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Trace-element contents of postorogenic granites of the eastern Arabian Shield, Kingdom of Saudi Arabia

by

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TRACE-ELEMENT CONTENTS OF POSTOROGENIC GRANITES OF THE EASTERN ARABIAN SHIELD, KINGDOM OF SAUDI ARABIA

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ABSTRACT

Trace-element contents for 46 postorogenic granitoids vary by as much as two orders of magnitude; most samples are strongly enriched in incompatible elements (such as the heavy rare earths, yttrium, niobium, and uranium) and depleted in the compatible elements (such as barium, strontium, scandium, europium, and cobalt). These trace-element characteristics are typical of A-type granites found in other areas of the world. In spite of the wide range in trace-element contents, no samples contained economically significant concentrations of a single element.

Samples range from peralkaline to strongly peraluminous; most are weakly peraluminous or metaluminous. All three subgroups (peralkaline, metaluminous, and peraluminous) are enriched in uranium and hafnium and are depleted in compatible elements. The peralkaline granites are generally enriched in yttrium and niobium - the strongly peraluminous granites in rubidium and tantalum; both groups are also somewhat enriched in the heavy-rare-earth elements. Several of the peraluminous granites are known to be tin-bearing and, like tin-bearing granites found elsewhere in the world, their chondrite-normalized, rare-earth-element patterns are flat and have large negative europium anomalies.

Samples from several plutons have very anomalous ratios for geochemically similar elements such as yttrium and holmium, niobium and tantalum, and zirconium and hafnium. These ratios may reflect differential complexing with a halogen-rich aqueous phase that may be characteristic of plutons that have been subjected to an ore-forming process. A program to test these hypotheses, through study of known mineralized areas and laboratory experiments, should be implemented.

The regional trends for the chemical data and geochemical correlations over the large area sampled, suggest that the postorogenic granites were derived from a single protolith that formed by the mixing of oceanic sediments from the west; continental sediments from the east.

1/ U.S. Geological Survey, Denver, CO

INTRODUCTION

Postorogenic and anorogenic granites have received considerable attention because of their anomalous concentrations of elements of economic interest and their relationships to ore deposits (Wilson and Akerblom, 1980; Doe and others, 1982; Kinnaird and others, 1982; Imeokparia, 1982; Hudson and Arth, 1983). These granites have also played a major part in interpretations of the evolution of the Earth's crust (Barker and others, 1976; Anderson and Cullers, 1978; Cullers and others, 1981; Collins and others, 1982; Farmer and DePaulo, 1983; Anderson, 1983).

Postorogenic granites of the Arabian Shield are intruded into metavolcanic, plutonic, and metasedimentary rocks that range in age from 1,100 to 660 Ma and in composition from mafic to felsic. (Greenwood and others, 1976; Delfour, 1977; Fleck and others, 1980; Stoeser and Elliott, 1980; Bokhari and Kramers, 1981; Schmidt and Brown, 1984; Calvez and others, 1983; Stoeser and others, 1985; Stacey and Hedge, 1984; Stacey and others, 1984). Deformation of the rocks is common and the oldest rocks have been multiply deformed. The character of magmatism during the formation of the Shield changed from unevolved mafic rocks to intermediate rocks to evolved silicic (or bimodal gabbroic-granitic) rocks. Towards the end of the last magmatic period the Arabian Shield was cut by the northwest trending Najd fault system that has a left-lateral displacement of as much as 240 km (Brown, 1972).

Many recent studies of the Arabian Shield have been centered around the youngest granitic rocks (variously referred to as postorogenic, anorogenic, or posttectonic) because of their common enrichments in several elements of economic interest (Elliott, 1985; Radain and others, 1981; Harris, 1981; du Bray and others, in press; Drysdale and others, 1984; Jackson and Odell, 1984). Within the Arabian Shield, occurrences of tungsten (Cole and others, 1981), rare-earth elements and thorium (Harris and Marriner, 1980; Stuckless, Knight, and others, 1982; Stuckless, Quick, and VanTrump, 1984), molybdenum (Dodge, 1979) and tin (Elliott, 1980; du Bray, 1984) have been reported, and a favorable potential exists for resources of niobium and tantalum (Ramsay and others, 1982; Elliott, 1983). The young granites also have provided information concerning the origin of the Arabian Shield (Stacey and others, 1980; Delfour, 1981; Schmidt and Brown, 1984; Fleck and Hadley, 1982; Stacey and Stoeser, 1983; Stuckless, Hedge, and others, 1984).

The postorogenic plutons of the Arabian Shield were emplaced from about 660 Ma to 520 Ma (Fleck and others, 1980; Jackson and others, 1984). Geochronologic investigations by Fleck and Hadley (1982), Calvez and Kemp (1982), Stuckless, Hedge, and others (1984), and Stuckless (unpub. data) indicate that postorogenic plutonism for the eastern part of the Shield occurred between 610 Ma and 570 Ma. Fleck and others, 1976, have postulated that an early Cambrian heating event reset K/Ar ages in the southern shield, but limited data suggest that this event did not extend all the way to the northern part of the exposed shield (Stuckless, Hedge, and others, 1984).

The work on which this report is based was performed in accordance with the cooperative agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey. The research is part of a program to study the petrogenesis and mineral potential of granitic rocks of the Arabian Shield. In particular, this report will focus on trace-element geochemistry of postorogenic granites of the eastern Shield and the bearing of these data on resource potential as well as implications for the petrogenesis of the Arabian Shield.

ANALYTICAL PROCEDURES

Rare-earth-element (REE) concentrations (table 1) 1/ and concentrations for a selected suite of trace elements (table 2, except Y and Nb) were determined by instrumental neutron activation analysis (INAA) by use of methods similar to those described by Gordon and others (1968). Samples 155500 through 155573 (table 1) were irradiated twice; once with a flux of 2.5 x 10^{13} neutrons per cm^2 followed by immediate counting, and once with a flux of 6.88 x 10^{16} neutrons per cm^2 followed by counting at approximately 7, 14, and 60 days. The remaining samples were irradiated once with a flux of 6.88 x 10^{16} neutrons per cm^2 and were counted at approximately 9 and 23 days after irradiation. The latter procedure is more rapid, but provides no information on potassium, manganese or dysprosium. However, data for the first two of these elements were obtained during analysis for major elements. Data for dysprosium (and any other REE's that were masked by interference in a given sample) were obtained by interpolation of chondrite-normalized values of adjacent REE's.

Accuracies for the values determined by INAA are estimated (on the basis of analysis of standards) to be ± 1 percent for tantalum; ± 2 percent for lanthanum, cerium, and neodymium; ± 3 percent for samarium, europium, ytterbium, scandium, and cobalt; ± 4 percent for terbium, hafnium, and antimony; ± 5 percent for dysprosium, lutitium, and cesium; ± 7 percent for thulium; and ± 14 percent for gadolinium. REE data reported in table 1 have been adjusted within counting statistics to yield smooth chondrite-normalized REE patterns (Stuckless and Miesch, 1981). The chondite values of Evensen and others (1978) have been used for normalization throughout this report.

Concentrations of yttrium and niobium were determined by X-ray fluorescence on loose, finely ground (-200 mesh) rock powder. Precision (based on replicate analyses) at the low concentrations found for most of the samples in the current study is ± 25.8 percent for yttrium and ± 42.9 percent for niobium (errors at the 95 percent level of confidence). Errors decrease to approximately ± 10 percent at concentrations greater than 50 ppm.

Statistical methods and formulae used to examine the data are described by VanTrump and Miesch (1977). Linear regressions use the two-error methods of York (1969). Trace-element contents of most geologic materials tend to follow a log-normal distribution (Ahrens, 1957), and therefore, means and standard deviations for trace elements were calculated as logarithms and are reported as antilog values (tables 3 and 4). Ratios of elements were examined arithmatically and logarithmically. Values of skewness and kurtosis suggest that the ratios Nb/Ta and Zr/Hf are best explained by arithmatic distributions, whereas other ratios (tables 3 and 4) more closely approximate a log-normal distribution. Chondrite-normalized values are used throughout this report for the La/Lu ratio.

Europium anomalies are reported as Eu/Eu^*, which is the ratio of the measured europium to that calculated from the values of samarium and gadolinium so as to yield a smooth pattern through the middle REE's. Thus, Eu/Eu^* of one is no europium anomaly; values less than one are referred to as negative anomalies; and values greater than one are referred to as positive anomalies.

1/ All tables used in this report are near the back: see page 21. 3

Data for an average granite reported in table 4 were assembled from the Handbook of Geochemistry and Stuckless and Van Trump (1982) as follows:

Element	Reference	Page
La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Tm, Yb, Lu, Y	Herrmann (1970)	39, 57-71-E-11
Ba	Puchelt (1972)	56-E-6
Cs	Heier and Billings (1970a)	55-E-1
Rb	Heier and Billings (1970b)	37-E-7
K/Rb		37-G-1
Sr	Faure (1978)	38-F-1
Nb	Wedepohl and Heinrich (1978)	41-E-15
Ta, Nb/Ta	Wedepohl (1978)	73-E-5
Zr	Erlank and others (1978a)	40-E-18
Hf, Zr/Hf	Erlank and others (1978b)	72-E-15
U, Th, Th/U	Stuckless and VanTrump (1982)	191
Sb	Onishi (1969)	51-E-3
Sc	Frondel (1970)	21-E-2
Co	Turekian (1978)	27-E-1

Correlation analysis (table 5) was made using logarthmically transformed values for trace-element contents. This transformation was used because the statistical distribution of trace-element data is log-normal (or nearly so), and because the range for the transformed trace element is more similar to that for the major elements. Data for major-element concentrations and sample localities are reported in Stuckless, VanTrump, and others (1982), Stuckless and others (1983), Stuckless, Quick, and VanTrump (1984), and Stuckless and others (1985).

The classification of plutonic rocks used in this report is that recommended by the International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Plutonic Rocks (Streckeisen, 1976). Subdivision of the rocks on the basis of aluminia saturation is modified from the definitions of Shand (1951) such that rocks with molar Al/(Na+K) <1 are peralkaline; Al/(Na+K+Ca) >1.05 are peraluminous; Al/(Na+K+Ca) <1.05 and Al/(Na+K) >1 are metaluminous. The boundary between peraluminous and metaluminous rocks was chosen at a higher degree of alumina saturation than defined by Shand (1951) in order to separate strongly peraluminous samples from those for which small analytical errors might move them from a truly metaluminous classification to apparent peraluminous affinity.

RESULTS AND DISCUSSION

The range in concentrations for the analyzed trace elements is very large and is generally in excess of two orders of magnitude (table 3). However, none of the samples analyzed contains economic concentrations of a single trace element, as is readily apparent from the maximum values listed in table 3. Comparison of the mean-trace-element contents (table 3) and those for an average granite (table 4) shows that the postorogenic granites of Saudi Arabia are generally depleted in compatible elements (such as barium, strontium, scandium, europium, and cobalt) and enriched in a few of the incompatible elements (such as the heavy-rare-earth elements, yttrium, niobium, and uranium).

The depletion in compatible trace elements is apparently independent of the degree of alumina saturation because the peralkaline, metaluminous to weakly peraluminous, and strongly peraluminous samples all have low mean contents of this group of elements (table 4). However, except for uranium and hafnium, which are enriched in each of the subgroups, elevated contents of trace elements are restricted to the peraluminous and peralkaline varieties. Yttrium and niobium are enriched in the peralkaline subgroup whereas tantalum and rubidium are enriched in the peraluminous subgroup. The heavy-rare-earth contents are somewhat elevated in both of these subgroups.

The REE contents of the postorogenic granites of the Arabian Shield yield a broad spectrum of chondrite-normalized patterns (fig. 1)[1/]. Although there are exceptions, rocks that are similar in terms of major-element chemistry tend to have similar REE patterns. The low-silica (less than 70 percent) granitoids are all metaluminous and have generally steep patterns. The chondrite-normalized La/Lu values range from 5.78 to 40.2, and the geometric average is 11.95. The europium anomalies range from weakly positive (Eu/Eu^*=1.295) to moderately negative (Eu/Eu^*=0.219), but are generally weakly negative (average Eu/Eu^*=0.709). Most of the low-silica granitoids have lanthanum contents that are 100 to 500 times chondrite, and lutitium contents that are 10 to 30 times chondrite.

The higher silica metaluminous to weakly peraluminous granites differ from the low-silica ones in the that europium anomalies are all negative and are generally more pronounced (average Eu/Eu^*=0.273) in the high silica group. The REE patterns are generally less steep (fig. 1). The geometric mean for the chondrite-normalized La/Lu ratio is 5.77. Both groups have similar absolute concentrations of light REE's, and thus the differing slopes reflect a relative enrichment of heavy REE's in the higher silica granites.

The REE patterns for the peralkaline granites are very similar to those of the higher silica, metaluminous to weakly peraluminous granites. The average Eu/Eu^* is 0.324 and the geometric mean for La/Lu is 6.74. REE patterns for these two varieties from the same pluton are virtually identical (fig. 1, Jabal Tuwalah and An Namar). There is however, a general tendency for the peralkaline granites to have a somewhat higher content of total REE's (table 4).

The peraluminous granites yield generally distinctive REE patterns. Although a few peraluminous granites, such as those at Jabal as Sukkah and Jabal Saqrah, have REE patterns and contents similar to those of the higher silica metaluminous granites (table 1 and fig. 1), most samples yield fairly flat REE patterns (geometric mean La/Lu=1.84) with pronounced negative europium anomalies (average Eu/Eu^*=0.134). Hudson and Arth (1983) have noted that such patterns are typical of tin-bearing granites of Alaska. The tin granites of Spain also show these distinctive features (Stuckless, unpub. data, 1982) . Samples from Jabal as Silsilah, which contains areas of high-grade tin granite (du Bray, 1984), also yield this distinctive pattern. Thus the process or processes that control the formation of tin deposits and those that generate flat REE patterns with pronounced negative europium anomalies may be the same.

REE patterns for the last four plutons shown on figure 1 differ from those for the rest of the plutons in that the total REE contents are much lower. The plutons at Wadi al Habbah and Madha have previously been identified as orogenic (Stuckless, Van Trump, and others, 1983). Jabal Zayd is the only strongly peraluminous pluton that does not exhibit strong europium anomalies, and may be unrelated to the postorogenic

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1/ All figures used in this report are near the back; see page 12 granites. The pluton at Wadi Tafshah yields REE patterns similar to other strongly peraluminous, postorogenic plutons except for its much lower total REE content. The relationship of this pluton to the other postorogenic samples is therefore uncertain. All four of these plutons may be orogenic, but on the basis of available data only the plutons at Wadi al Habbah and Madha are excluded from the statistical treatment and diagrams for the postorogenic data set.

The absolute concentrations of trace elements and their relative distributions in igneous rocks are dependent on a number of factors. The concentration of incompatible chalcophile elements, such as antimony, has long been thought to be controlled by province or source region chemistry (Lindgren, 1919). If there is an anomalously high content of chalcophile elements in the source region, the magma generated in that source region will be even more enriched in chalcophile elements. Magmatic and post-magmatic processes may then operate to further concentrate these elements into economic deposits.

Most trace elements behave as compatible or incompatible elements during crystal-liquid fractionation such that the absolute and relative concentrations change according to the Raleigh fractionation law (Hanson, 1978). This law states that the concentration of a particular trace element in the liquid, divided by the concentration in a crystallizing solid, is a constant (the partitioning coefficient). If the partitioning coefficient is greater than one, the element is considered to be incompatible and the concentration of that element will increase as the volume of liquid decreases. Thus, the concentration of any trace element will depend on the mineralogy of the crystallizing solid which is in turn dependent upon major-element chemistry and physical conditions such as temperature, pressure, water activity, and oxygen fugacity.

Several effects of varying physical conditions upon the concentrations of REE's have been well studied. For example, crystallization at high pressure may stabilize garnet as a solidus phase with consequent depletion of heavy REE's in the evolving liquid (Arth and Hanson, 1972). High oxygen fugacity (greater than the nickel - nickel oxide buffer) can stabilize epidote and allanite in metaluminous and peraluminous magmas (Naney and Swanson, 1980) with consequent depletion of light REE's in the final liquid (Christiansen and others, 1984). High oxygen fugacity may also decrease the size of the negative europium anomaly that typically forms by the separation of feldspar from a magma (Sun and Hanson, 1976). High-temperature crystallization and peralkaline chemistry both suppress crystallization of zircon (Watson and Harrison, 1983) which is a phase that would preferentially remove heavy REE's, uranium, and hafnium from the melt (Buma and others, 1971). These same conditions also suppress the crystallization of epidote and allanite, and thus high-temperature, peralkaline magmas favor high concentrations of total REE's.

Recent studies have shown that Rayleigh fractionation alone will not account for all observed trace element distributions (Hildreth, 1979; Christiansen and others, 1983). Complexing of trace elements with a volatile phase may preferentially move some trace elements to the upper portion of a magma chamber in sufficient quantity to create economic deposits. Christiansen and others (1984) have proposed that volatile transfer in fluorine-dominated systems may cause enrichments of lithium, rubidium, cesium, tantalum, thorium, beryllium, and heavy REE's. Both fluorine- and chlorine-dominated systems have been proposed to explain various rare-element mineralizations in the postorogenic granites of the Arabian Shield in which some geochemically similar elements have been separated (Drysdale and others, 1984).

Further evidence for processes other than Rayleigh fractionation has been presented by Krauskopf (1970), who has noted that the separation of tungsten from molybdenum can be accounted for by their differing abilities to complex with sulfur. The two elements are geochemically similar in most respects (such as charge and ionic radius) as a result of the lanthanide contraction. The theoretical basis for differences in affinities for various anionic species is poorly understood, but may relate to differing electron configurations on either side of the lanthanide contraction and consequent differing percentages of ionic bonding (Felsche, 1978). Regardless of the actual mechanism, if one pair of geochemically similar elements can be separated by action of an aqueous or vapor phase, other pairs, such as niobium and tantalum (Krauskopf, 1970), may also be separated. Identification of plutons that have evolved by means other than Raleigh fractionation may help locate regions where ore-forming processes have acted. Such information may be particularly useful in the search for tungsten, because unlike tin, tungsten does not show abnormal concentrations in granites associated with ore deposits (Krauskopf, 1970).

Yttrium and holmium have the same valence and very similar ionic radii (Felsche, 1978). Thus, if both elements behave according to Rayleigh fractionation, the two should be highly correlated. Correlation analysis of all data for the postorogenic granites shows that yttrium is well correlated with the heavy REE's (table 5). Holmium contents were not measured during the current study, but can be estimated from the chondrite normalized pattern (fig. 1). These estimates multiplied by the chondritic ratio of yttrium to holmium yield a calculated value of yttrium for each sample. The plot of the measured yttrium versus the calculated yttrium (fig. 2) shows that the latter are generally about 20 percent greater (the slope of the regressed line is 0.80 ± 0.04), but that values for most samples are highly correlated.

