Part A
Reconnaissance Surveys

The purpose of a reconnaissance survey is to explore or evaluate a large area, up to hundreds or even thousands of square kilometers, for indications of mineralization. There is no intention that a reconnaissance survey will find individual mineral deposits. Rather, the spacing and type of samples chosen are intended to: (a) identify and subdivide rapidly, and at relatively low cost, favourable geochemical provinces and mineralized districts; or (b) provide geochemical discrimination to geophysical or geological features which appear favourable for follow-up surveys. In this manner, barren ground is eliminated and emphasis is placed on the more promising areas.

There are seven problems in this section of the book which will enable the student to study and evaluate how four sampling media (stream sediments, rocks, surface water, and vegetation), on four continents, have been used in reconnaissance surveys.

1 / QUESTIONS

The Influence of Geology and Geography in Determining Thresholds, Colorado, U.S.A.

BASIC DATA

Source: S. L. Bolivar

Acknowledgement: S. L. Bolivar

Location: Montrose 1° × 2° quadrangle, southwestern Colorado

Geology:

  rock types: very diverse (see "Introduction" below and Broxton et al., 1979)

  known mineralization: three major uranium districts with over 90 uranium occurrences; also the Colorado Mineral Belt (base and precious metal mineralization) traverses the quadrangle from northeast to southwest

  anticipated target: areas favorable for potential uranium mineralization

Topography:

  relief: highest elevation is 4393 m in mountains (northeast); lowest elevation is 1500 m in basins (northwest)

  drainage: West Elk, San Juan and Sawatch Mountains form major divides; stream velocities moderate to low in summer

Climate: precipitation 600 mm per year in higher elevations to 250 mm per year in valleys (semi-arid); fairly constant throughout year

Vegetation characteristics: altitudinally zoned; sagebrush in lower elevations, pine and aspen in higher elevations

Type of survey: reconnaissance and follow-up

Survey conditions:

  density: 1 sample per 10 km^2 (nominal); follow-up at 1 sample per 1 km^2

  field conditions: fairly good access with 4-wheel drive vehicles

  time of year sampled: summers of 1976 and 1977; follow-up in Fall, 1979

  overburden conditions: not applicable

Materials sampled: composite sample collected from three spots at each location; 1857 stream sediments and spring precipitates were initially collected; 2087 locations were sampled during a follow-up study

Analytical:

  preparation procedure: samples sieved in the field

  size fraction used: that which passed through 100 mesh screen

  extraction: all elements determined by "total" analysis methods

  elements determined: U and 43 other elements

  analytical methods: U by delayed neutron counting; 9 elements (base metals) by X-ray fluorescence; remainder by NAA (neutron activation analysis)

Special comments: Analytical procedures have been reported in Broxton et al. (1979). These samples were originally collected as part of the NURE program.

INTRODUCTION

As part of the National Uranium Resource Evaluation (NURE) program, 1857 stream sediment and spring precipitates were collected at a nominal density of 1 sample per 10 km^2 for the Montrose 1° × 2° quadrangle, Colorado. These samples were collected during the summers of 1976 and 1977 according to established field procedures. Analytical results (uranium by delayed neutron counting; 43 other elements by X-ray fluorescence and neutron activation analysis) are accurate to ±10% of the amount present for most elements. An open-file report containing the raw data and a preliminary evaluation of the quadrangle for potential uranium mineralization was released in 1979 (Broxton et al., 1979).

As a result of the initial survey, sediment samples underlain by Precambrian crystalline rocks were found to contain high concentrations of uranium. A follow-up study was conducted in the Fall of 1979 during which samples were collected at a density of 1 sample per 1 km^2 from 2087 locations that drained Precambrian rock units (Maassen, 1981). These samples were collected and analyzed in the identical manner as the reconnaissance samples described above. The elemental analyses from these

two studies provided data on both the reconnaissance and follow-up scales for the 19,200 km² Montrose quadrangle.

The Montrose quadrangle has extremely diverse geology and geography; in a broad sense the quadrangle can be divided into three geologic-geographic provinces which are shown in Fig. 1-A. (1) The easternmost Crystalline Province dominantly contains metasediments and metavolcanics intruded by 1400-1700 m.y. granitic batholiths and mafic plutons. The terrane is mountainous and rugged. (2) The central and southeast portions of the quadrangle comprise the Volcanic Province. Here, the West Elk and San Juan volcanic fields provide rugged topography. These rocks are mostly Oligocene in age and cover about 35% of the quadrangle. (3) The western Plateau Province is underlain by relatively flat-lying Cretaceous shales and sandstones. Climate in the Plateau Province is semi-arid and topography consists of gentle rolling hills.

There are three major uranium districts and several uranium deposits found throughout the quadrangle. Vein-type uranium mineralization is typically found in the mountainous granitic terrane of the Crystalline Province whereas the Plateau Province is favorable for sedimentary-type uranium deposits (there are several uranium mines just west of the western quadrangle boundary). Uranium deposits are also associated with alkalic rocks and/or pegmatites (Crystalline Province) and there may be some potential for uranium mineralization associated with volcanic rocks (Volcanic Province). The Colorado Mineral Belt runs from the northeast quarter of the quadrangle diagonally across to the southwest corner. Its maximum width is 50 miles although the Belt generally averages 20 miles. This northeast-trending belt is rich in metal deposits associated with Laramide and Middle Tertiary plutons. Metal concentrations (Au, Ag, Pb, Mo, W, Zn, Cu, U) in sediments here are very high (compared to normal crustal abundances).

PROCEDURE

The student will be required to consider and evaluate the data in Tables 1-A and 1-B at appropriate times in order to answer the questions below. Study these tables, as well as Fig. 1-A, and then proceed to the questions.
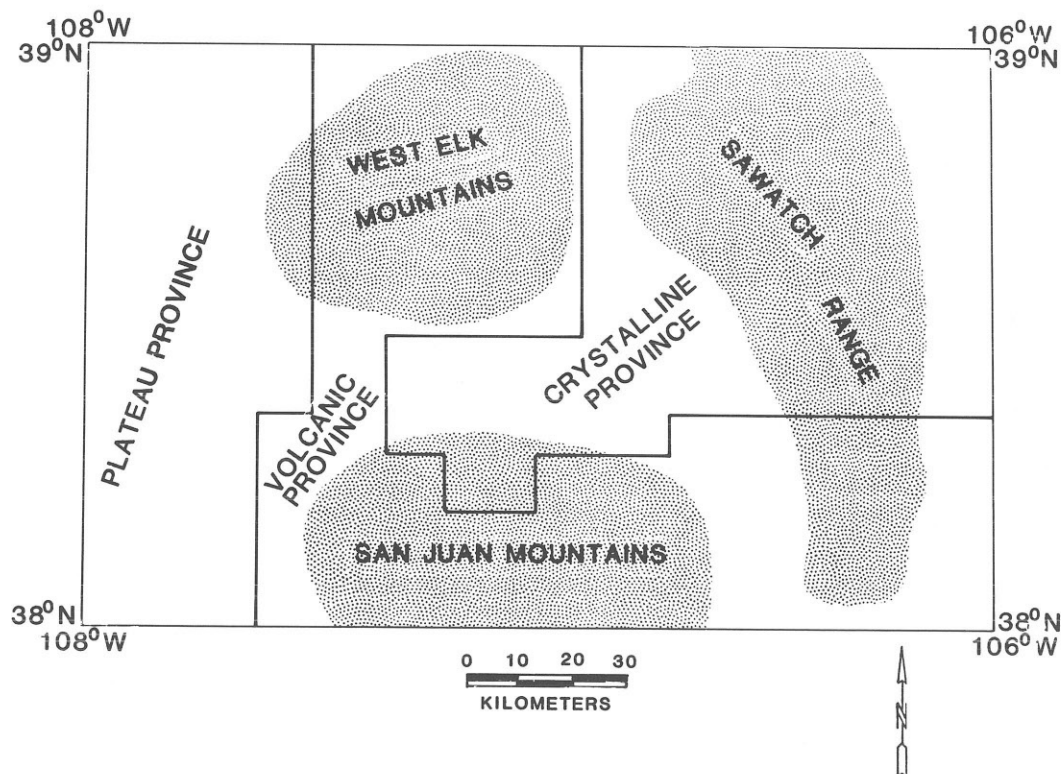

Fig. 1-A.   Map showing the major geologic-physiographic provinces for the Montrose 1° × 2° quadrangle, Colorado.

Table 1-A
Summary of uranium data for stream sediment and spring precipitate
samples from the Montrose Quadrangle, Colorado

Sample type	Sample size	Mean (ppm)	s.d. (ppm)	Median (ppm)	Mean plus 2 s.d. (nearest ppm)
A. Data from samples obtained during the reconnaissance survey, 1976 and 1977					
All sediments and precipitates	1857	6.4	9.0	3.9	24.
Wet stream sediments	1087	7.1	10.5	4.0	28.
Dry stream sediments	474	4.9	4.5	3.7	14.
Wet spring precipitates	261	6.0	8.6	4.0	23.
Dry spring precipitates	35	4.5	3.0	3.7	11.
B. Data from samples obtained during the follow-up survey, 1979					
All sediments and precipitates	2087	14.3	25.0	6.6	64.
Wet stream sediments	984	18.5	24.5	9.5	68.
Dry stream sediments	1020	9.5	22.3	5.1	54.
Wet spring precipitates	77	24.2	24.7	7.6	74.
Dry spring precipitates	6	17.8	17.3	7.5	52.
C. Statistics from combined studies (from combined A and B)					
	3944	10.6	19.6	—	50.
D. Statistics from the individual provinces (from combined A and B)					
Crystalline Province	2321	14.9	24.5	—	64.
Volcanic Province	1214	4.5	3.5	—	12.
Plateau Province	409	3.7	0.9	—	6.

