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Preliminary assessment of the geochemistry and mineral favorability of the postorogenic granites of the southeastern Arabian Shield, Kingdom of Saudi Arabia

by

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PRELIMINARY ASSESSMENT OF THE GEOCHEMISTRY AND MINERAL FAVORABILITY OF THE POSTOROGENIC GRANITES OF THE SOUTHEASTERN ARABIAN SHIELD, KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

Chemical analyses of samples for 19 postorogenic plutons from the southeastern Arabian Shield show that these rocks have average potassium/rubidium ratios (162) and average rubidium/strontium ratios (11.8) characteristic of highly evolved granites. Most of the analyzed samples are peraluminous. Three plutons are physically similar in terms of shape and megascopic textural zonation to peralkaline complexes in the northeastern part of the Shield, but none of the samples from these plutons is peralkaline. However, these plutons do contain the least-evolved samples.

Zinc, yttrium, uranium, thorium, and possibly copper, each occur in anomalously high concentrations in at least one pluton relative to contents typically cited for granite. The average regional concentrations of copper and zinc are anomalously high. These facts suggest at least a moderate potential for mineralization in the southeastern part of the Shield. Good correlations (r of 0.5 to 0.8) between uranium, thorium, yttrium, and rubidium and an excellent correlation (r=0.98) between uranium and radium-equivalent uranium suggest that secondary deposits of these elements are unlikely and that magmatic deposits, especially of a pegmatitic nature, are more likely.

Concentrations of some major elements and several trace elements covary with sample location as measured by latitude and longitude. This fact is interpreted to reflect regional variations in the protolith that have been proposed on the basis of lead isotopic data. The chemical variations suggest a largely oceanic crustal component for granites in the southwestern part of the southeastern Shield and a largely continental crustal component to the northeast.

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Further quantitative analysis is recommended to verify and accurately delineate anomalous concentrations of trace elements. Trend surface analysis of all available data for postorogenic granites from the eastern Arabian Shield is suggested as a method for testing regional variations in the protolith that might control locations of highly favorable areas of ore deposition.

INTRODUCTION

This report is the result of research performed by the U.S. Geological Survey (USGS) in accordance with a work agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia. The research is part of a study of the petrogenesis and mineral potential of the granitic rock of the Arabian Shield. This report provides reconnaissance results for postorogenic granites within a region (fig. 1) identified as anomalously metalliferous by du Bray and others (1983).

Postorogenic granites were intruded throughout the Arabian Shield from about 650 m.y. ago until at least 540 m.y. ago (Fleck and others, 1980). The granites are typically hypersolvus members of the calc-alkaline suite (Stoeser and Elliott, 1980), although subsolvus examples are common, particularly in the southeastern part of the Shield (du Bray and others, 1983). Chemically, the granites have high silica contents and range from peralkaline to peraluminous (Stoeser and Elliott, 1980; Stuckless and others, in press).

Postorogenic granites were chosen for this investigation because of their probable association with ore deposits in other parts of the world (for example, Wilson and Åkerblom, 1980; Doe and others, in press) and because of their importance to investigations of crustal evolution (for example, Anderson and others, 1980; Anderson, 1983). Many of these granites are highly evolved petrologically (for example, Barker and others, 1976; Anderson and Cullers, 1978; Cullers and others, 1981), and, in the area of the Arabian Shield, they contain anomalous amounts of incompatible trace elements (Harris and Marriner, 1980; Cole and others, 1981; Radain and others, 1981).

The classification of igneous rocks used in this report is that recommended by the IUGS Subcommission on the nomenclature of plutonic rocks (Streckeisen, 1973). The granites are subdivided on the basis of alumina saturation as defined by Shand (1951). Rocks with molar ratios of $Al/(Na+K)<1$ are peralkaline, $Al/(Na+K)>1$ and $Al/(Na+K+Ca)<1$ are metaluminous, and $Al/(Na+K+Ca)>1$ are peraluminous.

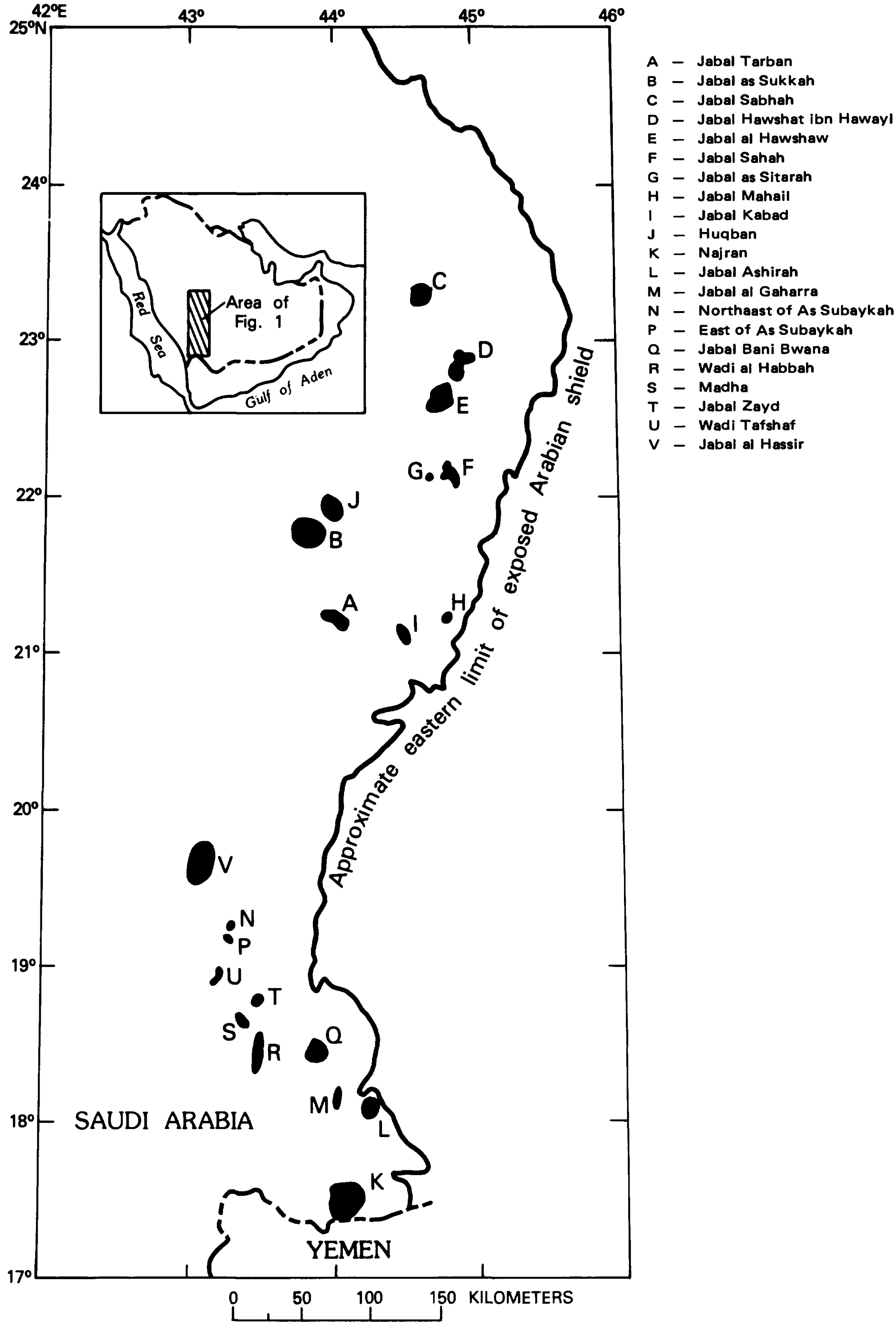

Figure 1.--Location map for plutons sampled in the southeastern part of the Arabian Shield. Letter designations correspond to symbol designations on table 1 and to location names on table 2.

ANALYTICAL PROCEDURES

Concentrations of major elements (table 1) were obtained by high-precision X-ray fluorescence (Taggart and others, 1982). This technique uses an 0.8 g aliquot of fused sample powder. Results are considered to be precise and accurate within $\pm$ 2 percent of the amount reported (2σ) for abundances in excess of 1 percent absolute. A fourth digit is reported for SiO_2 and Al_2O_3, which is not significant for any one sample but which may be significant in the statistical treatment of the entire data set (A. T. Miesch, oral commun., 1980). Values for MgO, TiO_2, P_2O_5, and MnO that are less than the detection limit (0.10, 0.02, 0.05, and 0.02, respectively) are arbitrarily assigned values of one-half the value of the detection limit for purposes of normative and statistical calculations.

Uranium and thorium concentrations (table 2) were determined on 8 to 10 g aliquots of sample powder by the delayed neutron technique (Millard, 1976). Accuracies for reported values, based on counting statistics, vary with concentration. Uranium concentrations are accurate to between $\pm$ 4 and $\pm$ 8 percent for more than 2 parts per million (ppm), to between $\pm$ 8 and $\pm$ 14 percent for 1 to 2 ppm, and to between $\pm$ 14 to $\pm$ 36 percent for less than 1 ppm. Thorium concentrations are accurate to between $\pm$ 8 and $\pm$ 30 percent for more than 6 ppm and to about $\pm$ 50 percent for less than 6 ppm (2σ). Thorium values greater than 10 ppm are generally accurate to within $\pm$ 15 percent of the amount reported.

Radium-equivalent uranium (RaeU), thorium (eTh), and potassium (eK) values (table 2) were determined by sealed-can gamma-ray spectrometry on 600 g of coarsely crushed (-32 mesh) sample (Bunker and Bush, 1966, 1967). The prefix "e" is used to designate this analytical method. The potassium value obtained by this technique is an actual measure of potassium and is generally precise and accurate (2σ) to within $\pm$ the quantity [2 percent of the amount reported plus 0.03 percent absolute]. The large sample size used for gamma-ray spectrometry essentially eliminates splitting errors, and, therefore, eK is used throughout this report for calculation of radioelement ratios and statistical parameters.

Although eTh is not determined directly from thorium, disequilibrium within the thorium decay chain is unlikely. The precision and accuracy (2σ) for eTh is better than $\pm$ the quantity (2 percent of the amount reported plus 0.1 ppm absolute). The value eTh is used in preference to Th for radioelement ratios and statistical calculations because of higher precision, lower detection limit, and smaller splitting error. RaeU is the amount of uranium needed for secular equilibrium with the indirectly measured ^{226}Ra. Radioactive

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield [Chemical composition in percent. Letter symbol refers to location of fig. 1. D.I. is the differentiation index of Thornton and Tuttle, 1960. Fe_2O_3 and FeO calculated from the total iron assuming 2/3 of the iron is present as FeO. LOI is loss on ignition at 920°C]

	55500	55501	55502	55503	55504	55505	55506	55507	55508	55509	55510
Symbol	A	A	A	A	A	A	B	B	B	B	B
SiO2	75.20	75.98	76.33	74.63	74.54	76.33	75.25	76.38	73.32	76.06	72.01
Al2O3	13.65	13.27	12.92	13.22	13.40	13.01	13.37	12.87	13.95	13.03	14.58
Fe2O3	0.19	0.21	0.19	0.49	0.47	0.24	0.37	0.32	0.47	0.38	0.58
FeO	0.34	0.38	0.34	0.89	0.84	0.43	0.67	0.58	0.84	0.69	1.05
MgO	<0.10	<0.10	<0.10	0.25	0.26	<0.10	0.18	0.17	0.34	0.16	0.52
CaO	0.30	0.16	0.25	0.88	0.92	0.24	0.60	0.50	1.09	0.51	1.52
Na2O	4.47	4.39	3.92	3.54	3.69	4.09	4.16	3.86	4.29	3.92	4.31
K2O	4.34	4.29	4.61	4.77	4.66	4.49	4.36	4.59	4.19	4.47	4.04
LOI	0.40	0.26	0.25	0.35	0.30	0.09	0.08	0.30	0.29	0.19	0.24
TiO2	<0.02	0.02	<0.02	0.14	0.15	<0.02	0.09	0.08	0.16	0.09	0.21
P2O5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	0.09
MnO	0.08	0.07	0.09	0.04	0.04	0.09	0.07	0.04	0.04	0.03	0.04
ZrO2	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.02
Total(-O)	99.05	99.11	98.99	99.24	99.31	99.09	99.24	99.73	99.06	99.56	99.21
Normative Minerals											
Q	31.957	33.669	35.402	33.340	32.709	34.800	32.702	34.846	29.486	34.633	27.372
C	1.112	1.172	1.086	0.687	0.666	1.043	0.770	0.693	0.524	0.868	0.573
Z	0.015	0.015	0.015	0.030	0.030	0.015	0.015	0.015	0.030	0.015	0.030
OR	25.892	25.579	27.519	28.403	27.730	26.776	25.963	27.198	24.996	26.530	24.063
AB	38.186	37.482	33.508	30.184	31.442	34.925	35.472	32.752	36.647	33.315	36.759
AN	1.371	0.669	1.121	4.267	4.464	1.070	2.868	2.356	5.063	2.410	7.008
EN	0.126	0.126	0.126	0.627	0.652	0.126	0.452	0.425	0.855	0.400	1.305
FS	0.601	0.649	0.629	1.075	0.991	0.745	0.915	0.747	0.977	0.862	1.184
MT	0.273	0.312	0.278	0.720	0.681	0.346	0.545	0.470	0.682	0.558	0.852
IL	0.019	0.019	0.019	0.268	0.287	0.019	0.172	0.152	0.307	0.172	0.402
AP	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.143	0.048	0.215
Total	99.598	99.740	99.750	99.649	99.699	99.911	99.921	99.701	99.711	99.811	99.763
SALIC	98.531	98.586	98.650	96.910	97.041	98.628	97.790	97.860	96.746	97.771	95.805
FEMIC	1.067	1.153	1.099	2.738	2.659	1.283	2.131	1.841	2.965	2.039	3.958
D.I.	96.034	96.730	96.428	91.926	91.881	96.501	94.137	94.796	91.129	94.479	88.194

