Petrogenetic Modeling of a Potential Uranium Source Rock, Granite Mountains, Wyoming

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By JOHN S. STUCKLESS *and* A. T. MIESCH

*A study of the origin of
a uraniferous granite*

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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PETROGENETIC MODELING OF A POTENTIAL URANIUM SOURCE ROCK, GRANITE MOUNTAINS, WYOMING

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ABSTRACT

Previous studies of the granite of Lankin Dome have led to the conclusion that this granite was a source for the sandstone-type uranium deposits in the basins that surround the Granite Mountains, Wyo. Q-mode factor analysis of 29 samples of this granite shows that five bulk compositions are required to explain the observed variances of 33 constituents in these samples. Models presented in this paper show that the origin of the granite can be accounted for by the mixing of a starting liquid with two ranges of solid compositions such that all five compositions are granitic.

There are several features of the granite of Lankin Dome that suggest derivation by partial melting and, because the proposed source region was inhomogeneous, that more than one of the five end members may have been a liquid. Data for the granite are compatible with derivation from rocks similar to those of the metamorphic complex that the granite intrudes. Evidence for crustal derivation by partial melting includes a strongly peraluminous nature, extremely high differentiation indices, high contents of incompatible elements, generally large negative Eu anomalies, and high initial lead and strontium isotopic ratios. If the granite of Lankin Dome originated by partial melting of a heterogeneous metamorphic complex, the initial magma could reasonably have been composed of a range of granitic liquids.

Five variables were not well accounted for by a five-end-member model. Water, CO_2, and UO_2 contents and the oxidation state of iron are all subject to variations caused by near-surface processes. The Q-mode factor analysis suggests that these four variables have a distribution determined by postmagmatic processes. The reason for failure of CsO_2 to vary systematically with the other 33 variables is not known. Other granites that have lost large amounts of uranium possibly can be identified by Q-mode factor analysis.

INTRODUCTION

The Granite Mountains are composed of Archean metamorphic rocks, granites, and diabase dikes (fig. 1). The metamorphic rocks are thought to represent a sedimentary-volcanic sequence that was metamorphosed at amphibolite grade about 2,860 m.y. (million years) ago (Peterman and Hildreth, 1978). Compositionally, the metamorphic assemblage ranges from tonalite to granite with volumetrically minor amounts of amphibolite and serpentinite (Peterman and Hildreth, 1978). The dominance of micaceous units suggests that the metamorphic sequence is strongly peraluminous.

The metamorphic rocks were intruded by at least two granites. Zircon ages show that the granite of Long Creek Mountain crystallized 2,640±20 m.y. ago, and the granite of Lankin Dome formed 2,595±40 m.y. ago (Ludwig and Stuckless, 1978).

The metamorphic rocks were intruded by at least two granites. Zircon ages show that the granite of Long Creek Mountain crystallized 2,640± 40 m.y. ago (Ludwig and Stuckless, 1978).

The granite of Lankin Dome forms most of the exposed Precambrian in the Granite Mountains region, and is of particular interest because of its probable relation to the three uranium districts that surround the Granite Mountains. Rosholt and Bartel (1969) used whole-rock U-Th-Pb analyses of surface samples to provide evidence that the granites of the Granite Mountains lost as much as 10^{11} kg (kilograms) of uranium during the Cenozoic. They proposed that this uranium was the source for the central Wyoming deposits. Subsequent, more detailed studies have shown that the upper 50 m (meters) of granite of Lankin Dome lost an average of 20 $\mu g/g$ (micrograms per gram) or about 80 percent of the original uranium (Rosholt and others 1973), and that uranium has been mobilized to depths in excess of 360 m (Stuckless and Nkomo, 1978). Analyses of the granite of Long Creek Mountain (Stuckless and Nkomo, 1978) and of the metamorphic rocks (Nkomo and Rosholt, 1972) suggest that these units have not lost as much uranium (in terms of either percent or absolute amount) as the granite of Lankin Dome.

In order to develop a model for the petrogenesis of this potential source rock we have examined major- and minor-element data for the granite of Lankin Dome by the use of an extended form of Q-mode factor analysis (Miesch, 1976a, b). This method of modeling allows examination of the variation in all the chemical variables simultaneously and can be used to determine the number of end members required to account for the variability in each variable to any degree specified.

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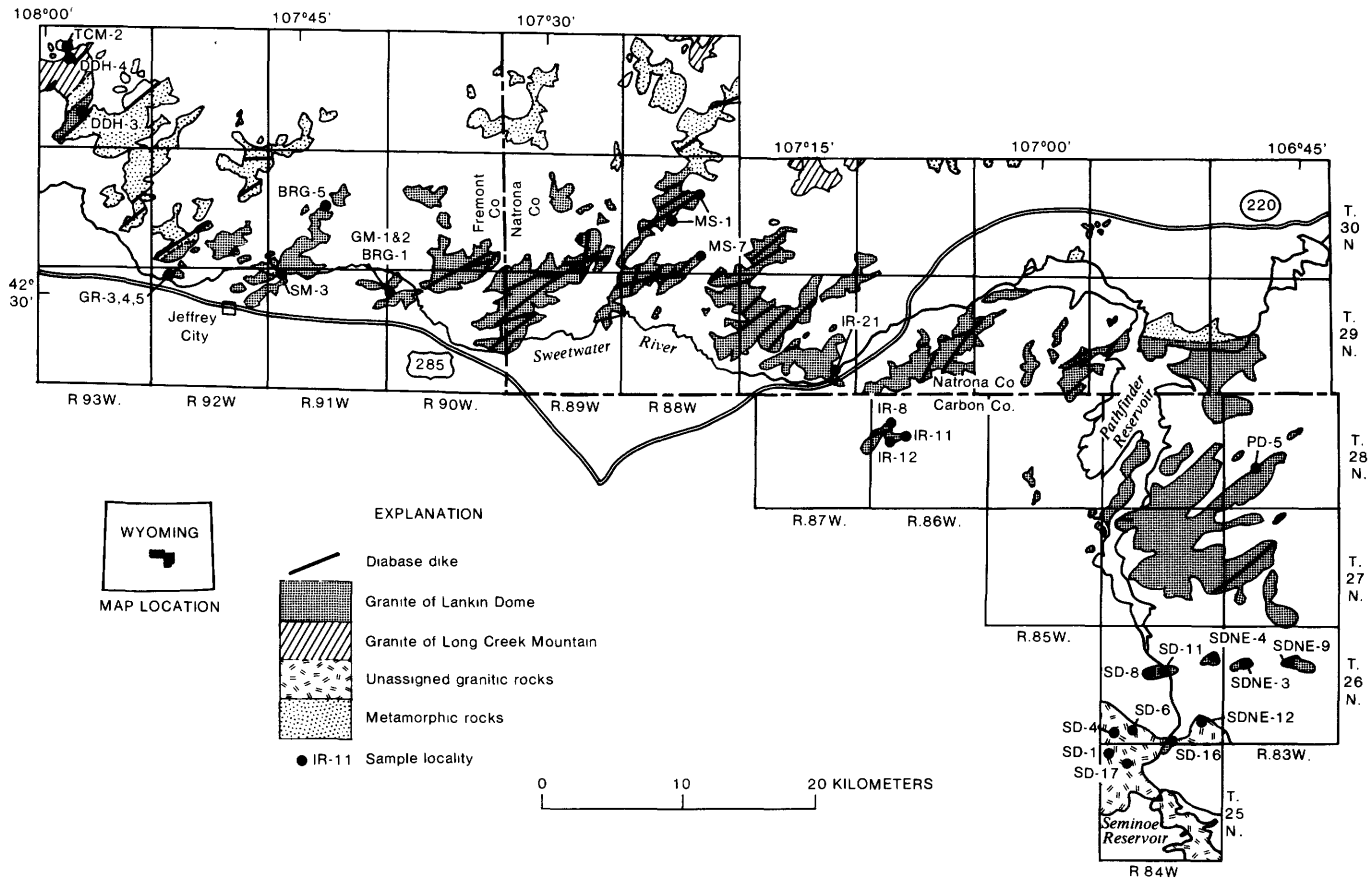
FIGURE 1.—Generalized geologic map showing Archean rocks and sample localities for the Granite Mountains, Wyoming. Geology from Stuckless and Nkomo (1978) and Peterman and Hildreth (1978).

ANALYTICAL METHODS

SAMPLE SELECTION AND PREPARATION

Samples analyzed in this study were selected from a suite of more than 300 drill-core samples and a suite of nearly 350 surface samples that had been collected at approximately 1600-m intervals. Samples, used for complete chemical analysis (column O, table 1), were selected on the basis of U, Th, and K concentrations and petrographic examinations so as to yield a group that showed the maximum observed diversity and a group typical of the majority of samples. Hydrothermally altered rocks and rocks of questionable relationship to the granite of Lankin Dome were analyzed for the sake of completeness (table 2), but these analyses were not used in the petrochemical modeling. As explained in the section on Q-mode factor analysis, certain of the chemical constituents were not used for petrogenic modeling. These data are given in table 3.

One to 5 kg of rock were crushed for each sample. All weathered or stained joint surfaces were removed prior to crushing. Samples were coarsely crushed to −32 mesh. A split of approximately 50 g (grams) was prepared at −100 mesh for chemical analyses.

CHEMICAL METHODS

Major-element concentrations were determined by the single-solution technique (Shapiro and Brannock, 1962; Suhr and Ingamells, 1966). Stated accuracies in terms of the amount present are: ±1 percent for SiO_2, ±2 percent for Al_2O_3 and ±1-10 percent for the remaining major oxides (those reported in terms of weight percent, tables 1, 2, and 3) depending upon the amount present.

Minor-element concentrations except for U and Th (those reported in terms of parts per million, tables 1, 2, and 3) were determined by instrumental neutron activation analysis (Gordon and others, 1968). Estimates of accuracy range from ±5 to 20 percent of the amount present. For a few samples, counting statistics for certain rare earths were poor (largely due to the interference of uranium), and the data reported in tables 1 and 2 were obtained by graphical extrapolation between the chondrite-normalized abundances of adjacent rare earths. Uranium and Th concentrations were deter-

mined by isotope dilution and mass spectrometry for most of the samples (Stuckless and Nkomo, 1978). These values were supplemented by delayed-neutron determinations for U (Millard, 1976) and gamma-ray spectrometry determinations for Th (Bunker and Bush, 1966, 1967). The general accuracy for reported U and Th values is ± 2 percent.

COMPUTER TECHNIQUES

The CIPW normative mineral compositions reported in tables 1 and 2 were computed using the program GNAP (Graphic Normative Analysis Program of Bowen, 1971). Petrochemical modeling was accomplished by the use of extended Q-mode factor analysis (Miesch 1976a, b) with scaling modifications as described in the section on Q-mode factor analysis.

DISCUSSION

PETROGRAPHY

The granite of Lankin Dome exhibits a wide range in grain size and texture. Most of the granite is medium grained, but fine- and coarse-grained zones are not uncommon. Samples are typically hypidiomorphic-granular, but allotriomorphic-granular textures are common and porphyritic textures have been observed.

The range in mineralogic composition for an estimated 95 percent of the granite is small (Stuckless and others, 1978). Subequal amounts of quartz, oligoclase, and microcline generally account for more than 90 percent of the granite by volume and commonly account for more than 95 percent; hence, the granite of Lankin Dome is a granite by the classification of Streckeisen (1973). Biotite is the dominant minor constituent with modal contents generally between 2 and 10 percent. In a few samples, the biotite content is as high as 20 percent (for example, IR-8 and IR-12, table 1) and some highly leucocratic samples have only trace amounts of biotite (for example, GM1-825 and GM1-1011, table 1). These extreme compositions are located within relatively small masses (tens of meters in diameter) that could be interpreted as largely reacted xenoliths or as magmatic segregates. For the most part, the granite is remarkably free of xenoliths, segregates, or schlieren.

Magnetite and primary epidote are either minor or trace constituents in all samples. Epidote is usually abundant enough to be considered a minor constituent, whereas magnetite is most commonly a trace constituent. Muscovite, some of which may be primary, is a trace constituent in most samples and is a minor constituent in most leucocratic samples. Garnet is abundant in a few leucocratic samples.

A variety of trace or accessory minerals has been identified, but only zircon and apatite are ubiquitous.

Uranothorite has been separated from one sample (Ludwig and Stuckless, 1978). Semiquantitative microprobe analyses have identified fine-grained ilmenorutile and highly altered sphene, monazite, and xenotime. These last three minerals have not been found in mineral separates, presumably due to their low abundance and friable nature.

The habit and character of the minerals is similar to that observed in most granites. Quartz is generally anhedral and exhibits undulatory extinction. Plagioclase varies from anhedral to subhedral. Most of the plagioclase is weakly zoned and contains minor amounts of sericite. Inclusions of quartz and accessory minerals are common. In some samples, plagioclase contains anhedral microcline. Phenocrystic microcline is generally subhedral and perthitic with sparse inclusions of plagioclase, quartz, and accessory minerals. In some samples, microcline is highly poikilitic with optically continuous, globular quartz.

Biotite is anhedral and invariably poikilitic with microscopic opaque oxides. Inclusions of euhedral zircon and apatite are common, as is minor alteration to chlorite. Primary epidote is subhedral to euhedral and generally occurs as large (5–10 mm) (millimeters) crystals rimmed by biotite, but single crystals 10–20 mm long are common. Secondary epidote, which is absent in most samples, but abundant in some hydrothermally altered zones, occurs as a fine-grained alteration product of plagioclase or as fine-grained veinlets. Within the hydrothermally altered samples, epidote pseudomorphically replaces biotite such that the poikilitic inclusions are preserved. Primary and secondary epidote also differ in trace-element content, as discussed in the section on paragenesis. Semiquantitative microprobe analyses show that most of the epidote is low in iron, but that some of the epidote tends towards an allanite composition. Magnetite occurs as subhedral to euhedral crystals as much as 1.5 cm (centimeters) in diameter.

GEOCHEMISTRY

The range in major-element compositions for the granite of Lankin Dome (table 4) is remarkably small, especially considering that the analyzed samples were selected to yield maximum diversity. Most of the samples are close to the average composition for all the samples as shown by the small standard deviations for the major elements (table 4). The compositions are highly evolved as indicated by the differentiation indices (Thornton and Tuttle, 1960) which range from 76 to 97 with all but five analyses greater than 90. All but one of the analyzed samples are peraluminous (fig. 2) according to the definition of Shand (1951) and all contain normative corundum (table 1). When projected onto the ter-

nary system Q-Ab-Or, all the samples plot near the center of the diagram (fig. 3), with nearly half the samples falling along the polybaric minimum-melt compositions for the system SiO_2-$NaAlSi_3O_8$-$KAlSi_3O_8$-H_2O (Tuttle and Bowen, 1958; Luth and others, 1964). The field occupied is similar to that for 281 peraluminous granites (Luth and others, 1964). The trace-element content of the analyzed samples is much more variable than the major-element content as can be seen by their ranges and standard deviations relative to their means (table 4). Except for scandium and rubidium, the range is greater than an order of magnitude, and for chromium and tantalum the range is greater than two orders of magnitude (table 4).

The REE (rare–earth–element) data are generally typical of highly evolved magmas. Four general types of patterns are presented in figure 4: (1) a steep, strongly light-rare-earth-enriched pattern with small negative to positive Eu anomaly, (2) a steep, strongly light-rare-earth-enriched pattern with a large negative Eu anomaly, (3) a pattern with moderate enrichment in the light rare earths, a negative Eu anomaly, and a heavy-rare-earth-trend much flatter than the light-rare-earth-trend, and (4) a pattern with middle-rare-earth depletion and generally low REE contents. Examples of all but the last of these types can be found in the Paleozoic granites of New England (Buma and others, 1971) and in the Pikes Peak Batholith (Barker and others, 1976).

Uranium and thorium contents for the granite of Lankin Dome are anomalously high relative to values cited as typical for granite (for example, U=4 ppm (parts per million) and Th=18 ppm, Rogers and Adams,
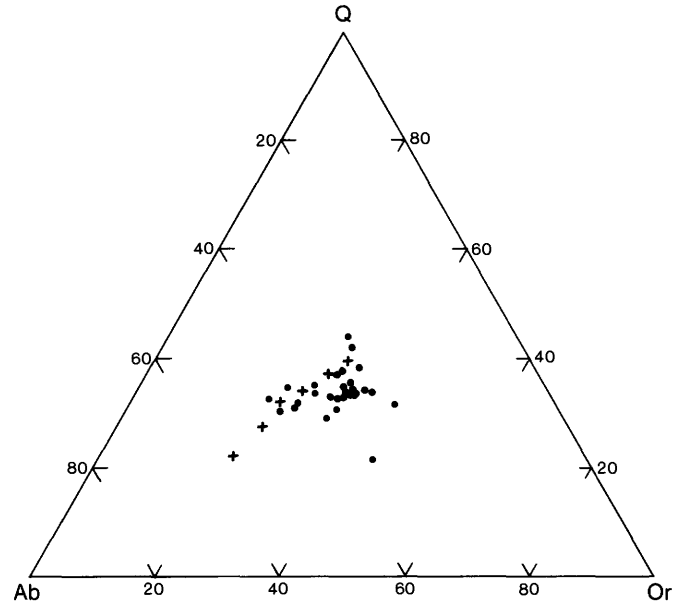
FIGURE 3.—Ternary plot of the normative quartz, albite, and orthoclase for the 29 samples of the granite of Lankin Dome, Wyo., used for the Q-mode factor analysis. Plus signs mark the position for the minimum melt compositions in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O (vapor present) for pressures of 0.5, 1.0, 2.0, and 3.0 kb (kilobars) (Tuttle and Brown, 1958) and of 5.0 and 10.0 kb (Luth and others, 1964).

1976a, b). The Th content for 255 surface samples, which contain more than 2 percent biotite, ranges from 17.9 to 200 ppm with an average content of 48.4 ppm (Stuckless and others, 1978). Uranium content for 236 unmineralized samples ranges from 0.53 to 19.7 ppm and averages 4.5 ppm (Stuckless and others, 1978), but this average value is also anomalous if the average loss of 80 percent U from surface samples is considered (Rosholt and others, 1973; Stuckless and Nkomo, 1978).

