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BIOGEOCHEMICAL SAMPLING IN THE MAHD ADH DHAHAB

DISTRICT, KINGDOM OF SAUDI ARABIA

by

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CONTENTS

	Page
ABSTRACT.....	1
INTRODUCTION.....	2
DATA STORAGE.....	4
GEOLOGIC SETTING.....	4
PLANT SAMPLING.....	5
Sample preparation.....	5
Analytical methods.....	6
Data presentation.....	7
RESULTS.....	10
CONCLUSIONS.....	13
REFERENCES CITED.....	14
APPENDIX. Description of sampling sites and samples.....	16

ILLUSTRATIONS

[Plate is in pocket]

Plate 1.	Concentrations of lead, zinc, selenium, and cadmium in <u>Acacia</u> ash samples, Mahd adh Dhahab district	
Figure 1.	Index map of western Saudi Arabia showing location of the Mahd adh Dhahab district...	3

TABLES

Table 1.	Elements in ash of <u>Acacia</u> sp. branches from Mahd adh Dhahab district, Kingdom of Saudi Arabia.....	8
2.	Statistics of element concentrations as a function of known mineralization of substrate.....	9
3.	Standard error of replicate analyses.....	11
4.	Comparison of geometric mean values for samples from mineralized areas and from areas of no known mineralization.....	11

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ABSTRACT

A biogeochemical reconnaissance of the Mahd adh Dhahab district, Kingdom of Saudi Arabia, confirms the ability of deep-rooted Acacia trees to reflect bedrock concentrations of some trace elements. The analytical values for lead, zinc, selenium, and cadmium in ash of tree branches are significantly higher in samples from areas of known mineralization (13 sites) than in samples from areas of no known mineralization (12 sites). Geometric mean concentrations of these elements in the two areas (mineralized; nonmineralized), quoted as parts per million in ash, are lead (122; 28), zinc (713; 443), selenium (1.2; 0.6), and cadmium (1.4; 0.5).

The range of molybdenum values in ash from the two areas is similar, but a cluster of four sites in an area classified as nonmineralized corresponds to an area where the U.S. Geological Survey reported anomalous molybdenum values in rock in 1965. Results for other elements were either equivocal (mercury, tellurium, silver) or showed no correspondence to the two areas. Mean values for barium, manganese, potassium, and sodium are significantly higher in areas of no known mineralization, but we conclude that this reflects a difference in country rock major-element chemistry rather than the effect of ore-forming processes.

The pattern of trace-metal values in Acacia ash is present whether the sampled tree grows on bedrock, on talus, or on residual or modern alluvium. This fact suggests that the trace-element chemistry of the trees reflects bedrock geochemistry and implies that Acacia biogeochemistry could be applied as a prospecting tool in areas where bedrock is not well exposed.

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INTRODUCTION

The Mahd adh Dhahab gold, silver, and base-metal deposit (MODS 00003) is the most significant known deposit in the Precambrian Arabian Shield (fig. 1) and is the only one with recent production. Approximately 800,000 fine ounces of gold and 1,000,000 ounces of silver were produced in the period 1939-1954 by the Saudi Arabian Mining Syndicate (SAMS). During ancient time, probably 1,000,000 ounces of gold were produced from this site. Previous investigations include those by SAMS (Dirom, 1946) and by the U.S. Geological Survey Saudi Arabian Mission (Theobald, 1965; Luce and others, 1975, 1976; Roberts and others, 1978; Worl, 1978, 1979). The deposit was under development by Gold Fields-Mahd adh Dhahab Ltd. in a joint venture with Petromin during the period of fieldwork in 1981.

The objective of this study was to explore the feasibility of biogeochemical methods in prospecting for minerals in the desert environment of Saudi Arabia. Previous studies have indicated the utility of biogeochemical methods (Allcott, 1970; El-Ghonemy and others, 1977; and El Shazly and others, 1971), but improvements in analytical methods have expanded the list of detectable elements in plant ash. The test at Mahd adh Dhahab was based on the presence of known deposits of metals in parts of the district and the absence of known deposits in other parts. We believed that the presence or absence of mineralization should be accompanied by rock geochemical differences that may be reflected in the chemical composition of certain plant parts. Further, samples of plants grown on the large expanse of allochthonous (surficial) deposits in the district should test the ability of deep-rooted plants to detect anomalous bedrock chemistry beneath the sampling sites. If plants respond to buried bedrock chemistry, then biogeochemical studies may constitute a useful adjunct to the more conventional geochemical prospecting methods.

This report contains the results of analyses of 27 elements in ash or dry material of 25 samples of Acacia, as well as analyses of splits of 10 of these samples. Fieldwork was completed during 7 days in January 1981.

