

Geochemical Soil Survey for the Exploration of Uranium ore Deposits, NE Vogelkop, Irian Jaya, Indonesia

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Abstract: A local geochemical soil survey was carried out for the exploration of uranium deposits in the area of north - east Vogelkop Irian Jaya, Indonesia. The study explores the use of trace elements associations as an indicator for the possible presence of uranium deposits. This selective association of trace elements is useful since radon, helium or any other gaseous daughter product of uranium can not be used, as there are no known uranium deposits in the area. Hence no local ore samples are available to establish the inter-elemental association as a guide. To establish the trace elements association in ores, known uranium deposits from different parts of the world are investigated. Fifteen ore samples are analysed by Instrumental Neutron Activation Analysis (INAA) for their total metal content. The comparative study of elemental association, established for these 15 ore samples with the elemental association shown by the soil is non-representative of the ore types that could be expected in such a geological environment. This study does not indicate the occurrence of local ore, however the geological set up in the area provides the environments in which granitic uranium deposits can occur.

Key Words: Geochemical Soil Survey, Exploration, Uranium Deposits

Introduction

The soil samples were collected from an area (Fig. 1) in the north - east Vogelkop, Irian Jaya, Indonesia. The selection of locations for detailed soil sampling was made on the basis of radiometric survey. A renewed interest for the exploration of uranium in the area is the driving force to carry out the present study. The objective of this local soil survey is to point out the uranium anomaly. In total 121 soil samples were collected on a 10-meter grid scale. The available 62 soil samples analysed in the present investigation originate from the area (Fig.1) where high levels of radioactivity (15-40 radiometric scintillation/second) was recorded. The objective of the study is to explore the occurrence of uranium deposits by using the model of trace element associations to distinguish between true and/or false anomaly.

So far there are no known (reported) uranium deposits in the area and no local ore samples are available to establish the inter-elemental association for any expected local ore. Therefore, to establish inter-elemental associations in ores, a study was carried out on samples from known uranium deposits from different parts of the world. Fifteen ore samples from known deposits of various classified deposit types (vein type, quartz, pebble, conglomerate type, sand stone type and polygenetic placer type) were obtained from the geological museum at Delft University of Technology. These samples are analysed by INAA to establish trace metal association, considered representative of those deposits. To conclude the study it is assumed that the trace element association in the soils should be consistent with the established elemental association shown by any one of the ore deposits. The study indicates that trace element associations can be useful in exploration surveys.

General and Geological Information About the ore Samples: A short summary of general and geological

information is given about the ore samples used in this study. The trace elements content of uranium in the variety of ore samples is listed in Table 1. The samples 1, 2, 3 and 4 are from different mines, which are classified vein deposits located in the Massif Central of France. There are four major regions in France containing vein type deposits, namely; Morvan, Limousin, Forez and Vendée. These regions are located in the massifs of Hercynian age; only Vendée is outside of the Massif Central. Metamorphic and sedimentary rocks, mainly sandstone, limestone and shale of Palaeozoic age are the oldest rocks in these regions. These rocks are characterised by intrusions of granite that contain two different kind of mica simultaneously and are called two-mica granite. Post Palaeozoic rocks are mainly sedimentary and followed by the volcanic rocks of Tertiary period. All of these uranium ore deposits are found in, or immediately adjacent to, intrusive bodies of these two-mica granites. The two-mica granite is about 330 m.y old, while the age of the uranium mineralization is about 250 m.y. Generally the veins are in the form of stock works and are associated with secondary features.

The samples 5, 6 and 7 are from the uranium district of south - west Erzgebirge, Czech Republic, classified as vein type deposits. The area covers about 35km². The country rock of the district consists of a metamorphic complex, mainly mica schists, phyllites, gneiss, calcic silicates and amphibolites of Proterozoic and early Palaeozoic age. The granites, generally of Hercynian age, intrude this complex.

The ore sample 8 is from a vein type deposit in the Příbram district, Central Bohemia, Czech Republic. The country rock consists of Proterozoic and Cambrian pelitic sediments and conglomerates, intruded by granites, generally of Lower Carboniferous age.

Mineralization is mainly in the form of pitchblende (UO₂),

while faults, dikes, sills and anticlinal folds are common ore controlling structural features.