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield--Continued

	55511	55512	55513	55514	55515	55516	55517	55518	55519	55520	55521
Symbol	C	C	C	C	C	C	C	D	D	D	D
SiO2	76.19	76.50	70.94	75.71	75.97	76.46	76.10	75.58	76.77	76.21	76.11
Al2O3	13.11	12.80	14.59	12.71	12.65	12.60	12.81	12.49	12.40	12.83	12.72
Fe2O3	0.28	0.30	0.77	0.37	0.39	0.32	0.33	0.57	0.32	0.32	0.41
FeO	0.51	0.54	1.39	0.67	0.71	0.57	0.59	1.03	0.58	0.58	0.74
MgO	<0.10	<0.10	0.46	<0.10	<0.10	<0.10	<0.10	0.15	<0.10	<0.10	0.05
CaO	0.28	0.38	1.48	0.73	0.69	0.54	0.48	0.60	0.39	0.39	0.41
Na2O	4.35	4.22	3.44	3.90	3.87	3.76	3.97	3.05	3.92	4.25	4.14
K2O	4.12	4.10	5.15	4.38	4.38	4.49	4.48	5.25	4.41	4.14	4.24
LOI	0.21	0.26	0.53	0.49	0.46	0.29	0.20	0.36	0.25	0.33	0.46
TiO2	<0.02	<0.02	0.30	0.03	0.03	<0.02	0.02	0.10	0.02	0.02	0.04
P2O5	<0.05	<0.05	0.13	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	<0.02	<0.02	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
ZrO2	0.01	0.02	0.03	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.02
Total(-O)	99.15	99.21	99.24	99.09	99.25	99.13	99.06	99.23	99.15	99.17	99.37
Normative Minerals											
Q	34.469	35.361	27.256	34.583	35.023	36.184	34.775	35.987	36.188	34.717	34.674
C	1.042	0.783	0.985	0.277	0.339	0.626	0.611	0.753	0.521	0.702	0.627
Z	0.015	0.030	0.045	0.030	0.030	0.015	0.015	0.030	0.015	0.030	0.030
OR	24.554	24.421	30.667	26.121	26.078	26.766	26.724	31.266	26.284	24.670	25.215
AB	37.123	35.993	29.333	33.305	32.994	32.096	33.910	26.010	33.456	36.265	35.254
AN	1.269	1.768	6.543	3.523	3.317	2.571	2.272	2.868	1.820	1.819	1.915
EN	0.126	0.126	1.154	0.126	0.125	0.126	0.126	0.376	0.126	0.126	0.125
FS	0.711	0.752	1.482	0.895	0.952	0.795	0.804	1.277	0.786	0.786	0.976
MT	0.414	0.438	1.124	0.541	0.574	0.463	0.478	0.832	0.467	0.467	0.598
IL	0.019	0.019	0.574	0.058	0.057	0.019	0.038	0.191	0.038	0.038	0.076
AP	0.048	0.048	0.310	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Total	99.789	99.739	99.473	99.507	99.538	99.709	99.799	99.638	99.749	99.668	99.538
SALIC	98.472	98.356	94.828	97.840	97.781	98.259	98.306	96.913	98.284	98.203	97.715
FEMIC	1.317	1.383	4.645	1.667	1.757	1.450	1.493	2.725	1.465	1.465	1.823
D.I.	96.146	95.775	87.256	94.010	94.095	95.047	95.408	93.262	95.928	95.652	95.143

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield--Continued

Symbol	55522 E	55523 E	55524 E	55525 E	55526 F	55527 F	55528 F	55529 F	55530 G	55531 G	55532 H
SiO2	73.08	75.68	75.85	76.00	77.56	76.34	76.02	76.32	73.95	75.44	75.95
Al2O3	14.27	12.60	12.84	12.91	11.71	12.77	12.70	12.60	13.73	13.09	13.96
Fe2O3	0.29	0.47	0.32	0.33	0.50	0.37	0.48	0.49	0.52	0.44	0.32
FeO	0.53	0.85	0.58	0.60	0.89	0.66	0.87	0.88	0.94	0.80	0.58
MgO	0.15	0.11	<0.10	<0.10	<0.10	0.11	0.13	<0.10	0.29	0.20	0.05
CaO	0.64	0.70	0.66	0.61	0.34	0.52	0.56	0.49	1.33	0.86	0.26
Na2O	3.24	3.09	3.63	3.41	3.30	3.67	3.66	3.63	4.26	3.90	3.98
K2O	6.48	4.78	4.51	4.57	4.50	4.68	4.57	4.64	3.58	4.00	3.66
LOI	0.64	0.53	0.58	0.49	0.41	0.21	0.32	0.30	0.53	0.37	0.52
TiO2	0.06	0.06	0.03	0.03	0.06	0.06	0.08	0.06	0.19	0.13	<0.02
P2O5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	<0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.03	0.03	<0.02	0.17
ZrO2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	
Total(-O)	99.42	98.92	99.11	99.05	99.37	99.44	99.45	99.52	99.40	99.28	99.49
Normative Minerals											
Q	27.758	37.708	35.996	37.329	40.112	35.671	35.583	36.013	31.955	35.195	37.911
C	0.815	1.130	0.842	1.305	0.846	0.774	0.767	0.767	0.480	0.835	3.042
Z	0.015	0.015	0.015	0.015	0.015	0.015	C.015	0.030	0.030	0.030	
OR	38.515	28.556	26.891	27.264	26.760	27.812	27.154	27.551	21.284	23.808	21.740
AB	27.576	26.433	30.993	29.130	28.101	31.231	31.140	30.863	36.266	33.240	33.852
AN	3.062	3.379	3.172	2.923	1.566	2.463	2.662	2.311	6.507	4.166	1.165
EN	0.376	0.277	0.126	0.126	0.125	0.276	0.326	0.125	0.727	0.502	0.125
FS	0.651	1.116	0.807	0.822	1.178	0.853	1.129	1.170	1.047	0.910	1.108
MT	0.427	0.688	0.468	0.487	0.724	0.534	0.704	0.708	0.763	0.647	0.471
IL	0.115	0.115	0.057	0.058	0.115	0.115	0.153	0.114	0.363	0.249	0.019
AP	0.048	0.048	0.048	0.048	0.048	C.048	0.048	0.048	0.048	0.048	0.048
Total	99.357	99.465	99.416	99.507	99.589	99.790	99.680	99.700	99.468	99.628	99.481
SALIC	97.741	97.221	97.910	97.966	97.399	97.966	97.321	97.535	96.521	97.273	97.710
FEMIC	1.616	2.245	1.506	1.541	2.189	1.824	2.359	2.165	2.947	2.355	1.770
D.I.	93.849	92.697	93.881	93.722	94.973	94.714	93.877	94.427	89.505	92.242	93.503

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield--Continued

Symbol	55533 H	55534 I	55535 I	55536 J	55537 J	55538 J	55539 J	55540 K	55541 K	55542 K	55543 K
SiO2	76.43	75.72	76.47	78.19	80.19	76.99	76.40	69.25	69.80	74.08	66.66
Al2O3	13.73	13.94	13.84	11.44	10.89	11.90	12.57	13.85	13.78	13.04	14.81
Fe2O3	0.33	0.31	0.32	0.47	0.22	0.59	0.44	1.42	1.30	0.76	1.76
FeO	0.60	0.56	0.58	0.84	0.40	1.06	0.79	2.55	2.33	1.36	3.17
MgO	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.17	0.14	<0.10	0.17	0.13
CaO	0.29	0.40	0.29	0.16	0.12	0.37	0.61	0.96	0.95	1.07	1.36
Na2O	3.84	3.87	4.01	3.25	3.80	3.40	3.34	4.30	4.29	4.04	4.50
K2O	3.48	3.88	3.10	4.69	3.58	4.88	4.90	5.59	5.45	4.09	5.67
LOI	0.69	0.69	0.91	0.33	0.28	0.27	0.27	0.24	0.18	0.18	0.26
TiO2	<0.02	<0.02	<0.02	0.06	<0.02	0.07	0.12	0.36	0.31	0.10	0.48
P2O5	<0.05	0.10	0.13	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05
MnO	0.17	<0.02	0.04	<0.02	<0.02	0.02	<0.02	0.07	0.06	0.04	0.09
ZrO2				0.02	0.02	0.02	0.01	0.11	0.09	0.02	0.13
Total(-O)	99.64	99.54	99.75	99.53	99.60	99.64	99.64	98.87	98.66	98.97	99.08
Normative Minerals											
Q	39.766	37.534	40.668	40.669	44.026	37.220	36.430	20.007	21.354	31.945	14.824
C	3.178	2.900	3.681	0.778	0.596	0.401	0.713			0.070	
Z				0.030	0.030	0.030	0.015	0.166	0.136	0.030	0.195
OR	20.638	23.034	18.365	27.846	21.241	28.941	29.059	33.412	32.643	24.421	33.818
AB	32.609	32.899	34.018	27.631	32.285	28.873	28.364	36.803	36.794	34.542	38.433
AN	1.313	1.337	0.591	0.666	0.467	1.711	2.906	2.003	2.278	5.232	3.498
WO								1.092	0.960		1.245
EN	0.125	0.125	0.125	0.125	0.125	0.125	0.425	0.353	0.227	0.428	0.327
FS	1.131	0.775	0.854	1.082	0.558	1.390	0.907	3.085	2.855	1.805	3.784
MT	0.485	0.451	0.465	0.679	0.325	0.858	0.635	2.076	1.904	1.107	2.578
IL	0.019	0.019	0.019	0.114	0.019	0.133	0.229	0.692	0.597	0.192	0.920
AP	0.048	0.238	0.309	0.048	0.048	0.048	0.048	0.072	0.072	0.048	0.120
Total	99.311	99.312	99.095	99.670	99.720	99.730	99.730	99.760	99.820	99.820	99.741
SALIC	97.504	97.704	97.324	97.621	98.645	97.176	97.487	92.390	93.205	96.240	90.767
FEMIC	1.807	1.608	1.771	2.049	1.075	2.554	2.243	7.369	6.615	3.580	8.974
D.I.	93.013	93.467	93.052	96.147	97.553	95.034	93.853	90.222	90.791	90.908	87.074

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield--Continued

Symbol	55544 L	55545 L	55546 M	55547 M	55548 M	55549 M	55550 N	55551 P	55552 P	55553 Q	55554 Q
SiO2	71.86	71.23	75.41	74.17	74.62	72.80	74.40	75.51	75.74	75.30	78.84
Al2O3	13.57	13.79	13.26	13.98	14.19	15.60	14.16	13.04	12.63	13.99	11.50
Fe2O3	0.35	0.95	0.93	0.16	0.16	0.12	0.33	0.39	0.49	0.19	0.44
FeO	1.53	1.71	1.67	0.28	0.29	0.22	0.60	0.70	0.89	0.35	0.79
MgO	0.28	0.28	<0.10	<0.10	<0.10	<0.10	0.12	<0.10	<0.10	<0.10	<0.10
CaO	1.02	1.05	0.28	0.70	0.34	0.35	C.67	0.54	0.61	0.12	0.17
Na2O	3.88	3.94	4.31	4.82	4.86	4.93	4.19	4.28	3.70	5.14	3.69
K2O	4.87	4.88	4.21	3.84	3.73	4.23	4.14	4.31	4.44	4.00	3.86
LOI	0.71	0.57	0.41	0.53	0.44	0.45	0.45	0.50	0.44	0.09	0.22
TiO2	0.20	0.23	<0.02	<0.02	<0.02	<0.02	0.03	0.03	0.07	<0.02	<0.02
P2O5	0.07	0.08	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05
MnO	0.04	0.05	0.04	0.04	0.05	0.08	0.07	<0.02	<0.02	<0.02	0.03
ZrO2	0.03	0.03		0.01	0.01		0.01	0.01	0.02	0.01	0.02
Total(-O)	98.91	98.79	100.59	98.61	98.78	98.86	99.23	99.38	99.11	99.28	99.64
Normative Minerals											
Q	27.692	26.560	32.314	30.131	31.491	27.284	32.571	32.720	35.696	29.810	41.847
C	0.232	0.313	1.121	0.679	1.607	2.350	1.725	0.403	0.682	1.042	0.994
Z	0.045	0.045		0.015	0.015		0.015	0.015	0.030	0.015	0.030
OR	29.095	29.191	24.731	23.012	22.314	25.286	24.653	25.627	26.472	23.808	22.892
AB	33.193	33.748	36.255	41.361	41.633	42.199	35.729	36.441	31.589	43.808	31.336
AN	4.654	4.744	1.316	3.389	1.575	1.624	2.955	2.564	2.922	0.468	0.715
EN	0.705	0.706	0.124	0.126	0.126	0.126	0.301	0.125	0.126	0.125	0.125
FS	1.873	2.095	2.351	0.453	0.488	0.435	0.915	0.934	1.137	0.485	1.135
MT	1.245	1.393	1.339	0.230	0.240	0.176	0.487	0.564	0.721	0.282	0.640
IL	0.384	0.442	0.019	0.019	0.019	0.019	0.057	0.057	0.134	0.019	0.019
AP	0.168	0.192	0.024	0.048	0.048	0.048	0.143	0.048	0.048	0.048	0.048
Total	99.286	99.428	99.593	99.464	99.556	99.547	99.551	99.498	99.557	99.910	99.781
SALIC	94.912	94.600	95.737	98.588	98.636	98.743	97.648	97.770	97.392	98.951	97.814
FEMIC	4.375	4.828	3.857	0.877	0.920	0.804	1.903	1.728	2.166	0.960	1.966
D.I.	89.981	89.498	93.300	94.504	95.438	94.769	92.953	94.788	93.758	97.426	96.075

