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Interpretation of geochemical data from panned concentrates of wadi sediments using R-mode factor analysis, Jabal Habashi quadrangle, sheet 26F, Kingdom of Saudi Arabia

by

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ABSTRACT

Panned-concentrate samples from wadi sediments were collected over terranes of Precambrian age intrusive, volcanic, sedimentary, and metamorphic rocks, within the Jabal Habashi quadrangle, sheet 26F, Kindgom of Saudi Arabia. Multivariate analysis of the chemical data indicates that a significant base-metal association occurs in three areas within the quadrangle. An association of strontium, barium, and calcium possibly indicates areas of hydrothermal alteration. Three other associations that were found define the major rock lithologies: niobium-yttrium-lanthanum outlines granitic terranes; magnesium-nickel indicates mafic rocks; and cobalt-vanadium-chromium have an indefinite relation with units mapped as graywacke in the central part of the quadrangle.

INTRODUCTION

Results of preliminary geologic mapping (see figure 1, Cole, written commun., 1982) and evaluation of the economic geology (Smith, written commun., 1982) within the Jabal Habashi 1:250,000-scale quadrangle, Kingdom of Saudi Arabia, indicate at least three localities that are suitable for further investigation of mineral occurrences, namely the Meshaheed, the Shiaila, and the Buqaya areas.

The Meshaheed area has ancient workings for gold in quartz veins that are spatially related to granodiorite plutons that intrude graywacke of the Murdama Group. The Shiaila area contains ancient gold workings in quartz veins in sediments of the Murdama Group. Some veins are related to pyritized aplite dikes, and alteration of wall rocks is present locally. A west-southeast trending thrust-fault system occurs near Buqaya. Large areas of calcareous rocks southwest of this fault have been replaced by red-brown, brecciated, vuggy jasperoid. Scattered intrusions of gabbro also occur in the area.

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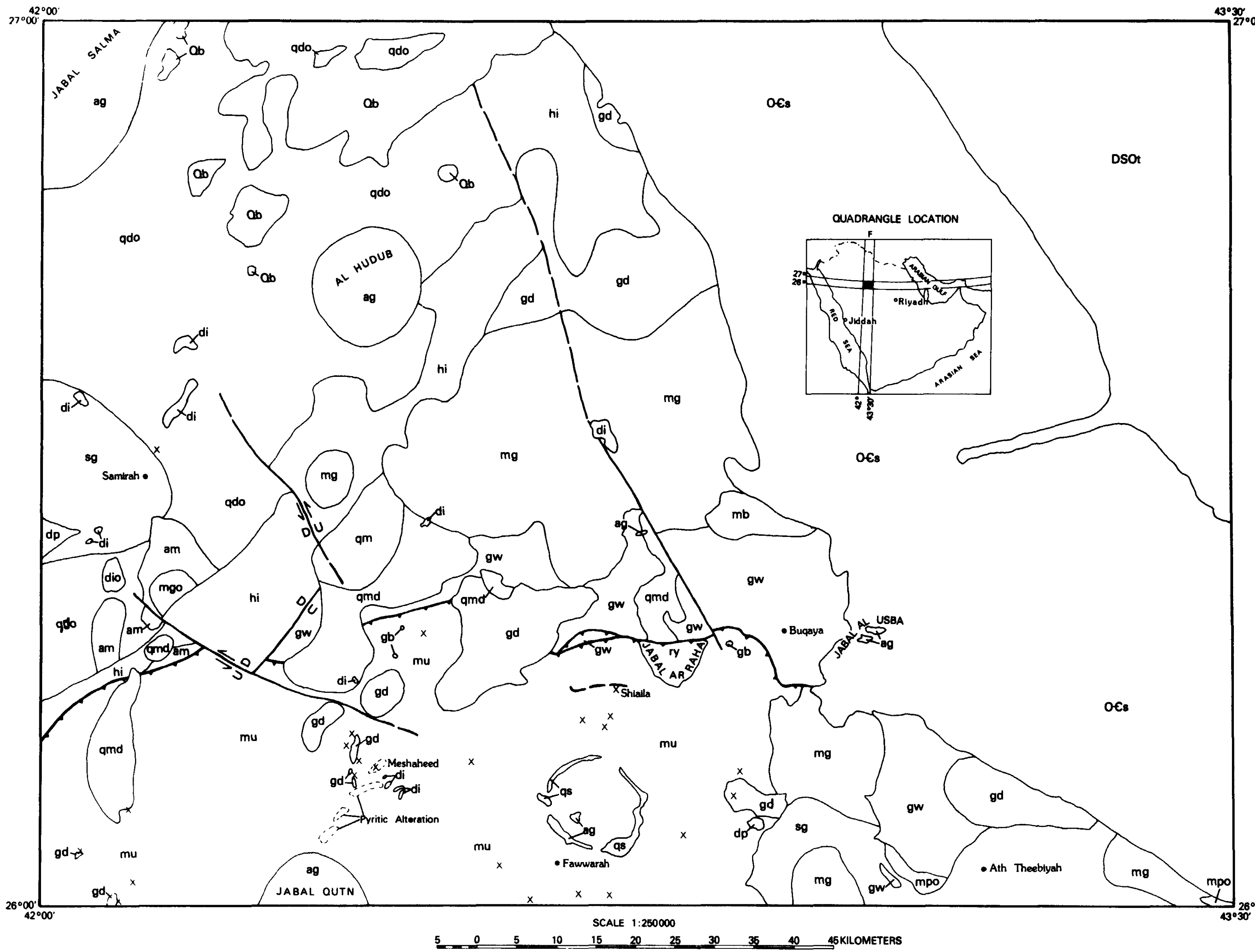

Figure 1.--Geologic map of the Jabal Habashi quadrangle, 26F, Kingdom of Saudi Arabia (from Cole, written commun., 1982).

EXPLANATION

[Surficial deposits not shown]

PHANEROZOIC ROCKS

Qb	Basalt and basalt tephra deposits
Dsot	Tabuk Formation
Oes	Saq Sandstone

YOUNGER IGNEOUS ROCKS (PRECAMBRIAN)

qs	Quartz syenite
ag	Alkali feldspar granite
di	Hornblende diorite and gabbro
dp	Dacite porphyry volcanic and hypabyssal rocks
sg	Syenogranite
mg	Monzogranite
qm	Quartz monzonite
gd	Granodiorite
qmd	Quartz monzodiorite
qd	Quartz diorite
gb	Gabbro

SEDIMENTARY AND VOLCANIC ROCKS (PRECAMBRIAN)

hi	Habashi Formation: lithic sandstone, conglomerate, and dacite
mu	Murdama Formation: fine-grained sandstone, silt-stone, shale all weakly calcareous; minor amounts of lime-stone, marble and basalt flows
gw	Fine-grained lithic graywacke
ry	Rhyolite and rhyolitic tuff
hb	Massive hornblende basalt

OLDER IGNEOUS ROCKS (PRECAMBRIAN)

qdo	Quartz diorite and tonalite
dio	Diorite
gbo	Gabbro
mgo	Monzogranite
mpo	Altered mafic plutonic rocks

METAMORPHIC ROCKS (PRECAMBRIAN)

am	Amphibolite, hornblende schist and gneiss, and quartzite
mb	Metabasalt

FAULT--Observed and inferred; relative movement indicated

THRUST FAULT

GEOLOGIC CONTACT

ANCIENT MINE

Heavy mineral concentrates were panned from wadi sediment samples representing several geologic units of Precambrian age that are exposed in the western two thirds of the quadrangle. The purpose of this report is to present an interpretation of the results of the chemical analyses of these samples using multivariate statistical procedures. Somewhat similar results to those of the multivariate procedures might also be obtained, at least in a qualitative way, from observation of single-element distribution maps, but only at a considerably larger investment of time than the multivariate approach. Even with that investment, the quantitative estimates of the importance of each element in an association would probably be missing. Further interpretation of the single-element data may be useful, however, once a satisfactory model is developed.

In this report we identify areas with potential for mineral occurrence and show areas where a clarification of uncertain identity of some geologic units is needed. Because of the apparent petrologic similarity of the rock types, alkali-feldspar granite (ag), quartz syenite (qs), and syenogranite (sg) as designated by Cole (written commun., 1982), we have used the term alkalic granite as a more general classification where appropriate. This usage aids in distinguishing between the compositions of the major rock types in the quadrangle.

Statistical procedures and interpretation are the responsibility of the authors, Michael S. Allen and Ronald R. Tidball; samples were collected by Rashid Samater. Spectrographic analyses of samples were performed at DGMR/USGS laboratory in Jiddah, Kingdom of Saudi Arabia. Gary Selner oversaw data entry into the USGS Rock Analysis Storage System (RASS) data file USGS-DF-04-13 and made magnetic tapes available. Through the interest of members of the Saudi Arabian Mission of the U.S. Geological Survey, the data were made available to the present authors.

The work on which this report was based was performed in accordance with a cooperative agreement between the U.S. Geological Survey and the Ministry of Petroleum and Mineral Resources.

METHODS

Wadi-sediment samples were collected from 1166 sites in the western two-thirds of the quadrangle. Generally, sample sites were uniformly distributed, except over certain areas with little or no topographic relief. The area sampled is underlain by rocks of Precambrian age; however, the large area in the northeastern part of the quadrangle, underlain by rocks of Phanerozoic age, was not sampled.

Concentrates were obtained by panning about 10K of unscreened material in drums of water in field camps.

Concentrates were air dried and then most magnetite and ilmenite was removed using a hand magnet. Concentrates were then submitted to the laboratory in Jiddah where they were pulvrized. These samples were then analyzed by 6-step semi-quantitative emission spectrography for 30 elements using the method of Grimes and Marazino, 1963. Reported precision is plus or minus one reporting interval at 68 percent confidence and two intervals at 95 percent confidence. Eight elements were not detected, or seldom detected, at their respective lower limits of determination: silver, arsenic, gold, bismuth, cadmium, antimony, tungsten, and zinc. Of the remaining 22 elements, the values for boron, beryllium, lanthanum, molybdenum, niobium, lead, tin, and strontium were censored (below detection limits) on the lower end of the scale by proportions ranging from 15 to 63 percent of the total number of samples. Censoring of 38 and 63 percent, respectively, was found at the upper end of the scale for zirconium and titanium.

Censored values at the lower end of the scale were replaced with arbitrary small values as follows: L (detected but less than the lower limit of determination) was replaced with a value equal to two steps below the lower limit; N (not detected) was replaced with a value equal to three steps below the lower limit. At the upper end of the scale, G (greater than the upper limit of determination) was replaced with a value two steps above the upper limit. The effect of these replacements on the final geologic interpretation is believed to be minimal because a trial run of the factor analysis, in which several highly censored elements were omitted, produced essentially the same results as those obtained from keeping these elements in the data set.

The data were transformed to logarithms because of the geometric analytical reporting scale. More rigorous treatments of factor analysis can be found in Davis, 1973 and Howarth and Sinding-Larson, 1983. Examples of factor analysis applied to geochemical exploration are presented by Saager and Sinclair, 1974, and Closs and Nichol, 1975. The data were analyzed by the multivariate procedure of R-mode factor analysis (Miesch, 1980, method 2) which is based on the correlation coefficients between the variables. Although the correlation coefficient expresses the association of one element to another, factor analysis takes account of all of the correlations simultaneously and seeks to identify several common associations of elements that best characterize the data. The procedure also provides a quantitative measure of the importance of each element in a given association. Each of these associations can often be related to a specific lithology or at least to a specific locality where the controlling features of the association might be inferred.

A plot of the communalities for each variable against the number of factors in the model is shown in a factor variance diagram (see figure 2). The diagram shows how much of the variance in each variable is being accounted for by a given factor model. The diagram aids in selecting the simplest model (smallest number of factors) that can be reasonably explained in geologic terms. Accordingly, a 5-factor model was selected, because of the geologic/geochemical meaningfulness and because the fifth factor is common (explains additional variance for several variables) whereas the sixth factor is unique (adds only one variable) for zirconium.