Table 1-B
Reconnaissance uranium data for each geologic unit
in the Montrose Quadrangle, Colorado
(modified from Bolivar et al., 1981)

Formation	Description	Number of samples	Mean (ppm)	Standard deviation (ppm)
Qal	alluvium, glacial, unconsolidated deposits	796	12.7	17.2
Tsd	Dry Union + Santa Fe fm., mostly Pliocene and Miocene sediments	129	8.8	9.9
Tig	Miocene basaltic intrusives	5	4.4	2.0
Tas	Oligocene rhyolitic ash-flow tuffs, andesitic lavas + breccias, + sedimentary deposits	381	5.9	6.9
Tga	Middle Tertiary granitic intrusives	148	15.2	16.7
Tuf	Oligocene andesitic lavas + breccias, densely welded rhyolitic tuff	579	4.5	4.1
Tgm	Includes Green River, Telluride, Wasatch formations, + Ohio Creek complex	31	3.3	0.6
Tci	Granodioritic Laramide intrusives, + alkalic + mafic intrusives of limited outcrop	27	13.9	12.2
Kj	Includes Mesaverde formation, Dakota + Jurassic sandstones	240	3.9	1.2
Km	Mancos Shale	278	3.9	1.2
Pal	Mostly Paleozoic sandstones + limestones	224	8.1	12.1
PCg	Includes Precambrian X and Y granitic rocks	704	20.5	35.2
PCm	Precambrian metamorphics + metavolcanics	423	10.6	19.4

QUESTIONS

1. A project geologist, whose job it was to select areas with potential for uranium mineralization, examined the raw statistics provided in the open-file report (Broxton et al., 1979), which is based on data obtained from the 1976 and 1977 reconnaissance survey. In order to make a rapid assessment of the data he decided to group all sample types and to look only at mean concentrations for "all sediments" (Table 1-A; part A) which includes the spring precipitate values. He calculated an anomaly threshold of 24 ppm by using the mean plus 2 s.d. (standard deviations). Do you believe 24 ppm is a representative threshold value for the data? At this time do not argue on the merits of using the method of selecting threshold values on the basis of the mean plus 2 s.d. but rather examine the statistics from the various sample populations (Table 1-A, part A) and discuss whether it is appropriate to lump the respective sample types and arrive at a threshold of 24 ppm.

2. Before the project geologist could plan any field investigations a follow-up study became available for the eastern portion of the Montrose quadrangle (Maassen, 1981). Samples that drain Precambrian granitic rocks were collected from this area. Statistics for the follow-up survey are given in Table 1-A (part B). How do these values compare to statistics based on the initial reconnaissance survey discussed above?

3. After examining both sets of statistics provided in the open-file reports the project geologist decided to combine both sets of data (Table 1-A, part C). Thus he selected an anomaly threshold of 50 ppm using the same method as above (mean plus 2 s.d.). He was aware of the fact that he was mixing sample populations in his statistics but he justified this on the basis of his time constraints and because he was only making a preliminary evaluation. Consequently, the project geologist was able to identify several clusters of samples with high uranium concentrations in the northeast quarter of the quadrangle (i.e., in the Crystalline Province). These areas generally coincided with areas identified as favorable for potential uranium mineralization by Broxton et al. (1979). The geologist was a little puzzled by the fact that there were no "anomalies" for the rest of the quadrangle. What might you attribute this to? (To answer this question, examine and carefully consider all the data in Fig. 1-A and in Table 1-A (including part D).

4. Frequently one may not have the desire (or facilities) to compute statistics based on geologic/physiographic

boundaries, especially when dealing with large numbers of samples. However, the benefits clearly outweigh any inconvenience. By looking at concentration ranges for each geologic unit one can make a much more accurate evaluation using reconnaissance data (Table 1-B). In the Montrose quadrangle some areas were heavily sampled, whereas other areas were not. Some samples were taken from drainages from the Colorado Mineral Belt where elements have concentrations that range from 10-100 times normal crustal levels. Each of these factors affect interpretation of the data. For example, assume there are two clusters of anomalous samples located somewhere in the Montrose quadrangle. One anomalous cluster (cluster A) has three samples with an average uranium concentration of 6 ppm uranium, and the other anomalous cluster (cluster B) has four samples with an average uranium concentration of 74 ppm. In which formation(s) would these clusters be considered "anomalous" based on the data in Table 1-B? (Consider anomalous to be concentrations greater than the mean plus 2 s.d.).

5. (a) For this problem, threshold was determined by using the method of calculating the mean plus two standard deviations and assuming that all values above this number (i.e., the upper 2½% of the data set) will be anomalous. What are the limitations of this method?

   (b) List at least five other possible methods of determining threshold.

6. What principles applicable to exploration geochemistry are illustrated by this problem?

REFERENCES

Broxton D. E., Morris W. A. and Bolivar S. L. (1979) Uranium hydrogeochemical and stream sediment reconnaissance of the Montrose NTMS Quadrangle, Colorado, including concentrations of forty-three additional elements. U.S. Department of Energy, Grand Junction, Colorado, Open-File Report GJBX-125(79).

Maassen L. W. (1981) Detailed uranium hydrogeochemical and stream sediment reconnaissance data release for the eastern portion of the Montrose NTMS Quadrangle, Colorado, including concentrations of forty-five additional elements. U.S. Department of Energy, Grand Junction, Colorado, Open-File Report GJBX-105(81).

Bolivar S. L., Balog S. H., Campbell K., Fugelso E. L., Weaver T. A. and Wecksung G. W. (1981) Multisource data set integration and characterization of uranium mineralization for the Montrose Quadrangle, Colorado. U.S. Department of Energy, Grand Junction, Colorado, Open-File Report GJBX-148(81).

2 / QUESTIONS

Petrological Interpretations From Multi-Element Stream Sediment Reconnaissance Data, Zimbabwe

BASIC DATA

Source: K. A. Viewing

Acknowledgment: K. A. Viewing and N. J. Topping

Location: Sabi Communal Land, Zimbabwe

Geology:

  rock types: a mixture of igneous and metamorphic rocks whose characterization is the objective of this problem

  known mineralization: none

  anticipated target: unspecified; various types of mineralization are known within a 100 km radius

Topography:

  relief: moderate relief; elevations range from 1200-1500 m

  drainage: dendritic

Climate: mild temperatures; annual precipitation averages about 700 mm/yr most of which is in the summer

Vegetation characteristics: open woodland dominated by leguminous fire-resistant species of trees; tall perennial grasses and flowering herbs occupy open ground

Type of survey: reconnaissance using stream sediments

Survey conditions:

  density: samples collected at intervals of about 600 m along streams; each sample represents 1 km² of catchment

  field conditions: good

  time of year sampled: dry season; stream channels dry

  overburden conditions; deeply weathered residual soils; little outcrop

Material sampled: stream sediments

Analytical:

  preparation procedure: samples dried (if necessary); sieved

  size fraction used: −100 mesh

  extraction: HF-HClO₄ digestion

  elements determined: Cr, Cu, K, Li, Mg, Na, Ni, P, Sr, Ti

  analytical method: atomic absorption

Special Comments: None

INTRODUCTION

Zimbabwe is a country with extensive and important mineral resources. These include base metals (e.g., Cr, Ni), precious metals (e.g., Au), metals obtained from pegmatites (e.g., Li, Be), as well as numerous other elements and non-metallic resources (e.g., asbestos, coal). It is not surprising, therefore, that much exploration effort has been centered in this country over the years and that resources from all types of rocks, ranging from ultramafic to pegmatitic, have been sought.

This problem is concerned with a reconnaissance survey, based on stream sediments, which was undertaken in the early 1970's, in the Sabi Communal Land (19°10′ − 19°30′S latitude; 31°40′ − 32°00′E longitude), which is about 170 km SE of Harare. The survey area consists of Archaean terrain and covers about 1300 km². A total of 1360 stream sediment samples were taken and the −100 mesh material was analyzed by atomic absorption.

Ten elements were determined: Cr, Cu, K, Li, Mg, Na, Ni, P, Sr and Ti. The results obtained for the first four elements are presented graphically in Fig. 2-A where dots of various sizes represent three different concentration ranges for the higher values; the lowest concentration range for each element, assumed to be background values in all cases, is not shown. However, in Table 2-A the lowest concentration range is listed as category I, along with the ranges for categories II, III and IV constituting higher values, for each element in Fig. 2-A. The boundaries (or range of values) for each category were determined by means of cumulative probability (frequency) curves, and can be assumed to be correct and useable for this problem.