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield--Continued

	55555	55556	55557	55558	55559	55560	55561	55562	55563	55564	55565
Symbol	Q	Q	R	R	R	S	S	T	T	U	U
SiO_2	76.14	73.14	71.29	67.76	74.45	72.39	73.31	74.09	70.35	75.44	75.05
Al_2O_3	13.38	13.89	16.03	17.24	14.84	15.68	15.27	14.78	15.80	13.89	14.15
Fe_2O_3	0.13	0.55	0.53	0.83	0.17	0.30	0.13	0.21	0.68	0.17	0.25
FeO	0.23	0.98	0.96	1.49	0.31	0.55	0.23	0.37	1.23	0.30	0.44
MgO	<0.10	0.33	0.58	1.14	<0.10	0.28	<0.10	0.25	0.83	<0.10	<0.10
CaO	0.17	0.83	3.52	4.58	1.28	2.50	1.23	1.00	2.68	0.55	0.53
Na_2O	4.85	3.54	4.72	4.63	4.28	4.76	4.03	4.34	4.39	4.17	4.51
K_2O	3.55	4.79	0.90	1.04	3.66	2.07	4.44	3.14	2.39	4.26	4.05
LOI	0.29	0.91	0.57	0.30	0.30	0.36	0.13	0.66	0.45	0.25	0.24
TiO_2	<0.02	0.19	0.17	0.28	0.02	0.09	<0.02	0.03	0.25	<0.02	<0.02
P_2O_5	<0.05	0.05	0.08	0.13	<0.05	<0.05	<0.05	0.09	0.11	<0.05	<0.05
MnO	0.05	<0.02	<0.02	0.04	0.03	<0.02	0.12	0.09	0.06	0.08	0.06
ZrO_2	0.01	0.02	0.01	0.01		0.01			0.01	0.01	0.01
Total(-O)	98.88	99.23	99.37	99.46	99.41	99.01	98.97	99.05	99.23	99.20	99.37
Normative Minerals											
Q	34.156	31.841	31.922	25.075	32.769	31.075	30.293	34.610	28.579	33.703	32.039
C	1.312	1.504	1.090	0.484	1.568	1.123	1.663	2.664	1.393	1.479	1.440
Z	0.015	0.030	0.015	0.015		0.015			0.015	0.015	0.015
OR	21.215	28.525	5.352	6.179	21.757	12.355	26.509	18.733	14.232	25.377	24.084
AB	41.503	30.187	40.191	39.389	36.433	40.681	34.454	37.077	37.434	35.571	38.404
AN	0.721	3.820	17.047	21.990	6.257	12.395	6.033	4.415	12.674	2.619	2.514
EN	0.126	0.828	1.454	2.854	0.125	0.704	0.126	0.629	2.083	0.126	0.125
FS	0.404	1.069	1.068	1.672	0.472	0.645	0.535	0.637	1.405	0.550	0.712
MT	0.190	0.798	0.777	1.204	0.253	0.444	0.190	0.302	0.997	0.243	0.360
IL	0.019	0.364	0.325	0.535	0.019	0.153	0.019	0.058	0.478	0.019	0.019
AP	0.048	0.119	0.191	0.310	0.048	0.048	0.048	0.215	0.263	0.048	0.048
Total	99.708	99.086	99.431	99.706	99.700	99.638	99.871	99.339	99.553	99.750	99.760
SALIC	98.921	95.907	95.616	93.131	98.783	97.643	98.953	97.499	94.327	98.764	98.497
FEMIC	0.787	3.179	3.814	6.574	0.917	1.995	0.918	1.840	5.226	0.986	1.263
D.I.	96.873	90.553	77.465	70.642	90.959	84.111	91.257	90.420	80.245	94.651	94.527

Table 1.--Chemical and normative compositions of granitic samples from the southeastern Arabian Shield--Continued

Symbol	55566 U	55567 V	55568 V	55569 V	55570 V	55571 V	55572 V
SiO2	76.69	75.00	75.19	75.21	75.02	74.98	74.52
Al2O3	12.99	11.87	11.99	12.49	13.64	11.95	13.56
Fe2O3	0.20	0.81	0.84	0.57	0.28	0.97	0.28
FeO	0.36	1.46	1.52	1.02	0.50	1.74	0.50
MgO	<0.10	<0.10	<0.10	0.11	<0.10	0.12	0.12
CaO	0.54	0.53	0.52	0.53	0.72	0.54	0.33
Na2O	3.83	3.55	3.41	3.72	3.71	3.42	3.88
K2O	4.20	5.02	5.12	4.77	4.63	5.17	5.49
LOI	0.14	0.31	0.33	0.35	0.53	0.19	0.38
TiO2	<0.02	0.20	0.21	0.12	0.06	0.25	0.05
P2O5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	0.04	0.06	0.06	0.03	0.04	0.07	<0.02
ZrO2		0.07	0.07	0.05	0.01	0.08	0.02
Total(-O)	99.08	98.96	99.33	98.98	99.20	99.50	99.15
Normative Minerals							
Q	37.196	33.672	34.011	33.792	34.126	33.309	30.073
C	1.197			0.271	1.274		0.689
Z		0.105	0.105	0.075	0.015	0.120	0.030
OR	25.049	29.977	30.459	28.479	27.579	30.706	32.719
AB	32.709	30.356	29.049	31.803	31.645	29.086	33.111
AN	2.638	1.645	2.304	2.591	3.469	1.997	1.519
WO		0.368	0.068			0.236	
EN	0.176	0.126	0.125	0.277	0.126	0.300	0.301
FS	0.559	1.818	1.870	1.277	0.667	2.126	0.628
MT	0.292	1.190	1.230	0.829	0.404	1.407	0.404
IL	0.019	0.384	0.402	0.230	0.115	0.477	0.096
AP	0.024	0.048	0.048	0.024	0.048	0.048	0.048
Total	99.360	99.689	99.670	99.647	99.467	99.811	99.618
SALIC	98.789	95.755	95.928	97.010	98.108	95.216	98.141
FEMIC	1.071	3.934	3.742	2.637	1.359	4.595	1.477
D.I.	94.955	94.005	93.520	94.074	93.350	93.100	95.903

Table 2.--Trace-element concentrations in granite samples from the southeastern Arabian Shield
[Letters in parentheses after pluton names refer to locations on fig. 1. Abbreviations are defined in text]

Sample	Latitude (north)	Longitude (east)	U (ppm)	RaeU (ppm)	Th (ppm)	eTh (ppm)	K (wt %)	eK (wt %)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)
					Jabal Tarban (A)							
155500	21 15 30	43 58 15	7.19	6.1	34.20	28.2	3.60	3.66	70	171	740	9
155501	21 15 30	43 58 0	10.70	8.9	28.40	28.9	3.56	3.62	78	164	759	6
155502	21 15 30	43 58 30	8.84	6.7	28.40	28.3	3.83	3.84	62	168	824	7
155503	21 14 40	44 0 0	8.04	7.9	24.40	22.7	3.96	3.99	56	95	303	93
155504	21 14 40	44 0 0	10.10	7.5	27.10	24.3	3.87	3.95	34	83	265	95
155505	21 13 45	44 2 15	7.76	6.7	27.80	27.3	3.73	3.72	63	166	780	10
					Jabal as Sukkah (B)							
155506	21 42 0	43 43 15	3.22	2.6	21.20	18.8	3.62	3.66	49	48	121	65
155507	21 42 15	43 44 0	1.76	2.0	8.80	10.5	3.81	3.73	65	69	102	52
155508	21 43 30	43 42 45	4.24	4.7	14.00	11.6	3.48	3.50	64	78	131	205
155509	21 43 30	43 41 15	2.23	2.3	9.71	10.0	3.71	3.74	47	65	102	72
155510	21 43 20	43 39 20	3.64	3.6	13.50	14.9	3.35	3.34	28	55	125	371
					Jabal Sabhah (C)							
155511	23 17 40	44 35 55	8.18	7.7	28.40	29.4	3.42	3.52	32	168	685	3
155512	23 17 45	44 35 55	13.80	12.5	46.20	44.4	3.40	3.41	72	71	490	3
155513	23 17 50	44 35 10	4.78	4.6	18.90	18.5	4.28	4.31	33	63	182	187
155514	23 17 10	44 37 45	18.20	16.0	53.40	49.1	3.64	3.76	39	102	390	3
155515	23 17 10	44 37 45	20.00	18.0	56.10	53.5	3.64	3.69	85	77	337	8
155516	23 15 10	44 38 30	8.40	7.1	45.20	44.2	3.73	3.85	31	69	425	4
155517	23 15 10	44 38 30	9.27	8.2	43.70	41.0	3.72	3.88	48	145	430	3
					Jabal Hawshat ibn Hawayl (D)							
155518	22 53 30	44 51 58	7.18	7.1	21.90	27.7	4.36	4.37	61	83	211	29
155519	22 49 50	44 51 28	4.16	4.8	16.30	18.7	3.66	3.77	31	49	246	<1
155520	22 49 55	44 51 30	9.32	9.2	36.40	33.6	3.44	3.56	86	164	610	5
155521	22 46 15	44 51 25	9.66	8.8	23.50	23.4	3.52	3.60	71	104	297	1
					Jabal al Hawshaw (E)							
155522	22 38 45	44 47 10	9.53	7.1	23.40	20.7	5.38	5.41	44	34	441	73
155523	22 37 30	44 43 15	15.20	13.4	46.00	44.1	3.97	3.98	79	79	592	16
155524	22 31 58	44 45 45	26.10	19.0	29.30	31.6	3.74	3.79	29	63	609	8
155525	22 31 55	44 45 55	15.90	15.9	43.30	37.8	3.79	3.89	64	76	532	14
					Jabal Sahah (F)							
155526	22 12 10	44 48 15	6.05	8.4	17.60	26.7	3.74	3.82	38	145	372	1
155527	22 11 0	44 49 15	9.33	9.5	20.30	21.8	3.89	4.00	24	84	212	20
155528	22 9 5	44 49 30	7.25	7.8	21.50	23.7	3.79	4.00	71	91	257	41
155529	22 6 40	44 52 0	9.28	9.0	21.10	25.8	3.85	3.97	63	118	317	14
					Jabal as Sitarah (G)							
155530	22 6 0	44 43 35	2.18	2.4	8.51	10.4	2.97	3.10	78	64	99	100
155531	22 6 0	44 43 35	3.08	3.2	13.80	12.7	3.32	3.44	73	63	112	64

Table 2.--Trace-element concentrations in granite samples from the southeastern Arabian Shield--Continued

Sample	Y (ppm)	Zr (ppm)	Th/U	eTh/U	K/U	eK/U	Th/K	eTh/eK	K/Rb	Rb/Sr	Al/(Na+K)	Al/(Na+K+Ca)
Jabal Tarban (A)												
155500	87	72	4.76	3.92	.50	.51	9.49	7.70	48.69	82.22	1.13	1.08
155501	102	80	2.65	2.70	.33	.34	7.97	7.98	46.92	126.50	1.12	1.09
155502	81	70	3.21	3.20	.43	.43	7.42	7.37	46.44	117.71	1.13	1.09
155503	36	121	3.03	2.82	.49	.50	6.16	5.69	130.69	3.26	1.20	1.05
155504	47	125	2.68	2.41	.38	.39	7.01	6.15	145.98	2.79	1.21	1.05
155505	78	68	3.58	3.52	.48	.48	7.46	7.34	47.79	78.00	1.12	1.08
Jabal as Sukkah (B)												
155506	8	96	6.58	5.84	1.12	1.14	5.86	5.14	299.13	1.86	1.16	1.06
155507	6	91	5.00	5.97	2.17	2.12	2.31	2.82	373.57	1.96	1.14	1.05
155508	19	139	3.30	2.74	.82	.83	4.02	3.31	265.52	.64	1.20	1.03
155509	7	83	4.35	4.48	1.66	1.68	2.62	2.67	363.81	1.42	1.15	1.07
155510	12	118	3.71	4.09	.92	.92	4.03	4.46	268.31	.34	1.27	1.02
Jabal Sabhah (C)												
155511	213	76	3.47	3.59	.42	.43	8.30	8.35	49.93	228.33	1.13	1.08
155512	221	112	3.35	3.22	.25	.25	13.57	13.02	69.46	163.33	1.12	1.06
155513	21	221	3.95	3.87	.89	.90	4.42	4.29	234.91	.97	1.30	1.05
155514	170	115	2.93	2.70	.20	.21	14.69	13.06	93.23	130.00	1.14	1.02
155515	154	127	2.81	2.68	.18	.18	15.43	14.50	107.90	42.13	1.14	1.02
155516	137	103	5.38	5.26	.44	.46	12.13	11.48	87.70	106.25	1.14	1.05
155517	179	89	4.71	4.42	.40	.42	11.75	10.57	86.49	143.33	1.13	1.05
Jabal Hawshat ibn Hawayl (D)												
155518	99	156	3.05	3.86	.61	.61	5.02	6.34	206.56	7.28	1.17	1.06
155519	87	83	3.92	4.50	.88	.91	4.45	4.96	148.82	>246.00	1.10	1.04
155520	123	133	3.91	3.61	.37	.38	10.59	9.44	56.34	122.00	1.12	1.05
155521	133	143	2.43	2.42	.36	.37	6.68	6.50	118.51	297.00	1.12	1.05
Jabal al Hawshaw (E)												
155522	32	69	2.46	2.17	.56	.57	4.35	3.83	121.98	6.04	1.16	1.06
155523	77	105	3.03	2.90	.26	.26	11.59	11.08	67.03	37.00	1.23	1.09
155524	107	60	1.12	1.21	.14	.15	7.83	8.34	61.48	76.13	1.18	1.07
155525	92	73	2.72	2.38	.24	.24	11.41	9.72	71.31	38.00	1.22	1.11
Jabal Sahah (F)												
155526	77	79	2.91	4.41	.62	.63	4.71	6.99	100.42	372.00	1.14	1.07
155527	78	109	2.18	2.34	.42	.43	5.23	5.45	183.26	10.60	1.15	1.06
155528	68	95	2.97	3.27	.52	.55	5.67	5.93	147.62	6.27	1.16	1.06
155529	119	119	2.27	2.78	.42	.43	5.48	6.50	121.51	22.64	1.15	1.06
Jabal as Sitarah (G)												
155530	22	112	3.90	4.77	1.36	1.42	2.86	3.35	300.20	.99	1.26	1.03
155531	30	121	4.48	4.12	1.08	1.12	4.16	3.69	296.49	1.75	1.22	1.06

Table 2.--Trace-element concentrations in granite samples from the southeastern Arabian Shield--Continued

