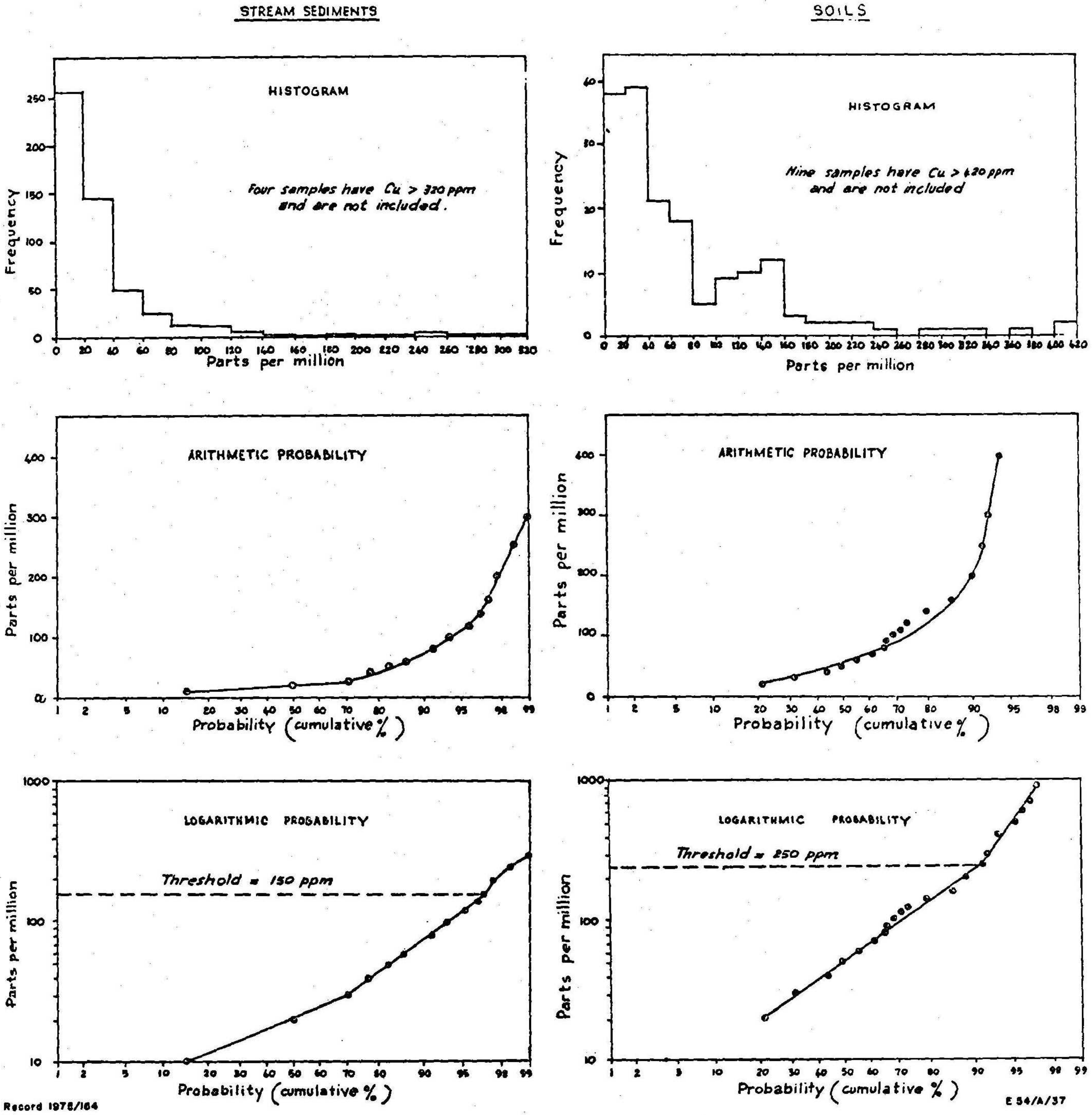

Fig.10: Distribution of copper in stream sediments and soils

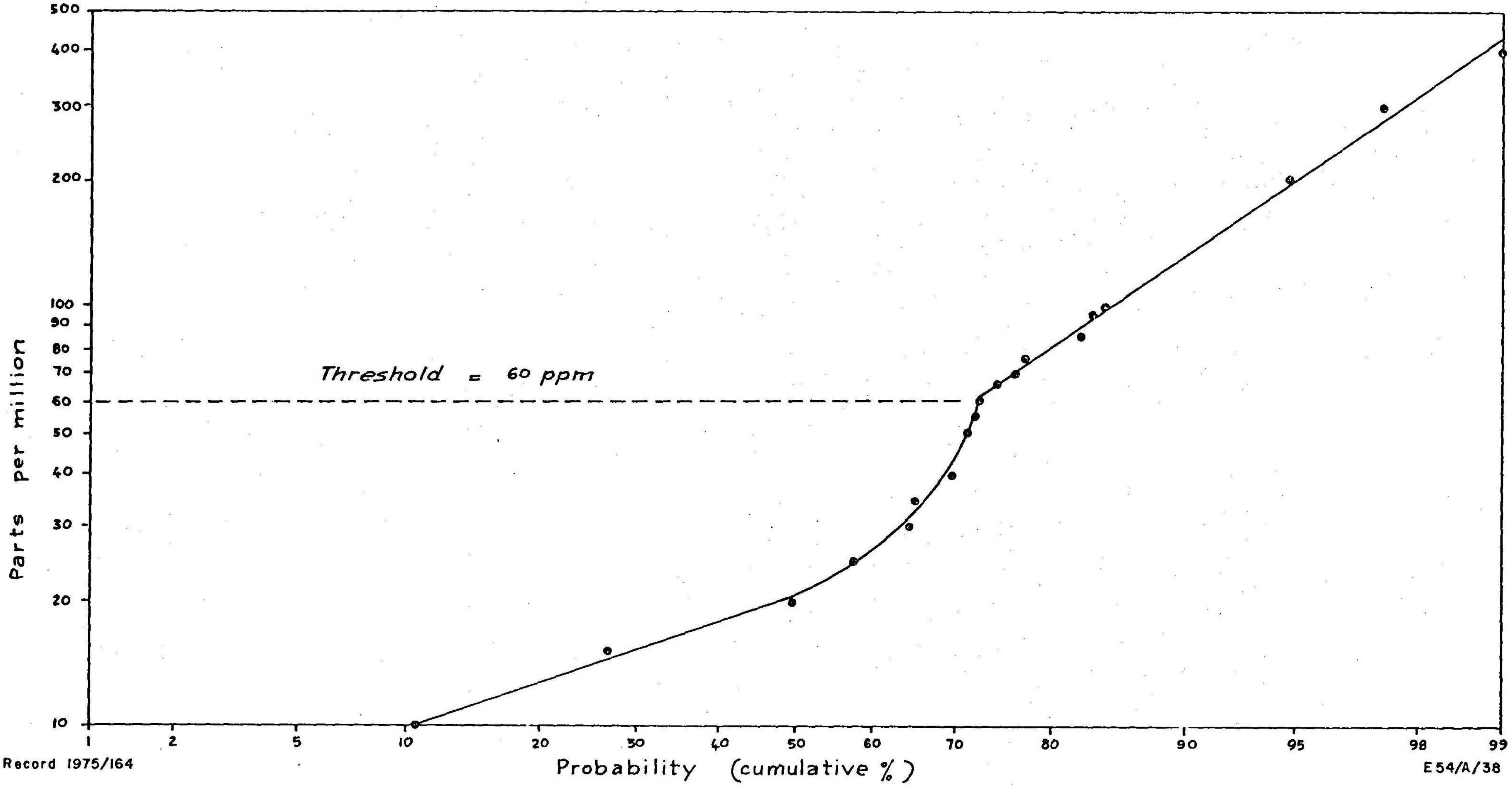

Fig. 11: Distribution of copper in stream sediments derived from granitic terrains

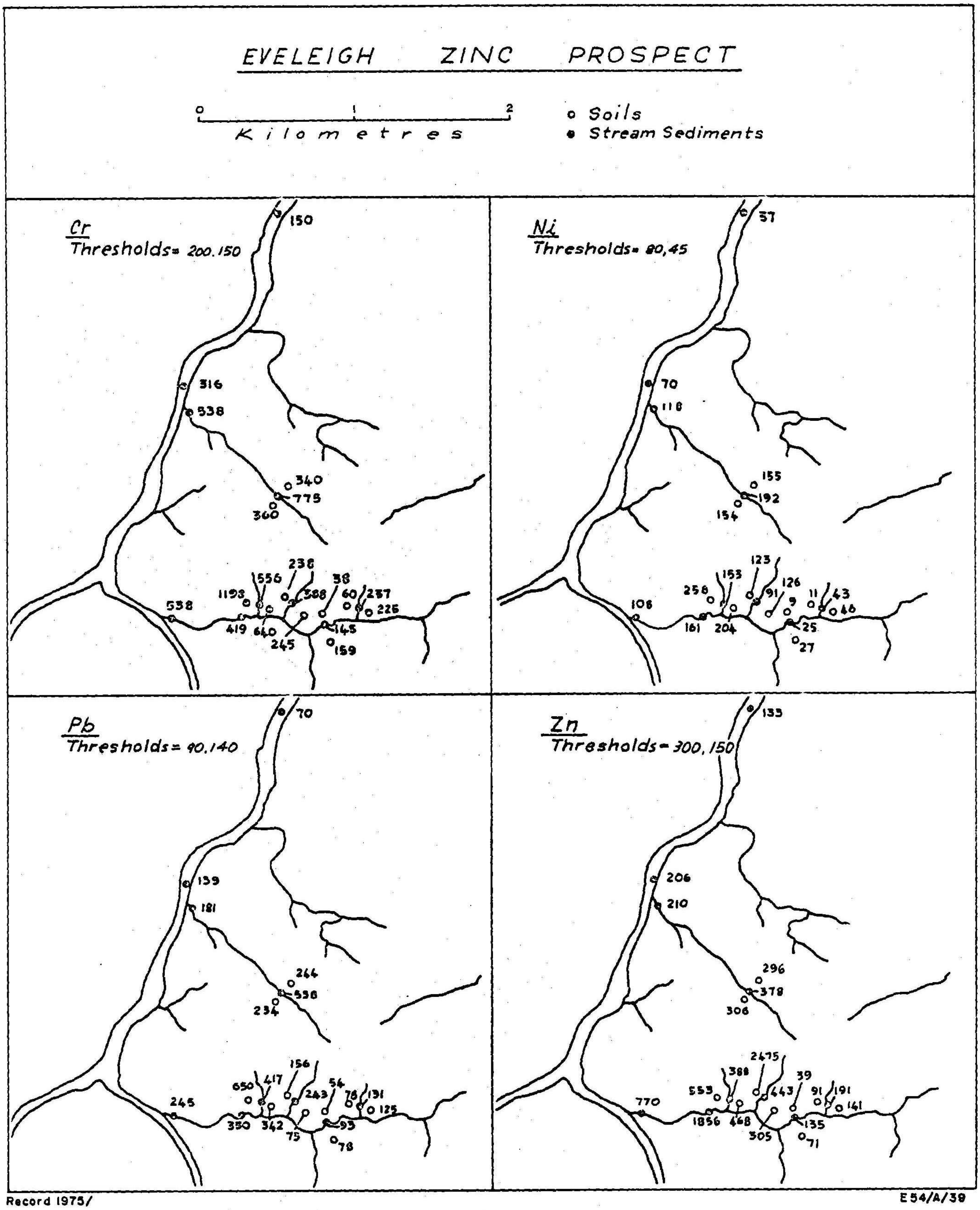

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Fig. 12: Results of geochemical sampling in the vicinity of the Eveleigh zinc prospect. Values are in ppm. The first threshold in each case refers to soils, the second to stream sediments

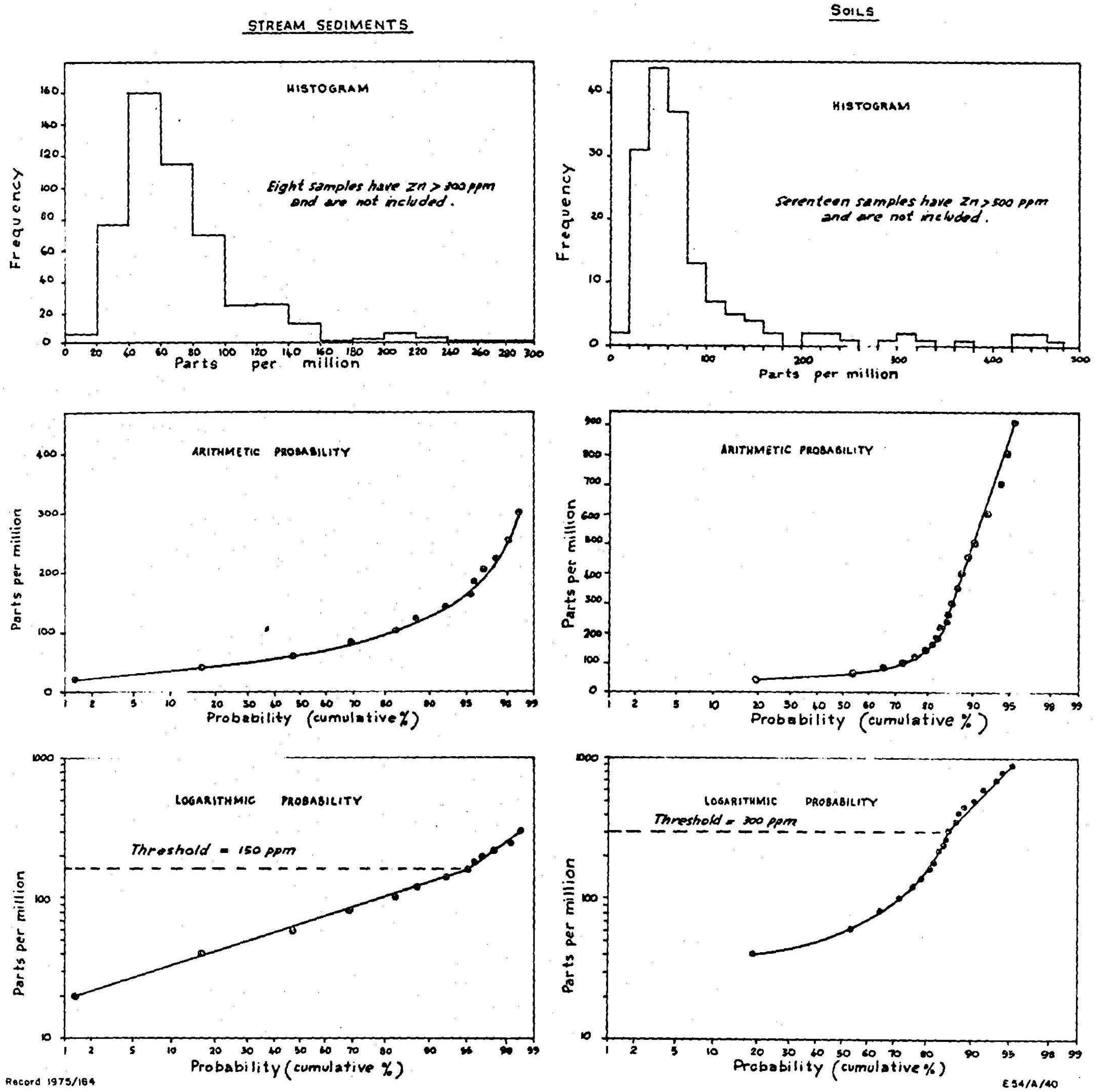

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Fig. 13: Distribution of zinc in stream sediments and soils

unlikely that cadmium values will provide any additional information to that given by zinc analyses during future surveys. The distributions of cadmium in stream sediments and soils are too poorly known (Fig. 14) for thresholds to be defined statistically, but values of 2 ppm or greater in either medium would appear to warrant closer examination.

Lead Although some lead is admitted to potassium minerals (notably the alkali feldspars) during the crystallization of igneous rocks, this element is concentrated mainly in the pneumatolytic and hydrothermal products of igneous activity. Lead is found associated with copper, silver, and sulphur (Table 7) in the mineral deposits of the Georgetown region.