A varimax rotation of the factors was selected as optimum after examining the distribution of the factor scores derived by a principal components model and an oblique model.

The factor scores represent a multivariate index for each sample that incorporates a contribution from each of the variables in proportion to their individual importance. The factor scores for each factor have both positive and negative values with a mean of zero and standard deviation of one. A sample with a large score (either positive or negative) is one that has a composition similar to the theoretical composition of the factor. A factor may have both a positive association of elements and a negative association, which means that each association behaves oppositely to the other one. For example, factor 2 has a positive association comprised of cobalt, vanadium, and chromium and a negative association of beryllium. Samples with large concentrations of beryllium will be depleted in cobalt, vanadium, and chromium, and vice versa.

The scores are classified and plotted on factor maps as departures from the mean in units of the standard deviation, as follows:

Classes ..	Symbols
Negative values (less than mean) to 1 std. dev. above mean	-
1.0 std. dev. to 1.5 std. dev.	+
1.5 " " to 2.0 " "	*
2.0 " " to 2.5 " "	
Greater than 2.5 " " above the mean	

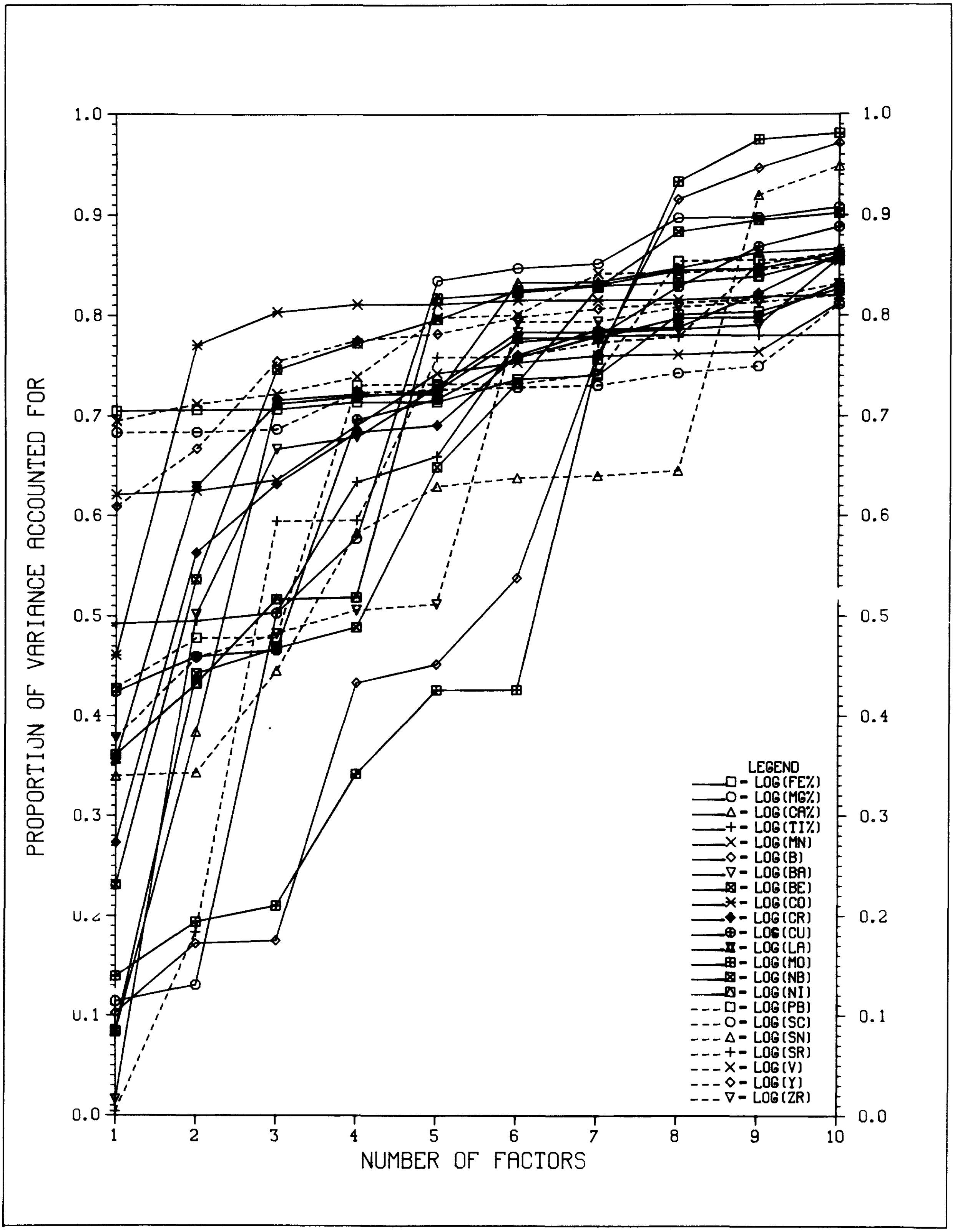

Figure 2.--Factor variance diagram.

Table 1.--Element associations for the 5-factor model in descending order of the factor loadings

[Dominant loadings enclosed in box]

Elements	Factors 1	2	3	4	5
Y	0.84				
Nb	.81				
La	.80				
Mn	.74	0.43			
Zr	.68				
Sc	.64	.41			
Fe	.64				
Ti	.60	.50			
Co		.75			
V	.57	.63			
Cr		.62			
Sr			0.86		
Ba			.79		
Ca			.72		
Pb				0.74	
Cu		.48		.67	
Sn	.40			.62	
B				.62	
Mo		.40		.45	
Mg					0.85
Ni					.77
Be		-.79			

Table 2.--Element associations for the 8-factor model in descending order of the factor loadings
[Dominant loadings enclosed in box]

Elements	Factors 1	2	3	4	5	6	7	8
Nb	0.87							
La	.83							
Y	.71					0.46		
Be		-0.91						
Sr			0.87					
Ba			.80					
Ca			.70					
B				0.92				
Mg					0.88			
Ni					.79			
Ti						.84		
Zr						.76		
Mn	.41					.70		
V						.61		
Sc						.61		
Co		.42				.54		
Fe						.51		0.50
Cr						.43	0.34	.39
Mo							.93	
Pb								.80
Cu								.80
Sn				.34				.46

Both the positive and negative associations for factor 2 are plotted. Symbols in the last class best indicate the locations of samples that contain the association of elements most similar to the factor.

Elements that are included in any association are those that have a significant correlation between variation in factor scores and the concentrations of each element, respectively. This correlation is equivalent to the factor loading. The magnitude of the loading measures the relative importance of each element in the association. For example, yttrium-niobium-lanthanum-manganese best characterize factor 1, with loadings of 0.84, 0.81, 0.80, and 0.74, respectively. Therefore, whatever factor 1 represents as a geologic control on this association, that control is best reflected by the distribution of yttrium and further modified by the distribution of niobium, and so forth.

For the purpose of examining the changes in the various associations, factor models ranging from four to eight factors were calculated. The associations for the 5- and 8-factor models are shown in tables 1 and 2. By increasing the number of factors some associations are pulled apart, but others are so stable they remain intact.

Factor 4 (5-factor model) appears to constitute a base-metal association (lead 0.74, copper 0.67, tin 0.62, boron 0.62, molybdenum 0.45), but there is some possibility that two different types of mineralization are represented: a lead-copper (base metal) type and a tin-boron type. At the risk of overextending the purpose of factor analysis method, the 8-factor model was used to pull apart the base-metal association to define three new associations: (1) boron 0.92, tin 0.34; (2) molybdenum 0.93, chromium 0.34; and (3) lead 0.80, copper 0.80, iron 0.50, and tin 0.46.

Plots of each of these new factors fail to identify any significant new target areas that were not recognized in the 5-factor model (see figures 7, 9, and 10). The principal effects are to: (1) divide tin between the base-metal and the boron factors, (2) separate out the Ath Theebiyah area as a tin-boron type distinct from the base-metal type, (3) define Jabal al Usba as predominantly a boron area, (4) diminish the role of the base metals in the Fawwarah and Jabal ar Raha areas, (5) raise the level of interest in a small base-metal type anomaly near the southwest corner of the quadrangle, and (6) create the unique factor, molybdenum. A plot of the molybdenum factor (not shown) corresponds closely to the single-element map of molybdenum.

Single-element data were also classified and plotted. Generally, plotting intervals were chosen by inspection of the histograms. Two analytical reporting values were usually included in each plotting interval, resulting in an interval approximately equal to one log standard deviation for most elements. Symbols representing the following classes were then plotted on each single-element map: low background, background, high background, possibly anomalous, anomalous, highly anomalous, and very highly anomalous.

RESULTS

Factor analysis

After the selection of the 5-factor varimax model as an appropriate statistical and geochemical model, the scores for each of the factors were classified and plotted on score maps. Histograms and plotting intervals that were chosen are presented on the respective maps (figures 3-8). The association of elements for each factor is shown in table 1. The relative importance of each element within the association is expressed by its loading on the factor (table 1).

Factor 1 is dominated by the elements yttrium, niobium, lanthanum and manganese. The association occurs over alkali feldspar granites in the Jabal Qutn, Al Hudub, Jabal Salma, and Jabal al Usba areas (figure 3). Exceptions to the above are found in the area northwest of Ath Theebiyah, where the association occurs over rocks mapped as graywacke, and in the northwest part of the quadrangle over outcrops of quartz diorite.

Factor 2 is dominated by the elements cobalt, vanadium, and chromium, with beryllium exhibiting a strong negative loading on this factor. A plot emphasizing the positive scores (figure 4) indicates an indefinite relation with the units mapped as graywacke in the central portion of the quadrangle. A plot emphasizing the negative factor 2 scores (fig. 5) indicates the association of beryllium with alkali feldspar granites in the Jabal Qutn, Fawwarah, and Jabal Salma areas.

Factor 3 consists of the elements strontium, barium, and calcium. Figure 6 suggests a relation between the factor and areas of possible hydrothermal alteration. This is particularly evident in the Shiaila and Buqaya areas, and in an area located to the northwest of the intersection of 26°30' N. latitude and 42°45' E. longitude. Each area is notable for the presence of a major fault. In the Shiaila and Buqaya areas listwänite zones are know to occur A large