Sample	Latitude (north)	Longitude (east)	U (ppm)	RaeU (ppm)	Th (ppm)	eTh (ppm)	K (wt %)	eK (wt %)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)
					Jabal Mahail (H)							
155532	21 19 15	44 47 50	4.88	6.4	7.60	10.5	3.04	3.27	48	76	311	4
155533	21 19 15	44 47 50	2.56	2.6	7.52	10.8	2.89	3.23	62	75	337	7
					Jabal Kebad (I)							
155534	21 10 20	44 34 0	5.12	5.2	8.16	9.2	3.22	3.41	101	86	335	6
155535	21 12 35	44 31 30	2.43	3.1	4.60	8.1	2.57	2.82	137	122	492	8
					Huqban (J)							
155536	21 46 35	43 49 30	8.94	10.9	18.40	36.6	3.89	3.94	72	139	323	9
155537	21 46 35	43 49 30	26.90	31.0	73.70	106.0	2.97	2.91	57	84	291	5
155538	21 49 55	43 50 5	7.77	11.3	19.20	31.0	4.05	4.09	85	90	228	10
155539	21 48 20	43 53 45	7.56	10.8	18.60	31.7	4.07	4.05	77	90	321	69
					Najran (K)							
155540	17 33 30	44 0 0	4.14	4.0	12.40	11.2	4.64	4.69	67	147	127	70
155541	17 33 30	44 0 0	4.94	5.0	15.60	11.3	4.52	4.62	55	111	123	64
155542	17 32 45	44 9 15	4.58	3.4	16.50	15.5	3.40	3.52	53	70	100	87
155543	17 32 45	44 9 15	1.29	1.5	9.13	7.0	4.71	4.82	148	166	78	116
					Jabal Ashirah (L)							
155544	18 0 45	44 12 15	3.36	3.8	14.00	14.1	4.04	4.15	22	91	175	92
155545	18 0 45	44 12 15	4.46	4.2	19.60	14.3	4.05	4.06	60	82	181	106
					Jabal al Gaharra (M)							
155546	18 3 15	44 0 15	3.94	8.8	18.30	13.6	3.49	3.61	54	120	606	6
155547	18 3 30	44 0 30	15.80	14.3	21.40	18.2	3.19	3.19	44	182	651	3
155548	18 3 45	44 0 0	12.00	12.0	24.40	19.2	3.10	3.14	46	80	680	4
155549	18 5 30	44 0 30	2.63	1.9	19.00	13.5	3.51	3.58	74	127	952	4
					Northeast of As Subaykah (N)							
155550	19 10 40	43 23 15	4.61	4.5	<3.20	3.1	3.44	3.53	87	83	84	130
					East of As Subaykah (P)							
155551	19 5 20	43 24 25	5.16	4.3	9.63	7.3	3.58	3.79	69	100	88	8
155552	19 7 10	43 23 25	2.92	2.2	6.00	7.8	3.69	3.93	65	90	77	40
					Jabal Bani Bwana (Q)							
155553	18 31 50	43 56 10	2.02	1.9	17.80	18.8	3.32	3.46	42	154	402	2
155554	18 31 50	43 56 10	2.19	1.6	37.10	32.0	3.20	3.28	68	240	378	2
155555	18 26 30	43 56 0	2.84	1.8	21.80	21.7	2.95	3.14	36	190	691	3
155556	18 29 30	43 55 45	4.68	3.2	17.30	16.0	3.98	4.10	64	87	181	126

Table 2.--Trace-element concentrations in granite samples from the southeastern Arabian Shield--Continued

Sample	Y (ppm)	Zr (ppm)	Th/U	eTh/U	K/U	eK/U	Th/K	eTh/eK	K/Rb	Rb/Sr	Al/(Na+K)	Al/(Na+K+Ca)
Jabal Mahail (H)												
155532	32	20	1.56	2.15	.62	.67	2.50	3.21	97.70	77.75	1.33	1.27
155533	29	22	2.94	4.22	1.13	1.26	2.60	3.34	85.73	48.14	1.36	1.29
Jabal Kebad (I)												
155534	9	26	1.59	1.80	.63	.67	2.53	2.70	96.15	55.83	1.32	1.23
155535	1	10	1.89	3.33	1.06	1.16	1.79	2.87	52.31	61.50	1.39	1.32
Huqbar (J)												
155536	44	133	2.06	4.09	.44	.44	4.73	9.29	120.54	35.89	1.10	1.07
155537	140	172	2.74	3.94	.11	.11	24.80	36.43	102.13	58.20	1.08	1.05
155538	64	130	2.47	3.99	.52	.53	4.74	7.58	177.68	22.80	1.09	1.03
155539	19	70	2.46	4.19	.54	.54	4.57	7.83	126.72	4.65	1.16	1.06
Najran (K)												
155540	82	794	3.00	2.71	1.12	1.13	2.67	2.39	365.40	1.81	1.06	.93
155541	62	663	3.16	2.29	.92	.94	3.45	2.45	367.84	1.92	1.06	.94
155542	33	115	3.60	3.38	.74	.77	4.86	4.40	339.54	1.15	1.18	1.00
155543	59	977	7.08	5.43	3.65	3.74	1.94	1.45	603.46	.67	1.09	.92
Jabal Ashirah (L)												
155544	22	227	4.17	4.20	1.20	1.24	3.46	3.40	231.02	1.90	1.16	1.00
155545	26	256	4.39	3.21	.91	.91	4.84	3.52	223.82	1.71	1.17	1.01
Jabal al Gaharra (M)												
155546	66	34	2.05	1.52	.39	.40	5.24	3.77	57.67	101.00	1.14	1.09
155547	63	49	1.35	1.15	.20	.20	6.71	5.71	48.97	217.00	1.16	1.05
155548	62	52	2.03	1.60	.26	.26	7.88	6.11	45.54	170.00	1.18	1.12
155549	35	37	7.22	5.13	1.34	1.36	5.41	3.77	36.89	238.00	1.23	1.17
Northeast of As Subaykah (N)												
155550	11	55	<.69	.67	.75	.77	<.93	.88	409.15	.65	1.24	1.12
East of As Subaykah (P)												
155551	35	104	1.87	1.41	.69	.73	2.69	1.93	406.59	11.00	1.11	1.03
155552	25	122	2.05	2.67	1.26	1.35	1.63	1.98	478.69	1.93	1.16	1.05
Jabal Bani Bwana (Q)												
155553	50	65	8.81	9.31	1.64	1.71	5.36	5.43	82.60	201.00	1.09	1.08
155554	141	113	16.94	14.61	1.46	1.50	11.58	9.76	84.77	189.00	1.12	1.09
155555	9	52	7.68	7.64	1.04	1.11	7.40	6.91	42.65	230.33	1.13	1.10
155556	28	175	3.70	3.42	.85	.88	4.35	3.90	219.69	1.44	1.26	1.11

Table 2.--Trace-element concentrations in granite samples from the southeastern Arabian Shield--Continued

Sample	Latitude (north)	Longitude (east)	U (ppm)	RaeU (ppm)	Th (ppm)	eTh (ppm)	K (wt %)	eK (wt %)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)
					Wadi al Habbah (R)							
155557	18 30 40	43 17 45	.29	.3	<1.40	.4	.75	.78	76	55	19	988
155558	18 31 45	43 17 45	.81	.7	2.80	2.4	.86	.92	79	81	22	803
155559	18 37 30	43 17 15	.27	.2	<1.50	.4	3.04	3.01	33	30	43	295
					Madha (S)							
155560	18 39 55	43 14 45	5.38	1.7	<3.30	.4	1.72	1.72	26	51	31	633
155561	18 41 45	43 12 50	.34	.3	<1.40	.3	3.69	3.50	80	45	52	401
					Jabal Zayd (T)							
155562	18 49 15	43 19 45	1.52	1.4	2.80	2.3	2.61	2.66	76	101	49	194
155563	18 49 30	43 19 20	.75	.7	2.10	1.9	1.98	2.03	75	95	37	562
					Wadi Tafshaf (U)							
155564	18 57 45	43 9 30	1.14	1.0	<1.90	1.5	3.54	3.50	70	67	47	13
155565	18 58 25	43 10 15	1.36	1.3	2.60	2.0	3.36	3.34	101	71	36	9
155566	18 59 55	43 10 5	.44	.5	<1.60	.5	3.49	3.46	99	62	28	26
					Jabal al Hassir (V)							
155567	19 40 45	43 6 40	3.31	3.3	8.90	8.4	4.17	4.12	101	141	82	15
155568	19 39 0	43 5 40	3.52	3.0	9.73	7.8	4.25	4.41	102	115	69	18
155569	19 36 0	43 5 20	6.36	6.2	14.90	13.9	3.96	3.96	81	197	154	29
155570	19 30 0	43 3 55	6.55	5.8	18.00	17.2	3.84	3.92	76	75	174	60
155571	19 25 25	43 4 35	2.92	2.8	9.75	8.9	4.29	4.45	75	155	63	31
155572	19 23 20	43 4 10	5.24	4.2	10.10	9.8	4.56	4.68	111	91	112	58

Table 2.--Trace-element concentrations in granite samples from the southeastern Arabian Shield--Continued

Sample	Y (ppm)	Zr (ppm)	Th/U	eTh/U	K/U	eK/U	Th/K	eTh/eK	K/Rb	Rb/Sr	Al/(Na+K)	Al/(Na+K+Ca)
						Wadi al Habbah (R)						
155557	<1	76	<4.83	1.38	2.58	2.69	<1.87	.51	393.23	.02	1.83	1.06
155558	6	58	3.46	2.96	1.07	1.14	3.24	2.61	392.44	.03	1.97	1.01
155559	<1	22	<5.56	1.48	11.25	11.15	<.49	.13	706.60	.15	1.35	1.11
						Madha (S)						
155560	<1	54	<.61	.07	.32	.32	<1.92	.23	554.33	.05	1.56	1.07
155561	12	32	<4.12	.88	10.84	10.29	<.38	.09	708.83	.13	1.34	1.12
						Jabal Zayd (T)						
155562	2	32	1.84	1.51	1.71	1.75	1.07	.86	531.98	.25	1.40	1.20
155563	3	56	2.80	2.53	2.65	2.71	1.06	.94	536.24	.07	1.61	1.08
						Wadi Tafshaf (U)						
155564	33	61	<1.67	1.32	3.10	3.07	<.54	.43	752.44	3.62	1.21	1.11
155565	38	45	1.91	1.47	2.47	2.46	.77	.60	933.93	4.00	1.20	1.11
155566	28	33	<3.64	1.14	7.92	7.86	<.46	.14	1,245.24	1.08	1.20	1.10
						Jabal al Hassir (V)						
155567	37	490	2.69	2.54	1.26	1.24	2.14	2.04	508.22	5.47	1.05	.97
155568	29	531	2.76	2.22	1.21	1.25	2.29	1.77	616.00	3.83	1.08	.99
155569	77	347	2.34	2.19	.62	.62	3.76	3.51	257.13	5.31	1.11	1.02
155570	17	98	2.75	2.63	.59	.60	4.68	4.39	220.90	2.90	1.23	1.10
155571	30	600	3.34	3.05	1.47	1.52	2.27	2.00	681.26	2.03	1.06	.98
155572	29	147	1.93	1.87	.87	.89	2.22	2.09	406.93	1.93	1.10	1.05

disequilibrium between ^{238}U and ^{226}Ra in granitic rocks is common (for example, Stuckless and others, 1977), and, therefore, U is used in preference to RaeU for radioelement ratios and statistical calculations. Accuracy and precision (2σ) for RaeU values are within $\pm$ the quantity (2 percent of the amount reported plus 0.1 ppm absolute).

Concentrations of copper (Cu), zinc (Zn), rubidium (Rb), strontium (Sr), yttrium (Y), and zirconium (Zr) (table 2) were determined by X-ray fluorescence on loose, finely ground (-200 mesh) sample powders. Estimated precision is $\pm$ 10 percent (2σ) for Rb, Sr, Y, and Zr, and $\pm$ 20 percent for Cu and Zn; however, Cu values may not be accurate within the limits of precision because standard values at low concentrations are not well known. Niobium and molybdenum were looked for, but concentrations were generally below the limits of detection (6 and 4 ppm, respectively), and, therefore, results for these elements are not reported.

Statistical formulae and methods used are those described by VanTrump and Miesch (1977). Statistical parameters: mean, standard deviation, skewness, kurtosis, and correlation, for trace elements (those reported in parts per million in table 2) were calculated from the logarithms of the data. Antilog values are reported for geometric means and standard deviations. Normative mineralogy (table 1) was calculated by methods described by Stuckless and VanTrump (1979).

RESULTS AND DISCUSSION

Petrogenetic considerations

The granitic samples from the southeastern Arabian Shield yield a large range of chemical compositions as shown by minimum and maximum values and by large standard deviations (table 3). Although the mean and range of major- and trace-element contents are similar to those reported for postorogenic granites from the northeastern part of the Shield (Stuckless and others, in press; 1982b) standard deviations for trace-element contents and ratios are much larger. Also, the fact that absolute values for skewness and kurtosis are larger for the trace-element contents of granites from the southeastern part of the Shield indicates a poorer fit to a log-normal distribution.

The granites sampled in the current study can be subdivided into three groups on the basis of field occurrence. The granites from Wadi al Habbah and Madha (R and S, respectively, fig. 1) are largely concordant bodies with regional metamorphic structures and, therefore, may be orogenic in origin. The granites of Najran, Jabal Ashirah, and Jabal al

Table 3.--Statistical summary for chemical compositions of granite samples from the southeastern Arabian Shield

[Oxide concentrations are in weight percent; trace-element contents are in parts per million. Average granite values from Krauskopf (1967) with major elements converted to oxides and normalized to 100 percent]

	Number of samples	Minimum	Maximum	Mean	Standard deviation	Skewness	Kurtosis	Average granite
SiO_2	73	66.66	80.19	74.81	±2.35	-1.25	2.32	72.64
Al_2O_3	73	10.89	17.24	13.41	±1.13	0.73	1.28	13.67
Fe_2O_3	73	0.36	5.29	1.38	±0.91	2.00	5.12	3.63
MgO	73	0.05	1.14	0.15	±0.18	3.30	13.32	0.25
CaO	73	0.12	4.58	0.76	±0.73	3.22	12.64	2.10
Na_2O	73	3.05	5.14	3.99	±0.46	0.23	-0.30	3.54
K_2O	73	0.90	6.48	4.28	±0.88	-1.49	4.81	3.74
TiO_2	73	0.01	0.48	0.09	±0.10	1.62	2.67	0.36
P_2O_5	73	0.01	0.13	0.03	±0.03	2.19	3.80	0.03
MnO	73	0.01	0.17	0.04	±0.03	1.71	3.88	0.05
U	73	0.27	26.9	4.46	+7.61 -2.81	-0.88	0.93	4.8
RaeU	73	0.2	31.0	4.16	+7.32 -2.65	-0.86	0.85	-
Th	66	2.1	73.7	16.7	+18.5 -8.8	-0.72	0.74	17
eTh	73	0.3	106	12.2	+30.1 -8.7	-1.49	2.07	-
Cu	73	22	148	59.9	+30.3 -20.1	-0.49	-0.11	10
Zn	73	30	240	92.6	+49.1 -32.1	-0.04	-0.14	40
Rb	73	19.0	952	195	+332 -123	-0.45	-0.67	150
Sr	72	1.0	988	24.0	+108.6 -19.7	0.25	-0.80	285
Y	70	1.0	221	38.2	+77.7 -25.6	-0.92	1.03	40
Zr	73	10.0	977	95.4	+128.5 -54.8	0.43	1.07	180
K/Rb	73	36.9	1250	176	+265 -106	0.09	-1.11	-
Rb/Sr	72	0.02	372	8.11	+92.9 -7.46	-0.35	-0.68	-
eTh/U	73	0.10	14.6	2.74	+2.68 -1.36	-2.01	10.17	-
eTh/eK	73	0.10	36.4	3.48	+7.22 -2.35	-1.35	2.28	-
eK/U	73	0.11	11.2	0.79	+1.16 -0.47	0.62	1.00	-

Hassir (K, L, and V, respectively, fig. 1) are similar to postorogenic peralkaline intrusive rocks in the northeastern part of the Shield in that rim phases are very coarse grained, one-feldspar granites in which black amphibole is the dominant mafic mineral. However, these three granites from the southeastern part of the Shield have molar Al/(Na+K) ratios greater than 1 (table 2) and are not peralkaline by the definition of Shand (1951) but rather are evenly divided between metaluminous and weakly peraluminous. These plutons are referred to as postorogenic hypersolvus granites. The remaining plutons are referred to as postorogenic subsolvus granites; all samples from these plutons have molar ratios Al/(Na+K+Ca) greater than 1 and are, therefore, peraluminous (table 2).

