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A geochemical reconnaissance survey of Sri Lanka using panned mineral concentrates of stream sediments

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Abstract

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Thirteen elements (Au, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sn, Th, U and Zn) were determined in 120 heavy mineral concentrates from Sri Lankan stream sediments of the Highland Group of rocks in central Sri Lanka. The data indicate sporadic occurrences of gold, notably in the north of the region where this metal had not previously been found. The possibility of the existence of a previously unknown area of ultramafic rocks near Balangoda close to the plate boundary with the Vijayan Complex was indicated by high levels of chromium and nickel in the sediments. Background levels of uranium (8 μg/g) were relatively high and three anomalies (>35 μg/g) were detected in stream sediment concentrates. The project has pinpointed several areas where localized intensive exploration for specific minerals should be undertaken. Background levels have also been established for thirteen elements in stream sediment concentrates derived from the Highland Group of rocks.

Introduction

Although large parts of Sri Lanka have a terrain favourable for geochemical reconnaissance surveys of stream sediments, very little work of this nature has been carried out. Indeed as far as is known, the only survey of any magnitude was a project initiated by the Sri Lankan Geological Survey with assistance from the International Atomic Energy Agency. During that survey, uranium (quantified fluorimetrically) and cold-extractable copper, nickel, zinc, lead and cobalt (quantified by atomic absorption spectrophotometry) were determined in samples obtained from 874 sampling sites (Abeysinghe 1980). Reported elemental concentrations (other than for uranium) were necessarily low because of the poor extraction afforded by cold-extractable procedures not involving breakdown of the silicate lattice. Concentrations for zinc reported were always below 100 μg/g and for the other four elements seldom exceeded 10 μg/g.

In 1982, we undertook a systematic survey of 13 elements in the heavy mineral fraction of panned stream sediment samples collected from 120 sites in and around the central mountain chain of Sri Lanka. The aim of this work was to carry out a survey which would pinpoint areas with anomalous concentrations of gold, cobalt, chromium, copper, iron, manganese, molybdenum, nickel, lead, tin, thorium, uranium and zinc; thereby obtaining data of significance for the fields of mineral exploration, agriculture and of animal and public health. It was considered at the same time that even non-anomalous data would be useful for future surveys by establishing normal background levels for each of the 13 elements. The results of this survey are reported below. Although the procedures used are standard and do not introduce new concepts in stream sediment sampling and analysis, we feel that publication of the findings is particularly justified in view of the absence of any previous work of any magnitude in this part of the world.

The geology of Sri Lanka

Sri Lanka has an area of about 66,000 km^2 and some 90% of the island is covered with Precambrian (mainly metamorphic) rocks. The metamorphic rocks (see Fig. 1) are divided into two major groups: The Vijayan Complex and a group of charnockite metasediments. The ancient Vijayan rocks consist mainly of granite gneisses, biotite gneisses and migmatites formed under amphibolite facies conditions and which are mainly confined to the north-western and eastern parts of the island (Abeysinghe 1980; Dissanayake & Navaratne 1981).

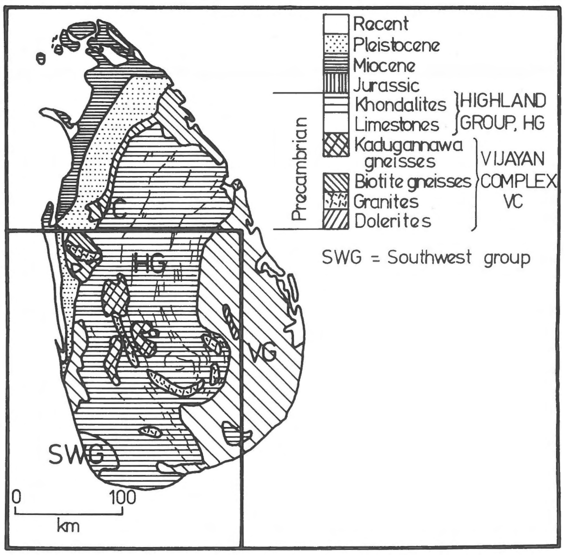

Fig. 1. Geological map of Sri Lanka. The inset shows the area covered by Fig. 2.

The rocks of the charnockite metasediment type have now been divided into the Highland Group (central highlands) and the South-west Group located on the coast near the town of Galle. Our stream sediment survey was confined to streams draining rocks of the Highland Group which are composed of metamorphosed sediments and associated charnockites. The metasediments are predominantly quartzites, crystalline limestones, garnet-sillimanite gneisses, graphite schists, granulites, charnockites and various other gneisses.