Most of the common lead salts such as the sulphate and the carbonate are relatively insoluble and as a consequence lead tends to be rather immobile in the supergene environment. The immobility of lead during weathering compared with other elements such as copper and zinc has been noted by many authors e.g., Naumov, Pachadzhanov, & Burichenko (1972). Some lead is released into solution as sulphate and bicarbonate (Boyle, 1972) but the amount is very small. Thus, theoretical considerations predict that mechanical processes should figure more prominently in the secondary dispersion of lead than chemical phenomena such as precipitation and adsorption. It is not surprising, therefore, to find the Georgetown heavy-mineral concentrates extremely rich in lead - often greater than 6000 ppm[*] near mineralization (Table 3). X-ray diffraction studies have shown anglesite ($PbSO_4$) and cerussite ($PbCO_3$) to be the lead-bearing minerals present. Anomalies in the sieved samples are probably also due to very small clastic grains of these two minerals.

The distribution of lead in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 15. The frequency diagrams for stream sediments suggest the presence of three populations - low values appear fairly normally distributed while higher values can be equally well approximated by normal or lognormal models. A threshold value for stream sediments of 140 ppm is obtained using either the arithmetic or the logarithmic cumulative frequency plots. A threshold for soils of 90 ppm is derived from the log-probability plot. The higher value in the stream sediments probably reflects the fact that they were sieved to a finer grainsize than the soils. Lower thresholds

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[*] upper limit of the emission spectrographic technique used.

could apply near amphibolite and dolerite (p. 14) but there are insufficient data at present for such values to be calculated. The lack of a precisely defined stream-sediment threshold is not likely to seriously handicap future surveys in the Georgetown region as basic intrusions are small and catchments containing a large proportion of basic rocks are rare.

Gold During the crystallization of granitic magmas gold is concentrated in the pegmatitic and hydrothermal products of differentiation; the result is the well known association of gold with quartz and sulphide veins. Narrow auriferous lodes containing varying amounts of iron, lead, zinc, copper, and silver sulphides are common in the Georgetown region.

Gold may be mobilized in the secondary environment as chloride (e.g. $AuCl_4^-$), thio- (e.g. $Au(S_2O_3)^{3-}$) and cyanide (e.g. $Au(CN)_2^-$) complexes (Lakin, Curtin, & Hubert, 1971). The mobilized gold may be reprecipitated in the presence of organic matter (Ong & Swanson, 1969) or some other reducing agent.

The only analytical data for gold available to date refer to soil samples collected near the Jubilee Plunger gold mine (Armstrong, 1975). A well defined gold anomaly occurs (Fig. 16) and it seems likely that in these soils gold is being chemically dispersed - if the element occurred in particulate form sampling errors would presumably lead to wild fluctuations in the gold values. There are insufficient data for a statistical appraisal but 0.1 ppm seems a reasonable level to use in outlining gold anomalies in soils. A close correlation exists between gold and copper, lead, silver, and zinc anomalies at the Jubilee Plunger (Fig. 16). The application of these more easily determined elements as pathfinders for gold deposits in the region is currently being further investigated by a soil-sampling program around the Big Reef and Two Micks mines near Forsayth. Whether or not chemically dispersed gold can be detected in stream sediments near mineralization is not known, but mechanically transported gold is fairly common in the heavy-mineral concentrates (Table 3).

Silver Like copper (p. 18), silver may be concentrated in the sulphides separating at an early stage during the crystallization of some basic magmas (Rankama & Sahama, 1950). More generally, however, this element is enriched in the late differentiates. In the mineral deposits of the Georgetown area silver is associated with copper, lead, and sulphur (Table 7).

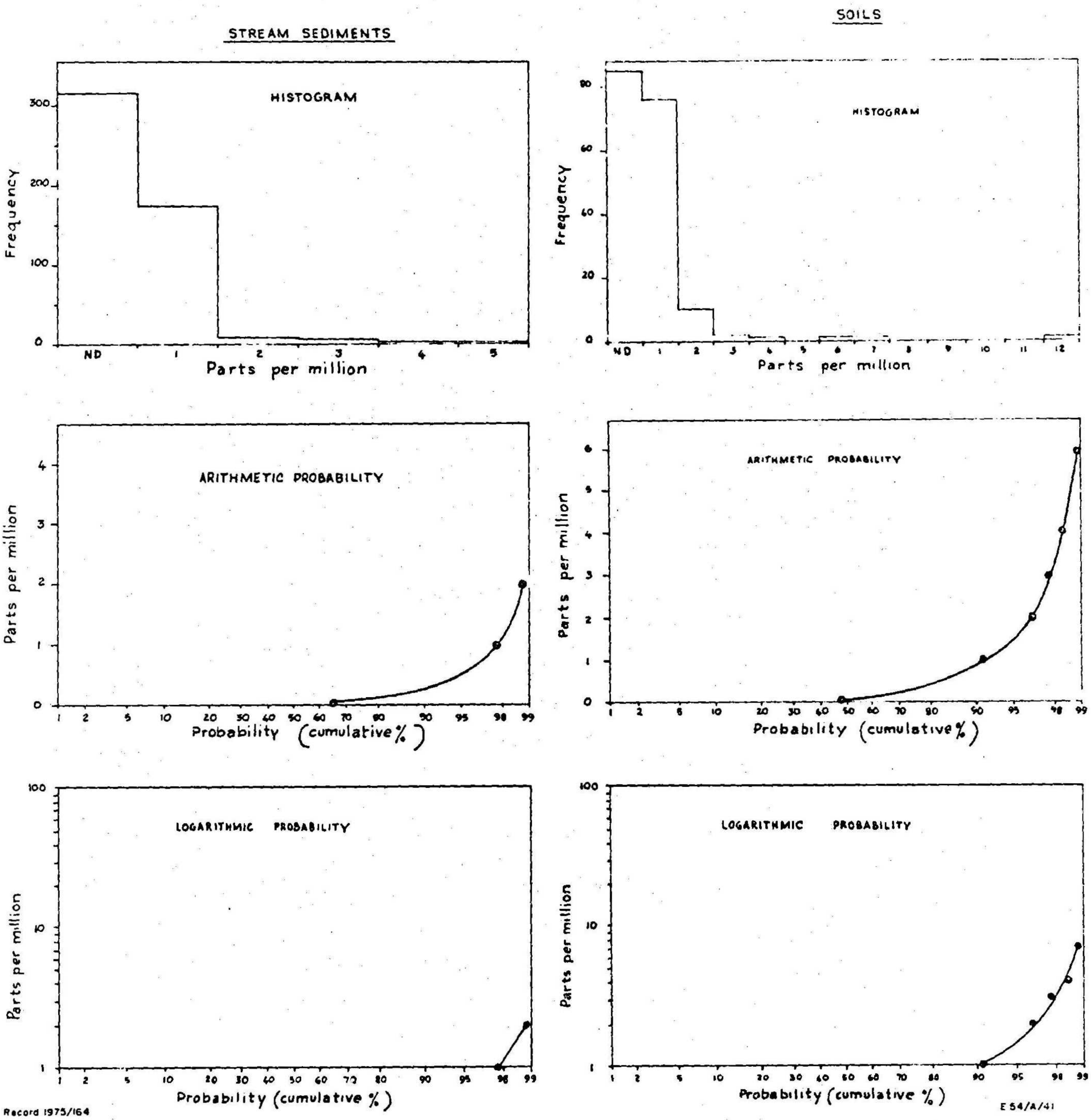

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Fig. 14: Distribution of cadmium in stream sediments and soils

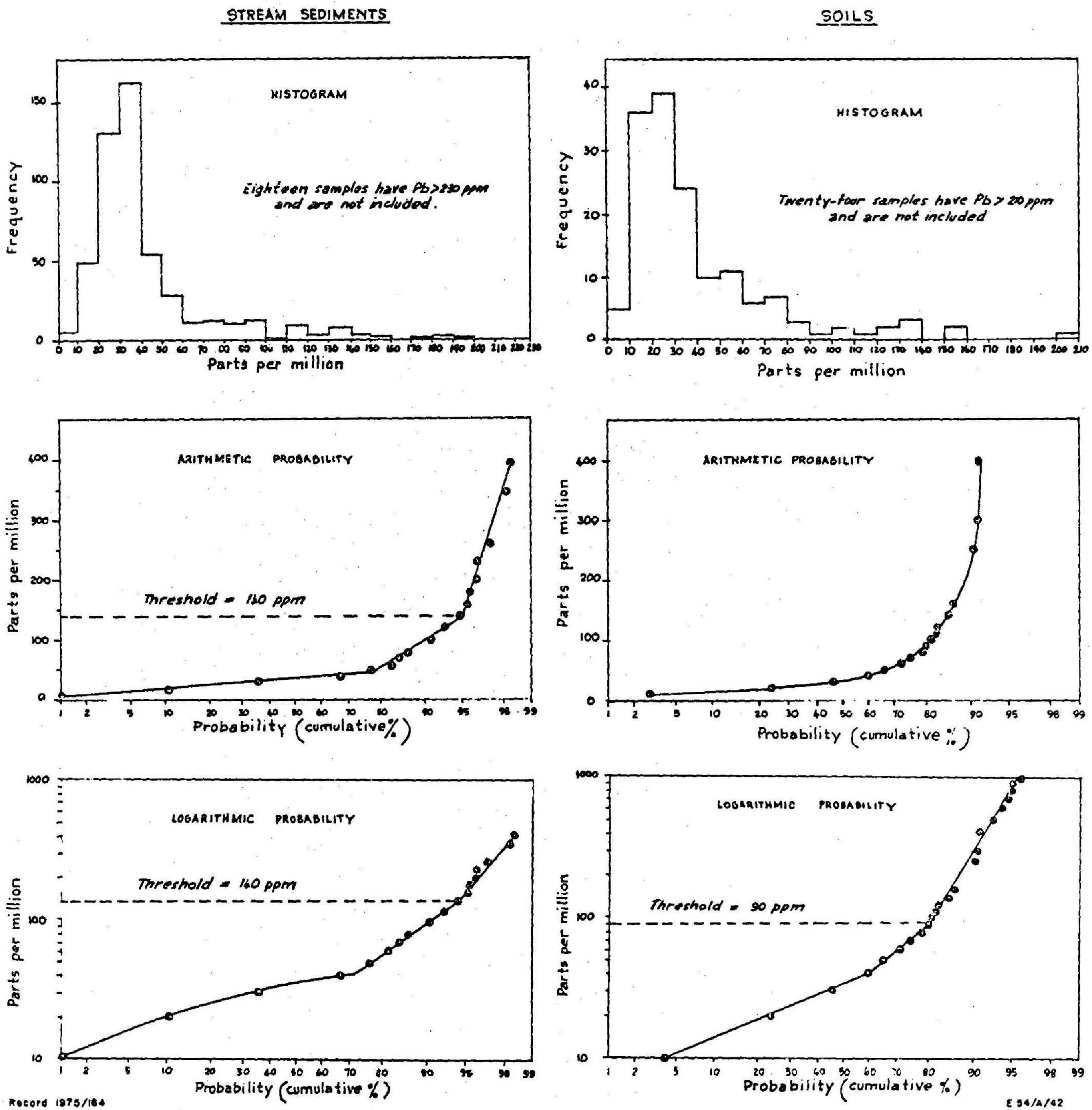

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Fig. 15 : Distribution of lead in stream sediments and soils

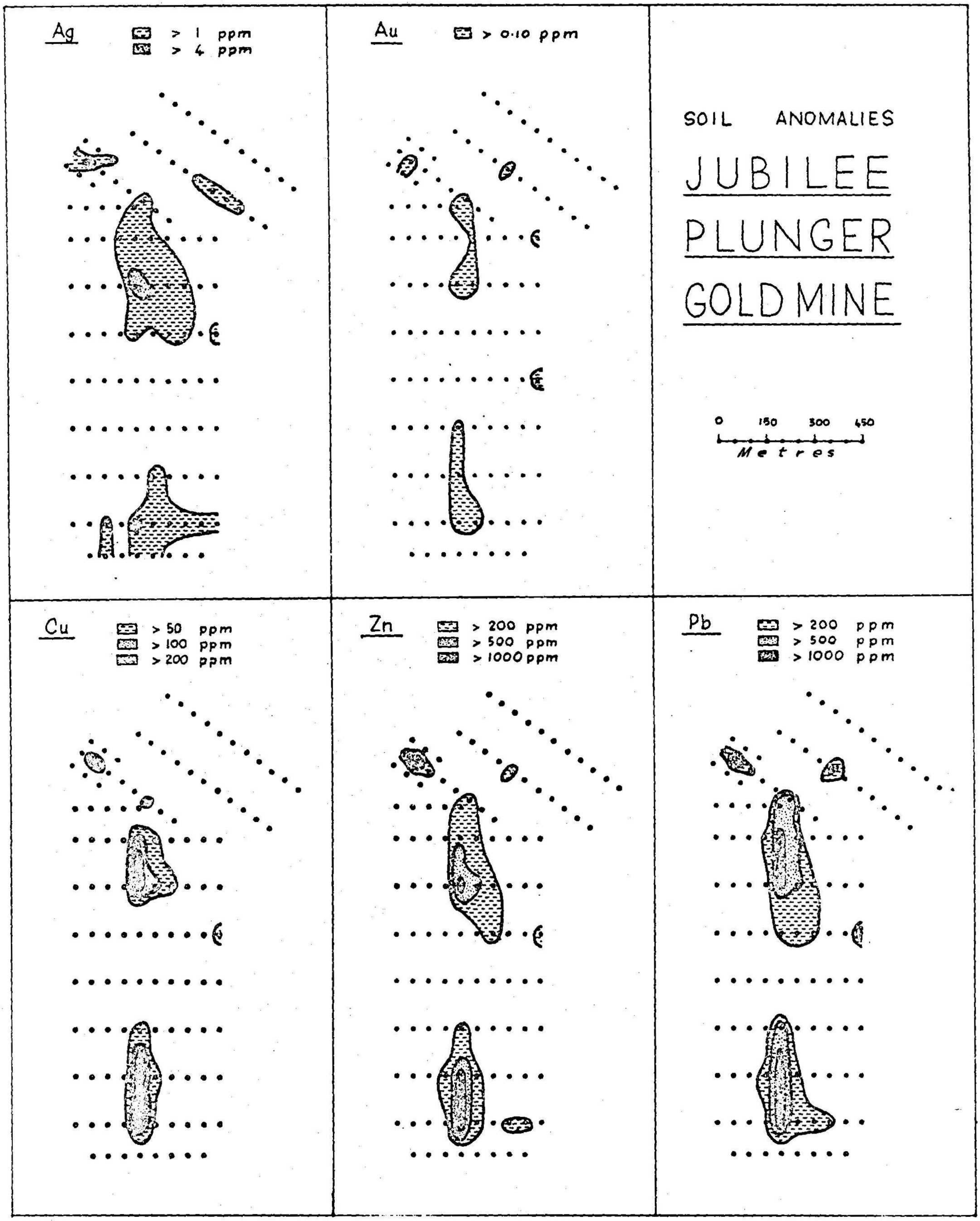

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Fig. 16 : Soil anomalies at the Jubilee Plunger gold mine

Silver contents of the Georgetown heavy-mineral concentrates are low (3 ppm or less) and the secondary dispersion of this element appears to be dominated by chemical processes rather than mechanical. Presumably silver has been released from sulphide minerals as the sulphate with subsequent precipitation as cerargyrite (AgCl) and adsorption in the stream sediments. Hydrated manganese oxides are especially efficient in the adsorption of silver (Anderson et al., 1973); clay minerals and organic matter probably play significant roles also (Boyle, 1968).

The distribution of silver in the stream sediments and soils of the area is shown in Figure 17. In both cases low silver results appear lognormally distributed while high values more closely approximate normality. Thresholds are estimated as 4 ppm in stream sediments and 3 ppm in soils.

Molybdenum Molybdenum is concentrated in the residual products of igneous differentiation (Kuroda & Sandell, 1954). In the ore deposits of the Georgetown area molybdenum is associated with copper (Fig. 9) and the other late-stage elements **fluorine and uranium** (p. 6)

The behaviour of molybdenum in the supergene environment is controlled largely by conditions of pH (Hansuld, 1966). At a pH of less than 6, molybdenum is essentially fixed as ferrimolybdite ($Fe_2(MoO_4)_3$) or as insoluble compounds of the acid molybdate ($HMoO_4^-$) ion. At a higher pH the element is much more mobile owing to the formation of soluble molybdate (MoO_4^{2-}) compounds. Molybdenum being transported in solution as molybdate may be incorporated into stream sediments in a number of ways. Mikhailov (1962) has shown that iron and molybdenum hydroxides coprecipitate according to the reaction:

$$MoO_4^{2-} + Fe^{2+} + 3H_2O = MoO(OH)_3 + Fe(OH)_3$$

Adsorption by oxidate iron and manganese (Horsnail & Elliot, 1971), organic matter (Szilagyi, 1967), and possibly clays may also occur.