Re-plotting of the original data for the remaining six elements into a format suitable for this problem (i.e., as in Fig. 2-A) was either: (a) not necessary, as in the case of Mg and Ni which have distribution patterns essentially identical to that of Cr; or (b) not feasible, as in the case of K or Na which would not show the necessary features at the scale required for this book. Accordingly, the impor-
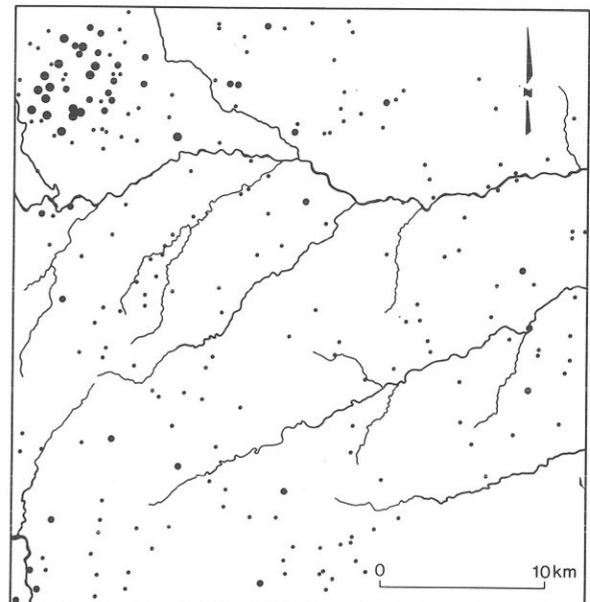
CHROMIUM
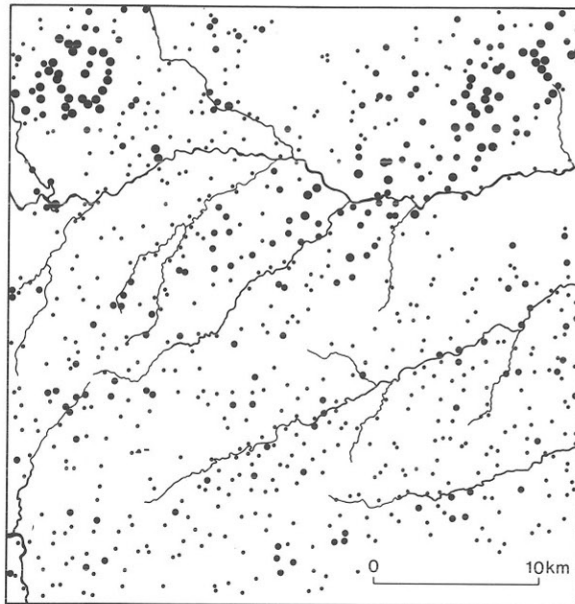
COPPER

- • > 500 ppm
- · 141 - 500 ppm
- · 56 - 140 ppm
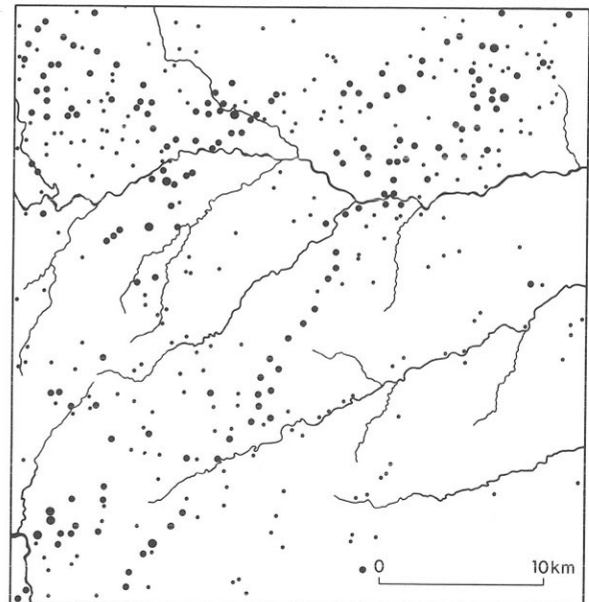
- • > 170 ppm
- · 61 - 170 ppm
- · 23 - 60 ppm

LITHIUM
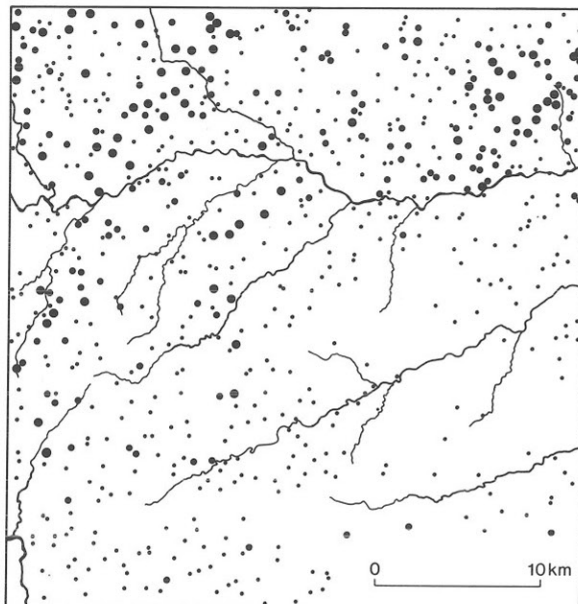
PHOSPHORUS

- • > 27 ppm
- · 17 - 27 ppm
- · 7 - 16 ppm

- • > 1.00 %
- · 0.21 - 1.00 %
- · 0.10 - 0.20 %

Fig. 2-A.   Display of the distributions of Cr, Cu, Li and P data obtained from a stream sediment reconnaissance survey, Sabi Communal Land, Zimbabwe.

Table 2-A

Geochemical characteristics of elements determined on stream sediment samples collected for a reconnaissance survey, Sabi Communal Land, Zimbabwe. The data are grouped into four categories (I-IV) based on their abundances (see text for details).

Element	Elements plotted in Fig. 2-A				Comments on characteristics of distribution pattern
	I	II	III	IV	
Cr (ppm)	<56	56-140	141-500	>500	—
Cu (ppm)	<23	23-60	61-170	>170	—
Li (ppm)	<7	7-16	17-27	>27	—
P (%)	<0.10	0.10-0.20	0.21-1.00	>1.00	—
Elements not plotted in Fig. 2-A					
K (%)	<2.20	2.20-3.50	3.51-4.50	>4.50	similar pattern to Li except that K has extremely low (<1.4%) values in upper left hand corner of map area where P is high
Mg (%)	<0.55	0.55-1.50	1.51-3.00	>3.00	pattern essentially identical to that of Cr
Na (%)	<1.80	1.80-2.50	2.51-3.60	>3.60	very uniform flat pattern with most values less than 2.50%; higher values limited to tributaries on both sides along entire extent of the main stream which emerges at the approximate mid-point of the right-hand boundary of map area; extremely low (<0.5%) values where K values are also low.
Ni (ppm)	<30	30-55	56-500	>500	pattern essentially identical to that of Cr
Sr (ppm)	<150	150-290	291-400	>400	similar pattern to that of Na except that Sr has very high anomalous values in upper left hand corner of map area (in the P area)
Ti (%)	<0.45	0.45-1.25	1.26-3.50	>3.51	pattern essentially identical to that of Cu

tant features of K, Na and Sr are explained in the right hand side of Table 2-A.

The objective of a reconnaissance survey, whether it be based on stream sediments, lithogeochemistry, hydrogeochemistry, biogeochemistry or any other survey technique, is not to find individual mineral occurrences but, rather, to find areas likely to contain mineralization and be worthy of follow-up work. A fundamental requirement for interpreting data from a reconnaissance survey is to be able to discriminate among the many different types of rock units which are almost certainly to be encountered in a large survey area (about 1300 km^2 in this case). Thus, the objective of this problem will be to interpret (discriminate) the survey data in terms of lithology.

Preliminary geological work in the Sabi Communal Land established that in this Archaean terrain the rocks are all igneous, or metamorphic rocks derived from previously existing igneous rocks.

PROCEDURE

The student should carefully study the pattern distributions in Fig. 2-A, and the data in Table 2-A, before proceeding to the Questions. Further, the serious student should obtain a modern textbook on igneous (and metamorphic) petrology because data on the average abun-

dances of elements found in the important major rock types (and in some unusual rock types) will be very helpful. The book by M. G. Best, *Igneous and Metamorphic Petrology* (1982, Freeman), is one such text.

QUESTIONS

1. Give two reasons why such an "unusual" group of elements, for example, Li, Ti, P, Sr and Cu, in combination with rock-forming elements such as K, Na, and Mg, was selected to be analyzed for this particular survey?

2. There are four main lithological units within the survey area. By means of the data contained in both Fig. 2-A and Table 2-A:

   (a) identify the main lithological units;

   (b) define these main lithological units in terms of their trace and major elements; and

   (c) describe any important features (e.g., shape) or regional trends these main lithological units may have.

3. The unit which has the most interesting characteristics from both a structural (shape) point of view, and also from its chemistry, is the unit which contains P in the upper left hand corner. However, other units

also have characteristic shapes. For the units you identified in your answer to Question 2 above:

(a) offer a geological explanation for those units which have characteristic shapes; and

(b) suggest an igneous (or metamorphic) rock name for each of the four units.

4. The northeast corner of the map area is characterized by a mafic, or even ultramafic, association of high Mg, Cr and Ni. Li is never part of the element associations related to these types of rocks. Therefore, offer an explanation for the high Li in this area (it is not related to analytical error).

5. The questions below require that the student know the name and geochemical characteristics of the rock unit which contains the high concentration of P (Fig. 2-A). If the student does not know the rock name applied to this unit, he/she should **look up the answer to Question 3(b) only** at this time.

(a) What other elements are typically enriched along with P, in this type of rock (or deposit)?

(b) Why do Cu, and Ti by analogy, have high values peripheral to (surrounding) the area with the highest P?

(c) What elements are mined economically from this type of deposit (consider this question on a worldwide basis)?

(d) If you had access to X-ray fluorescence equipment, for what additional elements would you analyze these same samples in order to confirm that the rock type in the upper left hand corner is carbonatite?