The authors express gratitude to personnel of Gold Fields-Mahd adh Dhahab Ltd. for providing much of the logistic support for the field operation. We thank A. T. Miesch for advice on statistical procedures and M. L. Tompkins for computer processing of data. L. P. Gough and J. L. Peard helped with sample preparation. The work for this report was performed by the U.S. Geological Survey in accordance with a work agreement with the Saudi Arabian Ministry of Petroleum and Mineral Resources as a part of subproject 3.31, Special Studies of Mineralization.

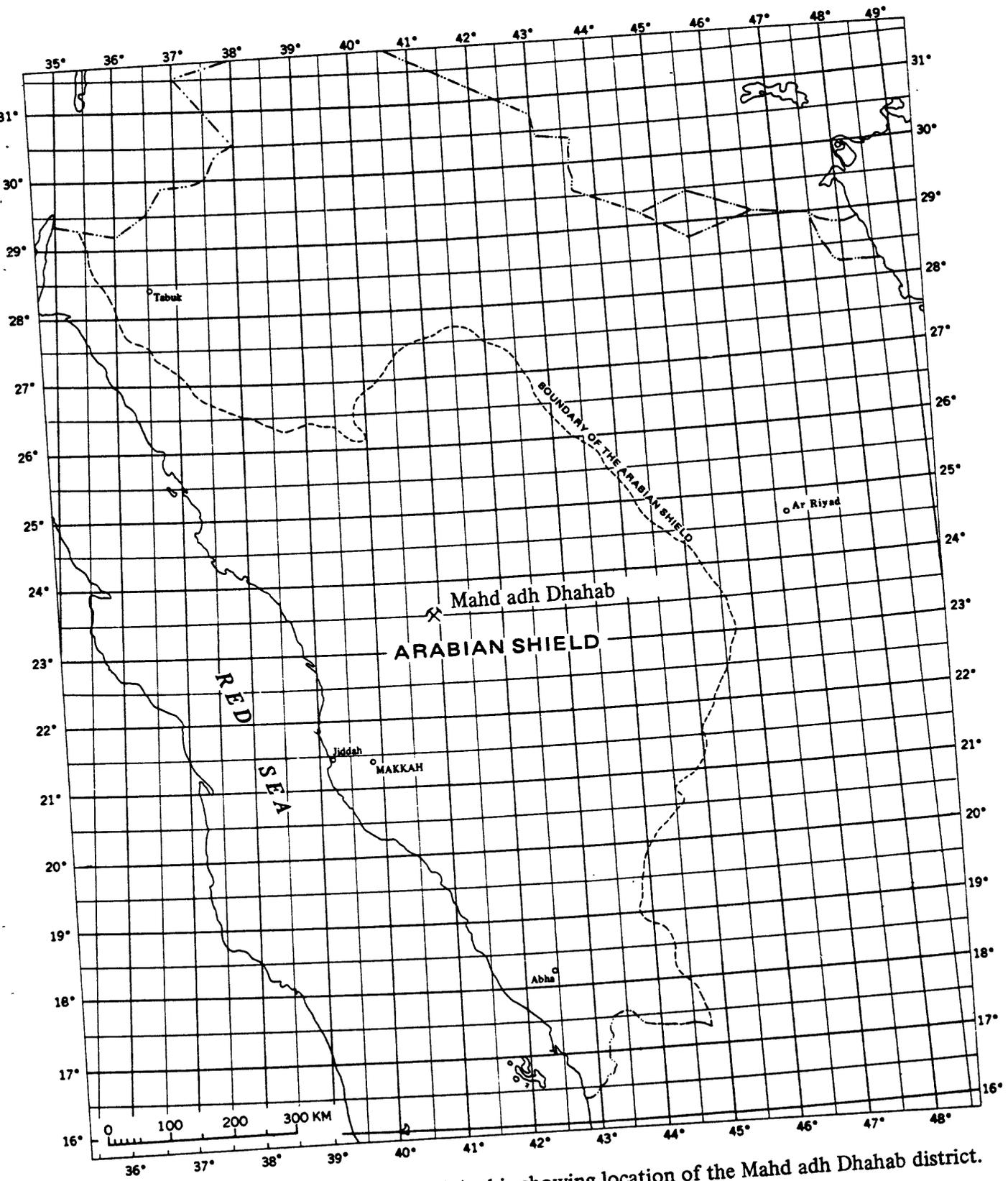


Figure 1.—Index map of western Saudi Arabia showing location of the Mahd adh Dhahab district.

DATA STORAGE

Mineral localities referred to in this report are recorded in the Mineral Occurrence Documentation System (MODS) data bank, and each is identified by a unique five-digit locality number. Documents relating to this project have been stored in data file USGS-DF-03-4.

Inquiries regarding either the MODS data bank or the data file may be made through the Office of the Technical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah.