The form in which molybdenum occurs in the Georgetown stream sediments is problematical. Secondary haloes associated with mineralization are rather limited in extent (Figs.9), suggesting that molybdenum is being fixed as ferrimolybdite and acid molybdate compounds. Nevertheless, molybdenum contents of heavy-mineral concentrates are relatively low (reaching a maximum of 20 ppm near the Maureen uranium prospect) and the possibility that some molybdenum is being dispersed chemically cannot be discounted.

The analytical data for molybdenum are as yet insufficient to allow a statistical estimate of threshold values for this element, but levels exceeding 5 ppm in either soils or stream sediments probably warrant closer examination.

Tin Tin has a strong affinity for volatiles (especially fluorine) and is typical of the late differentiates of magmas (Barsukov, 1957; Tauson, 1967); it is particularly characteristic of greisens (Hamaguchi & Kuroda, 1969). Tin is associated with the other late-stage elements beryllium, lithium, rubidium, tungsten, and uranium* in the Georgetown area (Fig. 18, Table 7).

The dispersion of tin in the secondary environment is dominated by mechanical processes because of the chemical stability of cassiterite. It is not surprising, then, that the Georgetown heavy-mineral concentrates are high in tin (ranging up to several percent near tin lodes). Although tin mineralization is very localized, small amounts of cassiterite are present in heavy-mineral samples from many parts of the region. Tin values in sieved stream-sediment samples are high (in excess of 400 ppm) near tin deposits and this indicates that some of the detrital cassiterite is quite fine-grained.

The distribution of tin in the stream sediments of the Georgetown area is shown in histogram and probability cumulative frequency form in Figure 19. A lognormal model appears to fit the background distribution quite well. The log-probability plot suggests that any value exceeding 20 ppm should be regarded as significant during future stream-sediment exploration for tin in the region. As yet insufficient data are available to define the threshold value for soils but it is likely to be of the same order.

Tungsten Geochemically tungsten is closely akin to molybdenum although it is more oxyphile and shows a lesser tendency to form sulphide minerals. Like molybdenum, tungsten is concentrated in the pneumatolytic and hydrothermal products of igneous differentiation. In the Georgetown region tungsten is associated with the other late-stage elements beryllium, cerium, rubidium, thorium, tin, and uranium (Table 7).

The tungsten mineral most commonly observed in the study area is wolframite ((Fe, Mn) WO_4) although one occurrence of scheelite ($CaWO_4$) is

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* Analytical work recently completed indicates that arsenic, bismuth, and molybdenum are also sometimes associated with tin mineralization.

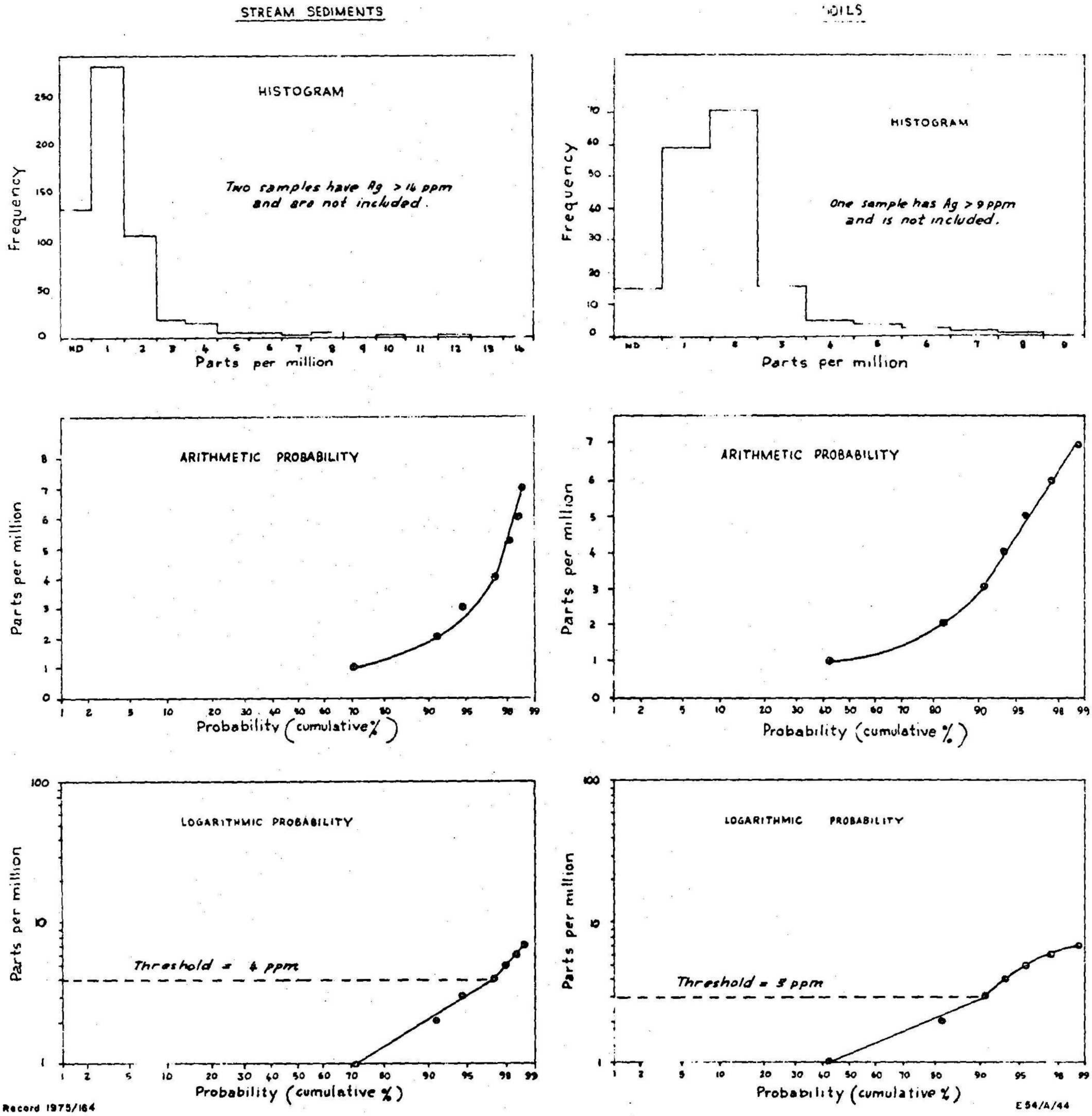

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Fig. 17: Distribution of silver in stream sediments and soils

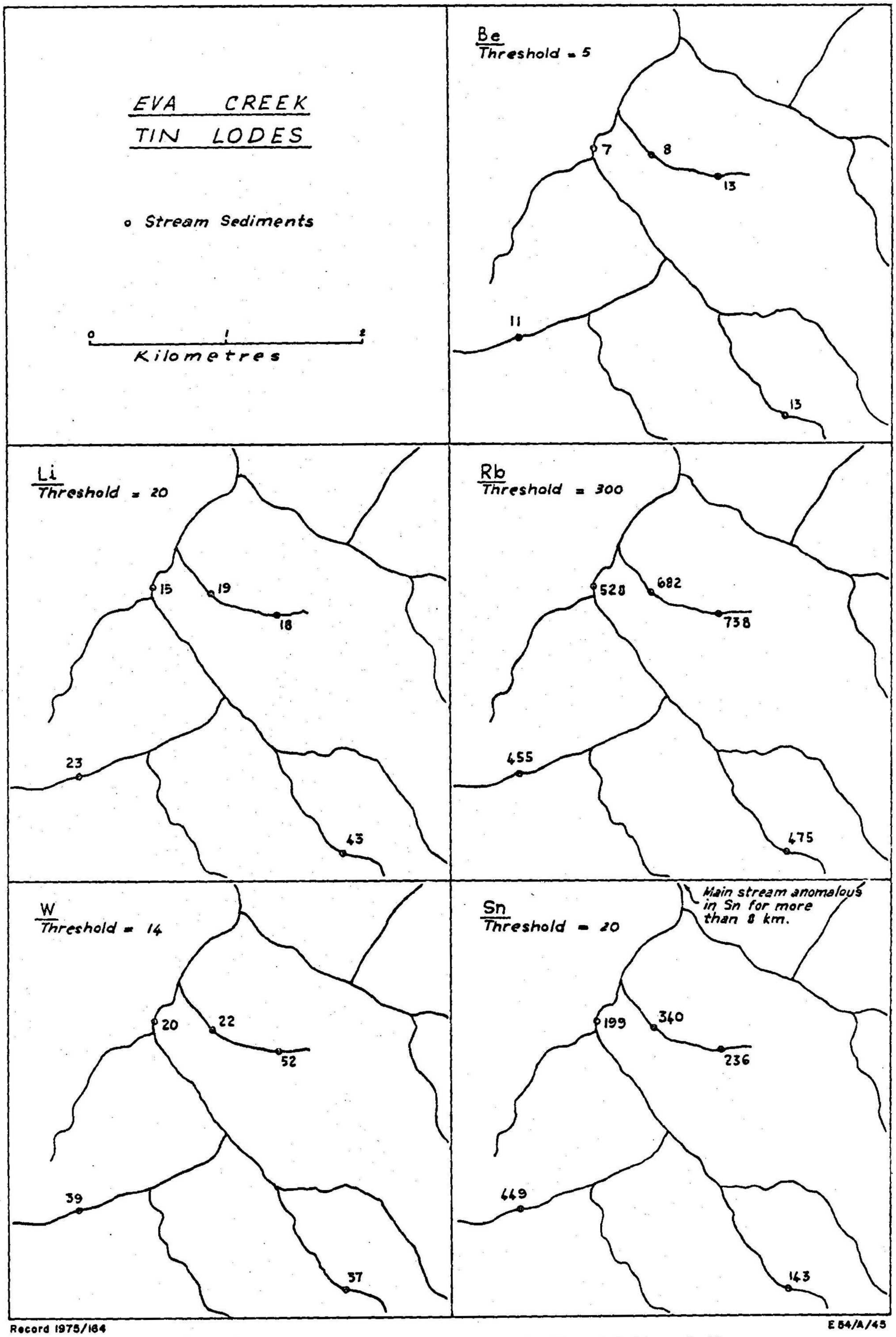

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Fig. 18 : Results of stream sediment sampling in the vicinity of tin mineralization, east branch Eva Creek Values are in ppm

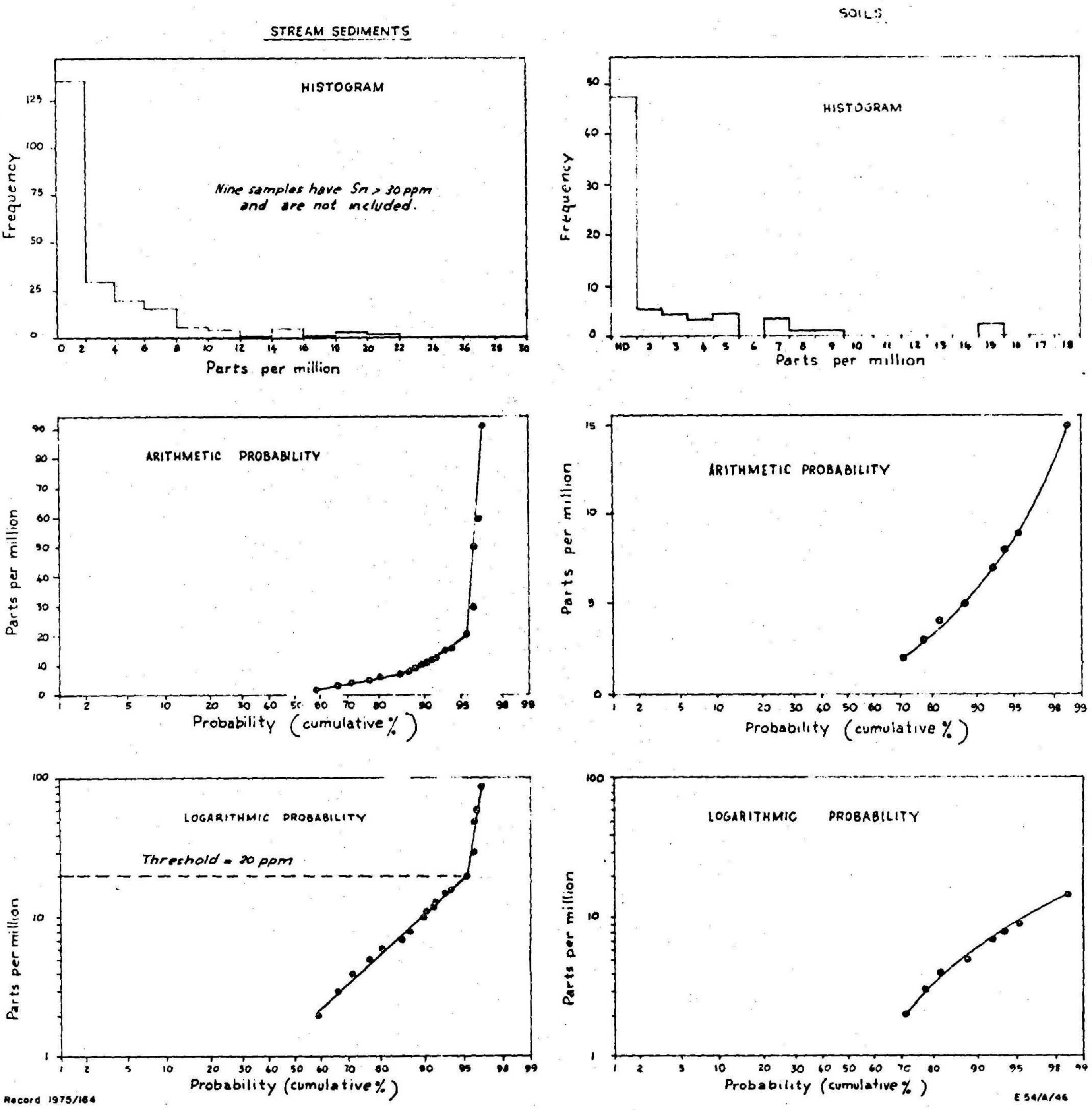

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Fig. 19: Distribution of tin in stream sediments and soils

known (p. 26). Wolframite and scheelite are both rather insoluble in the pH range of surface waters (Krauskopf, 1970) and it seems likely, therefore, that the dispersion of tungsten in the secondary environment is dominantly mechanical. This view is supported by the fact that heavy-mineral concentrates collected near tin-molybdenum-tungsten mineralization show high tungsten levels (occasionally greater than 1800 ppm[*]); presumably the element is present as wolframite. This mineral is rather brittle and becomes finely ground during alluvial transport - thus high values in the sieved stream sediments (to 52 ppm) can also be attributed to detrital wolframite. It is possible, however, that under acid conditions brought about by oxiding sulphides, small amounts of tungsten go into solution perhaps as the HWO_4^{2-} ion or in the form of polysilicic acids (e.g. $H_8Si\ (W_2O_7)_6$) (Krauskopf, 1970). The mechanisms by which soluble tungsten might be adsorbed into stream sediments are poorly understood but manganese oxides and hydroxides are probably effective (Boyle, 1968).

The distribution of tungsten in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 20. Both background populations closely approach normality and threshold values of 14 ppm in stream sediments and 9 ppm in soils are obtained from the arithmetic probability plots.

Niobium and tantalum Niobium and tantalum are reluctant to enter silicates because of their high ionic charge (Nb^{5+}, Ta^{5+}) and so are enriched in late-stage igneous rocks especially pegmatites (Rankama & Sahama, 1950). The minerals columbite ($(Fe, Mn)Nb_2O_6$) and tantalite ($(Fe,Mn)Ta_2O_6$) are stable both mechanically and chemically during weathering and niobium and tantalum would thus be expected to occur mainly in the heavy-mineral fraction of stream sediments. These elements were not detected in any sample but as columbite-tantalite deposits are known in the Georgetown region the analysis of heavy-mineral concentrates for niobium and tantalum may still be worthwhile during future surveys.

Fluorine Pronounced concentration of fluorine occurs during the hydrothermal stage of igneous activity. It is associated with the other late-stage elements molybdenum and uranium in the ore deposits of the Georgetown area (p. 6).

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[*] upper limit of emission spectrographic technique used.

Fluorite (CaF_2) is by far the most important ore mineral of fluorine. It is rather resistant to weathering and therefore the supergene dispersion of fluorine from mineral deposits is probably dominantly mechanical. Small amounts of fluorine may go into solution as alkali fluorides and be subsequently precipitated in secondary phosphates (Hawkes & Webb, 1962) or adsorbed by clays, etc. (Koritnig, 1972).