Ten samples were excluded from the regression analysis because of their divergence from the pattern generated by the rest of the data. However, even with these samples eliminated the scatter of data about the regressed line exceeds that predicted by analytical error (MSWD=2.25). Six of the excluded samples are peraluminous, three are weakly peraluminous, and one is peralkaline. Six of the nine samples are from two plutons (Jabal Sabhah and Jabal Hawshat ibn Hawayl) that occur close together. A seventh sample is from Jabal Huqban and was collected adjacent to a zone of altered rock. The remaining three samples are from Jabal Sahah, Jabal Qutn, and Jabal Hadb ash Sharar; the latter contains zones of hydrothermally altered rock. All ten of the excluded samples have notably flat REE patterns and large negative-europium anomalies relative to other samples that have similar major-element chemistry.

The average zirconium-hafnium ratio (Zr/Hf) for granitic rocks is 39, and this ratio does not appear to be affected by differentiation processes (Erlank and others, 1978b). However, data compiled by these authors show that metasomatically altered rocks contain more hafnium and zirconium than their unaltered equivalents. Furthermore, the Zr/Hf decreases in metasomatically altered granites such that albitized granites have Zr/Hf of about 12 and greisenized granites have Zr/Hf of about 22 (Erlank and others, 1978b).

The Zr/Hf value for the postorogenic granitoids of the Arabian Shield seems to vary as a function of whole-rock chemistry such that the ratio decreases in the sequence peralkaline to metaluminous to peraluminous (table 4). Zirconium and hafnium are highly correlated in the peralkaline rocks (r=0.98). The zirconium-hafnium ratio derived by either averaging the data (table 4) or from the slope of a line regressed through the data (fig. 3) is not distinguishable from that of an average granite (table 4).

Zirconium and hafnium are fairly well correlated in the metaluminous rocks (r=0.84) and the Zr/Hf calculated from a line through the data (fig. 3) is indistinguishable from that of an average granite. However, the intercept of this line is significantly different from 0 (2.87 $\pm$ 1.16) because most samples are enriched in hafnium relative to zirconium as reflected by the mean Zr/Hf of 28.3 $\pm$ 8.0 (table 4). Samples most strongly enriched in hafnium are largely from Jabal Aja. The three metaluminous samples identified previously as enriched in yttrium relative to REE's are also enriched in hafnium relative to zirconium.

The correlation between zirconium and hafnium is poorest in the peraluminous rocks (r=0.78), and the Zr/Hf derived by either averaging the data (table 4) or from the slope of a line regressed through the data (fig. 3) is lowest for the peraluminous granites. Nearly all of the peraluminous samples are enriched in hafnium relative to zirconium as compared to an average granite, but samples from Bani Bwana, Jabal al Gaharra, Jabal Minya, Jabal Khinzir, Jabal Sabhah, Jabal Hawshat ibn Hawayl, Jabal Huqban, and Jabal as Silsilah are most notably enriched in hafnium. Samples from these plutons are also characterized by large negative europium anomalies and flat REE patterns.

Niobium and tantalum have very similar crystal chemistries except that nonmineral halide and oxyhalide complexes of niobium are easily produced in the laboratory, but similar tantalum compounds are unknown (Florke and Gebert, 1974). Limited data suggest that Nb/Ta may increase with increasing degree of magma evolution in alkalic sequences and decrease in other suites, but such systematics have not been confirmed (Wedepohl and Heinrich, 1978). High fluorine contents inhibit the precipitation of niobium (Wedepohl, 1978) and may cause high concentrations of tantalum relative to niobium. Greisenized granites have reported Nb/Ta values as low as 2 which contrasts with a normal granite value of 12 (Wedepohl, 1978.)

The ratio and correlation of niobium to tantalum, like those of zirconium to hafnium, vary as a function of degree of alumina saturation. Niobium and tantalum are well correlated in the peralkaline granites (r=0.97), and Nb/Ta, either calculated as an average (table 4) or calculated from the slope of a line regressed through the data (fig. 4), is not significantly higher than that of an average granite.

Niobium and tantalum are less well correlated in the metaluminous granitoids (r=0.84), and the average Nb/Ta is slightly lower than that of an average granite (table 4 and fig. 4). The greatest tantalum enrichments in the metaluminous suite (Nb/Ta<4) are for samples from Jabal Dumah, Jabal Khinzir, and Jabal Haslah. Less anomalous are samples from Jabal Aja, Baid al Jimalah, and Jabal Qutn.

Correlation between niobium and tantalum is poorest in the peraluminous suite (r=0.83). Most of the samples have Nb/Ta less than 12 (fig. 4), but the ratio is highly variable within this group as indicated by the large standard deviation (table 4). Samples with the most anomalous enrichment in tantalum relative to niobium (Nb/Ta<4) are from Jabal al Gaharra, Jabal Minya, Bani Bwana, Jabal as Silsilah, Jabal Khinzir, Jabal Mahail, Jabal Kebad, Jabal Kazaz, and Jabal Haslah. All of the low Nb/Ta samples, except those from Jabal Haslah, have pronounced negative europium anomalies and flat REE patterns.

Although there is considerable overlap among samples that have the nearly flat REE patterns, strong europium anomalies, and enrichments of yttrium, hafnium, and tantalum relative to heavy REE's, zirconium, and niobium, respectively, no samples exhibit all these features. Furthermore, samples from Jabal al Gaharra and Jabal Minya, which have the lowest Nb/Ta ratios, are not anomalously enriched in yttrium relative to the heavy REE's (table 6). Thus, it seems likely that either more than one process is in operation or that differing levels of erosion have exposed differing effects of one process.

The anomalous ratios for geochemically similar elements occur in 19 of the 46 plutons for which data are available. Two of the 19 plutons are known to be mineralized, and most of the others have been suggested previously as favorable for mineralization. Development of the anomalous ratios and formation of ore deposits may be linked to the same process or processes, and therefore, the location of trace-element anomalies and their mechanism of formation may prove to be useful in the search for ore deposits.

Maps of trace-element ratios may be more useful in delineating areas of high-resource potential than maps of absolute concentrations; however if average data are used, some anomalous plutons may be overlooked. Compatible data for niobium (that is data determined by the same method and in the same laboratory) are available for approximately 400 samples of postorogenic granite. For purposes of graphical presentation (fig. 5), these data have been averaged with 7.5 by 7.5 minute areas. Tantalum data are available for only 173 of these samples (table 2), and therefore, except for three plutons for which a large number of analyses are available (Jabal Aban al Ahmar, Jabal Qutn, and Jabal Aja), the data have been averaged by pluton (fig. 6). Comparison of figures 5 and 6 shows that anomalously high niobium contents (those that exceed the geometric mean by more than one standard deviation) exist in only three areas, whereas eight plutons have anomalously low Nb/Ta averages.

The anomalous niobium contents correspond to three areas of known hydrothermal alteration: the northeastern edge of Jabal Aja which contains radioactive pegmatites (Matzko and Naqvi, 1978), Jabal Ba'gam which hosts small pockets of thorium enriched rock (Stuckless, Quick, and VanTrump, 1984), and Jabal Tarban which contains several small metallic-mineral veins (du Bray, in press). Of the eight plutons for which the average Nb/Ta is anomalously low, three are known to be tin bearing; Jabal al Gaharra (Elliott, 1985), Jabal as Silsilah (du Bray, 1984), and Jabal Minya (Moore, 1984). The remaining five plutons are represented by single analyses, and are therefore perhaps less significant. Somewhat less anomalous Nb/Ta averages exist for several plutons that have known or suspected economic importance. These lesser anomalies include Baid al Jimalah, Jabal Khinzir, and Jabal Bani Bwana. Detailed investigations of only plutons that exhibit the strongest anomalies might therefore exclude some areas for which the resource potential is at least good.

The yttrium and REE data form some interesting regional patterns. The map for yttrium (fig. 7) was obtained by the same method as that described for niobium data, whereas the maps for REE data (figs. 8 and 9) were constructed by the method described for the Nb/Ta ratio. The yttrium data, like niobium data, define a broad east-west band of low concentrations between latitudes 23° and 25° N., but in contrast to the niobium data, the yttrium data define a large area of anomalously high concentrations in the east-central portion of the exposed Shield (figs. 5 and 7). The yttrium highs generally correspond to regions in which yttrium is enriched relative to the heavy REE's. These highs may therefore be useful in delineating areas for which pluton evolution included processes besides crystal-liquid fractionation.

Stuckless, Hedge, and others (1984) noted that Rb/Sr and K/Rb values formed regional patterns such that postorogenic granites to the west are generally less evolved than those to the east. Additionally, the postorogenic granites along the eastern edge of the exposed shield are generally peraluminous, whereas those to the west tend to be peralkaline (Stuckless and others, 1985). These features have been attributed to a regionally variable protolith that formed by the mixing of continental sediments from the east and oceanic sediments from the west.

The REE data yield an east-west pattern similar to those for K/Rb, Rb/Sr, and degree of alumina saturation. Low La/Lu values are restricted to the eastern edge of the Shield and plutons with higher average La/Lu tend to be to the west; however, most of the highest La/Lu values are in the same east-west band as the yttrium and niobium lows (fig. 8). The pattern for europium anomalies is more similar to that generated by K/Rb and Rb/Sr data. Large negative europium anomalies are all along the eastern edge of the exposed Shield, whereas all but one pluton, for which the average europium anomaly is slightly positive to slightly negative, is in the western part of the study area (fig. 9). Data for Jabal Zayd constitute the only exception to the Eu/Eu^* pattern, and as noted previously, this pluton may not be postorogenic.

Lindgren (1919) attributed the occurrence of ore deposits to an ore-forming process acting within a metalliferous province. These same general principles can be used to explain the observed regional variation in chemistry of the postorogenic granites. Chemical features that generally reflect degree of magmatic evolution, such as K/Rb, Rb/Sr, and Eu/Eu^* values, may be attributed to a general east-west change in the degree of protolith evolution such that the protolith to the east is more evolved than that to the west. Superimposed on this trend are the effects of magmatic processes that have fractionated geochemically similar elements.

The degree to which chemical features inherited from the protolith have been modified by magmatic processes cannot be evaluated with the present data. Small degrees of partial melting or large degrees of fractional crystallization can both cause features such as high Rb/Sr values, large negative europium anomalies, and low K/Rb values if feldspar is an important solidus phase. However, it seems too fortuitous that either or both effects should be of a regional nature as suggested by the plot of average Eu/Eu^* data (fig. 9). Small differences in degree of magma evolution between adjacent plutons or within individual plutons are probably best explained by differing amounts of fractional crystallization or differing degrees of partial melting, but the regional pattern more likely reflects a regional feature, such as gradations in the protolith chemistry.

The separation of geochemically similar elements may represent the effect of an aqueous or vapor phase that has an unusual chemistry, such as a large amount of flourine or chlorine. If so, anomalous trace-element ratios may provide a mechanism for the identification of plutons that have been acted upon by an ore-forming process. Collins and others (1982), have concluded that all A-type (anorogenic) granites are characterized by high contents of flourine or chlorine, and that complexing of these dissolved halogens with highly charged atoms (such as the REE's, yttrium, niobium, and tantalum) accounts for the anomalously high contents of these incompatible elements in most A-type granites.

Collins and others (1982) further suggest that evolution of A-type granites to peralkaline or peraluminous compositions is dependent on a chlorine dominance for the peralkaline compositions and a fluorine dominance for the peraluminous compositions.

Chlorine-dominated systems might reasonably develop in the western part of the area studied if the protolith were largely formed by oceanic sediment. An eastward gradation to continentally derived sediment might then yield a fluorine-dominated system. In either system, a halogen-rich aqueous phase could evolve and transport metals of economic interest. Differences in ability to complex with this aqueous phase for elements that are otherwise similar might then produce anomalous ratios as evidence for the existence of an ore-forming process.

Examination of the data in table 6 shows that most plutons that have anomalous ratios also have a large range of ratios. This large range could result from a process that did not act uniformly over an entire crystallizing pluton. Intensive parameters should be fairly uniform throughout a single magma chamber, and therefore crystal-liquid fractionation would not be expected to produce highly variable ratios. In contrast, the distribution of an aqueous phase might well be nonuniform. Thus, the large range and anomalous absolute values may both be diagnostic features of mineralized plutons.

SUGGESTIONS FOR FURTHER WORK

All of the plutons listed in table 6 seem to merit some type of further work. However, most of these plutons have been studied to some degree by standard field techniques and mineralized areas have been found only at Jabal as Silsilah and Baid al Jimalah. It may be that mineralizing solutions left the plutons prior to deposition of dissolved metals or that erosion has removed any mineralized portions of the plutons. Alternatively, mineralized areas may exist in the subsurface, and consequently, geophysical techniques would be needed to locate them.

The recommendations for further work on the plutons listed in table 6 are based on an untested theory; therefore, research should be done to test it's validity. The first step should be to verify the anomalous ratios noted in this report by use of other analytical techniques. Re-analysis by ICP, for example, would reduce the analytical error for yttrium and niobium, and thus might more clearly define anomalous and normal values. Furthermore, analyses for all elements by a single dissolution would eliminate splitting errors.

Once the anomalous ratios for the Arabian granites have been determined more accurately, similar anomalies, both in terms of absolute values and range within similar plutons, should be looked for in areas with mineable deposits. Finally, a program of laboratory experiments should be initiated to provide an explanation for the fractionation of the geochemically similar elements and to assist in the development of a model for ore genesis.

DATA STORAGE

Data and work materials used in preparation of this report are archived as Data-File USGS-DF-06-6, which is stored at the office of the U.S. Geological Survey Mission in Jiddah, Saudi Arabia.

No new mineral localities resulted from this work, and therefore no Mineral Occurrence Documentation System (MODS) entries were prepared. No other data for the samples used in this study are available in RASS. However, reports on other analytical work done on samples described here are in preparation or referred to in the analytical procedures section.

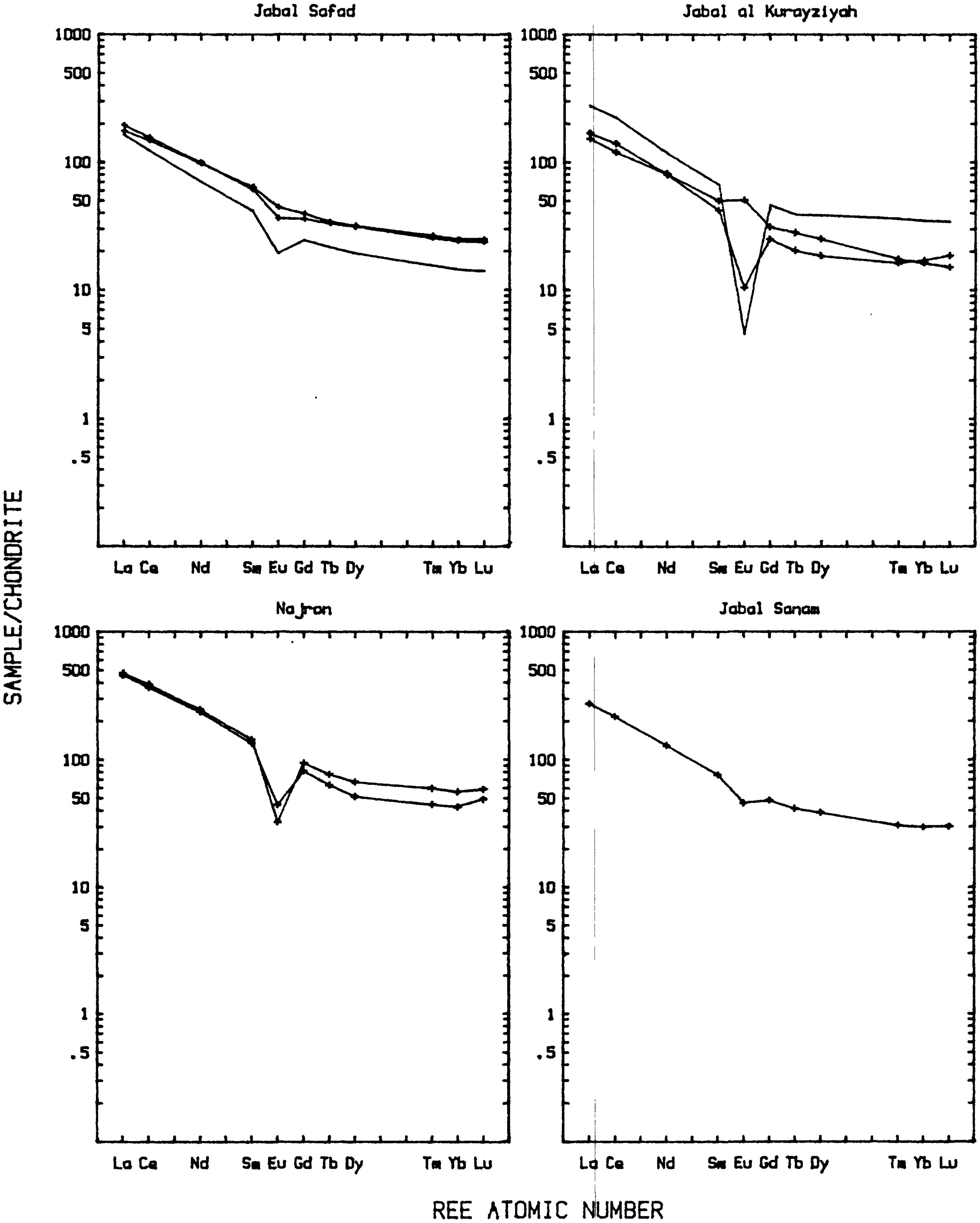


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite from the eastern Arabian Shield, Kingdom of Saudi Arabia. Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