Q-MODE FACTOR ANALYSIS

The method of extended Q-mode factor analysis is used to resolve a complex compositional system into one that is simpler and easier to contemplate and represent in diagrams or on tabular summaries. Examples of this type of resolution are plentiful in petrology. For example, the plagioclase system contains five essential elemental constituents—Si, Al, Na, Ca, and O. However, the universal practice is to describe approximate plagioclase compositions in terms of only two constituents, albite and anorthite. In the same manner, granitic rocks of the Granite Mountains are composed of several dozen elements, but the approximate compositions of most samples can be given in terms of only five end members. The end members for the plagioclase system are taken by convention as pure albite (Ab) and pure anorthite (An), but it is theoretically possible, even though somewhat awkward for most common purposes, to
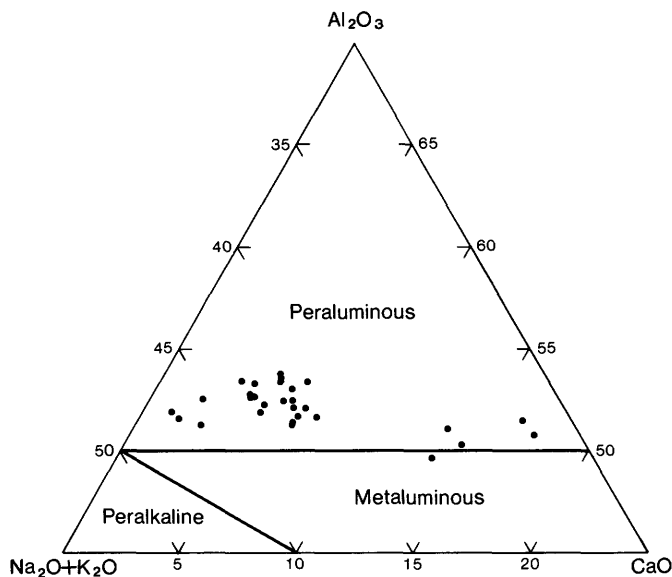

FIGURE 2.—Molar plot in the ternary system Al_2O_3, Na_2O + K_2O, CaO for the 29 samples of the granite of Lankin Dome, Wyo., used for the Q-mode factor analysis.

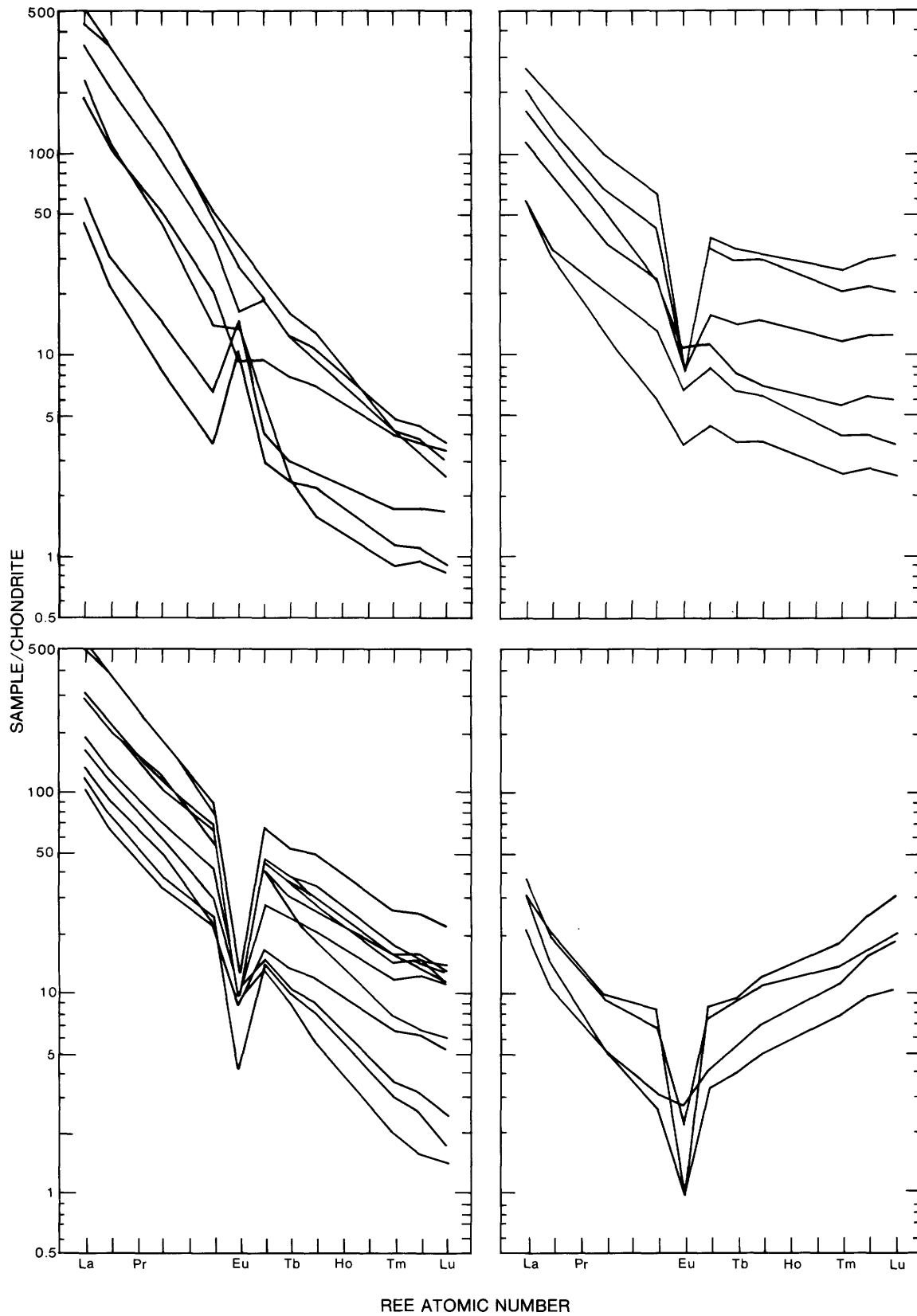FIGURE 4.—Chondrite-normalized REE (rare-earth element) patterns for the 49 samples of the granite of Lankin Dome, Wyo., used for the Q-mode factor analysis model. Chondrite values from Evensen and others (1978).

use, for example, An_5 and An_{95}. The end members could have any compositions within the plagioclase system. Similarly, there are no unique end members for the Granite Mountains system; they are chosen not by mathematical criteria, but by geologic judgment that is based on other field and laboratory observations. The end members must, however, have compositions within the Granite Mountains compositional system. The remainder of this section describes in sufficient detail the Q-mode procedures that were used so that anyone so inclined may reproduce the computations by the methods described in references already cited. Others may find the mathematical discussion of little interest and can proceed to the sections that discuss the results.

In order to examine the data by the extended form of Q-mode factor analysis, the analytical data were first expressed as oxides, except for F and Cl, and then the sum was adjusted to 100 percent. These adjusted values are referred to as the original data throughout this report to distinguish them from recomputed values obtained from the factor models.

The statistics in table 4 show that the constituents vary greatly in average (mean) concentration (73.75 weight percent for SiO_4 to 0.000028 weight percent for Tm_2O_3 and Lu_2O_3) and in variability as measured by the standard deviation (2.16 weight percent for SiO_2 to 0.000021 weight percent for Tm_2O_3). If the data were used in this form, the outcome would be dominated overwhelmingly by the constituents with the higher variabilities, such as the major oxides and especially SiO_2. However, minor constituents may be at least as diagnostic of magmatic processes as the major constituents; also, as just discussed, the relative variabilities for each of the minor constituents are larger than those for the major constituents. The data were therefore scaled to give each constituent equal weight in the outcome of the analysis.

Scaling for Q-mode factor analysis is commonly done by adjusting the range of each variable to extend from zero to one. If this is done, the means and variances of the scaled data remain unequal, even though they are much closer to being equal than before scaling. In order to avoid this problem, each variable was scaled to yield a mean of precisely 0.5 and a standard deviation of 0.17. The value of 0.17 is the largest possible standard deviation that will yield all positive value in the scaled data, thus preserving the properties of the cosine-theta measure of similarity described by Imbrie and Purdy (1962).

Extraction of the principal components of the cosine-theta matrix followed the procedures of Klovan and Imbrie (1971). Methods of extended Q-mode factor analysis (Miesch 1976a, b) were then used to derive matrices of principal-component composition scores and composition loadings. The product of the complete matrix of composition loadings (29 rows and 29 columns) and the complete matrix of composition scores (29 rows and 38 columns) is precisely equal to the matrix of the original data (tables 1 and 3). Repetition of this procedure using only 2 to 10 principal components, rather than the complete matrices, and comparison of the computed data with the original data, led to the factor variance diagram in figure 5.

The factor variance diagram (fig. 5) shows that when the 29 sample vectors are projected from 29 dimensions onto a plane (two factors), the resulting vectors represent compositions that are markedly different from the original compositions. The variances for about one-half the variables in the computed data (represented by the projected vectors) are less than 26 percent of the variances in the original data. Hence, a two-factor solution, which could have been used to develop a model with two end members, is clearly inadequate.

Figure 5 also shows that a three-factor solution is considerably better than the two-factor solution and that four- and five-factor solutions are better still. Note that at least five factors are required to account for the variance in Na_2O which is a major constituent. The five-factor solution preserves more than 64 percent of the variance of the original data for each constituent except for Fe_2O_3, CO_2, H_2O, Cs_2O_3, and UO_2. Expressed in another way, the data as represented by the five-dimensional vector system compare rather closely with the original data of the 29-dimensional system. Except for the five constituents just listed, the correlations between the original data and the data represented by the five-factor solution are all better than 0.80 (square root of 0.64). The proportions of variance accounted for do not improve substantially for a six-factor solution, and the variances in all 38 constituents are not satisfactorily accounted for until the nine-factor solution is reached (fig. 5).

Three of the five constituents that are not well accounted for by the five-factor model (Fe_2O_3, CO_2, and H_2O) are known to be sensitive to alteration processes, such as weathering. Stuckless and Nkomo (1978) have shown that uranium was lost from most of the analyzed samples during the Tertiary and that a few drill-core samples gained uranium. Consequently, the variabilities for these four constituents are not expected to be closely related to those controlled largely by magmatic processes. The reason for Cs_2O not to vary closely with the remaining 33 constituents is not known, but high analytical error does not appear to be the cause. A second derivation of a factor solution was attempted after elimination of the apparently mobile oxides and with Fe_2O_3 mathematically combined wtih FeO as total iron.

The revised factor-variance diagram (fig. 6) based on
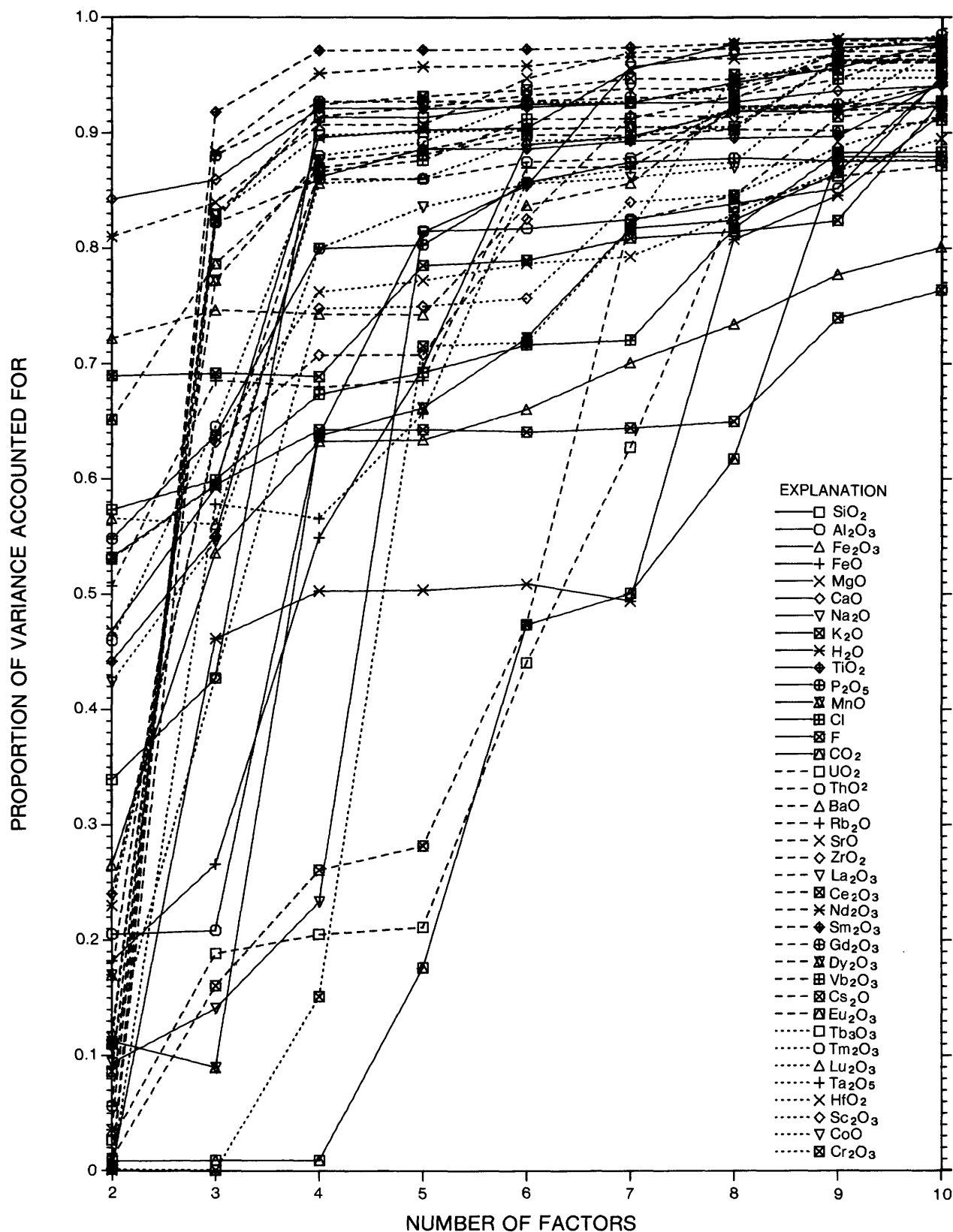
FIGURE 5.—Factor variance diagram for 29 samples of the Lankin Dome, Wyo., and 38 constituents.
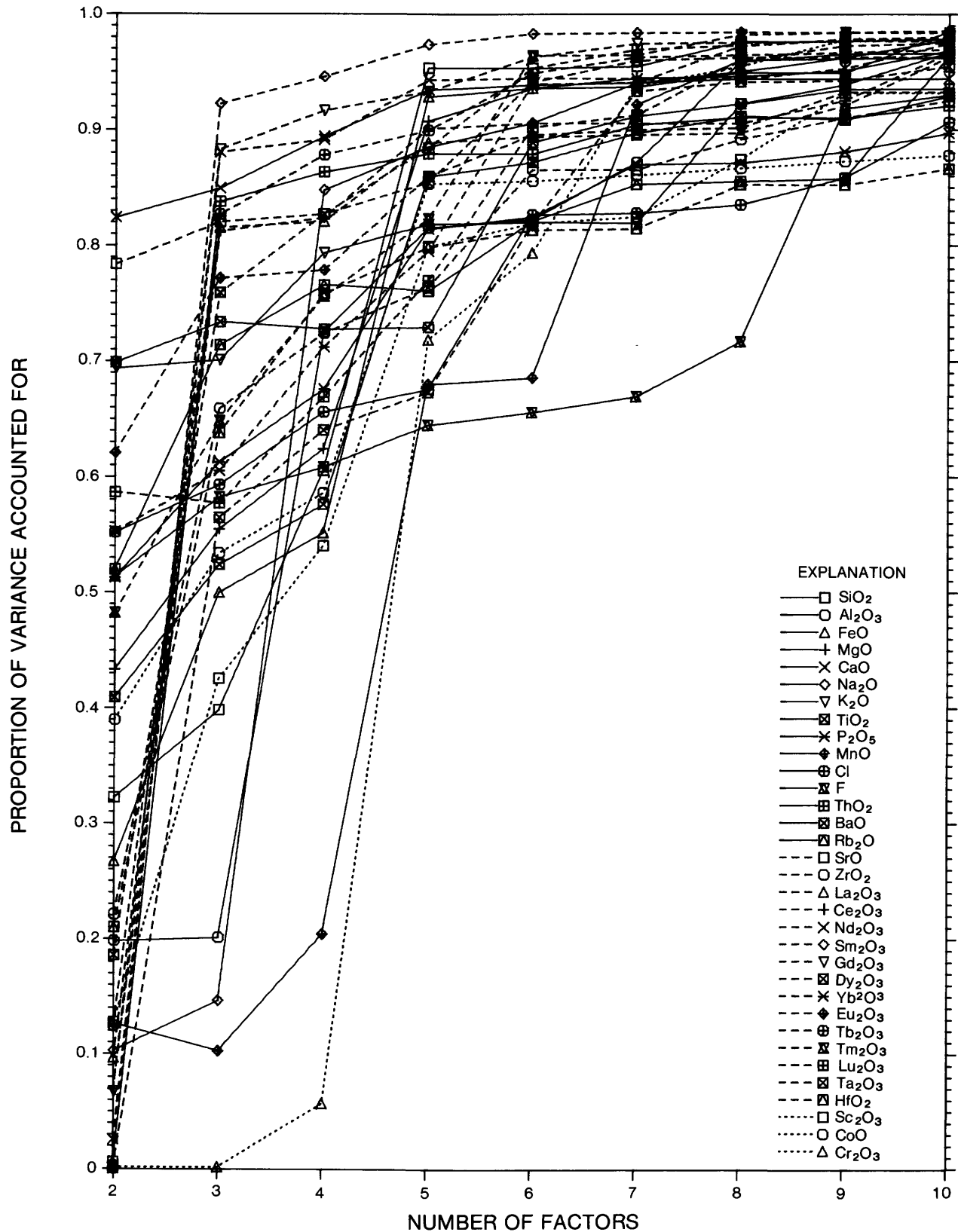
FIGURE 6.—Factor variance diagram for the matrix of 29 samples of the granite of Lankin Dome, Wyo., and 33 constituents. FeO is total iron calculated as FeO.