The sample 9 and 10 are from the classified vein type deposits of Shinkolobwe, Democratic republic of Congo. Mineralization is usually associated with dolomite rocks of Pre-Cambrian age. Quartzite is another major rock type in the area. Brecciated faults and fracture zones generally control mineralization.

The ore sample 11 and 12 are from the Schwartzwalder mine of Golden, Colorado, USA. The ore deposit of this mine is also classified as a vein type deposit. Most of the country rock is Pre-Cambrian and belongs to the Idaho spring formation. The uranium ore is mostly concentrated in granitiferous biotite genesis and quartz-rich muscovite schist. Fault zone breccias and fractures are favourable structural sites for mineralization.

Ore sample 13 is from a quartz-pebble conglomerate type from Quirk mine, Elliot Lake region, Ontario, Canada. This region is part of the Canadian Shield and the geology here is very complex. The major rocks in the region, usually of Pre-Cambrian age, range from granites to volcanic and sedimentary. Uranium mineralization is mostly confined to tightly packed quartz-pebble conglomerates with a matrix of sand and silt.

The sample 14 is from the well-known sandstone type deposits of Green River basin, Utah, USA. In this region continental facies are major contributors to stratigraphy, which is generally of Tertiary age. Carbonate rocks, shale, sandstone, mudstone and unsorted conglomerates are the major rock types. Uranium mineralization is mainly confined to reduced, bleached sandstone or conglomerates usually at the base of the channels.

The last sample, no.15 is from the Rabbit Lake uranium deposits of North Saskatchewan, Canada. Many phases of uranium transport and concentration contribute to the still controversial genetic classification of the deposits. The deposits are located within the Wallstone lake fold belt. The rocks of Wallstone lake belt are generally of Lower Proterozoic age and are dominantly composed of crust rocks, mainly of granitic composition. The strata are generally of arkosic character. Arkose, hornblende, biotite and silicates rich in calcium are the main contributors. Mineralization is commonly polymetallic ore in the form of disseminated veins.

Detailed geological information about these areas is available in literature (Jane, A, Plant *et al.*, 1999; OECD, Nuclear Energy Agency, 1998; International Atomic Energy Agency, 1996; Finch, W.I, 1996; Eckstrand *et al.*, 1995; Dahlkamp, 1993; Dahlkamp, 1989; Voto, 1978; Robert, 1977; Morse, 1977; IAEA, 1974; Carpenter, 1970; Cordfunke, 1969).

General and Geological Information About the Area of Soil Samples: The rock type deposits of NE Vogelkop exhibit Palaeozoic to Tertiary age (Fig. 1). These rock types vary from andesite and gabbrodiorite in the north-eastern part to a metamorphic crystalline series in the south-west, with pegmatite as principal rock (Fig. 1). Further to the south - west the rock type is of predominantly clastic composition, conglomerates, marl, arkosic sand, sandstone, siltstone and limestone are the important constituents. These clastic sediments are also of different facies: littoral, terrestrial and continental (OECD, Nuclear Energy Agency, 1998; International Atomic Energy Agency, 1996; Finch, W.I, 1996; Eckstrand *et al.*, 1995; Dahlkamp, 1993; Dahlkamp, 1989; Voto, 1978; Robert *et al.*, 1977; Morse, 1977; IAEA, 1974; Carpenter, 1970; Cordfunke, 1969; Audretsch, 1966; Visser and Herman, 1962).