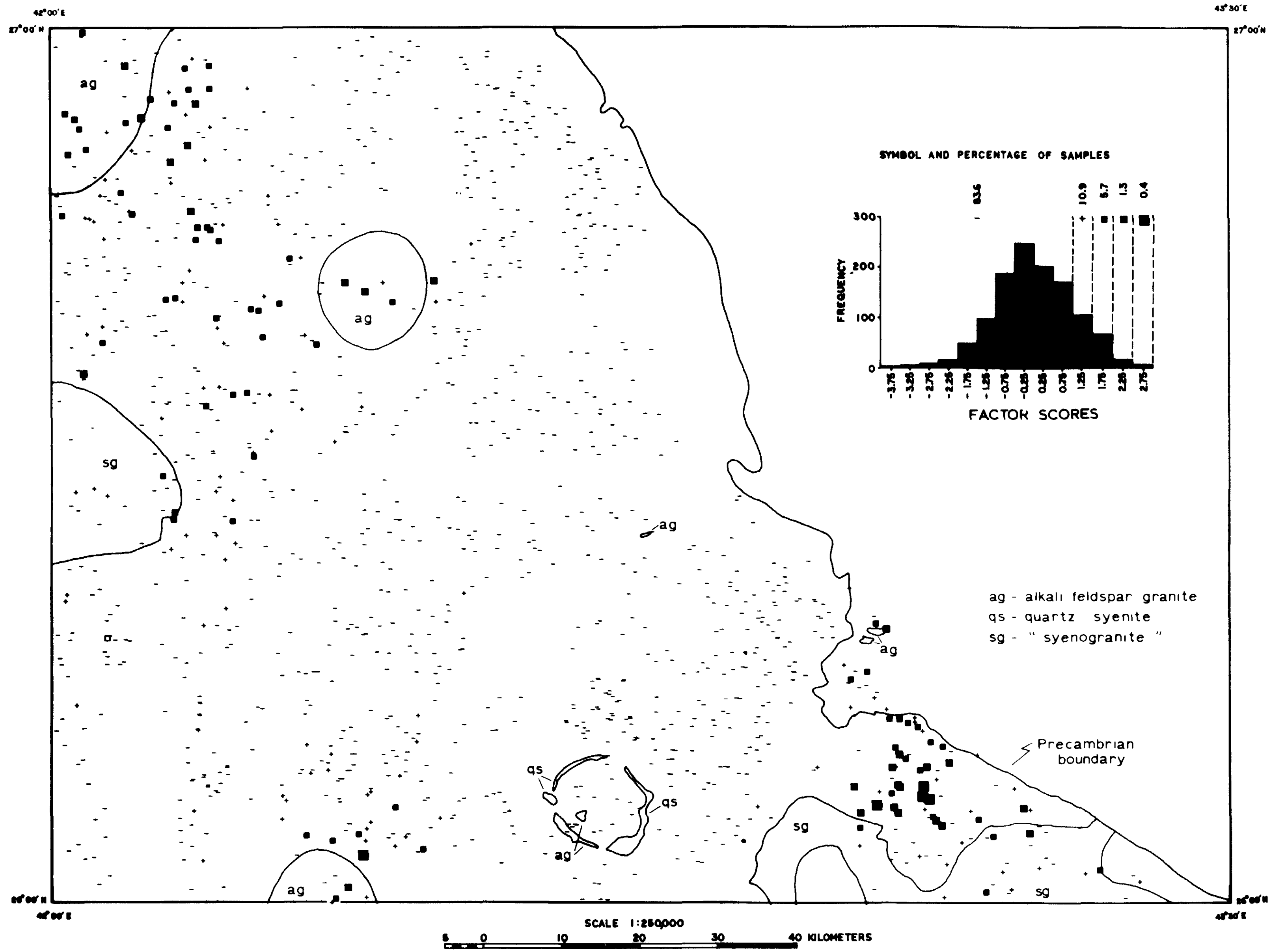

Figure 3.--Factor 1 scores, yttrium-niobium-lanthanum-manganese association (5-factor model).

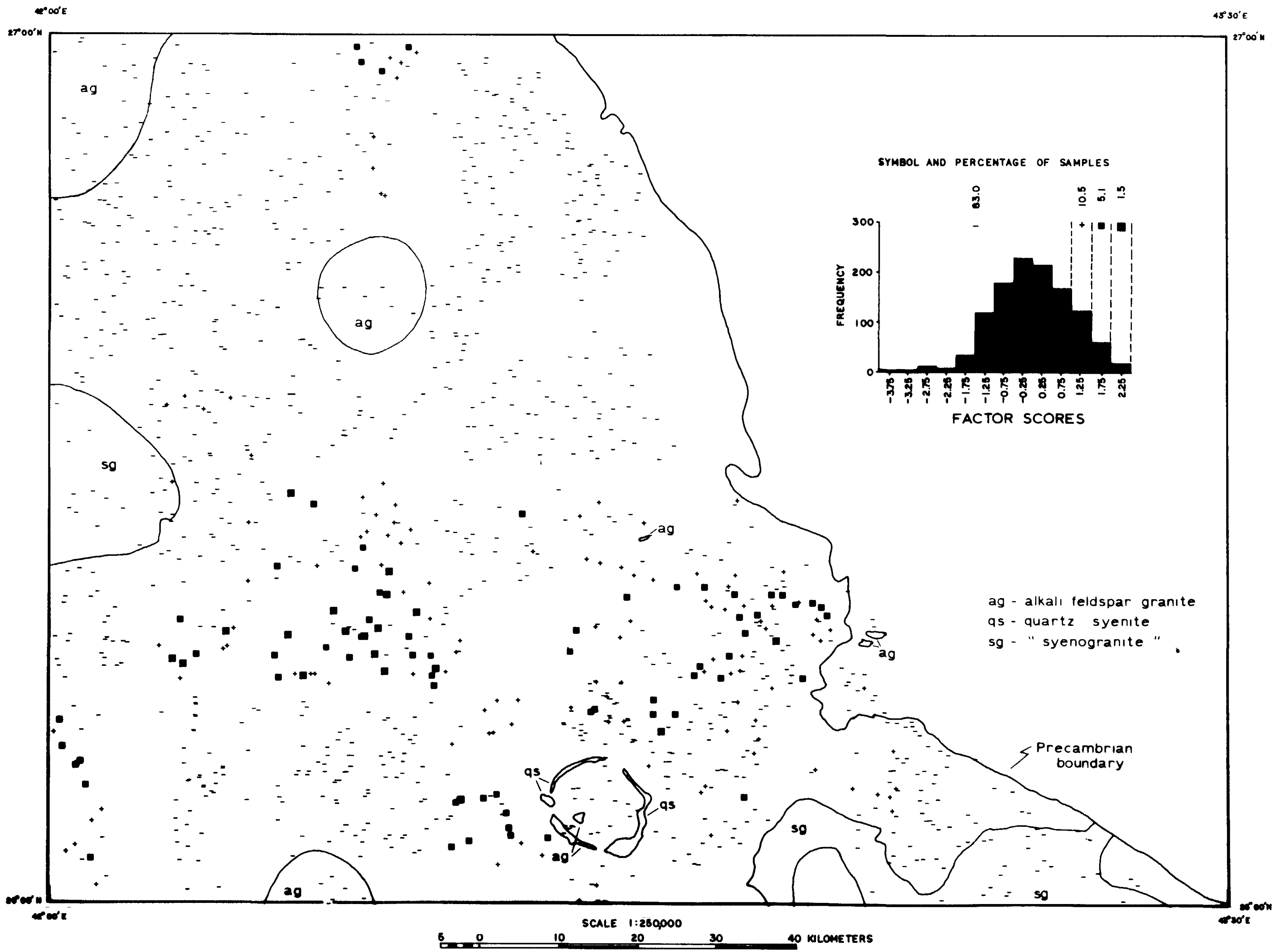

Figure 4.--Factor 2 scores, (positive) cobalt-vanadium-chromium association (5-factor model).

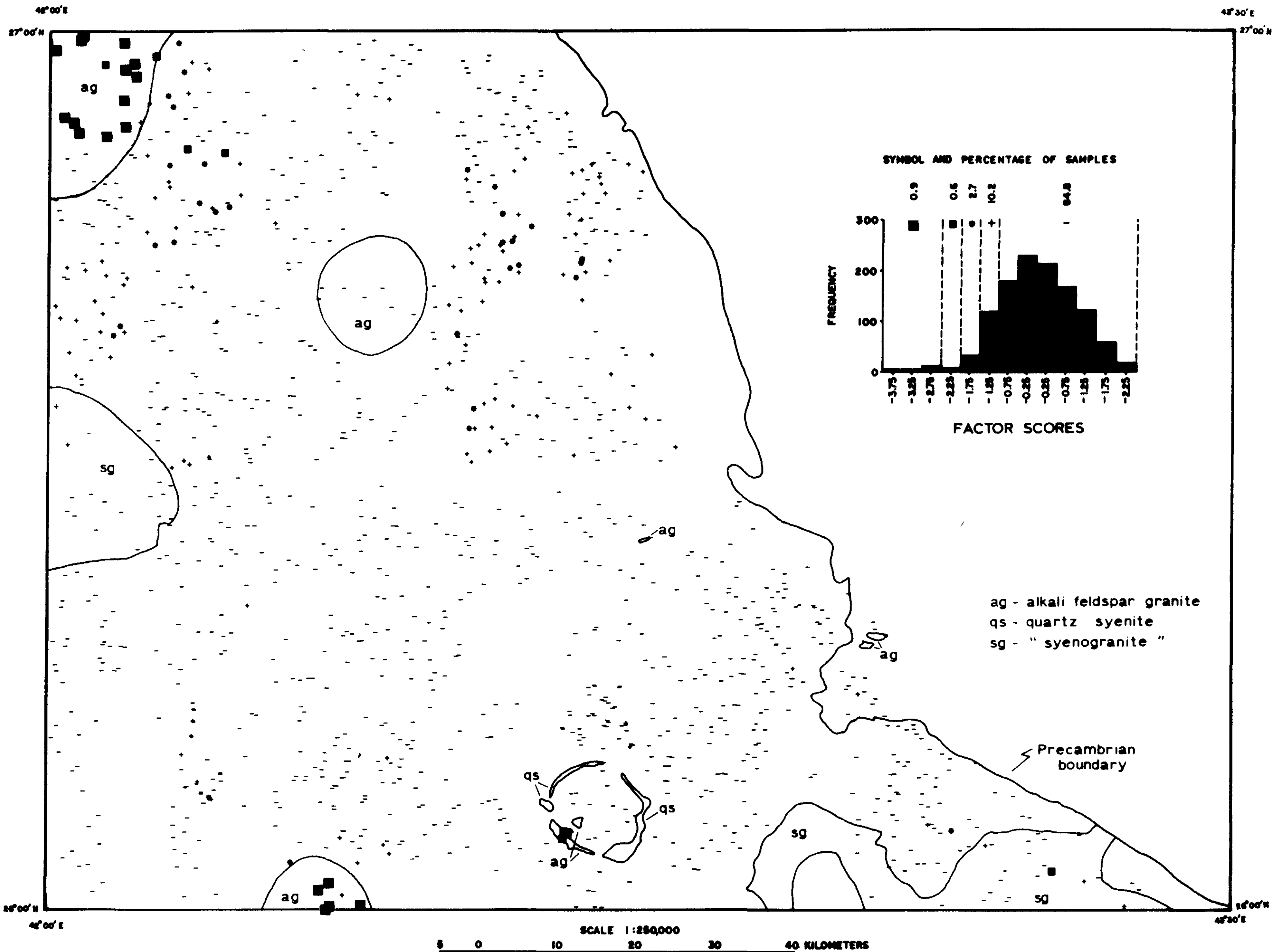

Figure 5.--Factor 2 scores, (negative) beryllium association (5-factor model).

