

**COMPARISON OF TOTAL AND COLD-EXTRACTABLE URANIUM IN STREAM
SEDIMENTS OF THE SOUTHWESTERN KAROO SUPERGROUP, SOUTH AFRICA**

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ATOMIC ENERGY BOARD
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PRETORIA
Republic of South Africa

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SAMEVATTING

Die Raad op Atoomkrag het tien oriënteringstudies in samewerking met die Geologiese Opname van Suid-Afrika naby bekende mineralisering uitgevoer met die doel om die nuttigheid van koudeksraaerbare uraan as 'n middel om uraanprospektering in stroomsedimente van die suidwestelike Karoo, Suid-Afrika, te evalueer. Die studies het aangedui dat die topografie die aard van die verspreiding bepaal. In gebiede met middelmatige of hoë reliëf gee die totale uraaninhoud van die stroomsediment 'n verspreiding tot ongeveer 500 m vanaf die mineralisering, en spits-tot-agtergrondverhoudings van ongeveer 3. Die gebruik van koudeksraaerbare uraan verdubbel die verspreidingsafstand, en spits-tot-agtergrondverhoudings is hoër as 10 en kan tot 35 styg.

In gebiede met lae reliëf, het die totale uraaninhoud van die sediment lae anomalieë tot gevolg, met beperkte stroomafwaartse verspreiding. Koudeksraaerbare uraan vorm anomalieë 500 tot 1 000 m vanaf die mineralisering. Die langer verblyftye van die kleimineraal in die stroom word as die rede hiervoor beskou.

Om die toepaslikheid van koudeksraaerbare uraan op 'n streekgrondslag te toets, is 720 monsters met 'n digtheid van een per vierkante kilometer versamel. Statistiese behandeling van die gegewens toon dat die U-inhoud van die stroomsedimente log-normaal versprei is. Vir koudeksraaerbare uraan kan polimodale verspreidings wat blykbaar agtergrond- en anomalieë monsters verteenwoordig, met 'n hoë mate van welslre geskei word, en kan betekenisvolle drumpelwaardes toegeken word. Dit is nie die geval met die totale uraaninhoud van die stroomsedimente nie.

ABSTRACT

In order to evaluate the usefulness of cold-extractable uranium as a tool of uranium prospecting in stream sediments of the southwestern Karoo, South Africa, ten orientation studies were conducted near known mineralisation jointly by the Atomic Energy Board and the Geological Survey of South Africa. These indicate that the topography determines the nature of the dispersion. In areas of moderate to high relief the total uranium content of the stream sediment gives dispersion trains up to about 500 m from the mineralisation, and peak-to-background ratios of about 3. The use of cold-extractable uranium doubles the length of the dispersion, and peak-to-background ratios are greater than 10 and may be as high as 35.

In areas of low relief, the total uranium content of the sediment gives low anomalies, with short dispersion downstream. Cold-extractable uranium gives anomalies 500 - 1 000 m from the mineralisation. This is interpreted to be due to the longer residence time of the clay minerals in the stream.

In order to test the applicability of cold-extractable uranium on a regional scale, 720 samples were collected at a density of one sample per square kilometre. Statistical treatment of the data shows the U content of the stream sediments to be log-normally distributed. For cold-extractable uranium, polymodal distributions, apparently representing background and anomalous samples, can be separated with a high rate of success, and meaningful threshold values can be assigned. This is not the case for the total uranium content of the stream sediments.

1. INTRODUCTION

1.1. Geochemical Considerations

Uranium occurrences in the southwestern Karoo sediments are almost always restricted to impure sandstone lenses in palaeochannels of the Permian Beaufort Group. Bands and lenses of sandstone and mudstone alternate over large vertical thicknesses. The mineralisation is invariably associated with organic carbon or carbonates and often with base metal sulphides.

At a first glance large parts of the Southwestern Karoo seem to comprise extremely unfavourable conditions for geochemical exploration. Monoclinical folds, which trend E-W and are several kilometres apart, often give rise to flat-lying sediments. Only a small vertical thickness of the succession may therefore be exposed over several square kilometres. The presence of impermeable mudstone bands may prohibit the development of large dispersion halos. Soil-geochemical exploration would therefore be restricted to surface or near-surface ore. On exposure the mudstones become extremely friable and readily disintegrate. This may give rise to large dilutions of the soil or the often only weakly developed streams. In flat areas the stream drainage patterns may often be insufficient for detailed sampling.

1.2 Secondary Dispersion

Despite the abovementioned unfavourable geochemical environment, analysis of the fine fraction of stream sediments has proved useful on several occasions, especially near the escarpment where streams are generally well developed and dilution from disintegrating mudstone is not extreme. Downstream dispersion of uranium is, however, short, and reasonably dense sampling is required. Pathfinder elements such as copper, molybdenum or arsenic have to date not proved to be as useful as uranium itself for delineating ore targets.

The most widespread primary uranium minerals in the Karoo sediments are uraninite and coffinite. These can give rise to secondary dispersion patterns in stream sediments in several ways. Firstly, when discrete unoxidized mineral grains are released into the stream, dispersion is entirely mechanical and the mineralised grains would be concentrated in the heavy mineral fraction of the sediment. Secondly, by oxidation of uranium from the insoluble (+ IV) valent to the soluble (+ VI) valent state, which takes place readily above the water table. This oxidation process is generally completed when the uranium mineralisation within the relatively resistant sandstone is released into the stream system. The oxidized uranium may 1) be occluded in secondary minerals, 2) be adsorbed onto clay minerals, 3) be co-precipitated, occluded or sorbed by hydrous oxides of iron or manganese, 4) form organometallic complexes with the organic material invariably present in the ore body. Alternatively, the oxidized uranium may be transported in the stream system in solution before it precipitates as a salt by one or more of the abovementioned

processes. In either case the uranium would be only weakly bonded in the lighter and smaller size fraction of the sediment, and dispersion downstream would be further than for the heavy mineral fraction.

1.3 Mobile Uranium

The oxidised uranium that is transported from the mineralised area to a locality downstream and fixed on the smaller size fraction of the stream sediments at that locality is defined as 'mobile' uranium. This will constitute only a very small fraction of the total uranium present in the sediment. The success of a geochemical approach hinges on the ability to distinguish between the uranium originating from the mineralised area (i.e. 'mobile' uranium) and the background concentration due to uranium present in a dispersed state in the silicate lattices or in the heavy mineral fraction of the sediment. Field work has shown that Karoo stream-sediment samples taken at a distance from mineralisation contain about 4 ppm total uranium, with a spread in the data that can be represented by a co-efficient of variation of 10 to 20%. This spread is due to natural sample variation and analytical errors. If the contribution of mobile uranium is not significantly larger than the natural sample variation, it would be impossible to distinguish anomalous samples from background variations, and hence even improvements in analytical precision could not make stream-sediment geochemistry, based on total uranium, a sensitive technique.

With present techniques it is impossible to determine the amount of mobile uranium present in a stream sediment. It might, however, be possible to use techniques that are more sensitive to mobile uranium, thereby enhancing this component while suppressing the background contribution. One possibility is to use readily leachable uranium as a measure of the mobile uranium.

About 5% (i.e. 0,2 ppm) of the total amount of uranium present in a stream sediment is weakly bonded and easily leached. This uranium probably originated from the *in situ* weathering of the soil itself. Exogenic addition of uranium from a source area would add to this easily extractable uranium. If, for example, only 0,3 ppm of exogenic uranium is introduced, the total uranium concentration in the stream sediment will increase from 4 to 4,3 ppm, and this change will probably not be discernable due to natural variation in background. However, the easily extractable uranium will increase from 0,2 to 0,5 ppm, i.e. by 150% – a change that could readily be detected analytically.

Partial-uranium analyses in the sediments can only be used for exploration purposes if the process of extraction is reproducible. Since this depends both on how the uranium is complexed in the sediment and on the extracting agent, it requires the use of a solvent which is equally applicable to the variety of sediments in the Karoo sequence. In addition, the method must be cheap enough to be used on a large scale and should be simple enough for analysis by unskilled laboratory personnel. A minimum sample handling is

required in order to prevent contamination at the low concentrations encountered.

Rose and Keith (1976) studied cold-extractable uranium in stream sediments which contain up to 30 % organic carbon. They employed an acetic acid-hydrogen peroxide leach to break down the uranium minerals and organic matter. Their approach cannot, however, be applied directly to the Karoo sediments since extremes of relief are found in the Karoo and the carbon content of stream sediments is generally below 1 %.

2. EXPERIMENTAL

2.1 Experimental Methods

At the Atomic Energy Board total uranium in powdered geological material is routinely determined by delayed-neutron counting on 500 mg of sample material (Smit, 1976). The sensitivity of the determination equals its precision, which is 0,25 ppm U. The Karoo sediments in the area investigated generally have thorium contents below 25 ppm and corrections, normally necessary for high concentrations of thorium, are therefore unnecessary. Uranium in water (Brits and Smit, 1977) is routinely determined on a sample volume of 250 ml. The sample is acidified to pH1 with hydrochloric acid and the uranium, concentrated on an anion exchange column from a thiocyanate-ascorbic acid medium, is again determined using the delayed-neutron method. The sensitivity is about 1 ppb U and the precision is 0,2 ppb U. In order to apply this method to the stream-sediment samples investigated in this study, the leach liquids had to be treated prior to analysis in order to establish similar matrix compositions. This meant the removal of possible interfering ions or complexing agents.

Adequate precision for the easily leached uranium in stream sediments was required in order to be in a position to evaluate potential anomalies. Previous experience with soil samples indicated that about 5 to 10 % of the total uranium would probably be leached (by dilute hydrochloric acid) from stream sediments away from a mineralised area. To obtain a precision of better than 10 % for stream-sediment samples, at least 4 g of material was required for analysis.

2.2 Leaching Agents

In order to test the effectiveness of various extracting agents, ten stream-sediment samples were collected at varying distances from an outcrop of mineralised sandstone in the southwestern Karoo. This stream has a gradient of about 1 in 70, and has no tributaries. These samples had previously been used for XRF analyses and were thus pulverized -80 mesh fractions. The crushing was not considered to affect the relative efficiencies of extraction of the various agents. The following chemicals were tested as extracting agents for uranium:

- 10 % v/v hydrochloric acid
- 10 % v/v hydrochloric acid plus 8 % hydrogen peroxide
- 10 % v/v nitric acid
- 1 % w/v sodium carbonate
- 5 % w/v ammonium citrate
- 5 % v/v acetic acid
- 5 % v/v acetic acid plus 8 % hydrogen peroxide
- 1 % w/v EDTA (Na salt)

A 4 g sample and 50 ml reagent were mixed in a conical polythene bottle for 30 min using a mechanical shaker. The samples were then filtered without delay through Whatman No. 44 filter paper, and the bottle, filter paper and sediment were well washed with water for the complete recovery of the filtrate. 5 ml perchloric acid was then added to each sample to destroy oxidising or complexing agents; the solutions were then evaporated to dryness and redissolved in 50 ml of warm 10 % v/v hydrochloric acid. After dilution to about 200 ml they were analysed by the method of Brits and Smit (1977). The test using EDTA was discontinued since no clear solutions could be obtained, even after repeated filtration. The results of the leach tests are given in Table I and are shown graphically in Fig. 1.