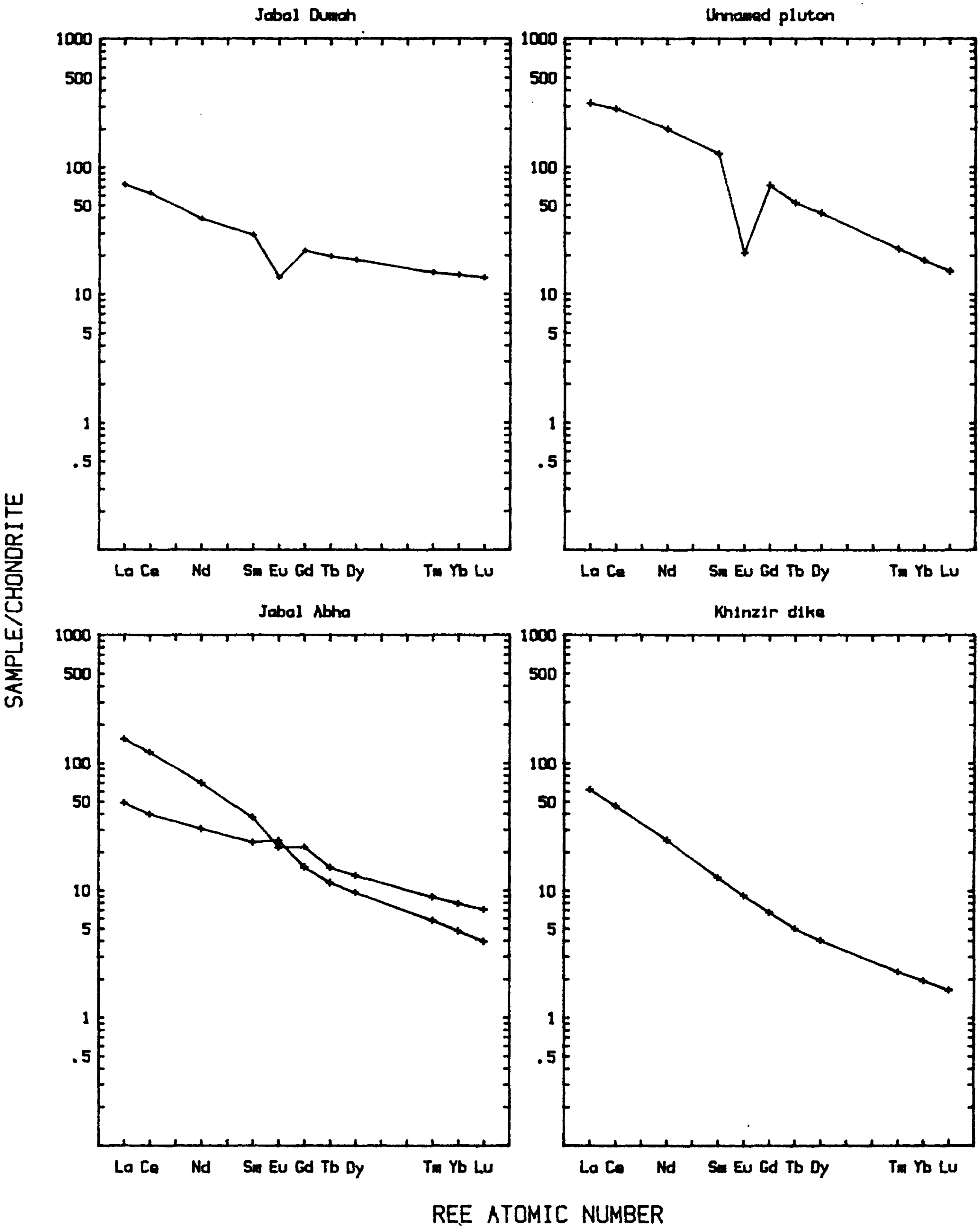
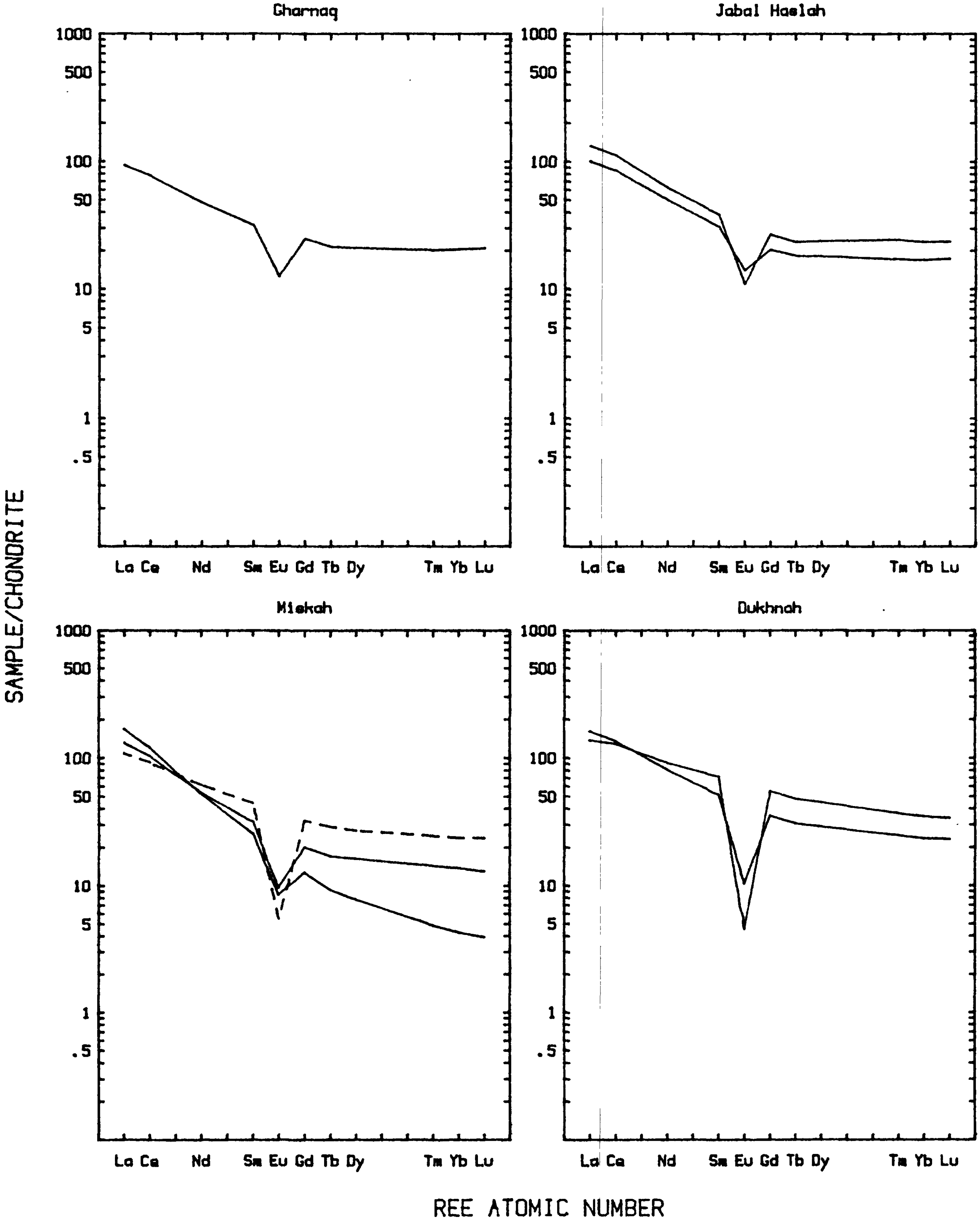


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*



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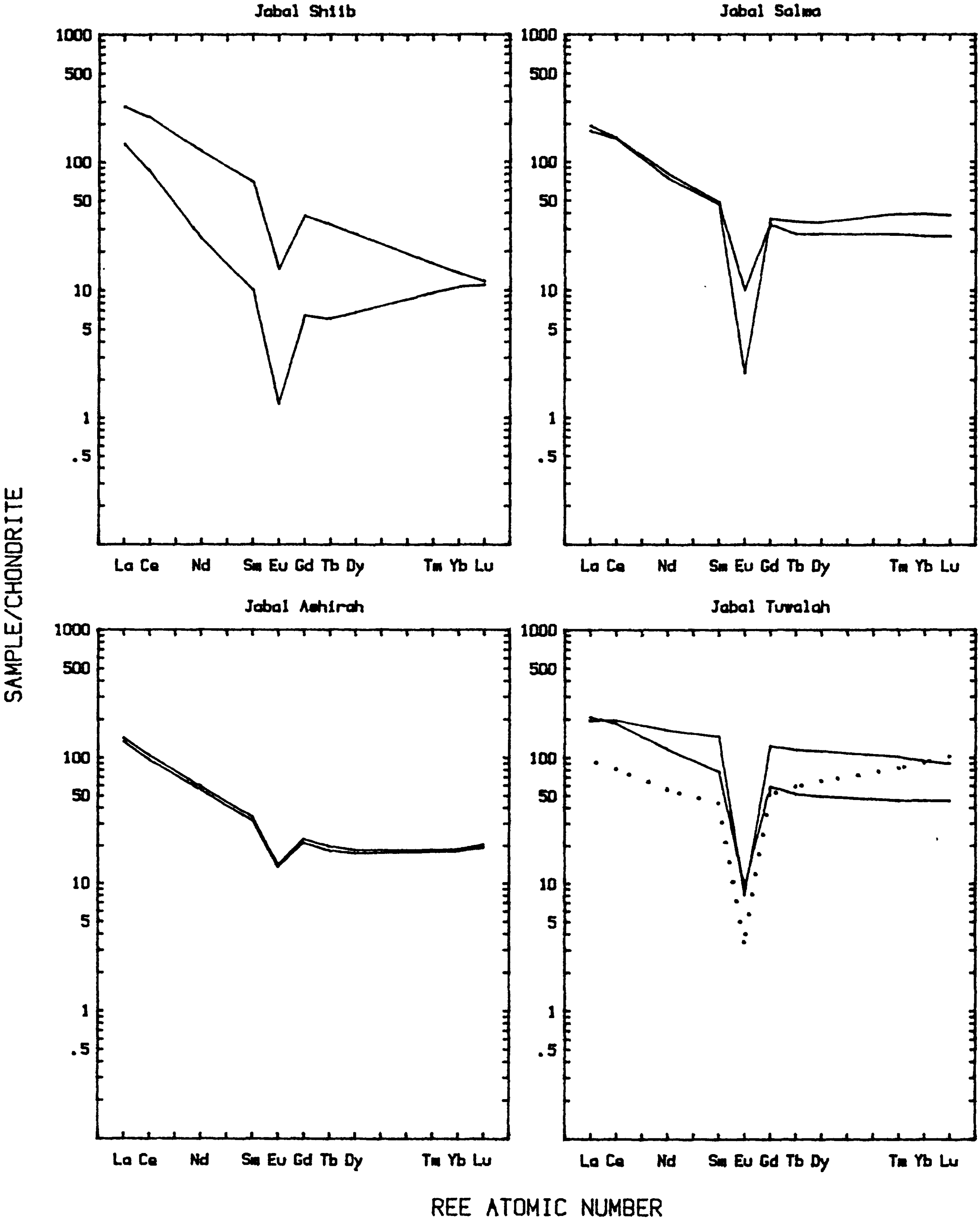