The precursors of the Highland Group rocks are presumed to have been laid down in an oceanic basin between two Vijayan complexes which were parts of two adjacent continental plates during the Archaean (Munasinghe & Dissanayake 1980). The collision of the two plates metamorphosed and deformed the sediments in the trough forming the present Highland Group. Analysis of the mineral assemblages in the Highland and South-west Groups suggests that granulite facies conditions prevailed during the metamorphism (Cooray 1961; Hapuarachchi 1975).

Most of the Highland Group forms steep mountains having a steep and highly-dissected terrain with numerous streams and rivers. The highest point of the mountain range is Mt Pidurutalagala (2524 m). There is good access through most of the area by an intricate network of roads many of which service the ubiquitous tea plantations.

Sampling programme

A total of 120 stream sediment samples were taken from an area of about 6000 km^2 encompassing the centres of Ratnapura, Rakwana, Pelmadulla, Balangoda, Haputale, Nuwara Eliya, Kandy, Matale, Kurunegala, Gampola, Nawalapitiya, and Avissawella. Collection localities are shown in Fig. 2.

The area covered by Fig. 2 is shown as an inset in Fig. 1.

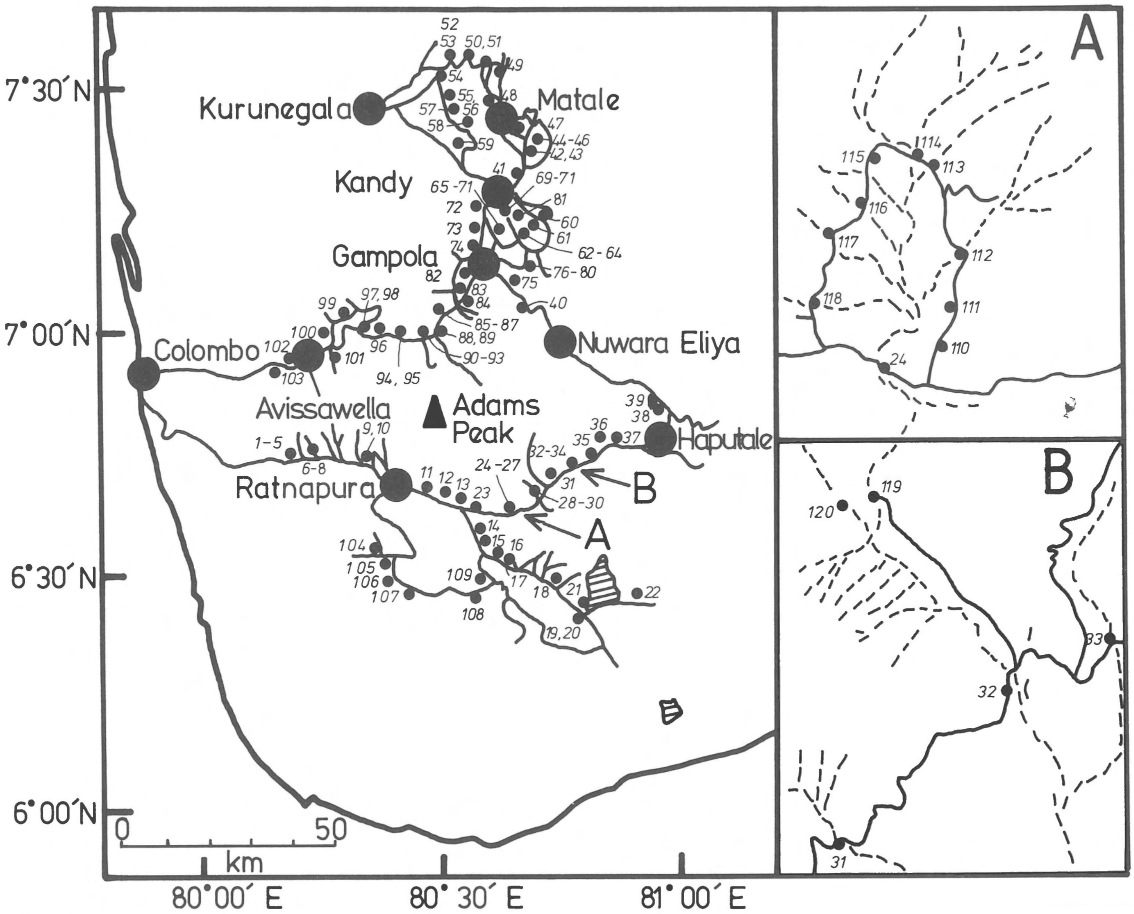

Fig. 2. Map of sampling sites of stream sediments in south-central Sri Lanka. Insets A and B indicate areas of further sampling near sites 24 and 32 of the earlier survey. Broken lines indicate rivers and continuous lines are roads.