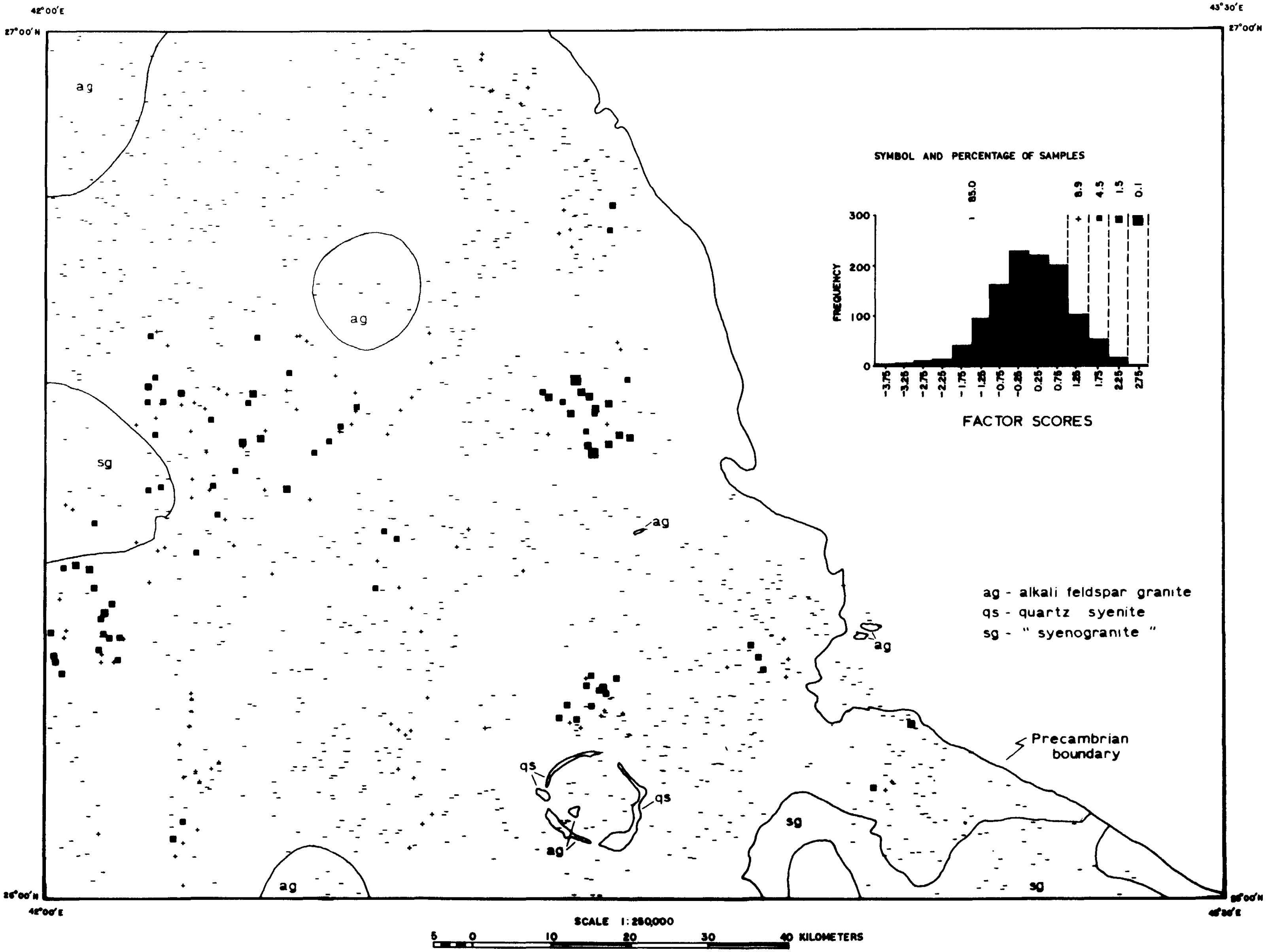

Figure 6.--Factor 3 scores, strontium-barium-calcium association (5-factor model).

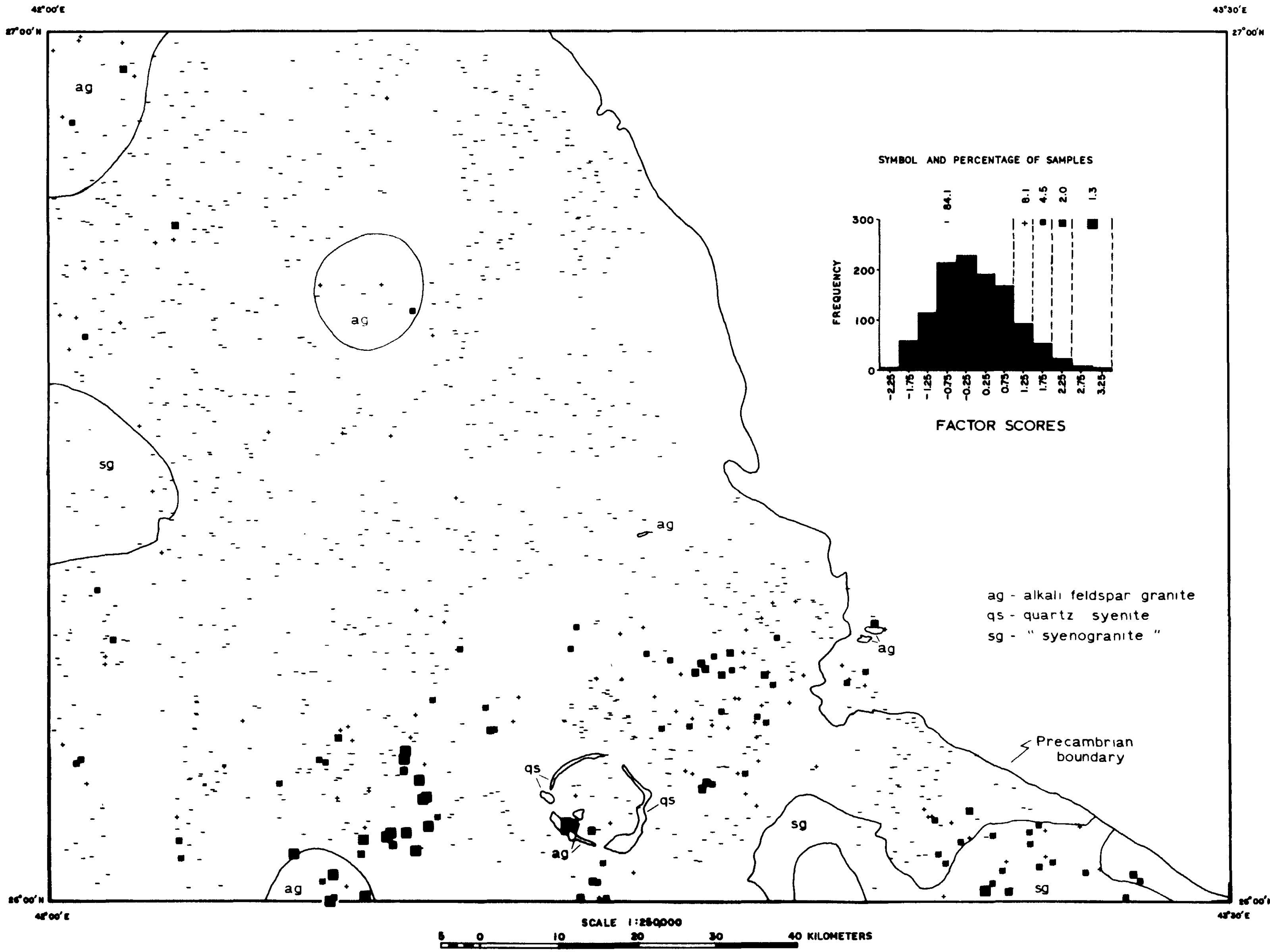

Figure 7.--Factor 4 scores, lead-copper-boron-tin association (5-factor model).

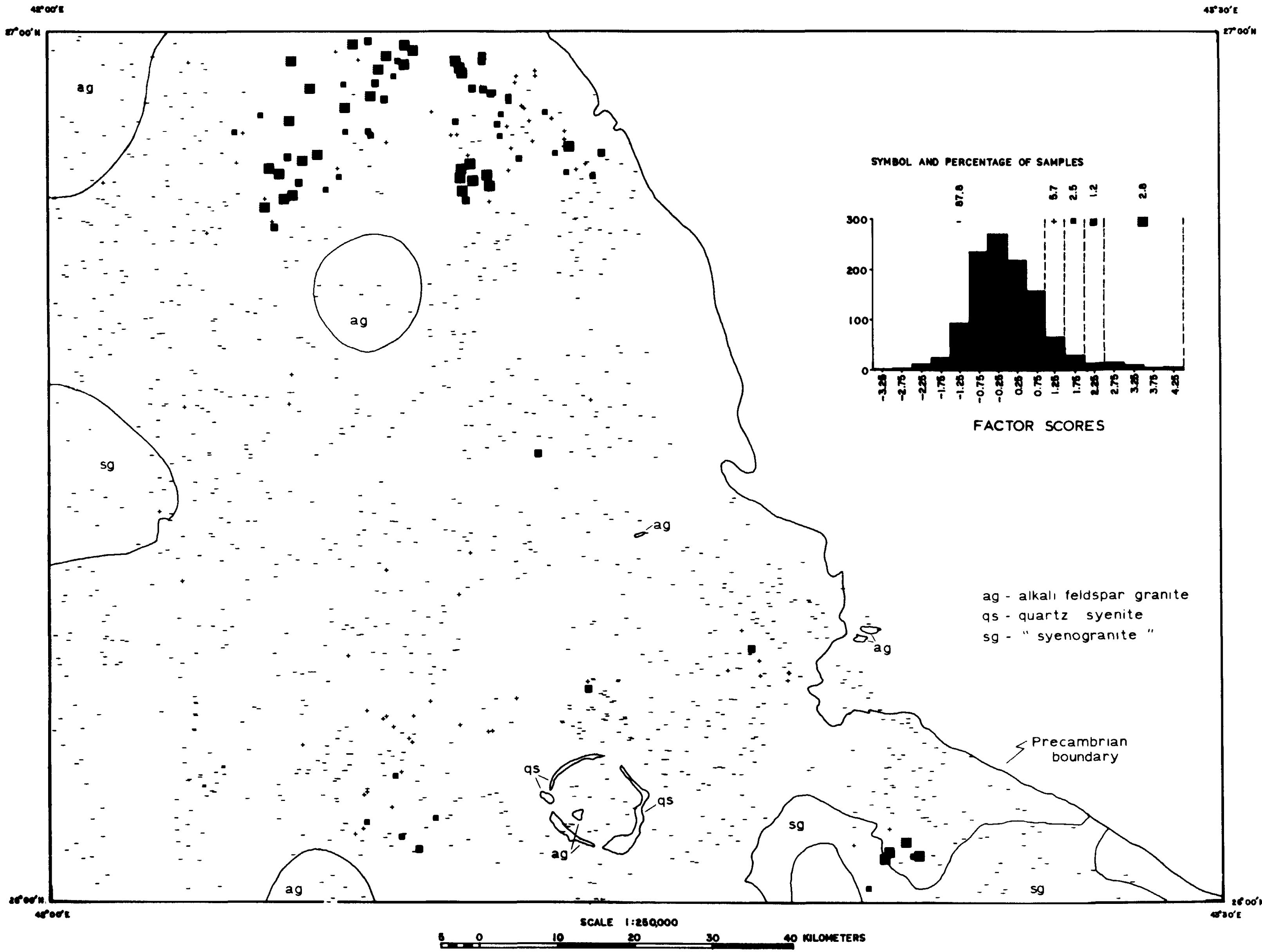

Figure 8.--Factor 5 scores, magnesium-nickel association (5-factor model).