Materials and Methods

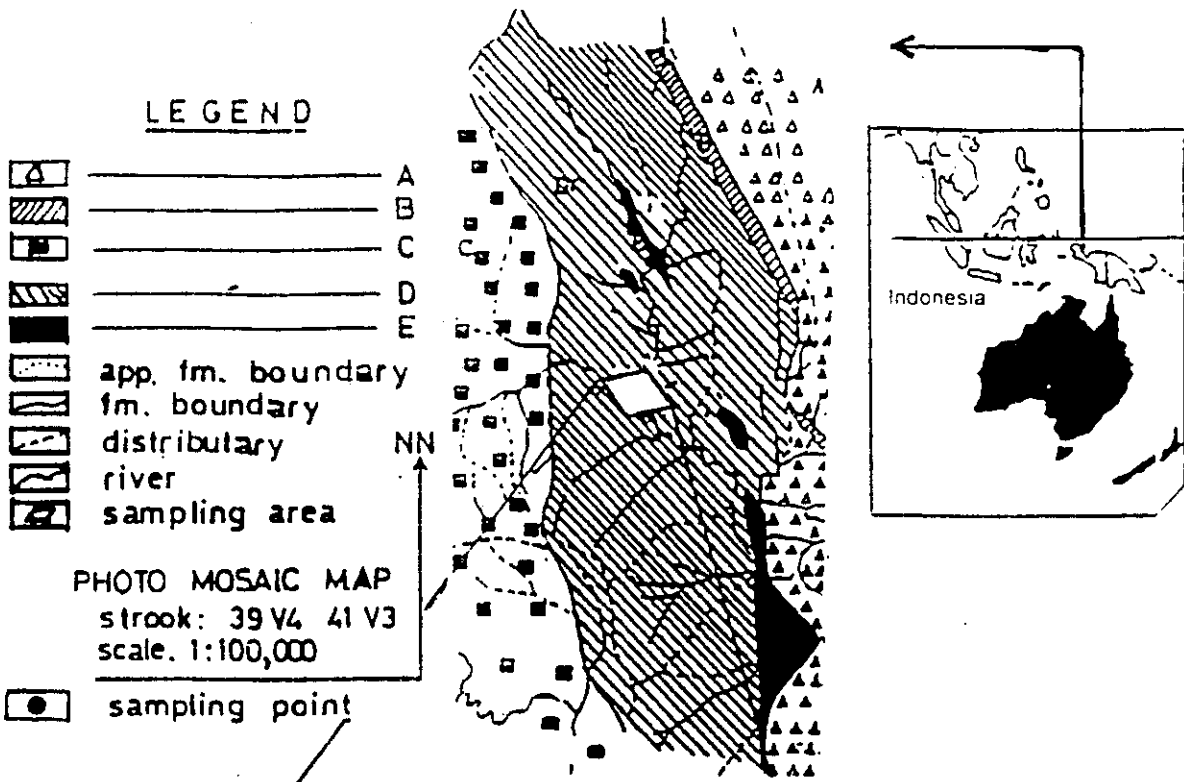
Preparation of Samples: The 62 soil samples were dried in an electric oven at 150°C for about 24 hours, to destroy the organic material, ground and sieved to minus 120 mesh (0-124mm). This fraction of soil samples was used for chemical digestion. The 15 uranium ore samples were ground in a Siebtechnik grinder to minus 200 mesh (0.074 mm), homogenised on a piece of paper and stored in polythene bags.

Total Extraction by HNO₃/HF/HClO₄ of Soil

Samples: The extraction was carried out on 1.g of each sample in Teflon beaker. The samples were digested in strong acids: 5 ml of concentrated HNO₃ then 7 ml of HF were added and heated on a sand bath till near dryness (Hoffman, 1992; Fletcher, 1981; Gatehouse *et al.*, 1977). 4 ml of HClO₄ was added and the samples were again heated to near dryness. The residue was transferred to a 25 ml volumetric flask by using 4-5 ml of 1:1 HCl and distilled water. With two exceptions, when very small amount of silica were still observed, the samples had completely gone into solution. This solution was then vigorously shaken, mixed and allowed to settle overnight. The clear supernatant solution was used to obtain the trace metal concentration by instrumental neutron activation analysis (INAA), (Hoffman and Fletcher, 1992; Bruin *et al.*, 1981). This little modified procedure dissolves the elements in all modes of occurrence e.g. absorbed, co-precipitated, sulphides, oxides and silica lattices.

Total extraction by HNO₃ / HF of uranium ore samples: During the extraction of uranium ore samples some serious problems were encountered, leading to a modification of the extraction method. For reason of safety against radiation, the manipulation such as sieving and weighing were carried out in a glove box under reduced pressure.