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

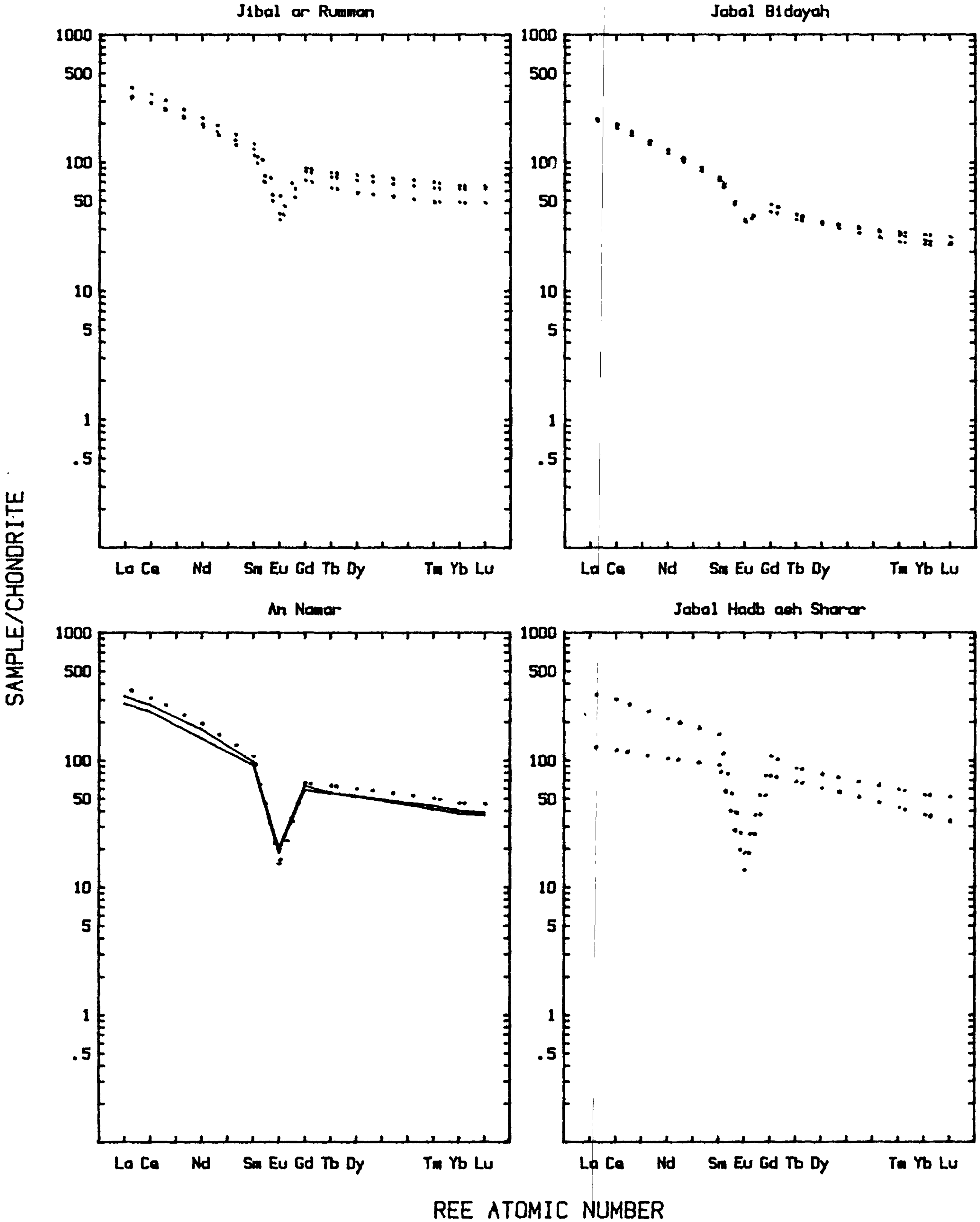


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

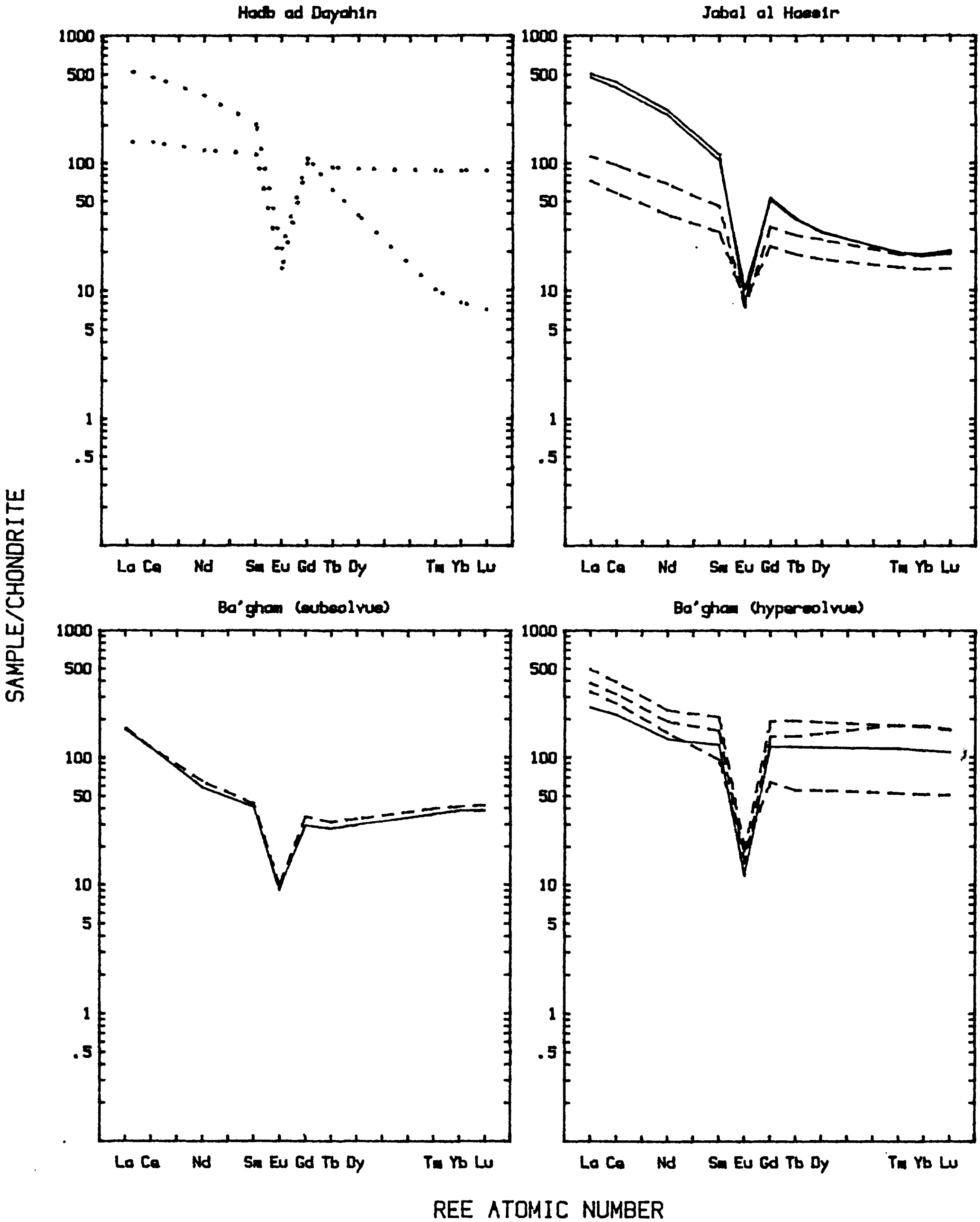


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

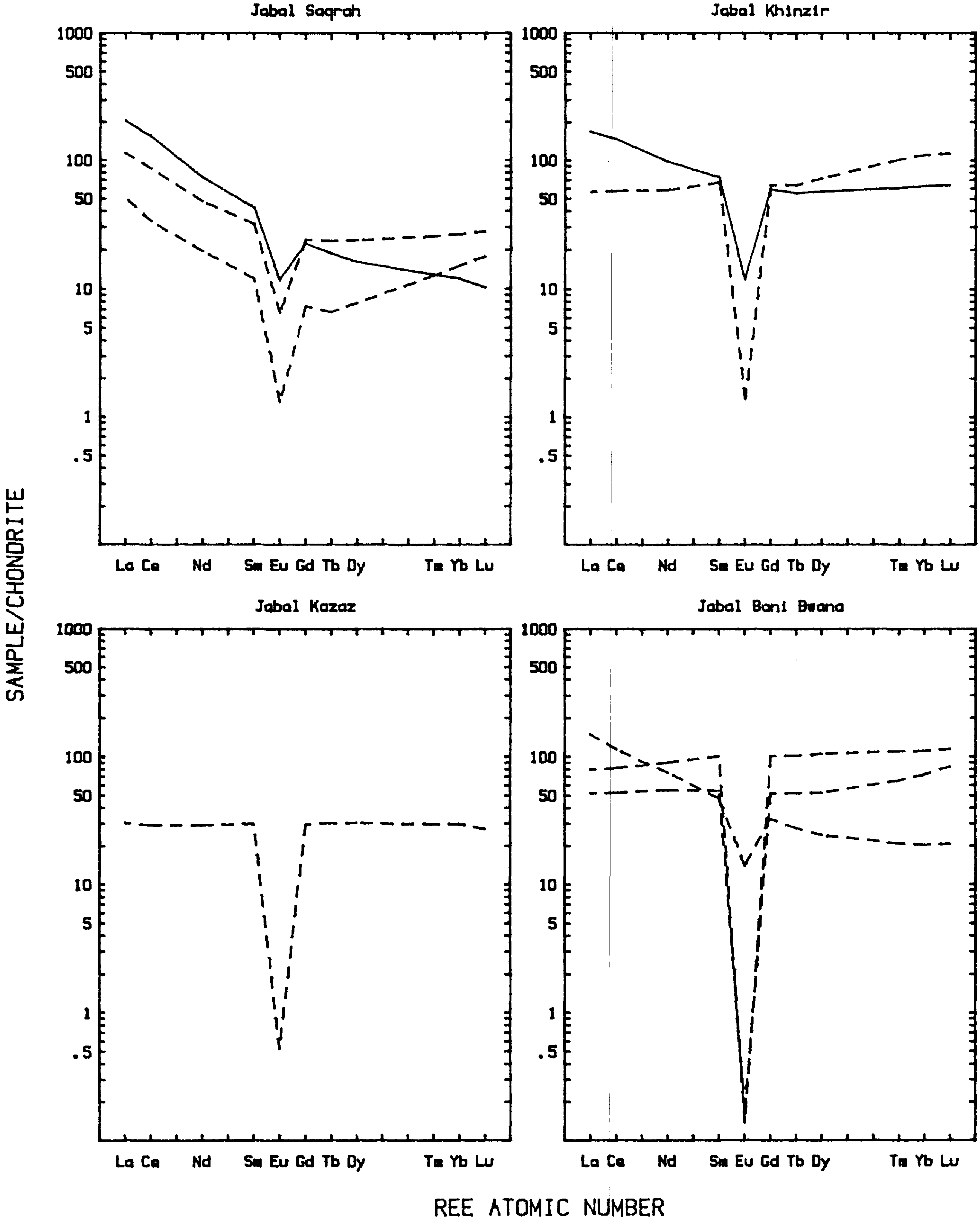


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

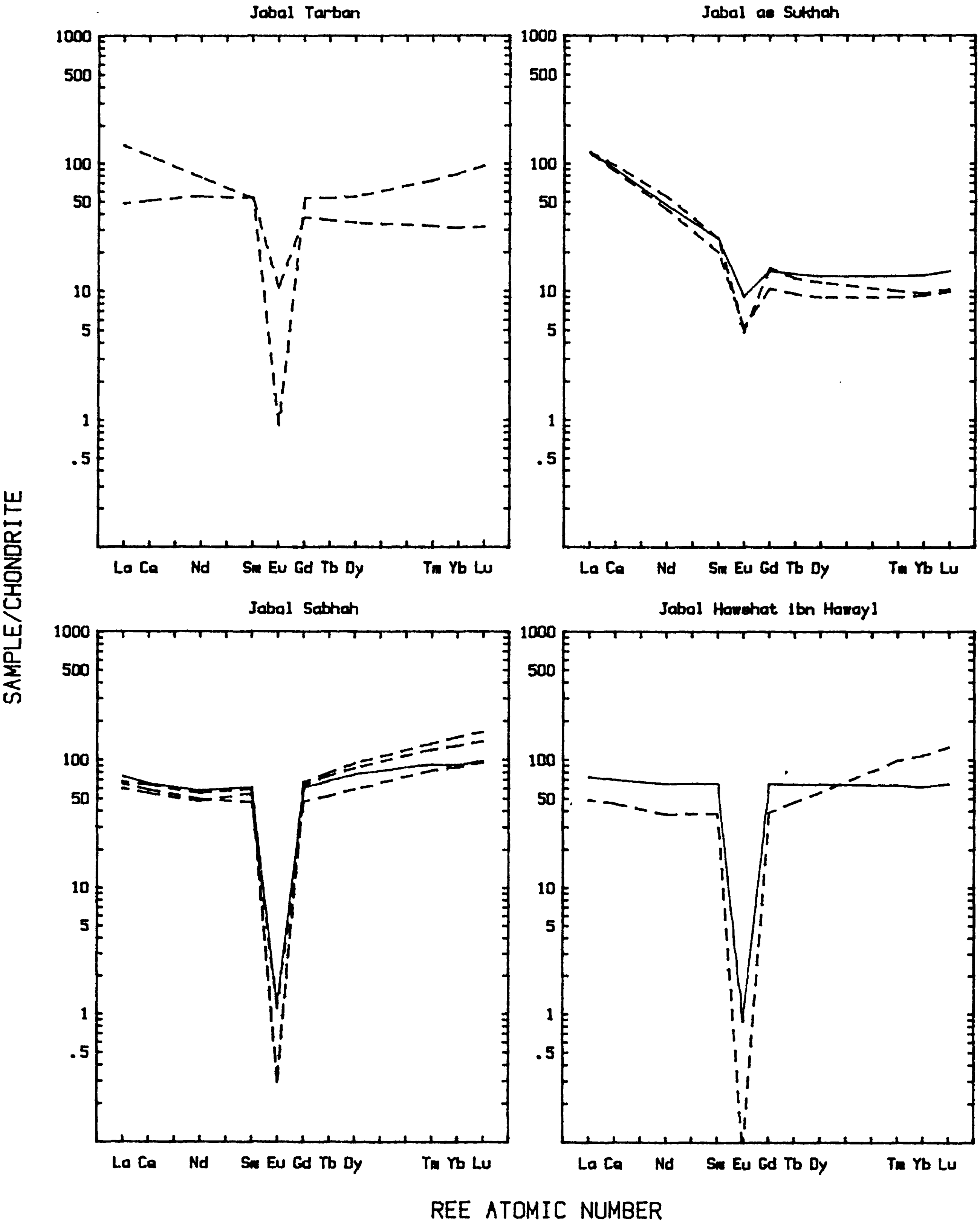


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

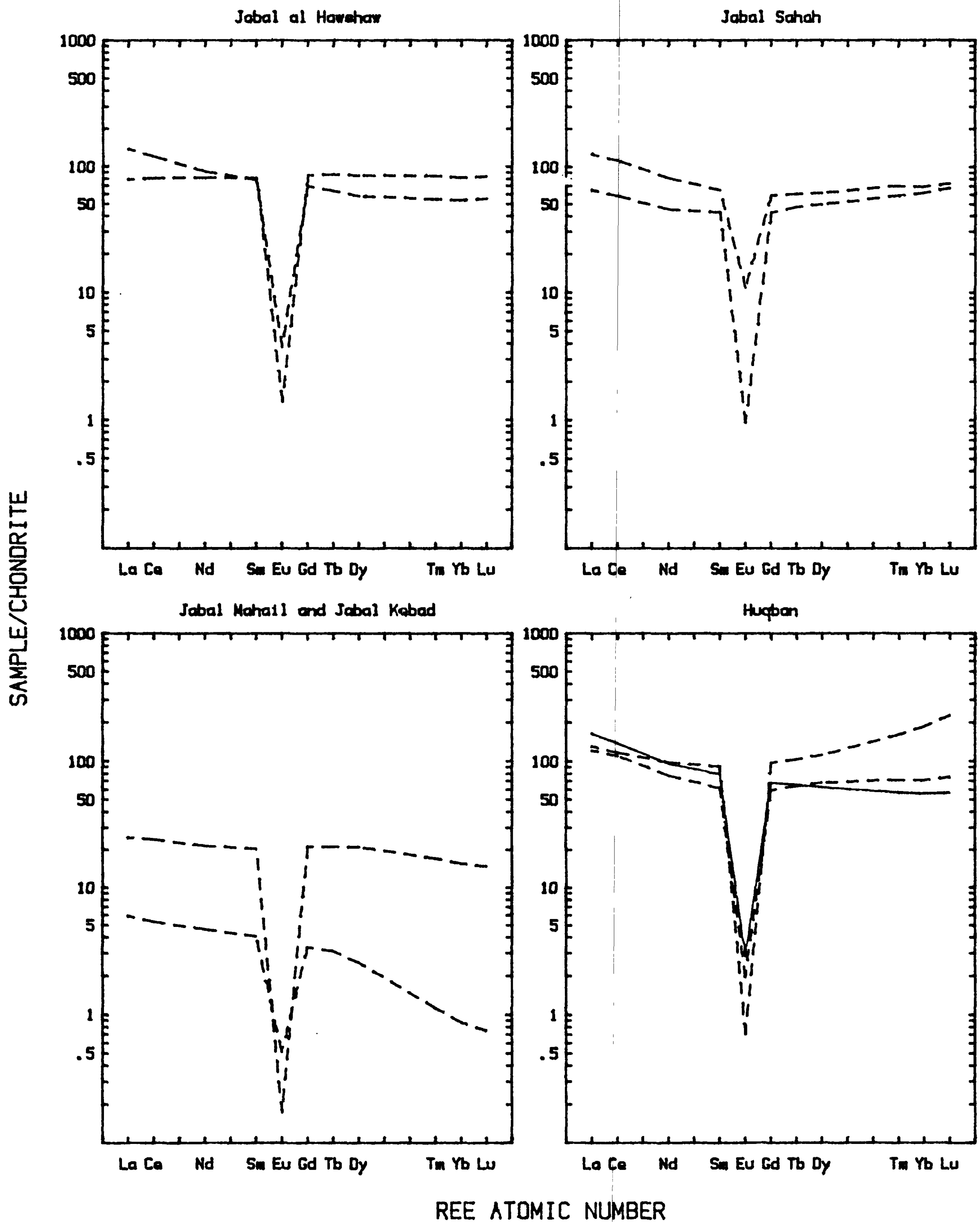


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*

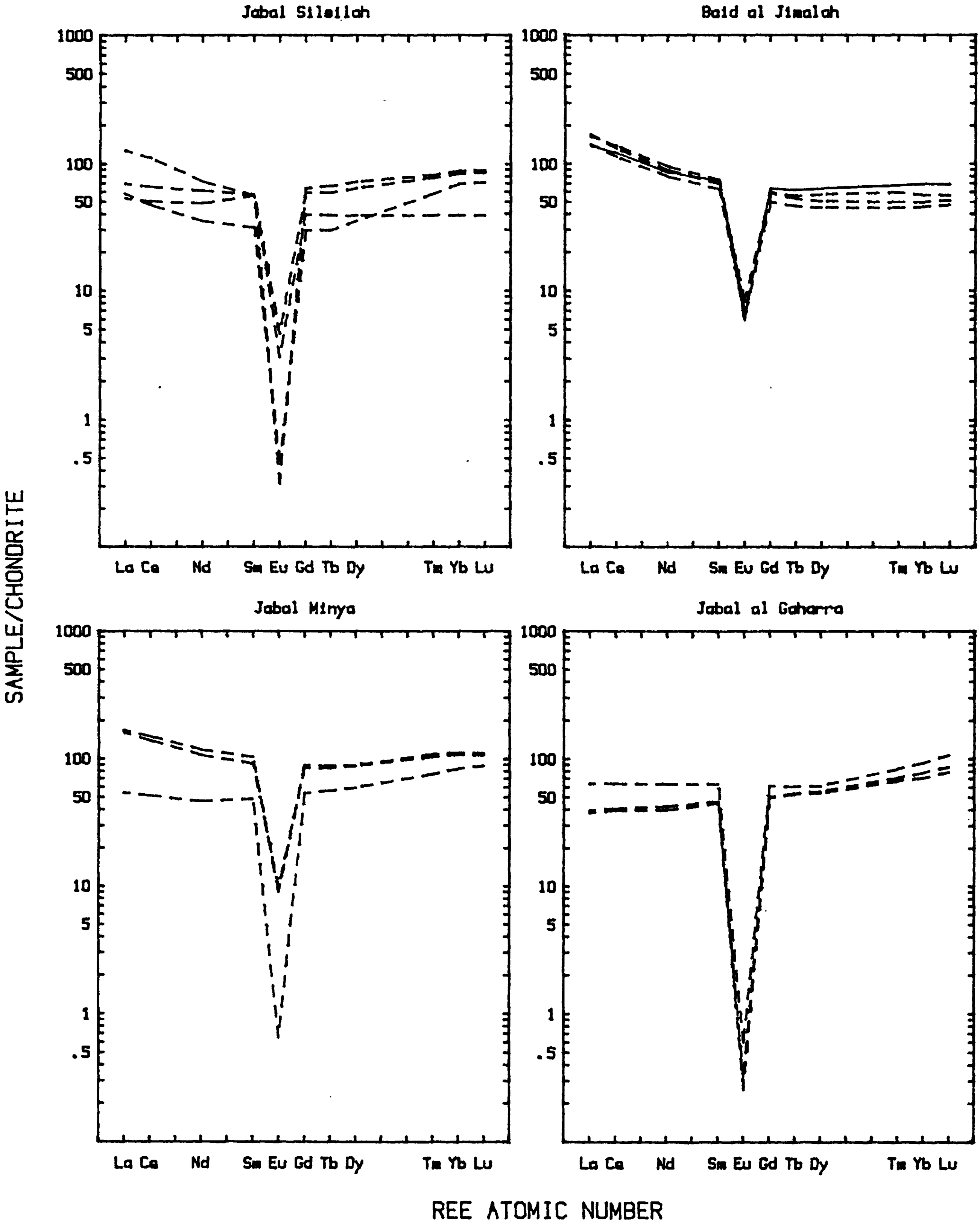
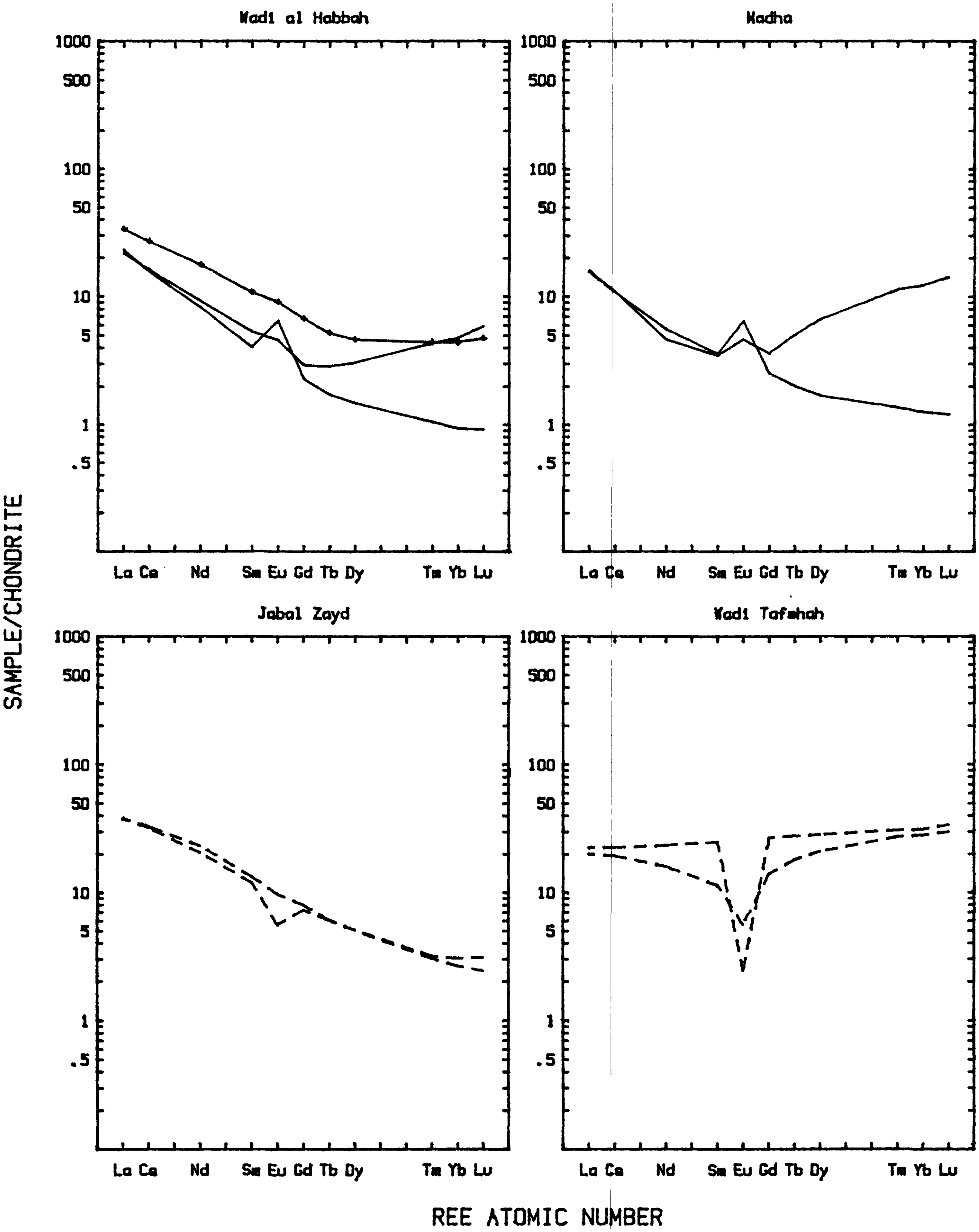


Figure 1.--*Chondrite-normalized rare-earth-element diagrams for samples of postorogenic granite*--Continued. *Solid lines with pluses represent metaluminous to weakly peraluminous samples for which silica is less that 70 percent. Dotted lines represent peralkaline samples. Dashed lines represent strongly peraluminous samples.*