At each site, panned heavy mineral concentrates were obtained from active sediments in the stream bed. These sediments were wet-sieved to -20 mesh size, were air dried in the laboratory and were then further sieved to -60 mesh size. Splits of this fine material were used to determine the fraction of heavy minerals in each sample by separation with bromoform to remove quartz and felspars. The -60 mesh material was then further ground to -200 mesh size in an agate mortar and pestle before chemical analysis.

Analysis of samples

The determination of gold in the samples was carried out by the method of Brooks et al. (1982). Samples (0.5 g) were digested on a hot plate with 10 ml of aqua regia and a few drops of bromine in 50 ml squat borosilicate beakers until the volume of digest was reduced to about one half. The digests were then filtered into 20 ml glass vials with screw tops and the volume was adjusted to 15 ml after washing with hot water. To each sample was added 1 ml of methylisobutylketone. The vials were shaken for 5 min and gold was determined in the supernatant layer using a Varian Model 95-GTA heated graphite atomizer coupled to a Varian Model 1275 atomic absorption spectrophotometer fitted with continuous background correction. Sample aliquots were of 10 μl size and the instrumental conditions were as described in Brooks et al. (1982).

The concentrations of nine other elements (Co,

Table 1. Elemental concentrations in heavy mineral fractions of Sri Lankan stream sediments. Except for gold (ng/g) and iron (%) all values are expressed as µg/g.

#	Latitude	Longitude	Heavy min. frac.	Au	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sn	Th	U	Zn
	SITES WITH AT LEAST ONE ANOMALOUS VALUE															
	° ′	° ′														
2	06 N. 44 08	80 E. 11 05	0.80	<4	44	60	14	41	2380	63	10	23	<38	266	29*	531*
3	43 52	12 10	0.74	<4	57	250*	31	39	2230	203*	41	32	<41			312
4	43 52	12 40	0.90	<3	41	101	6	56	2500	139*	7	37	<33	206	36*	344
6	44 20	14 25	0.64	<5	53	94	33	45	2420	<16	19	41	66	431	44*	342
8	43 30	17 30	0.81	6	47	68	35	33	2350	37	15	31	<37	537	52*	309
10	42 00	21 45	0.92	<3	43	67	34	34	2010	<11	11	38	<33	247	30*	288
12	38 40	30 00	0.79	11	52	82	44	42	2220	32	19	35	<38	575	48*	356
14	35 00	34 10	0.79	<4	51	68	92	39	1770	25	13	35	<38	287	34*	471
16	31 50	35 30	0.76	<4	42	61	30	37	1840	<13	<7	39	<39	193	26*	474
18	28 30	43 15	0.90	3	40	61	50	29	1610	22	6	37	<33	241	41*	433
20	24 30	47 25	0.90	<3	41	62	43	36	1890	<11	<6	30	<33	255	41*	422
23	3635"	35 05	0.66	<5	35	47	64	24	1440	<15	8	30	<45			523*
24	36 35	35 45	0.55	13	36	436*	31	25	1180	136*	351*	44	<55	122	12	173
25	36 50	37 40'	0.50	<6	50	270*	18	26	1200	<20	44	66	<60			100
27	37 20	30"00	0.52	<6	58	269*	31	27	1440	<19	67	60	<58			173
28	38 00	42 00	0.69	10	55	261*	23	29	1300	<14	72	33	<43	84	13	174
30	39 20	42 50	0.83	5	39	96	24	24	1150	<12	24	37	<36	489	51*	241
32	43 00	46 00	0.74	9	67	350*	80	32	1780	<30	215*	25	<45			512*
33	43 10	46 50	0.76	9	79	199*	22	53	2040	<13	99*	33	<39			232
34	43 15	47 20	0.83	10	72	175*	36	48	1330	30	88*	36	<36	292	20*	277
35	43 50	49 00	0.73	21*	79	226*	26	53	1710	<14	115*	41	<41			240
38	51 20	57 50	0.62	<5	39	126	21	26	1530	<16	26	56	<48	276	20*	210
41	07 N. 21 05	40 50	0.48	13	48	146	25	25	2400	<21	85*	108*	<63			302
43	22 40	40 40	0.68	<4	22	99	18	22	6770*	<15	18	44	<44			138
45	24 11	41 00	0.75	27*	36	80	17	29	1470	<13	27	41	<40			220
58	26 00	32 45	0.87	<3	67	220*	16	40	2240	<11	77	17	<34	29	2	126
59	22 00	34 20	0.78	51*	54	122	6	45	2820	<13	51	13	<38			186
62	12 20	39 45	0.71	<4	52	127	14	35	2180	49	28	75	<42	459	41*	211
63	12 20	39 46	0.56	<5	36	63	13	21	1880	<18	9	63	<54	477	48*	188
64	12 20	39 20	0.73	10	48	85	23	33	1710	34	23	38	8	343	31*	247
66	12 05	37 45	0.57	60*	61	105	104	30	1140	<18	54	44	<53	95	9	167
69	13 10	36 10	0.73	29*	62	92	44	37	1510	27	27	27	<62	289	29*	41
71	15 20	35 50	0.69	20*	72	109	80	35	1590	<14	42	74	<43			399
72	15 15	35 20	0.92	3	65	190*	40	65	3750	<11	49	49	<33			207
76	08 10	40 50	0.87	5	43	47	40	32	1610	29	17	40	<34	120	26*	264
78	08 45	40 50	0.78	<4	59	77	29	33	1670	<13	49	38	<38	156	21*	231
81	13 55	39 00	0.70	<4	66	116	30	43	2140	<14	40	7	<43	142	22*	314
82	09 30	33 50	0.83	20*	75	108	37	92	2890	<12	36	12	<36			301
83	06 10	33 40	0.61	<5	44	70	21	41	2700	<16	8	18	<49	255	27*	279
84	04 20	32 20	0.92	463*	63	109	60	47	1900	<11	46	27	<33			288
85	03 00	31 15	0.60	<5	45	83	27	35	2500	<17	13	15	<50	302	26*	217
89	00 30	29 10	0.58	<5	38	71	17	28	1380	<17	17	28	<52	472	58*	293
100	06 N. 59 30	15 35	0.67	60*	60	97	16	51	4550*	<15	55	60	<45			276
107	27 55	25 35	1.00	3	45	46	39	54	2100	125*	6	52	<30			400
110	36 42	36 05	0.73		58	481*	38	23	1580	<20	51	34	<50			431
111	37 05	36 15	0.36		38	819*	88	27	2080	<20	88*	57	<50			1061*
112	37 27	36 15	0.35		57	957*	10	25	2070	<20	200*	17	<50			785*