33 constituents, shows rather clearly that the original data can be represented well by a five-factor solution (that is, a five-dimensional vector system). The proportions of the variances in each constituent accounted for by the two five-factor solutions, one based on 38 constituents and the other based on 33, are given in table 5. The lowest value from the solution based on 33 constituents is 0.645 which is for F. This and the other three constituents for which the proportion of variance accounted for is less than 0.75 (Cl, BaO, and Ta_2O_5) all have poor analytical precisions relative to their standard deviations (table 4). The proportions of variance accounted for are especially high for the major oxides and light rare-earth oxides.

END-MEMBER COMPOSITIONS

The calculated chemical analyses derived from the five-factor solution based on 33 constituents are given in table 1 (column R) where they may be compared with the original data (column O). These calculated analyses can be produced from any petrochemical model containing five end-members, providing that each of the five end-member compositions can be represented by a vector within the vector system defined by the factor solution. Therefore, any number of petrochemical models may be derived, all of them mathematically satisfactory. The choice among the models must be based on petrologic or geologic criteria.

The five-dimensional vector space can be scanned and an infinite number of mathematically possible end-member compositions identified. Once five compositions have been selected, the mixing proportions (composition loadings) required for each sample must be determined in order to arrive at the calculated sample compositions given in column R (table 1). If end members are selected arbitrarily, the calculated mixing proportions are generally unreasonable for most of the samples.

In the present study, the search was narrowed considerably by assuming that four of the five end members could be represented as solid materials that were either subtracted from or added to another end member that consisted of a liquid. It was reasoned that the four solid materials might be represented among the 29 samples which were selected to include all compositional extremes observed within the intrusive body. Alkali feldspar might be expected to be a dominant phase in any subtracted solid and such solids could therefore be identified by positive or small (relative to the rest of the intrusive body) negative europium anomalies. Solid material either similar to that melted to form the granite or residium brought up with the granite would likewise be expected to have less negative europium anomalies than the average for the batholith. Four samples with positive or only slightly negative Eu anomalies are the following: IR-8, IR-12, IR-21, and SDNE-3.

As is evident from table 1, the compositions represented by the vectors for the chosen samples, in the five-dimensional vector system, are partly negative (that is, the calculated concentrations of a few trace elements are less than zero). The reason for the negative concentrations is that these four samples are of extreme compositions and their representative vectors occur near the margins of the vector system, slightly beyond the limit at which the values for some of the least abundant constituents are zero. In order to avoid the negative values, the four vectors representing the compositions of samples IR-8, IR-12, IR-21, and SDNE-3 were moved at increments towards a central vector, which represented the average compositions of all 29 samples, until the composition represented was entirely positive. The modified compositions were labeled IR-8+, IR-12+, IR-21+ and SDNE-3+, and are given in table 6; the extent of modification may be seen by comparing the compositions in table 6 with the corresponding values in table 1.

Having identified four compositions that might be those of solid materials subtracted from or added to a liquid phase to cause petrochemical variations, only identification of plausible compositions of the liquid remained. This identification was done by a computer trial-and-error procedure wherein a vector representing the liquid was moved systematically throughout the five-dimensional vector space. Each change in the vector position represented a change in the starting composition for use in the trial-and-error calculations. After each change, the required mixing proportions were derived for the remaining 25 samples (the samples listed in table 1, excluding those chosen as end members: IR-8, IR-12, IR-21, SDNE-3).

Regardless of the liquid composition used, the composition of sample IR-11 (table 1) could be approximated only by subtracting liquid from a combination of the four solid compositions (IR-8+, IR-12+, IR-21+, and SDNE-3+, table 6). The composition of sample IR-11 is similar to that of sample IR-8 (table 1) and may have originated by much the same process that produced IR-8. The Q-mode models to be developed will make no attempt to account for the origin of the four solid end members, nor do they account for the origin of sample IR-11; they will account for only the remaining 24 samples.

In interpretation of the results for the trial-and-error procedure, any liquid that led to non-negative proportions for the liquid, for all 24 samples, was tentatively satisfactory. These liquid compositions and required mixing proportions of the five end members were then printed and examined. Three general types of

petrochemical models became apparent. One type of model would explain the compositional variation in the granite by adding and subtracting the four solid phases in a completely unsystematic way. One sample would be explained by the subtraction of three solids and addition of one, but another sample might require the addition of 'all four solids. All possible combinations occurred among the 24 samples for each starting liquid for this type of model. All models of this type were rejected as unnecessarily complex.

The second type of model that emerged from the trial-and-error calculations explained the compositional variation by addition to the starting liquid of materials ranging in composition between IR–8+ and IR–12+ (table 6) and subtraction of materials ranging in composition between IR–21+ and SDNE–3+ (table 6). Thus, only one material would be added and only one subtracted, even though each material varied in composition within a two-component range. As an example of this type of model, one of the possible liquid compositions is given in table 6 (model A), and the required mixing proportions are given in table 7. The mathematical adequacy of model A can be tested by mathematically mixing the five end-member compositions in table 6 in the proportions given in table 7 for each sample. The resulting compositions are those shown under the (R) columns of table 1, which approximate the original compositions given under the (O) columns. The specific compositions of the materials added and subtracted for each sample according to this model can be calculated from the end-member compositions and the mixing proportions.

An attractive feature of model A is that compositions ranging between IR–8+ and IR–12+ are added to the magma in the formation of each sample composition, and compositions ranging between IR–21+ and SDNE–3+ are subtracted in the formation of each sample. Thus, the compositions in each range play a consistent role. Physically, this model could be envisioned as incorporating a range of contaminants from the metamorphic sequence and settling of precipitated minerals. Conceivably, materials were first added to the magma (and possibly melted) and subtraction by precipitation occurred later. However, a more reasonable expectation is that addition of material from higher parts of the magma chamber occurred simultaneously with subtraction. Part of the solid material added must also have been subtracted because the absolute sums of the negative mixing proportions generally exceed the proportions of liquid (table 7).

A less attractive feature of model A is the general magnitude of the mixing proportions for most samples. The mixing proportions for sample GM1-739, for example, call for separation of approximately 81 parts of solid phases from approximately 82 parts of liquid plus accumulated crystals. This mixing proportion indicates that sample GM1–739 represents little more than 1 percent of the total materials that were at one time present in the part of the magma chamber represented by this sample. This high degree of differentiation is not impossible inasmuch as this sample, like many of the other 29, represents only a small part of the intrusive body that was selected as being compositionally extreme. The compositions of less extreme samples can be approximated by mixing the end-member compositions in smaller proportions (table 7), and therefore, according to the model may have originated by lesser degrees of magmatic differentiation. Nonetheless, the large absolute magnitude of the mixing proportions and the strong probability of the addition of precipitated crystals to lower parts of the magma chamber led to consideration of a third type of model.

The third type of model that emerged from the trial-and-error calculations involves the same two compositional ranges of solid materials as used for the type-2 models, but neither range is consistently added or subtracted. Also, models of the third type involve mixing proportions that are considerably smaller than those involved with models of the second type. One of the possible liquid compositions for models of the third type is given in table 6 (model B) and the required mixing proportions are given in table 8. The mixing proportions for sample GM1–739 indicate that it may have formed from about 10 percent of the total liquid plus accumulated solid materials rather than about 1 percent as in model A. Mixing proportions for most other samples are smaller as well. According to model A, 18 of the 24 samples represent less than 5 percent of the liquid plus accumulated oxide materials, whereas according to model B, 20 of the 24 samples represent more than 10 percent of the liquid plus accumulated solid materials. Although in both models the volume of subtracted materials is large, model A suggests that much of the batholith should consist of cumulates with compositions intermediate to IR–21+ and SDNE–3+. Such compositions are not observed. Model B suggests that the batholith is a mixture of five bulk compositions, which is consistent with the observed data.

All the Q-mode models of mixing examined during this study require large amounts of solid relative to the volume of the starting liquid. Thus, more than one of the five end-member compositions seem likely to have been actually a liquid. If these liquids were partial melts of the various felsic units in the metamorphic sequence, they would be fairly similar to each other in major-element composition (Steiner and others, 1975), but each liquid would have a trace-element composition that depended on that of its specific source unit (Hanson,

1978). These predicted relations can be seen graphically on figure 6. The variance in SiO_2, Al_2O_3, CaO, Na_2O, and K_2O can be explained well by a four-end-member system; it is the variances in several of the trace elements that require a five-end-member system to adequately reproduce the data.

Specific criteria needed to search the infinite number of vectors for possible liquid compositions were not available, and therefore no attempt was made to model the petrogenesis by mixing of liquids with or without solids. Such a model would be based on the same data as that used in the construction of figure 6, and hence five end members would still be required.

The degree to which each of the 29 samples fits the five-factor solution based on 33 constituents can be seen in table 9. The body of the table shows the change in concentration value, caused by projection, for each of the 33 constituents in each sample as a proportion with respect to the original value. Thus, the values in table 9 are derived by (R-O)/O, where O is the value under column O of table 1 and R is the value under column R. Note that the largest absolute values in the body of table 9 tend to be for the constituents that are less well accounted for by the five-factor solution based on 33 variables (table 5, fig. 6).

The degree to which individual samples fit the five-factor solution is given by the communalities on the last line of table 9. The original sample compositions were first represented as vectors in 29-dimensional space and were then projected into 5-dimensional space on the basis of the factor variance diagram (fig. 6). Each of the vectors was of unit length before projection and somewhat less than unit length in its projected position. The differences in length are related to the distances of projection, and therefore serve as indicators of the differences between the compositions represented by the vectors before and after projection. The communalities on the last line of table 9 are the squares of the vector lengths after projection. Note that most of the communalities are greater than 0.980 and that the lowest sample communality for the 29 samples is 0.939.

The values in table 10 were derived in the same manner as those in table 9, but pertain to sample compositions not used to derive the factor solution. The first six samples are of albitized granite; the next seven samples are of silicified-epidotized granite (sample GR-3 is only partially altered); the next two samples are from the granite of Long Creek Mountain; and the last five samples are of uncertain relationship to the granite of Lankin Dome. The communalities suggest that three of the granites of the last group (SD-1, SDNE-12, and SD-4) are probably related to the granite of Lankin Dome. The communalities also show that the granite of Long Creek Mountain is at least in part chemically similar to the granite of Lankin Dome.

The communalities for the albitized and silicified-epidotized granites show that the chemical compositions of these rocks have been changed markedly by hydrothermal alteration. The proportional differences between the chemical values as projected into the five-dimensional system (defined by the orginal 29 samples) and the actual compositions (table 2) show which elements have most likely been strongly affected by the hydrothermal alteration. The compositions of the albitized samples differ most strongly from those of the projected compositions in K_2O, CaO, P_2O_5, MnO, CoO, Rb_2O, SrO, ZrO, and BaO. The compositions of the silicified-epidotized samples differ most strongly from those of the projected compositions in FeO, MgO, K_2O, P_2O_5, CoO, Rb_2O, BaO, and Lu_2O_3. Note that, in general, the actual and projected values for the REE are similar. This similarity can be seen qualitatively in figure 7 where REE paterns of altered granite are compared with spatially related, unaltered granites. The REE and other elements for which original and projected values are similar probably were not mobilized during the hydrothermal alteration.

MAGMA DERIVATION

The granite of Lankin Dome has several characteristics that suggest derivation by partial melting of rocks similar to the metamorphic sequence that it intrudes. The granite is highly evolved as indicated by the high differentiation index of Thornton and Tuttle (1960), the strongly enriched light REE, the large negative Eu anomaly for most of the samples, the high Rb in relation to K or Sr (K/Rb=200 to 400, Rb/Sr=2 to 6), and high contents of incompatible elements such as U and Th. Although all these features can result from either high degrees of fractional crystallization or low degrees of partial melting, partial melting of a granitic (and already evolved) source appears to be necessary to account for such a highly evolved character. The initial liquids calculated by Q-mode factor analysis are already highly evolved in both major and minor elements and even these liquids require large amounts of differentiation to match the observed sample compositions. Furthermore, the granite is fairly homogeneous and lacks mafic equivalents. The most mafic samples are quartz monzonites and these appear to be xenolithic.

The characteristics of the granite of Lankin Dome are similar in most respects to granites described as S-type (Chappell and White, 1974). The most obvious feature is the strongly peraluminous nature of the granite of Lankin Dome; a characteristic that Chappell and White (1974) ascribe to derivation from pelitic rocks. As pointed out by Whitney and others (1976), peraluminous compositions cannot be developed from metaluminous magmas by simple fractionation of quartz and feldspar. Thus, peraluminous granites seem to necessitate

REE ATOMIC NUMBER
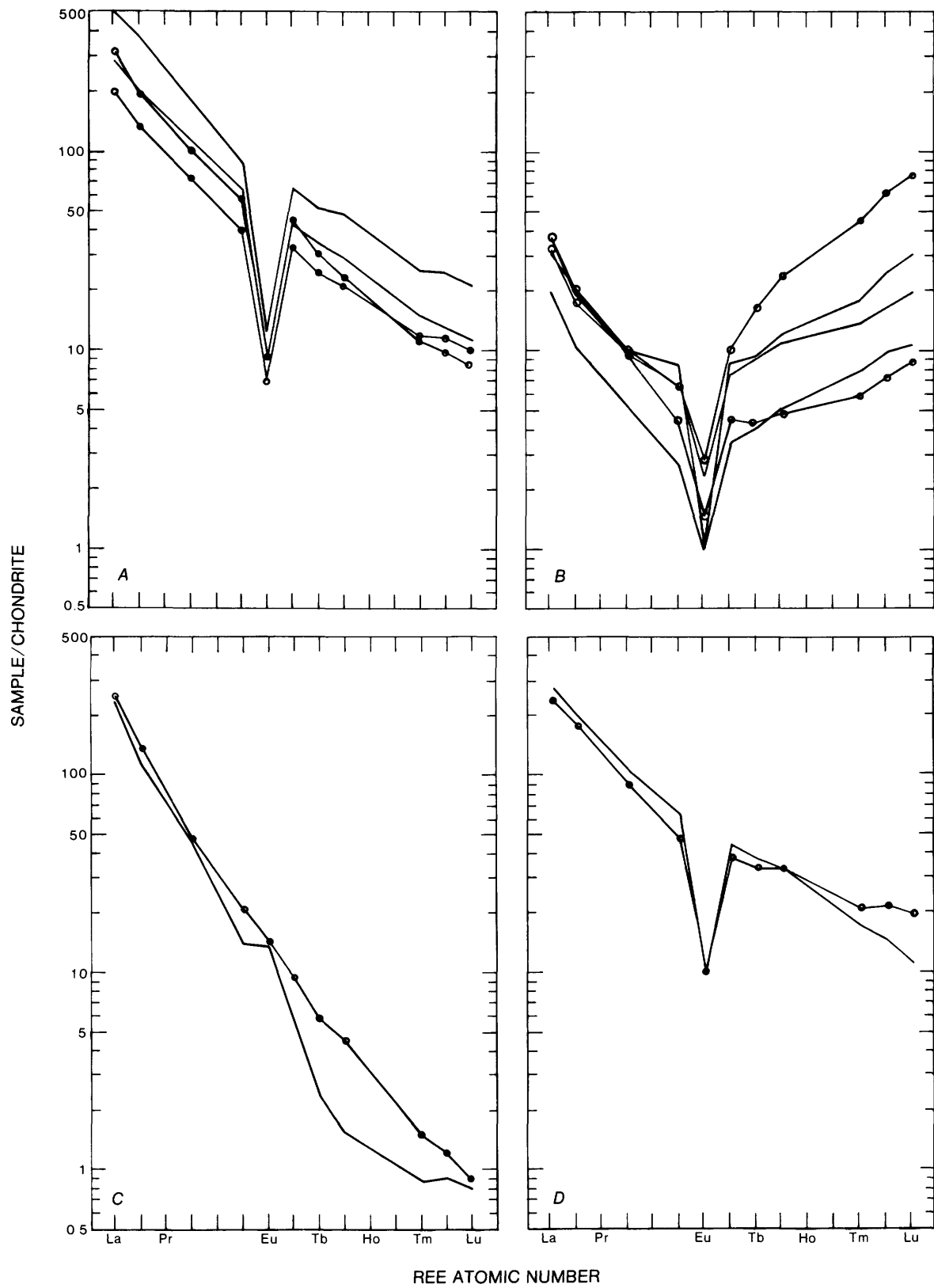
peraluminous sources. Because such sources are crustal, high initial isotopic ratios, such as $^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$, are expected. Although large errors are assigned to published values of these ratios for the granite of Lankin Dome, the ratios are somewhat high relative to those expected for mantle-derived rocks (Peterman and Hildreth, 1978; Stuckless and Nkomo, 1978).

The granite of Lankin Dome differs from typical S-type granites in one important aspect. O'Neil and others (1977) have reported that S-type granites have consistently high δO^{18} values relative to spatially related I-type granites (10.4 to 12.5 versus 7.7 to 9.9). Four δO^{18} values for samples that span most of the compositional range in the granite of Lankin Dome range from 5.88 to 8.45‰ (per mil) (J. R. O'Neil, written communications, 1976). The low δO^{18} values observed in the Granite Mountains may be due to derivation from moderately high grade metamorphic rocks. Epstein and Taylor (1967) have reported that the δO^{18} values for pelitic rocks decrease with increasing grade of metamorphism.

Derivation of the granite from amphibolite facies rocks suggests that the granite might have relatively low water content and that therefore most of the partial melting and crystallization would take place under water-undersaturated conditions. Although the data are equivocal, the major-element data do suggest water-undersaturated conditions. Compositions projected into the Q-Ab-Or system (fig. 3) lie to the right of the polybaric minimum for water-saturated melts. Although this shift can be caused by the anorthite component of plagioclase (Winkler, 1967), it is in the same direction as that observed for the polybaric anhydrous minimum (Luth, 1969). If the whole-rock compositions represent liquids at equilibrium, then their positions, as plotted in figure 3, suggest water undersaturation.