GEOLOGIC SETTING

Two known ore bodies have been defined within a north-trending zone of quartz veins and quartz breccias, faults, alteration, and metallization that is approximately 400 m wide and 1,000 m long (plate 1). The ancient and SAMS workings are located in the northern part of this zone, whereas a significant new discovery is being developed in the southern part of the zone. Country rocks consist of a slightly deformed, north-dipping sequence of pyroclastic and transported (reworked) pyroclastic rocks. These units have been informally designated, from bottom to top, andesite, lower agglomerate, lower tuff, upper agglomerate, and upper tuff (Luce and others, 1975, 1976; Worl, 1978). On the whole, the country rocks are or were derived from volcanic rocks of intermediate to felsic composition and, with the exception of the andesite unit, are of fairly uniform composition throughout the district. The major variations that define the map units are clast size and related parameters of sorting, grading, and bedding. Somewhat younger rhyolite porphyry bodies are spatially associated with the northern and southern ore bodies, although only the northern rhyolite porphyry crops out.

Geologic setting of ore bodies is similar in both zones. Significant mineralization occurs only where metalliferous quartz veins cut altered and fractured agglomerate directly beneath a cap of fine-grained tuff and sedimentary rock. The quartz veins are continuous through all lithologies and contain trace to anomalous amounts of base and precious metals. Hydrothermal alteration (silicification, pyritization, and propylitization) is centered on the quartz-vein zone, but potassium feldspar alteration is more widespread and pervasive. The veins include an assemblage of quartz-chlorite-pyrite-hematite-chalcopyrite-sphalerite and precious metals (chiefly as telluride minerals).

The geologic units from which Acacia samples were collected are described in the appendix. They include talus, upper and lower agglomerate, wadi alluvium, older alluvium, lower tuff, and andesite. Acacia trees are the most prominent vegetation of this district and grow most commonly and vigorously in wadi alluvium. This district is in the western

Najd phytogeographical region, as mapped by Migahid (1978, p. 7).

PLANT SAMPLING

Among the plant species in the sparse flora of this district, woody plants in the Acacia genus (Leguminosae family) were selected for investigation of the applicability of biogeochemical prospecting in the desert region. Trees or shrubby trees of this genus are widely distributed throughout the dry regions of the Near East and are characterized as phreatophytes because their deep root systems extend to ground-water levels. The very thorny branches deter browsing by large animals; nevertheless, camels, goats, and probably other animals feed on the young stems and leaves. The branches can be sampled at any season of the year.

In this study the trees were sampled in January when the branches were either bare or just beginning to produce leaves and flowers. Sample M01 is tentatively identified as Acacia nubica Benth.; all other samples were of A. tortilis (Forssk.) Hayne. Identifications were based largely on thorn characteristics and pubescence, as indicated by Migahid (1978); only A. nubica bore pods, and they were immature. The terminal 10- to 20-cm-long portions of branches were cut from the trees and placed in strong canvas bags, and voucher specimens were pressed for use in species identification.

Sample preparation

Sample preparation was completed at the U.S. Geological Survey plant analysis laboratory in Denver. Plants in the canvas sample bags were thoroughly dried in an oven with forced air at about 40°C and were lightly pounded to remove leaves. Some samples were heavily contaminated with dust. To reduce the effect of this material on analytical values, all samples were cleaned with a jet of compressed air. Cleaning was considered complete when visible dust was no longer produced by the air blast. Every fourth sample was weighed before and after cleaning, and it was determined that the following amounts of extraneous materials were removed:

Sample	<u>Weight in grams</u>		Sample	<u>Weight in grams</u>	
	<u>Before cleaning</u>	<u>Dust removed</u>		<u>Before cleaning</u>	<u>Dust removed</u>
M01	115.3	1.3	U19	93.5	5.5
M02	112.4	2.4	U20	96.7	2.1
M05	138.5	4.2	U24	81.1	2.3
M10	75.7	2.5			

The samples were pulverized in a Wiley mill, and the dry pulp material was stored in cardboard boxes. Ten samples were split to provide duplicate analyses for estimating laboratory error for each element. The pulverized samples were placed on clean paper and quartered; two opposite quarters were combined to form the splits. The original sample was designated "A" and the split designated "B". All samples from areas of known mineralization bear the prefix "M" in the sample number; those from areas not known to be mineralized bear the prefix "U". The samples were arranged in random order before they were submitted to the analytical laboratory and were analyzed in this order to reduce the effects of analytical drift and operator bias.