*anomalous value

Table 1 (continued) Elemental concentrations in heavy mineral fractions of Sri Lankan stream sediments. Except for gold (ng/g) and iron (%) all values are expressed as μg/g.

#	Latitude	Longitude	Heavy min.frac.	Au	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sn	Th	U	Zn
SITES WITH AT LEAST ONE ANOMALOUS VALUE																
	° ′	° ′														
113	38 04	36 00	0.53		48	936*	7	18	1550	<20	167*	<10	<50			490
114	06 N. 38 10	80 E. 35 50	0.44		46	750*	19	19	1530	<20	122*	<10	<50			613*
115	38 01	35 30	0.34		53	916*	37	26	1870	<20	105*	44	<50			764*
116	37 45	35 30	0.59		38	440*	36	20	1270	<20	59	17	<50			567*
117	37 30	35 15	0.68		37	1170*	20	20	1400	<20	75	37	<50			433
118	37 00	35 12	0.50		25	490*	18	17	1180	<20	71	<10	<50			620*
119	44 25	44 56	0.73		72	376*	23	29	1740	<20	99*	<10	<50			472
120	44 15	44 53	0.63		57	333*	42	21	1420	<20	83*	<10	<50			539*
BACKGROUND VALUES (MEAN OF 66 SITES)																
				4	47	93	25	37	2140	<20	31	41	<50	50	10	230

*anomalous value

Cr, Cu, Fe, Mn, Ni, Pb, Sn, and Zn) were determined by atomic absorption spectrophotometry using an IL457 instrument with continuous background correction. Solutions for analysis were prepared in the following manner.

Samples (0.5 g) were digested with 10 ml of a mixture of 1:1 nitric/hydrofluoric acids in 50 ml polypropylene squat beakers suspended in a water bath. After heating to dryness, the residues were redissolved in 10 ml of 2 M hydrochloric acid with gentle warming. The solutions were then filtered, washed, and adjusted to 25 ml.