Figure 8 shows the normative feldspar compositions plotted on the An-Ab-Or system. Also shown are the low-temperature bivariant liquid positions for 2 and 8 kb (kilobars) projected from the system $CaAl_2Si_2O_8$–$NaAlSi_3O_8$–SiO_2 (Whitney, 1975). The plot of the data suggests fractional crystallization and (or) partial
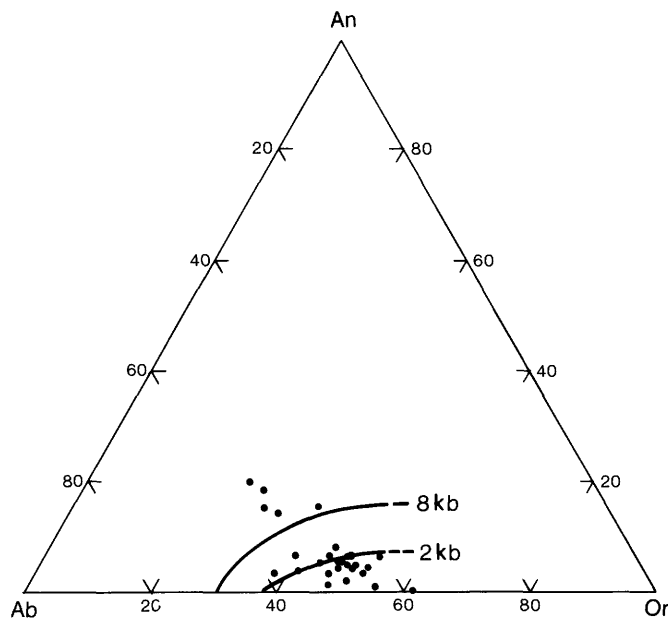
FIGURE 8.—Ternary plot of the normative anorthite, albite, and orthoclase for the 29 samples of the granite of Lankin Dome, Wyo., used for the Q-mode factor analyses. The position of the bivalent liquid in equilibrium with quartz, two feldspars and vapor is shown for water vapor pressures of 2 and 8 kb (kilobars) (Whitney, 1975).

melting at less than 2 kb for water-saturated conditions or at higher pressures for water-undersaturated conditions. The five samples that plot above the 8-kb curve (fig. 8) include three mafic rocks that could be interpreted as largely reacted xenoliths and two leucocratic rocks that may represent late-stage liquids. The abundant zones of hydrothermal alteration and ubiquitous deuteric alteration indicate that a free vapor phase had evolved by the end of the crystallization. If the two leucocratic samples represent late-stage liquids that coexisted with a free vapor phase, then the total pressure during partial melting and crystallization must have been at least 8 kb, and the apparent low water pressure for most of the samples probably represents a water-undersaturated history.

Probably the end stages, and possibly all the crystallization, took place under conditions of high oxygen fugacity. This high f_{O_2} is indicated by the occurrence of

◁ FIGURE 7.—Chondrite-normalized REE (rare-earth element) patterns for hydrothermally altered samples (shown by circles) and unaltered equivalents (shown by lines only). Chondrite values from Evensen and others (1978). A, Four patterns for samples from drill hole GM-1 with albitized samples from depths of 48.2 and 50.3 m and unaltered samples from depths of 38.4 and 49.7 m. B, Five patterns for samples from drill hole GM-1 with albitized samples from depths of 230.7 and 290.5 m and unaltered samples from depths of 225.3, 251.5, and 308.2 m. C, Pattern for a silicified-epidotized sample (SD-8) and an unaltered sample SDNE-3 from the southeast part of the Granite Mountains (samples are separated by nearly 4 km). D, Pattern of a silicified-epidotized surface sample (BRG-1) collected 60 m east of drill hole GM-1 and an unaltered sample from 2.7-m depth in GM-1.

primary epidote and magnetite, both of which are ubiquitous. Semiquantitive microprobe determinations and optical data show that the epidote has a fairly low iron content and as such would be in equilibrium with magnetite only under conditions of high f_{O_2} (Holdaway, 1972; Naney, 1977). In several samples, magnetite and hematite appear to be intergrown. This intergrowth suggests crystallization on the magnetite-hematite buffer, but the hematite may have formed secondarily.

PARAGENESIS AND EFFECTS ON DIFFERENTIATION

Petrographic data and published experimental studies indicate that the paragenesis for the granite of Lankin Dome was simple and support the conclusion of the Q-mode factor model that large amounts of solid separation would be necessary to effect the observed changes in the whole-rock chemistry. Zircon and apatite occur as early, near-solidus phases and although separation of neither phase has a significant effect on major-element concentrations, both phases have a pronounced effect on REE concentrations (Buma and others, 1971; Nagasawa, 1970). However, both minerals are present in extremely low abundances (Stuckless and Nkomo, 1980), and the high affinity of zircon for uranium coupled with the anomalously high uranium content of the granite at the time of crystallization provide evidence against significant separation of these minerals.

Quartz was the first major phase to crystallize, as indicated by the lack of inclusions of all but the accessory minerals in the larger quartz phenocrysts. It was probably followed shortly by the penecontemporaneous crystallization of oligoclase and potassium feldspar (now microcline). In general, the major mineral assemblage was probably close enough to the liquid composition so as to cause little change in the major-element composition through fractional crystallization. Such features as low Sr content and strong Eu anomalies observed in several samples may have developed by separation of these major phases, but as suggested by the Q-mode models the net separation of any group of major phases was probably minor.

Small amounts of magnetite are included within all the felsic minerals, and hence magnetite may have formed throughout the crystallization history. The separation of magnetite would have a pronounced effect on iron concentration as well as on the concentrations of several of the transition metals. However, most of the magnetite is associated with epidote and biotite and probably formed late in the crystallization sequence with these minerals.

Experimental work by Naney (1977) has shown that epidote forms in rocks of granite composition by reaction of biotite with the melt toward the end stages of crystallization. Petrographic examinations indicate that biotite and epidote were both late-forming phases in the granite of Lankin Dome and as such are likely loci for incompatible elements left in the melt. Isotopic studies (Stuckless and Nkomo, 1980) have shown that these two minerals are the dominant sites for U and Th in an unleached sample of the granite of Lankin Dome. REE analysis of epidote from three samples and biotite from two samples show that epidote does indeed have high REE concentrations (fig. 9).

Barker and others (1976) have proposed that epidote may have a strong effect on the REE concentrations in granitic rocks. However, the late appearance of epidote makes separation of this mineral unlikely except for small volumes of filter-pressed material. Furthermore, our data suggest that epidote may have an equal affinity for all the rare earths or that it may possibly accept the light REE in preference to the heavy REE. Figure 9 shows the REE concentrations in three epidote samples relative to REE concentrations in the whole rock. The diagram indicates an exclusion of Eu and a preference for light REE relative to heavy REE. However, if epidote formed extremely late in the crystallization history, the liquid with which it was in equilibrium would be strongly impoverished in Eu due to feldspar crystallization (Nagasawa and Schnetzler, 1971) and somewhat impoverished in heavy REE relative to light REE due to zircon crystallization (Buma and others, 1971). Hence, epidote seems likely to be simply a good host for many of the incompatible trace elements that are available toward the end stage of crystallization (U, Th, and REE). For this reason, epidote's apparent high partitioning coefficients may not accurately reflect true partitioning coefficients because the melt in which it formed was greatly enriched in trace elements relative to the whole rock.

Sample MS-1 is from a silicified-epidotized zone. The analyzed epidote is judged to consist of both primary and secondary epidote. The REE contents and distribution are similar to those in the epidotes of primary origin (fig. 9). The REE content of the epidote of mixed origin relative to that of the whole rock is the lowest of the three samples. This may suggest dilution effect by the secondary epidote that formed as a replacement of all the biotite and hence may have had lower contents of REE available during crystallization.

Lead-isotope studies show that all the analyzed epidotes have lost U and Th (Ludwig and Stuckless, 1978; Stuckless and Nkomo, 1980). Therefore, the reported REE abundances possibly are different from those present at the time of crystallization. Isotopic data for the analyzed biotites (Stuckless and Nkomo, 1980) show that these have been open systems to an even larger degree. The biotite from PD-5 has lost large amounts of U, Th, and Pb. The low REE content relative to that of the whole rock may be due to loss of REE.
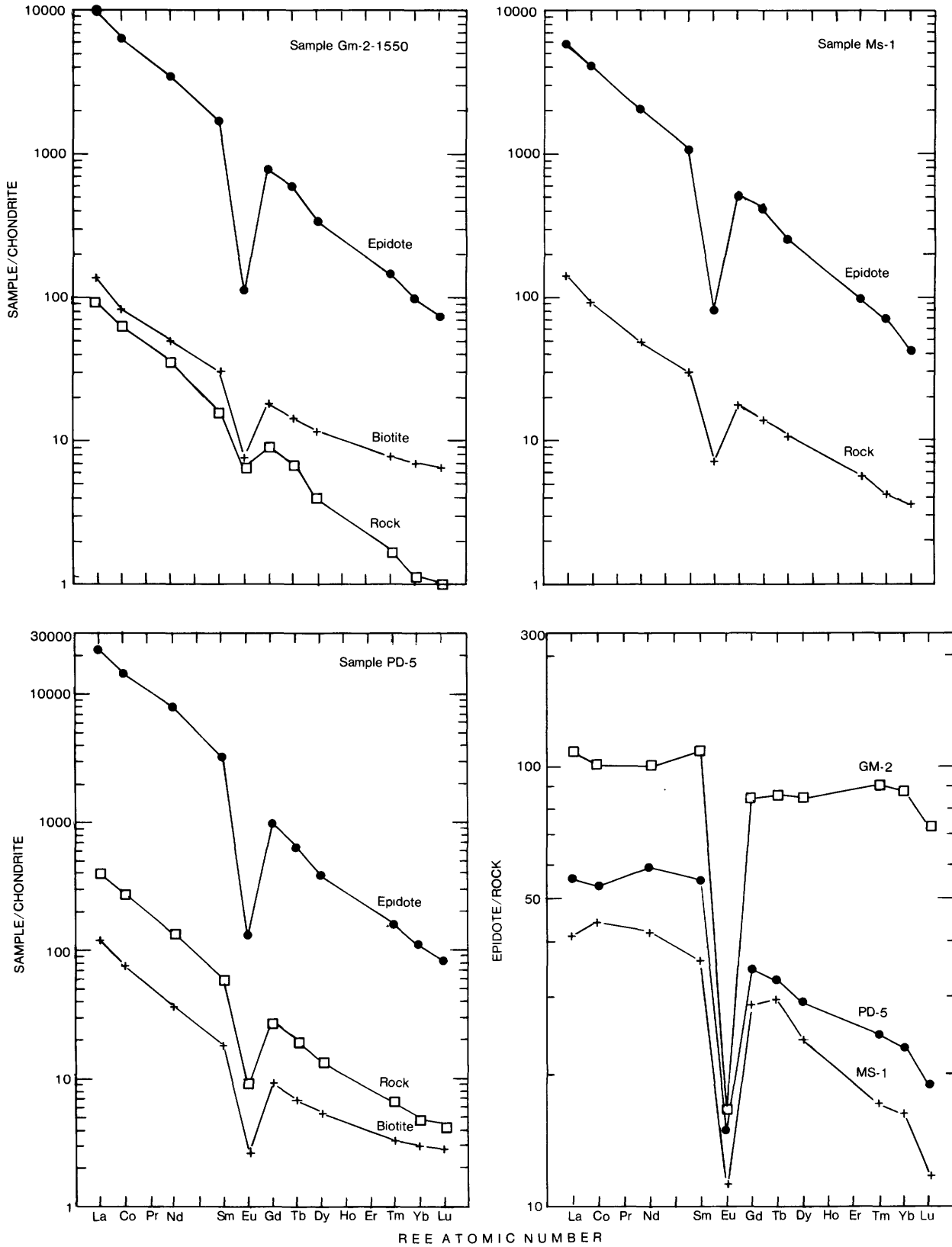
FIGURE 9.—Chondrite-normalized REE (rare-earth element) patterns for epidote and biotite with their host rocks and epidotes normalized to their respective host rocks. Analyzed biotites contained abundant opaque inclusions that are associated with uranium and possibly thorium (Stuckless and others, 1977: Stuckless and Nkomo, 1980).

SUMMARY AND CONCLUSIONS

If the granite of Lankin Dome has been a particularly favorable source rock for secondary uranium deposits, then rocks with similar characteristics and petrogenesis might reasonably be expected to be favorable uranium source rocks. The extended Q-mode factor analysis of the chemistry of the granite of Lankin Dome has placed several constraints on the petrogensis of this granite and has provided independent evidence for the secondary mobility of the uranium within the granite. In addition, Q-mode analysis has provided some insights into the chemical effects of two types of late-stage hydrothermal alteration that are prevalent in the granite of Lankin Dome and which may be common to other favorable uranium source rocks.

Five-end-member compositions are required to account for most of the variance of 33 oxides in 29 analyzed samples. Models presented in this paper consist of mixing a liquid with two ranges of solid compositions. However, if adequate constraints for end-member liquid compositions could be developed, the mixing of more liquids and fewer solids (still with a total of five end members) would be equally satisfactory in a mathematical sense and might be more accurate petrogenetically if the granite formed by the partial melting of an inhomogeneous section of metamorphic rocks. Regardless of the physical interpretation of the mathematical results, obviously the relationships among the 29 samples are moderately complex.

Four elements and the oxidation state of iron are not well accounted for by the five-factor model. Water and CO_2 contents and the oxidation state of iron are all subject to variations caused by near-surface processes. Isotopic studies have shown that near-surface processes have affected U contents in this granite as well. The reason for the failure of Cs_2O to vary closely with the other 33 constituents is unknown, but it may be that for this granite, the cesium content is subject to near-surface effects and thus, like the four variables, has a distribution determined mostly by post-magmatic process.

Several features of the granite suggest derivation by partial melting of rocks similar to those of the metamorphic complex which it intrudes. The granite is strongly peraluminous and hence was most likely derived from a crustal source. The major-element compositions yield high differentiation indices and even the most mafic samples approximate the minimum melt composition in the system Q-Or-Ab. The granite is strongly enriched in several incompatible minor elements such as U, Th, and the light rare earths. These major- and minor-element characteristics suggest derivation from an evolved granite source. The generally large negative Eu anomalies indicate that feldspar was

an important mineral in the residium after partial melting, which would be expected for rocks similar to those of the metamorphic complex. Initial isotopic ratios for both lead and strontium are high relative to those expected for an Archean mantle and similar to those that probably existed in the metamorphic complex at the time the granite was formed.

All the chemical characteristics of the granite of Lankin Dome are consistent with those of S-type granites. The δO^{18} values are low relative to those cited as typical of S-type granites. The low δO^{18} values are reasonable if the S-type source experienced a high grade of metamorphism prior to the partial melting event. This metamorphism would also have the effect of forming a fairly dry source region such that only small degrees of partial melting could take place under water-saturated conditions. The existence of vapor-absent liquids is suggested by the compositions for most of the granite of Lankin Dome as projected into the normative An-Ab-Or system.

The evolution of a water-saturated liquid towards the end stage of crystallization is suggested by ubiquitous zones of late-stage hydrothermal alteration and by the An-Ab-Or projection of two samples interpreted as late-stage liquids. Projection of the composition of the hydrothermally altered samples into the five-dimensional system defined by the 29 samples of the granite of Lankin Dome shows that both albitization and silicification-epidotization have changed the distribution of several elements, but that REE distribution was apparently unaffected.

At least the end stages of crystallization must have taken place under conditions of high f_{O_2} as indicated by the coexistence of epidote and magnetite. It has been postulated previously that separation of epidote might have a pronounced effect on REE patterns of granitic magmas; however, the late-crystallization of epidote makes such an effect unlikely. Furthermore, epidote analyzed during the present study seems to have incorporated large amounts of most of the incompatible elements that were enriched in the last crystallizing melt such that no REE were strongly enriched relative to others.