TABLE I
URANIUM EXTRACTED FROM STREAM
SEDIMENTS WITH VARIOUS LEACHING AGENTS

LEACHING AGENT	DISTANCE FROM MINERALISATION (m)									
	75	150	225	325	425	650	900	1 150	2 150	3 150
	URANIUM (ppm)									
10 % Hydrochloric acid	7,81	2,86	0,85	0,72	0,74	0,40	0,37	0,45	0,27	0,14
10 % Hydrochloric acid + 8 % hydrogen peroxide	8,50	3,40	0,95	0,80	0,96	0,45	0,45	0,48	0,27	0,19
10 % Nitric acid	7,05	2,87	0,79	0,62	0,65	0,35	0,36	0,40	0,26	0,17
1 % Sodium carbonate	1,16	0,34	0,12	0,09	0,08	0,08	0,06	0,10	0,03	0,10
5 % Ammonium citrate	1,96	0,96	0,32	0,19	0,17	0,38	0,13	0,16	0,13	0,05
5 % Acetic acid	1,66	0,70	0,15	0,23	0,15	0,10	0,10	0,12	0,07	0,06
5 % Acetic acid + 8 % hydrogen peroxide	4,35	0,50	0,36	0,34	0,47	0,23	0,16	0,23	0,11	0,11

Sodium carbonate, acetic acid and ammonium citrate are clearly ineffective leaching agents. These chemicals extracted less than 10 % of the uranium in the sediments and therefore yielded low peak-to-background ratios and short dispersion trains. Acetic acid with hydrogen peroxide was more effective than acetic acid alone, but extracted less than 22 % of the anomalous uranium, compared to more than 36 % for nitric and hydrochloric acids. Nevertheless, there was little difference between the extractions of hydrochloric acid, with or without peroxide, nitric acid and acetic acid with peroxide, with respect to peak-to-background ratios and dispersion downstream from the anomaly. The application of any of these four leaching agents is therefore clearly more useful than the total uranium concentration in the sediment in delineating an anomaly, both in terms of peak-to-background ratio and downstream dispersion. This is shown in Fig. 1 by the decrease of the total uranium anomaly further than 600 m from the outcropping ore.

Oxidising agents such as nitric acid or peroxide are no more effective in leaching uranium than is hydrochloric acid alone. This agrees with the field observation that most of the ore is oxidised before it is incorporated into the stream system. The organic carbon content of the Karoo stream sediments is not known but in most streams is below 1 %. If

adsorption of uranium on organic material has in fact taken place. It is thus removed by hydrochloric acid alone.

The above results do not indicate positive preference for any one of these four leaching reagents and the final selection was therefore based on practical considerations. The addition of oxidising agents is not recommended in view of the additional cost and, as a final choice, hydrochloric acid was preferred to nitric acid because it forms a solution similar to that used in the routine analyses of subsurface water samples. However, it is appreciated that other laboratories, using other analytical techniques, might well decide differently.

2.3 Experimental Parameters

2.3.1 LEACHING TIME

The effect of contact time was investigated using one sample taken near a highly mineralised outcrop and another taken further away and supposedly representing a background value. In all cases the samples were shaken with a 10% v/v hydrochloric acid solution as described in section 2.2.

The results are shown in Fig. 2. Short agitation times are preferred in order to save time, but too short a time might lead to experimental errors due to the relatively higher slope of the extraction curve. A leaching period of 30 min was selected as most of the cold-extractable uranium has been leached at that stage. Any error introduced by delay in the filtration step, as might be the case when handling large batches of samples, will be negligible.

2.3.2 ACID CONCENTRATION

Fig. 3 shows the effect of different hydrochloric acid concentrations on the extraction of uranium from the samples discussed in 2.3.1 above. The suggested 10% v/v hydrochloric acid is sufficient and effective even if moderate amounts of carbonate are present. Since the acid concentration might, however, be dramatically reduced by very high carbonate contents, it is recommended that it be checked for those samples showing strong effervescence on addition of the acid solution.

2.3.3 DISSOLVED SOLIDS

The method used for the determination of uranium in water (Brits and Smit, 1977) provides reliable data even if the total dissolved solids reach concentrations equivalent to that of seawater. In this type of study even larger amounts of material could be dissolved, leading to saturation of the ion-exchange resin and loss of uranium.

In order to investigate this problem, the uranium content was determined for a leach solution to which 50 mg Fe_2O_3 (equivalent to 1.25% soluble Fe_2O_3 in a sample of 4 g), 200 mg CaCO_3 (i.e. 5% soluble CaCO_3), and 50 mg SiO_2 had been added. These additions did not suppress the

uranium yield by more than 10%.

2.3.4 EXPERIMENTAL ERRORS

The precision of the method was investigated by analysing about thirty duplicate samples in the course of the project. In this way the performance of the overall procedure could be evaluated under the conditions of normal routine analysis. Experimental values for the cold-extractable uranium concentration in fact differed by not more than 0.02 ppm between duplicates.

In this work the experimental value obtained (i.e. concentration of cold-extractable uranium in a sample) is by definition the value sought, and in this context it can be said that the method is 100% accurate. However, the concept of cold-extractable uranium should not be confused with mobile uranium. The various terms are used in the following manner in this report:

The *total uranium* content of the sediment constitutes all the uranium in the sediment, whether it was originally present in the sediment or was introduced exogenically from a different source.

The *mobile uranium* content of the sediment is that fraction of the total uranium that was exogenically introduced into the soil from another source and did not result from the *in situ* weathering of the soil itself. Further distinction is made in this report between the various forms of mobile uranium, i.e. the uranium present in the insoluble heavy minerals e.g. zircon, is not included in the fraction termed mobile uranium since it is largely insoluble in dilute hydrochloric acid. Most mobile uranium has probably been transported in solution in an anionic form, adsorbed to clay minerals or to organic material.

Leachable uranium is that amount of uranium that can be leached from the sediment with various leaching reagents. It forms part of both the total and mobile uranium. The amount of leachable uranium in a sediment depends both on the form in which the uranium is present in the sediment and on the leaching reagent, which may be applied hot or cold.

Cold-extractable uranium (cxU) is that amount of leachable U that can be extracted with a cold reagent from the sediment. For comparison purposes the term becomes meaningful only if the concentration of the reagent in the leaching medium is specified, e.g. 10% HCl cxU.

The method finally adopted for the cold-extractable uranium for the Karoo sediments is given in Table II below.

TABLE II

PROCEDURE FOR THE COLD 10 % HYDROCHLORIC ACID EXTRACTION OF URANIUM FROM KAROO STREAM SEDIMENTS

- (1) Weigh 4,0 g sample into a 100 ml conical polythene bottle.
- (2) Add 50 ml of 10 % v/v HCl and swirl to dissolve any carbonates present. Stopper.
- (3) Shake for 30 min in a mechanical shaker. (The sediment should form a suspension during the agitation and should not be allowed to settle to the bottom. To avoid settling the bottles are packed horizontally.)
- (4) Filter through a wet Whatman No. 44 or equivalent filter paper into a 250 ml polythene bottle. Wash the polythene bottle in which the agitation was done and the filter paper with the sediment several times with uranium-free water.
- (5) The sample may be submitted for analyses as is. If uranium in the filtrate is to be determined by delayed-neutron counting, the solution should be diluted to about 200 ml before proceeding with the analysis as detailed by Brits and Smit (1977).

3. CASE STUDIES

In order to compare the relative efficiencies of total and cold-extractable uranium (cxU) for delineating uranium occurrences, streams draining known occurrences in Karoo sediments were sampled. Several of the areas investigated were, at the time of sampling, being actively prospected by drilling, with the result that the extent of mineralisation was not always known and the possibility of contamination from wind-blown drill-hole material existed. A sample was routinely collected over an area of several square metres and the uppermost 10 – 50 mm of sediment was rejected. At each sample site three size fractions were collected, viz. –40 +80, –80 +200, and –200 mesh.

The areas investigated are widely separated, striking from southwest of Beaufort West to near Richmond in the east, a distance of 300 km (see Map 1). Extremes of relief are found over this distance and, in the proximity of the escarpment where streams cut through near-vertical cliffs, gradients of 1 in 10 are found. Dispersion is mainly through mechanical transport of rock fragments. The finer fraction is easily washed away and what fines remain constitute only a small percentage of the sediment. In the flat areas, stream gradients are closer to 1 in 1 000, and the fine fraction constitutes a significant percentage of the total sediment if dilution from soil adjacent to the stream has not been excessive. Dispersion is due mainly to the fine fraction and possibly also to hydromorphic action. Because of these different modes of dispersion the areas investigated may conveniently be divided into areas near the escarpment and those in the flats.

3.1 Case Studies Near the Escarpment

3.1.1 LOCALITY A

This stream system with its extreme relief is shown, together with the sample locations, in Fig. 4. The results of the three size fractions for both total uranium and cxU are given in Table III.

TABLE III
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS FOR THE STREAM SYSTEM AT LOCALITY A

SAMPLE NO.	URANIUM (ppm)					
	–40 +80 Mesh		–80 +200 Mesh		–200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
1	4,8	0,80	3,4	0,57	4,6	0,55
2	4,2	0,52	3,9	0,45	5,2	0,60
3	4,8	0,70	4,2	0,54	4,9	0,59
4	3,2	0,26	3,1	0,37	3,9	0,30
5	3,2	0,24	2,4	0,27	3,9	0,24
6	2,8	0,26	2,5	0,25	4,3	0,32
7	1,8	0,11	1,7	0,11	4,1	0,19
8	2,2	0,11	1,7	0,08	3,2	0,14
9	2,4	0,17	2,1	0,11	3,1	0,25
10	3,4	0,57	2,5	0,43	3,7	0,47
11	3,4	0,79	2,3	0,36	4,0	0,42
12	3,1	0,41	2,5	0,32	3,5	0,34
13	4,3	0,44	4,3	0,80	5,2	1,01
14	3,9	0,41	3,5	0,34	4,7	0,42
15	3,4	0,39	2,9	0,37	3,6	0,33
16	3,6	0,28	3,0	0,27	3,9	0,33
17	3,7	0,19	2,9	0,21	4,2	0,28
18	3,5	0,24	2,9	0,29	4,3	0,35
19	3,4	0,14	2,9	0,15	4,2	0,21
21	4,9	0,53	4,6	0,56	5,4	0,81
22	4,1	0,54	3,9	0,53	5,3	0,72
23	4,2	0,20	3,3	0,20	4,3	0,27
24	5,2	0,80	4,1	0,58	6,4	0,85
25	5,1	1,59	4,2	0,95	5,4	1,08
26	4,9	1,06	3,9	0,72	4,8	0,85
27	4,0	0,66	3,8	0,39	4,2	0,47
28	3,7	0,34	3,6	0,38	5,3	0,57
29	3,6	0,40	2,9	0,32	4,5	0,41
30	3,8	0,36	3,0	0,27	4,0	0,34
31	3,7	0,50	2,9	0,32	3,7	0,34
32	2,8	0,26	2,4	0,21	3,0	0,25

There are two problems associated with the interpretation of these data. Firstly, at the time of sampling the extent of the mineralisation, which is sporadic, was not known and may well continue along the stratigraphic zones indicated in Fig. 4. The second problem concerns the selection of threshold values from the samples available. Since it is known that the apparent uranium dispersion, based on the total uranium contents of stream sediments, is short, sampling was restricted to streams in proximity to the mineralisation. The use of cxU, however, shows much longer dispersion than expected, and samples that were quite satisfactory for establishing a background for total uranium might in fact still be anomalous with regard to cxU. Threshold selection for the Karoo stream sediments is thus problematical and is discussed in detail in section 4.