Mean values and standard deviations for oxide and trace-element contents and ratios of samples from the southeastern Shield collected for this study are given in table 4 for the three groups of granites and for all of the postorogenic granites combined. The data clearly demonstrate that the concordant and possibly orogenic granites are chemically distinct from the postorogenic granites in that they contain more aluminum, magnesium, calcium, and strontium and less silica, potassium, uranium, thorium, rubidium, and yttrium. All of the trace-element ratios (table 4) and the Na/K ratio are markedly different for the two groups, and it is unlikely that they are related genetically.

Differences also exist between the hypersolvus and subsolvus postorogenic granites, but these are generally smaller than the differences noted between the postorogenic and possibly orogenic granites. The average iron content of the hypersolvus granites is more than double that of the subsolvus granites (table 4). The most striking difference is in zirconium content, which is more than four times greater in the hypersolvus granites. This high mean value (343 ppm, table 4) is similar to that noted for metaluminous postorogenic granites from the northeastern part of the Shield (381 ppm, Stuckless and others, 1982b), and is distinctly anomalous relative to the approximately 100 ppm saturation limits for zirconium cited by Watson (1979) for experimental systems that have similar molar ratios of Al/(Na+K). Both iron and zirconium enrichments are commonly associated with silicic peralkaline igneous rocks. The hypersolvus granites also differ from the other postorogenic granites from the southeastern part of the Shield in trace-element ratios. The mean K/Rb ratio is larger and the mean Rb/Sr ratio is smaller in the hypersolvus granites (table 4). These differences are similar to those noted between metaluminous and peralkaline or peraluminous samples from single plutons within the northeastern part of the Shield (Stuckless and others, 1982b), and can therefore be attributed to differing degrees of magma

Table 4.--Comparison of means and standard deviations for subgroupings of granite samples from the southeastern Arabian Shield

	Postorogenic samples							
	All samples		Hypersolvus samples		Subsolvus samples		Possible orogenic samples	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
SiO_2	75.02	±2.20	72.73	±2.91	75.52	±1.68	71.84	±2.56
Al_2O_3	13.24	±0.93	13.20	±0.93	13.24	±0.94	15.81	±0.91
Fe_2O_3	1.40	±0.92	2.69	±1.31	1.12	±0.48	1.18	±0.87
MgO	0.13	±0.13	0.13	±0.09	0.13	±0.14	0.42	±0.46
CaO	0.62	±0.41	0.80	±0.31	0.58	±0.04	2.62	±1.45
Na_2O	3.96	±0.45	3.89	±0.35	3.97	±0.47	4.48	±0.32
K_2O	4.42	±0.64	5.06	±0.46	4.28	±0.59	2.42	±1.58
TiO_2	0.09	±0.10	0.21	±0.13	0.06	±0.07	0.11	±0.12
P_2O_5	0.03	±0.03	0.03	±0.02	0.03	±0.03	0.05	±0.05
MnO	0.04	±0.03	0.05	±0.02	0.04	±0.04	0.04	±0.05
U	5.14	+6.53 -2.88	3.93	+2.13 -1.38	5.44	+7.60 -3.17	0.65	+1.64 -0.47
RaeU	4.89	+6.24 -2.74	3.71	+1.69 -1.16	5.19	+7.33 -3.04	0.46	+0.63 -0.27
Th	17.13	+18.02 -8.78	12.74	+4.18 -3.15	18.31	+21.27 -9.84	--	--
eTh	15.39	+22.98 -9.22	11.17	+3.83 -2.85	16.48	+27.69 -10.33	0.54	+0.71 -0.31
Cu	60.4	+29.9 -20.0	72.2	+44.9 -27.9	58.1	+26.6 -18.2	52.8	+38.3 -22.2
Zn	97.0	+47.0 -31.7	114	+46 -33	93.7	+46.1 -30.9	49.8	+21.5 -15.0
Rb	224	+317 -131	113	+51 -35	259	+373 -153	31	+17 -11
Sr	18.9	+67.8 -14.8	51.8	+51.1 -25.7	15.2	+57.7 -12.0	569	+366 -223
Y	39.9	+79.2 -26.5	37.2	+24.5 -14.8	40.5	+92.0 -28.1	8.5	+5.4 -3.3
Zr	101.0	+134.9 -57.8	343.3	+401.7 -185.1	77.7	+63.9 -35.1	44.1	+28.6 -17.4
K/Rb	162	+235 -96	372	+189 -125	136	+189 -79	533	+183 -136
Rb/Sr	11.8	+92.6 -10.5	2.2	+1.8 -1.0	17.0	+141 -15.2	0.05	+0.08 -0.03
eTh/U	2.99	+2.02 -1.21	2.85	+1.00 -0.70	3.03	+2.23 -1.29	0.83	+2.60 -0.63
eTh/eK	4.15	+5.96 -2.45	2.62	+1.16 -0.80	4.58	+7.14 -2.79	0.32	+0.92 -0.24
eK/U	0.72	+0.88 -0.40	1.09	+0.68 -0.42	0.66	+0.85 -0.37	2.57	+9.04 -0.63

evolution such that the subsolvus granites represent more evolved members of a single petrogenetic suite, all of which is highly evolved.

Permissive evidence for a genetic relationship among all the postorogenic granites is provided by plots of the data in the normative feldspar system (fig. 2) and the normative Q-Ab-Or (granite) system (fig. 3). The fact that most of the data for both the hypersolvus and subsolvus granites (fig. 2) cluster along the 2-kb water-saturated boundary curve suggests equilibration under similar physical conditions. Significantly, data for three of the five possibly orogenic granite samples plot far from equilibrium feldspar compositions within the area where plagioclase is expected to crystallize first.

The trend of data within the Q-Ab-Or system (fig. 3) is similar to that noted for single postorogenic plutons in the northeastern part of the Shield (Stuckless, unpublished data). Data for several samples of hypersolvus granite plot well below the water-saturated, polybaric minimum and form a trend directly toward the quartz apex. This trend can be interpreted to reflect a high-pressure partial melting at water-undersaturated conditions and crystal fractionation at lower pressure and increasing water activity. As in the feldspar system, more than half of the data for the possibly orogenic granites plot well away from the data for the postorogenic granites.

Correlation analysis (table 5) also yields permissive evidence for a genetic relationship between the two types of postorogenic granites. Several elemental pairs that typically covary in single petrogenetic suites exhibit high correlation coefficients (for example, CaO or MgO with Sr and TiO_2 with Fe_2O_3) in spite of the wide geographical separation of plutons. This fact suggests that the various plutons were derived from similar source material by similar processes and that differentiation followed similar paths. However, as would be predicted from geographical consideration, several low correlation coefficients (such as K_2O with most variables) preclude a true cogenetic relationship.

Economic considerations

Concentration data indicate at least a moderate favorability for mineralized areas in the southeastern Arabian Shield. Copper, zinc, uranium, and yttrium each occur in at least one pluton in concentrations that are well above average levels for granite. Although individual values for copper (and to a lesser extent zinc) have large analytical uncertainties, the average concentrations of these elements

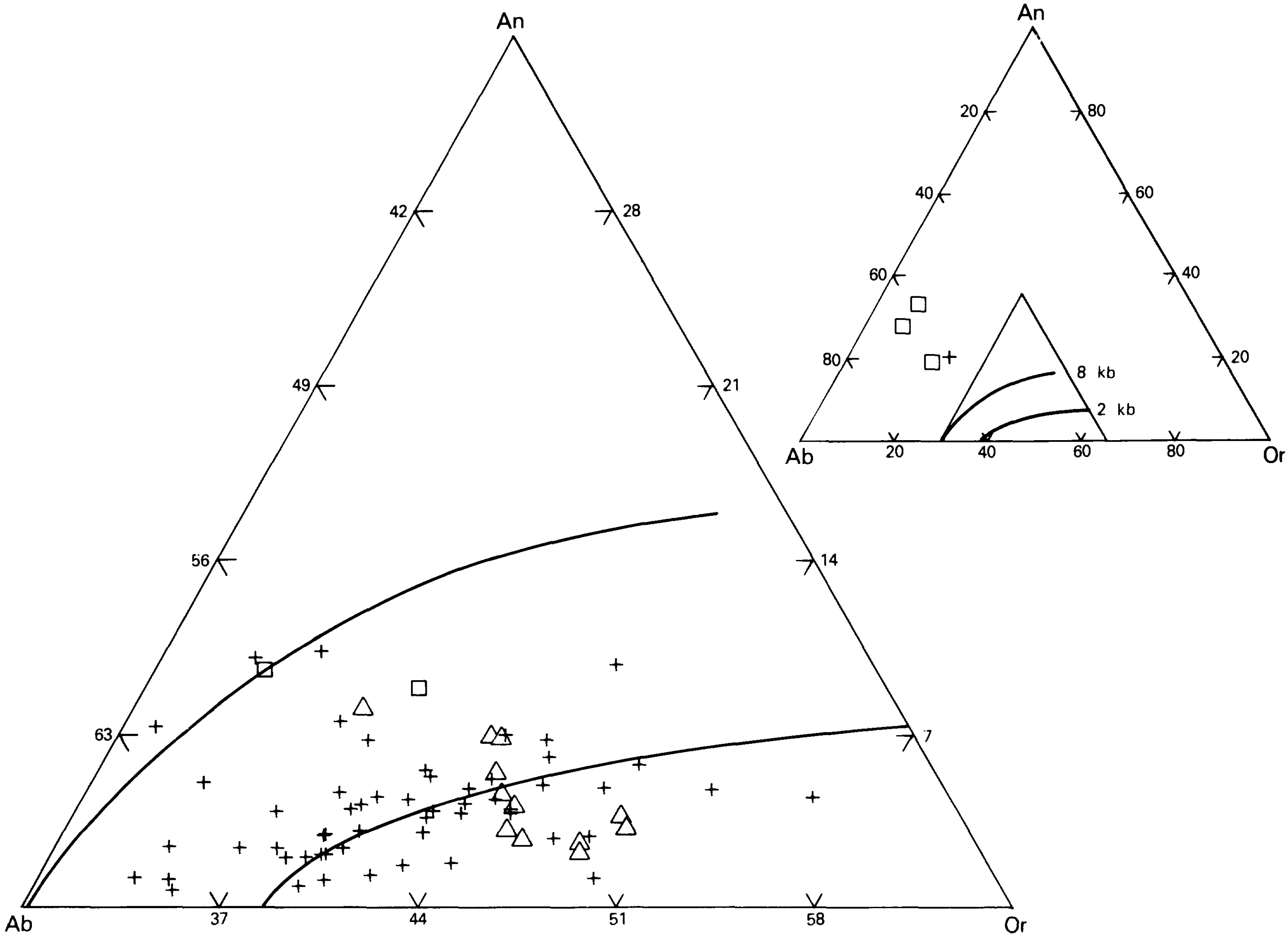

Figure 2.--Ternary diagram showing normative feldspar data for granite samples from the southeastern Arabian Shield; An, anorthite, Ab, albite, Or, orthoclase. Curved lines show the position of water-saturated, eutectic compositions at 2 and 8 kb (Whitney, 1975). Squares represent possible orogenic granites, triangles represent postorogenic hypersolvus granites, and pluses represent postorogenic subsolvus granites.

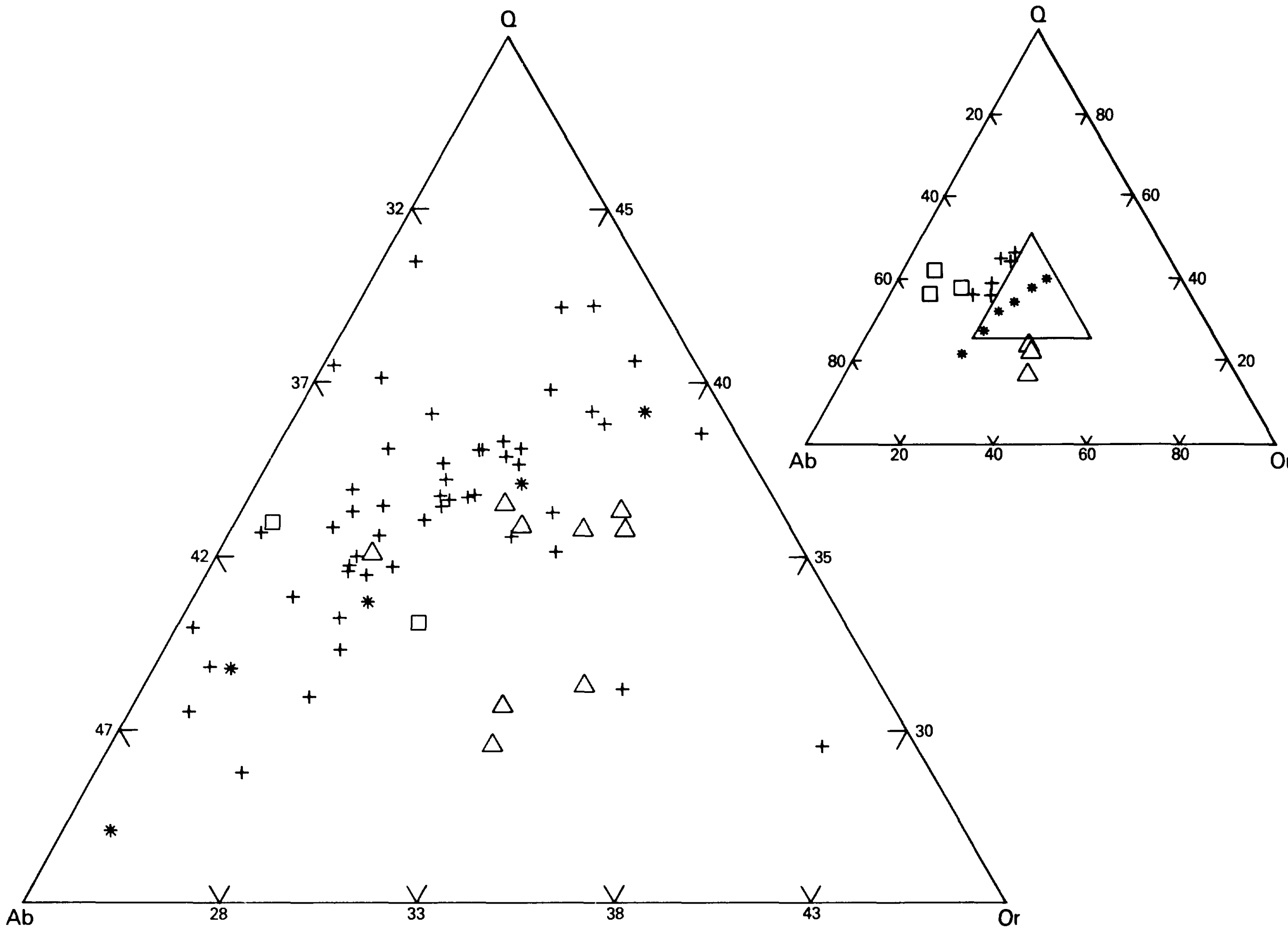

Figure 3.--Ternary diagram showing normative quartz (Q), albite (Ab), and orthoclase (Or) data for granite samples from the southeastern Arabian Shield. The position of the polybaric ternary minimum (Tuttle and Bowen, 1958; Luth and others, 1964) is shown by asterisks. Squares represent possible orogenic granites, triangles represent postorogenic hypersolvus granites, and pluses represent postorogenic subsolvus granites.