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TABLES 1-10

TABLE 1.—*Original chemical data and normative mineralogy (O) for 29 samples of granitic rocks from the Granite Mountains, Wyo., and corresponding data represented by the factor solution (R)*

Sample	IR-8		SDNE-4		IR-11		SD-11		GM1-67		GM1-374	
	O	R	O	R	O	R	O	R	O	R	O	R
Weight Percent												
SiO2	67.44	67.81	69.50	69.95	68.56	67.96	71.80	72.18	73.15	73.55	73.17	72.82
Al2O3	16.00	15.86	15.42	15.21	15.51	15.90	14.99	15.24	14.36	14.42	14.73	14.68
FeO	3.88	3.77	2.66	2.94	3.70	3.65	1.73	1.58	2.13	1.72	1.87	1.75
MgO	1.21	1.15	1.01	0.85	1.10	1.11	0.57	0.50	0.28	0.37	0.40	0.35
CaO	2.82	3.11	2.44	2.24	2.90	3.00	2.23	1.81	0.93	0.94	0.75	0.51
Na2O	4.03	3.99	3.65	3.70	4.10	4.07	4.25	4.26	3.57	3.67	3.56	3.68
K2O	3.12	3.10	4.46	4.20	2.80	3.14	3.85	3.82	5.09	4.84	5.08	5.82
TiO2	0.72	0.54	0.32	0.41	0.64	0.52	0.20	0.23	0.15	0.17	0.20	0.16
P2O5	0.24	0.19	0.14	0.14	0.19	0.19	0.11	0.10	0.10	0.07	0.02	0.06
Cl	0.05	0.05	0.04	0.04	0.07	0.05	0.03	0.03	0.03	0.02	0.02	0.01
F	0.07	0.06	0.05	0.04	0.05	0.05	0.03	0.03	0.03	0.02	0.00	0.01
Parts per million												
Sc2O3	3.75	5.14	6.47	5.05	5.60	5.33	3.30	2.96	7.20	6.02	7.44	8.03
Cr2O3	27.07	32.26	32.62	34.02	25.45	29.46	4.00	4.42	7.46	11.24	23.32	24.49
MnO	294	217	249	235	287	223	133	152	124	186	397	350
CoO	10.61	9.83	8.76	7.07	11.25	9.46	0.00	3.75	2.31	2.90	1.83	2.59
Rb2O	98	95	128	121	100	107	113	137	256	227	248	256
SrO	650	591	498	420	568	563	337	316	87	143	118	38
ZrO2	423	396	215	286	425	392	178	222	277	261	206	204
BaO	2068	1807	1450	1322	1665	1723	1101	1097	663	700	604	219
La2O3	151.10	119.95	97.45	88.22	124.42	117.96	53.21	53.13	81.96	94.60	74.96	74.01
Ce2O3	251.11	209.83	156.87	153.66	249.70	207.26	79.12	89.09	146.77	172.60	141.64	140.14
Nd2O3	75.84	67.37	50.53	49.90	76.93	67.15	28.11	29.16	61.67	65.05	54.76	54.17
Sm2O3	9.26	8.23	6.49	6.37	8.52	8.45	3.64	3.93	10.05	11.23	11.35	10.07
Eu2O3	2.340	1.783	1.120	1.306	1.820	1.711	0.620	0.942	0.660	0.726	0.550	0.401
Gd2O3	5.52	4.93	4.52	4.16	4.40	5.28	2.25	2.65	9.42	9.63	9.12	9.34
Tb2O3	0.680	0.583	0.540	0.534	0.530	0.648	0.340	0.356	1.280	1.385	1.460	1.434
Dy2O3	3.71	2.81	3.10	2.90	2.71	3.27	2.07	2.09	7.25	8.06	9.37	8.91
Tm2O3	0.110	0.046	0.140	0.140	0.120	0.083	0.120	0.111	0.450	0.438	0.780	0.627
Yb2O3	0.61	-0.01	0.84	0.85	0.71	0.25	0.69	0.69	2.91	2.71	5.69	4.35
Lu2O3	0.070	-0.052	0.110	0.119	0.090	-0.010	0.100	0.088	0.370	0.368	0.910	0.677
HfO2	10.47	9.28	5.83	6.78	10.35	9.28	5.28	5.81	7.17	6.78	5.99	5.45
Ta2O5	0.66	0.62	0.50	0.45	0.70	0.67	0.63	0.62	0.86	0.99	0.68	0.81
ThO2	44.44	48.46	52.41	38.39	49.65	49.88	33.65	28.01	74.54	67.44	79.67	59.56
Norms (weight percent)												
Q	22.49	22.44	23.10	24.74	24.38	22.34	25.89	27.49	29.33	30.08	29.53	26.40
C	1.53	0.81	0.56	0.89	0.99	0.87	0.07	1.10	1.60	1.61	2.06	1.55
Z	0.06	0.06	0.03	0.04	0.06	0.06	0.03	0.03	0.04	0.04	0.03	0.03
Or	18.49	18.39	26.44	24.87	16.60	18.58	22.78	22.62	30.14	28.67	30.06	34.40
Ab	33.80	33.42	30.68	31.06	34.30	34.11	35.82	35.84	29.99	30.96	29.98	31.07
An	12.46	14.27	11.16	10.27	13.25	13.76	10.39	8.34	3.90	4.25	3.71	2.19
Hl	0.08	0.09	0.07	0.06	0.12	0.09	0.05	0.06	0.05	0.04	0.03	0.02
En	3.02	2.88	2.53	2.12	2.75	2.78	1.41	1.24	0.69	0.92	0.99	0.87
Fs	6.01	6.08	4.40	4.77	5.81	5.89	2.87	2.55	3.68	2.92	3.17	3.01
Cm	0.00	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IL	1.38	1.04	0.62	0.78	1.22	1.00	0.39	0.44	0.29	0.32	0.39	0.31
Ap	0.57	0.45	0.34	0.34	0.45	0.44	0.26	0.25	0.24	0.17	0.05	0.14
Fr	0.10	0.08	0.08	0.05	0.07	0.08	0.04	0.04	0.04	0.03	0.00	0.00

Sample	GM1-163		DDH-3		IR-21		GM1-8		PD-5		GM2-1550	
	O	R	O	R	O	R	O	R	O	R	O	R
Weight percent												
SiO_2	73.95	73.98	73.66	73.37	72.86	72.77	73.24	73.41	74.22	74.39	73.71	73.70
Al_2O_3	14.50	14.08	14.65	14.44	15.25	15.14	14.62	14.40	14.07	13.81	13.58	13.56
FeO	1.35	1.86	1.27	1.50	1.14	1.21	1.82	1.82	1.36	1.94	2.56	2.04
MgO	0.41	0.33	0.55	0.36	0.40	0.43	0.41	0.37	0.29	0.37	0.13	0.44
CaO	0.52	0.61	0.77	1.02	2.21	1.85	0.76	0.79	0.95	0.93	0.98	0.96
Na_2O	3.78	3.40	3.46	3.57	4.21	4.28	3.34	3.59	3.36	3.25	3.02	2.64
K_2O	5.11	5.30	5.29	5.30	3.41	3.75	5.39	5.15	5.30	4.79	5.73	6.15
TiO_2	0.14	0.16	0.14	0.18	0.19	0.20	0.12	0.17	0.19	0.18	0.10	0.24
P_2O_5	0.01	0.06	0.06	0.07	0.05	0.10	0.06	0.07	0.05	0.07	0.07	0.07
Cl	0.02	0.02	0.00	0.02	0.04	0.04	0.03	0.02	0.00	0.02	0.00	0.01
F	0.02	0.01	0.00	0.02	0.03	0.03	0.01	0.02	0.00	0.02	0.00	0.02
Parts per million												
Sc_2O_3	6.95	7.43	6.03	4.53	1.06	1.33	8.18	6.86	5.00	5.97	2.23	4.76
Cr_2O_3	30.00	15.91	20.07	23.07	2.96	1.57	7.55	16.00	13.41	12.51	74.66	48.83
MnO	84	208	167	242	93	117	260	228	167	109	205	262
CoO	1.48	2.74	1.47	2.61	3.38	3.04	2.33	2.94	2.35	3.18	2.62	3.55
Rb_2O	169	263	146	170	89	106	259	241	219	231	188	142
SrO	106	77	166	171	338	335	126	110	170	161	48	198
ZrO_2	276	280	103	154	190	173	270	258	314	306	299	133
BaO	570	545	651	660	1255	1160	786	576	584	898	304	783
La_2O_3	141.35	113.68	28.52	47.51	16.95	29.98	79.02	96.82	159.02	124.72	35.62	59.14
Ce_2O_3	273.96	210.77	47.19	82.28	22.68	43.28	146.49	178.55	283.00	226.51	64.31	100.81
Nd_2O_3	98.64	81.06	18.16	29.16	8.11	11.39	58.35	67.82	100.83	85.46	26.39	34.55
Sm_2O_3	15.52	14.39	3.73	4.67	1.16	0.72	11.31	11.91	14.19	14.47	3.79	4.90
Eu_2O_3	0.830	0.655	0.580	0.620	0.960	0.907	0.680	0.659	0.800	0.901	0.590	0.762
Gd_2O_3	15.54	12.62	3.80	3.93	0.96	-0.22	10.47	10.40	9.12	12.12	2.94	3.76
Tb_2O_3	2.270	1.823	0.560	0.587	0.130	-0.064	1.640	1.514	1.070	1.684	0.370	0.515
Dy_2O_3	14.30	10.60	3.41	3.68	0.76	-0.34	9.93	8.91	5.27	9.39	1.62	3.00
Tm_2O_3	0.750	0.576	0.190	0.280	0.050	-0.018	0.510	0.512	0.220	0.419	0.060	0.222
Yb_2O_3	4.65	3.58	1.15	2.01	0.32	-0.11	2.77	3.26	1.23	2.31	0.29	1.61
Lu_2O_3	0.620	0.488	0.150	0.325	0.050	-0.019	0.330	0.460	0.170	0.264	0.040	0.275
HfO_2	5.97	7.24	3.71	4.01	5.36	4.62	5.80	6.69	6.52	7.72	3.34	2.95
Ta_2O_5	0.74	1.13	0.62	0.43	0.21	0.42	0.90	0.99	1.47	1.13	0.20	0.09
ThO_2	63.92	84.33	13.31	30.53	5.33	10.87	70.35	70.63	79.46	85.33	26.78	29.68
Norms (weight percent)												
Q	29.85	30.95	29.99	28.76	29.50	28.51	29.82	29.43	31.03	33.42	30.04	30.80
C	1.88	1.81	1.93	1.16	0.78	0.94	2.07	1.65	1.16	1.76	0.78	0.96
Z	0.04	0.04	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.04	0.02
Or	30.22	31.34	31.29	31.33	20.19	22.18	31.87	30.49	31.37	28.37	33.89	36.37
Ab	31.87	28.68	29.30	30.11	35.42	36.02	28.07	30.29	28.51	27.41	25.54	22.27
An	2.48	2.65	3.56	4.66	10.68	8.63	3.47	3.53	4.48	4.20	4.44	4.42
Hl	0.03	0.03	0.00	0.03	0.07	0.06	0.05	0.03	0.00	0.04	0.00	0.02
En	1.02	0.83	1.37	0.90	1.00	1.07	1.03	0.92	0.71	0.93	0.33	1.10
Fs	2.26	3.21	2.13	2.50	1.80	1.91	3.19	3.10	2.20	3.29	4.56	3.39
Cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Il	0.27	0.30	0.27	0.34	0.36	0.39	0.23	0.33	0.37	0.34	0.34	0.46
Ap	0.02	0.14	0.14	0.16	0.12	0.23	0.14	0.16	0.12	0.17	0.17	0.16
Fr	0.04	0.02	0.00	0.02	0.05	0.04	0.01	0.02	0.00	0.03	0.00	0.02

TABLE 1. Original chemical data and normative mineralogy (O) for 29 samples of granitic rocks from the Granite Mountains, Wyo., and corresponding data represented by the factor solution (R)—Continued

Sample	BRG-5 O	BRG-5 R	GM1-126 O	GM1-126 R	GM2-65 O	GM2-65 R	GM2-125 O	GM2-125 R	SD-16 O	SD-16 R	GM1-285 O	GM1-285 R
Weight Percent												
SiO_2	74.61	75.34	73.93	73.94	73.01	72.99	74.72	74.48	75.40	74.86	74.36	74.49
Al_2O_3	14.01	13.88	14.18	14.25	14.56	14.62	13.55	14.07	14.09	14.51	14.27	14.17
FeO	1.11	0.97	1.60	1.64	2.26	1.87	1.69	1.46	0.70	0.58	1.10	1.19
MgO	0.18	0.17	0.31	0.33	0.33	0.42	0.29	0.26	0.14	0.14	0.26	0.20
CaO	0.74	0.71	0.87	0.80	0.88	1.04	0.73	0.68	1.01	0.86	0.66	0.43
Na_2O	3.25	3.47	3.52	3.57	3.76	3.75	3.54	3.49	4.05	4.02	3.49	3.52
K_2O	5.68	5.16	5.13	5.02	4.79	4.79	5.06	5.17	4.36	4.76	5.49	5.72
TiO_2	0.08	0.09	0.15	0.15	0.13	0.19	0.12	0.13	0.07	0.07	0.17	0.10
P_2O_5	0.08	0.05	0.07	0.06	0.09	0.08	0.08	0.06	0.05	0.05	0.03	0.04
Cl	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.01
F	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01
Parts per million												
Sc_2O_3	3.30	3.62	7.20	6.13	5.16	6.35	6.26	5.74	2.73	2.65	6.29	5.84
Cr_2O_3	2.23	9.46	6.92	11.98	7.98	12.82	10.85	11.76	1.84	-0.57	19.84	17.38
MnO	183	132	199	186	190	210	239	175	222	146	186	250
CoO	1.15	1.02	2.40	2.55	6.52	3.35	3.12	2.00	0.67	0.52	1.47	1.24
Rb_2O	226	189	248	234	218	226	260	231	185	173	243	228
SrO	179	116	94	117	98	158	104	97	95	130	110	41
ZrO_2	162	158	260	252	207	270	249	229	86	124	94	158
BaO	1120	669	711	640	599	705	592	601	341	618	636	337
La_2O_3	51.31	56.32	80.80	94.76	86.55	95.70	81.58	87.57	16.40	26.42	58.18	58.33
Ce_2O_3	93.09	97.77	146.09	173.32	154.32	175.16	148.03	159.55	25.64	42.31	99.96	106.94
Nd_2O_3	38.00	37.31	62.06	65.96	58.93	65.53	56.25	61.81	11.82	16.07	36.55	41.99
Sm_2O_3	7.20	6.54	11.41	11.55	12.06	11.23	11.16	10.84	2.39	3.01	7.55	7.91
Eu_2O_3	0.670	0.551	0.630	0.673	0.530	0.755	0.550	0.610	0.460	0.450	0.570	0.373
Gd_2O_3	6.33	5.66	9.99	10.01	10.74	9.60	10.42	9.48	2.06	2.73	7.96	7.34
Tb_2O_3	0.990	0.810	1.480	1.444	1.600	1.387	1.480	1.368	0.290	0.424	1.260	1.113
Dy_2O_3	5.79	4.76	8.46	8.41	8.37	8.11	7.80	7.99	1.87	2.78	8.66	6.87
Tm_2O_3	0.340	0.275	0.440	0.461	0.410	0.451	0.400	0.443	0.120	0.215	0.600	0.474
Yb_2O_3	2.27	1.75	2.46	2.87	2.56	2.83	2.72	2.78	0.76	1.53	4.08	3.26
Lu_2O_3	0.310	0.247	0.330	0.391	0.350	0.390	0.390	0.383	0.110	0.237	0.590	0.502
HfO_2	4.81	4.29	6.90	6.58	5.46	7.00	6.21	6.02	3.36	3.68	4.97	4.35
Ta_2O_5	0.82	0.65	0.86	0.99	0.80	0.99	1.10	0.93	0.83	0.58	0.65	0.70
ThO_2	44.12	42.35	75.08	69.18	61.88	67.17	65.69	65.43	31.02	23.78	51.22	48.78
Norms (weight percent)												
Q	31.54	33.14	30.58	30.75	29.15	28.90	31.81	31.65	32.42	30.97	30.54	30.14
C	1.35	1.43	1.46	1.65	1.87	1.58	1.15	1.64	0.99	1.29	1.43	1.51
Z	0.02	0.02	0.04	0.04	0.03	0.04	0.04	0.03	0.01	0.02	0.01	0.02
Or	33.64	30.51	30.35	29.72	28.13	28.35	29.91	30.57	25.77	28.17	32.47	33.81
Ab	27.38	29.25	29.68	30.14	31.67	31.63	29.83	29.48	34.25	33.92	29.52	29.75
An	3.26	3.26	3.86	3.58	3.82	4.67	3.10	3.05	4.72	4.02	3.19	1.90
Hl	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.03	0.02	0.02
En	0.46	0.41	0.78	0.81	0.82	1.05	0.73	0.66	0.35	0.34	0.65	0.49
Fs	1.95	1.66	2.74	2.81	3.97	3.15	2.95	2.50	1.20	0.98	1.77	2.07
Cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00
Il	0.15	0.16	0.29	0.29	0.24	0.37	0.23	0.24	0.13	0.12	0.32	0.18
Ap	0.19	0.11	0.17	0.15	0.21	0.19	0.19	0.13	0.12	0.12	0.07	0.10
Fr	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.01	0.02	0.00	0.01

Sample	SM-3		SDNE-9		SDNE-3		GM1-841		GM1-814		GM1-581	
	0	R	0	R	0	R	0	R	0	R	0	R
Weight percent												
SiO_2	75.16	74.85	75.24	75.58	76.85	76.64	72.20	73.69	74.72	74.78	75.11	74.89
Al_2O_3	13.75	14.08	13.76	13.82	13.36	13.24	15.72	14.87	14.95	14.94	14.88	14.58
FeO	1.17	1.05	0.85	0.83	0.55	0.68	0.37	0.66	0.54	0.25	0.36	0.53
MgO	0.25	0.23	0.20	0.17	0.18	0.12	0.10	0.16	0.00	0.09	0.00	0.12
CaO	1.00	1.01	0.98	0.96	0.87	0.96	0.28	0.49	0.65	0.96	0.63	0.80
Na_2O	3.51	3.59	3.42	3.48	3.04	3.09	3.95	3.99	4.62	4.51	4.22	4.11
K_2O	4.72	4.80	5.22	4.83	4.76	4.95	7.20	5.95	4.30	4.22	4.62	4.72
TiO_2	0.16	0.12	0.08	0.09	0.09	0.08	0.05	0.08	0.04	0.03	0.00	0.05
P_2O_5	0.07	0.06	0.05	0.05	0.05	0.04	0.03	0.04	0.06	0.05	0.04	0.05
Cl	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
F	0.02	0.02	0.02		0.00	0.02	0.00	-0.00	0.01	0.01	0.01	0.01
Parts per million												
Sc_2O_3	2.94	2.85	2.19	1.97	0.50	0.49	4.57	4.56	0.34	2.07	2.29	2.96
Cr_2O_3	5.05	8.27	3.11	6.80	2.20	10.41	15.86	19.72	2.17	-14.93	4.02	-3.80
MnO	162	113	79	77	44	13	293	353	105	118	72	147
CoO	1.82	1.57	1.34	1.01	0.45	0.61	0.13	0.44	0.38	0.01	0.48	0.34
Rb_2O	171	163	147	151	116	118	195	185	215	177	164	186
SrO	152	181	197	179	263	206	50	37	40	132	104	110
ZrO_2	213	163	109	140	71	108	14	35	305	130	96	133
BaO	708	842	652	881	1515	1044	250	103	288	615	581	563
La_2O_3	46.02	52.16	43.94	44.90	65.07	39.10	8.75	-8.63	16.25	17.60	32.28	29.37
Ce_2O_3	79.69	87.85	80.24	72.66	85.56	57.75	10.35	-17.38	22.93	26.41	57.02	48.95
Nd_2O_3	29.14	32.03	31.28	26.43	25.04	20.13	2.89	-5.95	7.23	10.54	20.30	19.21
Sm_2O_3	4.12	5.18	5.11	4.18	2.52	2.70	0.58	-0.23	1.08	2.30	4.30	3.76
Eu_2O_3	0.740	0.676	0.670	0.657	0.920	0.723	0.190	0.097	0.240	0.406	0.560	0.412
Gd_2O_3	2.74	4.18	3.39	3.27	1.37	1.72	0.99	0.64	1.07	2.21	3.76	3.50
Tb_2O_3	0.360	0.578	0.440	0.435	0.100	0.168	0.230	0.227	0.160	0.363	0.620	0.544
Dy_2O_3	2.07	3.34	2.52	2.44	0.46	0.66	2.08	2.33	1.09	2.52	4.38	3.52
Tm_2O_3	0.160	0.178	0.100	0.115	0.030	-0.023	0.340	0.373	0.080	0.201	0.350	0.258
Yb_2O_3	1.18	1.10	0.58	0.66	0.18	-0.32	2.91	3.11	0.51	1.42	2.37	1.80
Lu_2O_3	0.170	0.147	0.070	0.080	0.020	-0.073	0.520	0.565	0.070	0.215	0.370	0.274
HfO_2	4.38	4.37	3.46	3.78	1.92	2.82	0.68	1.48	2.43	4.11	8.43	3.99
Ta_2O_5	0.83	0.58	0.66	0.51	0.19	0.32	0.05	0.20	1.08	0.72	0.20	0.67
ThO_2	45.56	35.00	16.92	29.86	31.68	21.82	6.89	3.81	17.02	21.10	28.33	28.15
Norms (weight percent)												
Q	33.60	32.60	32.64	34.19	38.62	37.18	20.72	26.04	29.79	30.28	31.46	30.83
C	1.23	1.29	0.86	1.26	1.69	1.14	0.97	1.07	1.67	1.36	1.91	1.38
Z	0.03	0.02	0.02	0.02	0.01	0.02	0.00	0.01	0.05	0.02	0.01	0.02
Or	27.90	28.38	30.90	28.57	28.16	29.29	42.56	35.20	25.41	24.98	27.30	27.93
Ab	29.61	30.22	28.71	29.30	25.59	26.06	33.40	33.72	39.03	37.99	35.59	34.70
An	4.55	4.72	4.56	4.50	4.27	4.59	1.26	2.18	2.86	4.47	2.91	3.70
Hl	0.03	0.04	0.05	0.03	0.03	0.03	0.02	0.01	0.02	0.04	0.03	0.03
En	0.63	0.58	0.50	0.42	0.45	0.29	0.25	0.39	0.00	0.23	0.00	0.29
Fs	1.92	1.76	1.45	1.38	0.88	1.12	0.64	1.15	0.94	0.43	0.68	0.91
Cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	-0.00
Il	0.31	0.22	0.15	0.17	0.17	0.15	0.10	0.15	0.08	0.06	0.00	0.10
Ap	0.17	0.14	0.12	0.12	0.12	0.10	0.07	0.09	0.14	0.12	0.10	0.11
Fr	0.03	0.03	0.03	0.03	0.00	0.03	0.00	0.00	0.01	0.02	0.01	0.02