Because of the lack of background samples the data are presented in the following manner: The sample

concentrations of both total U and cxU are ranked independently of each other or their position in the stream system, on the assumption that the lowest ranks represent background or near-background values and that the higher ranks are anomalous. Fig. 5 shows a plot of uranium concentration vs sample rank of the Locality A -200 mesh fraction for both total U and cxU. The cxU value for background or near-background samples is a factor of more than ten lower than the total uranium in the stream sediment. This means that only 5 - 10 % of the total uranium is leached from background or near-background sediments. In addition, Fig. 5 shows the range of cxU to be much larger than that for total uranium. This is because a larger percentage of the total uranium is leached from anomalous samples. In practice, therefore, the contrast (peak-to-background ratios) between anomalous and background samples is more strongly enhanced by the leaching procedure.

The effect of size fraction is shown in Fig. 6. For both the total uranium and cxU, the -200 mesh fraction has the highest absolute uranium concentration, while the intermediate -80 +200 mesh fraction is lowest in uranium. In all cases the cxU shows a better contrast between background and anomalous values.

The high values for cxU in the coarse -40 +80 mesh fraction (Fig. 6) are probably due to rock fragments from the occurrence. Uranium, when transported in the finer fractions, does not reach such extreme values and longer downstream dispersion can be expected.

The uranium contents of the stream sediments in the main course draining Locality A are shown in Fig. 7. Sample positions 7, 8 and 9 (Fig. 4) were situated almost on top of the escarpment above any known mineralisation. At least samples 7 and 8 are therefore expected to represent background concentrations. The contrast between the first two or three samples and samples 10 and 27, taken below a projected mineralized zone, is much higher for cxU than for total uranium in all three size fractions. The coarse fraction shows the best contrast but, because the cxU in sample 17 is almost background, the coarse fraction also has the shortest dispersion train. This is probably directly related to the mode of dispersion, as mentioned earlier.

3.1.2 LOCALITY B

The stream system which drains the escarpment at Locality B is situated about 20 km from Locality A. Sampling was concentrated near the mineralisation and only samples 29, 30 and 31, taken on top of the escarpment above the mineralisation, are likely to represent background values (Fig. 8 and Table IV).

The large range of cxU concentrations in the -200 mesh fraction (Fig. 9) results in an improved contrast between background and anomalous values, as well as in more anomalous samples. The improvement in the contrast is due to the higher percentage of uranium leached from

anomalous samples (up to 55 %) compared to background samples (<10 % leached). The ranges of uranium concentration in the various size fractions are shown in Fig. 10. Assuming the first two or three samples to represent background, then the -200 mesh fraction is much more sensitive to mineralisation than the coarser fractions. This is shown by the steep slope of the -200 mesh fraction at the lower-ranked samples. The total uranium content of the fine fraction increases more gradually than the cxU.

3.1.3 LOCALITY C

This is the largest stream system along the escarpment which was investigated (Fig. 11 and Table V). Although the sample density is only two samples per square kilometre, several highly anomalous values were obtained, e.g. samples 31, 61 and 62.

TABLE IV
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS FOR THE STREAM SYSTEM AT LOCALITY B

SAMPLE NO.	URANIUM (ppm)					
	-40 +80 Mesh		-80 +200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
1	2.8	0.25	2.5	0.23	3.9	0.38
2	2.9	0.22	2.5	0.26	4.5	0.49
3	4.3	0.39	3.5	0.38	4.8	0.55
4	3.1	0.31	2.8	0.27	4.4	0.45
5	5.2	0.79	3.8	0.53	4.6	0.60
6	3.9	0.65	3.2	0.40	4.0	0.45
7	4.8	0.62	4.4	0.60	5.8	1.09
8	3.5	0.24	2.6	0.26	4.2	0.45
9	3.2	0.29	2.6	0.32	4.1	0.43
10	6.6	1.02	6.0	0.94	6.5	1.26
11	2.6	0.31	2.6	0.30	4.1	0.46
12	4.3	0.30	3.7	0.32	4.5	0.39
13	3.0	0.26	2.8	0.28	4.4	0.48
14	3.6	0.38	3.2	0.55	4.5	0.75
15	3.9	0.66	3.8	0.77	5.1	1.31
16	4.9	1.09	4.9	1.50	8.1	2.68
17	13.0	5.7	12.5	6.35	17	9.42
21	6.2	1.8	5.1	2.16	6.5	2.63
22	3.7	0.59	3.1	0.59	4.2	0.75
23	1.8	0.16	1.8	0.22	2.7	0.24
24	4.6	0.56	3.8	0.51	5.2	0.75
25	2.9	0.26	2.6	0.41	3.9	0.60
26	2.7	0.34	2.6	0.33	3.8	0.61
27	2.9	0.44	2.8	0.51	4.7	1.07
28	2.0	0.13	2.1	0.09	4.4	0.32
29	2.3	0.15	1.7	0.13	2.0	0.15
30	2.2	0.12	1.8	0.09	3.3	0.17
31	2.1	0.12	1.6	0.12	2.0	0.16

TABLE V
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS FOR THE STREAM SYSTEM AT LOCALITY C

SAMPLE NO.	URANIUM (ppm)			
	-80 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU
16	3.3	0.21	3.9	0.28
17	4.6	0.85	4.0	0.65
18	3.6	0.22	4.6	0.27
19	3.4	0.24	3.3	0.29
20	2.6	0.07	2.1	0.10
21	3.2	0.26	2.7	0.17
22	3.2	0.23	4.6	0.31
24	3.3	0.20	3.1	0.25
26	3.9	0.18	3.4	0.20
27	3.6	0.16	4.0	0.17
28	3.7	0.19	3.0	0.26
29	4.0	0.23	3.4	0.25
30	2.0	0.18	2.6	0.19
31	4.1	0.50	5.1	0.19
34	3.1	0.25	3.2	0.30
35	4.5	0.49	4.1	0.45
36	3.4	0.29	2.9	0.27
37	5.3	0.46	4.7	0.52
38	4.9	0.32	4.5	0.34
39	3.8	0.30	3.9	0.26
40	3.8	0.31	4.3	0.36
41	7.0	1.55	9.1	2.61
42	5.8	1.24	6.0	1.70
43	2.4	0.17	3.5	0.27
44	2.5	0.13	2.3	0.10
45	3.4	0.30	3.1	0.33
46	2.6	0.38	2.7	0.41
47	4.8	0.90	8.0	2.11
48	2.7	0.10	2.8	0.12

A comparison of the total U and cxU of the -200 mesh fraction for the ranked data is shown in Fig. 12. Fewer samples from Locality C have such a marked contrast as have samples from Localities A and B. The breaks in the slopes of the ranked data at sample rank 8 for cxU and rank 15 for total U are near the respective uranium concentrations which are expected to be close to the threshold values and may be due to mineralisation. In general the results are similar to those obtained from Localities A and B. Because of the lower sample density at Locality C, these results may represent a regional survey more realistically.

Samples 22 and 60 were collected in higher-order streams. Both are probably anomalous and may indicate the type of dispersion to be expected in higher-order streams away from the mineralisation. This and the fact that sample 86, which was taken 3,5 km from the nearest known mineralisation and has a similar background concentration as have samples from first-order streams when away from mineralisation, may indicate the usefulness of sampling higher-order streams in a regional survey.

3.2 Case Studies in Areas of Moderate Relief

3.2.1 LOCALITY D

The single stream which drains the mineralised sandstone outcrop at Locality D constitutes an ideal system for a geochemical stream-sediment orientation survey. The stream has an intermediate gradient, no tributaries, and traverses interlayered sandstones and mudstones. The gradient is steep enough for sediment of intermediate size to be transported for some distance, yet not active enough to wash out the fine-sediment fraction. Because of the absence of tributaries which may cause dilution, this stream can be used to ideally observe the distance that uranium is transported downstream from the mineralisation.

Sampling was conducted for more than 3 km downstream (Fig. 13). Sample 6 is somewhat low in total uranium in the -200 mesh fraction (Table VI and Fig. 14) but the uranium

TABLE VI
TOTAL AND COLD EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY D

SAMPLE NO	DISTANCE FROM ORE (m)	URANIUM (ppm)					
		-40 + 80 Mesh		-80 + 200 Mesh		-200 Mesh	
		Total U	cxU	Total U	cxU	Total U	cxU
1	75	24	6,48	19,5	5,50	23	8,9
2	150	13	2,89	10,0	2,78	10,1	2,42
3	225	7,4	1,00	5,3	0,78	5,0	0,50
4	325	5,4	0,59	4,7	0,51	5,5	0,59
5	425	5,2	0,75	4,2	0,64	5,8	0,7
6	650	3,9	0,21	3,2	0,29	3,1	0,38
7	900	4,7	0,34	3,5	0,24	4,7	0,36
8	1 150	4,0	0,22	3,5	0,28	5,1	0,34
9	2 150	4,0	0,21	3,2	0,17	4,4	0,23
10	3 150	3,8	0,12	2,7	0,11	3,8	0,13
13	3 650					4,5	0,11
14	4 150					3,7	0,13
16	4 500					3,7	0,09
19	5 200					4,5	0,11
21	5 600					3,5	0,13
23	6 400					3,9	0,15
25	7 000					4,3	0,13

concentration in the sediment decreases regularly downstream in the coarser fractions. The fine fraction probably gives the best indication of mineralisation for total uranium in the sediment. For cxU, the coarse fractions give somewhat erratic results, but all three size fractions decrease in cxU more than in total U away from the anomaly. This results in a better peak-to-background ratio and longer dispersion downstream (Fig. 14).

3.2.2 LOCALITY E

The stream system and sample locations at Locality E are shown in Fig. 15. Mineralised outcrops occur along a small stream which undergoes great dilution when it enters the main river. This dilution reduces the total uranium content of the stream sediments to background concentrations, while the cxU anomaly persists for at least one kilometre downstream from the confluence (Fig. 16 and Table VII). The erratic pattern of the anomalous dispersion below the confluence in the main river may be due to variations of soluble uranium concentrations within the large streambed.

TABLE VII
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY E

SAMPLE NO.	-40 + 80 Mesh		-80 + 200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
7			2,5	0,24		
8			2,7	0,28		
9			3,4	0,40		
10			11,8	1,42		
11			10,3	5,3		
12			10,3	4,1		
13			10,0	6,1		
14			2,9	0,58		
15			2,7	0,30		
16			3,0	0,51		
101	3,8	0,16	3,5	0,16	4,5	0,21
102	4,0	0,20	3,0	0,15	4,9	0,22
103	3,6	0,14	3,1	0,20	4,3	0,22
104	4,1	0,74	3,2	0,15	4,6	0,21
105	4,3	0,17	3,2	0,11	4,7	0,13
106	3,7	0,23	3,3	0,55	4,4	0,28
107	4,2	0,47	3,5	0,31	4,3	0,52
108	3,9	0,22	3,3	0,31	4,5	0,39

3.3 Case Studies in Areas of Low Relief

Large areas of the Karoo sediments are extremely flat-lying and stream coverage in these areas is often unsatisfactory. Any realistic orientation program with practical applications has to include sites from these areas. Very little sediment of medium and coarse size fraction is probably transported in these stream systems, and dispersion depends on the transport of uranium within the very fine fraction or by hydromorphic action. Because these sediments are inactive, large lateral dilutions from the surrounding sandstone and mudstone are likely.