Table 5.--Correlation matrix for postorogenic granite samples from the southeastern Arabian Shield and correlation of selected variables with latitude and longitude

[Oxides are treated arithmetically. Elements and ratios are treated logarithmically. Numbers below the diagonal blank space indicate the number of samples used in the correlation analysis. Abbreviations are defined in text]

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	U	Y	eTh	Rb	Sr	Zr	Rb/Sr	K/Rb	eTh/U	eTh/ek	eK/U
SiO_2		-0.71	-0.68	-0.55	0.73	-0.29	-0.30	0.79	0.32	0.25	0.34	0.34	-0.62	-0.43	0.57	-0.37	0.10	0.39	-0.37
Al_2O_3	68		0.05	0.49	0.53	0.58	-0.20	0.24	-0.40	-0.48	-0.48	-0.15	0.41	-0.27	-0.35	0.10	-0.21	-0.45	0.37
Fe_2O_3	68	68		0.27	0.47	-0.13	0.47	0.88	-0.18	0.01	-0.11	-0.36	0.43	0.73	-0.44	0.43	0.08	-0.19	0.26
MgO	68	68	68		0.88	0.0	0.15	0.55	-0.33	-0.48	-0.26	-0.40	0.76	0.13	-0.69	0.36	0.06	-0.22	0.29
CaO	68	68	68	68		0.03	-0.05	0.68	-0.31	-0.36	-0.33	-0.50	0.75	0.28	-0.73	0.47	-0.09	-0.32	0.29
Na_2O	68	68	68	68	68		-0.47	-0.10	-0.26	-0.11	-0.24	0.07	-0.16	-0.23	0.14	-0.15	0.02	-0.17	0.18
K_2O	68	68	68	68	68	68		0.43	0.22	0.32	0.19	-0.04	0.22	0.65	-0.16	0.20	0.0	0.04	-0.04
TiO_2	68	68	68	68	68	68	68		-0.29	-0.17	0.19	-0.47	0.66	0.75	-0.65	0.53	0.12	-0.25	0.36
U	68	68	68	68	68	68	68	68		0.61	0.83	0.69	-0.37	0.10	0.54	-0.64	-0.12	0.81	-0.98
Y	68	68	68	68	68	68	68	68	68		0.59	0.46	-0.54	0.31	0.57	-0.39	0.07	0.54	-0.57
eTh	68	68	68	68	68	68	68	68	68	68		0.76	-0.39	0.16	0.59	-0.71	0.45	0.99	-0.81
Rb	68	68	68	68	68	68	68	68	68	68	68		-0.61	-0.31	0.84	-0.99	0.26	0.78	-0.71
Sr	67	67	67	67	67	67	67	67	67	67	67	67		0.31	-0.95	0.63	-0.11	-0.43	0.40
Zr	68	68	68	68	68	68	68	68	68	68	68	68	68		-0.34	0.41	0.21	0.17	-0.06
Rb/Sr	67	67	67	67	67	67	67	67	67	67	67	67	67	67		-0.84	0.18	0.62	-0.57
K/Rb	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68		-0.25	-0.76	0.68
eTh/U	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68		0.46	0.13
eTh/eK	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68		-0.81
eK/U	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	
lat.	0.47	-0.37	-0.35	-0.07	-0.16	-0.45	0.04	-0.30	0.49	0.30	0.54	0.36	-0.21	-0.14	0.29	-0.35	0.18	0.54	-0.49
long.	0.13	-0.10	-0.07	-0.14	-0.10	-0.17	0.0	-0.16	0.47	0.40	0.56	0.59	-0.32	-0.18	0.47	-0.58	0.25	0.57	-0.47

for all of the postorogenic plutons exceed average concentrations for granitic rock (Cu=10 ppm, Zn=40 ppm, Krauskopf, 1967) by factors of approximately 6 and 2.5, respectively. Furthermore, semiquantitative spectrographic analyses for these elements in more than 600 granitic samples from the southeastern Shield also yield anomalous average values (du Bray and others, 1983).

In addition to generally anomalous levels of copper and zinc in the postorogenic granites in the southeastern Arabian Shield, there are a few plutons for which chalcophile-element contents are distinctly greater than the anomalously high regional background levels. Even though the low number of samples and large analytical uncertainties preclude a statistically valid assessment of average copper and zinc contents for individual plutons, it is noteworthy that average copper contents at Jabal Kebad and Jabal al Hassir (locations I and V, fig. 1) are more than one standard deviation greater than the regional background. The average zinc content at Jabal Bani Bwana (location Q, fig. 1) is, likewise, more than one standard deviation greater than the regional background. Average zinc and copper contents from several other areas, although not anomalous relative to the regional high background, are distinctly high relative to average granite: Jabal Tarban, Jabal Sabhah, Jabal Hawshat ibn Hawayl, Jabal Sahah, Najran, and Jabal al Gaharra (locations A, C, D, F, K, and M, respectively, fig. 1).

Yttrium is geochemically very similar to the rare-earth elements (REE) dysprosium and holmium (Felsche and Herrmann, 1978). Yttrium, therefore, provides an accurate prediction of at least middle REE contents. The average yttrium content (40 ppm, table 4) for the postorogenic granites from the southeastern Arabian Shield is identical to that listed by Krauskopf (1967) for granites in general, and it is, therefore, not considered to be anomalous. However, average yttrium content (156 ppm) for samples from Jabal Sabhah (location C, fig. 1) is greater than the regional mean value plus one standard deviation (119, tables 2 and 4). Samples from Jabal Hawshat ibn Hawayl (location D, fig. 1) yield a mean yttrium content of 111 ppm, which is just slightly less than the regional mean plus one standard deviation. These anomalous values suggest the possibility of REE mineralization in the northern part of the southeastern Shield. In addition to these larger scale anomalies, there are a few anomalous samples. One of these, sample 155537, was collected along the margin of a pegmatite. Such pegmatites could provide sites for significant REE concentrations.

Average uranium and thorium contents for postorogenic granites from the southeastern Shield (table 4) are nearly identical to those reported for approximately 2,500 granitic samples from the contiguous United States (U = $3.54\,^{+4.58}_{-2.00}$, Th = $16.76\,^{+22.47}_{-9.60}$, Stuckless and VanTrump, 1982) and are slightly lower than those reported for postorogenic granites of the northeastern Arabian Shield (U = $5.63\,^{+4.08}_{-2.36}$, Th = $16.54\,^{+11.00}_{-6.61}$, Stuckless and others, (in press). Thus, the postorogenic granites of the southeastern Shield do not indicate a region that has an anomalous endowment of radioelements. However, like yttrium, uranium and to a lesser extent thorium occur in anomalous amounts in a few plutons.

A comparison of uranium content in granite samples from the southeastern Shield with normal contents (the mean plus or minus one standard deviation) of granites from the contiguous United States was plotted as a function of areal distribution (fig. 4). Five plutons (Jabal Tarban, Jabal Sabhah, Jabal Hawshat ibn Hawayl, Jabal al Hawshaw, and Jabal Sahah) from the northern part of the southeastern Shield (locations A, C, D, E, and F) and the pluton at Jabal al Gaharra (location M) exhibit anomalously high uranium contents. At least four of these six plutons, Jabal Tarban, Jabal Sabhah, Jabal Hawshat ibn Hawayl, and Jabal al Gaharra, are also anomalous with respect to other elements of economic interest.

The areal distribution of thorium values relative to the mean and standard deviation of thorium values in granites from the contiguous United States (fig. 5) shows that thorium content is anomalously high at Jabal Sabhah and Jabal al Hawshaw (locations C and E) and that only one other sample is anomalously rich in thorium. This sample (155537, location J) is a distinctly banded rock that was collected next to a pegmatite at Huqban and is, therefore, probably not representative of the pluton as a whole. This sample is also anomalously enriched in uranium and yttrium. These elements could also have been introduced from a late-stage pegmatite that was anomalously rich in incompatible elements.

Stuckless and VanTrump (1982) have pointed out that Th/U ratios can be useful in the assessment of uranium favorability for secondary deposits. Very large or highly variable Th/U ratios may indicate a significant post-crystallization loss of uranium from granite. The mean Th/U ratio for the postorogenic granites (2.99, table 4) is much smaller than that reported for the average granite in the United States (4.73, Stuckless and VanTrump, 1982), and the standard deviation for the postorogenic granites (+2.02, -1.21, table 4) is much smaller than that for the United States granites (+5.97, -2.64). Therefore, the data do not suggest any significant amount of post-magmatic mobility of uranium. This conclusion is supported by the high correlation coefficient for

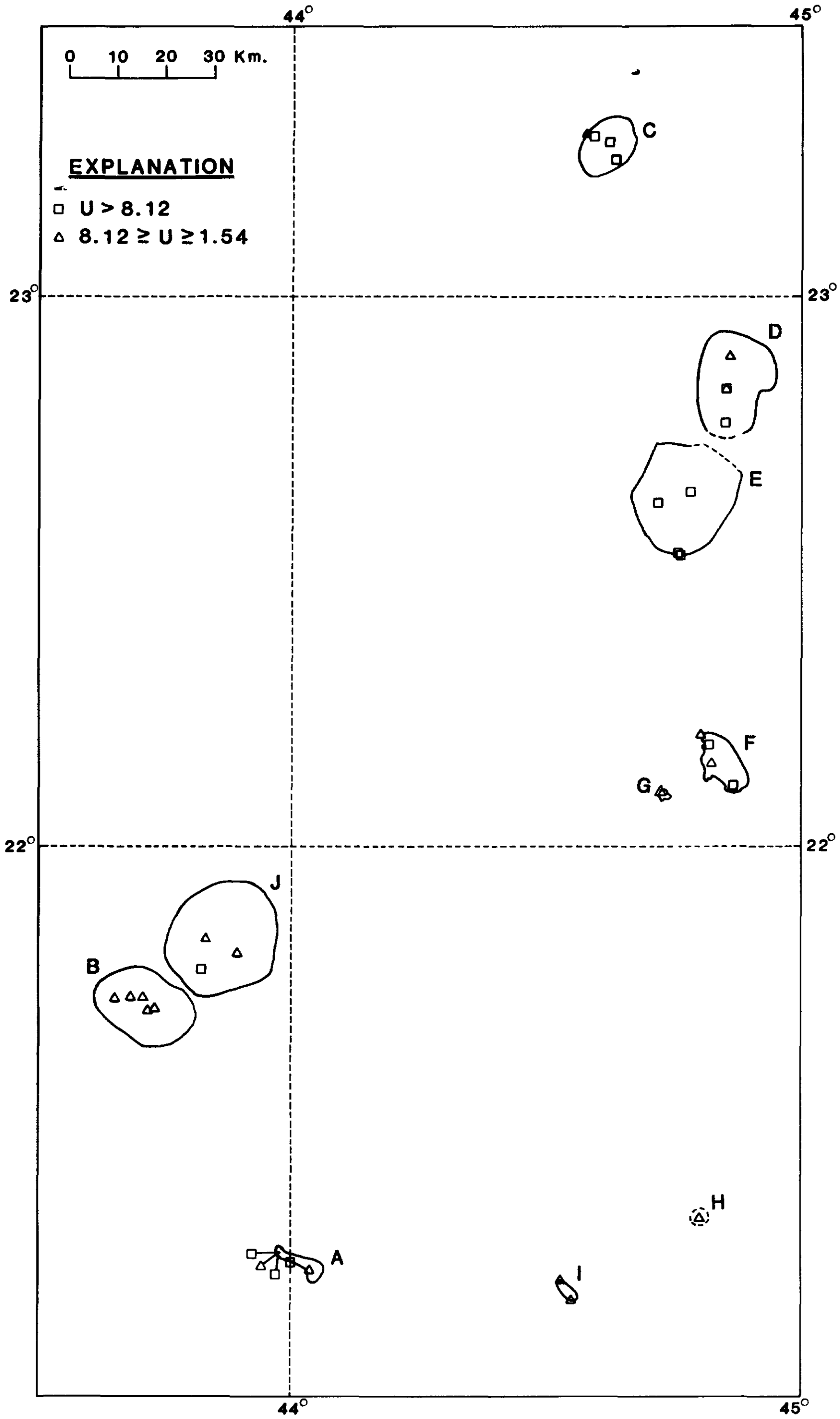

Figure 4.--Map showing areal distribution of uranium values for granite samples from the southeastern part of the Arabian Shield; sample locations and approximate pluton outlines also shown. Symbols represent uranium contents in parts per million relative to the mean and standard deviation of uranium contents in approximately 2,500 granitic samples from the contiguous United States (Stuckless and VanTrump, 1982): triangles, samples having uranium contents within a normal range for granites; squares, anomalously uraniferous samples; circles, anomalously uranium-poor samples.