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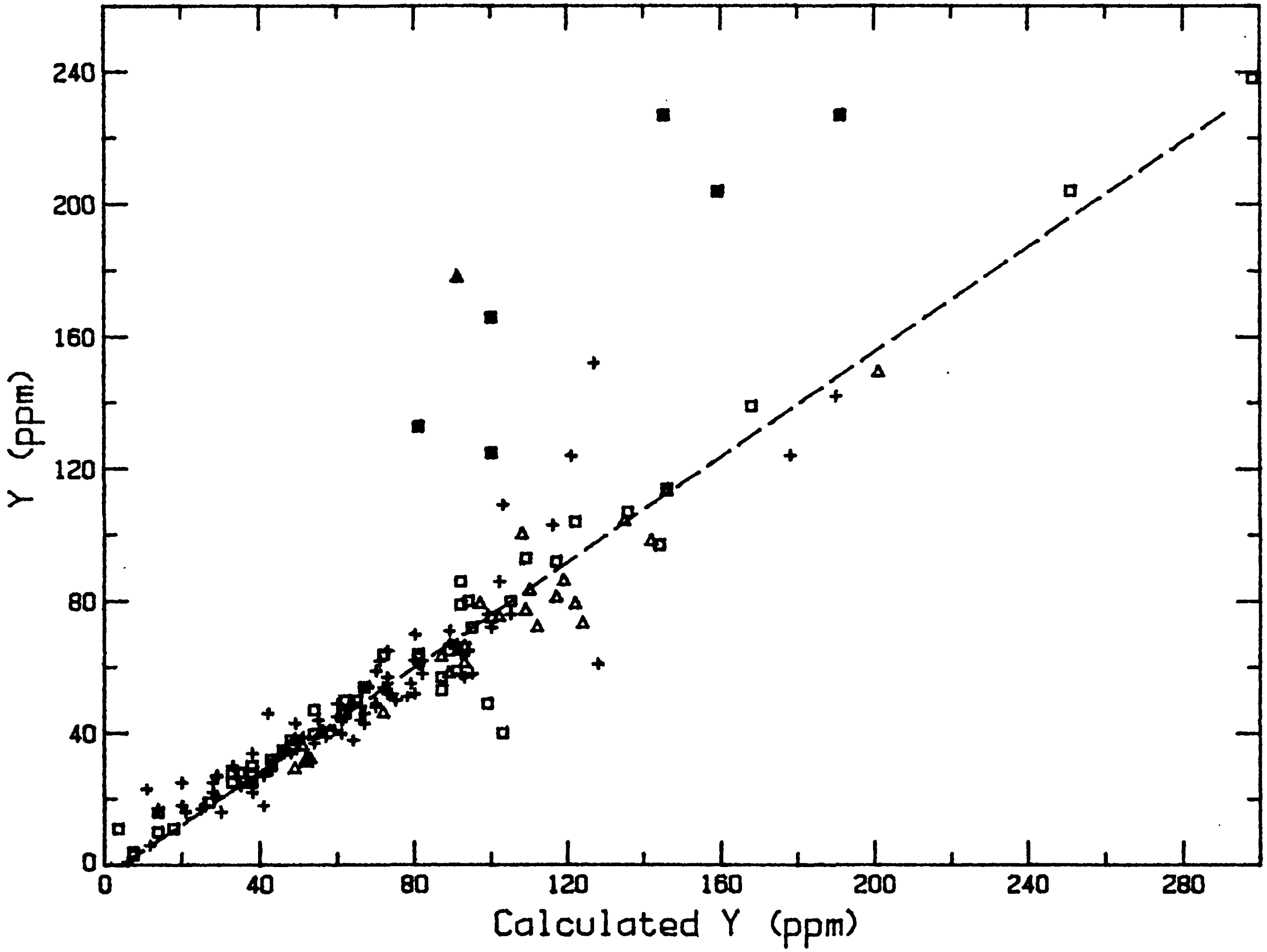

Figure 2.--*Plot of yttrium values versus calculated yttrium (on the basis of heavy rare-earth-element contents) for samples of postorogenic granite from the eastern Arabian Shield, Kingdom of Saudi Arabia. Dashed line represents the least squares fit to the data excluding solid symbols and the three pluses that plot furthest above the regressed line. Pluses represent metaluminous to weakly peraluminous samples. Triangles represent peralkaline samples. Squares represent peraluminous samples.*

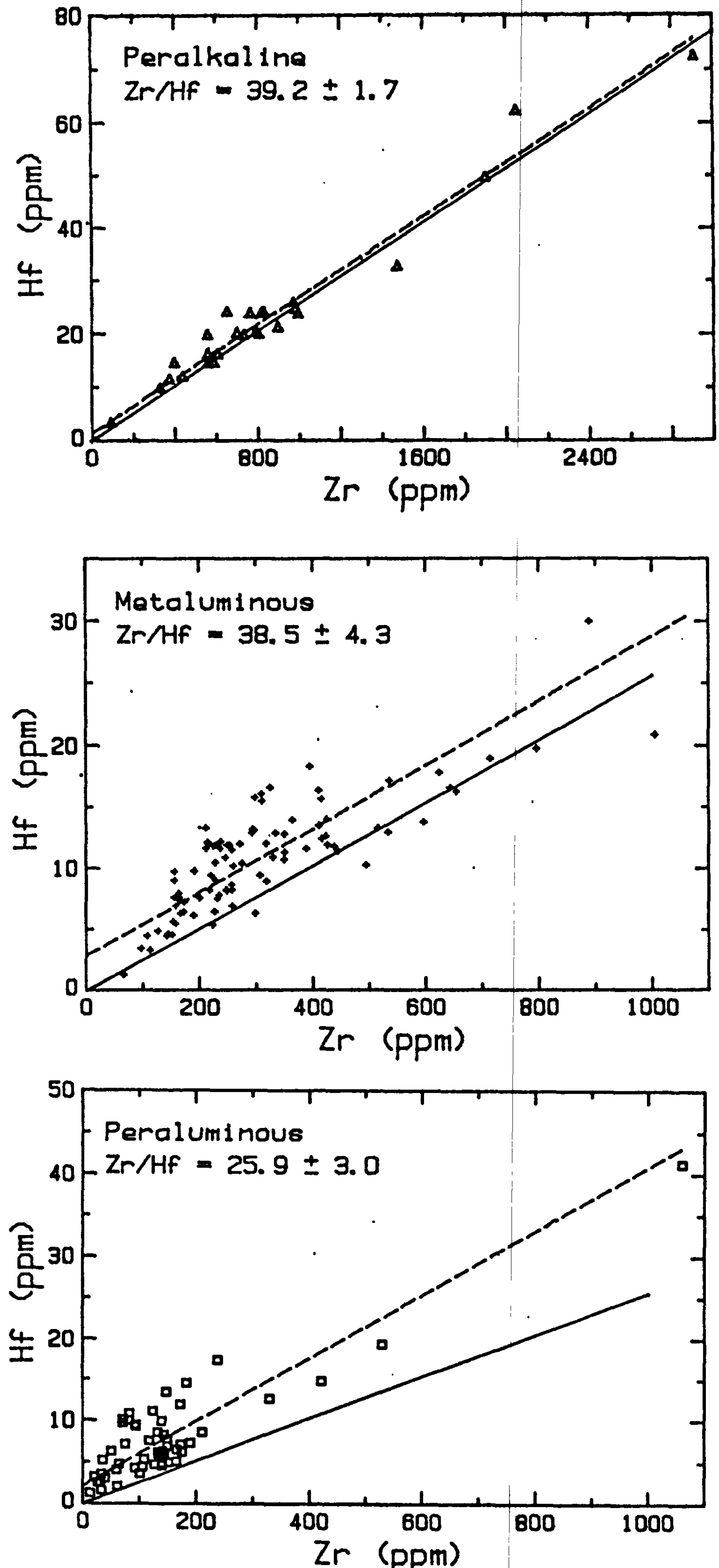

Figure 3.--*Plots of hafnium versus zirconium for samples of postorogenic granite from the eastern Arabian Shield, Kingdom of Saudi Arabia. Dashed lines represent the least squares fits to the data, and the solid lines represent a Zr/Hf value of 39.*

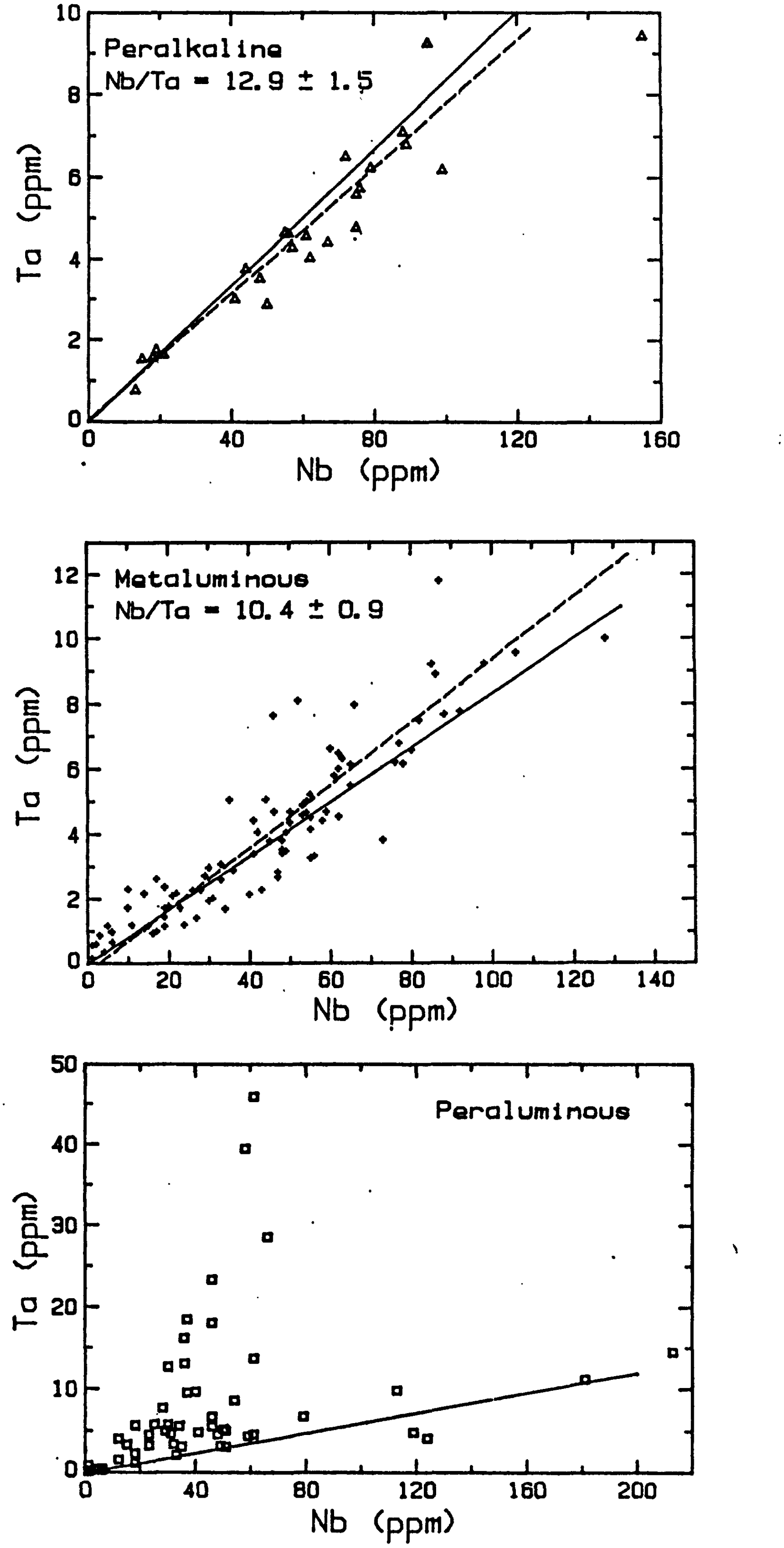

Figure 4.--*Plots of tantalum versus niobium for samples of postorogenic granite from the eastern Arabian Shield, Kingdom of Saudi Arabia. Dashed lines represent the least squares fits to the data, and the solid lines represent a Nb/Ta value of 12.*

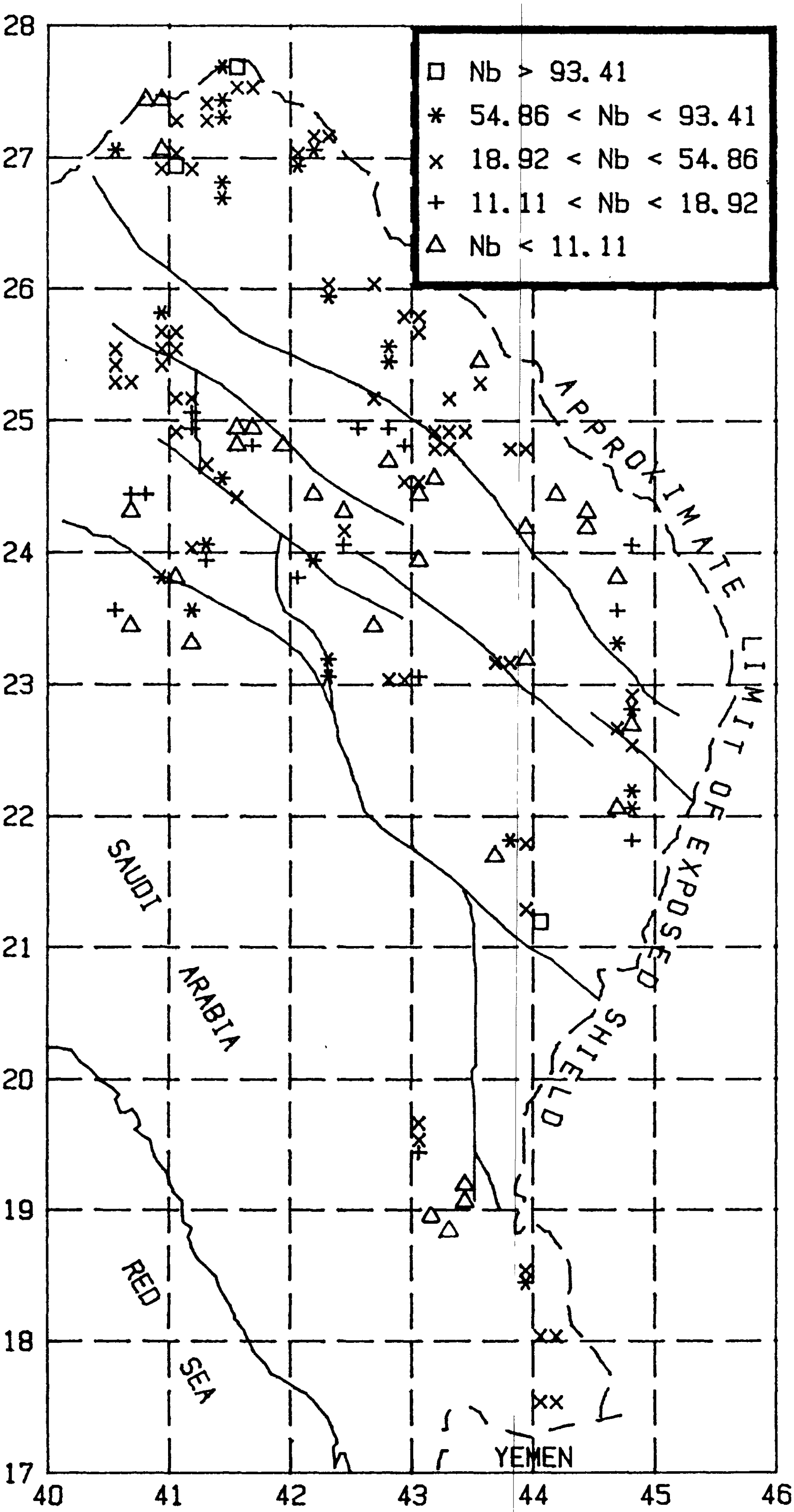

Figure 5.--*Map of the Eastern Arabian Shield showing approximate location of Najd faults and niobium concentrations averaged over 7.5 minute areas, relative to geometric mean and deviation.*

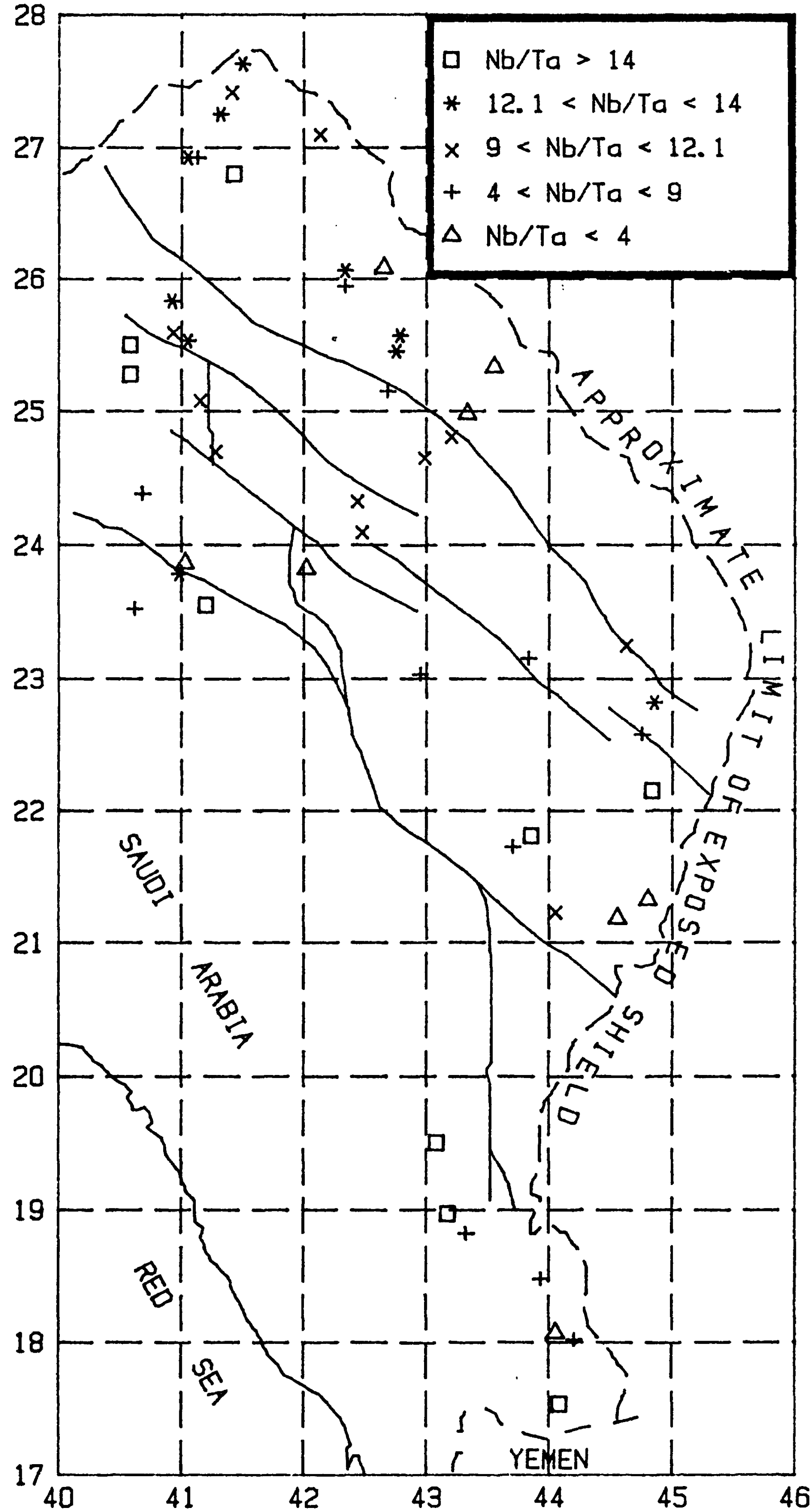

Figure 6.--*Map of the eastern Arabian Shield showing approximate location of Najd faults and Nb/Ta values averaged by pluton.*