3.3.1 LOCALITY F

This relatively small stream system and the sample locations are shown in Fig. 17. The analyses of the various size fractions are given in Table VIII.

TABLE VIII
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY F

SAMPLE NO.	URANIUM (ppm)					
	-40 +80 Mesh		-80 +200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
1	3,0	0,43	1,9	0,30	3,8	0,74
2	2,8	0,17	2,1	0,13	3,1	0,20
3	2,0	0,12	1,9	0,10	3,3	0,17
4	2,3	0,10	1,8	0,10	3,2	0,15
5	3,3	0,21	2,3	0,15	3,9	0,25
6	3,8	0,35	3,4	0,31	3,6	0,38
11	5,4	1,76	4,0	1,44	7,5	3,14
12	5,8	0,36	4,7	0,68	5,9	0,78
13	3,8	0,38	2,7	0,43	4,7	0,69
14	3,8	1,43	3,0	1,25	5,5	2,42
15	5,3	2,53	5,9	3,22	9,9	6,7
16	3,7	0,97	3,1	1,44	4,3	1,51
17	5,5	3,37	5,1	2,87	9,7	7,1

The dispersion pattern of the -200 mesh fraction is shown in Fig. 17. This pattern is completely different from those in streams with higher relief. Both total uranium and cxU are low in the sediments of the first-order streams closest to the mineralized sandstone outcrop, but increase downstream in the second-order stream (Fig. 17).

Up to 73% of the total uranium in some sediment samples is present in soluble form and is only weakly bonded. This suggests that chemical traps are responsible for this type of anomaly.

(a) For several months a year the water table in the second-order stream is very high. Consequently brine, which is so often present in Karoo waters, evaporates and precipitates white crusts of salts on the stream-sediment surface. These salts consist mainly of sodium chloride with much sulphate and carbonate. These salts form soluble uranium complexes and are therefore unlikely to directly cause the precipitation of uranium. However, precipitation and concentration of any salt may be caused by evaporation of seepage water. The high uranium concentrations in samples 12 and 15 (Fig. 17) may suggest that seepage is not from the water table itself, but from the smaller first-order streams and surroundings.

(b) The stream system at locality F is relatively inactive because of the slow run-off. Any clay minerals present are likely to remain for a considerable time in the sediment before they are washed out by run-off. The clay minerals can therefore take part in ion-exchange reactions and concentrate uranium for longer periods than in areas of higher relief where the residence times of clays in the sediments are much shorter.

No evidence was found of a higher carbon content in these stream sediments, which could be the controlling factor in the concentration of uranium.

Several streams in the Karoo have a reducing environment some 10 - 50 mm below the surface. Although this was not specifically noticed at Locality F, even a mildly reducing environment may cause the precipitation of uranium. However, since no oxidizing agent was used in the leach liquor, it is regarded unlikely that such high concentrations of (IV) valent uranium are oxidized and leached with the method suggested here (Table II).

Apart from the observations noted above, we have no explanation as to the formation of such an anomaly and the anomaly found at Locality F may appear to be a false one. However, because there is seepage from the surroundings, and the extent of mineralisation is unknown, it is more likely that this is a true anomaly and is not caused by concentration of uranium from groundwater, either by direct evaporation or by adsorption on clay minerals.

3.3.2 LOCALITY G

This stream system is located only a few kilometres from Locality F described above. The mineralisation outlined in Fig. 18 was confirmed by 'Track Etch' surveys but no evidence was found of surface mineralisation. Sample 1 is a soil sample collected in a minor depression. The drainage channel past samples 2, 3 and 4 is not well developed and a large proportion of the sediment consist of weathered rock material.

The analytical results (Table IX) indicate background concentrations for total uranium in all three size fractions. The cxU gives an anomaly at a distance of more than 1 km from the mineralisation (Fig. 18). At the time of sampling no seepage or salt deposition, which could concentrate uranium in the sediment, was observed. Adsorption of uranium to the fine fraction of the sediment is the most likely explanation of the stream anomaly which is present both above and downstream of the dam.

TABLE IX
TOTAL AND COLD EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY G

SAMPLE NO.	URANIUM (ppm)					
	-40 +80 Mesh		-80 +200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
1	2,9	0,07	1,5	0,06	3,2	0,13
2	3,8	0,12	2,1	0,07	3,5	0,13
3	3,3	0,23	2,2	0,19	3,3	0,23
4	3,1	0,25	1,9	0,17	3,4	0,27
5	2,7	0,22	2,4	0,18	3,4	0,25
6	2,9	0,24	2,2	0,22	2,8	0,21
7	2,6	0,37	1,9	0,26	2,8	0,33
8	2,4	0,61	1,8	0,46	2,9	0,70
9	2,4	0,67	1,7	0,53	3,2	0,93

The results in Table IX indicate that all three size fractions give a cxU anomaly and that the total uranium and the cxU in the -80 +200 mesh fraction are lower than in the other size fractions.

3.3.3 LOCALITY H

The stream system investigated and the patchy mineralisation on either side of it are shown in Fig. 19. The results (Table X) of the -200 mesh fraction indicate that samples 6 to 11 are anomalous in total uranium and that the dispersion is normal. For cxU an anomaly (sample 14) is present at approximately 1 km downstream from the mineralization. This might possibly extend upstream to samples 12 and 13. Similar, though less pronounced, anomalies are indicated for the total uranium and cxU of the coarse size fractions, which have much lower backgrounds.

TABLE X
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY H

SAMPLE NO.	URANIUM (ppm)					
	-40 +80 Mesh		-80 +200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
1	2,7	0,12	2,4	0,08	3,5	0,14
	2,1	0,21	2,5	0,15	3,4	0,10
3	2,4	0,08	2,5	0,08	2,8	0,13
4	3,0	0,11	2,4	0,10	3,2	0,15
5	2,4	0,13	2,4	0,09	3,9	0,18
6	2,6	0,08	2,7	0,08	4,9	0,17
7	3,4	0,11	3,6	0,10	5,4	0,17
8	3,3	0,10	4,2	0,13	6,7	0,20
9	4,3	0,21	3,4	0,11	4,8	0,20
10	3,7	0,11	4,8	0,14	7,4	0,19
11	4,8	0,11	3,8	0,11	4,5	0,18
12	3,1	0,11	2,3	0,11	3,4	0,23
13	2,7	0,19	2,9	0,13	3,7	0,27
14	3,5	0,16	2,8	0,20	4,1	0,51

3.3.4 LOCALITY I

This small stream system (Fig. 20) is situated near Locality H. The results (Table XI) are inconclusive because not enough samples downstream of the anomaly were taken. The -200 mesh fraction of sample 21, however, may indicate a normal anomaly for total uranium, while sample 25 may indicate an anomaly for cxU. The coarser size fractions have lower backgrounds but the cxU in these may suggest a dispersion similar to the fine fraction.

TABLE XI
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY I

SAMPLE NO.	URANIUM (ppm)					
	-40 +80 Mesh		-80 +200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
21	2,5	0,08	2,3	0,08	4,3	0,14
22	2,8	0,13	2,8	0,11	3,5	0,18
23	2,9	0,11	2,5	0,10	3,8	0,15
24	3,1	0,12	2,7	0,11	3,1	0,15
25	3,9	0,23	2,8	0,21	3,8	0,25

3.3.5 LOCALITY J

Dark-weathered mineralised sandstone is confined to the upper section of the flat-topped mesas (Fig. 21). Sample 10 for the -80 +200 and -200 mesh fractions is anomalous for total uranium, while no single anomalous value was obtained for cxU (Table XII).

TABLE XII
TOTAL AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS
FOR THE STREAM SYSTEM AT LOCALITY J

SAMPLE NO.	URANIUM (ppm)					
	-40 +80 Mesh		-80 +200 Mesh		-200 Mesh	
	Total U	cxU	Total U	cxU	Total U	cxU
1	2,8	0,15	2,3	0,11	3,4	0,22
2	3,2	0,11	2,7	0,12	4,0	0,12
3	3,5	0,13	3,0	0,14	3,8	0,18
4	2,5	0,11	2,8	0,11	4,0	0,16
5	2,7	0,13	2,3	0,10	3,4	0,12
6	2,8	0,12	2,2	0,09	3,4	0,10
7	3,1	0,10	2,4	0,08	4,2	0,11
8	3,5	0,22	2,4	0,10	4,5	0,13
9	2,9	0,11	2,2	0,13	3,1	0,18
10	2,9	0,10	3,8	0,11	7,5	0,12
11	2,6	0,10	2,3	0,07	3,0	0,11
12	3,2	0,11	3,0	0,08	3,8	0,10
13	3,2	0,10	2,6	0,09	3,5	0,09
14	2,7	0,11	2,2	0,09	4,4	0,12
15	2,8	0,08	2,6	0,10	4,7	0,11
16	2,7	0,13	2,4	0,10	3,5	0,13
17	2,9	0,09	2,2	0,07	3,7	0,09

It is clear that dispersion patterns are not well developed in this area, but no explanation exists as to why, in sample 10 of the -200 mesh fraction, the anomalous total uranium is not easily extractable. The decrease in total U with increasing size fraction in sample 10 is probably due to dilution from soil adjacent to the stream.

3.4 Discussion of the Results of the Case Studies

The case studies reported in the previous sections were performed in order to select the optimum parameters for a regional geochemical exploration program in the southwestern Karoo sediments, and the following information was gained:

3.4.1 SAMPLE MATERIAL

Stream sediment samples collected over an area of several square metres proved to be suitable material for detecting a uranium-dispersion pattern. The results of Locality C indicate that both first-order and higher-order streams can be sampled successfully. Samples should not be taken close to stream banks because of the possibility of lateral dilution.

3.4.2 SAMPLE DEPTH

Samples were collected 10 - 50 mm below the surface in order not to incorporate wind-blown material present.

3.4.3 SAMPLING ERROR

This was not estimated since the samples were collected over an area of several square metres. Sampling was considered to be as representative as is possible in a regional survey. The seasonal variation of the uranium content of the sediment has not been investigated.

3.4.4 SIZE FRACTION

The -200 mesh fraction has the highest uranium content and generally gives the best dispersion and peak-to-background ratios. On the other hand, this size fraction is often difficult to obtain and large volumes of stream sediment have to be sifted. The coarse -40 +80 mesh fraction may have a very high content, both in total U and in cxU, but the resulting dispersion is very erratic and generally shorter than for the finer fractions. The -80 +200 mesh fraction has invariably the lowest uranium content.

3.4.5 SAMPLE INTERVAL

In areas of moderate to high relief the downstream dispersion of cxU extends to at least 500 m, and generally to more than 1 km below the mineralisation. The cxU dispersion often extends to twice as far downstream as does the total U dispersion. In order to prevent point anomalies and to decrease the possibility of missing such a point anomaly, at least two samples should be taken within the downstream dispersion pattern in a regional survey. The present case studies in areas of moderate to high relief therefore suggest a sample interval of 250 m, or at the most 500 m, apart. In areas of flat to moderately flat relief the downstream dispersion is often less pronounced than in areas of higher relief and the anomaly may not be detected at all. Generally, however, a cxU anomaly is present 500 - 1 000 m downstream from the mineralization. In this case the sample interval should be 250 - 500 m.