Analytical data for fluorine are limited to samples collected near the Maureen prospect. Here the element reaches levels of 2.2 percent in soils and 6000 ppm in stream sediments. Detrital fluorite is conspicuous in heavy-mineral concentrates near the deposit. There are insufficient determinations for thresholds to be statistically defined.

Bismuth Bismuth is concentrated in the residual phases of crystallizing magmas (Greenland, Gottfried, & Campbell, 1973). The other late-stage elements antimony, arsenic, fluorine, tin, and tungsten are common associates. The only recorded bismuth occurrence in the Georgetown area is at the Eight-Mile mine near Percyvale station. At this locality bismuth carbonates occur with scheelite.

The behaviour of bismuth in the secondary environment is rather poorly known. The most common bismuth-bearing minerals, galena and bismuthinite (Bi_2S_3), are both readily attacked during the oxidation of ore deposits and presumably the element is released to the soil solution. Precipitation as oxy salts by hydrolysis and adsorption in soils and stream sediments probably ensues. Rankama & Sahama (1950) considered that ferric hydroxides play a major role in bismuth adsorption. Bismuth is probably also dispersed mechanically in minerals such as bismite (Bi_2O_3) and bismutite ($Bi_2 (CO_3) O_2$) as well as secondary lead minerals.

Data for bismuth in the Georgetown samples are sparse owing mainly to the lack of a sufficiently sensitive analytical technique. In most cases to detect the element at all is to detect a geochemical anomaly. Traces have been found in heavy-mineral concentrates collected near tin mineralization, and a value of 180 ppm was encountered in a heavy-mineral sample at the Big Reef gold mine. Preliminary results on soils near the Eva Creek tin lodes give bismuth contents as high as 410 ppm.

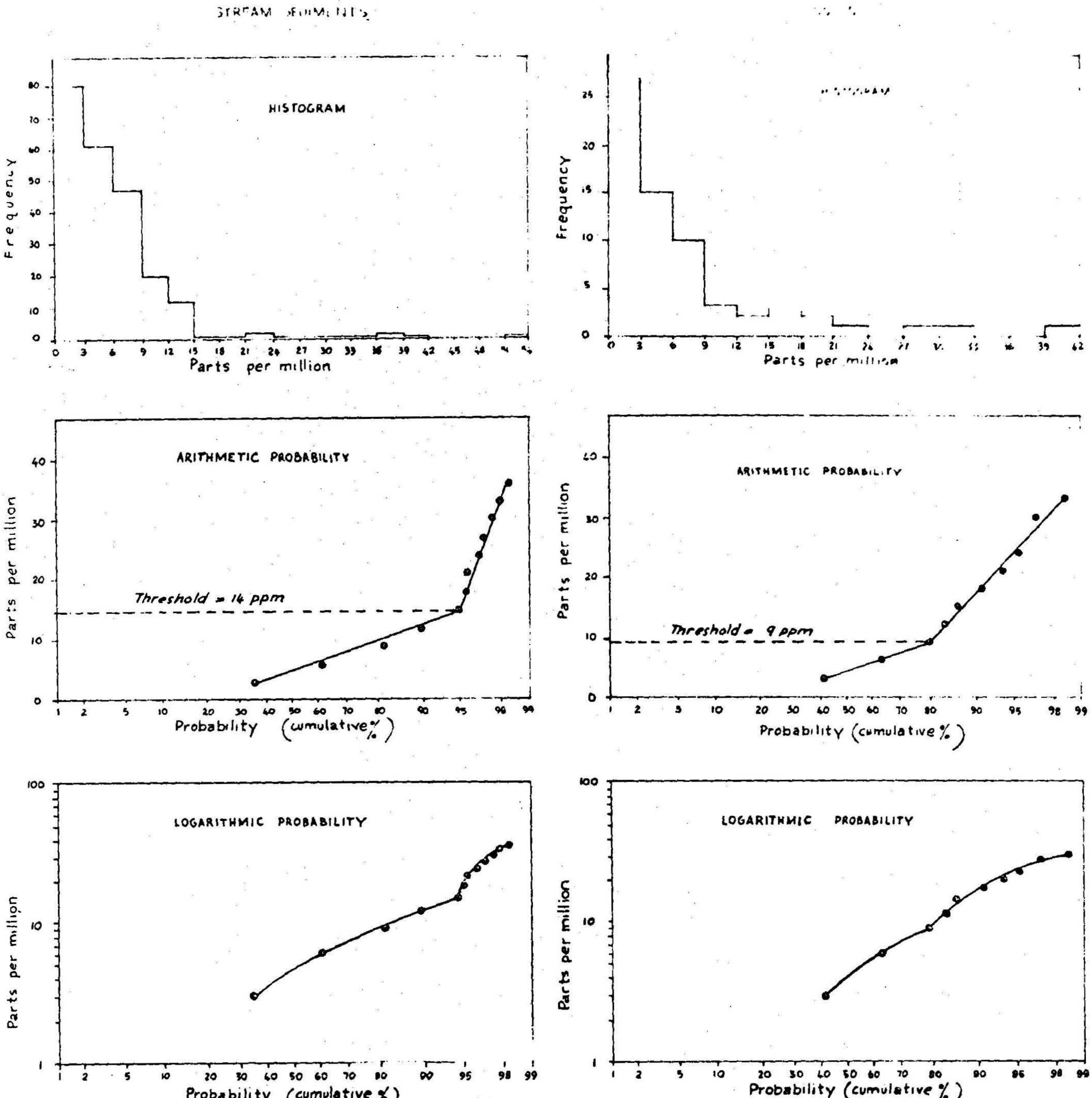

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Fig. 20: Distribution of tungsten in stream sediments and soils

Arsenic Arsenic is concentrated in the residual products of igneous differentiation (Onishi & Sandell, 1955). In the mineral deposits of the Georgetown area arsenic is associated with the other late-stage elements uranium (Fig. 6).

Arsenic occurs in sulphide bodies as sulpharsenides of iron, cobalt, copper, and nickel - the most common ore mineral is arsenopyrite (FeAsS). On weathering the arsenides are readily oxidized to arsenates and most of the arsenic mobilized in the supergene environment occurs as the arsenate (AsO_4^{3-}) ion. The bulk of the arsenic present in the stream sediments has probably been precipitated as scorodite ($FeAsO_4 \cdot 2H_2O$), with some being adsorbed by hydrated ferric oxide. The positive charge of iron hydrosols renders them more effective in the adsorption of AsO_4^{3-} ions than colloidal manganese compounds which have a negative charge.

The distribution of arsenic in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 21. Both distributions are complex, low arsenic values showing approximately lognormal character and higher levels apparently having normal Gaussian affinities. From the logarithmic cumulative frequency plots anomalous values are defined as greater than 8 ppm in both stream sediments and soils.

Cobalt, nickel, and chromium Cobalt, nickel, and chromium all separate during the initial stages of the crystallization of magmas. The cobalt and nickel not incorporated in the early sulphide phase enters Fe^{2+} and Mg sites in the first silicates to form i.e. olivines, pyroxenes, and amphiboles. Chromium can either crystallize as chromite or proxy for Fe^{2+} and Mg in early-forming silicate minerals such as garnets, pyroxenes, and micas. The result is that significant concentrations of cobalt, nickel, and chromium are almost entirely confined to ultrabasic rocks; granites and their differentiates are impoverished in these elements. High nickel and chromium values associated with the Eveleigh zinc deposit (Fig. 12) support field evidence that the mineralization is genetically related to basic intrusive rocks.

The mobilities of cobalt, nickel, and chromium in the supergene environment are strongly influenced by the nature of the mineral species in which the elements occur. Clearly cobalt occurring as a sulphide or an arsenide will be released to the weathering solution more readily than cobalt incorporated in the lattice of a resistant pyroxene. At the Eveleigh deposit cobalt, nickel, and chromium probably occur in sulphide minerals. Heavy-mineral concentrates collected near the deposit generally contain low cobalt, nickel, and chromium - this suggests that the three elements are being dispersed mainly by chemical processes. Presumably cobalt is being released as the sulphate (Boyle, 1972) and possibly the bicarbonate; nickel as the sulphate (Boyle, 1972) and chromium in the form of the chromate (CrO_4^{2-}) ion. Little is known of the mechanisms by which the three elements are incorporated into stream sediments although oxidate manganese is probably responsible for at least some fixation of cobalt.

The distributions of cobalt, nickel, and chromium in the stream sediments and soils of the area are shown in histogram and cumulative frequency form in Figures 22, 23 and 24 respectively. With the exception of cobalt in soils, background populations show strong tendencies to lognormality. The number of anomalous samples is so few that anomalous populations are poorly defined by the stream-sediment cumulative frequency curves (in fact for cobalt no anomalous population at all can be distinguished). As the distributions approach a single population situation so closely, threshold values defined in terms of geometric mean and deviation (p. 14) are probably just as meaningful as those estimated from the break in slope of the probability plots (Table 6).

	A	B
Co	30	-
Ni	45	50
Cr	150	200

Table 6: Threshold values for cobalt, nickel, and chromium in stream sediments
A - geometric mean multiplied by the square of the geometric deviation (approximated by the 97.72 percentile of the log-probability cumulative frequency curve - Lepeltier, 1969).
B - break in slope of the log-probability curve

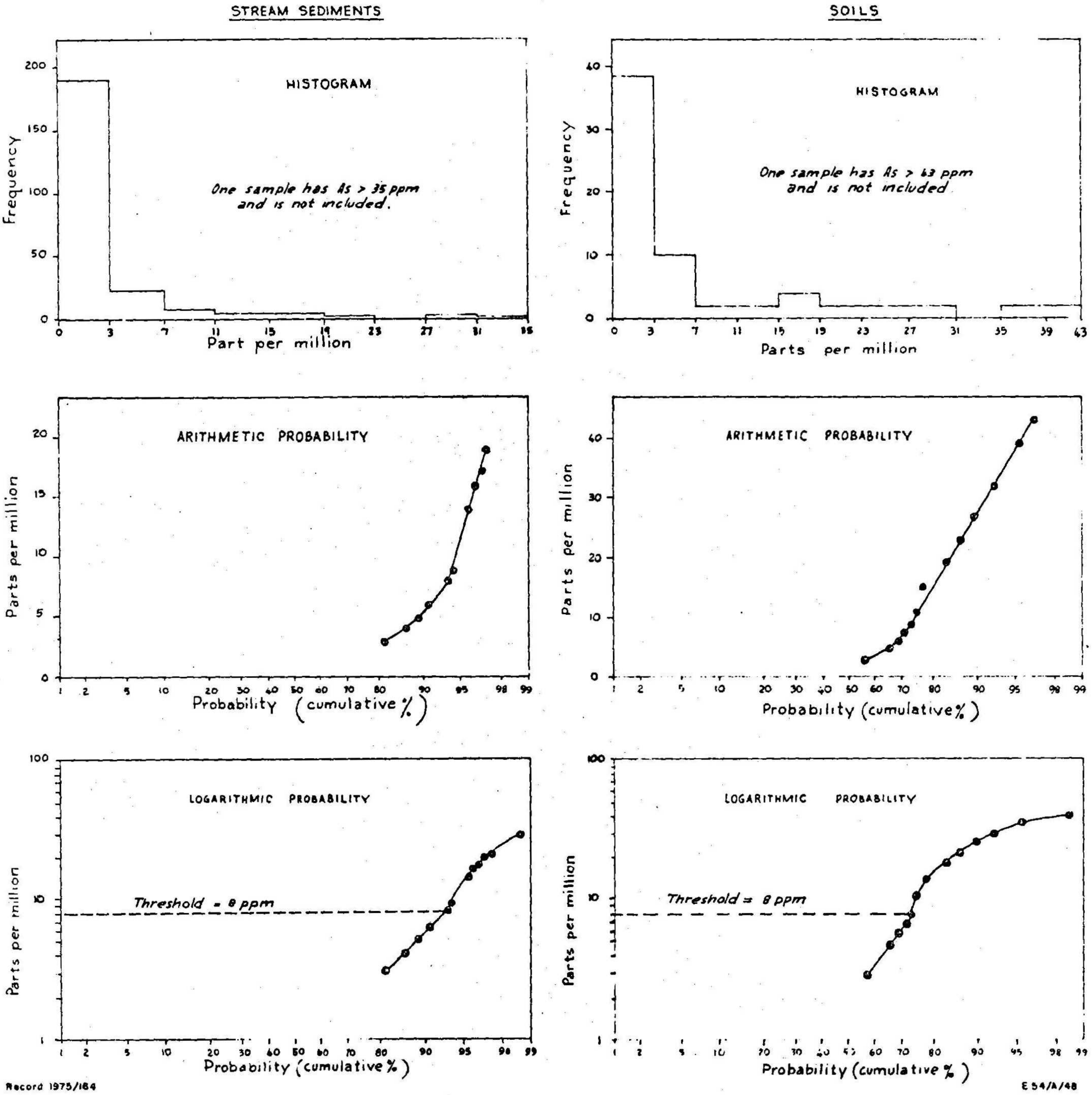

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Fig. 21: Distribution of arsenic in stream sediments and soils

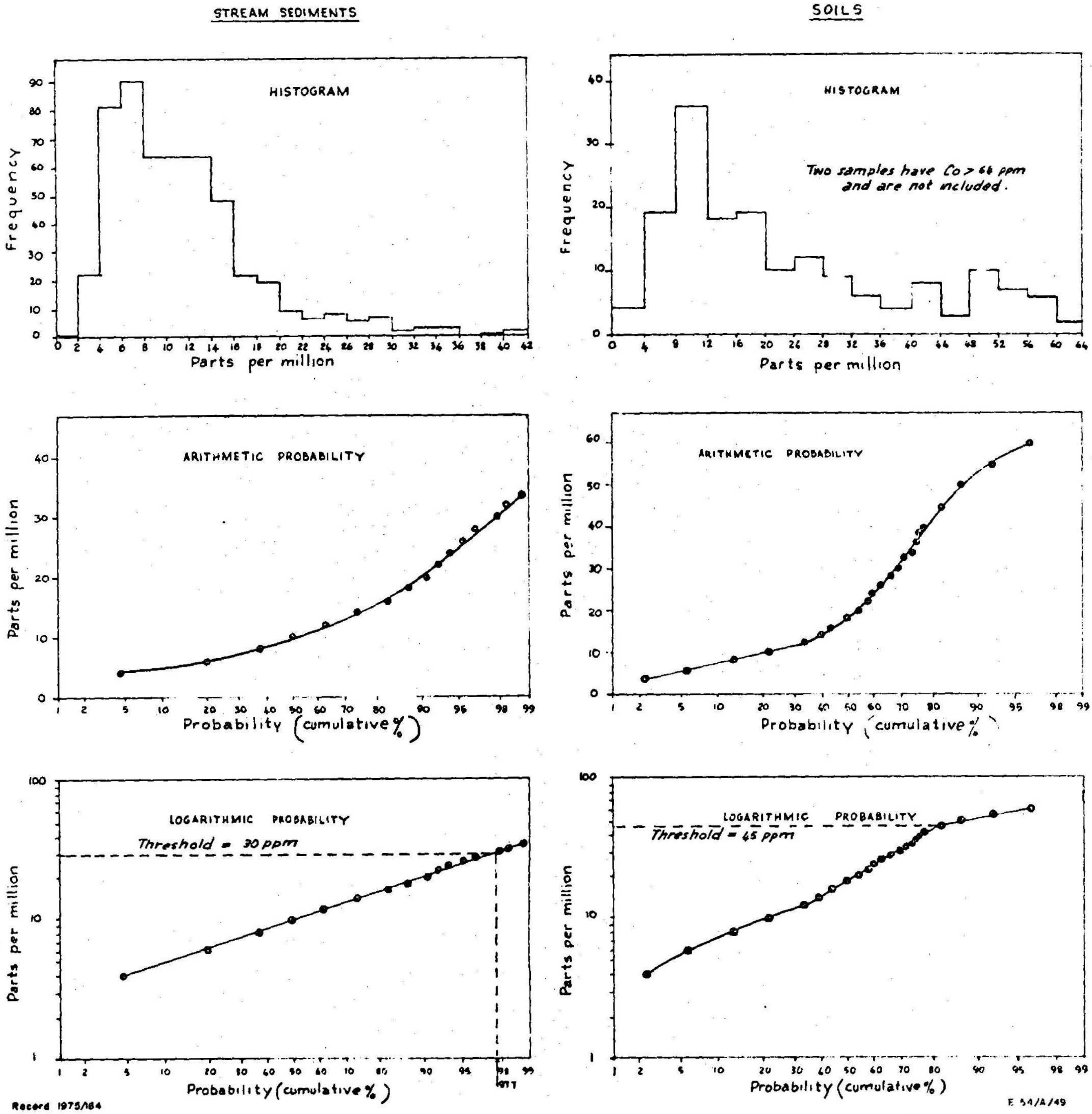

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Fig 22: Distribution of cobalt in stream sediments and soils