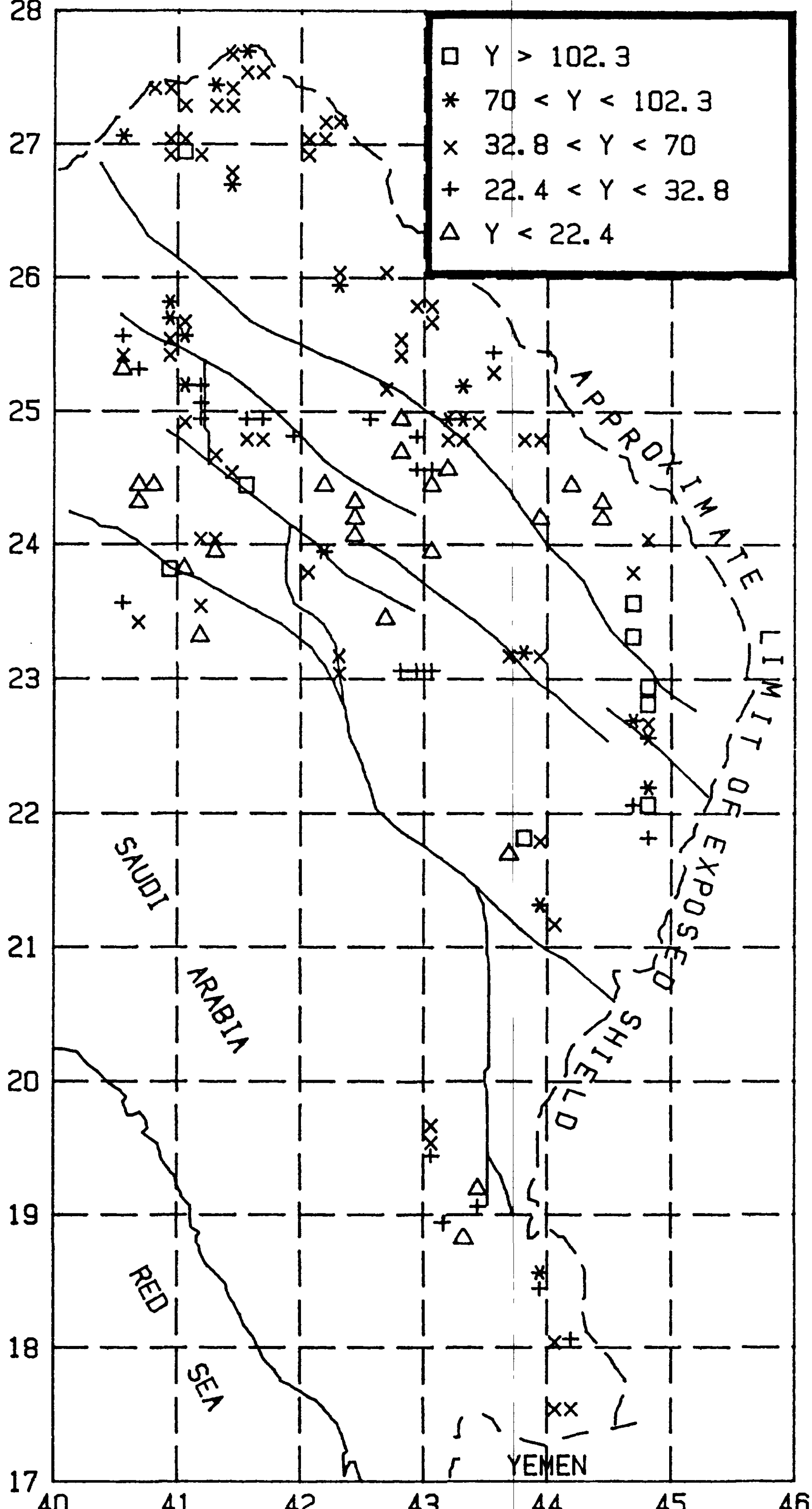

Figure 7.--*Map of the eastern Arabian Shield showing approximate location of Najd faults and yttrium concentrations averaged over 7.5 minute areas, relative to geometric mean and deviation.*

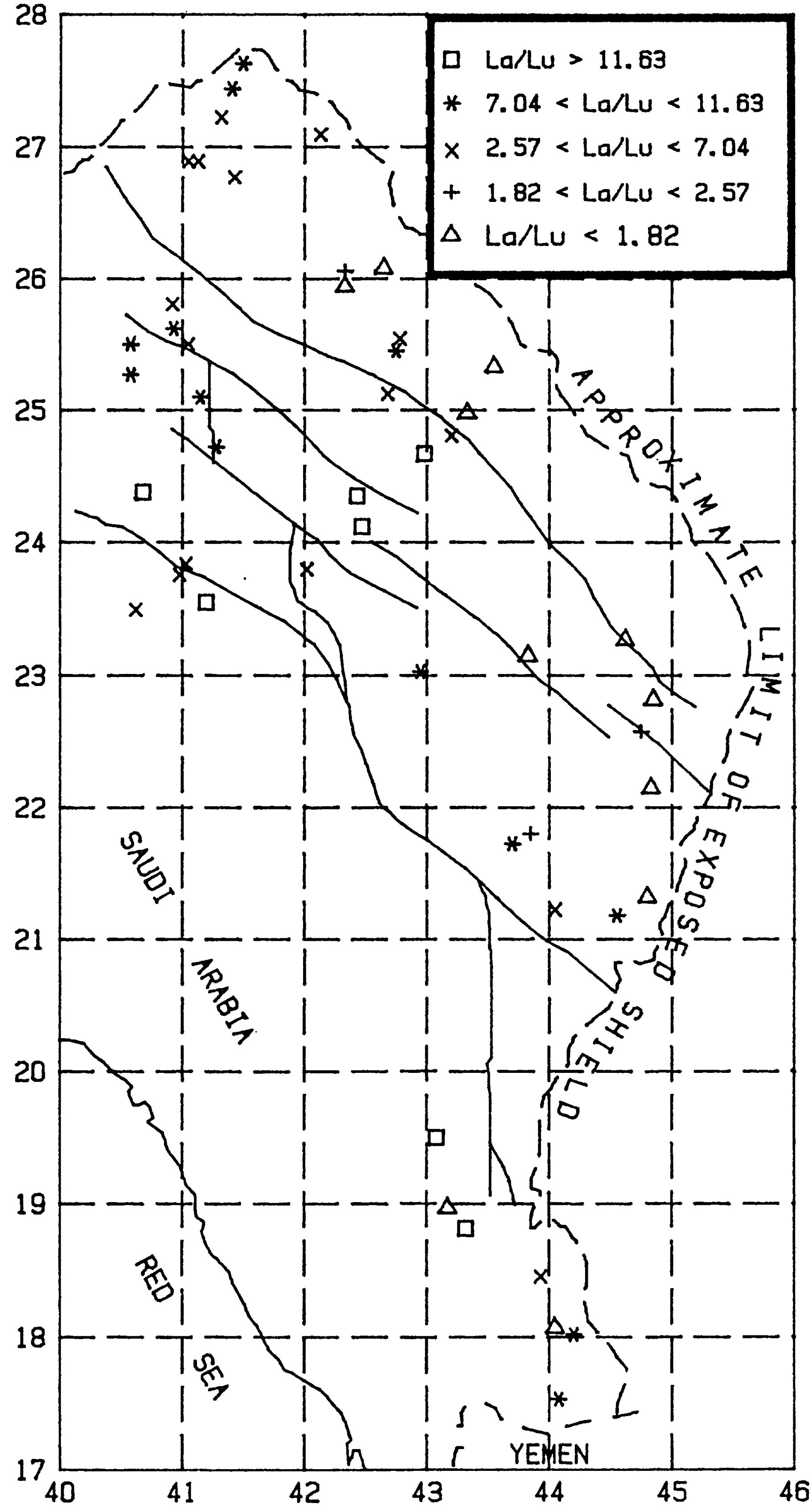

Figure 8.--*Map of the eastern Arabian Shield showing approximate location of Najd faults and chondrite-normalized La/Lu values averaged by pluton.*

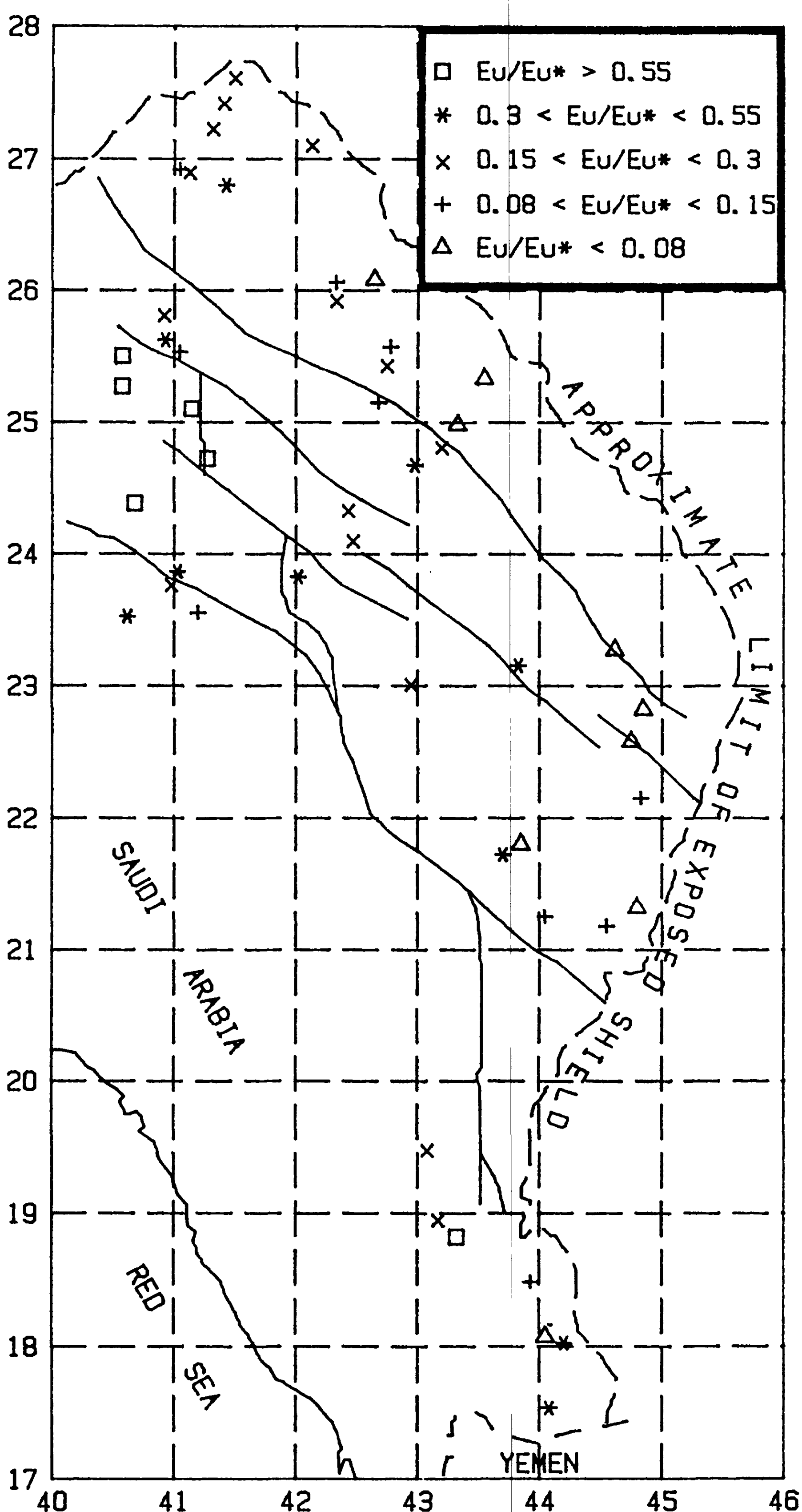

Figure 9.--*Map of the eastern Arabian Shield showing approximate location of Najd faults and europium anomalies averaged by pluton.*

Table 1.--Rare-earth-element concentrations (in parts per million) for granitic rocks from the Arabian Shield, Kingdom of Saudi Arabia

SAMPLE	La	Ce	Nd	Sm	Eu	Gd	Tb	Dy	Tm	Yb	Lu
Jabal Tuwalah											
155042	23.4	52.2	26.5	6.69	.202	10.4	2.21	16.6	2.12	15.1	2.6
155047	51.2	119	55.6	12	.553	12.2	1.94	12.6	1.18	7.58	1.16
155053	47.6	126	78.4	22.8	.472	25.5	4.36	28.9	2.63	15.6	2.29
An Namar											
155056	88	196	90.7	16.5	.883	13.5	2.36	15.2	1.28	7.54	1.15
155058	68.1	154	70.5	14.2	1.08	12	2.08	13.4	1.13	6.62	.979
155059	78	174	83.2	15.2	1.19	13	2.09	13.2	1.06	6.29	.94
Jabal al Kurayziyah											
155079	37.5	76.6	38.5	7.76	2.94	6.4	1.06	6.41	.452	2.7	.386
155080	41.3	89.5	38.2	6.55	.607	5.13	.761	4.73	.418	2.83	.476
155083	68.1	143	56	10.4	.267	9.55	1.47	9.87	.942	5.83	.88
Jabal Safad											
155086	43.2	94.2	46.5	9.91	2.6	8.11	1.29	8.11	.69	4.12	.64
155087	47.7	100	47.2	9.51	2.13	7.4	1.25	7.97	.654	4.01	.607
155088	40.2	78.5	33.5	6.43	1.12	5.03	.812	4.93	.399	2.4	.357
Jabal Bidayah											
155095	54.9	122	58.4	11.3	1.99	8.37	1.33	8.24	.609	3.73	.573
155097	53.2	117	55.3	11	1.97	9.51	1.46	8.53	.728	4.45	.657
155098	54.3	126	59.1	11.7	2.05	9.46	1.45	8.6	.684	4.04	.581
Jibal ar Rumman											
155148	80.3	186	92.8	19.3	2.27	17.3	2.87	18.3	1.61	10.1	1.57
155151	97	219	104	21.3	3.12	18.3	3.11	20.2	1.78	10.8	1.65
155154	81.3	184	89.4	17.2	2.03	14.7	2.36	14.6	1.26	7.95	1.22
Jabal Salma											
155172	47.4	100	38.8	7.5	.583	6.7	1.03	6.98	.706	4.38	.672
155177	43.3	97.8	35.7	7.23	.131	7.42	1.29	8.54	1.01	6.54	.978
Ba'gham (hypersolvus)											
155190	121	250	112	32.1	1.12	39.2	7.32	48.07	4.58	28.8	4.16
155196	60.7	139	66.5	19.4	.685	24.9	4.57	30.48	3.02	18.8	2.78
155198	94.1	202	91.1	25	.859	29.94	5.47	38.94	4.59	29.5	4.21
155208	80.6	178	74.2	14.8	1.07	13.2	2.09	14.06	1.35	8.49	1.29
Ba'gham (subsolvus)											
155192	40.7	76.4	27.9	6.36	.529	6.03	1.04	7.53	.921	6.35	.976
155205	42.1	76.6	31.2	6.72	.577	7.09	1.17	8.37	1.02	6.79	1.07
Jabal Tarban											
155500	11.8	32.4	26.1	8.22	.053	10.9	1.98	13.9	1.88	13.7	2.3
155504	34.2	73.6	36.9	8.2	.616	7.72	1.34	8.73	.83	5.14	.758
Jabal as Sukkah											
155506	30.1	61.4	25.9	3.99	.279	3.1	.47	2.96	.258	1.59	.247
155507	29.8	54.7	20.6	3.09	.305	2.14	.357	2.26	.23	1.52	.237
155510	30.2	57.2	22.3	3.96	.525	2.94	.512	3.29	.335	2.19	.343
Jabal Sabhah											
155511	16.6	41	26.1	9.1	.018	13.6	2.97	23.7	3.4	24.7	3.93
155512	14.7	35.3	22.5	8.46	.017	12.9	2.81	21.8	3.06	21.1	3.31
155515	18.3	42	27.3	9.44	.068	12.3	2.55	19.5	2.36	15	2.32
155516	16	37.6	23.5	7.24	.064	9.59	1.95	15	2.11	14.4	2.28
Jabal Hawshat ibn Hawayl											
155519	18.1	45.1	31.1	10.1	.051	13.4	2.43	16.5	1.64	10.2	1.56
155520	12	29.3	17.9	5.88	.005	7.91	1.76	14.2	2.53	17.9	3.01
Jabal Mahail											
155533	6.2	15.6	10.3	3.18	.01	4.34	.8	5.39	.44	2.58	.356