3.4.6 ANALYTICAL PROCEDURE

The analytical method in use at the AEB for the analysis of water samples can be used successfully for the analysis of cxU in the Karoo sediments. In order to obtain the necessary precision, a 4 g sample should be taken. The use of 10% v/v HCl is effective in delineating uranium anomalies, and the precision of extraction and analysis is high.

3.4.7 THRESHOLD ESTIMATION

This has been problematical in view of the relatively few background samples collected in the case studies. This is dealt with in detail in section 4 below.

4. REGIONAL STUDY

4.1 Motivation

The case studies discussed in the previous section were carried out for two specific purposes, viz. to evaluate the general applicability of using stream-sediment geochemistry for delineating near-surface uranium mineralization in the Karoo sediments, and to compare the relative effectiveness of total uranium and cxU to discover such mineralisation.

The case studies conducted clearly show that the dispersion of cxU in areas of rapid run-off is sufficient to delineate mineralisation. In the flat-lying areas closer sample intervals are required. In either case, the success of a stream-sediment survey depends on the ability to recognise the differences in uranium concentration between background and anomalous samples. Because these differences are shown to be extremely subtle, the case studies in themselves cannot be conclusive for several reasons, viz.:

- (a) Sampling was conducted in great detail near the ore and anomalous samples are adequately represented. However, this is not the case for background samples and the regional variation of the background remains unknown.
- (b) The samples were collected over an area of several square metres and, where possible, sediment of similar appearance was collected. The samples were sieved carefully and experimental procedures were strictly adhered to. Orientation studies similar to those described in the previous section, are therefore "a case after the fact" and need not be applicable to routine surveys.

In order to overcome these objections, about 720 samples covering the sheet 3222 AC PAALHUIS, where uranium mineralisation is known to occur, were also analysed for both cxU and total uranium. These samples form part of an extensive Geological Survey geochemical stream-sediment exploration program, that is being undertaken over large parts of the Republic of South Africa. Sampling of the -200 mesh fraction had been carried out at a density of one sample per square kilometre. Only first-order streams were sampled for the following reasons: It was assumed that the downstream dispersion of total uranium is short; uraniumiferous sandstones may outcrop over considerable distances; the number of samples could be kept to a minimum; the possible difficulty of comparing uranium concentrations in first-order streams to that in higher-order streams. As a consequence, the sample representing a square kilometre in areas where drainage is not well developed was taken from the most prominent depression that is likely to carry run-off during rains. For practical purposes these samples thus represent the whole range from soil to first-order stream-sediment samples. Near the escarpment first-order streams give a better coverage and this problem arises less frequently. Nevertheless, any stream sediment dispersion resulting from a uraniumiferous outcrop shorter than

one kilometre in length, may result in a point anomaly. This in turn necessitates interpretational aids which have a high probability of detecting low-order single-point anomalies.

4.2 Results

As is often the case in geochemical exploration, it was impossible, by simple inspection of the analytical results, to establish which samples justify further attention. Statistical methods had to be employed to estimate the threshold values. A preliminary study had shown that the experimental data could be better described in terms of a log-normal, rather than by a normal distribution. It was therefore assumed that the suite of samples represented one or more log-normal populations that had to be separated. Two methods were used for this purpose, viz.:

- (i) A very simple approach was used first because any elaborate data reduction system will detract from the applicability of the method. The mean and the standard deviation (SD) on the transformed data were calculated, and all values that differed by more than 3 SD from the mean value were removed from the set. This procedure was repeated for the remaining samples until no more values could be discarded. The values remaining at this stage were assumed to represent the background population. The results obtained from calculations on the transformed data were then expressed as the normal concentrations as follows:

	Total U	cxU
Mean value (ppm)	3,96	0,139
Mean + 2 SD	4,80	0,270
Mean + 3 SD	5,28	0,376
Mean + 4 SD	5,82	0,524
Mean + 5 SD	6,40	0,729
Mean + 6 SD	7,05	1,016

The samples with higher uranium concentrations for both cxU and total uranium were then subdivided into categories according to these class intervals, so that the more significant anomalous samples could be isolated. If it is assumed that this simple approach will in fact be able to isolate anomalous samples, the same sample numbers should appear in the higher categories for both total uranium and cxU when samples are taken near the escarpment. The experimental data did not come up to this expectation. Except for a few samples where both cxU and total uranium showed abnormally high concentrations, the two sets of data showed very poor correlation. This is probably due to the fact that this simple method does not take into account the extensive range of overlap of the background and anomalous populations. The class intervals given above do not have any physical or statistical significance. It is clear that a more rigid approach is required.

- (ii) Cumulative probability plots provide an effective graphical means of obtaining meaningful threshold values. Such a threshold indicates a specific concentration that will effectively divide the sample set into two groups; a lower and probably insignificant group of samples and one which will justify further investigation. In an ideal case these two groups will coincide exactly with the background and anomalous populations respectively. In practice, however, there will be some degree of overlap, and threshold values must be selected in such a way that the probability of recognition of anomalous values is maximised, while, at the same time, the number of background values included in the potentially significant category is minimised. Methods must therefore be devised that will enable the extraction of individual populations from the polymodal distribution. Such partitioning procedures are adequately described by Sinclair (1976).

4.2.1 TOTAL URANIUM

Evaluation of the distribution obtained in the case of the total uranium content indicates that the sample set can be partitioned into three distinct log-normal populations, as shown in Fig. 22. These populations can be described as follows:

Population	A	B	C
Mean U (ppm)	2,02	3,90	5,03
Mean + SD	2,90	4,34	6,92
Mean - SD	1,45	3,52	3,76
Presence	2 %	95 %	3 %

The validity of this accepted partitioning can now be verified by combining these three populations in the proportions given above, and comparing the resulting polymodal distribution with the original data. The solid curve in Fig. 22 represents the distribution calculated from the three populations, and is in fact a very good reflection of the experimental points. It can therefore be stated with a reasonable degree of confidence that the three postulated populations are in fact a reasonable representation of the true distribution.

Populations A and B (comprising about 97 % of the sample set) can probably be described as background values, while population C (forming only 3 % of the total) might be considered as anomalous. These populations must now be used for establishing a threshold value.

Scrutiny of Fig. 22 indicates that it is virtually impossible to select an acceptable threshold value. The threshold must, on the one hand, be selected as low as possible to include the majority of the anomalous population in the potentially significant category. An arbitrary decision, that a loss of not more than 25 % of the anomalous population can be tolerated, will set a threshold value at 4,1 ppm. For the background population B, on the other hand, 31 % will exceed this value of 4,1 ppm and must therefore be considered as potentially significant. Setting the threshold

value at 4,1 ppm will cause 191 samples to be classified as potentially significant, i.e. 14 samples from the anomalous, and 177 samples from the background populations. This low success rate of only 7 % is definitely not acceptable from an exploration point of view.

Increasing the threshold to 5,0 ppm will cause only 13 samples to be classified as potentially significant, i.e. 9 samples from the anomalous and 4 samples from the background populations. This respectable success rate of 69 % was reached, however, at the cost of losing about half of the anomalous population. This is also unacceptable in view of the low sample density of most regional surveys.

4.2.2 COLD-EXTRACTABLE URANIUM

The observed distribution is clearly polymodal, as shown in Fig. 23. Partitioning leads to two log-normal populations plus about five extremely high values which might represent another population. These high values are, however, too few to allow proper statistical treatment and will, for the purpose of discussion, be included with the higher population. These populations can be described as follows:

Population	A	B	?
Mean (ppm)	0,317	0,130	—
Mean + SD	0,468	0,179	—
Mean - SD	0,225	0,097	—
Presence	4 %	95 %	1 %

Here again the partitioning was verified by combining the two populations in order to generate a theoretical bimodal distribution, shown by the solid curve in Fig. 23. Since the correspondence with the experimental data is very good, except for the few high values mentioned earlier, it is assumed that the indicated populations reflect the true distribution. Population B (95 %) is assumed to represent background values, while population A (4 %) and the few values (1 %) are regarded as being anomalous.

Comparison of the populations described above with that obtained in the case of total uranium, shows much less overlap of the ranges covered by background and anomalous populations. It was therefore simpler in this case to select an acceptable threshold concentration. A decision that a loss of 25 % of the anomalous population was still tolerated set the threshold value at 0,25 ppm. This threshold is exceeded by only 1,5 % of the background population. The potentially significant category contained 32 samples — 23 from the anomalous and 9 from the background population. This success rate of 72 % obtained at a loss of 25 % of the anomalous population represents a marked improvement on the results for total uranium.

4.3 Discussion of the Results of the Regional Study

Comparison of the data discussed in the two previous sections clearly illustrates that the determination of cxU

provides a superior method for isolating potentially anomalous samples. The determination of cxU is, however, also the more expensive analytical method, and these two factors must be considered before any recommendations can be made.

The following cost figures per sample are based on data provided by the Geological Survey and on the analytical procedures and laboratory equipment currently being used at the Atomic Energy Board:

Sampling, preparation, and records	R6,00
Analysis: Total uranium	R1,50
Cold extractable uranium	R3,50
Data reduction, mapping, and printing	R0,50

The determination of cold-extractable uranium (at a total cost of R10,00 per sample) instead of total uranium concentration (at R8,00 per sample) involves a cost increase of 20 % for the overall project. Unless this increase can be justified by the improved discriminating ability of the cxU method, the more complex method should not be used.

It is unfortunately much more difficult to quantify the relative improvement in the data when analysing for cxU. Two conflicting parameters must be evaluated for this purpose. On the one hand as few as possible of the anomalous samples should be excluded from the potential category because *only* this group is supposed to warrant further attention and will be investigated in greater detail. On the other hand, as few as possible of the background samples should be included in the potential category since large contamination of this category involves a low success rate and unnecessary expenditure due to detailed investigation of barren areas.

The effects of these contradicting requirements are clearly illustrated in Fig. 24 for both cxU and total uranium. It might be argued that for the PAALHUIS sheet the use of total uranium and the present sampling policy will not easily lead to the identification of anomalous locations. The use of cxU, on the other hand, will yield a relatively high success rate with a very small loss of anomalous samples.

It can therefore be stated with confidence that, for the areas investigated, the additional cost of analysing for cxU is more than justified by the improvement in the data.