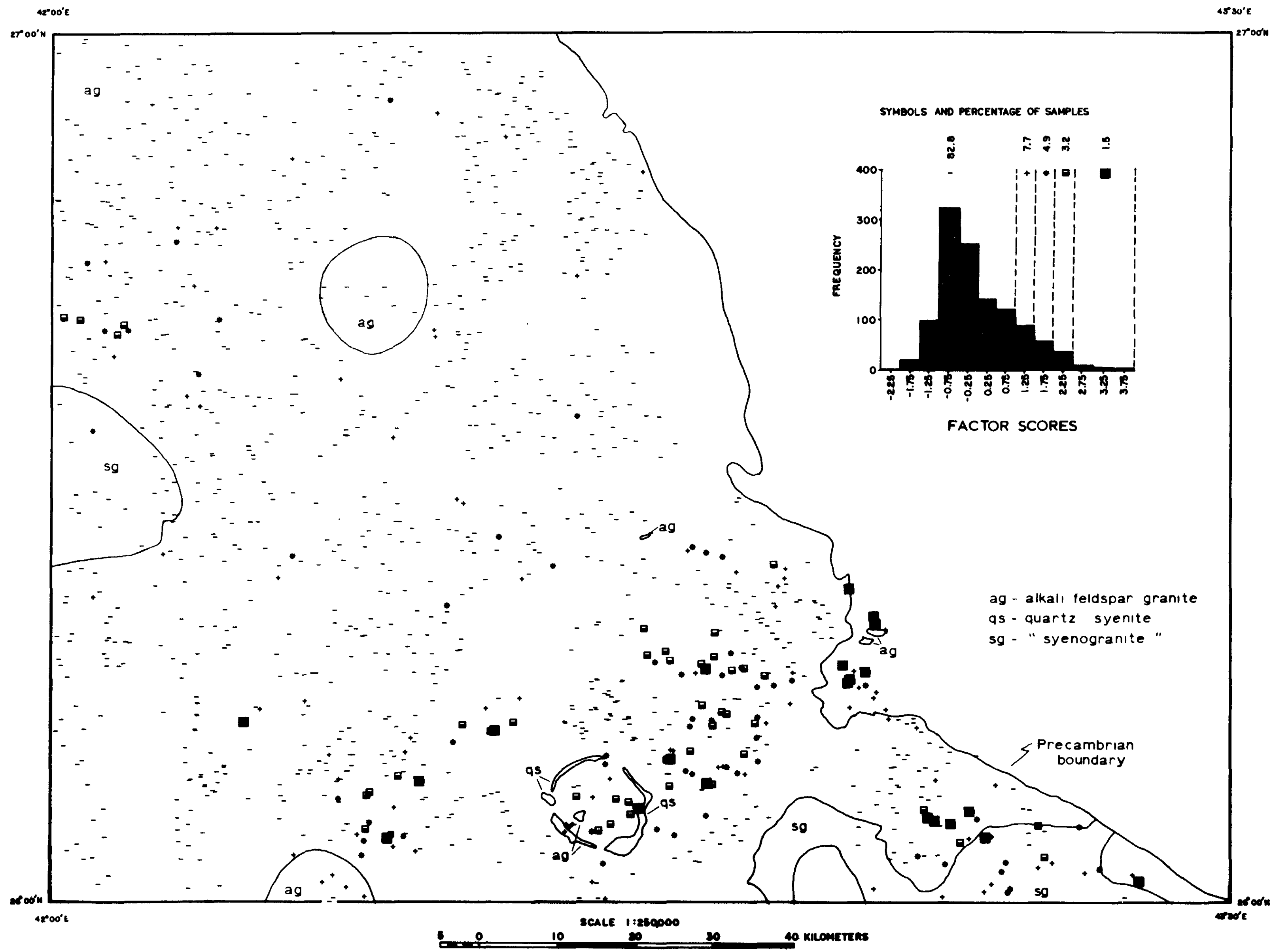

Figure 9.--Factor 4 scores, boron-tin association (8-factor model).

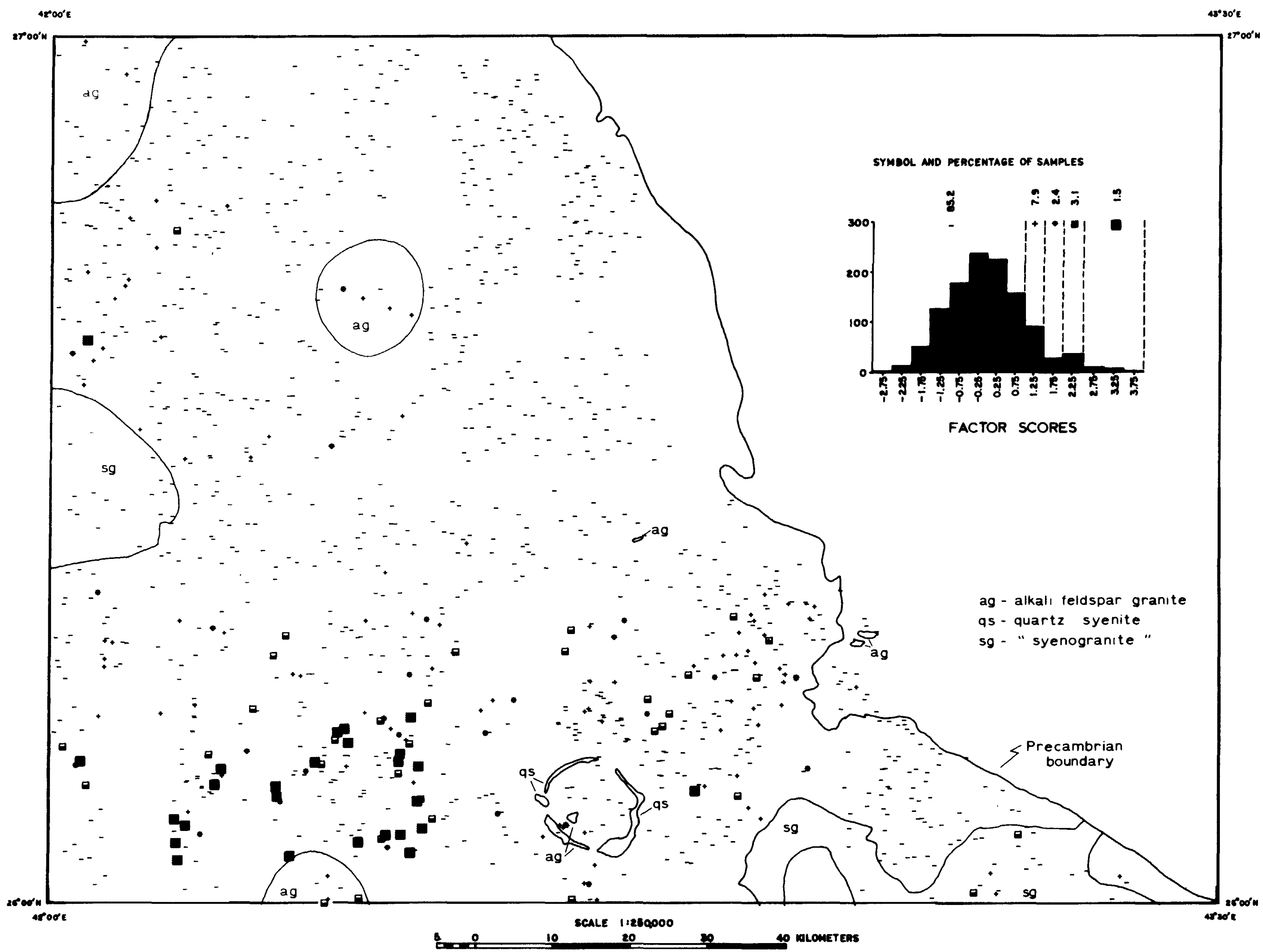

Figure 10.--Factor 8 scores, lead-copper-tin association (8-factor model).

number of high scores also appears in the west-central portion of the quadrangle where mafic rocks identified as quartz diorite, diorite, gabbro, and amphibolite are present.

Factor 4 is dominated by the elements lead, copper, tin, and boron, with molybdenum having a weaker loading. This suite of elements is interpreted as potentially indicating areas of mineralization, and the distribution of the factor 4 scores presented in figure 7 supports this hypothesis. A large area surrounding the Meshaheed district is indicated, as well as three other significent areas: near Fawwarah, Ath Theebiyah, and Jabal ar Raha. Other areas of lesser importance are also indicated.

Factor 5 consists of the elements magnesium and nickel. The factor 5 scores, represented in figure 8, indicate a strong relationship between this factor and the Quaternary basalt cover rocks in the northwest portion of the quadrangle. High positive scores also define an area hosting altered mafic plutonic rocks in the southeast corner of the quadrangle. In addition, the Meshaheed, Shiaila, and Buqaya areas all have high scores suggesting a relation with mafic intrusives that are known to occur in these areas.

Single element data

Whereas factor analysis provides a rapid method of identifying and quantifying multielement associations useful in the interpretation of the geochemical data, some information may not be obtained because of the simple model selected. Histograms and maps for single elements are presented in figures 13-35. Only elements contributing additional information as they relate to the results of factor analysis are discussed here.

The well-recognized association of rare-earth elements with granites generally might lead to the expectation that the rare-earth association of factor 1 would outline all the alkalic granites of this quadrangle (figure 11). This expectation is only partially fulfilled, and the relations are interpreted to indicate that the several plutons of alkalic granites have dissimilar geochemical signatures of rare earths and other elements. Factor 1 outlined several areas which are mapped as alkalic granites--Jabal Salma, Jabal Qutn, Jabal al Usba, Ath Theebiyah--but factor 1 also outlined the area to the northwest of Ath Theebiyah, which is mapped as graywacke. If our interpretation of the geochemical signature belonging to an alkalic granite is correct, then the presence of this signature over the graywacke in-

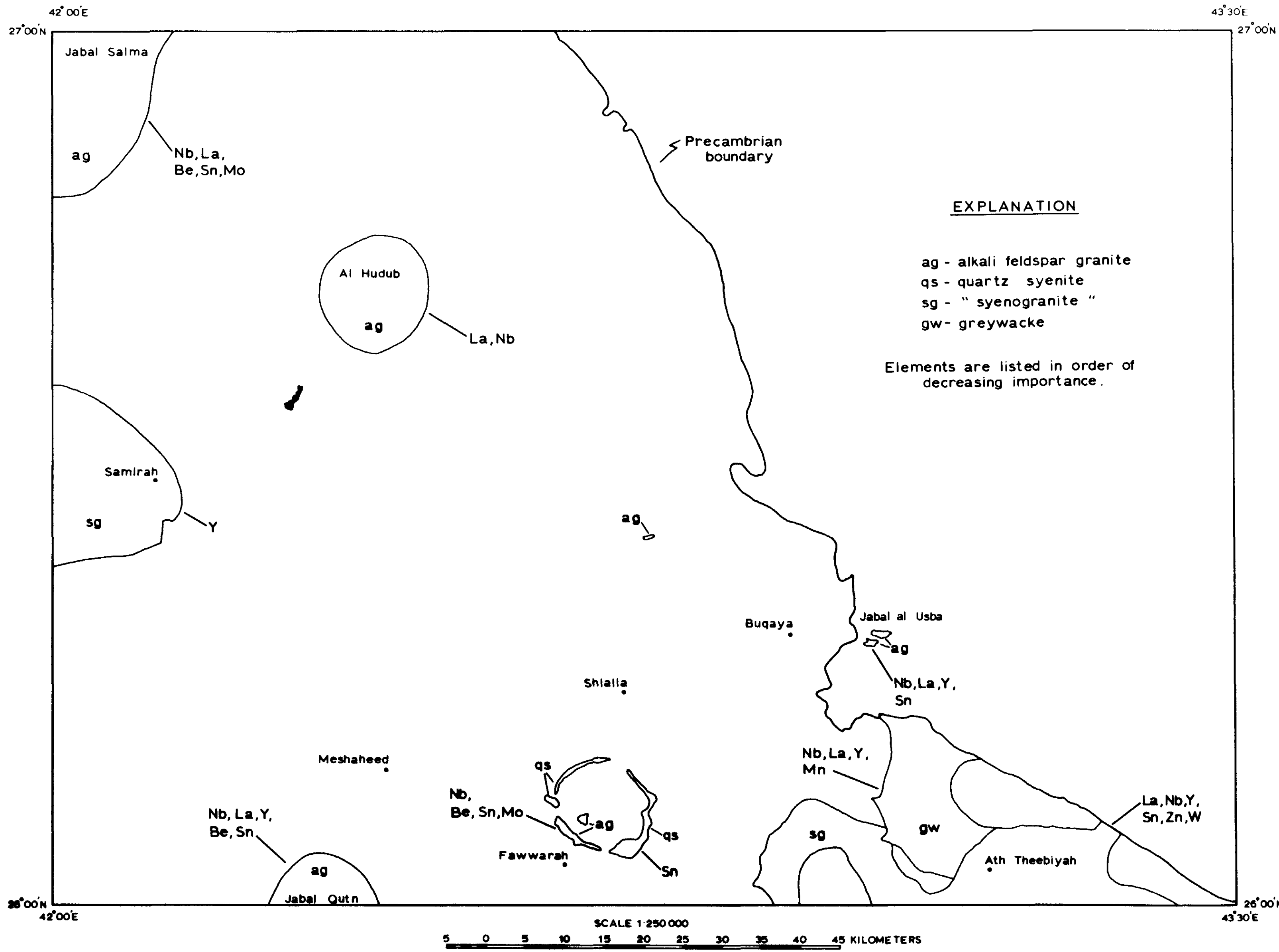

Figure 11.--Summary of trace elements in alkalic granites and related rocks, Jabal Habashi quadrangle, Saudi Arabia.

dicates the possibility of a shallow alkalic granite pluton but requires further study. Factor 1, however, failed to outline other mapped bodies of alkalic granites, for example, Fawwarah, Samirah, and Al Hudub which suggests that the several plutons do not have the same geochemical signature.