Analytical methods

The samples were analyzed by Skyline Labs, Lakewood, Colorado. A portion of each sample was weighed and burned to ash in a muffle furnace. The ash yield of the dry sample was calculated from the weight of the ash. All samples were analyzed for 30 elements by emission spectrography. The elements were antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, gallium, germanium, iron, lanthanum, lead, magnesium, manganese, molybdenum, nickel, niobium, scandium, strontium, tin, titanium, tungsten, vanadium, yttrium, zinc, and zirconium. This analytical method was not sufficiently sensitive for many elements, and therefore special methods were used for some elements as follows:

1. Bismuth, cadmium, cobalt, copper, lead, nickel, and zinc were determined by atomic absorption from a single nitric-perchloric acid digestion of 0.2 g of ash. This method provided detection levels for most elements of 5 ppm in ash.
2. Molybdenum and silver were determined by atomic absorption after a potassium pyrosulfate fusion of 0.2 g of ash, followed by a phosphoric acid-hydrogen peroxide digestion and extraction into MIBK-Aliquat. Detection limits are 0.2 ppm in ash for silver and 2 ppm for molybdenum.
3. Aluminum, barium, calcium, iron, lithium, magnesium, manganese, phosphorus, potassium, sodium, strontium, and vanadium were determined by inductively coupled argon-plasma spectrography. Sample preparation required hydrofluoric-nitric-perchloric acid digestion of 0.1 g of ash, and dissolution of the dry residue in hydrochloric acid. Detection limits for most elements are 100 ppm.

4. Silicon and titanium were determined by inductively coupled argon-plasma spectrography. A 50-mg ash sample was digested with HF-aqua regia and hydrofluoric acid in a Teflon bomb, and the resulting solution was diluted with boric acid.
5. Antimony was determined colorimetrically, following hydrofluoric-nitric-perchloric acid digestion of 0.2 g of ash. The detection limit is 2 ppm in ash.
6. Fluorine was determined on a 25-mg portion of the sample by a specific-ion-electrode technique that has a lower detection limit of 100 ppm in ash.
7. Arsenic, tellurium, and selenium were determined by a modified hydride-evolution method from dry pulverized pulp. Detection limits are 1, 0.05, and 0.3 ppm, respectively.
8. Mercury was determined by a mercury-vapor method applied to dry pulverized pulp. The detection limit is 0.1 ppm.

Data presentation

Table 1 lists the analytical values for all elements detected in at least some of the samples. In addition, several elements were looked for by emission spectrography but were not detected in any sample. These elements, undetected at the parts-per-million limit of detection indicated in parentheses, include antimony (100), beryllium (2), bismuth (10), gallium (10), germanium (20), niobium (20), scandium (10), tin (10), and yttrium (10).

A total of 35 samples was analyzed, consisting of 13 samples from mineralized areas (seven replicate splits) and 12 samples from areas of no known mineralization (three replicate splits). Geometric mean values and geometric deviations, calculated from logarithmically transformed concentration data, are reported on table 2 for all sites and for the separate populations of mineralized sites and sites of no known mineralization. Censored analytical values (those reported on table 1 as less than the detection limit) were quantified by the method of Cohen (1959) to permit calculation of group mean and deviation parameters. For cobalt, mercury, lithium (in part), and tellurium, so many analytical values were censored that means and deviations were not calculated. In these cases, only the range of reported values is indicated on table 2; this range represents the lowest and highest values determined by the analyst.

Plate 1 shows the sample sites on a simplified geologic base map (from Luce and others, 1975, 1976, and Worl, 1978). The

Table 1.--Elements in ash of Acacia branches from Mahd adh Dhahab district, Kingdom of Saudi Arabia

[Boron and chromium by semiquantitative emission spectrography; other data determined as described in text; analyses by Skyline Labs, Denver, Colorado]