5. ACKNOWLEDGEMENTS

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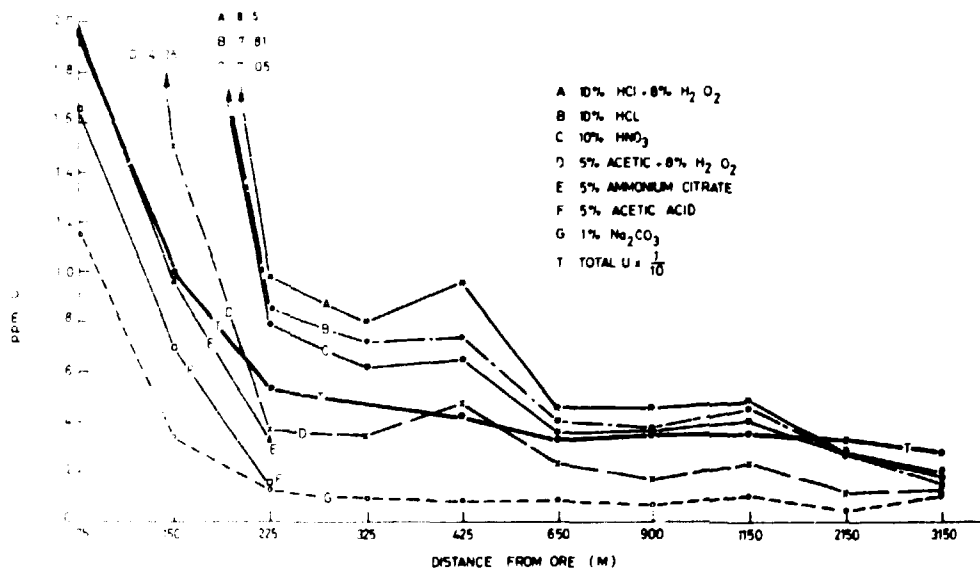
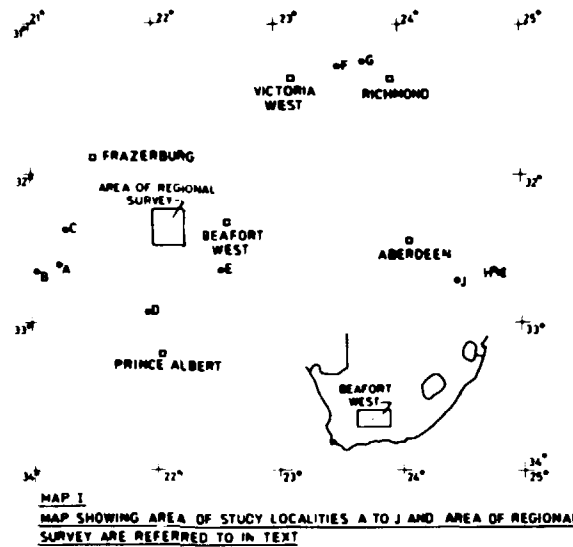


FIG 1 LEACH TESTS USING VARIOUS REAGENTS FOR THE COLD-EXTRACTION OF URANIUM FROM STREAM SEDIMENTS

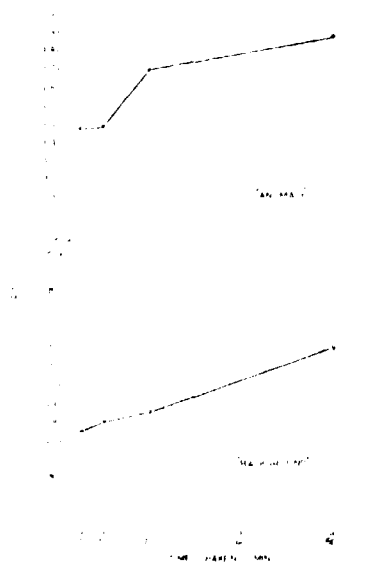


FIG 2 EFFECT OF SHAKING TIME FOR EXTRACTION OF URANIUM FROM STREAM SEDIMENTS WITH 10% CONCENTRATED HYDROCHLORIC ACID

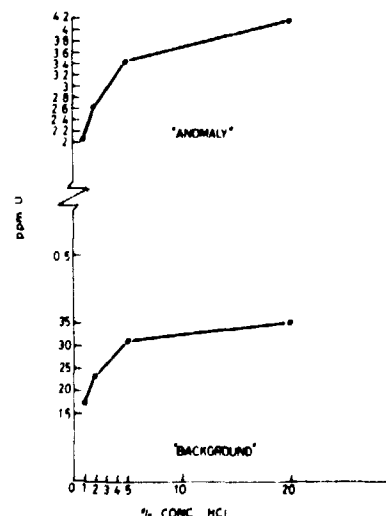


FIG 3 EFFECT OF ACID CONCENTRATION (% CONCENTRATED HYDROCHLORIC ACID IN LEACHING MEDIUM) ON URANIUM EXTRACTION IN STREAM SEDIMENTS

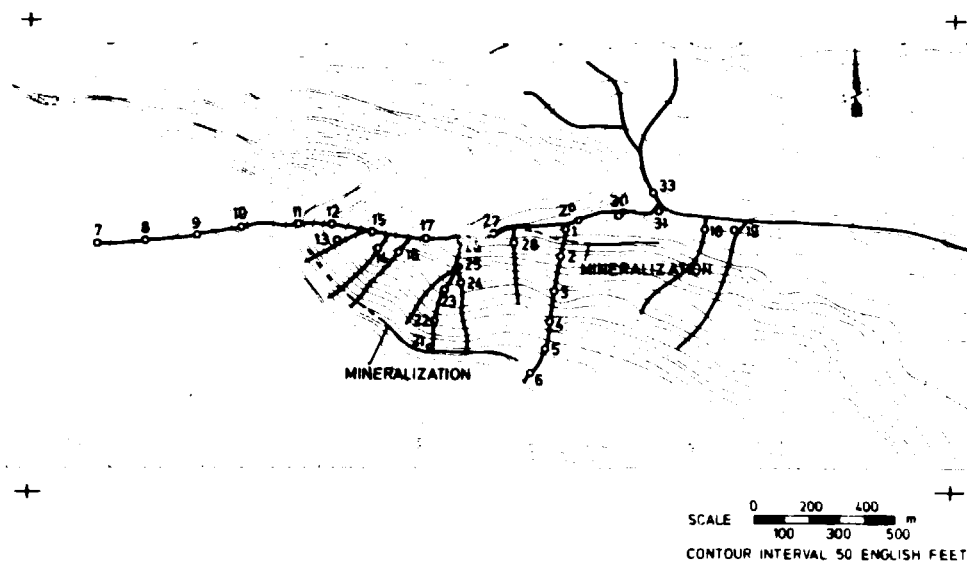


FIG 4 LOCALITY A. SAMPLE LOCATION MAP SHOWING APPROXIMATE POSITION OF MINERALIZATION

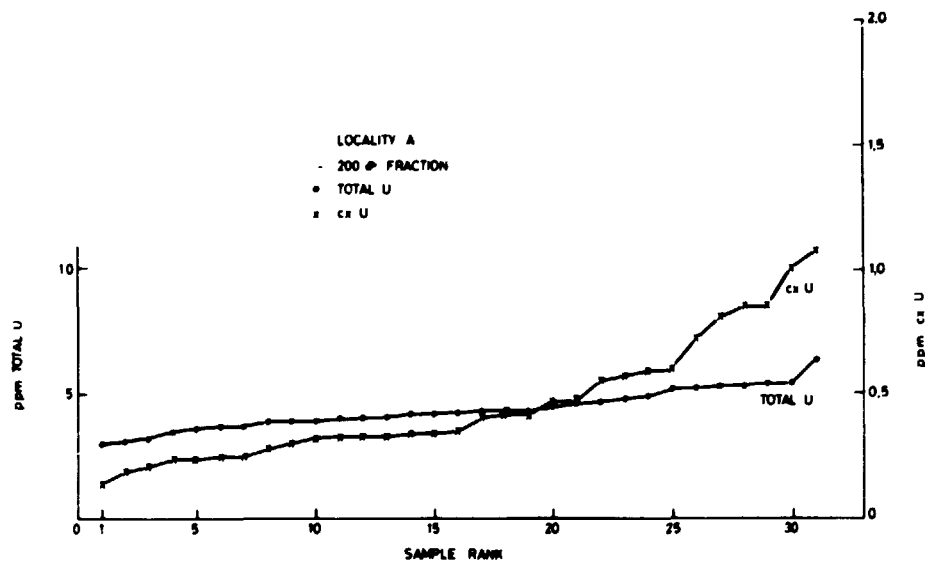


FIG 5. TOTAL URANIUM AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS OF THE MINUS 200 MESH SIZE FRACTION AT LOCALITY A.

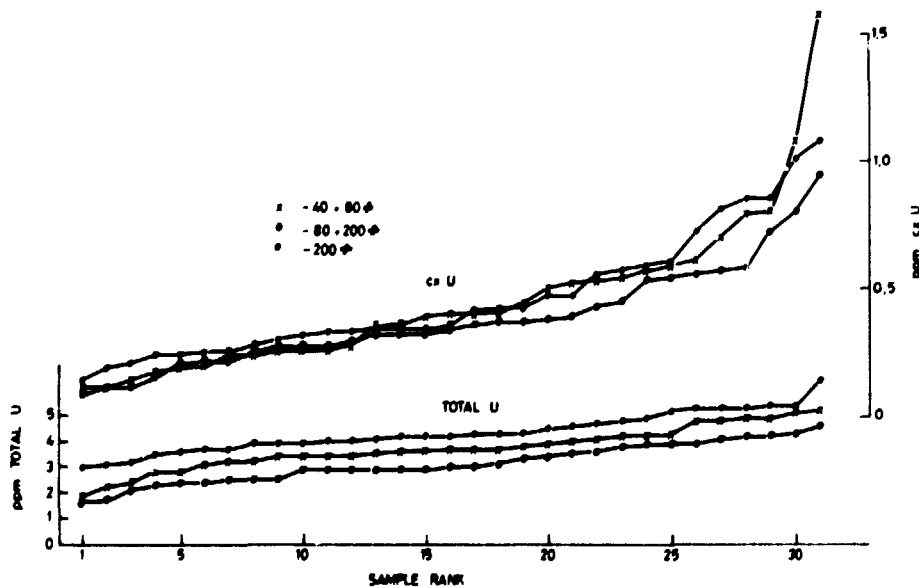


FIG 6. EFFECT OF PARTICLE SIZE ON THE TOTAL URANIUM AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS AT LOCALITY A.