6. What are the main principles applicable to exploration which can be derived from this problem?

3 / QUESTIONS

Discrimination of Significant Nickel Anomalies in Multi-Element Drainage Reconnaissance Data, Zambia

BASIC DATA

Source: Hale (1978)

Acknowledgment: Martin Hale, Applied Geochemistry Research Group, Department of Geology, Imperial College, London

Location: Zambia

Geology:

rock types: granitic and gneissic basement (dated 1800 My BP); Precambrian and early Palaeozoic metasediments; and Permo-Jurassic continental sediments

known mineralization: mafic and ultramafic intrusives are scattered through the basement rocks and metasediments; some in Zimbabwe have nickel sulphide mineralization

anticipated target: primary nickel sulphide mineralization

Topography:

relief: gently undulating

drainage: moderate to high density dendritic drainage; stream velocity variable

Climate: tropical; seasonal rainfall about 800 mm per year; distinct dry season

Vegetation characteristics: open grassland to near-forest

Type of survey: reconnaissance using stream sediments

Survey conditions:

density: samples collected at intervals of 500 m along streams (averaging 4 samples per km^2)

field conditions: warm, dry

time of year sampled: dry season; stream channels dry

overburden conditions: deeply weathered residual soils; little outcrop

Materials sampled: stream sediments

Analytical:

preparation procedure: samples dried (if necessary); sieved

size fraction used: minus 80 mesh

extraction: none ("total" analysis obtained)

elements determined: Ni, Co, Cr, Cu, Fe, Mn (and others not reported here)

analytical method: DC arc emission spectrometry

Special Comments: None

INTRODUCTION

Rocks of the mafic-ultramafic suite typically contain average concentrations of Ni, Cr and Co which are higher than other crustal rocks, and exhibit Ni:Co ratios in the range 3:1 to 13:1. Associated with some mafic and ultramafic bodies is primary nickel sulphide mineralization, usually comprising mainly pyrrhotite, pentlandite and chalcopyrite (plus subordinate other sulphides and gangue minerals). The recognition (discrimination) of bodies with which mineralization is associated has been successfully demonstrated using whole rock lithogeochemistry. Cameron *et al.* (1971) showed that the Ni, Cu and Co content of sulphide minerals (determined by means of selective leaching with an ascorbic acid-hydrogen peroxide mixture) provided the basis for discrimination in a large number of mafic and ultramafic bodies in eastern Canada. Hausen *et al.* (1973) found that the S/Ni ratio was useful for discriminating between mineralized and non-mineralized ultramafics. Specifically, they found that S/Ni ratios near 1 are favorable indications of economic potential. However, if the ratio is significantly less than 0.5, the environment is sulphur-poor and a major part of the nickel will likely be in the silicate lattice(s) (e.g., olivine typically contains approximately 3000 ppm Ni).

Surficial materials, such as soils and stream sediments, retain some of the trace element characteristics of mafic and ultramafic parent material, but in regions where oxidation and chemical weathering are pronounced, the features of rock geochemistry which discriminate mineralized bodies are at least considerably modified and, at worst, effectively lost. For example, the autochthonous (chemically precipitated) enrichment by Mn of Co and, to lesser extents, Ni, Cu and Cr derived from other sources, is one type of alteration that occurs.

In the lateritized landscape of Western Australia, gossan outcrops derived from primary nickel sulphides can be distinguished from other ferruginous outcrops derived from ultramafic rock by their higher Ni and Cu and lower Cr contents. Various discriminant functions based on about six trace elements have been proposed by Clema and

Stevens-Hoare (1973), Joyce and Clema (1974), and Bull and Mazzucchelli (1975) for distinguishing true nickel gossans in Western Australia. High levels of Ni and Cu impart strong positive loadings to these discriminant functions, and high levels of Mn, Co and Cr impart negative loadings.

Multi-element stream sediment drainage reconnaissance surveys were carried out over much of central Zambia in the 1960s. Stream sediments from central Zambia tend to have both a detrital (mechanically-derived) and autochthonous component. Nickel was not an exploration target when sampling and analysis was in progress, but the data have since been re-examined to locate hitherto unmapped mafic-ultramafic bodies and to discriminate between those (both previously known and discovered in the data appraisal) likely to contain nickel mineralization and those that are non-mineralized. There is little possibility for the occurrence of nickeliferous laterite and oxide ores in Zambia, and the sole target is, therefore, primary nickel sulphides.

To answer some of the questions below, it will be useful to have available the average concentrations of Ni, Co, Cr and Cu in ultramafic, mafic and granitic rocks, as well as their average abundance in the Earth's crust. These values (in ppm) are presented below (data from Levinson, 1980).

	Ni	*Co*	*Cr*	*Cu*
Ultramafic	2000	150	2000	10
Mafic	150	50	200	100
Granite	0.5	1	4	10
Earth's crust	75	25	100	55

PROCEDURE

A number of stream sediment samples from central Zambia, all with anomalous Ni contents, are listed in Table 3-A. Study these data and proceed to the questions.

QUESTIONS

1. Why are all the Ni values in Table 3-A considered potentially anomalous with respect to Ni?

2. Which of the elements determined in Table 3-A, either singly or in some (specified) combination, might be used to characterize the principal rock type at each prospect?

3. Which of the elements in Table 3-A, either singly or in combination, might indicate rocks favorable for the occurrence of primary nickel mineralization?

4. How may the concentrations of the elements given in Table 3-A be affected by environmental conditions, such as weathering and groundwater transport, in the drainage area? In your answer give particular attention to Fe and Mn, and the effect they may have on the contents of the other elements shown in the table.

   Specifically, consider the mobility of the elements in groundwater when preparing your answer.

5. Review the geochemical drainage characteristics of the Kariba prospect, interpreting, if possible: (a) the principal rock type; and (b) the mineralization potential.

Table 3-A
Multi-element geochemical analyses of stream sediment samples from Zambia with anomalous nickel contents.

Location	*Sample No.*	*Ni (ppm)*	*Co (ppm)*	*Cr (ppm)*	*Cu (ppm)*	*Fe (%)*	*Mn (ppm)*
Kariba	11542	110	25	170	180	7.2	425
	11543	165	30	155	180	8.2	440
	11545	195	26	250	83	14.6	460
	11546	120	25	170	195	11.4	400
	11573	225	36	165	160	9.7	485
Zambesi	31393	2000	170	2400	32	10.8	1450
	31404	1850	160	2100	31	9.6	1650
	31407	2100	200	2800	27	15.0	1750
	31423	1850	125	2150	36	7.8	1200
Serenje	41019	185	54	350	75	4.9	990
	41020	180	28	400	85	8.0	430
	41022	155	22	311	50	4.3	450
	41041	170	47	230	75	4.2	440
	41047	230	62	185	90	3.9	380
Musofu	41083	135	120	71	31	3.2	4350
	41090	210	265	58	39	7.9	4800
	41091	220	275	36	44	8.6	4900
	41092	245	210	90	105	9.2	4850

6. Review the geochemical drainage characteristics of the Zambesi prospect, interpreting, if possible: (a) the principal rock type; and (b) the mineralization potential.

7. Review the geochemical drainage characteristics of the Serenje prospect, interpreting, if possible: (a) the principal rock type; and (b) the mineralization potential.

8. Review the geochemical drainage characteristics of the Musofu prospect, interpreting, if possible: (a) the principal rock type; and (b) the mineralization potential.

9. At which prospect(s) would you recommend further, detailed investigation for primary nickel mineralization?

10. What is the reason(s) for the statement at the end of the Introduction that "There is little possibility for the occurrence of nickeliferous laterite and oxide ore in Zambia"? (To answer this question consider the general environmental-climatic conditions required for the formation of laterites.)

11. What principles applicable to exploration are illustrated by this problem?

REFERENCES

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4 / QUESTIONS

Discrimination of Tin-Mineralized Granites by Lithogeochemistry, British Isles

BASIC DATA

Source: Martin Hale

Acknowledgment: Martin Hale and David Jones, Applied Geochemistry Research Group, Department of Geology, Imperial College, London

Location: British Isles

Geology:

   rock types: granitoids

   known mineralization: cassiterite-bearing veins associated with some granitoids

   anticipated target: tin (cassiterite) mineralization

Topography:

   relief: not applicable

   drainage: not applicable

Climate: temperate; precipitation about 800 mm per year

Vegetation characteristics: moorland, grass, shrubs

Type of survey: reconnaissance lithogeochemical

Survey conditions:

   density: low and variable; average approximately 1 sample per 10 km^2

   field conditions: not applicable

   time of year sampled: not applicable

   overburden conditions: extensive thin soil and peat with limited outcrops

Materials sampled: outcrop samples (with no obvious signs of weathering)

Analytical:

   preparation procedure: pulverization

   size fraction used: entire sample used

   extraction: HF-HNO$_3$-HClO$_4$ ("total" digestion)

   elements determined: Fe, Mg, K, Na, Li

   analytical method: atomic absorption

Special Comments: None

INTRODUCTION

Tin mineralization (usually in the form of cassiterite) is uniquely associated with granites. Primary mineralization occurs as veins or stockworks within granites or intruding the adjacent country rocks. Weathering of tin-mineralized granites can give rise to eluvial and alluvial placer accumulations of cassiterite. It is, therefore, desirable to recognize tin-mineralized granites at the reconnaissance stage of exploration, so that "tin-barren" granites can be eliminated at any early stage and detailed work can be focussed on the most promising granites.

The geochemistry (lithogeochemistry) of granites, as determined from specimens of fresh outcrop or drill core, has received considerable research attention as a basis for discrimination of Sn-mineralized from Sn-barren granites (see Levinson, 1980, for a general review of this subject). Granites with a relatively high Sn content have a much greater probability of being tin-mineralized than those with a low Sn content. Hesp and Rigby (1975) found that a 12 ppm Sn threshold was suitable for Sn-mineralized granitic rocks of the Tasman Geosyncline, eastern Australia, and similar thresholds have been proposed elsewhere. The resulting discrimination is imperfect, however, because some granites with low Sn are tin-mineralized whereas some with high Sn are tin-barren. Most of the Sn in a non-mineralized granite specimen is contained in biotite. Bradshaw (1967) found that the Sn content of biotites discriminated mineralized granitoids in the British Isles; specifically, granites with high contents of Sn in their biotites are likely to contain Sn mineralization. Hesp (1971), however, following a study of granitic rocks from Australia, concluded that the Sn content of biotite (and its relationship to other trace elements in biotite) was not suitable for discrimination.