Sample	Weight percent											Element and concentration																
	Ash	Al	Ca	F	K	Na	P	Si	Ti	Ag	B	Ba	Cd	Co	Cr	Cu	Hg	Li	Mn	Mo	Ni	Pb	Se	Sr	Te	V	W	Zn
M01-A	7.0	0.78	27.1	0.048	7.3	0.41	0.43	2.2	0.06	<0.2	100	130	2.0	5	30	160	0.3	10	190	6	10	225	1.3	2500	<0.05	15	6	1550
-B	6.9	.82	26.7	.044	7.0	.41	.42	2.3	.05	< .2	150	130	3.0	<5	50	155	.1	10	195	6	10	225	1.5	2450	.05	20	7	1550
M02-A	6.9	.90	27.2	.024	7.6	.39	.37	2.7	.06	.4	200	200	7.0	<5	50	180	<.1	<10	240	4	15	195	2.4	2600	<.05	15	4	1700
-B	6.9	.89	26.7	.027	7.3	.39	.37	2.8	.07	.4	200	200	9.0	<5	50	180	<.1	<10	220	4	15	190	2.5	2550	<.05	15	7	1750
M03-A	9.3	.75	29.6	.042	5.4	.19	.27	2.3	.06	< .2	200	250	<.5	<5	50	95	<.1	<10	210	<2	65	100	.6	2800	<.05	15	6	320
-B	9.1	.74	29.5	.025	5.6	.19	.27	2.2	.06	< .2	100	270	<.5	<5	50	95	<.1	<10	200	<2	10	100	.6	2850	<.05	15	4	305
M04-A	5.6	.82	25.6	.044	10.8	.39	.96	2.5	.06	.6	200	270	1.0	<5	30	170	<.1	<10	280	20	10	115	.7	2250	<.05	15	10	740
M05-A	7.7	.77	29.6	.052	6.6	.35	.33	2.3	.05	< .2	150	420	3.0	<5	70	155	.1	<10	210	6	10	160	1.5	2350	.10	15	5	800
-B	7.7	.80	29.9	.046	4.8	.38	.38	2.3	.06	.6	100	380	3.0	<5	30	150	<.1	<10	220	4	15	165	.9	2350	<.05	20	6	780
M06-A	6.7	1.5	26.7	.054	6.2	.67	.53	4.4	.11	.6	200	560	3.0	<5	50	193	.2	15	390	4	20	265	1.5	2300	<.05	25	4	750
-B	6.6	1.5	27.1	.030	6.2	.72	.55	4.5	.11	.6	300	590	3.0	<5	70	215	.1	10	395	4	15	270	1.6	2400	<.05	30	4	790
M07-A	7.0	1.1	26.6	.048	9.3	.50	.73	3.1	.08	.2	200	220	1.0	5	50	115	<.1	10	255	4	4.5	65	.6	2150	<.05	25	10	520
-B	7.1	1.1	26.4	.044	9.5	.52	.78	3.2	.08	< .2	150	220	1.0	<5	70	120	<.1	15	260	4	20	65	.9	2150	<.05	25	4	530
M08-A	7.3	1.5	22.5	.029	11.7	.72	.59	4.4	.11	1.8	200	530	.9	<5	70	130	<.1	10	340	12	20	60	1.1	1650	<.05	30	6	700
M09-A	9.2	1.0	27.1	.044	6.5	.61	.44	3.1	.08	.2	200	230	2.0	<5	50	145	.1	10	220	6	15	160	2.0	3100	<.05	20	9	600
M10-A	8.2	.88	28.7	.029	4.8	.33	.42	2.6	.06	.2	300	260	.5	<5	50	135	<.1	<10	185	4	10	80	1.7	2850	<.05	15	7	495
M11-A	6.0	.85	27.7	.046	5.4	.30	.82	2.6	.07	< .2	200	320	1.0	<5	50	180	<.1	<10	225	10	15	90	1.1	2250	<.05	20	6	600
M12-A	6.2	.73	28.9	.048	6.3	.31	.49	2.2	.05	< .2	150	320	2.0	<5	50	140	.1	10	205	6	20	95	.9	1700	<.05	15	7	780
-B	6.3	.77	28.9	.029	6.3	.33	.51	2.2	.05	.2	200	310	2.0	<5	50	145	<.1	15	210	6	10	95	.7	1700	<.05	20	4	790
M13-A	6.6	.84	25.4	.052	10.5	.40	1.1	2.4	.06	.6	200	260	1.0	<5	30	155	.2	10	185	12	10	145	3.6	1900	<.05	15	7	650
U14-A	7.3	.56	27.2	.024	9.5	.40	.69	1.8	.04	< .2	150	260	<.5	<5	30	165	<.1	<10	200	8	10	20	.5	2900	<.05	15	7	360
U15-A	5.6	.92	24.5	.048	10.9	.72	2.0	2.5	.07	< .2	100	330	<.5	<5	50	155	<.1	<10	260	26	15	35	.4	2450	<.05	20	10	1050
U16-A	5.7	1.3	23.2	.054	11.1	.98	.81	3.6	.10	.2	200	300	.5	5	50	185	.1	10	375	4	15	45	.3	1950	<.0	7	600	
-B	5.3	1.4	23.4	.058	11.5	1.0	.83	3.8	.10	< .2	300	300	<.5	<5	50	190	<.1	20	375	6	30	35	.6	1950	<.05	30	7	640
U17-A	7.3	.92	26.9	.048	6.7	.99	.59	2.6	.07	.2	200	230	.5	<5	30	130	<.1	<10	245	10	15	35	1.0	2350	<.05	20	7	570
U18-A	7.5	1.0	25.2	.046	11.6	.47	.56	2.8	.07	.2	200	500	.5	<5	50	140	<.1	<10	255	10	15	55	.4	1950	<.05	20	10	440
U19-A	5.7	.83	25.8	.044	9.5	.68	.95	2.4	.06	.2	200	400	<.5	<5	100	130	<.1	<10	295	26	15	25	.7	2250	<.05	15	19	385
U20-A	8.2	1.1	27.1	.056	8.3	.48	.56	3.0	.08	.4	100	700	<.5	5	50	100	<.1	15	300	6	10	35	.7	2650	<.05	20	7	355
-B	8.1	1.0	25.9	.048	8.4	.47	.54	3.0	.07	<.2	150	690	<.5	<5	70	100	.1	15	285	8	10	35	.6	2550	<.05	20	7	360
U21-A	5.7	1.7	22.4	.048	11.5	.79	.70	4.3	.11	.2	200	510	<.5	<5	300	140	<.1	15	475	2	25	20	1.1	1700	<.05	35	7	510
U22-A	7.0	1.3	26.3	.030	7.6	.47	.45	3.7	.10	<.2	500	490	<.5	<5	70	110	<.1	<10	350	<2	25	15	.6	2850	<.05	20	4	300
-B	6.9	1.3	27.0	.050	7.6	.47	.45	3.6	.09	<.2	300	470	<.5	5	50	110	.1	10	360	<2	30	25	.5	2900	<.05	20	10	305
U23-A	5.3	1.1	22.4	.032	10.7	.68	.62	3.1	.08	.8	200	430	<.5	<5	50	150	<.1	<10	425	6	15	25	.5	1650	<.05	20	7	560
U24-A	7.4	1.3	26.3	.050	7.4	.75	.67	3.6	.10	<.2	200	540	.5	<5	70	120	.1	15	470	8	20	35	.6	2800	<.05	25	4	255
U25-A	5.3	1.2	21.3	.048	13.9	.53	1.0	3.4	.09	.2	100	630	<.5	5	50	130	.1	10	425	2	20	20	.7	2050	.10	25	4	340