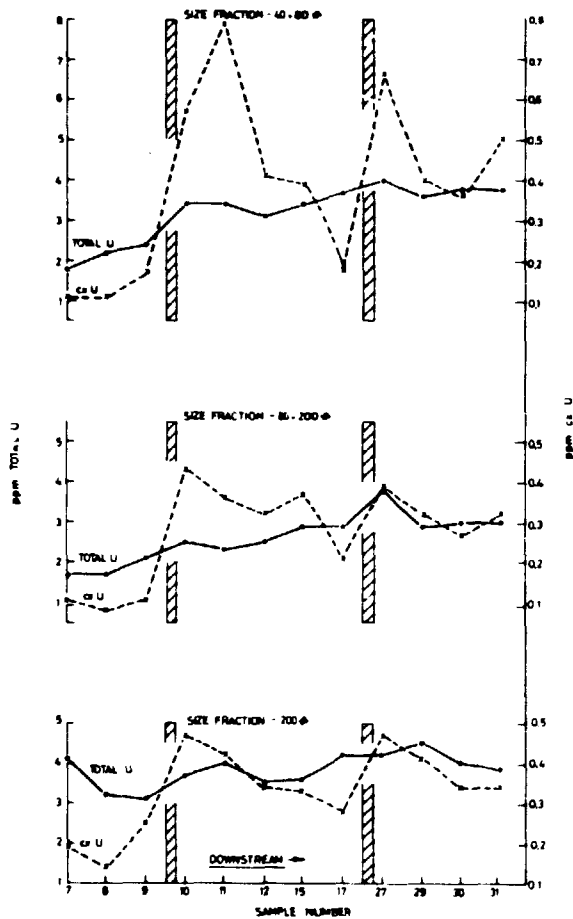


FIG 7 DOWNSTREAM DISPERSION OF URANIUM AT LOCALITY A SIZE FRACTIONS AND TWO PROJECTED MINERALISED ZONES ARE INDICATED

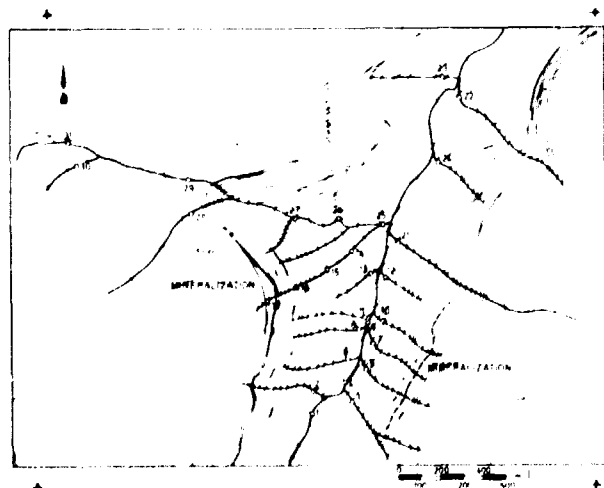


FIG 8 LOCALITY B SAMPLE LOCATION MAP SHOWING APPROXIMATE POSITION OF MINERALIZATION

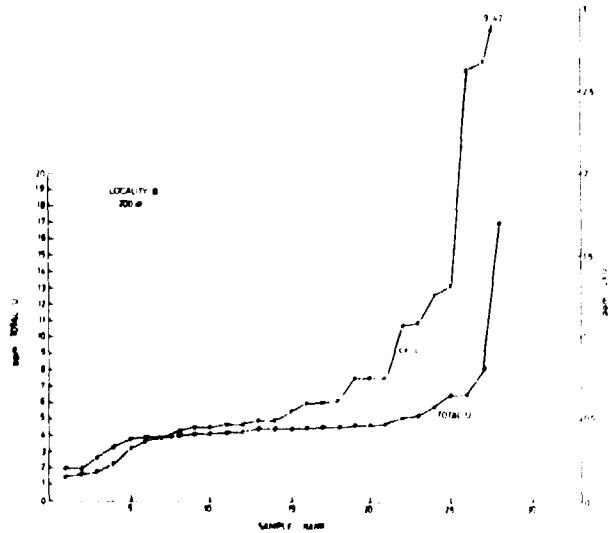


FIG 9 TOTAL URANIUM AND COLD EXTRACTABLE URANIUM CONCENTRATION IN THE LOCALITY B MINUS 200 MESH SIZE FRACTION

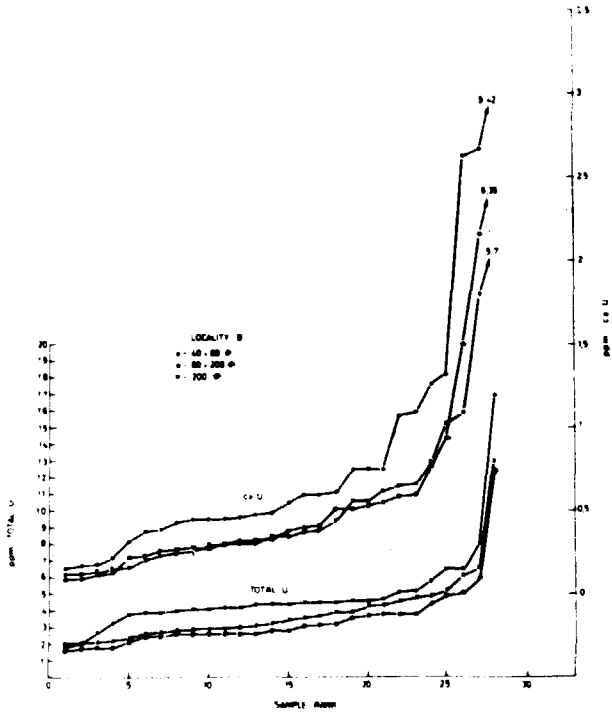


FIG 10 EFFECT OF PARTICLE SIZE ON THE TOTAL URANIUM AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS AT LOCALITY B

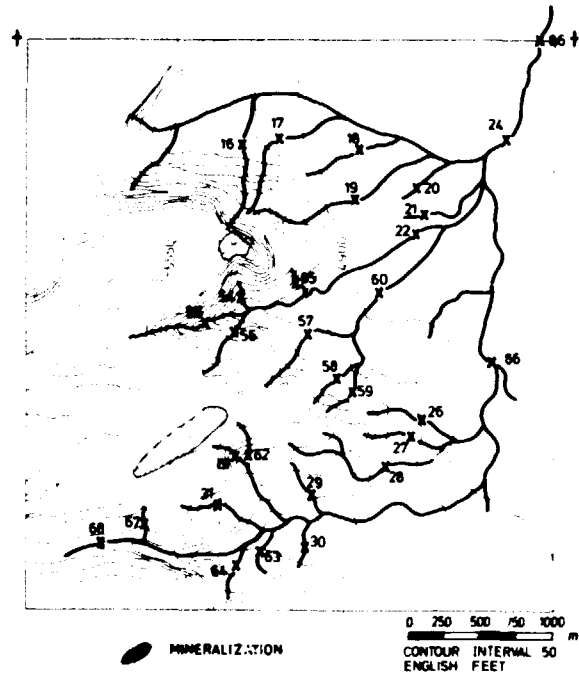


FIG 11 LOCALITY C SAMPLE LOCATION MAP APPROXIMATE POSITION OF MINERALIZATION

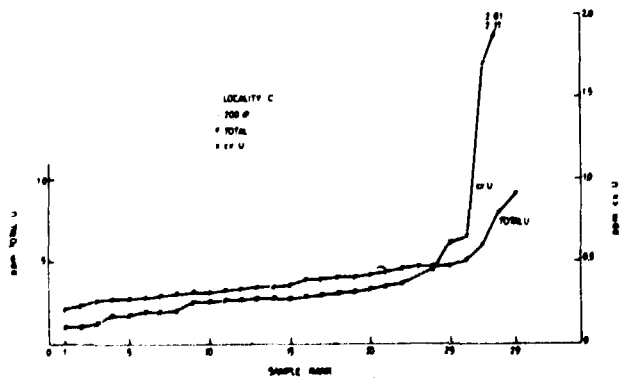


FIG 12 TOTAL URANIUM AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS IN THE LOCALITY C MINUS 200 MESH SIZE FRACTION

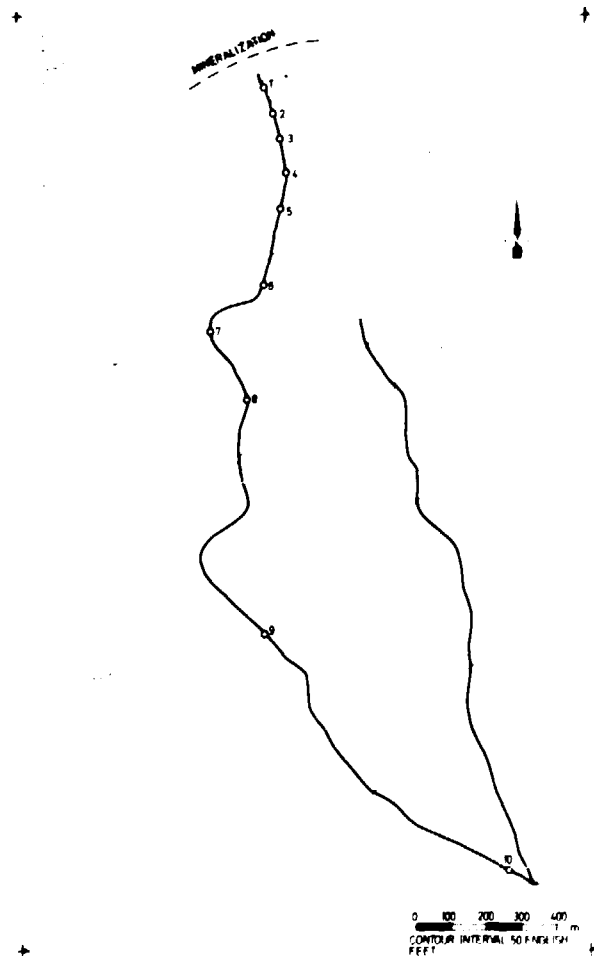


FIG 13 LOCALITY D SAMPLE LOCATION MAP SHOWING APPROXIMATE POSITION OF MINERALIZATION

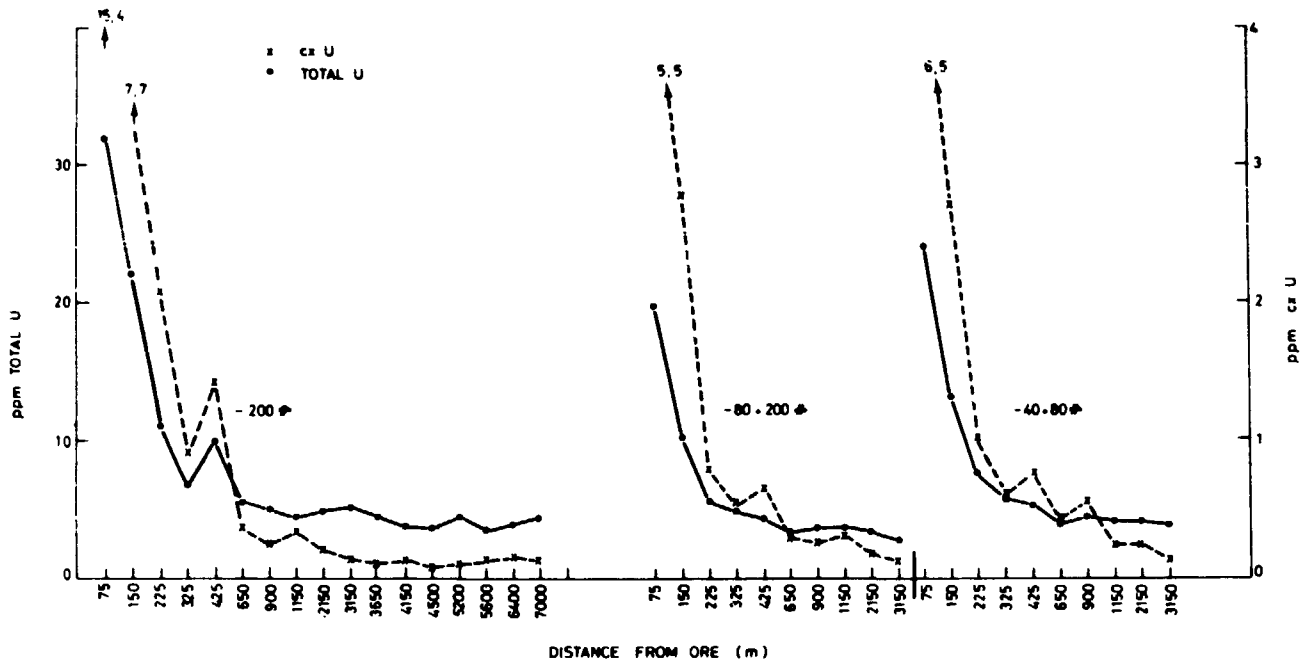


FIG 14 TOTAL URANIUM AND COLD-EXTRACTABLE URANIUM CONCENTRATIONS IN DIFFERENT SIZE FRACTIONS AT LOCALITY D.