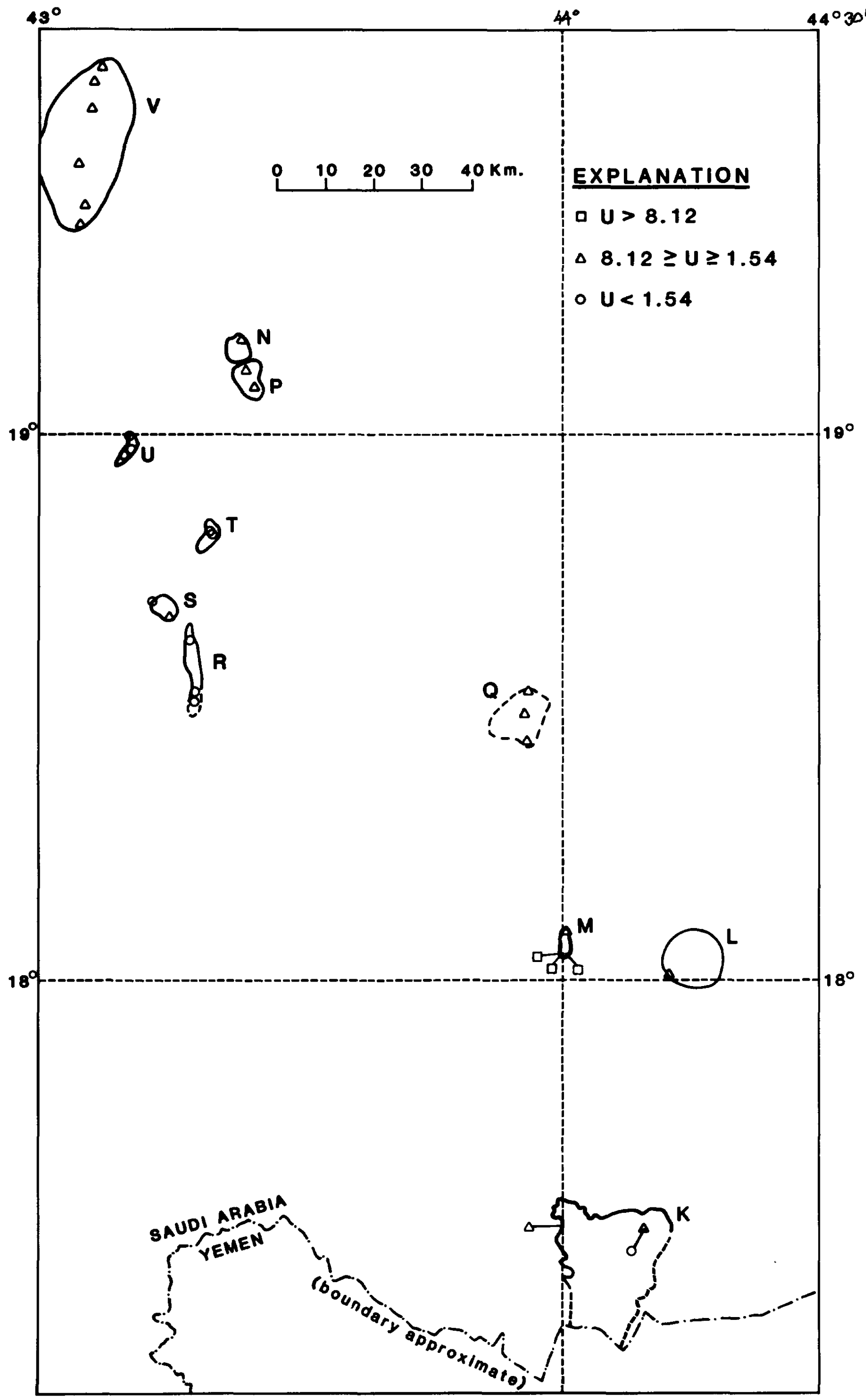

Figure 4.--Continued.

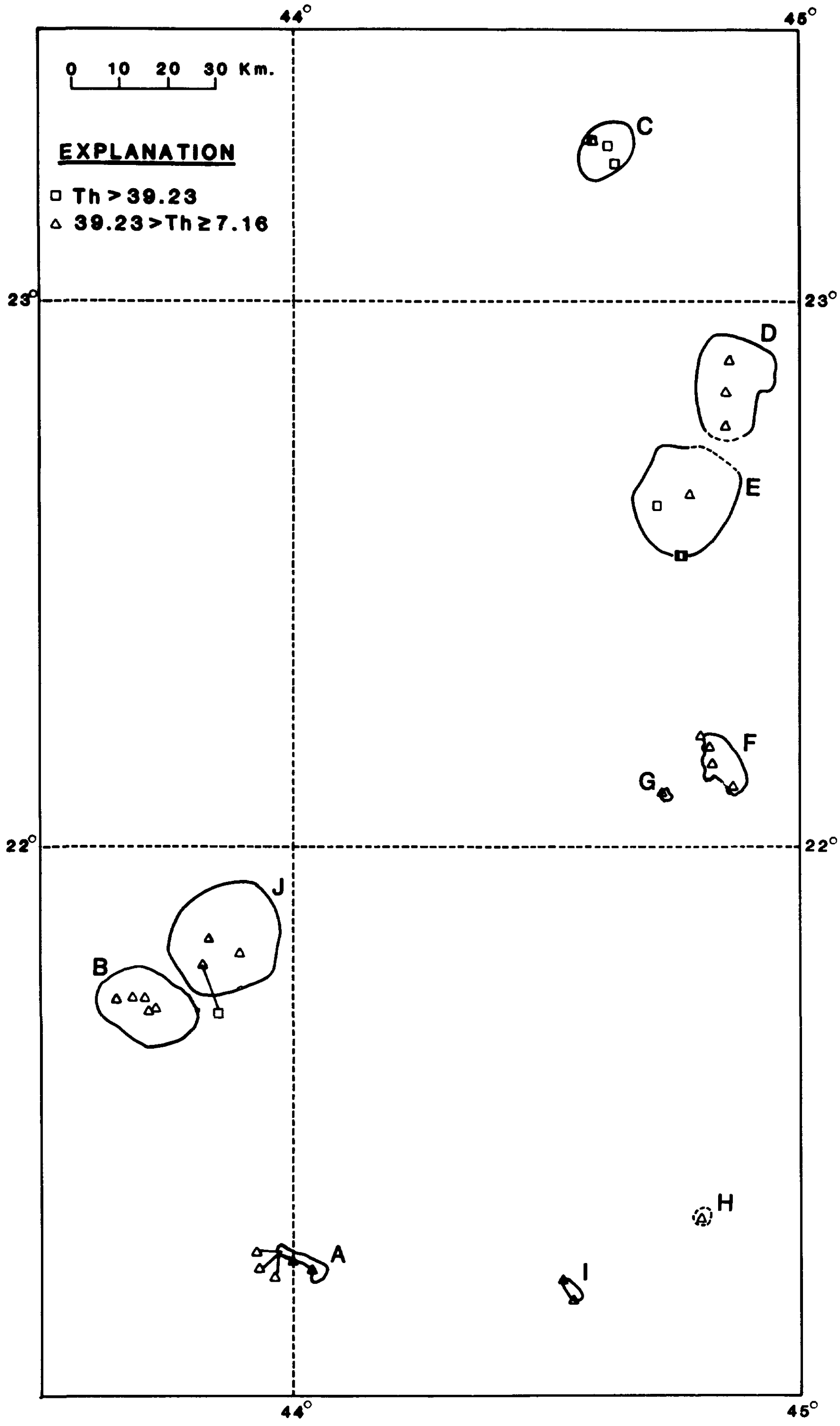

Figure 5.--Map showing areal distribution of thorium values for granite samples from the southeastern part of the Arabian Shield; sample locations and approximate pluton outlines also shown. Symbols represent thorium contents in parts per million relative to the mean and standard deviation of thorium contents in approximately 2,500 granitic samples from the contiguous United States (Stuckless and VanTrump, 1982): triangles, samples having thorium contents within a normal range for granites; squares, anomalously thorium-rich samples; circles, anomalously thorium-poor samples.

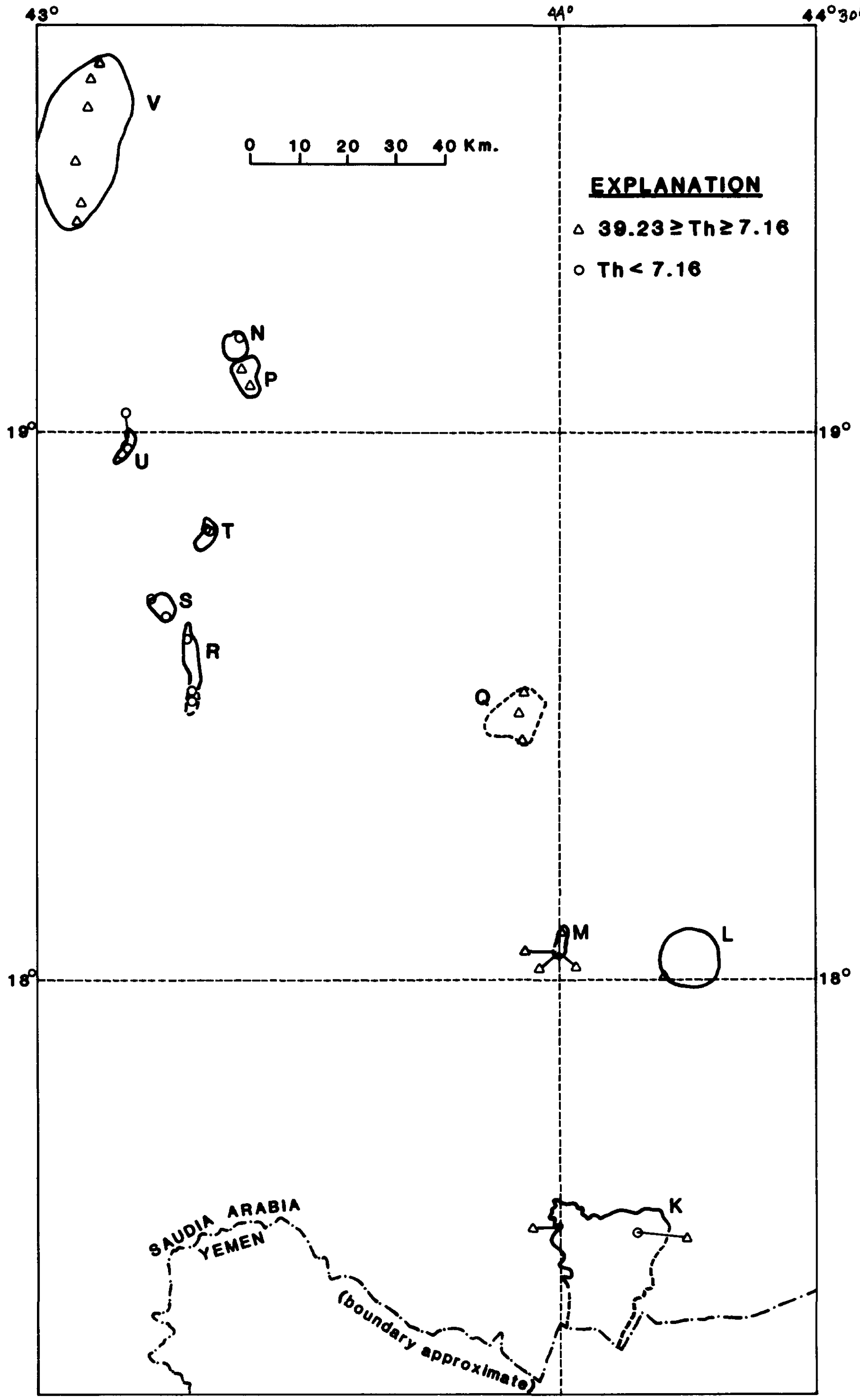

Figure 5.--Continued.

uranium and thorium (0.83, table 5) and the very high correlation coefficient for uranium and radium equivalent uranium (0.98). The latter high correlation coefficient and the general agreement of U and RaeU values within the limits of analytical precision (table 2, fig. 6) indicate that neither uranium nor its relatively short-lived daughter products have been mobilized in the last several thousand years (Stuckless and others, 1977). A map of Th/U ratios (fig. 7) shows that only one of the analyzed samples is anomalously deficient in uranium relative to thorium, and that, on the average, none of the plutons seems to be deficient in uranium relative to thorium.

As noted previously, many of the variations in oxide and trace-element contents can be ascribed to petrogenetic variations such as degree of partial melting or degree of fractional crystallization. It is, therefore, somewhat surprising that a significant percent of the variance in some concentrations can be correlated with sample location. Aluminum, iron, and sodium contents all exhibit a weak, but significant, negative correlation with latitude (table 5). Several trace-element contents are as well or better correlated with latitude (uranium, thorium, and rubidium, table 5). None of the major elements are correlated with longitude to a significant degree; however, several trace elements covary with longitude: uranium, yttrium, thorium, rubidium (table 5), and copper ($r = 0.36$). This is particularly noteworthy in view of the wide range of latitudes (5°34'55") relative to the range of longitudes (1°49'03"). Thus, there is an apparent trend from southwest to northeast, but because this is the general trend of sample locations, the true variations in chemistry could be nearly north-south or east-west.

The observed concentration variations with sample location could be attributed to an increasing degree of magma evolution from southwest to northeast or to a protolithic control in which incompatible-element contents increase from southwest to northeast. The latter interpretation is particularly attractive in view of regional variations in initial-lead isotope compositions noted by Stacey and others (1980) and Stacey and Stoeser (in press). These workers attribute the more radiogenic initial leads (in the east) to an older, continental crustal component in the protolith and the less radiogenic initial leads (in the west) to a younger, oceanic crustal source.