1. While attempting to weigh the sample, due to the build-up of electrostatic charge in the plastic glove box, electrostatic interaction was observed between sample and Teflon beaker and part of the sample was lost. To avoid this, platinum crucibles were used in the analytical procedure.
2. The exhaust cistern in which the samples were irradiated during INAA, composed of polyethylene. Because polyethylene reacts with HClO₄ thus the use of HClO₄ was dropped and the procedure was modified from the generally used procedure for total extraction. One gram of sample was weighed into a platinum crucible inside the glove box. Some drops of distilled water were added, to avoid contamination by radio -active material in the form of dust particles. 10 ml of concentrated HNO₃ was added drop by drop to avoid a vigorous reaction. Then 10 ml of HF was added and slow heating on a hot plate was started. With few exceptions the samples were dissolved completely with this procedure, in these cases again 5 ml of concentrated HNO₃ and 5 ml of HF was added and again heated slowly to near dryness. This residue was transferred to a 50 ml volumetric flask by using 5-10 ml of 1:1 HCl and distilled water. This solution, diluted 1:50, was used for INAA.



A-- ANDESITE B-- GABBRODIORITE C-- METAMORPHIC SERIES
 D-- CRYSTALLINE METAMORPHIC SERIES E-- GRANITIC INTRUSION.

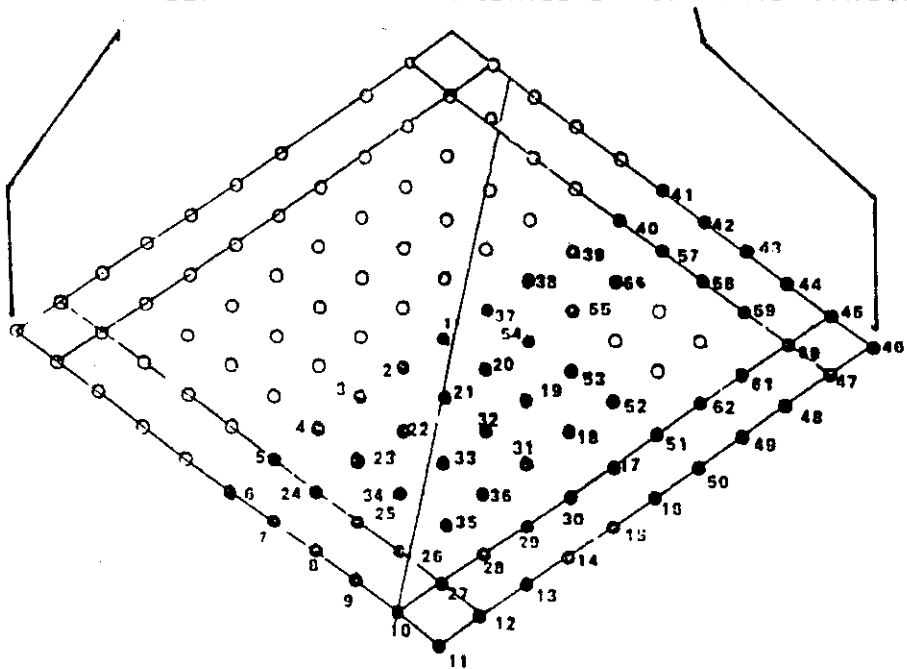


Fig. 1. Geological Map of Breukdal Ransiki, NE Vogelkop, Irian Jaya, Indonesia.
 The Numbers Show the Location of Soil Samples

Table 1: The Trace Metals Content in 15 Uranium ore Samples from Various Locations of the World (all values are in ppm)

S. No Element	France Vein Type				Czech Republic Vein Type				D. R of Congo Vein Type		U.S.A Vein Type		Canada Qtz, Peb, Cong Type	U.S.A Sand Stone Type	Canada Pol. Placer Type
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cr	135	120	115	80	85	70	225	100	140	220	200	150	23	200	7000
Cu	2150	2470	6500	2130	2030	1840	1020	2880	2270	24100	1760	1030	110	3730	1160
W	143	150	285	215	280.4	421.6	560	436.7	283.7	75	2260	557.6	610	859.8	383
Sb	200	225	215	155	690	292	500	175	121	65	1010	130	11.6	353.9	100
Se	270	445	395	225	335	150	365	150	360	370	400	365	11	345	325
La	155	244.5	365.7	140	85	95	371.2	111	313	350	320	350	511	315	339
Sm	34.7	22.5	12.5	7.2	700	60	2250	135	65	34.4	85	50	130	315	100
Au	9.2	27.9	23.7	7.14	13.7	21.1	9.7	5.5	13.6	7.7	16.8	7.3	13.7	17.1	10.3
Th	150	600	950	700	700	600	750	850	550	350	850	650	950	850	600
U	130	86170	44720	188	25240	3710	87600	4770	2430	149100	161200	1958	1270	120000	46500

Results and Discussion

The trace metals content in the uranium ore samples are listed in Table 1 and the trace metals content in the soil samples are listed in Table 2. During the discussion the following signs are interpreted according to this scheme.