Table 1.--Rare-earth-element concentrations for granitic rocks--Continued

SAMPLE	La	Ce	Nd	Sm	Eu	Gd	Tb	Dy	Tm	Yb	Lu
					Jabal al Hawshaw						
155523	33.9	77.3	43.6	12.2	.217	14.3	2.39	14.8	1.41	8.86	1.32
155524	19.3	51.5	38.8	12.6	.081	17.5	3.27	21.7	2.18	13.5	2
					Jabal Sahah						
155526	15.9	37.4	21.6	6.64	.056	8.68	1.77	12.6	1.5	10.2	1.61
155528	30.9	72	38.8	10.1	.636	12	2.26	15.6	1.81	11.5	1.77
					Jabal Kebad						
155535	1.45	3.41	2.21	.63	.03	.687	.117	.649	.029	.144	.018
					Huqban						
155536	29.9	70.4	36.9	9.53	.114	12.1	2.39	17.3	1.83	11.7	1.8
155537	32.2	75	46.8	14.1	.041	19.9	3.87	28.5	4.13	30.7	5.44
155538	40.6	88.7	45.7	12.3	.165	14	2.47	16	1.46	9.21	1.35
					Najron						
155540	116	247	117	22.3	1.9	19.3	2.89	17.1	1.54	9.28	1.41
155543	112	235	112	20.8	2.58	16.7	2.39	13.1	1.15	7.08	1.18
					Jabal Ashirah						
155544	32.7	61.7	26.3	4.89	.783	4.32	.685	4.4	.456	2.96	.463
155545	35.2	67.2	28.1	5.26	.818	4.63	.744	4.7	.471	3.09	.486
					Jabal al Gaharra						
155546	9.63	26	20.1	7.15	.015	10.3	1.98	13.7	1.72	11.7	1.89
155547	9.26	25.1	18.8	6.9	.019	10.1	2.01	14.2	1.83	13	2.08
155549	15.7	41	30.1	9.78	.035	12.7	2.28	15.6	2.15	15.4	2.57
					Jabal Bani Bwana						
155553	12.7	33.4	26.2	8.42	.01	10.6	1.95	13.3	1.67	12	2
155554	19.5	51.9	42.7	15.5	.008	20.7	3.8	26.6	2.82	18.3	2.75
155556	36.7	73.1	35.9	7.35	.809	6.71	1.04	6.22	.536	3.37	.494
					Wadi al Habbah						
155557	5.64	9.93	3.91	.624	.377	.47	.065	.377	.027	.155	.022
155558	8.24	17.2	8.4	1.66	.529	1.38	.196	1.18	.114	.727	.113
155559	5.3	10.3	4.4	.828	.268	.601	.107	.774	.111	.787	.14
					Madha						
155560	3.81	6.94	2.66	.558	.376	.52	.076	.433	.035	.21	.029
155561	3.9	6.99	2.21	.538	.271	.742	.19	1.69	.29	2.03	.34
					Jabal Zayd						
155562	9.42	20.6	9.77	1.85	.324	1.49	.229	1.3	.082	.503	.074
155563	9.22	21.2	11.1	2.07	.568	1.64	.229	1.29	.078	.439	.058
					Wadi Tafshah						
155564	5.53	14.4	11.1	3.85	.141	5.47	1.04	7.2	.789	5.19	.815
155566	4.93	12.4	7.6	1.76	.327	2.85	.675	5.34	.7	4.66	.717
					Jabal al Hassir						
155568	124	279	125	18	.47	10.9	1.38	7.19	.507	3.05	.461
155570	17.7	36.9	18.7	4.4	.476	4.53	.714	4.43	.389	2.4	.352
155571	116	252	114	16.2	.595	10.5	1.35	7.31	.502	3.16	.487
155572	27.7	61.5	32.4	7.04	.431	6.43	1.01	6.33	.49	3.07	.47
					Jabal Silsilah						
181859	13	32.31	23	8.64	.0183	13.04	2.5	18.26	2.09	14.5	2.25
181871	17.1	41.91	29.2	8.78	.27	12.03	2.2	16.25	1.98	13.8	2.17
181964	31	71	34.5	8.72	.178	8.11	1.47	9.84	.999	6.44	.986
181872	14.14	29.98	16.71	4.81	.0276	6.1	1.11	8.93	1.48	11.4	1.82
					Jabal Dumah						
184387	18	40.1	18.7	4.51	.786	4.48	.741	4.74	.378	2.34	.343

Table 1.--Rare-earth-element concentrations for granitic rocks--Continued

SAMPLE	La	Ce	Nd	Sm	Eu	Gd	Tb	Dy	Tm	Yb	Lu
					Hadb ad Dayahin						
184004	129	301	161	30.7	1.22	22.1	2.26	9.65	.26	1.33	.181
184171	35.8	92.8	59.6	17.8	.855	20.1	3.43	22.7	2.22	14.1	2.19
					Jabal Hadb ash Sharar						
184009	80.8	190	99.8	24.4	1.07	21.9	3.24	19.7	1.5	8.79	1.3
184056	31.3	76.1	48.8	14.1	.781	15.4	2.52	15.3	1.08	6.06	.835
					Jabal Khinzir						
184080	41.4	94.1	46.7	11.4	.688	12.2	2.07	14.4	1.55	10.4	1.63
184420	13.73	36.48	27.65	10.3	.0806	13.08	2.4	18.27	2.59	18.2	2.86
184422	15.3	29.7	11.9	1.97	.535	1.38	.189	1.03	.059	.324	.042
					Miskah						
184242	26.7	59	29.4	6.89	.32	6.67	1.09	6.91	.634	3.96	.604
184427	32.3	66.2	25.6	4.91	.562	4.15	.646	4.2	.371	2.29	.329
184430	41.2	77	24.9	3.97	.493	2.61	.35	1.99	.125	.71	.0997
					Jabal Minya						
184359	41	96.9	56.2	16	.523	18.3	3.3	22.5	2.79	18.5	2.82
184424	39.4	89.6	50.9	14.2	.568	17.3	3.16	22.4	2.65	17.9	2.73
184425	13.2	33.1	21.9	7.43	.0381	10.9	2.09	15.1	1.94	13.8	2.24
					Jabal Abha						
184374	12	25.4	14.57	3.69	1.44	3.13	.433	2.46	.149	.793	.101
184375	37.8	78	33.2	5.8	1.27	4.5	.571	3.36	.229	1.31	.181
					Jabal Sanam						
184376	67.1	139	61.5	11.8	2.66	9.87	1.56	9.82	.788	4.94	.769
					Gharnaq						
184382	22.9	49.4	22.73	4.9	.733	5.1	.807	5.38	.519	3.38	.531
					Jabal Haslah						
184388	32.7	71.7	30	5.98	.639	5.57	.879	6.06	.632	3.89	.601
184389	24.8	54.6	24	4.81	.818	4.2	.69	4.64	.443	2.8	.44
					Jabal Saqrah						
184403	50	99.1	35	6.56	.681	4.59	.706	4.12	.333	2	.261
184404	12.5	21.2	9.29	1.86	.0764	1.51	.248	1.98	.325	2.49	.45
184406	27.9	55.22	22.6	4.88	.382	4.92	.874	6.01	.652	4.36	.704
					Dukhnah						
184431	40	87	38.7	7.96	.607	7.3	1.16	7.44	.64	3.9	.59
184432	33.9	82.7	43.7	11.1	.263	11.4	1.81	11.54	.948	5.81	.859
					Jabal Kazaz						
184435	7.48	18.7	13.76	4.62	.0305	6.03	1.14	7.74	.766	4.94	.695
					Jabal Shiib						
184439	34	53.7	12	1.55	.0751	1.31	.225	1.71	.245	1.76	.279
184441	67.9	144	58.1	10.8	.854	7.85	1.22	6.97	.415	2.26	.299
					Unnamed						
184442	77.9	184	95	19.7	1.22	14.7	1.96	11.03	.58	3.04	.382
					Baid al Jimalah						
889494	33.9	78.4	40.9	11.4	.343	13.19	2.32	16.17	1.73	11.5	1.75
893039	34.9	72.97	37.8	9.77	.362	10.25	1.73	11.44	1.14	7.5	1.2
893159	40.3	89.1	45.6	11.6	.416	12.15	2.08	14.48	1.52	9.39	1.43
893235	41.66	84.5	42.6	10.72	.49	12.11	1.98	12.96	1.27	8.2	1.31

Table 2.--Contents of miscellaneous trace elements (in parts per million) for samples of postorogenic granites from the Arabian Shield, Kingdom of Saudi Arabia

SAMPLE	Cs	Ba	Ta	Hf	Sb	Sc	Co	Y	Nb
				Jabal Aban al Ahmar					
155019	2.07	50	7.08	23.9	1.07	.496	.213	83	88
155020	3.48	86	5.57	20	2.02	.742	.317	61	75
155021	1.4	234	3.43	12.6	.777	1.72	.481	45	48
155022	2.03	401	3.55	11.6	.793	3.55	1.09	41	48
155023	2.14	405	4.37	13.5	1.08	3.5	1.07	49	50
155024	3.02	359	2.69	5.4	.624	1.62	.627	46	47
155025	3.83	222	5.03	12	.538	1.63	.633	54	54
155026	2.52	126	5.22	10.2	1.04	1.09	.423	48	55
155027	3.75	202	4.7	11.3	.565	1.57	.58	43	50
155028	4.15	452	3.82	10.9	.759	3.08	.894	41	48
155029	1.42	313	2.89	7.82	.926	1.73	.602	29	36
				Jabal Qutn					
155030	1.77	84	3.1	8.49	.096	.395	.124	97	51
155031	5.55	249	2.3	7.58	.366	.506	.253	72	43
155032	9.66	33	6.8	7.98	.17	.963	.083	124	77
155033	10.1	153	5.22	5.95	.149	1.68	.182	80	50
155034	12.1	130	5.49	7.26	.229	1.69	.211	103	65
155035	10.4	268	3.39	4.93	.131	3.39	.526	54	32
155036	11	241	4.89	4.54	.202	3.3	.553	50	41
155037	14.5	212	5.58	6.45	.288	2.34	.53	72	46
155038	16.4	290	5.08	7.35	.609	3.03	.821	58	44
155039	17.5	36	7.65	11.6	.974	.494	.138	61	46
				Jabal Tuwalah					
155042	.758	47.1	4.41	19.6	.702	.417	.295	100	67
155047	1.29	181	2.28	14	.114	1.52	.83	51	28
155053	.984	25	4.7	30	.892	.147	.186	124	46
				An Namar					
155056	.776	152	3.75	20.2	.154	1.4	.56	66	44
155058	1.25	372	3.4	17.8	.174	2.61	1.33	58	41
155059	1.22	5.07	3.08	17.2	.211	3.48	2.9	52	33
				Jabal Awja					
155062	1.12	10	6.51	49.5	.242	.335	.124	113	72
155063	1.24	20	5.72	32.6	.555	.313	.142	104	76
155064	1.38	37	4.65	23.6	.207	.281	.111	75	55
155065	1.56	110	9.24	72.2	1.03	.893	.494	149	95
155066	1.1	16	1.64	16	.113	.223	.263	38	21
155067	.662	231	4.28	23.7	.128	2.46	1.17	79	57
155068	.797	44	1.58	9.73	.147	.326	.203	36	18
				Jabal al Kuraziyah					
155079	1.12	1270	1.43	6.35	.249	14.9	16.9	22	27
155080	.252	209	1.22	13.3	.204	7.33	2.04	21	24
155083	.92	39.3	4.56	16.4	.155	2.08	.305	40	62
				Jabal Safad					
155086	1.31	998	2.04	10.7	.393	10.3	4.45	38	31
155087	1.56	1010	1.95	9.44	.905	7.08	2.79	34	30
155088	2.71	470	2.28	8.24	.47	4.12	2.32	16	26

Table 2.--Contents of miscellaneous trace elements for postorogenic granites--Continued

SAMPLE	Cs	Ba	Ta	Hf	Sb	Sc	Co	Y	Nb
				Jabal Bidayah					
155095	.944	417	1.53	11.9	.228	5.78	1.05	29	15
155097	1.98	399	1.75	14.4	.204	5.18	1.46	32	19
155098	1.87	451	1.56	11.4	.153	6.04	2.02	31	18
				Jabal Aja					
155100	1.78	53	6.62	12.1	.272	.481	.335	49	60
155101	1.3	60	6.8	12.6	.213	.257	.24	64	79
155102	1.07	35	6.49	11.9	.165	.528	.312	65	62
155103	1.78	20	8.91	15.5	.091	.214	.15	64	86
155104	2.55	23	9.22	16.1	.399	.243	.149	67	85
155105	1.84	29	7.97	11.6	.356	.371	.207	57	66
155106	2.6	60	4.62	21.1	.205	.482	.149	63	56
155107	.802	25	6.57	15.7	.151	.323	.219	71	80
155108	.953	37	6.15	11.8	.153	.392	.258	62	78
155109	1.92	18	6.2	12.2	.137	.315	.198	54	76
155110	1.65	27	7.49	15.8	.146	.343	.169	58	82
155111	2.01	595	.515	5.95	.076	3.79	.96	30	6
155112	2.1	487	1.1	8.89	.129	2.14	.394	18	14
155113	1.07	775	1.19	11.9	.0859	4.09	1.17	25	15
155114	1.39	772	1.17	16.6	.0849	4.86	1.74	24	19
155115	1.33	56	7.77	13.1	.122	.385	.196	67	92
155116	.89	15	6.23	24.5	.078	.45	.15	79	79
155117	1.02	470	4.52	19	.123	3.83	.448	65	55
155118	1.59	80	6.32	11.9	.044	.724	.503	50	63
155119	1.18	28	9.24	16.6	.21	.313	.256	61	98
155120	1.67	31	9.57	18.4	.187	.627	.331	57	106
155121	2.27	24	6.13	11.9	.105	.568	.584	44	65
155122	2.14	40	3.79	11.5	.228	.472	.343	44	45
155123	1.14	109	5.8	13.2	.171	.746	.423	50	61
155124	1.42	20	4.66	9.82	.189	.641	.26	52	54
155125	.872	27	7.69	12.9	.078	.48	.24	70	88
155126	4.99	578	2.19	6.33	.158	2.07	1.44	22	22
155127	1.99	210	1.73	9.03	.135	.994	.75	27	23
155128	2.77	134	4.9	12	.2	.64	.439	48	53
155129	1.14	74	3.51	14.3	.087	.889	.323	46	48
155130	1.49	111	4.59	9.4	.1	.622	.332	45	53
155131	3.1	127	4.08	10.9	.13	.705	.464	39	49
155132	.886	181	3.5	10.4	.128	.937	.514	37	49
155133	1.42	162	4.44	12.9	.113	.861	.6	46	58
155134	1.06	163	4.69	14	.051	1.07	.621	52	59
155135	3.16	267	2.11	7.25	.266	.996	.69	25	33
155136	.838	50	4.77	14.5	.04	.331	.115	77	75
155137	1.6	652	3.33	16.3	.136	6.23	.768	55	56
155138	2.34	75	4.18	7.61	.424	.54	.31	39	55
155139	6.95	92	11.8	13.3	.907	.8	.394	62	87
155156	2.41	508	2.61	8.64	.08	2.34	1.98	34	33
155157	3.4	382	2.73	7.52	.195	1.98	1.34	38	29
155158	4.87	17	4.08	10.5	.242	.126	.118	54	42
155159	.949	117	6.18	19.8	.12	1.13	.513	81	99

Table 2.--Contents of miscellaneous trace elements for postorogenic granites--Continued

SAMPLE	Cs	Ba	Ta	Hf	Sb	Sc	Co	Y	Nb
			Jibal ar Rumman						
155148	.369	103	4.03	23.7	.116	.753	.456	72	62
155151	.595	500	4.56	24	.095	4.41	1.36	73	61
155154	.807	140	2.87	16	.24	.644	.386	58	50
			Jabal Salma						
155172	1.98	322	2.98	8.22	.084	2.66	1.3	32	30
155177	3.2	57	6.01	9.03	.291	1.01	.388	44	62
			Ba'gham (hypersolvus)						
155190	1.27	102	11.2	19.4	.8	.651	.498	238	181
155196	1.42	35	9.99	12.8	.308	.448	.329	142	128
155198	1.6	25	14.5	41.2	.357	.377	.27	204	213
155208	1.02	210	4.4	14.8	.124	.768	.346	57	59
			Ba'gham (subsolvus)						
155192	5.74	429	5.07	6.44	.314	2.64	1.06	43	35
155205	4.18	463	4.67	7.06	.493	2.72	1.69	40	31
			Jabal Tarban						
155500	11.5	45	13.8	9.93	.355	.92	.145	86	61
155504	3.29	371	3.22	5.92	.121	1.99	1.08	47	49
			Jabal as Sukkah						
155506	2.87	263	.252	4.35	.344	2.33	.637	11	2
155507	2.65	305	.454	3.6	.45	1.3	.574	16	4
155510	3.27	709	.669	4.58	.438	2.81	2.68	16	6
			Jabal Sabbah						
155511	17.1	32	5.81	10.8	.05	.188	.09	204	25
155512	11.1	15	6.7	11.1	.034	.245	.12	227	46
155515	4.93	15	3.84	9.75	.05	.389	.164	152	73
155516	8.45	23	4.59	9.85	.057	.559	.134	166	61
			Jabal Hawshat ibn Hawayl						
155519	2.43	10	2.85	7.62	.067	.059	.066	109	47
155520	10.3	25	9.91	14.5	.178	.057	.099	125	113
			Jabal al Hawshaw						
155523	11.8	56	4.56	5.29	.05	4.56	.369	79	23
155524	13.7	15	5.74	4.74	.067	4.61	.243	107	30
			Jabal Sahah						
155526	4.93	34	4.18	5.04	.258	1.02	.1	133	124
155528	4.72	288	4.57	7.53	.547	1.15	.453	75	48
			Jabal Mahail						
155533	9.56	32	5.69	2.6	.087	3.17	.1	28	18
			Jabal Kebad						
155535	5.81	15	7.8	1.26	.04	2.85	.085	11	28
			Huqban						
155536	6.45	26	4.85	11.9	.146	.05	.192	93	119
155537	3.06	10	5.05	17.4	.13	.112	.098	227	51
155538	4.07	40	3.28	9.78	.109	.144	.179	76	55

Table 2.--Contents of miscellaneous trace elements for postorogenic granites--Continued

SAMPLE	Cs	Ba	Ta	Hf	Sb	Sc	Co	Y	Nb
				Najron					
155540	1.55	438	2.17	19.8	.441	1.66	.69	76	40
155543	1.13	641	1.7	20.9	.11	2.34	.997	62	34
				Jabal Ashirah					
155544	2.14	413	2.39	6.52	.193	2.76	1.72	25	19
155545	2.39	425	2.4	6.92	.192	3.16	1.88	27	19
				Jabal al Gaharra					
155546	4.19	28	16.2	3.58	.365	1.11	.356	65	36
155547	7.54	34	23.4	6.26	.272	.955	.16	66	46
155549	14.7	30	45.9	5.22	.274	.925	.358	40	61
				Jabal Bani Bwana					
155553	2.55	52	12.7	10.1	.03	.132	.11	53	30
155554	5.9	64	13.1	13.4	.028	.185	.099	139	36
155556	3.37	759	2.28	6.18	.111	2.54	1.33	28	18
				Wadi al Habbah					
155557	.219	462	.037	2.12	.028	1.54	2.11	1	1
155558	.492	502	.26	2.09	.01	5.29	5.65	6	2
155559	.178	762	.039	1.31	.055	1.11	.146	1	1
				Madha					
155560	.644	826	.087	1.9	.031	1.44	.952	1	1
155561	.283	1200	.024	1.47	.044	2.88	.16	12	2
				Jabal Zayd					
155562	.623	1150	.269	1.61	.038	1.69	.6	3	2
155563	1.04	869	.161	2.1	.059	3.31	4.22	4	1
				Wadi Tafshah					
155564	.241	70	.285	4.08	.01	1.41	.134	35	6
155566	.04	313	.108	2.54	.36	1.19	.057	28	1
				Jabal al Hassir					
155568	.518	77	1.01	13	.085	2.98	.311	29	17
155570	3.82	296	1.56	4.27	.102	1.84	.243	19	12
155571	.521	161	.952	13.8	.091	3.35	.496	29	16
155572	.472	252	1.16	4.85	.038	.897	.251	30	18
				Jabal Silsilah					
181859	16.3	15	9.69	9.22	.925	1.6	.119	92	40
181871	13.5	24	18.1	9.44	.549	1.98	.249	80	46
181872	11.8	25	28.6	9.64	.44	1.8	.17	46	66
181964	12.8	59	3.38	5.66	.69	1.8	.394	50	15
				Hadb ad Dayahin					
184004	1.93	25	.775	3.23	.23	.036	.769	32	13
184171	.872	11	9.41	62.2	.088	.094	.906	98	155
				Jabal Hadb ash Sharar					
184009	1.87	5	6.78	25.8	.485	.05	.669	86	89
184056	1.62	2.7	3	19.6	.096	.057	.553	178	41
				Jabal Dumah					
184387	3.18	559	.611	6.2	.293	12.8	11.4	27	2