The overlap between the areas with chemical data and areas with isotopic data is insufficient to make a direct comparison between the two data sets; however, the northeastern-most area of the current study is close to the area of radiogenic leads. If plutons within the southwestern part of the current study area were shown to contain non-

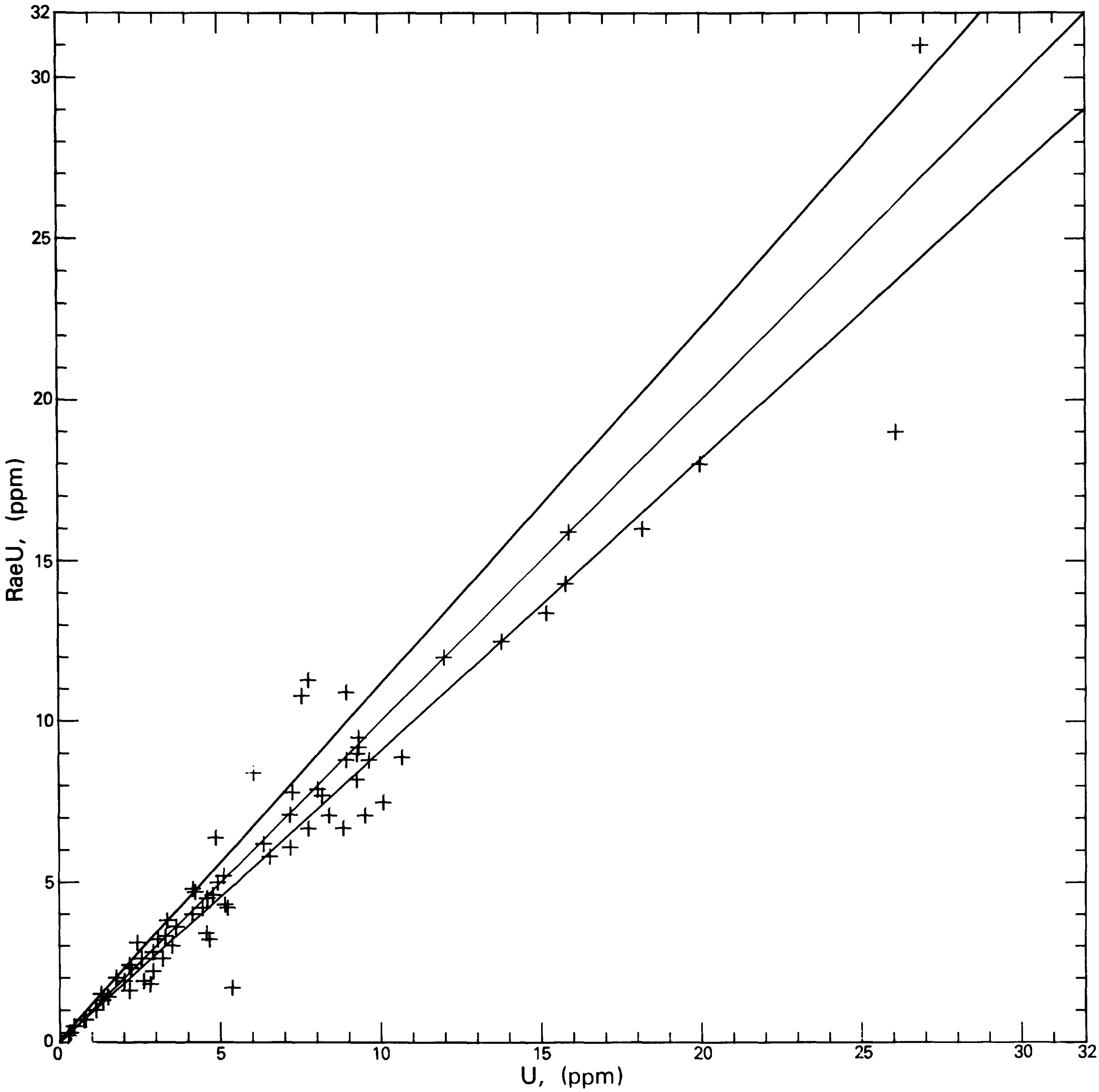

Figure 6.--Diagram showing plot of uranium (U) versus radium equivalent uranium (RaeU) values for granite samples from the southeastern Arabian Shield. Lines show a 1:1 correlation and ± 10 percent.

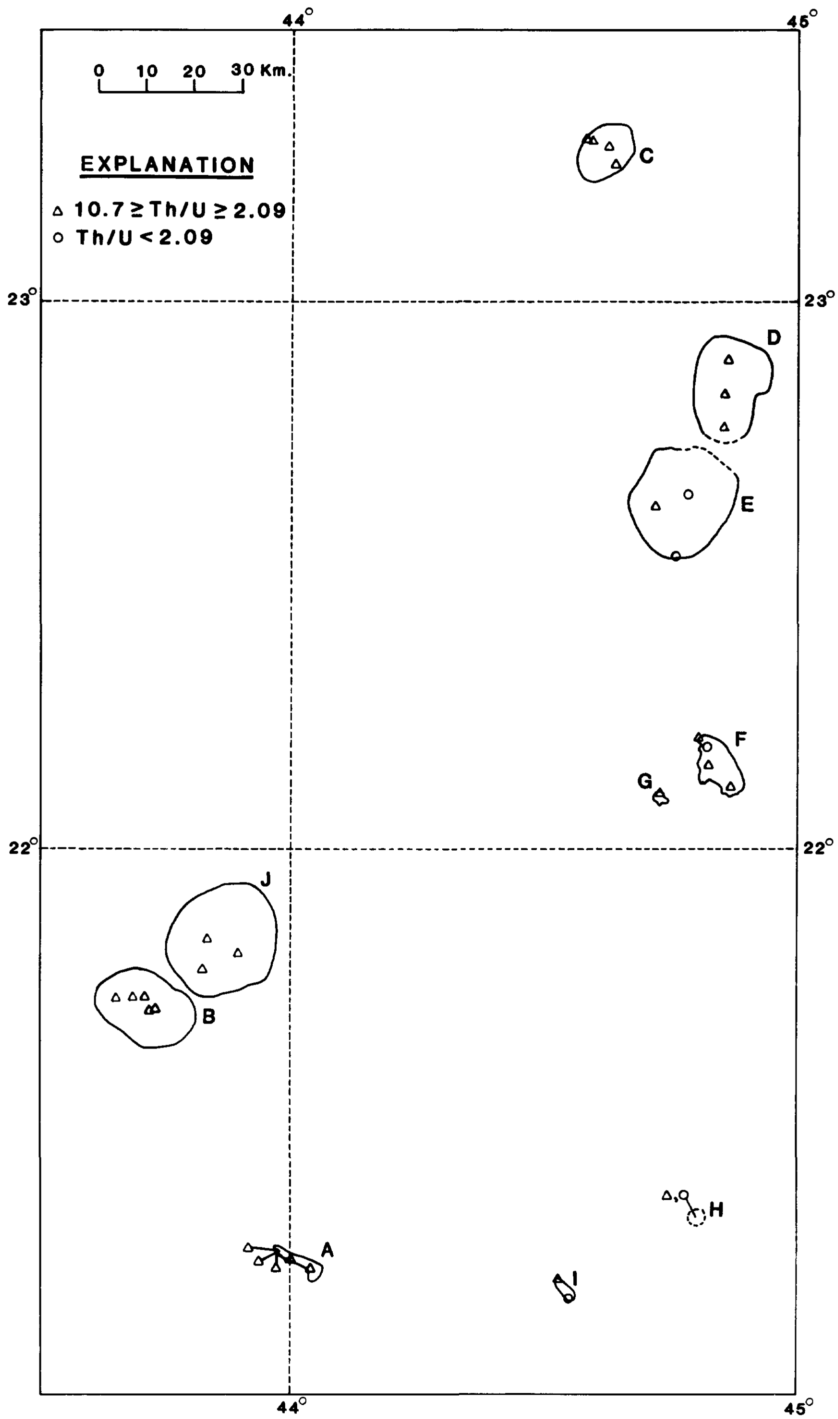

Figure 7.--Map showing areal distribution of Th/U ratios for granite samples from the southeastern part of the Arabian Shield; sample locations and approximate pluton outlines also shown. Symbols represent Th/U ratios relative to the mean and standard deviation of Th/U ratios for approximately 2,500 granitic samples from the contiguous United States (Stuckless and VanTrump, 1982): triangles, samples having Th/U ratios within a normal range for granites; squares, samples having anomalously high Th/U ratios; circles, samples having anomalously low Th/U ratios.

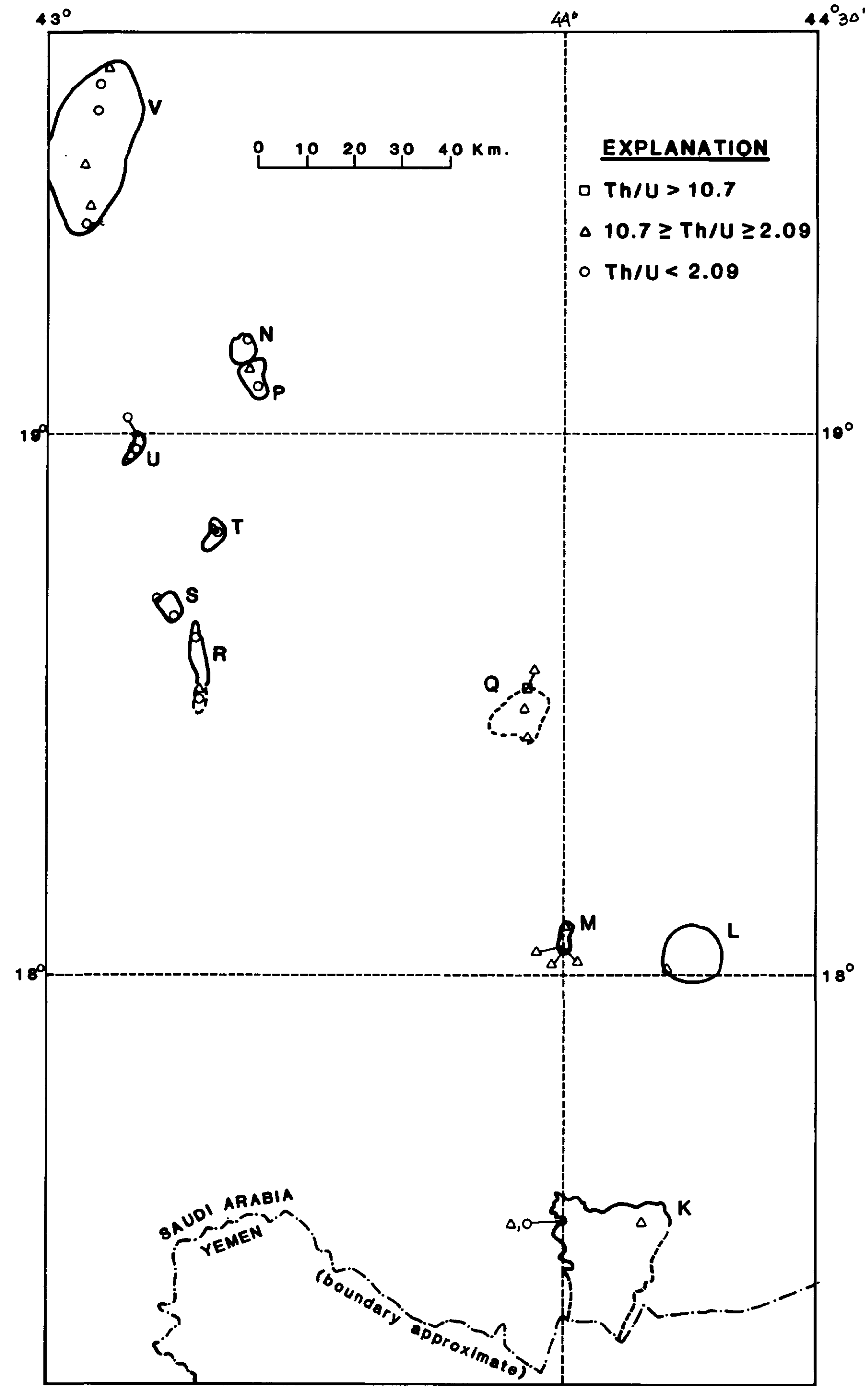

Figure 7.--Continued.

radiogenic leads, the chemical data would strongly support the proposed regional variations in protolith. Higher contents of aluminum, iron, and sodium would be expected from oceanic crustal materials and higher contents of incompatible trace elements would be expected from continental crustal materials.

Suggestions for further work

Concentrations of zinc and copper reported in table 2 are distinctly anomalous, but are not sufficiently precise and accurate to permit detailed evaluation. Reanalysis of at least samples from the more anomalous areas by more accurate techniques (such as induction-coupled plasma spectrometry) is strongly suggested as a first step in confirmation of anomalies. This same technique could be used to simultaneously check tin and tungsten contents, which are known to occur in anomalous amounts elsewhere in postorogenic granites of the eastern Arabian Shield (Cole and others, 1981).

The data in table 5 strongly suggest an areal control for anomalous concentrations of trace elements. A quantitative check of this suggestion should be made by some sort of trend surface analysis. Ideally, compatible data from all postorogenic granites of the Arabian Shield should be used. Most forms of trend surface analysis require a uniform distribution of sample points for a given unit of area, and, therefore, some computer programming and data adjustment would be needed before this approach could be used. Furthermore, the variations in contents of trace elements of interest is dependent in part on degree of magma evolution, and, therefore, some sort of normalizing factor would have to be developed to minimize variations caused by this factor. In spite of the difficulties, the trend-surface-analysis approach should identify the most promising areas for mineral deposits.

The trace-element evolution of granitic rocks, and hence potential for generation of ore deposits, is controlled by the mineralogy of the crystallizing magma. This control is especially important for such elements as uranium, rare-earth elements, niobium, tantalum, tin, and tungsten. For example, tin, and to a lesser extent tungsten, deposits are associated with granites that lack sphene and magnetite (Lehman, 1982), whereas uranium may be assoicated with sphene-, magnetite-, and allanite-bearing granites (Pagel, 1982). In view of the fact that regional chemical anomalies exist, the determination of trace-mineral suites within the granites and examination of mineral chemistry by microprobe analysis could prove useful in the delineation of probable types of ore deposits.

SUMMARY AND CONCLUSIONS

Copper and zinc occur in anomalous amounts in the postorogenic granites of the southeastern Arabian Shield (table 4) as compared to average granite and are especially anomalous at Jabal Kebad, Jabal Bani Bwana, and Jabal al Hassir (table 2). The southeastern part of the Shield may, therefore, be a favorable area for concentrations of these elements. Data gathered during this study do not suggest a particular mode of occurrence.

The concentrations of yttrium, uranium, and to a lesser extent thorium are on the average at background levels in the postorogenic granites of the southeastern Arabian Shield (table 4), but anomalous concentrations do occur in the northeastern part of the area sampled (figs. 4 and 5, table 4). This area forms the end of a southwest-to-northeast trend of increasing trace-element enrichments. This trend may correspond to recently discovered isotopic patterns and may, therefore, reflect a protolithic control. If a protolithic or other predictable regional control can be identified, optimum areas for detailed work can be defined.

Uranium, thorium, yttrium, and the rare-earth elements have similar geochemical behaviors in an igneous environment, but uranium in particular can be separated readily from these elements in the low-temperature, near-surface environment. High correlation coefficients for uranium, thorium, and yttrium contents, uranium and radium-equivalent uranium contents, and the enrichment of all three elements near a pegmatite indicate that economic deposits of these elements or rare-earth elements would most likely be controlled by magmatic processes. It is suggested that pegmatites associated with anomalous postorogenic granites would have the highest economic potential.

Finally, more detailed field work, quantitative geochemistry, and advanced mathematical techniques are all recommended for further work in the region of the southeastern Arabian Shield.

DATA STORAGE

All results obtained in the course of this study are presented in this report; no data files were created. No existing mineral localities were studied and no specific sites were identified for inclusion in the Mineral Occurrence Documentation System (MODS) of the Saudi Arabian Deputy Ministry for Mineral Resources.

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