- (+), +, (++) , ++ Relatively increasing association/abundance.
- , (-) , -- Relatively decreasing association/abundance.

Comparing the numerical metal values in ores (Table 1) with the average global background values. It is observed that in some particular cases some elements show values, which are low in global terms but significantly high (Fig 1) in local terms. For instance copper in sample 1, is low in global terms, while it is significantly high in local terms. The same applies to Cr and Cu in sample no 15. We translate this numerical comparison of metal values into anomalous inter-elemental relationship or association. On the basis of this comparative study we present (Table 3) the following: association of trace metals in uranium ore deposits.

The established elemental association in different types of uranium deposits is considered as a model for the desirable selection of trace elements for geochemical exploration survey with reference to economic geology and on the basis of information available about the area of soil survey. It is noted that geological environments are not inconsistent with the potential occurrence of uranium deposits, particularly the following two types.

1. Vein type deposits.
2. Sandstone type deposits.

However it is notable that this study is different from usually conducted geochemical exploration surveys as such as that:

1. There are no local ore samples available.
2. There are no local rock samples available.

With reference to Table 1, we present the following symbolic association of trace metals in the mentioned types of deposits. (see at the end of this page)

Comparing the trace metal values in local rocks with that of trace metal values in earlier mentioned types of ore, we present comparison in the following symbolic form: (see at the end of this page)

It is observed that the elemental associations in local rocks are consistent with the elemental associations shown by the ores. This comparison provides indication that the trace metals values in the secondary environments do have the probability of establishing association, which might pose difficulties in differentiating the source of metal contribution, (true or false).

The data of 62 soil samples (Table 2) show that uranium values vary from 0.25 ppm to 22 ppm. This fairly wide variation in values of leading element provides us the cause not to treat the data in total. Thus we split the data into two groups and assume the value of 9 ppm uranium as threshold value. On this basis we find that 15 samples show uranium values, which are higher than 9 ppm, while the rest (47) show values below threshold.

To establish the correlation relation among the trace metals the data is treated by the statistical Spearman's correlation method. Table 4 presents the Spearman's correlation for 62 samples, the Table 5 for 15 and the Table 6 for 47 samples.

The purpose of this exercise is to explore, if higher values of uranium in soil show association with trace metals (group of trace metals) different from the soils with low to very low uranium content. We observe from Table 5 and Table 6 that both of these groups of soil samples show in general a common elemental association. To examine the association of trace metals in the soils, we assume that selection of threshold values for correlation coefficient may elaborate this further.

Type of Deposits	Trace Elemental Association					
	U	Cu	Au	Th	W	Sb
Vein Type	+++	++	++	(+)	(++)	+
Sandstone Type	++++	(+)	++	+	++	-

Ore/Rock	Trace Elemental Association					
	U	Cu	Au	Th	W	Sb
Vein Type	+++	++	++	(+)	(++)	+
Sandstone Type	++++	(+)	++	+	++	-
Granite/Pegmatites	+	+	+	+	+	-
G. Diorites	+	+	+	+	+	+

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Table 3: The Multi-elemental Association in Uranium ore Samples from Various Locations of the World

Type of Deposits	Multi -elemental Association					
Vein Type	U	Cu	Au	Th	W	Sb
Quartz - pebble Type	U	Au	Th	W	La	Sm
Sand stone Type	U	Au	Th	W	(Cu)	

Table 4: The Spearman's (rank) Correlation Coefficient Showing the Trace Elements Association in the Soil Samples, Which Exhibit Uranium Content from 0.25-22 ppm. The Number of Samples N is = 62