TABLE 1. Original chemical data and normative mineralogy (O) for 29 samples of granitic rocks from the Granite Mountains, Wyo., and corresponding data represented by the factor solution (R)—Continued

Sample	IR-12		GM1-825		GM1-1011		GM1-739		GM1-1325	
	O	R	O	R	O	R	O	R	O	R
Weight percent										
SiO2	75.97	76.19	74.79	74.28	75.14	75.30	75.95	74.85	76.42	76.15
Al2O3	13.79	13.71	14.56	14.67	13.66	13.74	13.49	14.31	13.40	13.37
FeO	0.42	0.42	0.51	0.56	0.76	0.77	0.53	0.50	0.60	0.83
MgO	0.08	0.10	0.12	0.13	0.11	0.09	0.12	0.05	0.16	0.13
CaO	1.12	1.02	0.35	0.56	0.18	0.20	0.41	0.14	0.60	0.73
Na2O	3.45	3.47	4.06	3.96	2.97	3.15	3.70	3.65	3.18	3.07
K2O	4.87	4.80	5.45	5.65	6.93	6.59	5.60	6.37	5.36	5.42
TiO2	0.04	0.06	0.05	0.06	0.14	0.06	0.08	0.03	0.14	0.08
P2O5	0.04	0.04	0.05	0.04	0.02	0.02	0.04	0.02	0.02	0.04
Cl	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01
F	0.01	0.02	0.00	0.00	0.00	-0.00	0.00	-0.00	0.05	0.01
Parts per million										
Sc2O3	0.54	0.08	5.39	3.79	5.11	4.37	3.09	4.71	2.04	2.08
Cr2O3	0.70	5.40	16.50	13.66	23.00	31.68	14.61	21.82	24.08	17.10
MnO	24	44	268	284	309	297	493	331	49	97
CoO	0.53	0.25	0.31	0.24	0.43	0.15	0.20	-0.37	0.63	0.71
Rb2O	99	110	182	179	171	182	183	201	130	147
SrO	273	204	25	59	34	15	19	-21	58	147
ZrO2	55	77	20	52	20	27	41	22	94	104
BaO	1302	951	66	250	233	190	49	10	246	798
La2O3	12.73	15.73	5.54	-0.93	10.07	10.30	8.63	-2.61	31.19	40.61
Ce2O3	16.28	15.08	7.60	-5.02	13.91	15.17	14.75	-5.84	53.24	64.37
Nd2O3	4.73	3.94	2.87	-1.29	5.15	6.81	5.41	-0.10	20.14	23.59
Sm2O3	0.65	0.08	0.47	0.43	1.18	1.76	1.48	1.09	4.05	3.71
Eu2O3	0.720	0.615	0.060	0.182	0.150	0.160	0.070	0.008	0.260	0.588
Gd2O3	0.70	-0.38	0.79	1.02	1.76	2.18	2.03	1.95	3.18	2.95
Tb2O3	0.100	-0.098	0.170	0.249	0.390	0.394	0.400	0.410	0.410	0.389
Dy2O3	0.64	-0.63	1.44	2.25	3.15	2.94	3.53	3.32	2.22	2.18
Tm2O3	0.030	-0.042	0.230	0.314	0.400	0.345	0.520	0.416	0.090	0.120
Yb2O3	0.21	-0.28	1.79	2.56	3.03	2.75	4.55	3.33	0.46	0.76
Lu2O3	0.030	-0.042	0.300	0.457	0.550	0.490	0.860	0.591	0.050	0.111
HfO2	1.99	2.22	0.60	1.90	1.19	0.96	1.63	1.13	3.52	2.75
Ta2O5	0.01	0.24	0.34	0.28	0.25	0.11	0.20	0.22	0.25	0.34
ThO2	6.21	7.77	1.48	3.17	9.50	14.08	16.37	11.05	27.67	26.52
Norms (weight percent)										
Q	34.67	35.19	29.18	27.96	30.34	30.68	31.67	28.49	35.78	35.30
C	0.90	1.04	1.48	1.12	1.00	1.13	0.70	1.20	1.47	1.20
Z	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.02
Or	28.81	28.41	32.20	33.43	40.97	38.93	33.08	37.66	31.69	32.07
Ab	28.99	29.27	34.30	33.41	25.07	26.62	31.30	30.89	26.82	25.93
An	5.47	4.88	1.41	2.55	0.80	0.86	1.78	0.57	2.52	3.45
Hl	0.05	0.03	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.02
En	0.20	0.24	0.30	0.31	0.27	0.23	0.30	0.13	0.40	0.32
Fs	0.71	0.68	0.90	0.97	1.23	1.37	0.92	0.93	0.88	1.41
Cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Il	0.08	0.12	0.09	0.12	0.26	0.12	0.15	0.07	0.26	0.16
Ap	0.10	0.11	0.12	0.09	0.05	0.05	0.09	0.05	0.05	0.09
Fr	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.02

TABLE 3.—Miscellaneous chemical data for 49 samples from the Granite Mountains, Wyo.,

Sample No.	IR-8	SDNE-4	IR-11	SD-11	GM1-67	GM1-374	GM1-163	DDH-3	IR-21	GM1-8	PD-5	GM2-1550	BRG-5
					Weight percent								
Fe₂O₃	1.40	1.80	1.00	1.10	1.10	0.60	1.20	0.90	0.33	0.76	0.50	0.27	0.64
FeO	2.60	1.00	2.80	0.72	1.10	1.30	0.24	0.44	0.84	1.12	0.88	2.30	0.52
H₂O	0.79	0.50	0.61	0.66	0.65	0.70	1.23	0.77	0.38	0.58	0.63	0.51	0.56
CO₂	0.02	0.03	0.03	0.01	0.08	0.02	0.00	0.02	0.06	0.01	0.02	0.08	0.02
					Parts per million								
U	1.01	2.27	0.86	1.77	12.30	11.00	1100.00	1.56	0.96	9.94	6.92	17.20	2.62
Cs	0.65	0.94	0.85	0.94	1.80	1.03	0.60	2.44	1.36	2.24	1.50	0.59	2.10

Sample No.	GM1-126	GM2-65	GM2-125	SD-16	GM1-285	SM-3	SDNE-9	SDNE-3	GM1-841	GM1-814	GM1-581	IR-12	GM1-825
					Weight percent								
Fe₂O₃	0.55	1.20	0.30	0.14	0.20	0.54	0.59	0.43	0.00	0.06	0.00	0.33	0.17
FeO	1.10	1.20	1.40	0.56	0.92	0.68	0.32	0.16	0.36	0.48	0.36	0.12	0.36
H₂O	0.72	0.53	0.53	0.68	0.59	0.70	0.44	0.40	0.39	0.38	0.51	0.32	0.39
CO₂	0.04	0.05	0.06	0.02	0.01	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.02
					Parts per million								
U	8.90	5.27	7.69	3.18	45.50	5.86	1.90	0.55	2.20	23.50	5.40	0.41	3.01
Cs	1.45	1.85	2.48	3.20	1.20	1.46	1.97	0.28	0.54	0.61	0.50	0.27	0.73

Sample No.	GM1-1011	GM1-739	GM1-1325	GM1-201	GM1-159	GM1-165	GM1-954	GM1-757	GM1-1156	GR-5	GR-3	GR-4	MS-6
					Weight percent								
Fe₂O₃	0.10	0.14	0.23	0.90	0.64	0.90	0.67	0.10	0.32	0.08	1.00	1.00	0.15
FeO	0.68	0.40	0.40	0.40	0.52	0.16	1.20	0.36	0.56	0.16	0.76	0.16	0.12
H₂O	0.47	0.38	0.64	1.78	0.77	1.28	0.56	0.59	0.41	0.99	0.78	0.67	0.59
CO₂	0.03	0.02	0.02	0.03	0.05	0.02	0.04	0.02	0.01	0.02	0.01	0.02	0.03
					Parts per million								
U	4.07	4.79	18.60	4.92	7.64	107.00	20.90	20.30	4.54	2.64	2.23	7.97	7.12
Cs	0.86	0.47	1.53	0.35	0.55	0.29	1.59	0.20	0.88	0.43	0.38	0.21	0.25

Sample No.	SD-8	MS-1	BRG-1	TCM-2	DDH-4	SD-1	SDNE-12	SD-4	SD-6	SD-17
				Weight percent						
Fe₂O₃	0.47	0.35	0.27	1.80	0.60	0.37	0.69	0.29	0.32	0.01
FeO	0.16	0.12	0.08	1.50	1.10	1.40	0.28	0.88	0.64	0.52
H₂O	0.53	0.55	0.59	0.91	0.52	0.58	0.48	0.47	0.46	0.51
CO₂	0.01	0.02	0.03	0.02	0.04	0.03	0.05	0.02	0.02	0.03
				Parts per million						
U	4.16	13.00	13.50	2.97	2.14	2.63	1.59	1.73	2.28	1.59
Cs	0.09	1.89	0.65	9.54	4.24	3.24	0.77	3.09	1.95	2.36

TABLE 2.—*Chemical data and normative mineralogy for 20 samples of altered granitic*

Sample No.	GM1-201	GM1-159	GM1-165	GM1-954	GM1-757	GM1-1156	GR-5	GR-3	GR-4	MS-6
Weight percent										
SiO_2	68.93	74.51	75.73	76.78	78.29	78.29	51.09	72.57	73.48	76.30
Al_2O_3	18.20	15.13	14.46	13.38	12.98	13.12	29.77	15.41	15.16	14.27
FeO	1.23	1.12	0.98	1.84	0.45	0.85	0.23	1.68	1.06	0.26
MgO	0.62	0.44	0.20	0.17	0.16	0.13	0.68	0.54	0.43	0.27
CaO	0.25	0.33	0.24	0.99	0.14	1.20	15.39	2.74	7.53	5.36
Na_2O	9.76	7.56	7.68	4.49	7.14	5.41	1.11	4.16	0.80	2.33
K_2O	0.54	0.56	0.30	1.94	0.56	0.80	1.21	2.33	1.00	0.76
TiO_2	0.23	0.14	0.23	0.06	0.14	0.14	0.32	0.26	0.32	0.19
P_2O_5	0.05	0.07	0.03	0.08	0.02	0.01	0.06	0.07	0.06	0.10
Cl	0.03	0.04	0.03	0.02	0.03	0.01	0.01	0.02	0.02	0.03
F	0.04	0.02	0.00	0.02	0.05	0.00	0.00	0.05	0.00	0.01
Parts per million										
Sc_2O_3	14.28	6.01	6.23	14.69	4.32	3.05	1.59	3.23	4.74	3.12
Cr_2O_3	16.19	6.51	31.62	6.82	18.53	24.87	12.42	21.92	26.70	5.69
MnO	18	50	33	1393	56	121	27	128	75	37
CoO	2.06	1.59	0.57	1.01	0.36	0.51	0.20	2.77	0.31	0.35
Rb_2O	32	45	18	90	21	32	32	48	27	29
SrO	58	42	45	42	11	19	843	382	504	388
ZrO_2	224	246	137	386	68	68	164	153	159	271
BaO	93	91	424	174	61	46	163	818	258	157
La_2O_3	196.72	58.01	90.71	10.99	9.28	19.14	8.95	38.99	87.11	64.44
Ce_2O_3	297.68	100.08	144.47	15.46	12.85	33.77	13.78	62.21	128.15	99.09
Nd_2O_3	97.94	40.53	55.31	5.70	5.22	12.26	4.80	19.74	41.68	37.77
Sm_2O_3	14.97	7.21	9.96	1.21	0.77	2.69	0.97	3.15	6.95	5.64
Eu_2O_3	1.260	0.473	0.620	0.189	0.098	0.185	0.128	0.704	1.616	0.973
Gd_2O_3	9.24	7.73	10.61	2.39	1.07	2.99	0.93	2.05	4.66	4.22
Tb_2O_3	1.263	1.059	1.129	0.705	0.185	0.415	0.139	0.268	0.635	0.606
Dy_2O_3	7.00	6.23	6.75	6.91	1.40	2.34	0.96	1.70	3.43	3.37
Tm_2O_3	0.360	0.350	0.323	1.329	0.172	0.126	0.069	0.081	0.138	0.173
Yb_2O_3	2.27	2.20	1.84	11.74	1.36	0.74	0.42	0.50	0.75	1.05
Lu_2O_3	0.312	0.291	0.241	2.206	0.252	0.097	0.062	0.061	0.091	0.138
HfO_2	6.49	6.89	6.22	6.81	3.97	2.23	4.96	4.48	4.46	7.57
Ta_2O_5	0.25	0.86	0.67	1.56	1.06	0.66	0.43	0.40	0.75	0.23
ThO_2	84.91	71.75	64.54	11.26	8.42	17.09	29.87	30.22	19.87	42.83
Norms (weight percent)										
Q	8.20	26.65	28.67	39.65	34.14	40.49	6.97	32.10	48.32	48.39
C	1.36	1.75	1.17	2.35	0.58	1.21	0.00	1.39	0.00	0.16
Or	3.19	3.32	1.79	11.47	3.33	4.73	7.14	13.80	5.94	4.49
Ab	82.47	63.75	64.87	37.90	60.26	45.69	9.30	35.08	6.65	19.49
An	0.67	1.05	1.01	4.29	0.21	5.90	72.83	12.81	34.91	25.97
Hl	0.05	0.07	0.05	0.03	0.05	0.02	0.02	0.03	0.03	0.05
Wo	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	0.87	0.00
En	1.55	1.10	0.50	0.43	0.40	0.32	1.71	1.34	1.08	0.68
Fs	1.88	1.83	1.42	3.54	0.61	1.35	0.00	2.68	1.44	0.16
Il	0.44	0.27	0.44	0.12	0.27	0.27	0.50	0.50	0.61	0.37
Tn	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Ap	0.12	0.17	0.07	0.19	0.05	0.02	0.14	0.17	0.14	0.24
Fr	0.07	0.03	0.00	0.03	0.10	0.00	0.00	0.09	0.00	0.00

rocks and rocks of uncertain relation to the main intrusion at the Granite Mountains, Wyo.,