Anomalous values for elements in alkalic granites, as determined from single-element maps, are shown in figure 11. Niobium occurs in all of the granitic bodies except the syenogranite of the Samirah area, which has only minor amounts of yttrium. Yttrium fails to appear in the granites in Fawwarah, Al Hudub, and Jabal Salma. Lanthanum occurs in the granites of all areas except Fawwarah and Samirah. Tin is present in at least minor amounts in all areas except Samirah, Al Hudub, and the graywacke near Ath Theebiyah. In the Fawwarah area, the alkali feldspar granite is characterized by high amounts of tin and other elements, whereas the nearby quartz syenite contain high values for tin only. Anomalous values for beryllium are restricted to the Jabal Salma, Jabal Qutn, and Fawwarah areas. Anomalous amounts of molybdenum were reported in the Jabal Salma and Fawwarah areas. The only values for zinc and tungsten that are reported above the limits of detection are found in the syenogranite of the Ath Theebiyah area.

The geochemical signature of the area underlain by graywacke near Ath Theebiyah is highly anomalous in yttrium, niobium, and lanthanum, but the signature differs from that of the alkali feldspar granites by the addition of highly anomalous manganese. This area is another potential target for rare-earth element mineralization accompanied by niobium, differing in this respect from the other graywackes.

Information useful in the distinction and further characterization of areas favorable for hosting mineral deposits was also obtained from the observation of single element maps for lead, copper, tin, boron, iron, and molybdenum. In the Meshaheed region, significant concentrations of copper, lead, boron, and iron define a large arcuate anomaly east of a zone of pyritic alteration. Some tin is also concentrated in the region. Lead is anomalously abundant in samples over the alkali feldspar granite near the southern margin of the quadrangle. Tin, molybdenum, and minor amounts of copper and lead are found in the Fawwarah area. The syenogranite in the Ath Theebiyah area is enriched in tin, zinc, and tungsten; it is also slightly enriched in lead and boron. Boron and tin are enriched, and iron and lead are slightly enriched, in the Jabal ar Raha area.

DISCUSSION

Previously identified mineral deposits

Our ability to recognize the three main areas (Meshaheed, Shiaila, and Buqaya) of economic interest as defined by Smith (written commun., 1982) serves as a measure of the utility of geochemical data and the factor analysis interpretation to locate the more prominent mineralized areas. The method was not entirely successful, however, for some mineralization types.

For example, most of the ancient prospects, which are related to localized occurrences of gold and silver in quartz veins, could not be detected because of the lack of direct geochemical information. The normal range of concentrations of gold, silver, and characteristically associated elements such as antimony and arsenic in this fraction of the concentration was below the analytical range of the spectrographic method. Even though data were available for other potential indicator elements such as copper, lead, and zinc, they were ineffective in defining these locally mineralized areas.

Nevertheless, a large arcuate zone to the south of, and including, the Meshaheed district was identified through positive anomalous values for copper, lead, boron, iron, and tin. The presence of this suite of elements and small intrusives of granodiorite and zones of pyritic alteration in the area, are interpreted to indicate favorable possibilities for copper porphyry or other base-metal sulfide deposits. Thus, the gold mineralization at Meshaheed may reflect a much larger hydrothermal system.

Mineralization at Shiaila and near Buqaya are not indicated by the base metals reported in the results of the geochemical analyses. However, alteration zones noted along faults in these areas are indicated by the strontium-barium-calcium association.

Newly defined areas of mineral potential

The newly identified areas discussed in this section are outlined in figure 12 by arbitarily selected boundaries that include but do not rigidly define areas of mineral deposit potential.

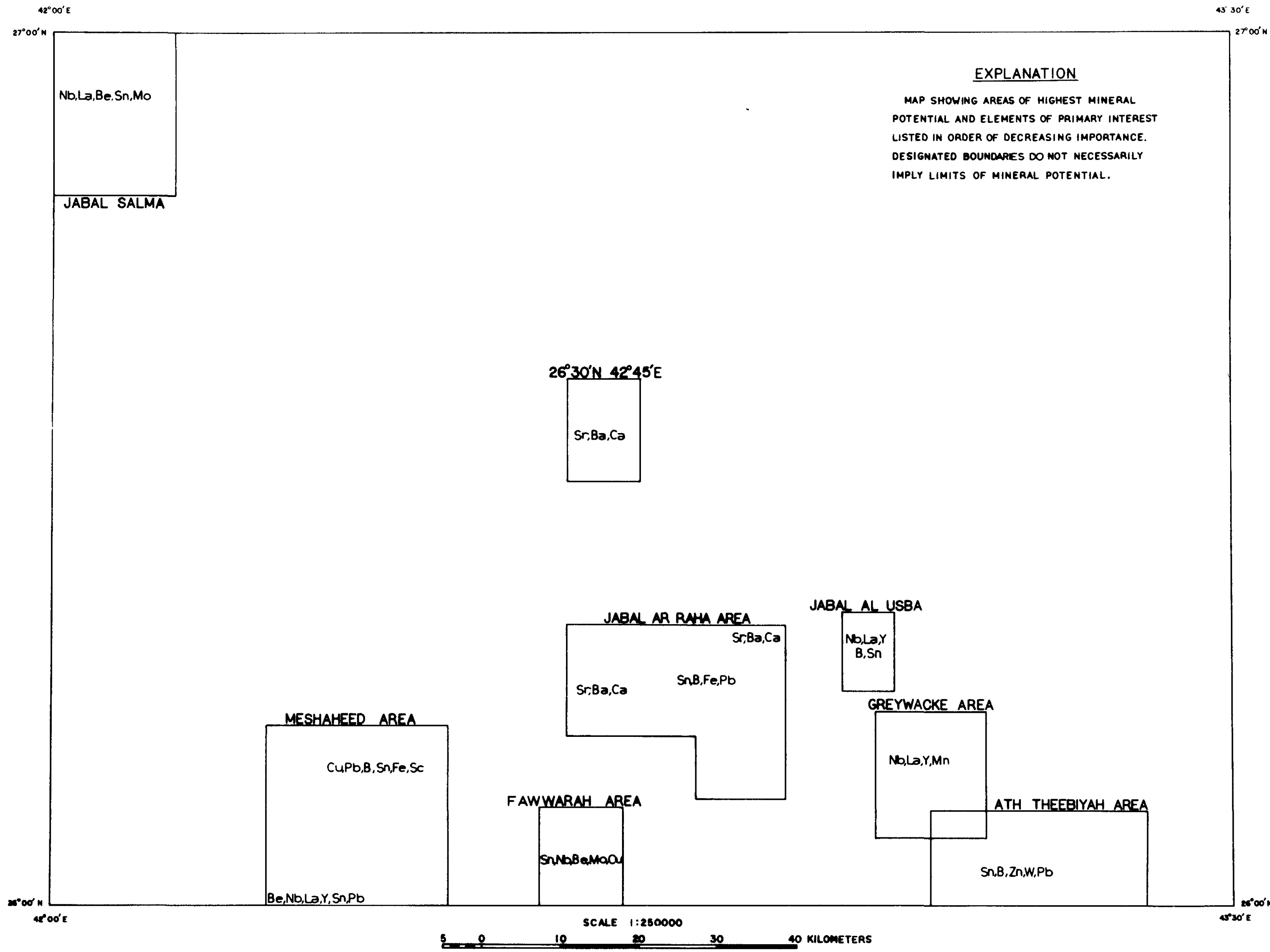

Figure 12.--Areas of highest mineral potential in the Jabal Habashi quadrangle.

Base Metal

The gold mineralization at Meshaheed is here interpeted to reflect a large and complex hydrothermally mineralized area that is considered favorable for hosting copper porphyry or other base-metal sulfide deposits, in addition to gold; hence, the area is given a new classification as a potential base-metal/precious metal deposit.

The enrichment of lead and tin in the alkali feldspar granite of Jabal Qutn also could be interpreted to indicate a potential for base-metal deposits. This interpretation is dependent, however, on the lead being enriched in ore forming minerals rather than being characteristically enriched in common granite minerals such as feldspars.

In the Fawwarah area, concentrations of tin, beryllium, niobium, molybdenum, and copper near alkali feldspar granites indicate favorability for tin greisen/molybdenum stockwork and related types of mineralization.

The Ath Theebiyah area contains numerous samples having high concentrations of tin, boron, zinc, tungsten, and lead. The syenogranite and associated rocks in the area are potential targets for base-metal and tin/tungsten mineralization. Indeed, the enrichment in zinc and tungsten is unique in the quadrangle.

Although the Jabal ar Raha area includes both the Shiaila and Buqaya known mineral deposits, the potential for base-metal mineralization in a much larger area is indicated by the results of the factor analysis. The known deposits are indicated indirectly by the association of strontium, barium, and calcium, but potentially more important areas are indicated by large concentrations of tin, boron, iron, and lead, especially near a rhyolite unit.

The concentration of molybdenum and tin in samples from the Jabal Salma area indicates a potential for tin/molybdenum mineralization in rocks related to the alkali feldspar granite of the area.

Although no base-metal association is observed in samples from the area located near the intersection of 26°30' N. latitude and 42°45' E. longitude, the strontium-barium-calcium association may indicate hydrothermal alteration and hence mineral deposit potential.

Rare earth and rare metal

Perhaps the most interesting geochemical signature is represented by the niobium-lanthanum-yttrium-manganese association which is related to the graywacke that is exposed to the northwest of Ath Theebiyah. A possible target for the rare earth elements and niobium exists here. Similarly, potential targets for these elements are also indicated in the Jabal Salma, Jabal Qutn, Jabal al Usba, and Fawwarah areas. High concentrations of niobium, lanthanum, and yttrium are related to occurrences of alkali feldspar granite in those areas.

RECOMMENDATIONS

Mineral exploration

The most favorable places for further mineral exploration are the larger Meshaheed area, the Fawwarah area, the Ath Theebiyah area, and the Jabal al Raha area, where more detailed geologic, geophysical, and geochemical programs are justified. Additional wadi-sediment sampling supplemented with geological and geophysical studies would more clearly define target areas. In future programs of wadi-sediment sampling, the nonmagnetic fraction (not magnetic at 0.6 amps on the electromagnetic separator) of a heavy-mineral concentrate should be used to concentrate the ore-related metals, silver, gold, arsenic, bismuth, molybdenum, antimony, tungsten, and zinc. Emission spectrographic analyses should be supplemented by other methods more sensitive for certain elements as necessary. Mineralogical analysis of at least selected concentrates is necessary to aid in determining indicator-element phases and to characterize the geochemical responses. Samples of rocks and mine dumps should be collected to aid in the determination of indicator elements. Follow-up exploration should also be a coordinated effort, relying on geologic, geochemical, geophysical, and remote sensing information.

Geologic interpretation

Further geologic and geochemical information is necessary for the assessment of the mineral deposit potential in the Jabal Salma region and in the area located near the intersection of 26°30' N. latitude and 42°45' E. longitude. In the vicinity of Jabal Salma, the mode of occurrence of the elements tin and molybdenum should be determined, the petrology of the alkali feldspar granite should be further defined, and the mapped contact of the granite with quartz diorite should be further studied. Because of the occurrence of high concentrations of niobium and lanthanum in samples from areas mapped as quartz diorite, dikes and pegmatites related to the granite may be present in diorite terrane. Possible hydrothermal alteration may be associated with a major fault and an occurrence of diorite in the area near the intersection of 26°30' N. latitude and 42°45' E. longitude. Additional information is needed in this area to confirm the presence of alteration and to determine if precious or base metals are concentrated locally.