An alternative multi-element lithogeochemical approach can be used to attempt discrimination based on the geological and geochemical evolution of granites. Groves (1972) recognized that tin mineralization in the Blue Tier Batholith, Tasmania, is associated with a highly fractionated granite which can be distinguished from other, tin-barren granites in the differentiation sequence by high ratios of Fe/Mg, Rb/Sr, Rb/K and a low Mg/Li ratio. Tauson and Kozlov (1973) classified granitoids into five geochemical types and, using examples from the USSR, showed that the type most likely to be tin-mineralized was characterized by high ratios of K/Na, Rb/K, Rb/Ba, Li x 10^3/K and F/Li. Juniper and Kleeman (1979) used ternary diagrams to illustrate that some tin-mineralized granites of southeastern Australia can be discriminated

by their enrichment in Na and K relative to Fe, Mg and Ca. Rehder and van den Boom (1983) found that factor analysis involving 23 elements distinguished between a tin-mineralized and a tin-barren granite in Thailand.

A number of geochemical parameters have, therefore, been shown to discriminate tin-mineralized granites within particular metallogenic provinces. These have been summarized and further refined by Govett (1983). Some, or all, of these parameters might be expected to assist in discriminating tin-mineralized granites elsewhere.

PROCEDURE

From each of ten granitoids in the British Isles, a small number (<20) of outcrop samples comprising seemingly fresh, unweathered rock were analyzed for Fe, Mg, K, Na and Li by atomic absorption spectrometry. The results are summarized in Table 4-A as the average values for several elements in the ten granitoids which can be used to calculate parameters likely to aid in the recognition of tin-mineralized granites. Study Table 4-A and proceed to answer the questions below.

Table 4-A
Average concentrations of Fe, Mg, K, Na and Li in outcrop specimens of granitoids from the British Isles.

Granitoid code	Fe(%)	Mg(%)	K (%)	Na(%)	Li (ppm)
BH	2.46	1.05	2.58	2.91	23
CD	1.70	0.77	2.94	3.20	93
CF	1.09	0.52	3.73	2.22	95
CM	0.11	0.02	0.44	0.22	31
DM	0.14	0.03	0.43	0.21	21
GD	0.12	0.01	0.47	0.12	72
GN	0.69	0.55	3.75	3.23	12
RG	1.60	0.46	3.19	4.03	12
SA	0.12	0.02	0.40	0.15	32
SH	1.78	0.73	4.03	2.49	83

QUESTIONS

1. (a) Calculate the following ratios (wt.%) for each of the granitoids:

     (i)   K/Na;
     (ii) Fe/Mg;
     (iii) Mg/Li;
     (iv) Li x 10^3/K

    (b) List each of the ratios in one table, and then rank the resulting values in a second table. For your ranking, place the highest ratios at the top of each column for i, ii and iv; for iii, place the lowest ratio

at the top of the column. Study the results and then divide the ranked ratios into groups if the values appear to lend themselves to clear division.

2. Based on data in Table 4-A, compile a ternary diagram showing the composition of the granitoids in terms of (Na + K), Fe and Mg. Insert any boundaries that appear to emphasize the natural geochemical differences and/or data clustering. Proceed to compile the diagram as follows: for each granitoid, calculate the percentage proportions of (Na + K), Fe and Mg in terms of the total concentrations of these four elements (i.e., Na + K + Fe + Mg = 100%). Set the lower left apex of the ternary diagram to 100% (Na + K), the upper apex of 50% Fe, and the lower right apex to 50% Mg (Fig. 4-A). Then plot the appropriate values for each granitoid.

3. (a) Briefly review the Introduction to this problem and the results of Questions 1 and 2 in terms of their implications for discriminating tin-mineralized granites; select granite(s) with which tin mineralization is most likely to be associated.

    (b) What are some possible limitations or pitfalls which may be encountered if this lithogeochemical method is used without caution?

4. (a) It was mentioned in the Introduction that most of the Sn in a non-mineralized granite is contained in biotite. Give an explanation for this substitution.

    (b) Name another silicate mineral in which Sn may be found in significant amounts and give the reason why.

    (c) In what non-silicate minerals(s) is Sn likely to be found in small amounts? Give an explanation for the occurrence of Sn in these minerals.

5. What are the main principles applicable to exploration which can be derived from this problem?

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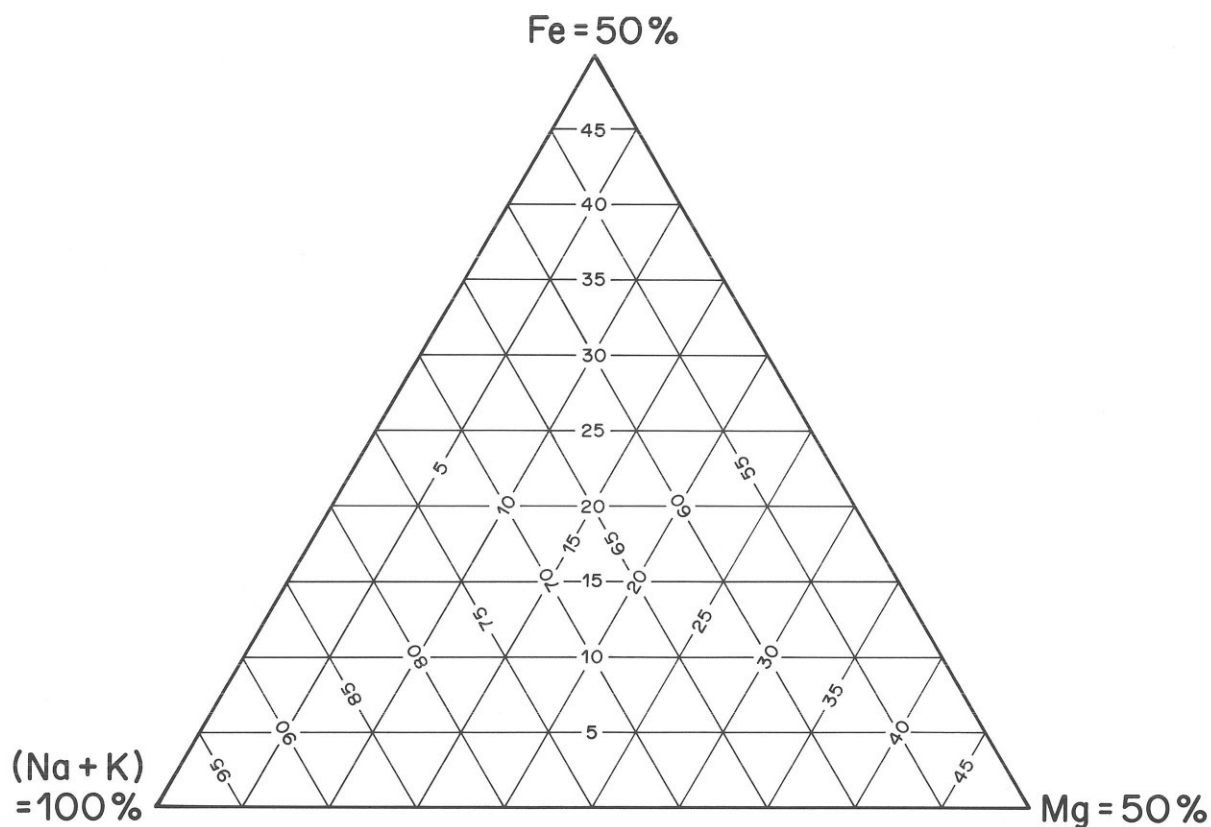
Fig. 4-A.   Ternary diagram for answering Question 2.

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5 / QUESTIONS

Evaluation of Reconnaissance Data for Uranium Mineralization Using a Grid Cell Method, New Mexico, U.S.A.

BASIC DATA

Source: S. L. Bolivar and L. W. Maassen

Acknowledgment: S. L. Bolivar and L. W. Maassen

Location: Albuquerque 1° × 2° quadrangle, central New Mexico

Geology:

  rock types: most common units are Cretaceous sediments, Pennsylvanian-Permian redbeds and Quaternary-Tertiary volcanics, although other PreCambrian through Quaternary (igneous, metamorphic, sedimentary) units can be found

  known mineralization: Grants Mineral Belt (U); small Cu, Au, Ag deposits

  anticipated target: areas favorable for potential uranium mineralization

Topography:

  relief: plateau country with badlands (300 m); scattered mesas and buttes (600 m); maturely eroded units (1000 m)

  drainage: major streams are Rio Puerco, Rio Grande, and Jemez River; discharge varies seasonally (high in spring and after summer showers)

Climate: Semi-arid; more humid in higher elevations

Vegetation characteristics: altitudinally zoned; sagebrush and cactus (low elevations) to juniper, pine, and aspen (higher elevations)

Type of survey: reconnaissance using stream and spring sediments

Survey conditions:

  density: 1 sample per 11 km^2 (nominal)

  field conditions: poor access to many areas, in particular Grants Mineral Belt; trail bike and 4-wheel drive vehicles used

  time of year sampled: summers of 1975, 1976, 1978

  overburden conditions: contamination possibility from windblown material(?)