Sample No.	SD-8	MS-1	RRG-1	TCM-2	DDH-4	SD-1	SDNE-12	SD-4	SD-6	SD-17
Weight percent										
SiO_2	75.39	75.88	82.29	67.76	72.31	73.67	74.15	74.88	76.05	72.58
Al_2O_3	14.80	14.75	11.11	15.76	15.47	14.41	14.05	14.09	13.43	15.60
FeO	0.58	0.44	0.33	3.13	1.65	1.76	0.90	1.15	0.93	0.54
MgO	0.16	0.09	0.18	1.71	0.57	0.45	0.29	0.20	0.31	0.17
CaO	6.60	5.62	3.06	3.01	2.31	1.62	1.10	0.99	0.81	1.33
Na_2O	2.00	2.71	2.14	4.42	4.52	3.35	3.21	3.62	4.21	4.38
K_2O	0.09	0.08	0.51	3.31	2.61	4.26	5.82	4.73	3.91	5.00
TiO_2	0.15	0.23	0.10	0.39	0.29	0.17	0.08	0.10	0.08	0.03
P_2O_5	0.08	0.05	0.10	0.25	0.06	0.09	0.08	0.07	0.08	0.07
Cl	0.02	0.03	0.02	0.00	0.00	0.01	0.03	0.01	0.03	0.02
F	0.01	0.00	0.02	0.00	0.04	0.02	0.02	0.02	0.02	0.00
Parts per million										
Sc_2O_3	2.27	4.61	5.34	10.83	1.37	5.36	0.65	5.81	4.31	1.84
Cr_2O_3	2.37	17.16	5.17	93.30	24.80	7.18	6.57	2.72	5.14	0.00
MnO	32	45	53	680	201	290	88	185	347	94
CoO	0.29	0.27	0.39	10.03	4.01	3.03	2.47	1.20	1.44	0.47
Rb_2O	16	2	62	124	76	165	180	192	183	167
SrO	665	576	463	610	355	89	399	52	75	291
ZrO_2	153	163	245	175	148	191	110	126	96	54
BaO	102	94	122	697	829	949	1725	690	587	2049
La_2O_3	70.94	55.09	69.60	49.80	32.51	45.70	32.59	33.87	16.69	27.26
Ce_2O_3	102.12	94.99	133.76	108.63	50.11	76.18	55.82	57.05	34.62	44.78
Nd_2O_3	26.36	35.47	50.19	41.09	15.93	25.33	19.66	22.30	13.09	21.40
Sm_2O_3	3.77	7.02	8.60	7.40	2.93	4.55	2.50	5.22	2.66	4.61
Eu_2O_3	0.972	0.639	0.697	1.325	0.709	0.705	0.511	0.524	0.348	1.145
Gd_2O_3	2.26	5.61	9.11	4.98	1.85	4.33	1.77	5.50	3.58	4.98
Tb_2O_3	0.045	0.751	1.478	0.612	0.243	0.607	0.208	0.880	0.600	0.763
Dy_2O_3	1.34	4.24	9.99	3.58	1.34	3.31	1.20	6.15	4.09	5.03
Tm_2O_3	1.678	0.195	0.629	0.195	0.046	0.127	0.069	0.448	0.332	0.442
Yb_2O_3	0.24	1.09	4.18	1.22	0.25	0.72	0.48	3.07	2.37	3.23
Lu_2O_3	0.026	0.137	0.591	0.171	0.026	0.082	0.064	0.446	0.330	0.487
HfO_2	3.28	4.70	6.06	4.02	4.22	5.32	3.36	3.67	2.99	1.17
Ta_2O_5	0.11	0.81	0.90	1.58	0.48	0.95	0.39	1.50	2.47	0.52
ThO_2	40.50	50.14	57.78	22.50	22.05	34.87	13.59	28.06	17.22	16.70
Norms (weight percent)										
Q	49.27	47.79	61.36	18.75	29.38	32.78	30.20	32.73	34.13	24.81
C	0.00	0.15	1.78	0.03	1.25	1.60	0.73	1.44	1.07	0.77
Or	0.53	0.48	3.02	19.61	15.46	25.23	34.48	27.99	23.12	29.60
Ab	16.79	22.73	17.99	37.44	38.31	28.31	27.02	30.62	35.43	37.04
An	31.25	27.59	14.45	13.32	10.83	7.38	4.87	4.34	3.41	6.13
Hl	0.03	0.05	0.03	0.00	0.00	0.02	0.05	0.02	0.05	0.03
Wo	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
En	0.40	0.23	0.46	4.26	1.43	1.11	0.73	0.50	0.77	0.43
Fs	0.83	0.43	0.45	5.24	2.59	3.00	1.55	1.98	1.64	0.96
Il	0.29	0.44	0.19	0.74	0.55	0.33	0.15	0.19	0.15	0.06
Tn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ap	0.19	0.12	0.24	0.60	0.14	0.22	0.19	0.17	0.19	0.17
Fr	0.01	0.00	0.02	0.00	0.07	0.02	0.03	0.03	0.03	0.00

TABLE 4.—*Statistical summary of chemical data for 29 samples of granitic rocks from the Granite Mountains, Wyo.,*

	Mean	Standard deviation	Minimum	Maximum
	Weight percent			
SiO_2	73.75	2.16	67.44	76.85
Al_2O_3	14.40	.72	13.36	16.00
FeO	1.40	.92	.36	3.88
MgO	.33	.30	.00	1.21
CaO	1.04	.72	.18	2.90
Na_2O	3.66	.41	2.97	4.62
K_2O	4.97	.92	2.80	7.20
TiO_2	.16	.16	.00	.72
P_2O_5	.07	.05	.01	.24
Cl	.02	.02	.00	.07
F	.02	.02	.00	.07
	Parts per million			
Sc_2O_3	4.25	2.27	3.40	8.18
Cr_2O_3	14.81	14.81	.70	74.66
MnO	192	106	24	493
CoO	2	3	0	11
Rb_2O	178	53	89	260
SrO	176	159	19	650
ZrO_2	182	114	14	425
BaO	744.48	490.57	49.09	2067.76
La_2O_3	58.58	43.67	5.54	159.02
Ce_2O_3	102.47	81.12	7.60	283.00
Nd_2O_3	37.11	28.23	2.87	100.83
Sm_2O_3	6.08	4.46	.47	15.52
Eu_2O_3	.67	.46	.06	2.34
Gd_2O_3	5.08	3.91	.70	15.54
Tb_2O_3	.74	.57	.10	2.27
Dy_2O_3	4.42	3.40	.46	14.30
Tm_2O_3	.28	.21	.03	.78
Yb_2O_3	1.88	1.49	.18	5.69
Lu_2O_3	.28	.24	.02	.91
HfO_2	4.78	2.55	.60	10.47
Ta_2O_5	.60	.35	.01	1.47
ThO_2	38.97	24.52	1.48	79.67

TABLE 5.—*Proportions of variances accounted for by the five-factor solutions developed from data for 29 samples with 38 and 33 variables*

[Leaders (- - -)indicate no value]

Constituent	38 variables	33 variables
SiO_2	0.913	0.953
Al_2O_3	0.815	0.815
Fe_2O_3	0.634	---
FeO	0.697	0.928
MgO	0.903	0.908
CaO	0.921	0.935
Na_2O	0.814	0.885
K_2O	0.785	0.819
TiO_2	0.886	0.860
P_2O_5	0.803	0.814
Cl	0.693	0.676
F	0.643	0.645
CO_2	0.176	---
H_2O	0.504	---
Sc_2O_3	0.750	0.799
Cr_2O_3	0.715	0.853
MnO	0.662	0.680
CoO	0.836	0.853
Rb_2O	0.686	0.761
SrO	0.907	0.884
ZrO_2	0.708	0.764
Cs_2O	0.282	---
BaO	0.742	0.729
La_2O_3	0.885	0.889
Ce_2O_3	0.932	0.901
Nd_2O_3	0.957	0.943
Sm_2O_3	0.972	0.974
Eu_2O_3	0.881	0.860
Gd_2O_3	0.927	0.933
Tb_2O_3	0.901	0.899
Dy_2O_3	0.885	0.855
Tm_2O_3	0.892	0.823
Yb_2O_3	0.876	0.795
Lu_2O_3	0.861	0.770
HfO_2	0.772	0.798
Ta_2O_5	0.657	0.673
ThO_2	0.860	0.879
UO_2	0.212	---

TABLE 6.—*Compositions of parent magmas and end members for the factor models*

Constitu-ent	Parent magmas		End members			
	Model A	Model B	IR-8+	IR-12+	IR-21+	SDNE-3+
Percent						
SiO_2	73.77	74.38	69.46	75.83	73.02	75.95
Al_2O_3	14.72	14.18	15.46	13.81	14.99	13.53
FeO	1.09	1.19	3.11	0.56	1.22	0.84
MgO	0.32	0.28	0.93	0.13	0.40	0.16
CaO	1.41	1.09	2.55	1.02	1.68	0.97
Na_2O	4.06	3.57	3.90	3.50	4.16	3.24
K_2O	4.16	4.89	3.61	4.84	4.00	4.97
TiO_2	0.15	0.14	0.44	0.08	0.19	0.09
P_2O_5	0.08	0.06	0.16	0.05	0.09	0.05
Cl	0.03	0.02	0.05	0.02	0.03	0.02
F	0.02	0.02	0.05	0.02	0.03	0.02
Parts per million						
Sc_2O_3	2.33	3.02	4.84	0.72	1.86	1.42
Cr_2O_3	1.00	13.25	27.43	6.82	4.00	11.37
MnO	113	144	208	67	130	58
CoO	2	2	8	1	3	1
Rb_2O	146	155	117	121	120	134
SrO	246	195	477	197	301	195
ZrO_2	180	156	335	91	172	123
BaO	966.83	840.03	1515.86	911.17	1071.86	955.52
La_2O_3	44.12	48.15	102.05	21.74	34.36	42.60
Ce_2O_3	72.21	80.39	178.29	27.48	52.56	66.46
Nd_2O_3	24.70	28.52	58.30	8.72	15.64	23.56
Sm_2O_3	3.63	4.42	7.51	0.97	1.65	3.44
Eu_2O_3	0.770	0.691	1.476	0.617	0.852	0.697
Gd_2O_3	2.66	3.49	4.85	0.44	0.73	2.49
Tb_2O_3	0.362	0.485	0.607	0.028	0.081	0.301
Dy_2O_3	2.13	2.85	3.15	0.14	0.52	1.56
Tm_2O_3	0.115	0.485	0.104	0.009	0.037	0.053
Yb_2O_3	0.71	1.12	0.47	0.06	0.26	0.24
Lu_2O_3	0.090	0.164	0.034	0.010	0.037	0.301
HfO_2	4.88	4.12	8.00	2.58	4.58	3.24
Ta_2O_5	0.60	0.49	0.61	0.29	0.45	0.38
ThO_2	26.98	30.33	45.16	12.39	15.78	25.56
Norms (weight percent)						
Q	30.28	31.52	24.51	34.37	28.84	35.35
C	1.19	1.20	0.93	1.08	1.00	1.18
Z	0.03	0.02	0.05	0.01	0.03	0.02
Or	24.62	28.93	21.37	28.61	23.63	29.38
Ab	34.14	30.04	32.67	29.49	34.96	27.28
An	6.54	5.04	11.66	4.81	7.82	4.56
Hl	0.05	0.04	0.07	0.03	0.05	0.03
En	0.80	0.71	2.31	0.32	1.00	0.41
Fs	1.77	1.97	5.03	0.92	1.95	1.39
Il	0.29	0.27	0.83	0.15	0.36	0.18
Ap	0.19	0.15	0.37	0.11	0.22	0.12
Fr	0.03	0.03	0.06	0.02	0.04	0.03

TABLE 7.—*Mixing proportions for model A*

Sample No.	Parent magma	IR-8+	IR-12+	IR-21+	SDNE-3+
SDNE-4	4.3164	3.2435	10.8313	-8.7660	-8.6252
SD-11	0.9695	0.2717	0.3598	-0.0499	-0.5511
GM1-67	9.6008	3.4394	13.7188	-14.4637	-11.2952
GM1-374	22.6205	9.7932	43.4927	-39.1160	-35.7903
GM1-163	13.5015	4.9882	20.1557	-21.1855	-16.4599
DDH-3	11.6548	5.6085	24.9539	-21.1699	-20.0473
GM1-8	13.2562	5.1777	21.5251	-21.2848	-17.6742
PD-5	5.0202	1.2091	2.2280	-5.9584	-1.4989
GM2-1550	12.8324	7.4746	31.9287	-26.5619	-24.6737
BRG-5	6.9359	2.5436	11.4486	-11.0240	-8.9041
GM1-126	10.5023	3.7958	15.4475	-16.1235	-12.6221
GM2-65	10.4998	3.9475	15.8444	-16.1487	-13.1430
GM2-125	10.4888	3.8053	15.9017	-16.3347	-12.8612
SD-16	6.5323	2.2052	11.4074	-9.8071	-9.3378
GM1-285	16.4833	6.9116	31.3047	-28.2720	-25.4276
SM-3	3.5660	1.2386	5.3953	-5.2280	-3.9719
SDNE-9	1.4267	0.3026	1.5121	-1.6613	-0.5802
GM1-841	21.6709	10.0714	48.3344	-39.5144	-39.5623
GM1-814	4.2836	0.5469	4.7183	-4.1774	-4.3713
GM1-581	7.2342	2.2446	11.6783	-10.4375	-9.7195
GM1-825	16.9425	7.6460	37.1089	-30.3949	-30.3024
GM1-1011	19.9388	9.6848	45.5271	-37.8111	-36.3396
GM1-739	22.6022	10.3566	49.6258	-41.2863	-40.2984
GM1-1325	3.9848	1.9421	8.9517	-7.6786	-6.2000

TABLE 8.—*Mixing proportions for model B*

Sample No.	Parent magma	IR-8+	IR-12+	IR-21+	SDNE-3+
SDNE-4	0.8745	1.3209	2.3788	-1.4406	-2.1337
SD-11	0.1964	-0.1601	-1.5386	1.5954	0.9069
GM1-67	1.9451	-0.8369	-5.0816	1.8298	3.1436
GM1-374	4.5829	-0.2823	-0.8032	-0.7266	-1.7708
GM1-163	2.7354	-1.0255	-6.2832	1.7279	3.8453
DDH-3	2.3613	0.4173	2.1313	-1.3905	-2.5194
GM1-8	2.6857	-0.7268	-4.4335	1.2125	2.2621
PD-5	1.0171	-1.0270	-7.6026	2.5614	6.0511
GM2-1550	2.5998	1.7589	6.8002	-4.7840	-5.3748
BRG-5	1.4052	-0.5458	-2.1335	0.7470	1.5270
GM1-126	2.1278	-0.8821	-5.1183	1.7000	3.1726
GM2-65	2.1273	-0.7293	-4.7166	1.6707	2.6479
GM2-125	2.1250	-0.8665	-4.6377	1.4660	2.9132
SD-16	1.3234	-0.7044	-1.3844	1.2790	0.4863
GM1-285	3.3395	-0.4303	-0.9732	-0.2981	-0.6379
SM-3	0.7225	-0.3497	-1.5877	0.8239	1.3910
SDNE-9	0.2891	-0.3328	-1.2817	0.7601	1.5654
GM1-841	4.3905	0.4189	5.8980	-2.7365	-6.9709
GM1-814	0.8678	-1.3610	-3.6699	3.0922	2.0708
GM1-581	1.4656	-0.9777	-2.4879	1.8397	1.1602
GM1-825	3.4325	0.0996	3.9318	-1.6417	-4.8222
GM1-1011	4.0396	0.8038	6.4825	-3.9728	-6.3531
GM1-739	4.5792	0.2893	5.3657	-2.9278	-6.3063
GM1-1325	0.8073	0.1672	1.1486	-0.9160	-0.2072

TABLE 9.—*Proportional differences between the original chemical data and data represented by the factor solution, for the 29 samples used to develop the solution*

[Leaders (- -) indicate indeterminate due to original value of zero]

Sample No.	IR-8	SDNE-4	IR-11	SD-11	GM1-67	GM1-374	GM1-163	DDH-3	IR-21	GM1-8
SiO2	0.01	0.01	-0.01	0.01	0.01	-0.00	0.00	-0.00	-0.00	0.00
Al2O3	-0.01	-0.01	0.03	0.02	0.00	-0.00	-0.03	-0.01	-0.01	-0.01
FeO	-0.03	0.10	-0.01	-0.09	-0.19	-0.06	0.38	0.18	0.06	-0.00
MgO	-0.05	-0.16	0.01	-0.12	0.34	-0.11	-0.18	-0.34	0.07	-0.10
CaO	0.10	-0.08	0.03	-0.19	0.02	-0.32	0.17	0.32	-0.16	0.05
Na2O	-0.01	0.01	-0.01	0.00	0.03	0.03	-0.10	0.03	0.02	0.08
K2O	-0.01	-0.06	0.12	-0.01	-0.05	0.14	-0.04	0.00	0.10	-0.04
TiO2	-0.25	0.26	-0.18	0.14	0.11	-0.20	0.09	0.26	0.06	0.42
P2O5	-0.21	-0.00	-0.02	-0.07	-0.30	1.89	4.88	0.13	0.96	0.12
Cl	0.08	-0.05	-0.24	0.15	-0.29	-0.44	-0.19	- -	-0.13	-0.38
F	-0.21	-0.24	0.07	-0.02	-0.39	- -	-0.29	- -	-0.03	0.56
Sc2O3	0.37	-0.22	-0.05	-0.10	-0.16	0.08	0.07	-0.25	0.26	-0.16
Cr2O3	0.19	0.04	0.16	0.10	0.50	0.05	-0.47	0.15	-0.47	1.12
MnO	-0.26	0.06	-0.23	0.15	0.50	-0.12	1.48	0.45	0.25	-0.13
CoO	-0.07	-0.19	-0.16	- -	0.26	0.42	0.85	0.77	-0.10	0.26
Rb2O	-0.03	-0.05	0.07	0.21	-0.12	0.03	8.56	-0.17	0.19	-0.07
SrO	-0.09	-0.16	-0.01	-0.06	0.65	-0.67	-0.28	-0.03	-0.01	-0.13
ZrO2	-0.06	0.33	-0.08	0.25	-0.06	-0.01	0.02	0.49	-0.09	-0.04
BaO	-0.13	-0.09	0.03	-0.00	0.06	-0.64	-0.04	0.01	-0.08	-0.27
La2O3	-0.21	-0.09	-0.05	-0.00	0.15	-0.01	-0.20	0.67	0.77	0.23
Ce2O3	-0.16	-0.02	-0.17	0.13	0.18	-0.01	-0.23	0.74	0.91	0.22
Nd2O3	-0.11	-0.01	-0.13	0.04	0.06	-0.11	-0.18	0.61	0.40	0.16
Sm2O3	-0.11	-0.02	-0.01	0.08	0.12	-0.27	-0.07	0.25	-0.38	0.05
Eu2O3	-0.24	0.17	-0.06	0.52	0.10	0.03	-0.21	0.07	-0.06	-0.03
Gd2O3	-0.11	-0.08	0.20	0.17	0.02	-0.02	-0.19	0.04	-1.23	-0.01
Tb2O3	-0.15	-0.01	0.22	0.05	0.08	-0.05	-0.20	0.04	-1.50	-0.07
Dy2O3	-0.24	-0.06	0.21	0.01	0.11	-0.19	-0.26	0.08	-1.45	-0.10
Tm2O3	-0.60	-0.01	-0.31	-0.05	-0.04	-0.24	-0.23	0.51	-1.35	0.01
Yb2O3	-1.02	0.01	-0.64	-0.00	-0.07	-0.26	-0.23	0.75	-1.33	0.18
Lu2O3	-1.71	0.12	-1.11	-0.10	-0.01	-0.09	-0.21	1.16	-1.39	0.38
HfO2	-0.11	0.16	-0.10	0.10	-0.05	0.19	0.21	0.08	-0.14	-0.02
Ta2O5	-0.07	-0.09	-0.04	-0.02	0.15	-0.25	0.54	-0.31	1.03	0.10
ThO2	0.09	-0.27	0.00	-0.17	-0.09		0.32	1.29	1.04	0.00
Communality	0.992	0.992	0.994	0.989	0.991	0.986	0.967	0.978	0.988	0.991