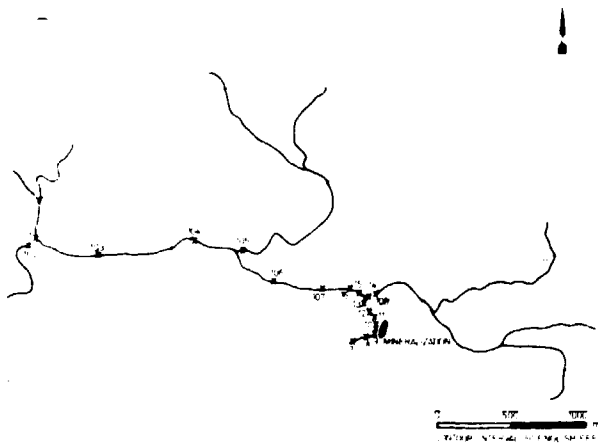


FIG 15 LOCALITY E. SAMPLE LOCATION MAP AND APPROXIMATE POSITION OF MINERALIZATION

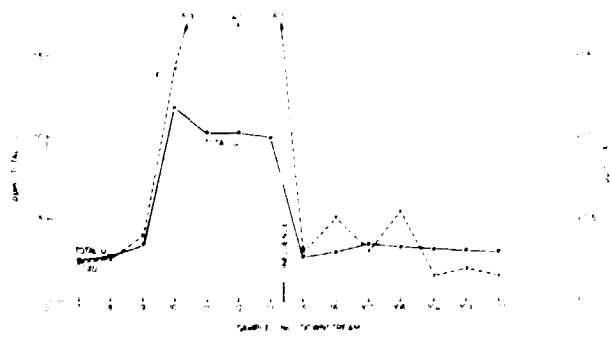


FIG 16 TOTAL U AND CXU IN THE STREAM SYSTEM DRAINING THE MINERALIZED OUTCROP AT LOCALITY E

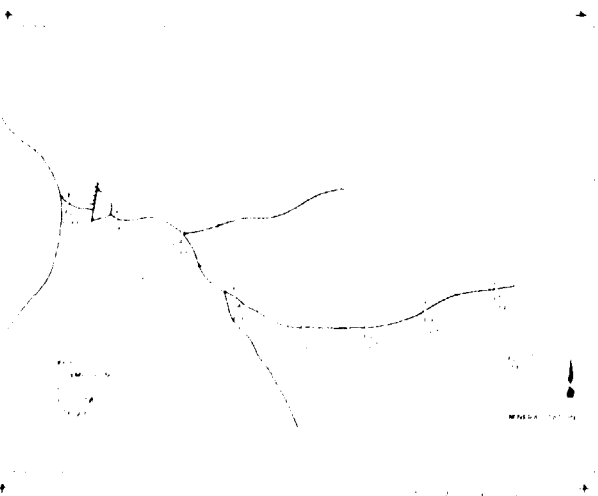


FIG 17 LOCALITY E. MAP SHOWING SAMPLE LOCATIONS, URANIUM CONTENT IN THE 200 MICROMETER AND APPROXIMATE POSITION OF MINERALIZATION

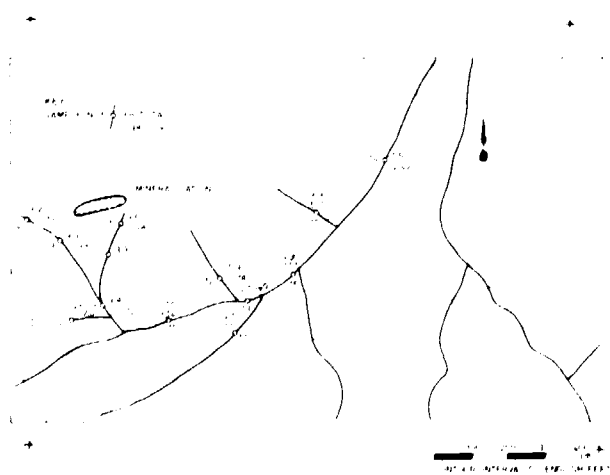


FIG 18 LOCALITY E. MAP SHOWING SAMPLE LOCATIONS, URANIUM CONTENT IN THE 200 MICROMETER AND APPROXIMATE POSITION OF MINERALIZATION

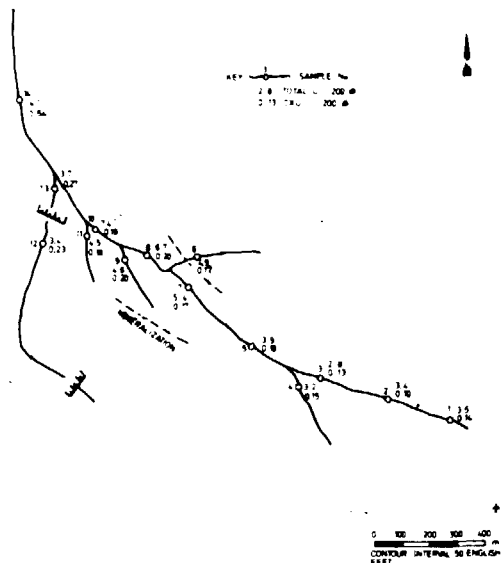


FIG. 19 LOCALITY 1. SAMPLE LOCATION MAP. APPROXIMATE POSITION OF MINERALIZATION

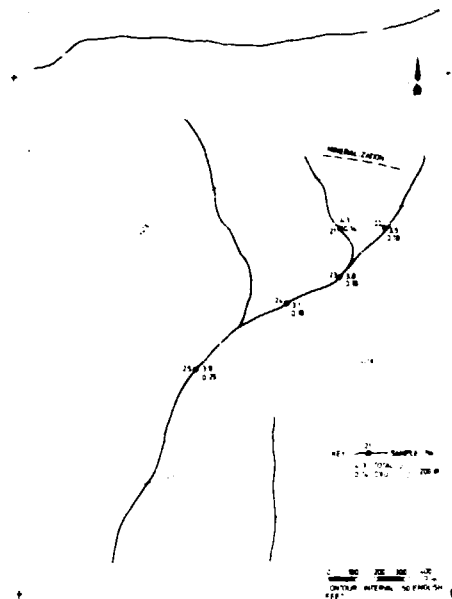


FIG. 20 LOCALITY 2. SAMPLE LOCATION MAP. APPROXIMATE POSITION OF MINERALIZATION

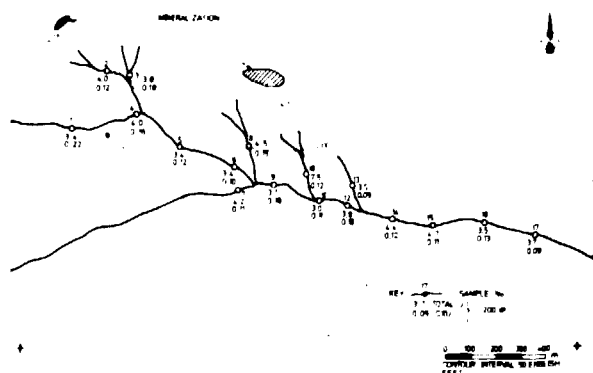


FIG. 21 LOCALITY 3. SAMPLE LOCATION MAP. APPROXIMATE POSITION OF MINERALIZATION IS SHOWN

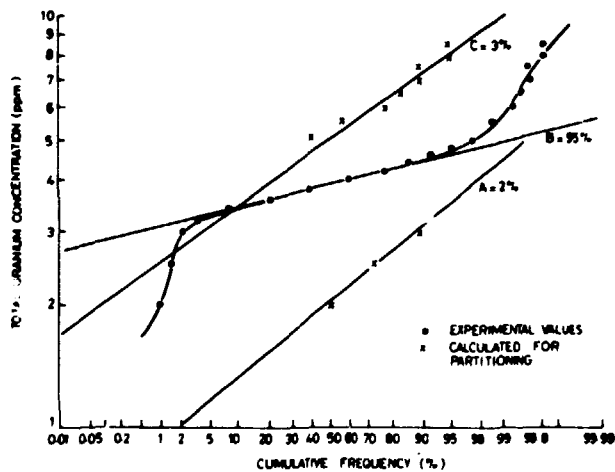


FIG. 22 CUMULATIVE FREQUENCY PLOTS FOR THE TOTAL URANIUM CONCENTRATIONS DETERMINED FOR THE SAMPLES FROM PAALHUS SHEET

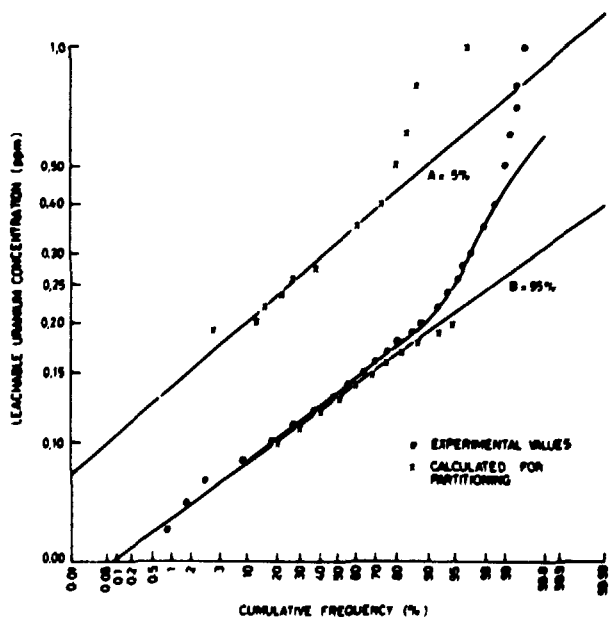


FIG. 23 CUMULATIVE FREQUENCY PLOTS FOR THE COLD-EXTRACTABLE URANIUM CONCENTRATIONS DETERMINED FOR THE SAMPLES FROM PAALHUS SHEET

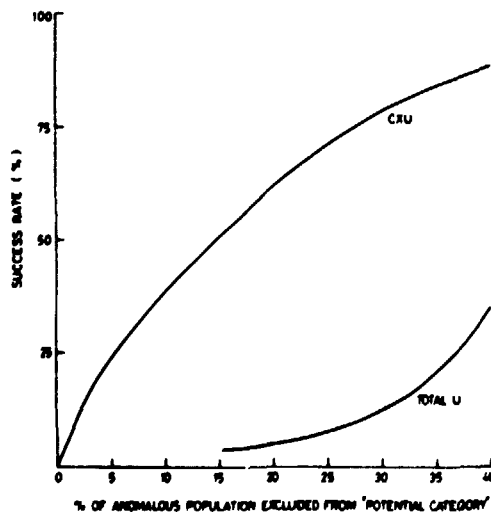


FIG. 24 THE SUCCESS RATE THAT CAN BE OBTAINED AT THE COST OF VARIOUS LOSSES OF THE ANOMALOUS POPULATION THE SUCCESS RATE IS DEFINED AS THE PERCENTAGE OF THE SAMPLES IN THE POTENTIAL CATEGORY THAT CAN BE ASCRIBED TO ANOMALOUS SAMPLES.

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