Table 2.--Statistics of element concentrations as a function of known mineralization of substrate
 [Values for aluminum, calcium, fluorine, potassium, sodium, phosphorus, silicon, titanium, and ash are in weight percent, all other values are in parts per million. Leaders indicate value not calculated (see text)]

Element	All sites (25)				Sites within mineralized areas (13)				Sites within areas of no known mineralization (12)			
	Range	Mean ¹	Dev ²	Range	Mean	Dev	Range	Mean	Dev	Range	Mean	Dev
Ag	<0.2-1.8	0.22	2.28	<0.22-1.8	0.24	2.78	<0.2 -0.80	0.30	1.80			
Al	0.56-1.7	0.99	1.30	0.73-1.5	0.93	1.27	0.56-1.7	1.70	1.33			
B	100-500	182	1.42	100-300	187	1.28	100-500	177	1.56			
Ba	130-700	342	1.52	130-560	284	1.49	230-700	420	1.42			
Ca	21.3-29.6	26	1.09	22.5-29.6	27	1.08	21.3-27.2	25	1.09			
Cd	<0.5-7	0.66	2.91	<0.5-7	1.40	2.24	<0.5-5	0.50	1.00			
Co	<5-5	-	-	<5-5	-	-	<5-5	-	-			
Cr	30-300	58	2.01	30-70	56	1.28	30-300	60	1.84			
Cu	95-195	142	1.21	95-195	147	1.22	100-190	136	1.19			
F	.024-.058	0.42	1.29	.024-.058	.042	1.30	.024-.058	0.43	1.30			
Hg	<0.1-0.3	-	-	<0.1-0.3	-	-	<0.1-0.1	-	-			
K	4.8-13.9	8.3	1.34	3.8-11.7	7.3	1.33	6.7-13.9	9.7	1.24			
Li	<10-15	9.3	1.31	<10-15	-	-	<10-15	9.2	1.43			
Mn	185-475	275	1.36	185-395	234	1.26	200-475	327	1.33			
Mo	<2-26	6.1	2.22	<2-20	6.1	1.92	<2-26	6.2	2.59			
Na	.19-1.0	0.50	1.49	.19-0.72	0.40	1.44	.40-1.0	0.64	1.35			
Ni	4.5-65	15	1.63	4.5-65	13	1.86	10-15	16	1.34			
P	.27-2.0	0.62	1.54	.27-1.1	0.53	1.53	.45-2.0	0.74	1.47			
Pb	15-265	61	2.35	60-265	122	1.60	15-55	28	1.47			
Se	0.3-3.6	0.89	1.78	0.6-3.6	1.2	1.68	0.3-1.1	0.6	1.40			
Si	2.2-4.4	2.9	1.27	2.2-4.4	2.8	1.27	2.4-4.3	3.0	1.27			
Sr	1650-3100	2279	1.21	1650-3100	2279	1.21	1650-2900	2256	1.22			
Te	<0.05-0.10	-	-	<0.05-0.10	-	-	<0.05-0.10	-	-			
Ti	.04-.11	0.073	1.32	.05-.11	0.067	1.29	.04-.11	0.078	1.33			
V	15-35	19	1.29	15-30	18	1.29	15-35	21	1.26			
W	4-19	6.7	1.45	4-10	6.4	1.35	4-19	7.2	1.56			
Zn	300-1700	568	1.60	320-1700	713	1.55	360-1050	443	1.47			
Ash	5.3-9.3	6.8	1.18	6.0-9.3	6.4	1.17	5.3-8.2	7.1	1.17			

¹ Geometric mean value, calculated as described in text.