Sc	1																				
Cr	0.6	1																			
Fe	0.2	0.3	1																		
Cu	0.4	0.6	0.4	1																	
As	0.4	0.5	0.5	0.3	1																
Sb	0.2	0.2	0	0.2	0.2	1															
La	0.1	0.5	0.8	0.2	0.7	0	1														
Ce	0.2	0.5	0.8	0.5	0.7	-0	0.9	1													
Sm	0.2	0.7	0.7	0.4	0.7	-0	0.9	0.9	1												
Eu	0	-0	0.2	-0	0.3	0.2	-0	0	-0	1											
Yb	0.2	0.2	0.4	0.2	0.9	0.3	0.5	0.5	0.5	0.3	1										
Lu	0	-0	0.4	0	0.6	0	0.2	0.4	0.2	0.8	0.6	1									
Hf	-1	-1	0.2	-0	0.1	-1	0.1	0.3	0.2	0.3	0.1	0.6	1								
Ta	-1	0	-0	-1	-0	-1	-0	-0	-0	0.4	-0	0.4	0.7	1							
W	0	0	-1	-0	-0	0	-0	-1	-0	-1	-0	-1	-0	0	1						
Au	0.3	0.2	0.4	0.7	0.3	0.4	0.1	0.3	0.2	0.4	0.3	0.5	0.4	0.3	0.1	1					
Th	0.3	0.5	0.8	0.7	0.7	0	0.7	0.9	0.8	0	0.5	0.4	0.2	-0	-1	0.5	1				
U	-0	0	-0	-0	0.3	-1	0.1	0.1	0.2	0	0.3	0.3	0.6	0.4	0.2	0.2	-1	1			
Sc		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	
		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	
		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	
		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	

Table 5: The Spearman's (rank) Correlation Coefficient Showing the Trace Elements Association in the Soil Samples, Which Exhibit Uranium Content < 9 ppm. The Number of Samples N is = 15

Sc	1																				
Cr	0.6	1																			
Fe	0.2	0.3	1																		
Cu	0.4	0.6	0.4	1																	
As	0.3	0.5	0.5	0.4	1																
Sb	0.2	0.2	0	0.2	0.2	1															
La	0.1	0.5	0.8	0.2	0.7	0	1														
Ce	0.2	0.5	0.9	0.5	0.7	-0	0.9	1													
Sm	0.2	0.7	0.7	0.4	0.7	-0	0.9	0.9	1												
Eu	0	-0	0.2	-0	0.3	0.2	-0	0	-0	1											
Yb	0.2	0.2	0.4	0.2	0.9	0.3	0.5	0.4	0.5	0.3	1										
Lu	0	-0	0.4	0	0.6	0	0.2	0.4	0.2	0.8	0.6	1									
Hf	-1	-1	0.2	-0	0.1	-1	0.1	0.3	0.2	0.3	0.1	0.6	1								
Ta	-1	-1	-0	-1	-0	-1	-0	-0	-0	0.4	-0	0.4	0.7	1							
W	0	0	-1	-0	-0	0	-0	-1	-0	0.7	-0	-1	-0	0	1						
Au	0.2	0	0.5	0.4	0.5	-0	0.1	0.5	0.2	0.5	0.4	0.8	0.6	0.3	-1	1					
Th	0.3	0.5	0.8	0.7	0.7	0	0.7	0.9	0.8	0	0.5	0.4	0.2	-0	-1	0.6	1				
U	-0	0.2	0.2	0	0.3	-1	0.7	0.6	0.6	-1	0.4	0	0.3	0	0.3	0.1	0.3	1			
Sc		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	
		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	
		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	
		Cr		Fe		Cu		As		Sb		La		Ce		Sm		Eu		Yb	

Table 6: The Spearman's (rank) Correlation Coefficient Showing the Trace Elements Association in the Soil Samples, Which Exhibit Uranium Content > 9 ppm. The Number of Samples N is = 47