Table 2.--Contents of miscellaneous trace elements for postorogenic granites--Continued

SAMPLE	Cs	Ba	Ta	Hf	Sb	Sc	Co	Y	Nb
				Jabal Khinzir					
184080	10.4	391	4.46	7.66	.833	2.33	1.98	66	41
184420	8.07	26	18.5	7.1	.104	.648	.167	104	37
184422	1.79	1170	.57	3.28	.476	3.29	3.97	1	1
				Miskah					
184242	12.1	261	3.12	6.19	.33	2.13	1.51	32	35
184427	7.47	548	2.18	5.53	.08	2.44	1.6	18	14
184430	1.56	235	.357	3.45	.149	1.79	.7	6	4
				Jabal Minya					
184359	17.9	169	8.7	8.25	.12	2.88	.959	114	54
184424	19.3	215	9.54	7.7	.194	2.98	.56	97	37
184425	13	146	39.5	3.25	.092	6.71	.143	49	58
				Jabal Abha					
184374	.572	263	.166	1.27	.246	20	35.5	17	1
184375	8.38	1120	1	11.8	.995	6.56	11.8	25	6
				Jabal Sanam					
184376	.941	1250	1.8	11.4	.075	8.29	5.35	49	20
				Gharnaq					
184382	4.2	597	2.33	4.5	.064	4.23	2.59	30	10
				Jabal Haslah					
184388	2.18	581	1.18	5.67	.147	3.6	1.56	34	5
184389	1.71	594	.885	4.66	.102	2.37	1.58	27	3
				Jabal Saqrah					
184403	1.13	228	1.75	4.88	.029	1.97	1.07	17	10
184404	.404	17	3.29	8.52	.03	1.65	.151	10	23
184406	.803	685	.837	4.72	.138	2.81	.886	25	1
				Dukhnah					
184431	4.49	526	1.74	8.19	.286	3.46	1.98	34	19
184432	4.3	187	2.11	12.4	.366	.924	.549	59	21
				Jabal Kazaz					
184435	20.6	17	4.07	3.05	.059	2.97	.112	38	12
				Jabal Shiib					
184439	6.16	33	2.64	4.49	.207	1.44	.112	23	17
184441	1.67	328	1.45	8.26	.082	3.23	1.28	18	19
				Unnamed					
184442	1.57	618	1.21	10.3	.127	1.56	.592	38	11
				Baid al Jimalah					
889494	8.45	105	8.11	6.92	.97	2.26	.896	86	52
893039	5.12	127	5.02	6.04	1.83	1.94	.94	64	29
893159	7.38	149	5.6	6.89	4.76	2.48	1.07	59	34
893235	7.74	127	5.04	6.28	4.06	2.67	1.2	63	29

Table 3.--Statistical analysis of trace-element contents and ratios for postorogenic granites from the eastern Arabian Shield

[Concentration data evaluated logrithmically. Analyses include previously published results for samples analyzed in the current study as well as trace-element data reported by Stuckless, Knight, and others (1982); La/Lu is chondrite normalized]

Element	Minimum	Maximum	Mean	Standard Deviations		Skewness	Kurtosis
La	1.45	200.4	38.87	41.75	-20.13	-1.02	1.97
Ce	3.41	450.7	85.77	87.27	-43.26	-.94	2.70
Nd	2.21	199.1	41.62	36.37	-19.41	-.80	2.36
Sm	.63	32.1	9.41	7.64	-4.22	-1.12	2.79
Eu	.005	3.12	.387	1.018	-2.81	-1.13	1.17
Gd	.687	39.2	9.34	8.16	-4.35	-1.19	2.48
Tb	.117	7.32	1.57	1.47	-.75	-1.20	2.29
Dy	.649	48.07	10.16	9.89	-5.01	-1.17	2.30
Tm	.029	4.59	.95	1.15	-.52	-1.18	2.79
Yb	.144	30.7	6.00	7.75	-3.38	-1.18	2.97
Lu	.018	5.44	.88	1.21	-.51	-1.22	3.14
Ba	3	1270	110	330	-83	-.26	-.78
Cs	.04	20.6	2.46	4.47	-1.59	-.07	.52
Rb	1	954	189	205	-98	-2.11	14.34
Sr	1	1633	30.3	74.1	-21.5	.28	.27
Y	1	238	47.9	54.4	-25.5	-1.24	4.65
Nb	.5	213	32.2	61.2	-21.1	-1.74	3.69
Ta	.108	45.9	3.48	5.89	-2.19	-.79	1.59
Hf	1.26	72.17	9.59	8.78	-4.58	-.18	1.12
Zr	13	2910	233	333	-137	-.21	.71
U	.44	26.9	5.99	6.35	-3.08	-.71	1.03
Th	.5	144	18.34	19.63	-9.49	-1.45	5.01
Sb	.01	4.76	.19	.34	-.12	.32	.43
Sc	.036	20	1.16	2.71	-.82	-.53	.18
Co	.057	35.5	.49	1.03	-.33	.71	.93
K/Rb	30	5400	200	200	-100	.38	2.61
Rb/Sr	.001	954	6.24	31.21	-5.20	-.75	3.58
Zr/Hf	6.15	52	26.4	9.6	-9.6	.03	-.03
Nb/Ta	1.19	29.7	10.6	4.8	-4.8	.29	.87
La/Lu	.414	78.8	4.55	7.93	-2.89	-.51	1.59
Th/U	.89	14.6	3.06	1.51	-1.01	.04	1.63

Table 4.--Means and standard deviations for trace-element contents and ratios in postorogenic granites from the Arabian Shield subdivided by degree of alumina saturation and compared to an average granite

[Average granite as described in Analytical Procedures section]

Element	Average Granite	Peralkaline Mean	Peralkaline Sigma	Metaluminous Mean	Metaluminous Sigma	Peraluminous Mean	Peraluminous Sigma
La	55	65.73	+51.62 -28.92	49.91	+26.74 -17.17	21.38	+26.08 -11.75
Ce	104	149.9	+114.0 -64.8	102.2	+57.5 -36.8	49.11	+55.06 -25.95
Nd	47	78.05	+48.93 -29.62	45.20	+25.80 -16.42	27.44	+25.82 -13.30
Sm	8	15.98	+8.13 -5.39	9.45	+5.65 -3.54	7.28	+7.22 -3.62
Eu	1.1	1.028	+0.907 -0.482	.525	+0.731 -0.306	.147	+0.511 -0.114
Gd	7.4	15.19	+6.71 -4.65	8.72	+6.08 -3.58	8.34	+9.58 -4.46
Tb	1.1	2.46	+1.06 -0.73	1.43	+1.10 -0.62	1.51	+1.87 -0.84
Dy	6.2	15.24	+6.97 -4.79	9.03	+7.21 -4.01	10.24	+13.70 -5.86
Tm	.69	1.24	+0.82 -0.50	.812	+0.778 -0.398	1.10	+1.93 -0.70
Yb	4.3	7.50	+5.35 -3.12	5.04	+5.06 -2.53	7.24	+13.70 -4.74
Lu	.68	1.08	+0.82 -0.47	.739	+0.799 -0.384	1.09	+2.80 -0.79
Ba	873	54.2	+182 -41.8	153	+429 -113	89.0	+229.3 -64.1
Cs	3-5	1.16	+0.77 -0.47	2.15	+2.54 -1.16	4.42	+11.31 -3.18
Rb	170-220	178	+81 -56	131	+131 -66	274	+337 -151
Sr	147	18	+22 -10	44	+105 -31	20.3	+50.5 -14.5
Y	38	67	+42 -26	41	+39 -20	52	+82 -32
Nb	22	50	+47 -24	32	+52 -20	26	+40 -19
Ta	2.3	3.79	+3.34 -1.78	3.06	+3.74 -1.68	4.18	+11.75 -3.08
Hf	4	20.1	+16.6 -9.1	9.88	+5.89 -3.69	6.45	+5.52 -2.98
Zr	50-700	718	+682 -350	269	+178 -107	108	+128 -59
U	3.54	5.82	+4.40 -2.51	5.75	+5.31 -2.76	6.53	+9.28 -3.83
Th	16.8	15.7	+12.6 -7.0	18.33	+15.21 -8.31	19.75	+31.09 -12.08
Sb	.2	0.20	+0.32 -0.12	.21	+0.29 -0.12	.168	+0.403 -0.118
Sc	3-10	0.55	+1.71 -0.42	1.41	+2.97 -0.95	1.19	+2.44 -0.80
Co	3-5	0.40	+0.54 -0.23	.704	+1.55 -0.484	.306	+0.498 -0.087
K/Rb	200-210	209	+116 -75	252	+188 -108	133	+166 -74
Rb/Sr	1-2	9.83	+18.34 -6.40	3.47	+16.06 -2.85	13.48	+71.21 -11.34
Zr/Hf	39	36.1	+4.9 -4.9	28.3	+8.0 -8.0	18.5	+7.8 -7.8
Lu/La	8.3	6.30	+7.18 -3.36	6.73	+7.02 -3.44	2.03	+3.87 -1.33
Nb/Ta	12	13.3	+2.1 -2.1	11.3	+3.8 -3.8	8.1	+6.0 -6.0
Th/U	4.73	2.70	+1.18 -0.82	3.19	+1.22 -.088	3.02	+2.04 -1.22

Table 5.--Correlations coefficients for chemical data for postorogenic granites from the Arabian Shield, Kingdom of Saudi Arabia

[Total iron is expressed as Feo; alk is the molar ratio of Al to Na+K; peral is the molar ratio of Al to Na+K+Ca]

	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	La	Ce	Nd
SiO_2	-.735	-.674	-.847	-.867	-.332	.218	-.899	-.730	-.509	-.007	.013	.033
Al_2O_3		.057	.569	.627	.366	-.109	.506	.499	.333	-.372	-.395	-.423
FeO			.615	.587	.210	-.234	.790	.525	.496	.349	.356	.380
MgO				.972	.042	-.488	.864	.847	.357	-.105	-.128	-.160
CaO					.011	-.466	.840	.801	.373	-.126	-.151	-.185
Na_2O						-.133	.208	.083	.324	-.103	-.082	-.025
K_2O							-.219	-.481	-.272	.501	.493	.434
TiO_2								.809	.485	.188	.167	.134
P_2O_5									.346	-.143	-.166	-.191
MnO										-.042	-.030	.014
La											.993	.931
Ce												.964

	Sm	Eu	Gd	Tb	Dy	Tm	Yb	Lu	U	Th	Nb	Ta
SiO_2	.125	-.423	.242	.301	.334	.388	.398	.410	.454	.496	.392	.410
Al_2O_3	-.473	.025	-.509	-.523	-.518	-.474	-.457	-.451	-.456	-.450	-.523	-.372
FeO	.3074	.599	.184	.113	.057	-.074	-.107	-.129	-.278	-.332	-.023	-.226
MgO	-.219	.281	-.291	-.327	-.343	-.378	-.385	-.401	-.370	-.383	-.430	-.418
CaO	-.244	.280	-.311	-.343	-.358	-.381	-.385	-.396	-.381	-.415	-.457	-.434
Na_2O	-.043	.039	-.078	-.102	-.113	-.134	-.132	-.129	-.292	-.336	-.064	-.051
K_2O	.335	.283	.231	.199	.173	.150	.143	.149	.118	.213	.257	.043
TiO_2	.019	.535	-.123	-.187	-.229	-.312	-.331	-.348	-.410	-.414	-.264	-.391
P_2O_5	-.241	.202	-.294	-.319	-.333	-.369	-.375	-.387	-.330	-.344	-.331	-.319
MnO	-.016	.220	-.056	-.083	-.104	-.147	-.154	-.158	-.297	-.400	-.162	-.128
La	.776	.644	.572	.481	.406	.260	.222	.203	.177	.226	.416	.099
Ce	.833	.621	.645	.555	.478	.323	.283	.263	.187	.222	.448	.136
Nd	.940	.542	.794	.709	.634	.467	.423	.401	.210	.218	.515	.229
Sm		.330	.948	.892	.838	.691	.650	.625	.345	.328	.640	.425
Eu			.099	-.001	-.080	-.228	-.261	-.279	-.273	-.302	-.108	-.409
Gd				.984	.960	.858	.825	.803	.454	.414	.706	.572
Tb					.989	.919	.892	.872	.500	.461	.729	.626
Dy						.961	.940	.924	.544	.505	.738	.665
Tm							.997	.991	.601	.576	.720	.714
Yb								.998	.606	.582	.705	.717
Lu									.598	.577	.698	.710
U										.846	.626	.686
Th											.647	.696
Nb												.835

Table 5.--Correlations coefficients for chemical data for postorogenic granites--Continued

	Ba	Cs	Rb	Sr	Y	Zr	Hf	Sb	Sc	Co	alk	peral
SiO_2	-.515	.177	.622	-.681	.354	-.085	.155	-.086	-.585	-.717	-.619	.370
Al_2O_3	.536	.127	-.366	.584	-.498	-.426	-.551	-.048	.636	.509	.640	.234
FeO	.210	-.392	-.523	.381	.013	.568	.346	.147	.204	.510	.207	-.781
MgO	.360	-.115	-.647	.584	-.311	-.053	-.273	.081	.453	.659	.813	-.315
CaO	.407	-.107	-.665	.623	-.331	-.089	-.317	.045	.511	.663	.861	-.272
Na_2O	.054	-.118	-.053	.080	-.157	.107	.133	-.063	.051	.100	-.219	-.299
K_2O	.205	-.055	.125	-.002	.112	.330	.279	.067	.049	-.076	-.522	-.015
TiO_2	.468	-.275	-.674	.632	-.255	.259	-.002	.092	.509	.705	.513	-.527
P_2O_5	.306	-.072	-.472	.493	-.294	-.068	-.247	.020	.369	.552	.624	-.209
MnO	.279	-.161	-.281	.365	-.167	.025	-.051	.015	.446	.305	.232	-.160
La	.090	-.329	-.155	.105	.241	.796	.677	.203	-.098	.185	-.404	-.575
Ce	.050	-.315	-.122	.066	.305	.807	.710	.192	-.132	.149	-.429	-.583
Nd	-.054	-.264	-.032	-.034	.453	.798	.758	.164	-.204	.063	-.452	-.578
Sm	-.237	-.103	.169	-.211	.677	.695	.762	.150	-.333	-.098	-.442	-.473
Eu	.557	-.453	-.566	.591	-.212	.614	.274	.205	.383	.631	-.054	-.611
Gd	-.386	.042	.348	-.376	.838	.545	.712	.145	-.429	-.279	-.422	-.321
Tb	-.427	.103	.415	-.431	.892	.475	.681	.148	-.456	-.356	-.419	-.252
Dy	-.450	.149	.468	-.465	.923	.419	.659	.146	-.466	-.401	-.406	-.197
Tm	-.452	.245	.547	-.504	.926	.292	.585	.141	-.440	-.468	-.373	-.075
Yb	-.445	.266	.563	-.510	.913	.254	.557	.135	-.426	-.477	-.365	-.043
Lu	-.439	.267	.565	-.514	.902	.237	.544	.126	-.424	-.490	-.369	-.027
U	-.460	.404	.670	-.430	.572	.132	.376	.147	-.315	-.321	-.308	.090
Th	-.396	.457	.663	-.401	.556	.155	.397	.150	-.339	-.326	-.323	.131
Nb	-.487	.176	.547	-.499	.731	.416	.646	.140	-.460	-.425	-.501	-.142
Ta	-.529	.445	.770	-.573	.660	.066	.410	.155	-.367	-.472	-.334	.152
Ba		-.116	-.515	.821	-.525	.005	-.274	.101	.731	.679	.274	-.062
Cs			.646	-.141	.236	-.441	-.278	.227	.045	-.115	.104	.466
Rb				-.623	.514	-.193	.139	.090	-.398	-.545	-.472	.412
Sr					-.508	.072	-.243	.022	.654	.808	.440	-.203
Y						.323	.571	.101	-.485	-.467	-.332	-.117
Zr							.884	.171	-.181	.131	-.466	-.780
Hf								.135	-.401	-.165	-.598	-.604
Sb									.100	.201	-.011	-.103
Sc										.639	.447	.060
Co											.430	-.323
alk												.198

Table 6.--Ranges of ratios for geochemically similar elements in postorogenic plutons that have anomalous ratios

[Values for average granite as described in the Analytical Procedires section]

Pluton	Y/Y-calc	Zr/Hf	Nb/Ta
Jabal Tuwalah	0.65 - 0.92	28.5 - 31.1	9.8 - 15.2
Jabal Qutn	0.47 - 1.02	18.3 - 30.6	6.0 - 16.5
Jabal Aja	0.61 - 0.89	15.9 - 42.5	8.3 - 16.8
Jabal Sabhah	1.19 - 1.66	7.6 - 15.9	4.3 - 19.0
Jabal Hawshat ibn Hawayl	1.05 - 1.25	12.6 - 21.0	5.0 - 5.2
Jabal Sahah	0.75 - 1.64	15.5 - 32.7	10.5 - 29.7
Jabal Mahail	0.84	10.0	3.2
Jabal Kebad	2.97	10.3	3.6
Jabal Huqban	0.76 - 1.18	13.7 - 19.4	10.1 - 24.5
Jabal al Gaharra	0.38 - 0.77	6.7 - 8.9	1.3 - 2.2
Jabal Bani Bwana	0.60 - 0.82	6.9 - 28.3	2.4 - 7.9
Jabal Habd ash Sharar	0.72 - 1.95	37.4 - 37.6	13.1 - 13.7
Jabal Khinzir	0.72 - 0.85	10.6 - 21.4	2.0 - 9.2
Jabal Minya	0.49 - 0.78	6.2 - 19.4	1.5 - 6.2
Jabal Haslah	0.89 - 0.93	27.0 - 30.9	3.4 - 4.2
Jabal Dumah	0.93	30.5	3.3
Jabal Kazaz	0.79	12.8	2.9
Jabal Silsilah	0.70 - 0.76	10.2 - 24.9	2.3 - 4.4
Baid al Jimalah	0.64 - 0.88	21.6 - 23.5	6.0 - 16.5
Average granite	0.76	39	12

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