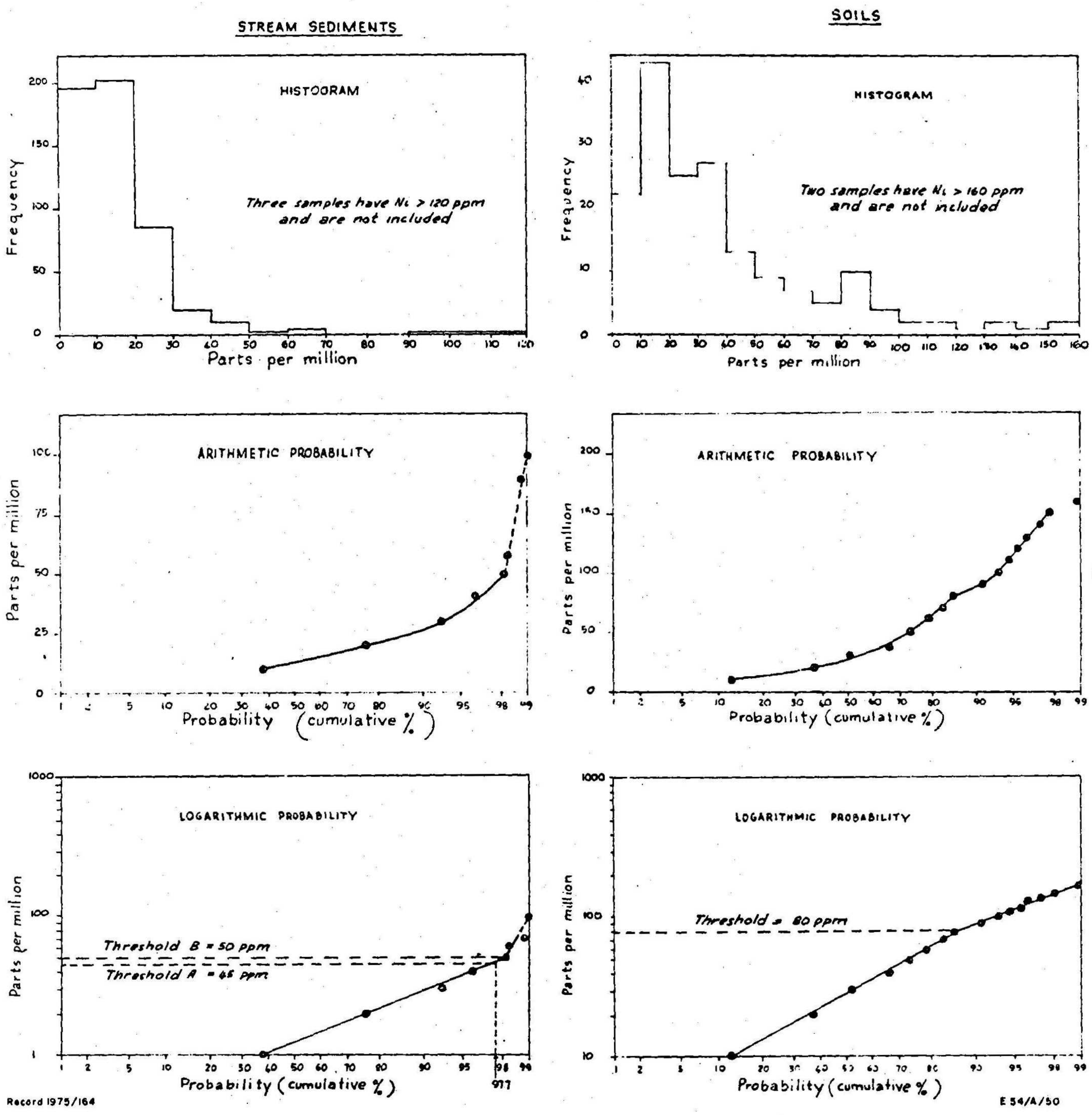

Fig 23: Distribution of nickel in stream sediments and soils

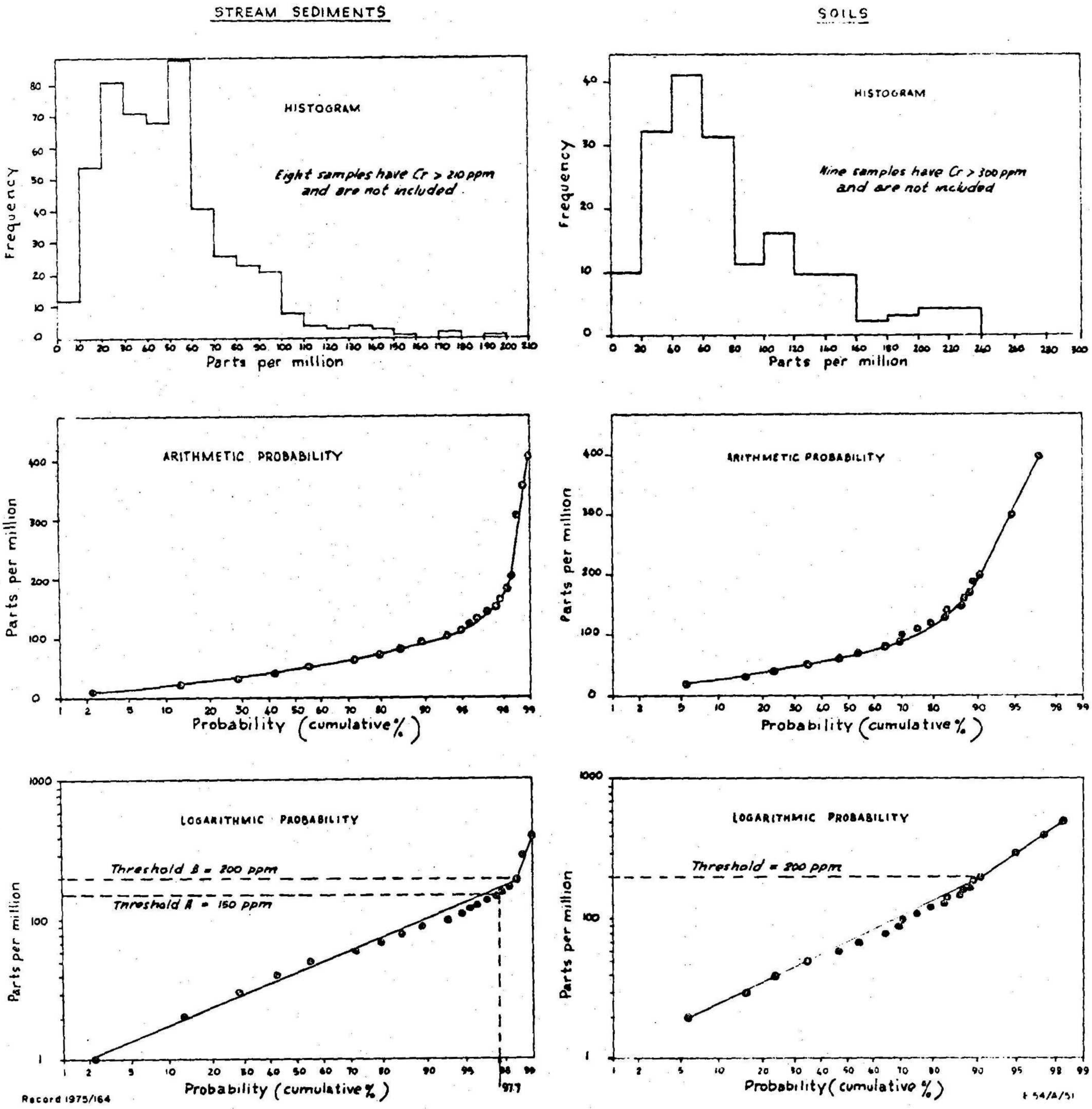

Fig 24: Distribution of chromium in stream sediments and soils

However, anomalous populations for soils are clearly defined by the log-probability diagrams and these plots are adequate for estimating thresholds. Values so obtained are 45, 80, and 200 ppm cobalt, nickel, and chromium, respectively.

As no ultrabasic rocks are known to occur in the Georgetown region and only one of the hydrothermal deposits has anomalous chromium and nickel associated, it seems doubtful whether future geochemical surveys in the area would benefit greatly by using these elements.

Sulphur During the crystallization of igneous rocks any sulphur not precipitated at an early stage with iron, copper, nickel, and cobalt is enriched in the residual differentiates. Sulphur is associated with most of the mineral deposits of the Georgetown area.

Nearly all sulphur in rocks occurs in the form of independent sulphide minerals which on weathering yield sulphates, some of which are soluble (e.g. $CuSO_4$), some insoluble (e.g. $PbSO_4$). It is logical to conclude, therefore, that the bulk of sulphur in soils and stream sediments is present as sulphate both chemically precipitated and mechanically dispersed. A little sulphate is coprecipitated with iron and manganese oxides and hydroxides (Boyle, 1972) but adsorption processes would appear to play only a minor role in the dispersion of sulphur. The strong correlation existing between sulphur and lead (and silver) in the stream sediments (Table 7) can be attributed to the presence of detrital anglesite (p. 21). Anomalous sulphur was found downstream from only those deposits rich in lead; in the absence of lead virtually all sulphate is removed in solution.

A value of 1200 ppm sulphur (Fig. 25) would appear realistic for distinguishing anglesite-bearing from anglesite-free stream sediments. The use of sulphur during future geochemical surveys in the Georgetown region seems limited - it is unlikely that sulphur values will furnish any information additional to that provided by lead analyses. The data presently available for sulphur in soils are too few to allow meaningful statistical analysis.

Barium During the crystallization of granitic magmas most of the barium present enters feldspar and mica lattices. On occasions, however, the element becomes sufficiently concentrated in the hydrothermal products of differentiation for barite ($BaSO_4$) to form. This mineral is commonly found in the gangue material of ore deposits, especially those rich in lead and zinc.

Barium occurs in stream sediments in a number of forms. It is transported mechanically as detrital feldspar, clay minerals, and barite and also chemically dispersed by solution and subsequent adsorption on clays, oxides and hydroxides (especially those of manganese), and organic matter (Puchelt, 1972). It seems likely that, in the Georgetown sieved samples, barium present in feldspar is obscuring the more economically interesting barium contribution due to barite. Possibly analysis of the heavy-mineral concentrates will be the solution to this problem and prove useful in the future delineation of deposits containing barite. At this stage, however, not enough barium analyses of heavy-mineral samples are available for this opinion to be validated.

The distribution of barium in the stream sediments and soils of the area is shown in histogram and probability cumulative frequency form in Figure 26. Although there is evidence of a group of anomalous (greater than 850 ppm barium) samples among the soils, the stream-sediment distribution closely approximates a single normal population. It is necessary, therefore, to define a threshold value for stream sediments in terms of arithmetic mean and standard deviation (p. 14). An adequate estimate is given by the 97.72 percentile of the arithmetic cumulative frequency plot - a value of approximately 1000 ppm is so obtained. More analyses of heavy-mineral concentrates for barium are required before it can be ascertained whether this element is likely to prove useful during future surveys in the Georgetown area or not.

<u>Lithium and beryllium</u> During igneous crystallization some lithium enters Mg sites in silicates such as pyroxenes, amphiboles, and micas; beryllium may replace silicon in micas and alkali feldspars. These substitutions, however, are somewhat restricted, so that both elements frequently become concentrated in the late-stage differentiates of magmas especially the pegmatites. Enrichment may be so great that independent lithium and beryllium minerals such as lepidolite (Li-mica), petalite ($Li\ Al\ Si_4O_{10}$), spodumene ($Li\ Al\ Si_2O_6$) and beryl ($Be_3Al_2Si_6O_{18}$) crystallize. The only anomalous lithium (to 43 ppm) and beryllium (to 13 ppm) encountered in the stream sediments occurs near the Eva Creek tin mineralization (Fig. 18).