Materials sampled: composite sample collected from three spots at each location; sample sieved to minus 100 mesh in field; 1538 stream and spring sediments

Analytical:

  preparation procedure: sieved in field

  size fraction used: sediment that passes through 100 mesh screen

  extraction: all elements determined by total analysis methods

  elements determined: U and 43 other elements

  analytical methods: delayed neutron counting (U); 9 elements (base metals) by X-ray fluorescence; remainder by NAA (neutron activation analysis)

Special Comments: Analytical procedures have been reported in Maassen and Bolivar (1979). These data were collected as part of NURE program

INTRODUCTION

A project geologist with a small uranium exploration company was given data from a reconnaissance-scale open-file report for the Albuquerque 1° × 2° quadrangle, New Mexico (Maassen and Bolivar, 1979). This quadrangle covers about 20,000 km^2. At a nominal density of one sample per 11 km^2, 1538 stream and spring sediments were collected during the summers of 1975, 1976, and 1978 as part of the National Uranium Resource Evaluation (NURE) program. Systematic sampling procedures and standard analytical techniques were followed from year to year. Samples were analyzed for uranium (by delayed neutron counting) and 43 additional elements by neutron activation analysis and X-ray fluorescence. The geologist was required to: (a) examine the preliminary evaluation contained in the open-file report; (b) indicate if the data required in-depth statistical evaluation; and (c) make a preliminary evaluation of the data which would aid in selection of favorable areas for uranium mineralization.

Basic statistics from the open-file report (Maassen and Bolivar, 1979) are presented in Table 5-A. The open-file report also contains the sample locations and uranium concentration plots at a scale of 1:250,000. A schematic

map of areas containing some potential for uranium mineralization was included in the open-file report (Fig. 5-A (top)).

Table 5-A
Basic statistics for uranium from the Albuquerque
$1° \times 2°$ quadrangle, New Mexico

Sample Type	Sample size	Uranium Median (ppm)	Uranium Mean (ppm)	Standard deviation (ppm)
All sediments	1538	3.1	3.5	1.8
Wet stream sediments	96	4.4	4.8	2.0
Dry stream sediments	1385	3.0	3.4	1.6
Spring sediments	57	4.3	5.0	4.0

The geologist initially wanted to confirm (by collecting additional samples) the location and existence of the uranium anomalies of Maassen and Bolivar (1979) but was under pressure for a rapid appraisal of the data. He realized that some areas in the quadrangle were inadequately sampled yet he believed there were enough data to evaluate the entire quadrangle if he could somehow interpolate data from collected samples into adjacent areas where sampling was inadequate. Therefore, the geologist decided to create a 12×24 grid for the $1° \times 2°$ quadrangle (Fig. 5-A (bottom)). Each grid cell would represent 5 minutes of longitude and 5 minutes of latitude. Approximate average concentrations (ppm) were calculated for the samples in each grid cell, e.g., a cell containing 5 samples with uranium concentrations of 2.1, 4.2, 3.7, 0.6, and 4.1 ppm uranium would be assigned a grid value of 3 (rather than 2.78), as shown in Fig. 5-A (bottom). (Cells with less than three samples are indicated with asterisks).

PROCEDURE

Before proceeding, the student should carefully consider the background information (above) supplied, as well as the data in Table 5-A and in Fig. 5-A.
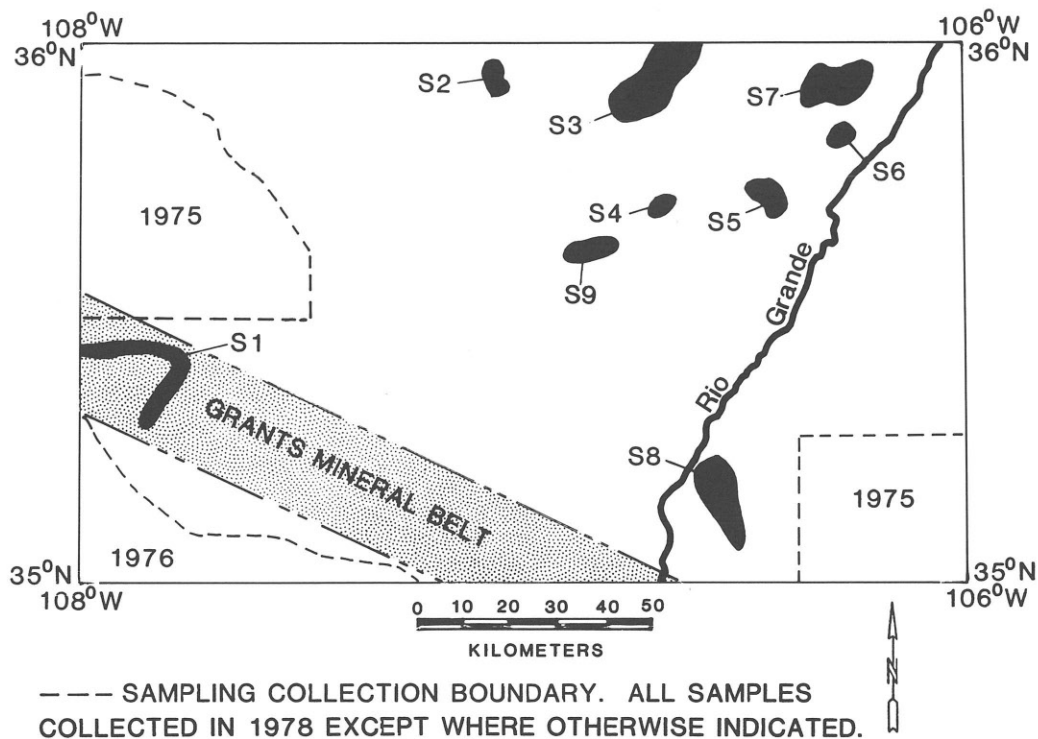
QUESTIONS

1. What pitfalls might be encountered by the geologist using the grid cell interpolation scheme as proposed for this situation? Alternatively stated, what factors might limit the utility and reliability of the conclusions based on the proposed interpolation scheme using the data of Maassen and Bolivar (1979)?

2. (a) Three types of sampling media were used in this reconnaissance survey. With reference to Table 5-A, discuss the utility (limitations, usefulness) of the different sampling media, and the significance of the variations in uranium concentrations presented in Table 5-A which are found in the three different sampling media.

   (b) Both "median" and "mean" values for uranium (in ppm) are presented in Table 5-A. State which of the values you would use and give a reason why.

3. Calculate the average uranium concentration for all grid cells in Fig. 5-A (bottom). How does this compare with the mean (average) for all sediments (3.5 ppm) in Table 5-A? If it does not compare favorably ($\pm 5\%$), give a possible explanation for the difference.

4. The geologist selected a value of 3.0 ppm uranium as representative background for the majority of the grid cells (in Fig. 5-A (bottom)). He felt, because the grid cell averages did not vary to a high degree, that any cell with an average greater than 3.0 might be significant. How do the cells thus identified compare to areas identified as anomalous in the open-file report (Fig. 5-A (top))?

5. The major uranium districts and deposits for the Albuquerque $1° \times 2°$ quadrangle are shown in Fig. 5-B. Department of Energy (DOE) management questioned the validity of the NURE data in this open-file report because the Laguna district (in an Indian Reserve), which previously contained the largest open-pit uranium mine in the U.S., was not immediately identifiable when examining samples with above average uranium concentrations as shown in Fig. 5-A (top) and Fig. 5-A (bottom). Can you offer any reason(s) why samples collected in the Laguna district did not appear to have anomalous uranium concentrations?

6. Some geologists felt the Laguna District (and Grants Mineral Belt) could be identified by using more sophisticated statistical evaluation methods. Although an estimation technique called kriging (kriging provides an unbiased estimate for the uranium values of a sample based on a weighted average of nearby samples) was later successfully used to identify the Laguna District, a similar (but not nearly as sophisticated) technique will be illustrated below.

In order to determine if the reconnaissance data for the Albuquerque $1° \times 2°$ quadrangle contained information on the Laguna District (and Grants Mineral Belt) not readily observable in the above grid cell evaluation (Fig. 5-A), the geologist calculated the average uranium concentration from the raw data in the open-file report (Maassen and Bolivar, 1979) for a portion of the Grants Mineral Belt and surrounding

Fig. 5-A. *Top.* Schematic diagram showing principal uranium anomaly clusters for sediment samples from the Albuquerque quadrangle, New Mexico. *Bottom.* Grid cell layout. Numbers represent average uranium concentrations (ppm) for all samples collected within the grid cell (to nearest whole number). An asterisk indicates two or fewer samples were used to calculate the average. Grid cell H3 has two samples with uranium concentrations greater than 14 ppm included in the cell average; grid cell I2 has one sample with greater than 12 ppm included in the cell average; grid cell J19 has two samples with uranium concentrations greater than 13 ppm included in the cell average; and cell L19 has one sample with greater than 13 ppm uranium included in the cell average.