² Geometric deviation about the mean.

analytical values for lead, zinc, selenium, and cadmium in ash are posted at each site for the whole sample or the "A" split only. These four elements in ash discriminate most clearly between mineralized areas and areas of no known mineralization.

RESULTS

In order to determine laboratory error in analyses, splits of 10 samples were selected randomly from the total of 25 sites and analyzed; then the standard error of replicates was determined. This statistical test requires more than two pairs of unqualified values for an element; the data in table 1 show that fewer than 10 pairs met this requirement for some elements: cadmium, 6 pairs; lithium, 5 pairs; molybdenum, 8 pairs; silver, 2 pairs, and mercury, 1 pair. Analyses of splits for arsenic, cobalt, tellurium, and mercury produced no pairs of samples with unqualified values, and the standard error for these elements, as well as that for silver and mercury, could not be calculated.

Table 3 contains the standard error of replicates for 23 elements and ash. Zinc, with an error term of 1.00, had identical concentrations in both samples of each of 10 pairs, and analytical precision was perfect. In contrast, chromium analyses were least precise with an error term of 2.07. The analytical values given for elements with large (greater than 1.20) standard errors (boron, chromium, copper, fluorine, lithium, nickel, selenium, and tungsten), as well as some others having a high percentage of qualified values (cobalt and silver), are of questionable utility in evaluating Acacia as a biogeochemical indicator of metal deposits, unless laboratory procedures are improved.

The high standard errors can be attributed to inadequate analytical methods, operator bias, heterogeneous sample material, or sample contamination. The very small size of sample available for analysis of some elements may also have contributed to high standard errors.

The statistical summaries in table 2 contain the geometric means, deviations, and ranges of each element for the 25 Acacia samples in three groups: all samples taken together, samples from the area classified as mineralized, and samples from the area where mineralization is not known. This classification of the two areas in order to compare element concentrations is justified primarily for elements that may have a relationship to geologic processes that formed the mineral deposits, although it is a very loose characterization of the total geochemical environment of the district. The samples from trees in the mineralized area will reflect the chemical nature of the sites where the trees grow, which may or may not be mineralized. Similarly, in the area characterized as

Table 3.--Standard error of replicate analyses

Element	Number of pairs	Standard error	Element	Number of pairs	Standard error	Element	Number of pairs	Standard error
Al	10	1.03	K	10	1.07	Se	10	1.26
B	10	1.34	Li	5	1.32	Si	10	1.02
Ba	10	1.03	Mn	10	1.03	Sr	10	1.02
Ca	10	1.01	Mo	8	1.17	Ti	10	1.08
Cd	6	1.16	Na	10	1.03	V	10	1.13
Cr	10	2.07	Ni	10	1.80	W	10	1.43
Cu	10	1.32	P	10	1.04	Zn	10	1.00
F	10	1.28	Pb	10	1.14	Ash	10	1.02

Table 4.--Comparison of geometric mean values for samples from mineralized areas (M) and from areas of no known mineralization (U)

[* indicates difference between geometric means is significant at 95 percent confidence level. ** indicates mean value in weight percent; all others in parts per million. Leaders (--) indicate mean not calculated]

Mean higher in mineralized area			Mean higher in area of no known mineralization			Mean similar in both areas		
Element	M	U	Element	M	U	Element	M	U
Cd	1.40	0.50	Al**	0.93	1.07	Ag	0.24	0.20
Cu	147	136	*Ba	284	420	B	187	177
*Pb	122	28	*K**	7.3	9.7	*Ca**	27	25
*Se	1.2	.6	*Mn	234	327	Cr	56	60
Sr	2279	2256	*Na**	.40	0.64	F**	.042	.043
*Zn	713	443	Ni	13	16	Li	--	9.2
			P**	.53	.74	Mo	6.1	6.2
			Si**	2.8	3.0			
			Ti**	.067	.078			
			V	18	21			
			W	6.4	7.2			
			Ash**	6.4	7.1			

having no known mineralization, site differences in metal content are expected. Nevertheless, this division of the district is a convenient means of making a first approximation of Acacia as a biogeochemical indicator of substrate chemistry.

In order to more readily compare the element values in Acacia samples from the two areas, data from table 2 are rearranged in table 4, and those differences between the two areas that are significant at the 95 percent level of confidence are marked with an asterisk. A two-level analysis of variance shows that the means of only lead, selenium, and zinc are significantly higher in the mineralized area. All are elements directly related to deposition from a hydrothermal system. In the area of no known mineralization, the elements commonly associated with feldspathic rocks (barium, potassium, and sodium), as well as manganese, are significantly more concentrated in the tree ash. These elements probably represent a difference in country rock composition rather than a reflection of the hydrothermal system. Although calcium concentrations in trees from the two areas are very similar, the mean value for mineralized areas is significantly higher (at the 95 percent confidence level). Cadmium could not be rigorously tested for significant difference between samples from the two areas because of many qualified values, but the distribution pattern of high and low values closely follows that of zinc, which is significantly enriched in the mineralized area.