Uranium and thorium were determined on 1 g samples by neutron activation analysis using a SLOWPOKE reactor at Dalhousie University, Canada. The following conditions were used: flux, 5 × 10″ ncm^{-2} s^{-1}; outer site; boron carbide shield; irradiation time, 5 min; decay time, 7 min; counting time, 30 min; counting performed with a low-energy photon detector in conjunction with a Jupiter multi-channel analyzer.

Results and discussion

Because of space limitations, not all data are reproduced in this report. In Table 1, elemental concentrations are presented only for sites containing at least one anomalous value for one element. Anomalies were determined on the basis of two standard deviations above the mean. Geometric means were used for lognormally distributed data and arithmetic means were used for normal data.

A correlation analysis was carried out on all of the data. The computations were made on data transformed to logarithms where the distributions were lognormal and retained as linear units where normal distributions occurred. The results of these tests are shown in Table 2. They show a number of interelemental relationships of varying degrees of significance which will be further discussed below.

Gold

A number of streams and rivers showed anomalous gold values. These were not randomly distributed but appeared to be clustered in the vicinity of sites 59 (Madadeniya), 84 (Gampola) and 100 (Avissawella). Gold was not correlated with any other element. Although this element has previously been reported from the Avissawella and Gampola areas (Dissanayake & Nawaratne 1981), it has not been reported from the Kandy-Matale-Kurunegala region (sites 45-71). It has commonly been supposed that gold is associated with gems in the gem beds of Sri Lanka which tend to be concentrated to

Table 2. Matrix of correlations for various pairs of elemental concentrations in Sri Lankan stream sediments.

	Au	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sn	Th	U
Co	NS											
Cr	NS	NS										
Cu	NS	NS	NS									
Fe	NS	S**	-S*	NS								
Mn	NS	NS	NS	-S*	S**							
Mo	NS	NS	NS	NS	NS	NS						
Ni	NS	S*	S**	NS	NS	NS	NS					
Pb	NS	NS	NS	NS	NS	NS	NS	NS				
Sn	NS	NS	NS	NS	NS	NS	NS	NS	NS			
Th	NS	NS	-PS	NS	NS	NS	NS	NS	NS	NS		
U	NS	NS	S	NS	NS	NS	NS	-S	NS	NS	S**	
Zn	NS	NS	S**	S**	NS	NS	NS	S	NS	NS	S*	S**

S**– very highly significant ($P < 0.001$)
S* – highly significant ($0.001 \leq P < 0.01$)
S – significant ($0.01 \leq P < 0.05$)
PS – possibly significant ($0.05 \leq P < 0.10$)
NS – not significant ($P \geq 0.10$)

N.B. Negative sign before grading implies inverse relationship

the south-west of the Highland Group near Ratnapura. Our work indicates that gold may also be found further north within this group. The highest value of 426 ng/g gold obtained at site 84 (10 km south of Gampola) in the Mahaweli Ganga, deserves follow-up investigations.

Cobalt, chomium and nickel

These three elements are discussed together as they are potential indicators of ultramafic rocks and associated mineralization. Cobalt levels were remarkably constant throughout the area and were exclusively in the range of 13-62 μg/g. There were however areas of anomalous chromium and nickel values. These were concentrated in sites 24 and 32 where maximum values of 259 μg/g and 193 μg/g were found for chromium and nickel respectively, and were far in excess of background values of 74 and 25 μg/g.

As a result of the above findings, a follow-up survey of the area near sites 24 (Hunuwella Ganga) and 32 (Belihul Oya) was carried out. The results (samples 110-118 near site 24, and 119 and 120 near site 32) indicate even higher values in both areas. Inset maps of the resampling programme are shown in Fig. 2. The highest values were 796 μg/g chromium and 89 μg/g nickel for the Hunuwella Ganga and 274 and 72 μg/g respectively for the Belihul Oya. The generally high levels of both elements indicate the possibility of the presence of ultramafic rocks in the local drainage areas, probably as a component of the sporadic ultramafic occurrences along the junction of the Highland Group and Vijayan Complex as at Uda Walawe and Welipatanwila as described by Munasinghe & Dissanayake (1979). The samples from this follow-up survey were low in magnetite as indicated from microscopic examination and by the relatively low iron contents. The high chromium and nickel values are therefore not likely to be derived from ferride minerals rather than ultramafic rocks.