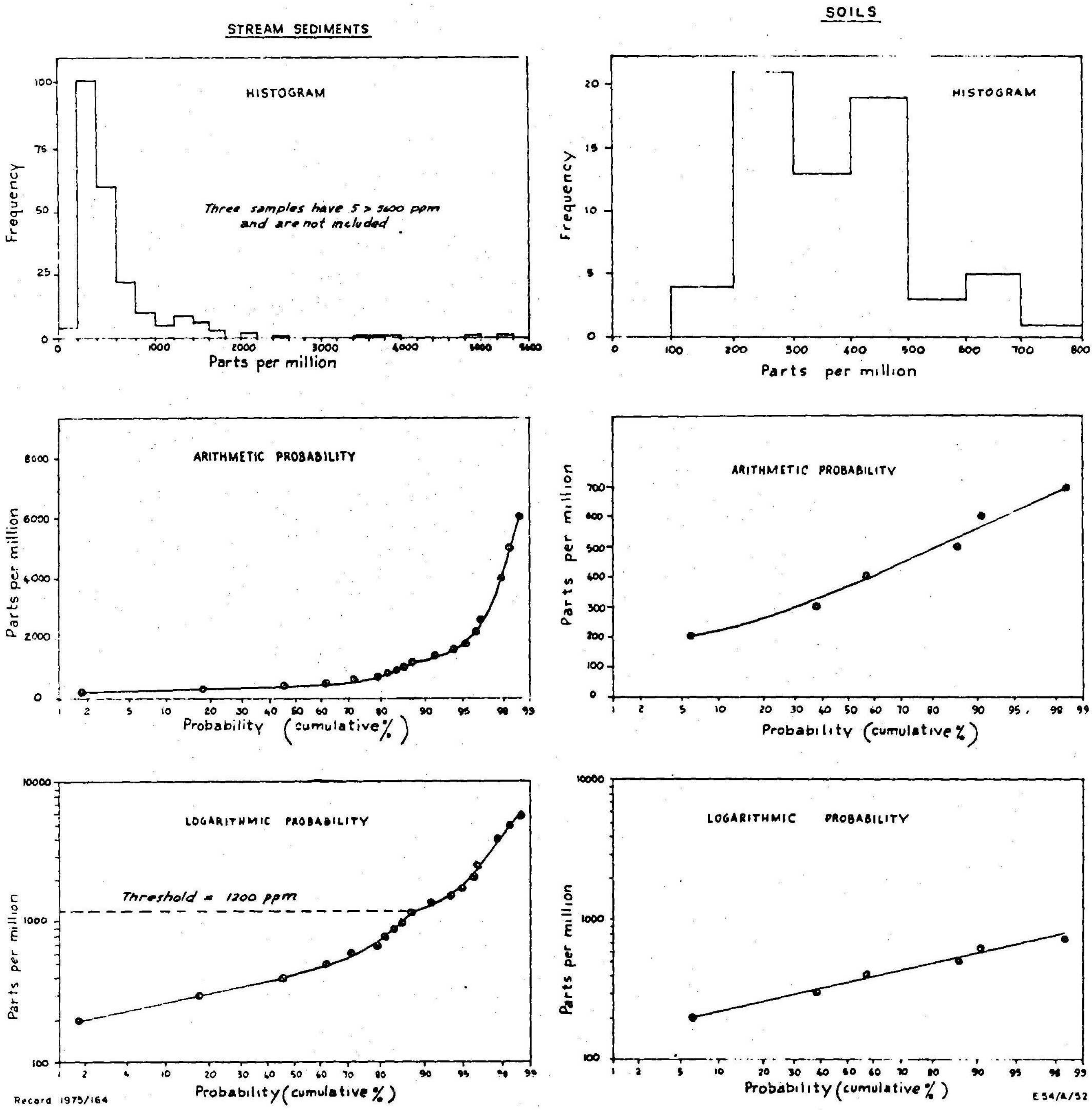

Fig 26: Distribution of sulphur in stream sediments and soils

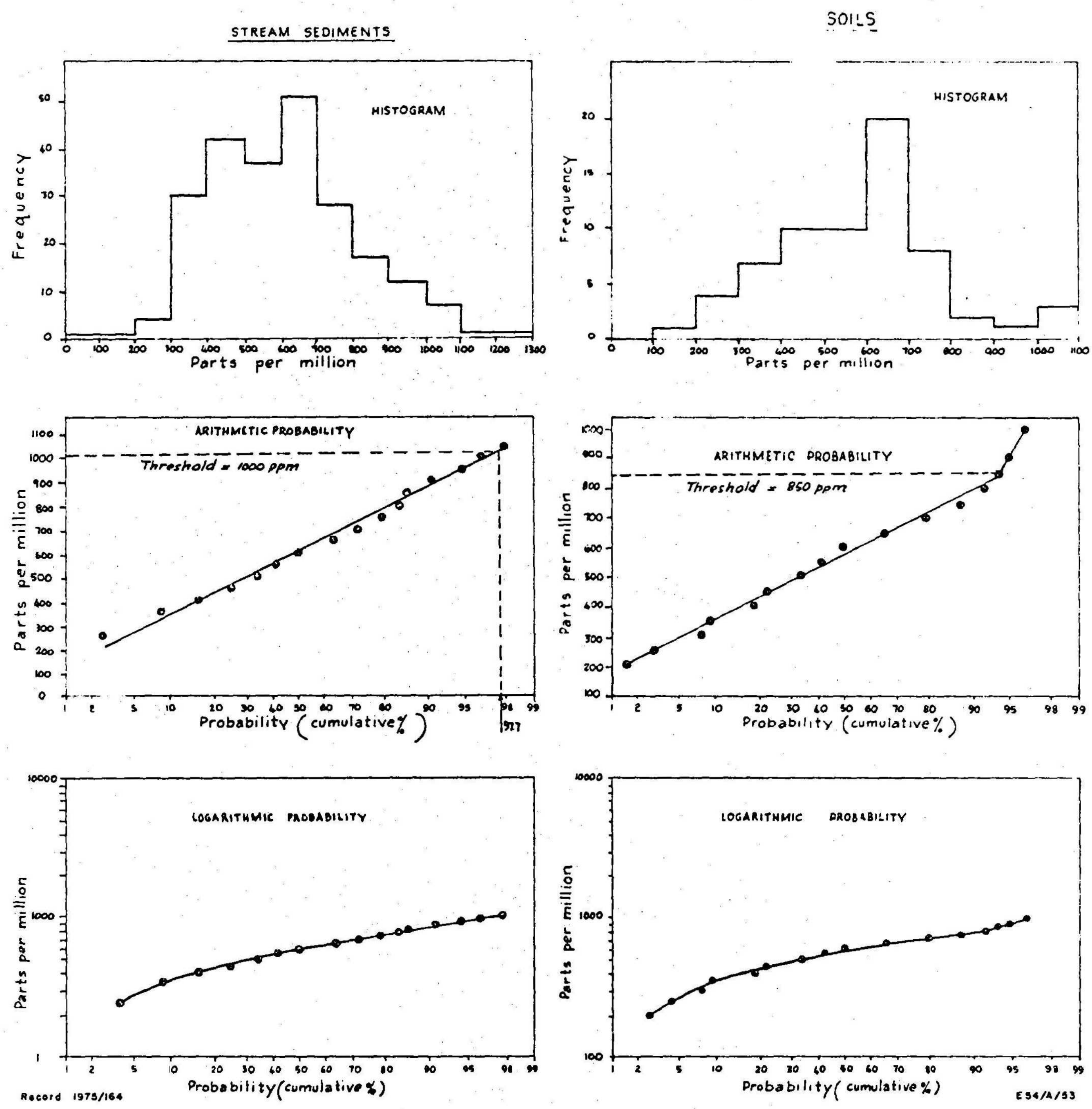

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Fig. 26 : Distribution of barium in stream sediments and soils.

The release of lithium during weathering depends on the mineral species in which the element is present. Lithium occurring in a resistant mineral such as tourmaline is obviously rather immobile but during the weathering of less resistant minerals like micas substantial amounts of lithium may go into ionic solution. The leaching of this element is especially efficient when chloride is abundant (Rankama & Sahama, 1950). The dissolved lithium may be adsorbed by the clay minerals (Heier & Billings, 1972) and perhaps the organic matter of soils and stream sediments. It is likely that lithium is being dispersed by both mechanical and chemical processes in the Georgetown region.

Beryllium is more immobile than lithium during weathering as beryl and the other common beryllium minerals are all very insoluble. Any beryllium released from feldspars and micas is very rapidly fixed on clay minerals (Hormann, 1969). It is likely, then, that the dispersion of this element is dominantly mechanical.

The distribution of lithium and beryllium in the stream sediments and soils of the Georgetown area is shown in histogram and probability cumulative frequency form in Figures 27 and 28 respectively. All distributions approximate closely to single lognormal populations. Thresholds as defined using graphically estimated geometric means and deviations are 20 ppm lithium and 5 ppm beryllium in both media.

Thorium The tendency of thorium to be incorporated in silicate and phosphate minerals (notably zircon and monazite) reduces its concentration relative to uranium in late-stage magmatic fluids (Rogers & Adams, 1969). It is not surprising therefore that many hydrothermal uranium deposits, including the Maureen prospect, have no significant thorium associated with them. Hence thorium is unlikely to prove a useful pathfinder element during uranium exploration in the Georgetown area - the apparent correlation existing between thorium and uranium (Table 7) can be attributed to detrital monazite, zircon, etc. in the stream sediments. The usefulness of thorium analyses in assessing whether a high uranium value is due to mineralization or to the rare-earth phosphate has already been referred to (p. 18). Values greater than 120 ppm thorium are considered to indicate the presence of monazite in a stream-sediment sample (Fig. 29).

Cerium The large ionic size of cerium and other rare earth elements

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such as yttrium and lanthanum precludes their entry into the lattices of early-crystallizing silicates and they are concentrated late in the igneous differentiation process. Granites and pegmatites are sometimes greatly enriched in these elements.

Although minor xenotime (YPO_4) is found in the Georgetown region, cerium, yttrium, and lanthanum occur mainly as the very resistant mineral monazite and so dispersion of these elements is dominantly mechanical. Cerium contents of several per cent are encountered in some Georgetown heavy-mineral concentrates. Enough of the monazite, however, is sufficiently fine-grained for high cerium values to be recorded in sieved samples also.

The distribution of cerium in the stream sediments of the area is shown in histogram and cumulative frequency form in Figure 30. Two populations can be distinguished - one representing monazite-free sediments and the other monazite-bearing. The log-probability plot shows that the discontinuity between the two populations occurs at 100 ppm cerium. This value can therefore be used to decide whether the cerium content of a certain sample is likely to be due to monazite or not. In soils a threshold value of 150 ppm can be used.

Rubidium It was considered worthwhile during the initial stages of the program to analyze soils and stream sediments for Rb as this element is often enriched in pegmatites, greisens, and potassic alteration zones associated with mineralization (Boyle, 1974). The only anomalous rubidium values (greater than 300 ppm - Fig. 31) obtained during the survey occur in stream sediments near the Eva Creek tin lodes (Fig. 18). High beryllium, cerium, lithium, thorium, tin, tungsten, and uranium are also recorded in the same area. It appears unlikely that rubidium will provide any information additional to that given by these other elements and its use during future surveys in the region does not seem justified.

Multivariate techniques

Multivariate statistical techniques are those which consider more than one variable (or element) simultaneously. The interrelation between two or more variables may be quantified by the use of Pearson correlation coefficients. These values for 20 elements have been calculated for 232 Georgetown stream-sediment samples and are shown in Table 7. As indicated in preceding sections and summarized in Table 9, the various

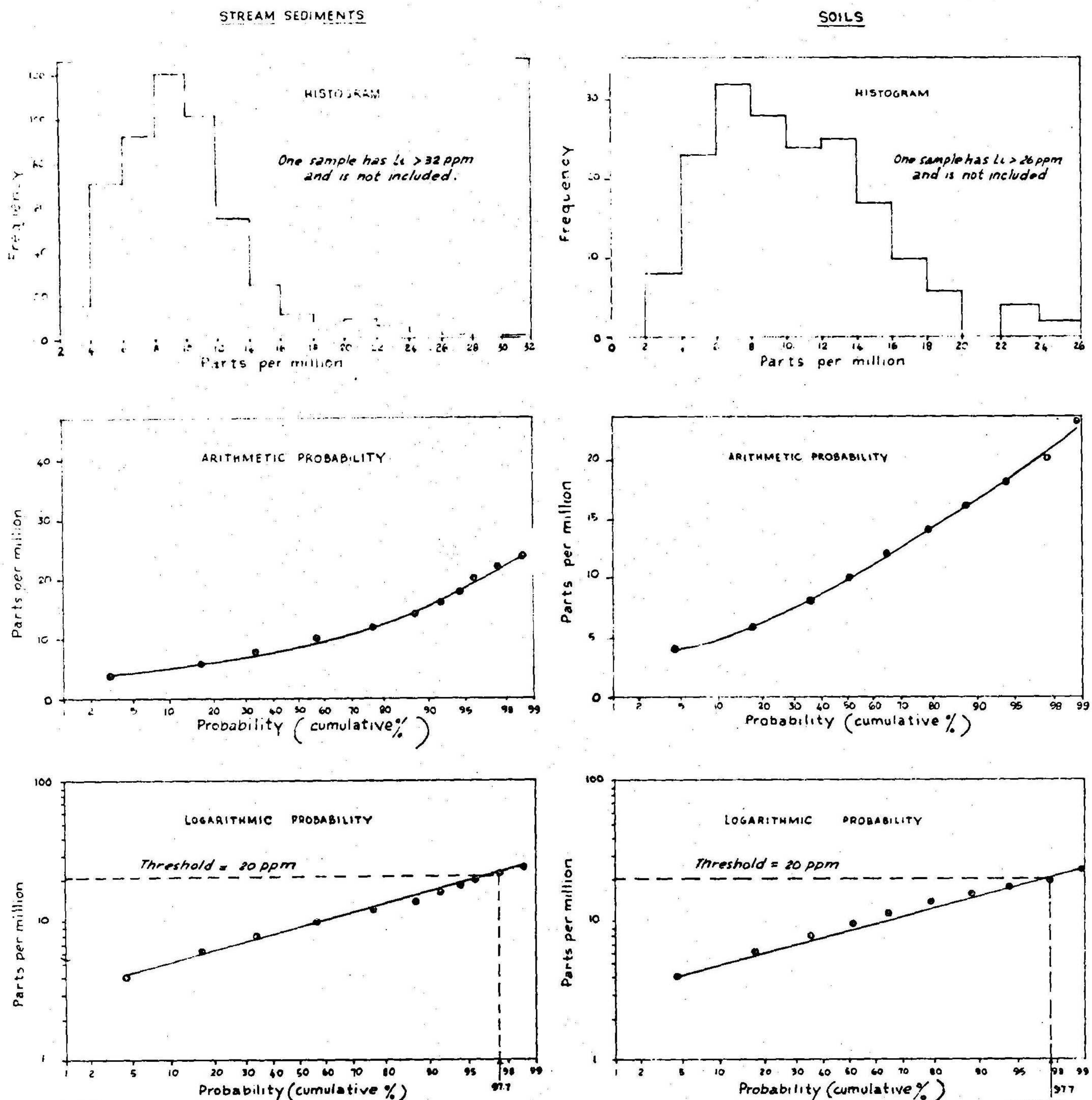

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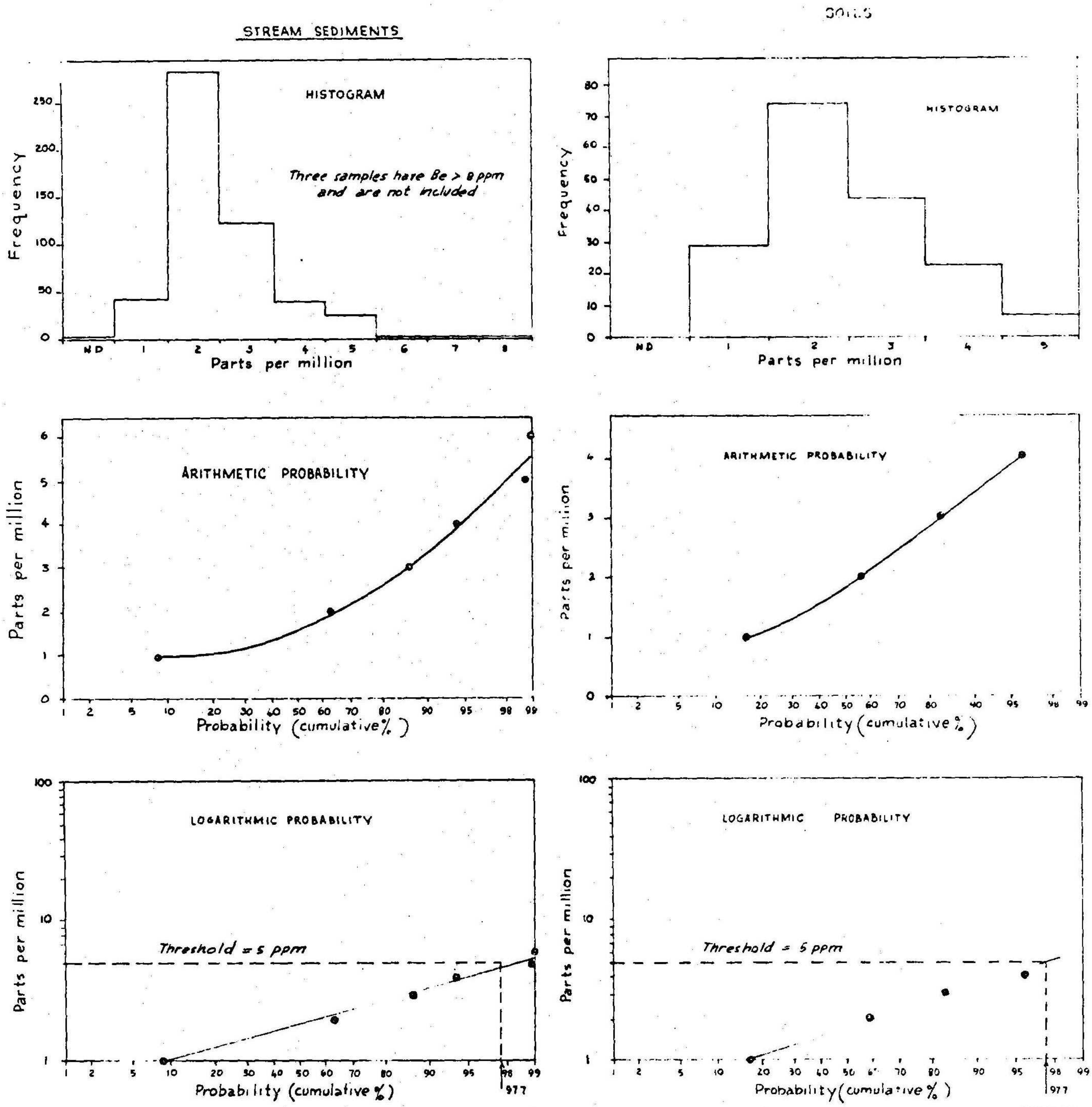
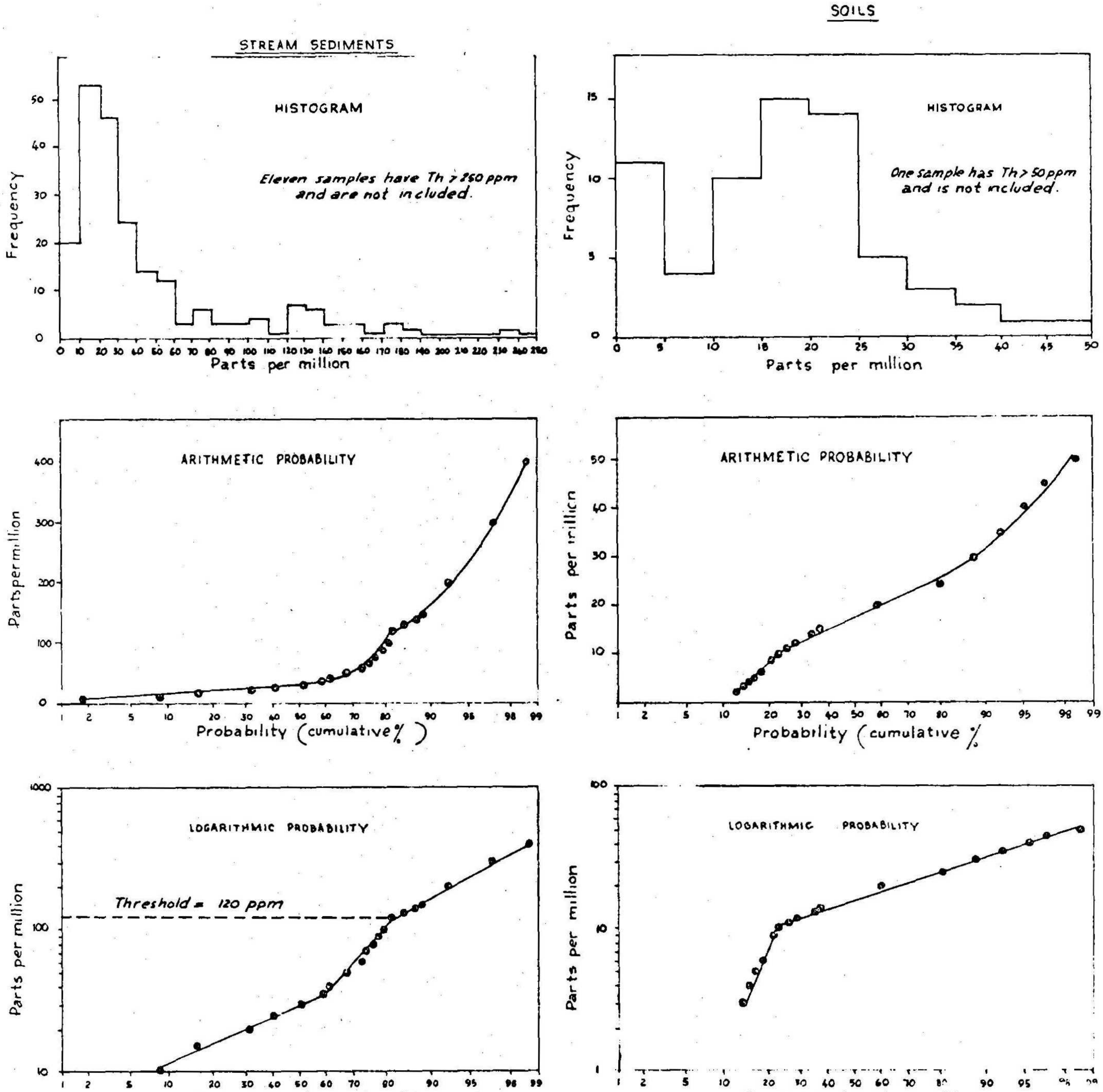
Fig. 27: Distribution of lithium in stream sediments and soils