TABLE 9.—*Proportional differences between the original chemical data and data represented by the factor solution, for the 29 samples used to develop the solution—Continued*

Sample No.	PD-5	GM2-1550	BRG-5	GM1-126	GM2-65	GM2-125	SD-16	GM1-285	SM-3
SiO_2	0.00	-0.00	0.01	0.00	-0.00	-0.00	-0.01	0.00	-0.00
Al_2O_3	-0.02	-0.00	-0.01	0.00	0.00	-0.04	0.03	-0.01	0.02
FeO	0.43	-0.20	-0.13	0.02	-0.17	-0.14	-0.17	-0.08	-0.10
MgO	0.30	2.38	-0.09	0.04	0.29	-0.10	-0.03	-0.24	-0.07
CaO	-0.02	-0.01	-0.05	-0.08	0.18	-0.07	-0.15	-0.35	-0.01
Na_2O	-0.03	-0.12	0.07	0.02	-0.00	-0.01	-0.01	-0.01	0.02
K_2O	-0.10	0.07	0.09	-0.02	0.01	0.02	0.09	-0.04	0.02
TiO_2	-0.09	1.38	0.06	0.09	0.51	0.03	-0.08	-0.43	-0.27
P_2O_5	0.38	-0.03	-0.44	-0.09	-0.12	-0.32	-0.03	0.40	-0.16
Cl	—	—	-0.19	-0.04	-0.22	-0.15	0.90	0.06	0.07
F	—	—	-0.38	-0.19	0.00	-0.31	0.22	—	-0.12
Sc_2O_3	0.19	1.13	0.10	-0.15	0.23	-0.08	-0.03	-0.07	-0.03
Cr_2O_3	-0.07	-0.35	3.24	0.73	0.61	0.08	-1.32	-0.12	0.64
MnO	-0.35	0.28	-0.28	-0.07	0.10	-0.27	-0.34	0.35	-0.30
CoO	0.35	0.35	-0.12	0.06	-0.49	-0.36	-0.23	-0.16	-0.14
Rb_2O	0.06	-0.24	-0.17	-0.06	0.04	-0.11	-0.07	-0.06	-0.05
SrO	-0.05	3.17	-0.35	0.24	0.60	-0.07	0.37	-0.62	0.19
ZrO_2	-0.03	-0.56	-0.02	-0.03	0.30	-0.08	0.43	0.68	-0.23
BaO	0.54	1.57	-0.40	-0.10	0.18	0.02	0.81	-0.47	0.19
La_2O_3	-0.22	0.66	0.10	0.17	0.11	0.07	0.61	0.00	0.13
Ce_2O_3	-0.20	0.57	0.05	0.19	0.14	0.08	0.65	0.07	0.10
Nd_2O_3	-0.15	0.31	-0.02	0.06	0.11	0.09	0.36	0.15	0.10
Sm_2O_3	-0.02	0.29	-0.09	0.01	-0.07	-0.03	0.26	0.05	0.26
Eu_2O_3	0.12	0.28	-0.18	0.07	0.43	-0.11	-0.02	-0.34	-0.09
Gd_2O_3	0.33	0.28	-0.11	0.00	0.11	-0.09	0.33	-0.08	0.53
Tb_2O_3	0.58	0.39	-0.18	-0.03	-0.13	-0.07	0.45	-0.12	0.62
Dy_2O_3	0.78	0.86	-0.18	-0.01	-0.03	0.03	0.49	-0.21	0.61
Tm_2O_3	0.90	2.87	-0.18	0.06	0.11	0.10	0.86	-0.22	0.11
Yb_2O_3	0.88	4.64	-0.23	0.17	0.11	0.02	1.01	-0.20	-0.06
Lu_2O_3	0.52	5.89	-0.21	0.18	0.12	-0.02	1.24	-0.15	0.14
HfO_2	0.19	-0.12	-0.11	-0.05	0.28	-0.03	0.10	-0.12	-0.00
Ta_2O_5	-0.23	-0.53	-0.20	0.15	0.23	-0.15	-0.30	0.08	-0.30
ThO_2	0.07	0.11	-0.04	-0.08	0.09	-0.00	-0.23	-0.05	-0.23
Communality	0.970	0.939	0.989	0.997	0.990	0.994	0.983	0.990	0.991

Sample No.	SDNE-9	SDNE-3	GM1-841	GM1-814	GM1-581	IR-12	GM1-825	GM1-1011	GM1-739	GM1-1325
SiO_2	0.00	-0.00	0.02	0.00	-0.00	0.00	-0.01	0.00	-0.01	-0.00
Al_2O_3	0.00	-0.01	-0.05	-0.00	-0.02	-0.01	0.01	0.01	0.06	-0.00
FeO	-0.03	0.23	0.81	-0.53	0.44	-0.00	0.10	0.01	-0.04	-0.38
MgO	-0.16	-0.36	0.54	---	---	0.20	0.06	-0.16	-0.57	-0.18
CaO	-0.03	0.11	0.72	0.47	0.27	-0.08	0.60	0.10	-0.65	0.22
Na_2O	0.02	0.02	0.01	-0.02	-0.03	0.01	-0.03	0.06	-0.01	-0.03
K_2O	-0.08	0.04	-0.17	-0.02	0.02	-0.01	0.04	-0.05	0.14	-0.01
TiO_2	0.13	-0.16	0.56	-0.16	---	0.56	0.30	-0.53	-0.56	-0.41
P_2O_5	0.02	-0.14	0.29	-0.16	0.15	0.10	0.22	0.12	-0.49	0.98
Cl	-0.32	-0.04	-0.25	1.28	-0.07	-0.34	0.04	-0.83	---	0.47
F	-0.16	---	---	0.35	0.13	0.58	---	---	---	-0.75
Sc_2O_3	-0.10	-0.00	-0.00	5.11	0.29	-0.85	-0.30	-0.15	0.52	0.02
Cr_2O_3	1.18	3.72	0.24	-7.88	-1.94	6.77	-0.17	0.38	0.49	-0.29
MnO	-0.04	-0.70	0.20	0.12	1.05	0.81	0.06	-0.04	-0.33	-1.00
CoO	-0.25	0.36	2.43	-0.99	-0.29	-0.52	-0.22	-0.66	-2.81	0.12
Rb_2O	0.02	0.02	-0.05	-0.18	0.14	0.12	-0.01	0.06	0.10	0.13
SrO	-0.09	-0.22	-0.26	2.28	0.06	-0.26	1.39	-0.55	-2.09	1.56
ZrO_2	0.29	0.51	1.59	-0.57	0.39	0.40	1.59	0.35	-0.46	0.11
BaO	0.35	-0.31	-0.59	1.13	-0.03	-0.27	2.76	-0.18	-0.78	2.24
La_2O_3	0.02	-0.40	-1.98	0.08	-0.09	0.23	-1.17	0.03	-1.30	0.30
Ce_2O_3	-0.09	-0.33	-2.68	0.15	-0.14	-0.07	-1.66	0.09	-1.39	0.21
Nd_2O_3	-0.16	-0.20	-3.06	0.46	-0.05	-0.17	-1.45	0.32	-1.01	0.17
Sm_2O_3	-0.18	0.07	-1.40	1.12	-0.12	-0.87	-0.08	0.49	-0.27	-0.08
Eu_2O_3	-0.03	-0.21	-0.48	0.66	-0.27	-0.14	1.83	0.08	-0.88	1.22
Gd_2O_3	-0.04	0.26	-0.35	1.08	-0.07	-1.54	0.30	0.24	-0.04	-0.07
Tb_2O_3	-0.01	0.60	-0.03	1.25	-0.12	-1.97	0.46	0.02	0.02	-0.05
Dy_2O_3	-0.03	0.43	0.12	1.30	-0.20	-1.99	0.56	-0.07	-0.06	-0.02
Tm_2O_3	0.12	-1.85	0.11	1.66	-0.26	-2.24	0.39	-0.13	-0.21	0.40
Yb_2O_3	0.14	-2.77	0.07	1.77	-0.24	-2.33	0.43	0.09	-0.27	0.65
Lu_2O_3	0.14	-3.99	0.09	1.94	-0.26	-2.56	0.50	-0.11	-0.32	1.24
HfO_2	0.09	0.46	1.18	0.69	-0.53	0.12	2.19	-0.19	-0.31	-0.22
Ta_2O_5	-0.23	0.71	2.99	-0.34	2.38	18.19	-0.16	-0.56	0.15	0.32
ThO_2	0.77	-0.31	-0.45	0.24	-0.01	0.25	4.53	0.48	-0.32	-0.04
Communality	0.993	0.980	0.977	0.955	0.970	0.986	0.988	0.992	0.969	0.963

TABLE 10.—*Proportional differences between the original chemical data and data derived from the factor solution, for 20 samples of altered granitic rocks and rocks of uncertain relation to the main intrusion*

[Leaders (- - -) indicate indeterminate due to original value of zero]

Sample No.	GM1-201	GM1-159	GM1-165	GM1-954	GM1-757	GM1-1156	GR-5	GR-3	GR-4	MS-6
SiO_2	-0.04	-0.04	-0.05	-0.08	-0.05	-0.05	-0.62	-0.02	-0.04	-0.04
Al_2O_3	0.06	0.12	0.13	0.21	0.21	0.14	0.14	0.00	-0.08	-0.00
FeO	0.63	-0.31	-0.17	-0.36	-1.48	-0.45	67.82	0.17	2.65	7.71
MgO	0.33	-0.19	0.56	0.72	-0.69	0.27	7.73	0.19	1.38	1.23
CaO	9.25	4.16	5.21	-0.74	7.48	-0.04	-0.10	-0.22	-0.65	-0.62
Na_2O	-0.25	-0.21	-0.29	0.04	-0.27	-0.17	10.31	0.02	2.23	0.48
K_2O	1.28	3.45	8.67	2.27	5.06	4.06	-6.54	0.59	3.13	3.87
TiO_2	0.32	-0.16	-0.52	1.05	-1.00	-0.51	7.25	0.14	0.59	0.54
P_2O_5	2.41	0.42	2.00	-0.38	1.80	5.10	14.03	0.74	1.67	0.15
Cl	0.92	0.01	0.22	-0.83	-0.03	1.60	21.16	0.93	1.21	0.31
F	0.00	0.31	---	-1.37	-0.68	---	---	-0.31	---	2.97
Sc_2O_3	-0.43	-0.29	-0.34	-0.37	-0.80	-0.34	15.02	-0.09	-0.02	-0.15
Cr_2O_3	-3.95	-7.34	-2.05	2.51	-2.84	-1.52	6.51	-0.47	0.91	1.49
MnO	17.67	2.23	3.25	-0.58	0.52	-0.08	60.95	0.38	0.58	-0.08
CoO	1.97	0.37	2.42	0.49	-2.65	0.32	245.50	0.79	28.89	13.98
Rb_2O	7.46	4.11	11.60	2.00	7.06	4.26	-2.94	1.37	2.17	3.14
SrO	4.52	3.96	3.27	-2.68	13.67	8.19	1.76	0.01	0.09	0.05
ZrO_2	1.03	0.19	1.01	-0.79	0.85	1.21	7.68	0.53	1.36	0.11
BaO	6.54	6.61	0.69	-3.80	9.62	15.09	23.93	0.53	6.55	9.03
La_2O_3	-0.60	-0.17	-0.41	-1.04	-1.38	0.27	26.95	0.40	0.70	0.61
Ce_2O_3	-0.48	-0.10	-0.32	-0.37	-2.00	0.12	33.47	0.46	1.01	0.79
Nd_2O_3	-0.43	-0.17	-0.33	0.08	-1.82	0.13	23.77	0.40	1.07	0.61
Sm_2O_3	-0.33	-0.10	-0.30	1.46	-1.11	-0.06	6.25	-0.02	0.61	0.48
Eu_2O_3	-0.31	0.29	-0.00	-1.95	2.66	1.82	41.71	0.56	0.16	0.41
Gd_2O_3	-0.05	-0.25	-0.42	0.81	-0.81	-0.27	-2.29	-0.22	0.54	0.33
Tb_2O_3	0.12	-0.13	-0.16	0.27	-0.48	-0.18	-1.45	-0.30	0.29	0.10
Dy_2O_3	0.32	-0.05	-0.12	0.00	-0.19	-0.02	0.06	-0.38	0.05	-0.07
Tm_2O_3	0.73	0.08	0.11	-0.41	-0.21	0.33	4.63	-0.37	-1.09	-0.95
Yb_2O_3	0.84	0.12	0.24	-0.47	-0.24	0.55	7.50	-0.37	-1.90	-1.42
Lu_2O_3	0.90	0.15	0.25	-0.51	-0.38	0.72	10.14	-0.35	-3.02	-2.07
HfO_2	0.98	0.24	0.28	-0.57	0.09	1.01	5.77	0.32	0.85	-0.04
Ta_2O_5	6.71	0.66	0.99	-0.68	-0.23	0.08	1.76	0.24	-0.38	2.01
ThO_2	-0.25	-0.37	-0.26	0.77	0.15	0.30	-0.12	-0.25	2.20	0.21
Communality	0.790	0.861	0.785	0.778	0.753	0.799	0.467	0.963	0.709	0.803

Sample No.	SD-8	MS-1	BRG-1	TCM-2	DDH-4	SD-1	SDNE-12	SD-4	SD-6	SD-17
SiO_2	-0.04	-0.05	-0.06	-0.03	-0.02	-0.01	0.02	-0.00	-0.01	0.03
Al_2O_3	-0.02	-0.01	0.15	0.05	0.01	0.01	-0.02	0.02	0.09	-0.05
FeO	2.94	4.11	2.56	0.30	0.11	0.00	-0.09	-0.25	-0.52	0.05
MgO	3.00	5.92	-0.24	-0.28	0.07	0.01	-0.33	-0.21	-0.71	-0.05
CaO	-0.70	-0.63	-0.78	-0.16	-0.11	-0.18	-0.00	-0.34	-0.11	-0.26
Na_2O	0.77	0.38	0.31	-0.08	-0.03	0.11	0.05	0.07	-0.00	-0.04
K_2O	43.17	43.01	8.82	0.44	0.46	0.10	-0.16	0.07	0.20	-0.08
TiO_2	1.07	0.29	-0.20	0.48	-0.02	0.26	0.36	-0.27	-0.55	1.48
P_2O_5	0.47	1.39	-0.60	-0.28	0.98	-0.06	-0.32	-0.35	-0.46	-0.23
Cl	0.86	0.36	-0.10	---	---	1.55	-0.30	0.61	-0.39	0.04
F	2.70	---	-0.08	---	-0.20	0.13	-0.11	-0.49	-0.48	---
Sc_2O_3	0.45	-0.32	-0.44	-0.16	1.27	-0.16	0.73	-0.25	-0.27	0.35
Cr_2O_3	7.28	-0.44	0.75	-0.35	-0.56	1.41	0.79	0.37	-2.41	---
MnO	2.43	0.34	-1.26	-0.20	0.02	-0.33	-0.11	-0.02	-0.58	0.68
CoO	17.16	18.50	2.01	0.01	0.16	0.16	-0.52	-0.31	-0.94	0.48
Rb_2O	6.40	59.60	2.04	0.12	0.56	0.02	-0.33	0.10	0.08	-0.01
SrO	-0.42	-0.31	-0.68	-0.28	0.02	1.63	-0.46	0.56	0.21	-0.49
ZrO_2	0.80	0.92	-0.10	0.73	0.45	0.14	-0.01	0.27	0.44	1.24
BaO	12.95	14.89	7.31	0.42	0.37	-0.06	-0.44	-0.29	-0.13	-0.69
La_2O_3	0.27	0.86	0.44	0.65	0.36	0.51	-0.05	0.45	0.85	-0.29
Ce_2O_3	0.52	0.86	0.31	0.38	0.44	0.59	-0.21	0.54	0.52	-0.35
Nd_2O_3	0.98	0.72	0.33	0.12	0.33	0.69	-0.26	0.54	0.63	-0.51
Sm_2O_3	0.86	0.23	0.29	-0.25	-0.25	0.46	-0.30	0.24	0.63	-0.57
Eu_2O_3	0.30	1.07	0.18	-0.04	0.41	0.18	0.36	-0.19	0.06	-0.60
Gd_2O_3	1.08	0.07	-0.00	-0.24	-0.45	0.22	-0.44	0.08	0.15	-0.63
Tb_2O_3	11.72	-0.00	-0.19	-0.05	-0.45	0.23	-0.54	0.02	0.07	-0.60
Dy_2O_3	1.11	-0.12	-0.36	0.08	-0.33	0.32	-0.62	-0.10	0.00	-0.57
Tm_2O_3	-0.97	-0.67	-0.67	0.93	0.75	0.97	-0.78	-0.18	-0.12	-0.56
Yb_2O_3	-0.69	-1.02	-0.79	1.38	1.43	1.26	-0.84	-0.19	-0.15	-0.55
Lu_2O_3	-2.48	-1.59	-0.93	1.99	2.81	1.82	-0.87	-0.17	-0.08	-0.52
HfO_2	1.03	0.64	-0.08	0.74	0.31	0.04	-0.14	0.25	0.41	2.12
Ta_2O_5	4.37	-0.00	-0.04	-0.85	-0.04	-0.35	-0.27	-0.49	-0.70	0.04
ThO_2	0.08	0.07	0.18	0.36	-0.20	0.20	0.19	0.51	0.83	0.09
Communality	0.609	0.770	0.795	0.911	0.958	0.976	0.972	0.971	0.890	0.936