Despite the relative constancy of the cobalt content of the sediments, this element has a strong positive correlation (Table 2) with both iron and nickel, though not with chromium. Nickel has a strong positive correlation with chromium also, as might be expected if it is derived from the weathering of ultramafic rocks. Nickel is also positively correlated with zinc and negatively with uranium. This latter observation is not unexpected as nickel is found predominantly in ultrabasic rocks, whereas uranium is usually concentrated in acid rocks such as pegmatites.

Copper, lead and zinc

The copper content of the sediments is quite uniform and lies in the range 4-59 μg/g with no anomalous values. The same is virtually true for lead (4-53 μg/g). The highest values (sites 41,62 and 107) are slightly above the anomalous threshold of 50 μg/g. Certainly there is no indication of high levels of both elements at any site as would be expected in cases of weathering of sulphide mineralization.

Zinc concentrations were never anomalous and copper was positively correlated with zinc and negatively with manganese. Zinc was in addition strongly correlated with chromium, thorium and uranium. The association with chromium is explained by its probable occurrence in ultramafic rocks in Sri Lanka, a pattern however which is not usual for ultramafic rocks elsewhere in the world. Lead was not correlated with any other element.

Iron and manganese

The iron content of the sediments was extremely high (ca. 28% Fe) and this element is found mainly in the ilmenite and magnetite fractions. Iron was positively correlated with both cobalt and manganese as might have been expected from their geochemical similarity. This implies a magnetite source for most of the iron, cobalt and manganese which contrasts with the low iron contents of sediments rich in chromium and nickel and which are presumably derived from ultramafic rocks.

Molybdenum and tin

Neither molybdenum nor tin was correlated with any other element. The data were however scanty because in most cases, concentrations of both elements were below the detection limit of the analytical method. There were no anomalous values for tin, but there were a few sites with anomalous molybdenum levels which could warrant further investigation as at sites 3 and 4 between Horana and Ratnapura and at the Hunuwella Ganga (site 24).

Thorium and uranium

Thorium and uranium values for 8 of 43 sites are presented in Table 1. It is noteworthy that background values for both elements (40 and 8 μg/g respectively) are relatively high and comparable to those reported by Abeysinghe (1980) for Sri Lankan sediments. Uranium in weathered material is very mobile but a maximum value of 42 μg/g (sites 8 and 30) is extraordinarily high. It is noteworthy that a sample obtained from site 62 (near Galaha) is from the confluence of two streams where uranium ore containing up to 3% U has been found only a few metres away. The uranium value for this site was 29 μg/g which is not highly anomalous. Clearly this site represents a very small but rich deposit with little influence on stream sediment geochemistry. Nevertheless it will be logical to pay special attention to other sites where comparable or higher values were obtained as for example at sites 4, 8 and 12 (near Ratnapura), 18 and 20 (Rakwana Ganga near Timbolketiya), and 30 (near Balangoda). Uranium anomalies in the Timbolketiya region have previously been reported by Abeysinghe (1980) and were presumably derived from weathering of pegmatites. It is noteworthy that this general area corresponds to a zone of tectonic activity proposed by Munasinghe & Dissanayake (1979).

Thorium/uranium ratios (9.65±3.67) were relatively constant throughout the test area, though it appeared that the differences which did exist, were on a regional rather than random basis. Thorium and uranium had a very strong mutual positive correlation and both elements correlated well with zinc. An association between uranium and zinc in sediments and soils has already been observed by Whitehead & Brooks (1969) in New Zealand.

It would seem that a worthwhile follow-up to this stream sediment survey would be an on-foot scintillometric survey of all regions where anomalous uranium values were found in stream sediments. There is no reason in theory why the Highland Group rocks could not be a source of economic-grade uranium mineralization since some of the world's largest and richest uranium deposits (e.g. the 'Ranger' deposit of Northern

Territory, Australia) occur in metamorphic rocks.

General conclusions

It is concluded that this reconnaissance survey of stream sediments derived from the Highland Group rocks has pinpointed a number of areas deserving follow-up investigations on a more intensive basis in localized areas. Of particular importance is the possibility of discoveries of ultramafic rocks between Pelmadulla and Haputale near the plate contact with the Vijayan Complex. Gold occurrences in the northern part of the Highland Group should also be further investigated. A number of uranium anomalies and the high general background of this element in the Highland Group indicates the possibility of discovery of mineralization in the future, particularly if a scintillometric survey were to be carried out.

It is suggested that future geochemical reconnaissance surveys of this type should concentrate on the plate boundary between the Vijayan Complex and Highland Group.

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