Record 1975/164

E 54/A/55

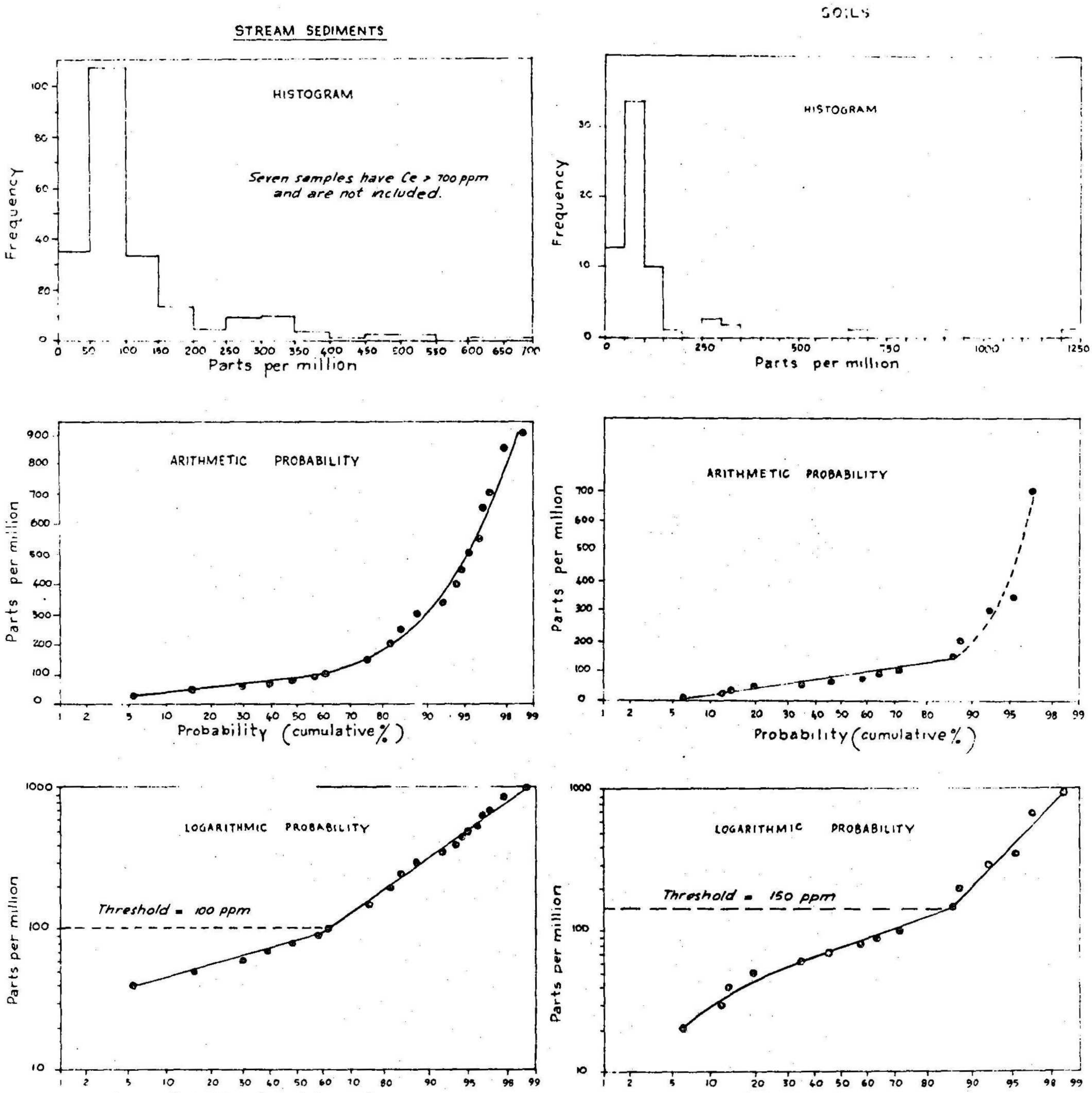
Fig. 28 : Distribution of beryllium in stream sediments and soils



Record 1975/164

E54/A/56

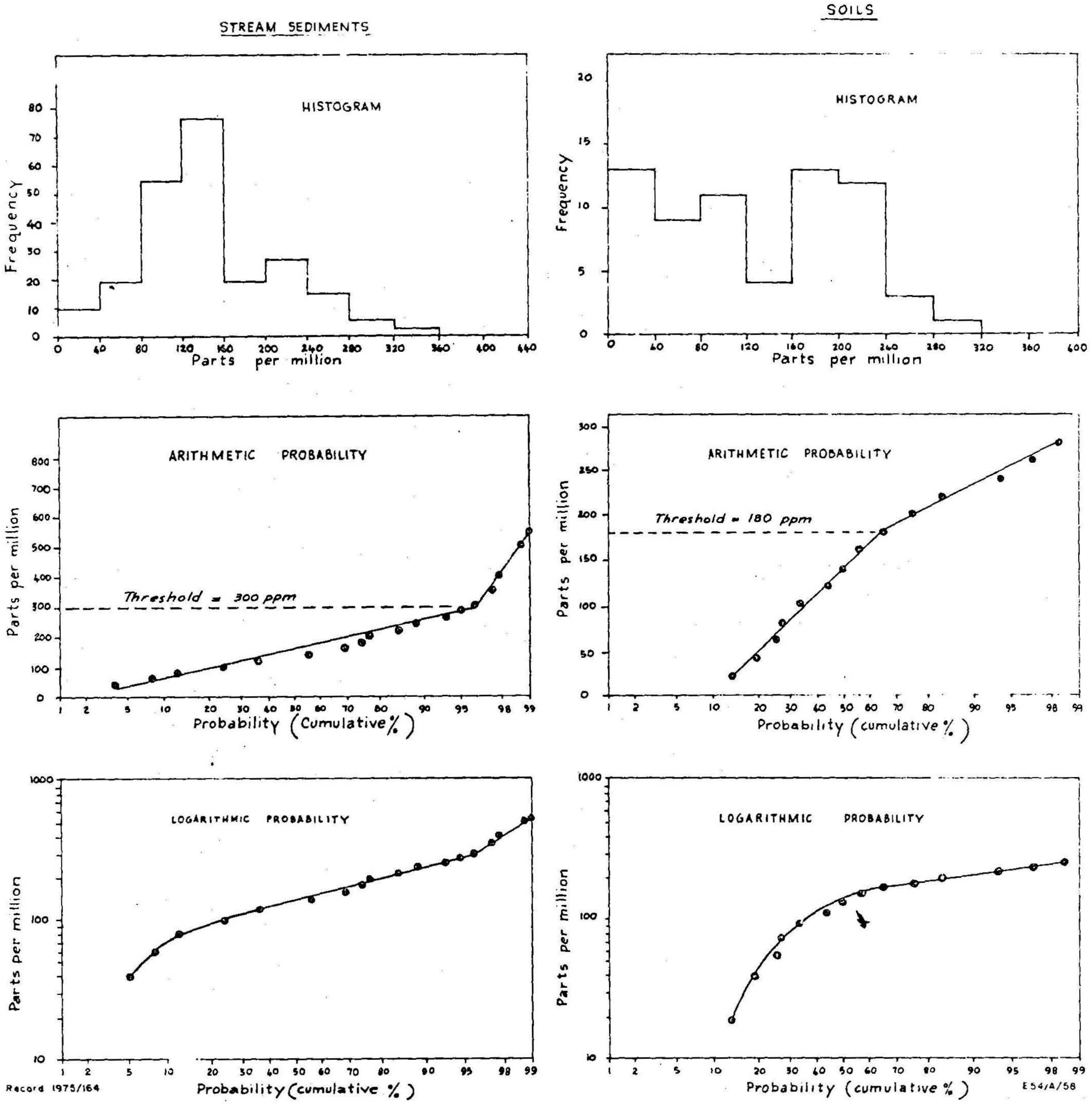
Fig 29 : Distribution of thorium in stream sediments and soils



Record 1975/164

E54/A/57

Fig. 30 : Distribution of cerium in stream sediments and soils



Record 1975/164

E54/A/58

Fig. 31 : Distribution of rubidium in stream sediments and soils

distributions of elements in the study area have a combination of both normal and lognormal affinities. Consequently correlation coefficients are computed from both raw and logarithmically transformed data. A correlation is not considered meaningful unless the coefficient is statistically significant for both raw and logarithmic values.

Significant interrelations between elements have already been mentioned in the discussions of the various metals and are indicated by asterisks in Table 7. It should be remembered that the correlation coefficient is a purely mathematical concept and great care must be exercised when attaching cause and effect implications to it. For example, the correlation between zinc and manganese might be interpreted as indicating adsorption of zinc by secondary manganese compounds in the stream sediments. A more likely explanation for the correlation, however, is that both elements are associated in detrital ferromagnesian minerals (p. 20). It should also be borne in mind that the correlation coefficients give an overall picture in that they are calculated for the total stream-sediment data; locally important correlations (e.g. the association of two elements on the scale of a single ore deposit) are sometimes hidden. Thus, although a strong relation exists between uranium and arsenic at the Merryl prospect (Fig. 6), the total data correlation coefficient for these two elements is not statistically significant (Table 7).

The interrelation of elements can also be studied by means of R-mode factor analysis. This technique generates a set of new variables (or factors), of which a few can usually represent most of the variance in a collection of data. Generally any elements showing covariation (either sympathetic or antipathetic) are combined in the one factor. Thus, 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 from a set of data are emtremely complex and will not be gone into in any depth here. Initially the Pearson correlation coefficients are calculated and expressed as vectors arranged 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). A simplified geometric illustration of these procedures is shown in Figure 32. 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.

The results of two factor analyses for the Georgetown stream sediments are shown in Table 8. The first matrix is calculated from the raw data. Although many different factor models have been investigated, that utilizing 8 factors proves to be the most easily interpretable on geological and geochemical grounds*. The 8-factor matrix for logarithmically transformed data is more difficult to explain - for example, it is difficult to assign geological significance to the association of copper, zinc, tin, and tungsten in Factor 4. For logarithmic values it is only when a 9-factor model is used that easily-accounted-for factors result. As the basic aim of factor analysis is to reduce the complexity of a set of data, it is considered preferable to adopt an 8-factor raw data model rather than a 9-factor logarithmic one. The 8-factor raw data matrix is interpreted as follows:

Factor 1: high loadings of Be, Li, Rb, Sn - may be described as a 'pegmatitic' factor, high positive factor scores are observed in areas of pegmatite and fractionated granitic rocks

Factor 2: -Co, -Mn, Ba, (Rb) - a lithological factor, high positive scores occur near granitic rocks, high negative scores are associated with basic rocks.

Factor 3: -Ag, -Cu, -Pb, -S - a mineralization factor, high negative scores are found near base-metal deposits.

Factor 4: -Ce, -Th, -U, (-W) - may be termed a 'monazite' factor, high negative scores are associated with monazite-bearing granites.

Factor 5: -Cd, -Cu, -Zn - a mineralization factor, high negative scores occur near base-metal deposits.

Factor 6: -Ba, Sn, W - a mineralization factor, high positive scores are associated with tin-tungsten mineralization.

Factor 7: -As - a mineralization factor, high negative factor scores are encountered near uranium mineralization.

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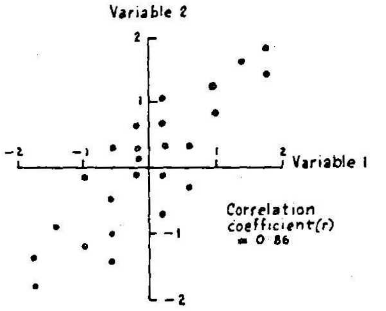
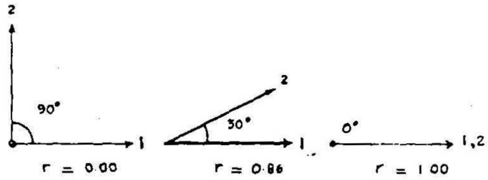
* The choice of the number of factors to be used is somewhat subjective. Although alternative procedures have been suggested it has become established practice in the interpretation of geochemical surveys 'to employ as many factors as are necessary to simplify the data to a predetermined degree of geochemical simplicity, or alternately use as many factors, as one can confidently interpret in terms of the local geochemistry' (Garrett & Nichol, 1969).

REPRESENTATION OF CORRELATION COEFFICIENTS AS VECTORS

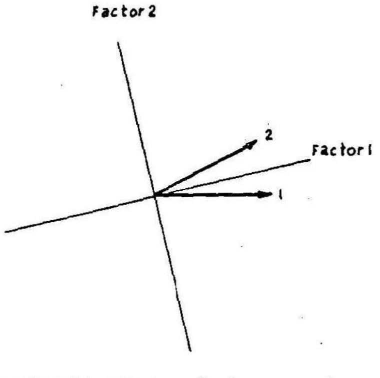


Scattergram showing interrelation of two variables. The data have been standardized by subtracting from each observation the mean of the data set and dividing by the standard deviation. The transformed variables have zero mean and unit variance

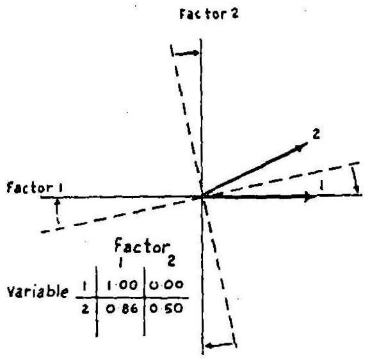


Representation of correlation coefficients as vectors. The cosine of the angle between the two vectors equals the coefficient.

R-MODE FACTOR ANALYSIS : SIMPLE TWO-FACTOR MODEL

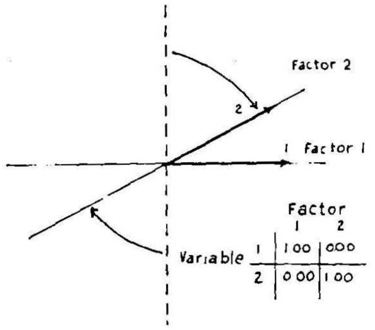


Factors 1 and 2 are coordinate axes superimposed on the vectors representing the correlation coefficient between the two variables. In actual examples the initial positions of the factor axes depend on the computational procedure used. The diagram shows the principle conponent solution which is the most commonly employed.