URANIUM MINING DISTRICT/AREA

A. AMBROSIA LAKE DISTRICT   D. SOUTH NACIMIENTO-JEMEZ AREA
B. LAGUNA DISTRICT   E. NAMBE AREA
C. NORTH NACIMIENTO-JEMEZ AREA   F. CERRILLOS HILLS AREA
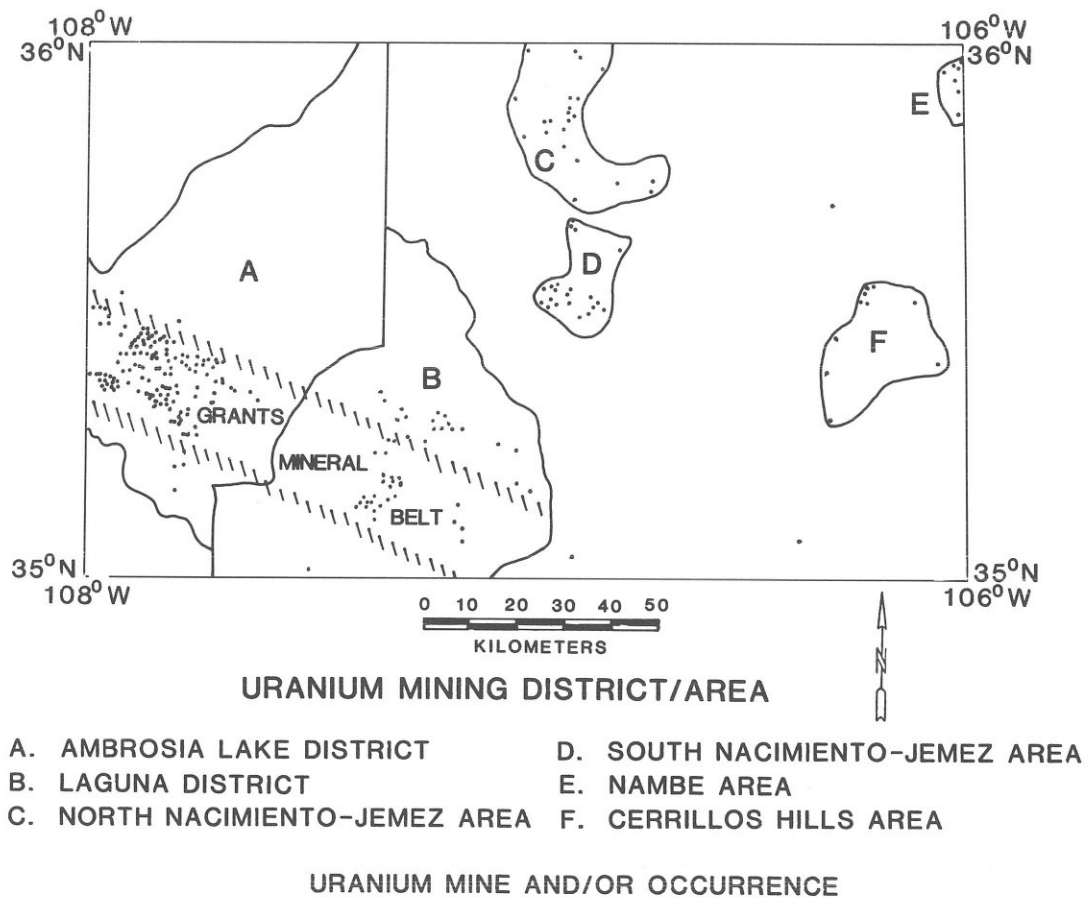
URANIUM MINE AND/OR OCCURRENCE

Fig. 5-B.   Principal uranium mining districts in the Albuquerque quadrangle, New Mexico.
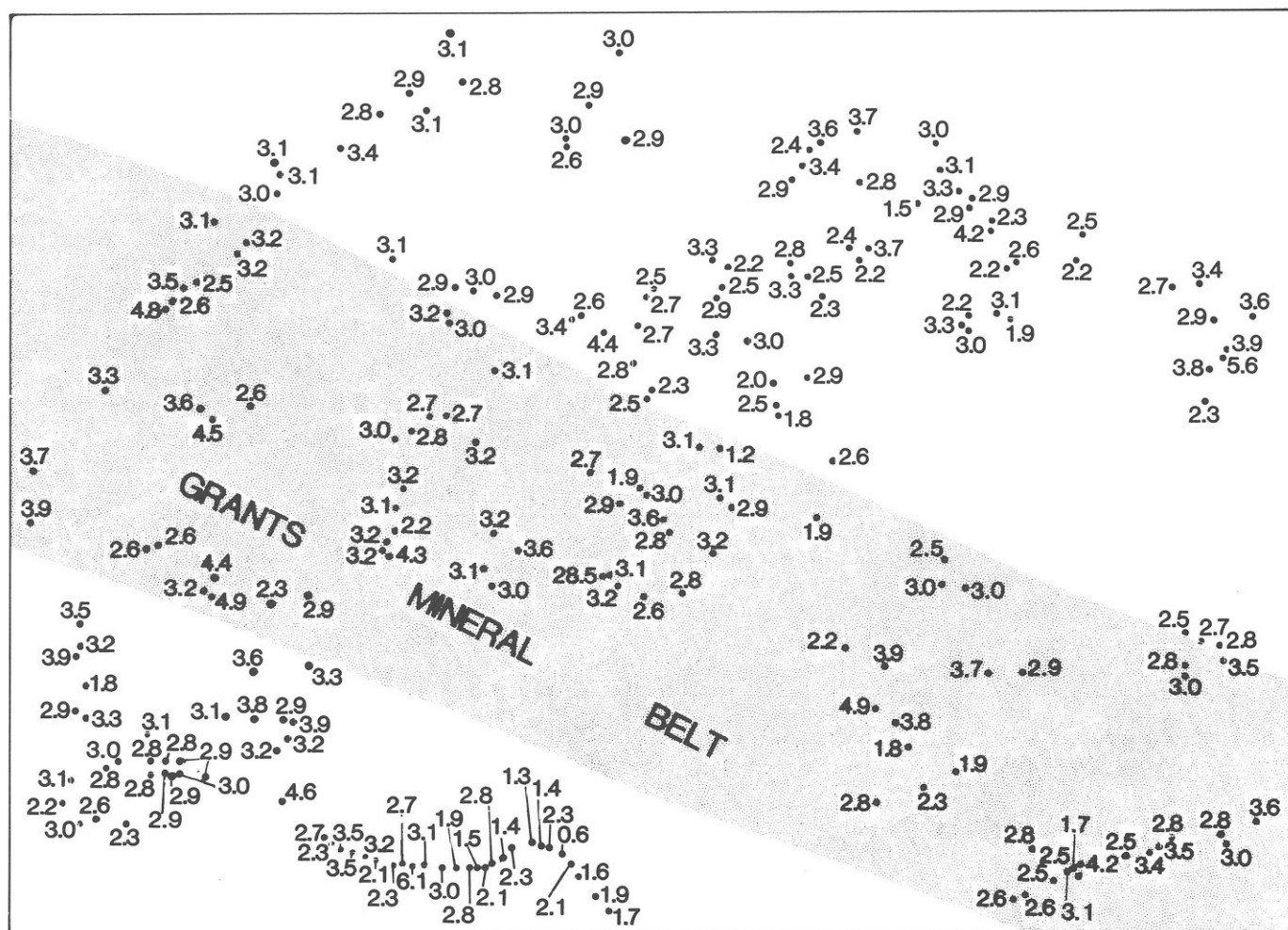
Fig. 5-C.   Uranium concentrations for a portion of the Grants Mineral Belt and surrounding area.

areas (Fig. 5-C). Calculate the average uranium concentration for all samples in Fig. 5-C and compare it to the mean (average) uranium concentration for all samples in Table 5-A (i.e., 3.5 ppm). If it does not compare favorably (±5%), give a possible explanation for the difference.

7.   Calculate the average uranium concentration only for the samples collected *within* the Grants Mineral Belt (Fig. 5-C). Is there a difference between this value and the value you obtained from Question 6? If there is, compare both values with the mean (average) uranium concentration for all samples for

the entire quadrangle (from the open-file report, i.e., 3.5 ppm), and briefly discuss the significance of the variations.

8.   What principles applicable to exploration geochemistry are illustrated by this problem?

REFERENCE

Maassen L. W. and Bolivar S. L. (1979) Uranium hydrogeochemical and stream sediment reconnaissance of the Albuquerque NTMS Quadrangle, New Mexico, including concentrations of forty-three additional elements. U.S. Department of Energy, Grand Junction, Colorado, Open-file Report GJBX-145(79).

6 / QUESTIONS

Hydrogeochemical Survey for Uranium in an Arid Region, New Mexico, U.S.A.

BASIC DATA

Source: Wenrich-Verbeek (1977); Wenrich-Verbeek and Suits (1979)

Acknowledgment: K. J. Wenrich

Location: north of Ojo Caliente, Rio Arriba County, New Mexico

Geology:

  rock types: A mixture of drainage basins: (a) north of La Madera most drainages are pre-Cambrian metamorphics and granites; (b) other drainages are in Tertiary and Quarternary sediments

  known mineralization: U in pegmatites

  anticipated target: sandstone- and vein-type uranium

Topography:

  relief: moderate

  velocity of streams: high at flood stage; moderate at other times

Climate: semi-arid; 250-400 mm/yr precipitation

Vegetation characteristics: scrub oak and juniper at low altitudes; pine at higher altitudes

Type of survey: reconnaissance; hydrogeochemical and stream sediment

Survey conditions:

  density: 1 sample per 4 miles of river

  field conditions: highly variable climatic conditions over the 3-year period

  time of year sampled: May-July

  overburden conditions: thin residual soil horizons

Materials sampled: water and stream sediments from Rio Ojo Caliente

Analytical:

  preparation procedure: water filtered through 0.45 μm filter and acidified with nitric acid

  size fraction used: not applicable to water

  extraction: not applicable to water

  analytical determinations: water temperature, conductivity, discharge, pH, Eh, alkalinity, U, Mo, Zn, As, Cu, F and at least 30 other variables

  analytical methods: U by fluorimetry; others by atomic absorption, emission spectrometry, etc.

Special Comments: None

INTRODUCTION

Hydrogeochemical surveys are, in some ways, the easiest type of survey to conduct owing to the homogeneity of the water and the simplicity of sample collection when surface waters are available. On the other hand, they are among the more difficult type of survey to interpret owing to a great number of variables, both physical and chemical, which can affect such surveys. This problem illustrates some of these variables.

A reconnaissance hydrochemical survey for uranium was run in the Rio Ojo Caliente, New Mexico, in July 1975, and additional measurements were taken at various times in 1976 and 1977. Stream sediments were also sampled, as well as waters and sediments from tributaries, but they are not of concern for this particular problem. At least 42 variables, both physical and chemical, were measured on, or calculated for, many of the samples. Table 6-A presents a selected group of variables which form the basis of questions for this problem.