Although the mean values for molybdenum in trees from the two areas are almost identical, there are interesting patterns in the molybdenum data. The highest concentration (26 ppm) was determined in samples from sites U19 and U15, that is, in the area classified as having no known mineralization. A cluster of relatively high values at sites U14, U15, U17, and U18 is located near two U.S. Geological Survey exploratory drill holes that penetrated an altered zone with anomalous molybdenum values (Theobald, 1965).

Most silver values were at or below the limit of detection (0.2 ppm), but the highest value (1.8 ppm) is from site M08, which is above the area of the recently defined southern orebody.

A comparison of descriptions of substrates at the sample sites (appendix) with metal values on table 1 and plate 1 suggests that high metal values are present in trees, regardless of whether they grow on wadi alluvium, older alluvium, colluvium, or andesite bedrock. This observation suggests that tree roots are able to sample the elements in geologic materials beneath surficial cover and to reflect bedrock metal-zonation patterns.

CONCLUSIONS

Lead, selenium, zinc, and cadmium concentrations in samples of Acacia trees, as measured in this exploratory study, are probably the most reliable indicators of anomalous metal values in the substrate. Silver, mercury, and molybdenum in tree samples appear to reflect high substrate concentrations at specific sites. Other metals appear to be of lesser or no value in identifying buried mineralization either because of inadequate methods of sampling and analysis or because Acacia trees do not respond to such elements in deposits of the Mahd adh Dhahab type. The results of this biogeochemical survey indicate that a greater Acacia-sample density for a larger area in this or other districts of Saudi Arabia would probably give a definite appraisal of the biogeochemical method of prospecting as an adjunct to more conventional desert-environment geochemical tools.

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APPENDIX--Description of sampling sites and samples

Site number	Site description		Mapped geologic unit (Luce and others 1975)	Substrate at site	Sample notes
	North latitude	East longitude			
M01	23°30'08"	40°51'52"	Talus	Mixture of bedrock and coarse alluvium	Browsed shrub
M02	23°30'07"	40°51'52"	Upper agglomerate	Bedrock on edge of narrow (1.6 km) wadi	Tree
M03	23°30'08"	40°51'50"	Upper agglomerate	Well-drained colluvium	Tree
M04	23°30'06"	40°51'49"	Upper agglomerate	Bedrock and very coarse alluvium	Tree
M05	23°30'05"	40°51'51"	Contact of upper agglomerate and older alluvium	Alluvium near bedrock	Tree, about 2.5 m tall
M06	23°29'58"	40°51'58"	Alluvium in wadis	Alluvium of large wadi	Browsed tree; very dusty
M07	23°29'50"	40°51'48"	Lower agglomerate	Bedrock at mineralized vein system planned for underground mining	Tree
M08	23°29'49"	40°51'49"	Older alluvium	Bedrock with some admixture of alluvium	Browsed tree
M09	23°30'16"	40°51'45"	Older alluvium	Alluvium near ancient tailings	Tree
M10	23°30'14"	40°51'43"	Upper agglomerate	Colluvium and bedrock	Tree
M11	23°30'11"	40°51'41"	Upper agglomerate	Agglomerate adjacent to large quartz vein	Tree
M12	23°30'13"	40°51'46"	Older alluvium	Bedrock of gully about 1 m from large andesite dike	Tree
M13	23°30'15"	40°51'47"	Upper agglomerate	Alluvium and bedrock 5 m from ancient slope	Tree
U14	23°30'07"	40°51'31"	Upper agglomerate	Upper agglomerate bedrock	Tree
U15	23°30'06"	40°51'35"	Upper agglomerate	Upper agglomerate bedrock near contact with lower tuff	Shrub, with thick branches
U16	23°30'06"	40°51'39"	Upper agglomerate at contact with talus	Upper agglomerate bedrock near siliceous zone	Tree
U17	23°30'09"	40°51'34"	Upper agglomerate	Contact of upper agglomerate and (?) lower tuff near chert zone	Tree; galvanized metal nearby
U18	23°30'07"	40°51'29"	Lower tuff	Wadi sediment	Tree
U19	23°30'00"	40°51'25"	Alluvium in wadis	Lower tuff and colluvium	Tree
U20	23°30'02"	40°51'17"	Alluvium in wadis	Wadi sediment	Dusty tree
U21	23°29'49"	40°51'18"	Talus	Wadi sediment	Tree
U22	23°29'43"	40°51'19"	Alluvium in wadis	Wadi sediment	Tree
U23	23°29'48"	40°51'37"	Andesite	Colluvium at base of Jabal Mahd adh Dhahab	Tree
U24	23°29'45"	40°51'37"	Alluvium in wadis	Wadi sediment near andesite outcrop	Tree
U25	23°29'40"	40°51'39"	Alluvium in wadis	Wadi sediment beside mine camp road	Tree