Variable	Factor 1	Factor 2
1	1·00	0·00
2	0·86	0·50

Following orthogonal (Varimax) rotation, Vector 1 can be expressed in terms of Factor 1 alone. Vector 2 still has finite projections (loadings) on both Factor 1 and Factor 2. The factor matrix is shown



Variable	Factor 1	Factor 2
1	1·00	0·00
2	0·00	1·00

Following oblique (Promax) rotation, Vector 1 can be expressed soley in terms of factor 1 and Vector 2 in terms of Factor 2 only. This example reduces so simply because the number of correlation vectors does not exceed the number of factors — normally there is a large excess.

Fig. 32: Geometric model illustrating the basic principles of R-mode factor analysis

TABLE 7. PEARSON CORRELATION COEFFICIENTS FOR 232 STREAM SEDIMENT SAMPLES ANALYSED FOR 20 significant at the 99% confidence level. Asterisks indicate positive correlations

	Ag	Be	Cd	Co	Cr	Cu	Li	Mn	Ni	Pb
Ag		0.01	0.28	0.25	0.30	0.33*	0.27	0.11	0.24	0.53*
Be	-0.01		0.03	-0.05	-0.15	-0.12	0.49*	-0.18	-0.16	0.25
Cd	0.04	0.15		0.25*	0.35*	0.21*	0.21*	0.21	0.32*	0.43
Co	0.03	-0.13	0.25*		0.76*	0.08	0.32*	0.77*	0.86*	0.07
Cr	0.07	-0.12	0.38*	0.64*		0.06	0.21	0.61*	0.88*	0.18
Cu	0.44*	-0.08	0.18*	-0.07	-0.02		0.09	-0.09	-0.03	0.41*
Li	0.12	0.65*	0.30*	0.19*	0.11	0.00		0.04	0.21	0.24
Mn	-0.02	-0.20	0.16	0.75*	0.37*	-0.12	-0.05		0.68*	-0.06
Ni	0.05	-0.15	0.39*	0.75*	0.94*	-0.03	0.10	0.45*		0.08
Pb	0.88*	-0.01	0.14	-0.02	0.14	0.51*	0.04	-0.05	0.11	
Zn	0.08	-0.07	0.62*	0.38*	0.56*	0.21*	0.14	0.25*	0.65*	0.17
As	-0.11	-0.13	0.01	-0.01	-0.05	-0.10	0.02	-0.12	0.00	-0.08
Ba	-0.10	-0.12	0.12	-0.29	-0.20	-0.10	-0.24	-0.16	-0.22	-0.17
Cs	0.04	0.28*	0.22	-0.05	-0.09	0.03	0.12	0.01	-0.12	0.03
Rb	-0.09	0.84*	0.03	-0.40	-0.27	-0.06	0.50*	-0.43	-0.34	-0.07
S	0.80*	0.07	0.10	0.00	-0.02	0.45*	0.21*	-0.04	-0.03	0.82*
Sn	-0.06	0.62*	0.01	-0.11	-0.05	-0.04	0.35*	-0.12	-0.06	-0.01
Th	0.01	0.43*	0.16	-0.18	-0.15	-0.10	0.16	-0.13	-0.20	0.01
U	-0.03	0.66*	0.13	-0.23	-0.18	-0.13	0.32*	-0.22	-0.23	0.00
W	-0.06	0.53*	0.03	-0.16	-0.13	0.12	0.24	-0.20	-0.14	0.01

Raw

ELEMENTS. For this number of samples a coefficient of greater than 0.17 is statistically
etween elements that are significant for both raw and logarithmically transformed data.

Zn	As	Ba	Ce	Rb	S	Sn	Th	U	W
0.32	-0.08	-0.09	0.00	-0.21	0.50*	-0.15	-0.07	-0.07	-0.03
-0.09	-0.12	-0.05	0.52*	0.71*	0.18	0.32*	0.58*	0.59*	0.27*
0.58*	-0.03	-0.16	0.05	-0.17	0.13	-0.03	-0.03	-0.06	0.06
0.52*	0.05	-0.16	-0.07	-0.47	0.16	-0.18	-0.28	-0.28	-0.18
0.49*	0.00	-0.01	-0.15	-0.49	0.12	-0.20	-0.36	-0.35	-0.28
0.60*	-0.09	-0.14	-0.13	-0.12	0.27*	0.19	-0.16	-0.17	0.23
0.24	0.11	-0.29	0.19	0.31*	0.36*	0.22*	0.19	0.28*	0.16
0.44*	-0.09	-0.02	-0.06	-0.54	0.00	-0.20	-0.28	-0.31	-0.30
0.47*	0.12	-0.05	-0.23	-0.55	0.10	-0.26	-0.43	-0.40	-0.28
0.53	-0.22	-0.23	0.17	0.01	0.50*	0.09	0.22	0.16	0.12
	-0.07	-0.23	-0.12	-0.34	0.18	0.14	-0.26	-0.27	0.06
-0.01		0.01	-0.17	-0.04	-0.19	-0.09	-0.13	-0.02	0.14
-0.19	-0.03		-0.03	0.06	-0.16	-0.39	-0.05	-0.11	-0.24
-0.01	-0.10	-0.12		0.48*	0.14	0.15	0.81*	0.70*	0.36*
-0.19	-0.10	-0.10	0.22*		-0.04	0.39*	0.69*	0.71*	0.26*
0.03	-0.08	-0.13	0.12	0.00		0.03	0.06	0.07	0.10
-0.02	-0.04	-0.33	0.01	0.62*	-0.02		0.21	0.24*	0.39*
-0.11	-0.12	-0.10	0.76*	0.42*	0.05	0.08		0.87*	0.33*
-0.13	0.04	-0.19	0.60*	0.66*	0.03	0.34*	0.85*		0.39*
-0.03	0.21	-0.24	0.36*	0.47*	0.03	0.52*	0.40*	0.60*	

Logarithmically
transformed
data.

data

TABLE 8. FACTOR MATRICES FOR

1. Raw data

Factor no.	1	2	3	4	5	6	7	8
Ag	0.05	0.03	-1.00	-0.03	0.12	-0.06	0.01	-0.09
Be	0.84	0.05	-0.02	-0.11	-0.02	0.08	0.11	0.02
Cd	0.28	-0.01	0.12	-0.18	-0.86	-0.19	-0.05	-0.16
Co	0.12	-0.83	-0.01	0.02	0.03	0.16	-0.03	-0.29
Cr	-0.08	0.00	-0.10	0.01	-0.06	0.00	0.05	-0.94
Cu	-0.19	0.12	-0.31	0.14	-0.57	0.29	0.12	0.28
Li	1.04	-0.28	-0.15	0.15	-0.22	-0.09	-0.13	0.12
Mn	-0.02	-1.00	0.10	-0.09	0.05	0.18	0.13	0.05
Ni	-0.08	-0.12	-0.05	0.05	-0.10	0.05	-0.01	-0.88
Pb	-0.07	0.17	-0.96	-0.03	0.01	0.05	0.01	-0.19
Zn	-0.03	0.10	0.10	0.04	-0.69	0.03	0.02	-0.50
As	-0.05	0.14	0.00	0.10	0.00	0.09	-0.98	0.04
Ba	0.05	0.48	0.06	0.05	-0.05	-0.84	0.04	0.02
Ce	-0.14	-0.20	-0.01	-0.96	-0.17	0.02	0.07	0.12
Rb	0.67	0.32	0.05	-0.07	0.01	0.10	0.13	0.05
S	0.18	-0.08	-0.94	-0.04	0.02	-0.04	-0.03	0.11
Sn	0.44	0.08	0.10	0.24	0.12	0.64	0.13	-0.09
Th	-0.04	0.02	-0.04	-0.99	0.01	-0.05	0.08	-0.03
U	0.21	0.12	-0.03	-0.75	0.07	0.12	-0.07	-0.05
W	0.04	0.16	0.06	-0.31	-0.03	0.61	-0.24	-0.01
Eigenvalues (cum %)	24.2	42.5	57.1	65.7	71.9	77.8	82.5	86.2
Principal Loadings	Be Li Rb Sn	-Co -Mn Ba (Rb)	-Ag -Cu -Pb -S	-Ce -Th -U (-W)	-Cd -Cu -Zn	-Ba Sn W	-As	-Cr -Ni -Zn

232 STREAM SEDIMENTS.

2. Logarithmically transformed data

1	2	3	4	5	6	7	8
0.03	0.80	–0.03	0.07	–0.05	0.03	0.05	0.09
–0.29	0.04	0.12	–0.03	0.07	0.14	0.66	0.04
0.01	–0.15	0.09	–0.05	–0.10	–0.11	–0.02	1.01
–1.02	0.05	0.08	0.04	–0.04	–0.03	0.18	–0.13
–0.78	0.03	–0.07	–0.04	–0.01	0.08	0.18	0.14
0.12	0.22	–0.21	0.92	0.04	0.22	–0.05	0.01
–0.15	0.26	–0.05	–0.06	–0.23	–0.14	0.83	–0.04
–1.01	–0.15	0.18	–0.05	0.19	–0.02	–0.10	–0.07
–0.86	0.01	–0.11	–0.11	–0.12	0.01	0.18	0.07
0.22	0.47	0.14	0.16	0.16	–0.07	0.06	0.52
–0.36	–0.08	–0.11	0.55	0.06	0.02	0.06	0.45
0.05	–0.10	–0.12	0.01	–0.95	0.05	0.11	0.08
0.02	–0.11	0.05	0.22	–0.03	1.06	0.07	–0.15
–0.26	0.04	1.05	0.02	0.11	0.08	–0.07	–0.01
0.46	–0.16	0.27	–0.03	0.02	0.19	0.59	–0.01
–0.01	0.90	0.05	0.12	0.13	–0.10	0.16	–0.31
0.12	–0.30	–0.11	0.36	0.19	–0.39	0.35	–0.11
0.10	0.00	0.90	–0.12	0.08	0.02	0.06	0.12
0.12	0.02	0.81	–0.14	–0.05	–0.05	0.15	0.07
0.02	–0.01	0.51	0.61	–0.34	–0.12	–0.17	–0.11
27.9	46.9	57.4	65.2	71.0	76.3	80.8	84.7
–Co –Cr –Mn –Ni (–Zn) Rb	Ag Pb S (–Sn)	Ce Th U W	Cu Zn (Sn) W	–As (–W)	Ba (–Sn)	Be Li Rb (Sn)	Cd Pb Zn (–S)

Factor 8: -Cr, -Ni, -Zn - a lithological factor, high negative scores are associated with basic rocks, high positive scores occur in areas of granitic rocks.

These 8 factors account for 86.2 percent of the total variance in the data. The 8-factor raw data analysis is successful in that a relatively small number of easily interpretable factors emerge. Factors 3, 5, 6, and 7 are obviously the critical ones from an exploration viewpoint. Whether or not factor analysis will prove a more sensitive tool than visual data examination and simple statistics during regional surveys in the Georgetown area remains to be seen. At this stage, no instance can be cited where factor analysis detects an anomaly overlooked by the other methods.

CONCLUSIONS

The questions posed during the planning of this survey (p. 9) can now be answered:

1. Both stream-sediment samples sieved to the optimum grainsize of minus 180 μm (85 mesh BSS) and heavy-mineral concentrates are useful and where possible both should be collected.

2. It matters little what part of the stream is selected for sampling; alluvial bank samples compare quite closely geochemically with more active sediment taken from the stream channel.

3. The errors associated with the sampling and analytical procedures used here are small and are unlikely to obscure important regional geochemical variations.

4. Statistical analysis of the stream sediment data for each element usually indicates the presence of two populations, one background and one anomalous (Table 9). The copper distribution is an exception as dissimilar levels of this element in basic rocks on the one hand and siliceous rocks on the other, lead to two background populations. The same is true of lead and there are indications that uranium and thorium background values are also bimodally distributed. The distributions of most elements have lognormal affinities and threshold values for these are defined from logarithmic cumulative frequency plots (Table 9). The data for lead and tungsten closely approximate combinations of normal distributions, however, and thresholds for these elements are obtained from arithmetic cumulative

frequency diagrams. Barium, beryllium, cobalt, chromium, lithium, and nickel each approximate unimodal behaviour and consequently a threshold for each is estimated in terms of mean and standard deviation. The barium distribution is normal in character and so the simple arithmetic mean and standard deviation are adequate. The remainder of these elements show lognormal tendencies and geometric means and deviations are considered more appropriate.

5. The characteristics of the geochemical anomalies associated with the major mineralization types of the area are summarized in Table 10. Chemical analysis of stream-sediment samples sieved to minus 180 μm is found to be efficient in delineating all types of deposit studied. For the detection of gold lodes it is convenient to use pathfinder elements such as copper, lead, and zinc. Other elements proving useful pathfinders in particular applications are listed in Table 10. The suitability of heavy-mineral sampling in prospecting for the various kinds of mineralization is also indicated. Geochemical anomalies commonly extend for several kilometres downstream from mineral deposits (see Figs. 9, 12, and 18). During a regional stream-sediment survey in the Georgetown region a sample spacing of 2-3 km along each stream should thus detect most major near-surface mineralization. Sampling of major streams proves rather ineffective owing to the dilutant effect of the very large volume of sediment transported.

6. Soil anomalies, although understandably more limited in area, compare quite closely with those in the associated stream sediments and threshold values are very similar in both media.

TABLE 9. NATURE OF ELEMENTAL DISTRIBUTIONS AND THRESHOLD VALUES FOR STREAM SEDIMENTS OF THE GEORGETOWN REGION. Thresholds refer to samples sieved to minus 180 μ m, and should be used only as a guide except in surveys using exactly identical analytical techniques to those followed here.

Element	Characteristics of the distribution	Threshold (ppm) and how defined
Manganese	Background population lognormal, anomalous population normal/lognormal	800 LCF
Uranium	Three lognormal populations ?	12 "
Copper	One normal/lognormal population followed by a lognormal population, then high values normally distributed	Basic rocks 150 LCF Siliceous " 60 LCF
Zinc	Two lognormal populations	150 LCF
Cadmium	Not known	1? E
Lead	Low values normally distributed, then two other normal/lognormal populations	140*ACF
Silver	Background lognormal, anomalous normal/lognormal	4 LCF
Molybdenum	Not known	5? E
Tin	Background lognormal, anomalous normal/lognormal	20 LCF
Tungsten	Background normal, anomalous normal	14 ACF
Fluorine	Not known	—
Arsenic	Background lognormal, anomalous normal	8 LCF
Cobalt	Single lognormally distributed population	30 GMS
Nickel	Background lognormal, anomalous ill-defined	45 GMS, 50 LCF
Chromium	" " " "	150 " 200 "
Sulphur	Two complex populations	1200 LCF
Barium	Single normally distributed population	1000 AMS
Lithium	" lognormally " "	20 GMS
Beryllium	" " " "	5 "
Thorium	One normal/lognormal population, then two lognormal populations	120 LCF
Cerium	Background normal/lognormal, anomalous lognormal	100 "
Rubidium	Background normal, anomalous normal/lognormal	300 ACF

Complex – distribution not adequately described by either normal or lognormal models

Normal/lognormal – distribution adequately described by either normal or lognormal models

LCF – logarithmic cumulative frequency plot

ACF – arithmetic " " "

GMS – graphically estimated geometric mean times geometric deviation squared

AMS – " " arithmetic " plus two standard deviations

E – empirical

* – a lower value might apply in sediments derived from basic rocks.

TABLE 10. APPLICATION OF STREAM-SEDIMENT PROSPECTING TO THE DETECTION OF THE MAJOR MINERALIZATION TYPES OF THE GEORGETOWN REGION.

Element	Type of deposits	Useful associated elements	Applicability of heavy mineral technique
Uranium	Hydrothermal veins and replacements	Arsenic, (see Table 9 for thresholds). Possibly flourine and molybdenum. Cerium and thorium contents exceeding 100 ppm and 120 ppm respectively indicate monazite	Examination of heavy-mineral samples by microscope is useful in deciding whether a high uranium value is due to mineralization or monazite
Copper	Hydrothermal veins and replacements	Lead, zinc	Examination by microscope of heavy-mineral samples for malachite
	Porphyries	Molybdenum. Possibly zinc	-
Zinc	Hydrothermal veins and replacements	Copper, lead. On rare occasions chromium, nickel	-
Lead	Hydrothermal veins	Copper, silver, sulphur, zinc	Chemical analysis of heavy-mineral samples
Tin	Hydrothermal veins	Beryllium, lithium, tungsten. Possibly arsenic, bismuth, molybdenum,	Examination by microscope of heavy-mineral samples for cassiterite
Gold	Hydrothermal veins	Copper, lead, zinc where the veins are sulphide-rich. Possibly bismuth	Examination by microscope of heavy-mineral samples for detrital gold
	Disseminated deposits e.g. in breccia pipes	Possibly arsenic	"

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