The data presented in Table 6-A were all taken from samples collected at the same location, a U.S. Geological Survey gauging station, on the various dates shown. Some measurements were performed in the field, e.g. conductivity, pH and Eh, but most were performed in the laboratory under ideal conditions and can be considered to be of the highest quality.

PROCEDURE

Study the data in Table 6-A only; do not look at Table 6-B until you have answered Question 3.

Table 6-A
Selected chemical analyses of water samples from the
Rio Ojo Caliente near Ojo Caliente, New Mexico,
over a 3-year period (from Wenrich-Verbeek and Suits, 1979)

Parameter	July 23, 1975	May 19, 1976	May 5, 1977
Water temperature (°C)	18.0	18.0	12.0
Conductivity (μmhos/cm)	715	235	1100
pH	7.6	7.0	8.3
Eh (mv)	105	120	175
Discharge (ft^3/sec)	15	109	9.2
U(μg/l)	16	3.3	30
Ca (mg/l)	76.9	38.0	98.0
Mg (mg/l)	21.3	5.6	34.0
Na (mg/l)	67.6	8.5	120.0
K (mg/l)	6.3	1.8	9.5
B (μg/l)	320	40	220
Mo (μg/l)	<1	<2	2.3
Li (μg/l)	160	30	240
As (μg/l)	4.3	2	8
Cu (μg/l)	<20	2	4
Zn (μg/l)	11	10	<20
F (mg/l)	—	0.17	0.62
Cl (mg/l)	—	—	68
HCO$_3$ (mg/l)	—	—	420
SO$_4$ (mg/l)	—	—	180
Alkalinity (mg/l)	—	84	238

Note: — means not determined.

QUESTIONS

1. The average U content of river waters of the world is 0.4 ppb (μg/l) although waters associated with certain rock types, such as carbonates, may have averages of approximately 2 ppb. Thus, it might appear that the 1975 and 1977 samples, with 16 and 30 ppb, respectively, represent potential economic uranium deposits, whereas the 1976 sample with 3.3 ppb does not. Explain how such "discrepancies" might occur (assume the analytical data are correct) when, in fact, all samples were obtained from the same locality.

2. How would you proceed to evaluate the true significance of the three U values: 16, 3.3, and 30.

3. Normalize all the major and trace element values in Table 6-A using the relationship:

$$\frac{\text{trace element}}{\text{conductivity}} \times 100.$$

(Multiplication by 100 results in numbers which simplify comparisons).

4. What can be said about the three U values?

5. What relationship(s) among the major cations Ca, Mg, and Na may be seen between the three water samples? Give a possible explanation for the relationship(s) or variation(s).

6. By means of further examination of the chemical analyses of the water samples (in addition to those of Ca, Mg and Na) it should be possible to confirm the suggested higher limestone (or dolomite) abundance in the source area of the 1976 sample. What are these chemical parameters?

7. What information, if any, can be gleaned from the data for the trace elements B, Mo, Li, As, Cu, Zn and F (Table 6-A or 6-B in the Answers section)?

8. What information, if any, can be gleaned from the water temperature, pH and Eh?

9. What are the main principles applicable to exploration which can be derived from this problem?

REFERENCES

Wenrich-Verbeek K. J. (1977) Anomalous uranium in the waters of the Rio Ojo Caliente, New Mexico. U.S. Geol. Surv. Circular 753, 73-75.

Wenrich-Verbeek K. J. and Suits V. J. (1979) Chemical data and statistical analyses from a uranium hydrogeochemical survey of the Rio Ojo Caliente drainage basin, New Mexico. Part I: Water. U.S. Geol. Surv. Open-File Rept. 79-996.

7 / QUESTIONS

Geobotanical Prospecting in Western Australia

BASIC DATA

Source: B. C. Severne, "Botanical Methods for Mineral Exploration in Western Australia" Ph.D. Thesis (unpublished), Massey University, 1972.

Acknowledgment: R. R. Brooks, Massey University, New Zealand

Location: Murchison Region, Western Australia

Geology:

  rock types: fine-grained gabbros (dolorites), quartzites and fine-grained sediments

  known mineralization: copper

  anticipated target: copper mineralization

Topography:

  relief: gently undulating

  drainage: arid terrain (200 mm/yr rainfall); rivers flood about once a year and they are dry the rest of the year

Climate: hot, arid

Vegetation characteristics: semi-desert scrub with 10% cover

Type of survey: geobotanical reconnaissance

Survey conditions:

  density: vegetation species counted in 10 m x 10 m quadrats

  field conditions: good

  time of year sampled: Spring

  overburden conditions: very little soil on quartzites and gabbros; elsewhere deep transported soils (from annual floods).

Materials sampled: vegetation counted; surface soils analyzed

Analytical:

  preparation procedure: soils air dried and sieved

  size fraction used: −100 mesh

  extraction: soils decomposed in HF/HNO_3 and then residues dried and redissolved in HCl

  elements determined: Cu, Zn, Cr

  analytical method: atomic absorption

Special Comments: None

INTRODUCTION

Geobotanical methods for mineral exploration are receiving increased attention primarily as a result of advances in the general field of remote sensing. However, remote sensing is not suitable for small-scale surveys so plant mapping is still a viable technique in certain situations. This problem is designed to show how geobotanical methods were applied in the Murchison Region of Western Australia before the widespread use of remote sensing. Fig. 7-A shows the species distribution in relation to the rock types and selected trace elements in soils.

PROCEDURE

Study Fig. 7-A and consult Brooks (1983).

QUESTIONS

1. How does one go about conducting a geobotanical survey?

2. Which species, if any, appear to be confined exclusively to the gabbro or to the quartzite?

3. How would you decide on the size of quadrat (a rectangular plot used for ecological or population studies) to be used for the geobotanical mapping?

4. (a) In this particular case, would soil trace element studies based on Cu, Zn and Cr distinguish the various rock types as well as the species noted in Question 2 above?

   (b) If your answer is "yes", would there be any advantage to geobotany in this area?

5. What are the main principles applicable to exploration which can be derived from this problem?

REFERENCE

Brooks R. R. (1983) *Biological Methods of Prospecting For Minerals.* Wiley.
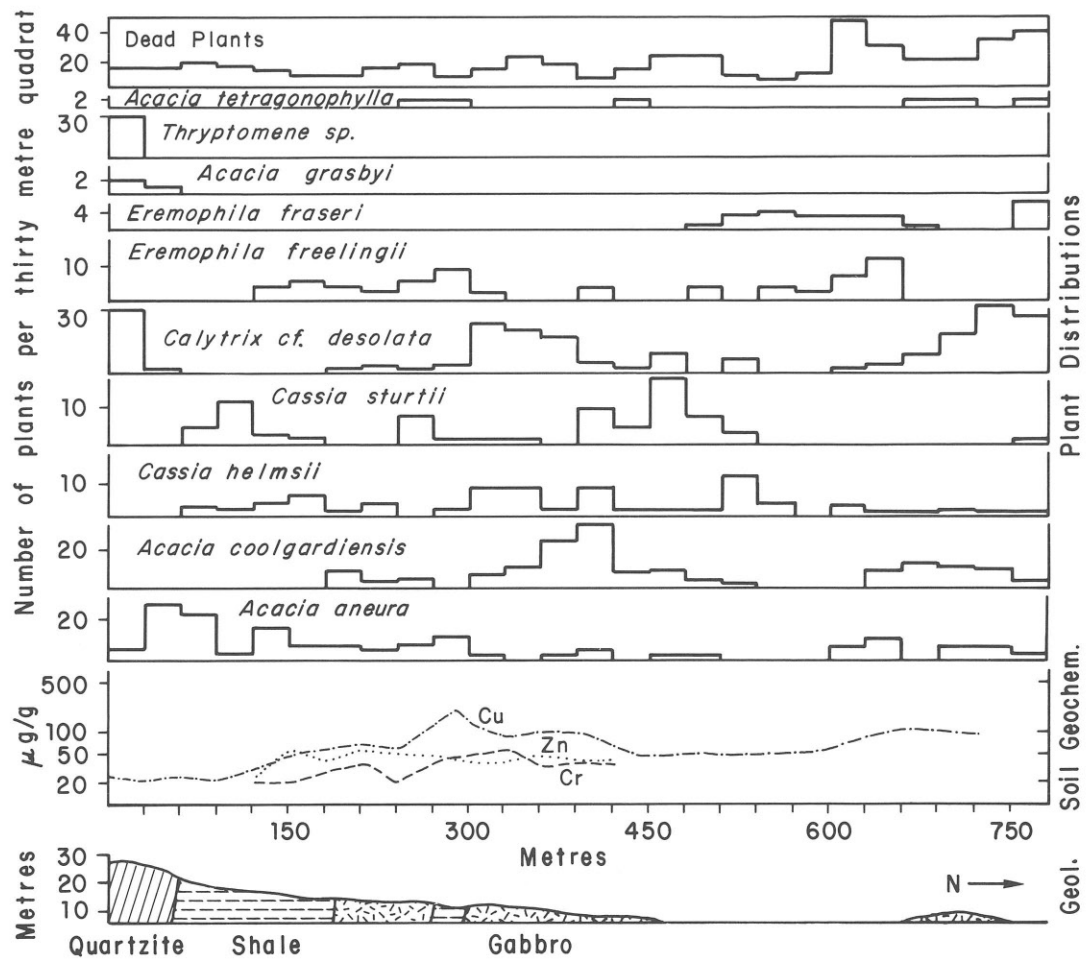
Fig. 7-A.   Results of a geobotanical survey in the Murchison Region, Western Australia. Rock types and results from the analysis of surface soils are also presented.