Sc	1																				
Cr	-0	1																			
Fe	0	0.7	1																		
Cu	0	-1	0	1																	
As	-0	0.9	0.8	-1	1																
Sb	-0	-0	-0	0	0	1															
La	0	0.7	0.8	-0	0.7	-0	1														
Ce	0.7	0	0.4	-0	0.1	-1	0.6	1													
Sm	0.5	0.4	0.7	-0	0.6	0	0.7	0.8	1												
Eu	0.2	0.6	0.8	-0	0.7	-0	0.9	0.7	0.9	1											
Yb	-0	-0	-0	0	-0	0.5	0.1	0	0.2	0.3	1										
Lu	0.5	-0	0.1	0	-0	-1	0.3	0.6	0	0.2	-0	1									
Hf	0.8	0.1	0.3	-0	0.2	-0	0.4	0.9	0.8	0.7	0.2	0.3	1								
Ta	0.8	-0	-0	-0	-0	-0	-0	0.3	0.1	-0	0.6	0.3	0.4	1							
W	0.9	-1	-0	0.2	-0	-0	0	0.8	0.5	0.2	0.2	0.4	0.7	0.5	1						
Au	-0	0.6	0.2	0	0.6	0.7	0.4	0	0.3	0.4	0.7	-0	0.2	-0	0	1					
Th	-1	0.8	0.7	-0	0.9	0.1	0.8	0	0.5	0.8	0.3	-0	0.1	-1	-0	0.7	1				
U	0	0.5	0.9	0.2	0.6	-0	0.8	0.4	0.6	0.8	0	0	0.1	-0	0	0.2	0.6	1			

Thus the following threshold values, a lower (0.2 correlation coefficient) and a higher (0.5 correlation coefficient) are selected for this purpose. The following order is observed for association of trace metals, when we apply the correlation coefficient limit of 0.2, with the uranium as an independent element,

> Increasing correlation coefficient, threshold is 0.2

N=15 Cr- Fe > As- Hf- W - Th > Yb > La- Ce- Sm>U

N=47 Cu- Au > Ce > Cr > As- Sm- Th > La- Eu> Fe>U

However it is noted that an almost identical order in association exist, when a correlation coefficient limit of 0.5 is applied.

> Increasing correlation coefficient, threshold is 0.5

N=15 Ce- Sm- La > U

N=47 Cr > As- Sm- Th > La- Eu > Fe > U

The only difference is that in the case of 47 soil samples (uranium 9 ppm or lower) the correlation is rather enhanced (or vice versa). The analysis of this correlation suggests the following conclusions.

Conclusion

1. The elemental association in soil samples from NE Vogelkop does not correspond to the association found in the uranium ore types expected in such geological environments.
2. Metal concentrations in the soil samples from NE Vogelkop were compared with the global average values of these metals in granites, granodiorites and soil. These concentrations rarely exceed the average values in different rock types or soils by a factor 2 to 3, indicating that these values do not point into the direction of the occurrence of uranium ores.
3. This association can be referred to that of lithology (pegmatites), as pegmatites are almost always characteristically rich in elements like, Cr, Fe, U and rare earth elements.
4. The high uranium content in the soils can represent a local enrichment by weathering of pegmatite minerals, like monazite, thorite and xenotime.
5. The exclusive association of the rare earth elements La, Sm and Ce with relatively high values of uranium in the soil samples confirm that the enrichment of uranium is due to weathering.

As we are dealing with soil samples, we also have to consider the trace element mobility in secondary environments. The area is generally forested with high rainfall. We assume the pH (< 5.5) and Eh (< 2) both to be fairly low. Under these conditions the trace elements in ores can be grouped in the following order according to their mobility in the secondary environments.

Th, W Highest mobility

U

Cu, Au Lowest mobility

Hence, in given secondary environments, the metal values in soils should be characterised in the following order:

Cu, Au > U > Th, W (In units of global abundance).

The numerical values in primary data (Table 2) show that the elements form a series that does differ from the earlier mentioned groups of elements (Sample 11, 15, 18, 29 and so on). Which again indicate that trace elements are concentrated in soil from a non-mineralised source, most probably pegmatites. The geology of the area is promising for the occurrence of uranium and further exploration is recommended.

Acknowledgments: The authors acknowledge with many thanks the guidance received from Dr. P. Bode of the Interfaculty Reactor Institute (IRI) Delft, for analysing the uranium ore and soil samples. Authors are thankful to the Geological Museum, Delft University of Technology for providing the uranium ore and soil samples. Authors thank the staff of the International Institute for Aerospace Survey and Earth Sciences (ITC), Delft, for help at various stages during the project.

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