The resource potential of the rare-earth element mineralization and the presence of niobium in numerous areas cannot be determined without further geologic and geochemical work. The strongest potential appears to be in the area to the northwest of Ath Theebiyah, where high concentrations of niobium, lanthanum, yttrium, and manganese were found in samples from a graywacke terrane. If these elements are in minerals related to pegmatites and dikes intruded into the graywacke host, some occurrences may be of sufficiently high grade to be economically important. The alkali feldspar granites of the Jabal Salma, Jabal Qutn, Jabal al Usba, and Fawwarah areas are also potential host rocks for rare earth elements and niobium.

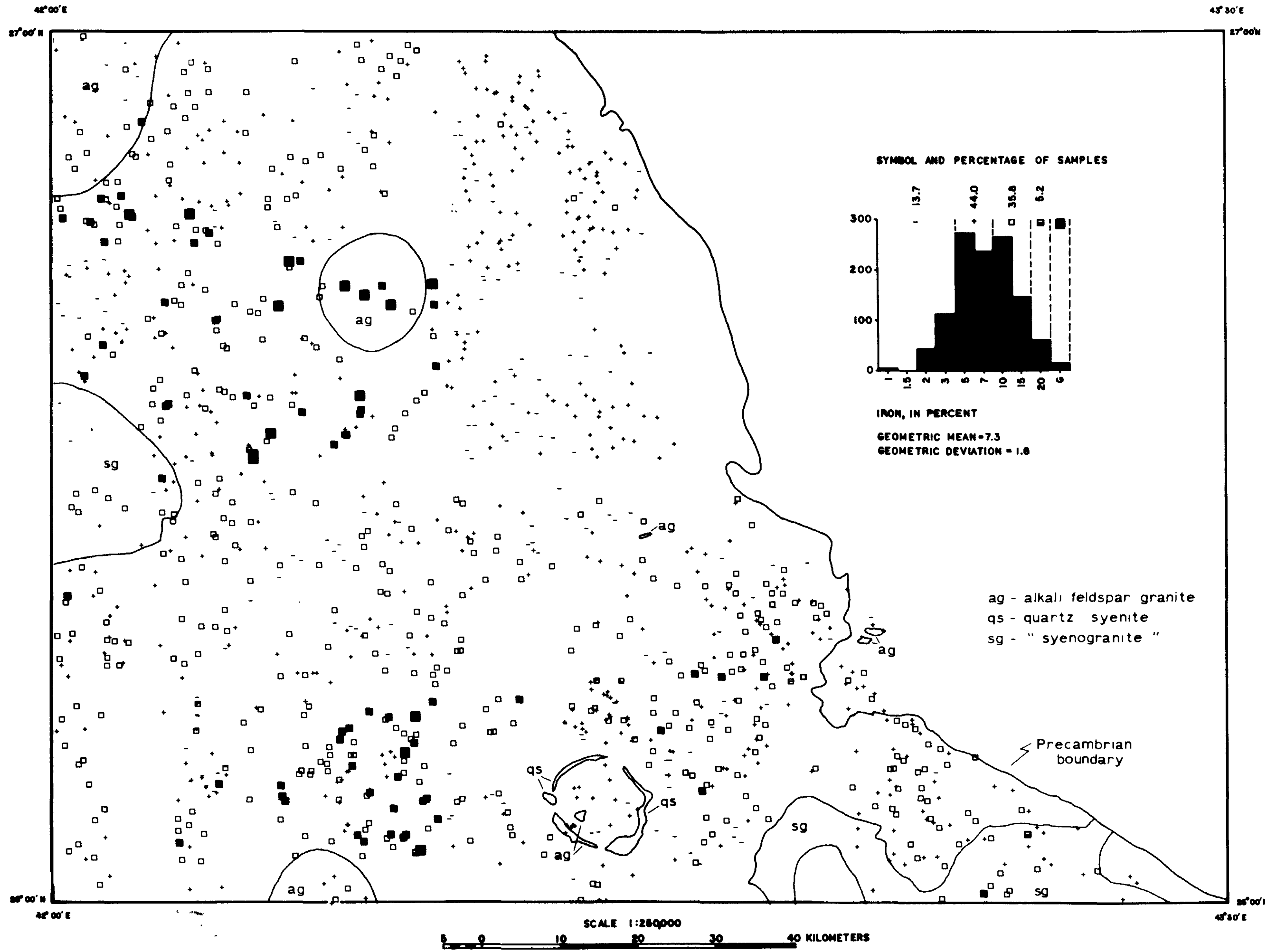

Figure 13.--Iron concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

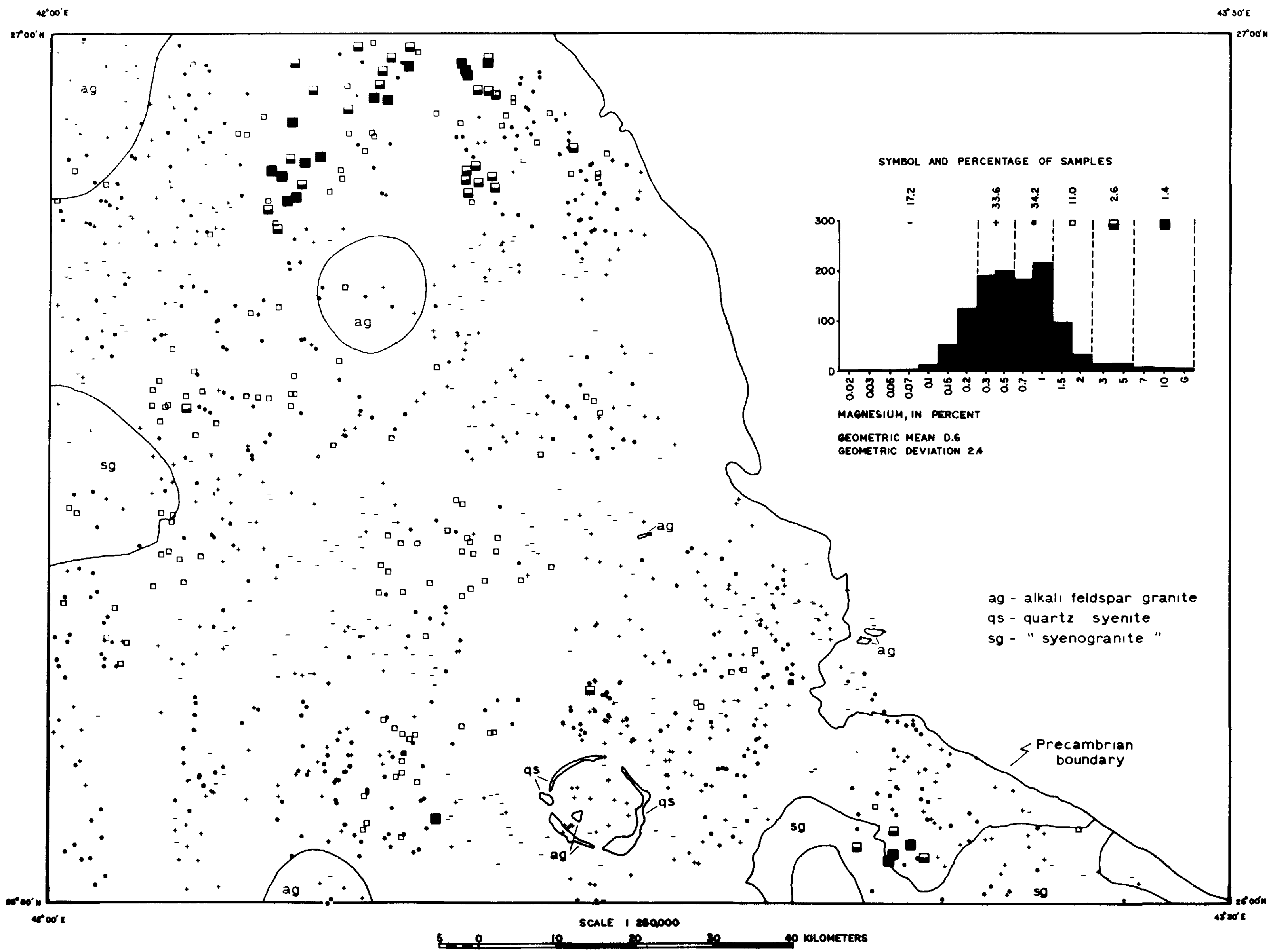

Figure 14.--Magnesium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

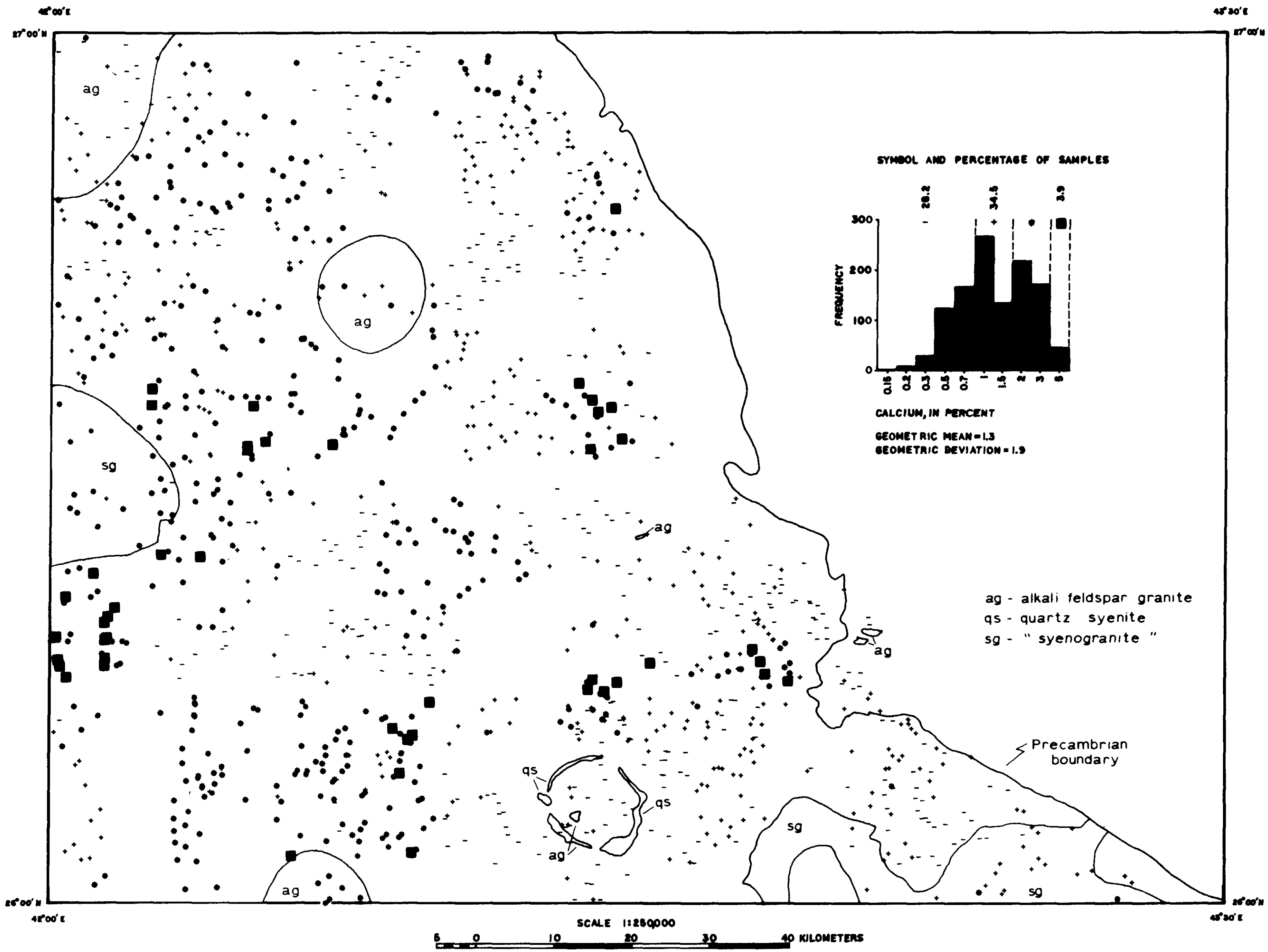

Figure 15.--Calcium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

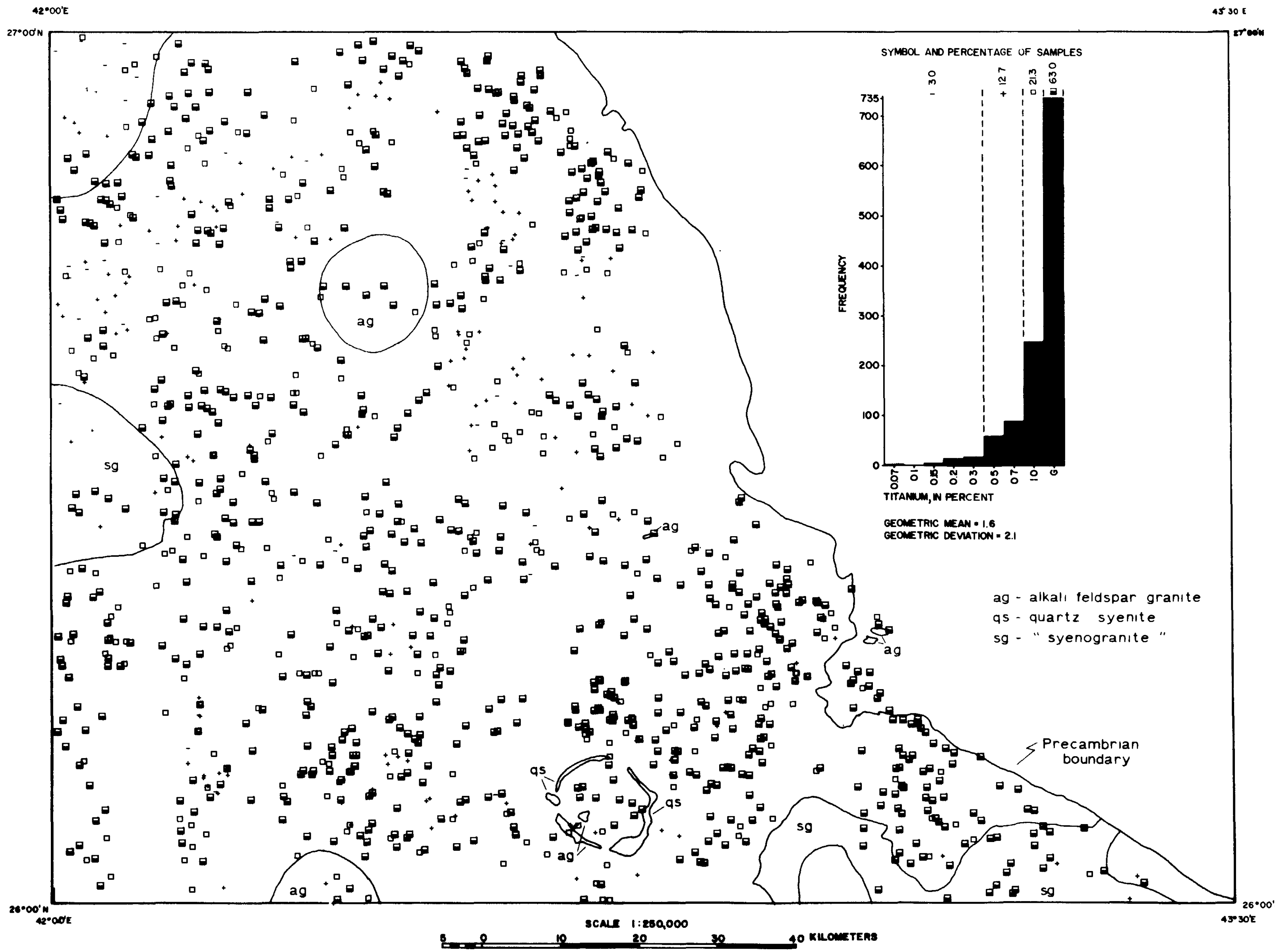

Figure 16.--Titanium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

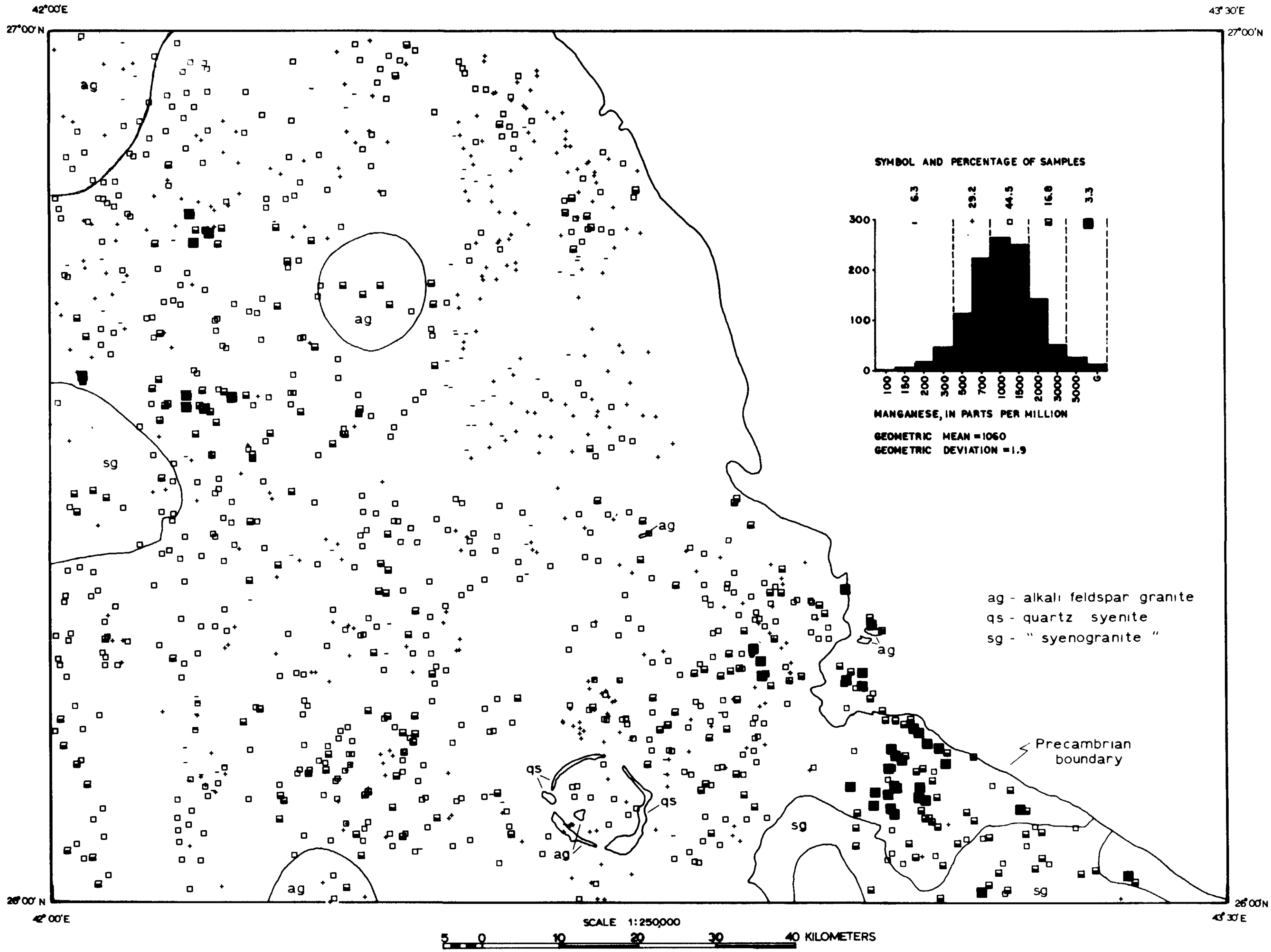

Figure 17.--Manganese concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

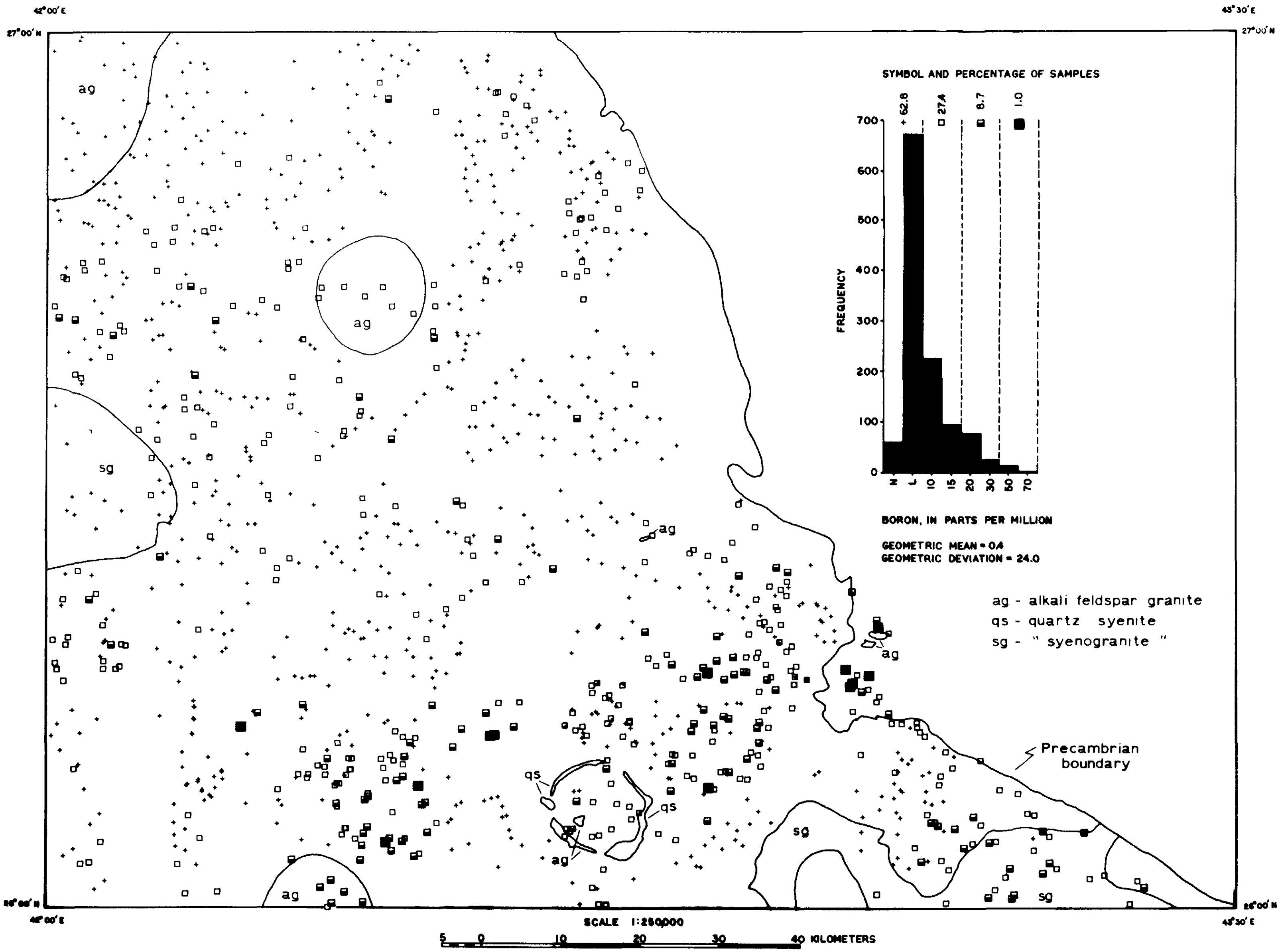

Figure 18.--Boron concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

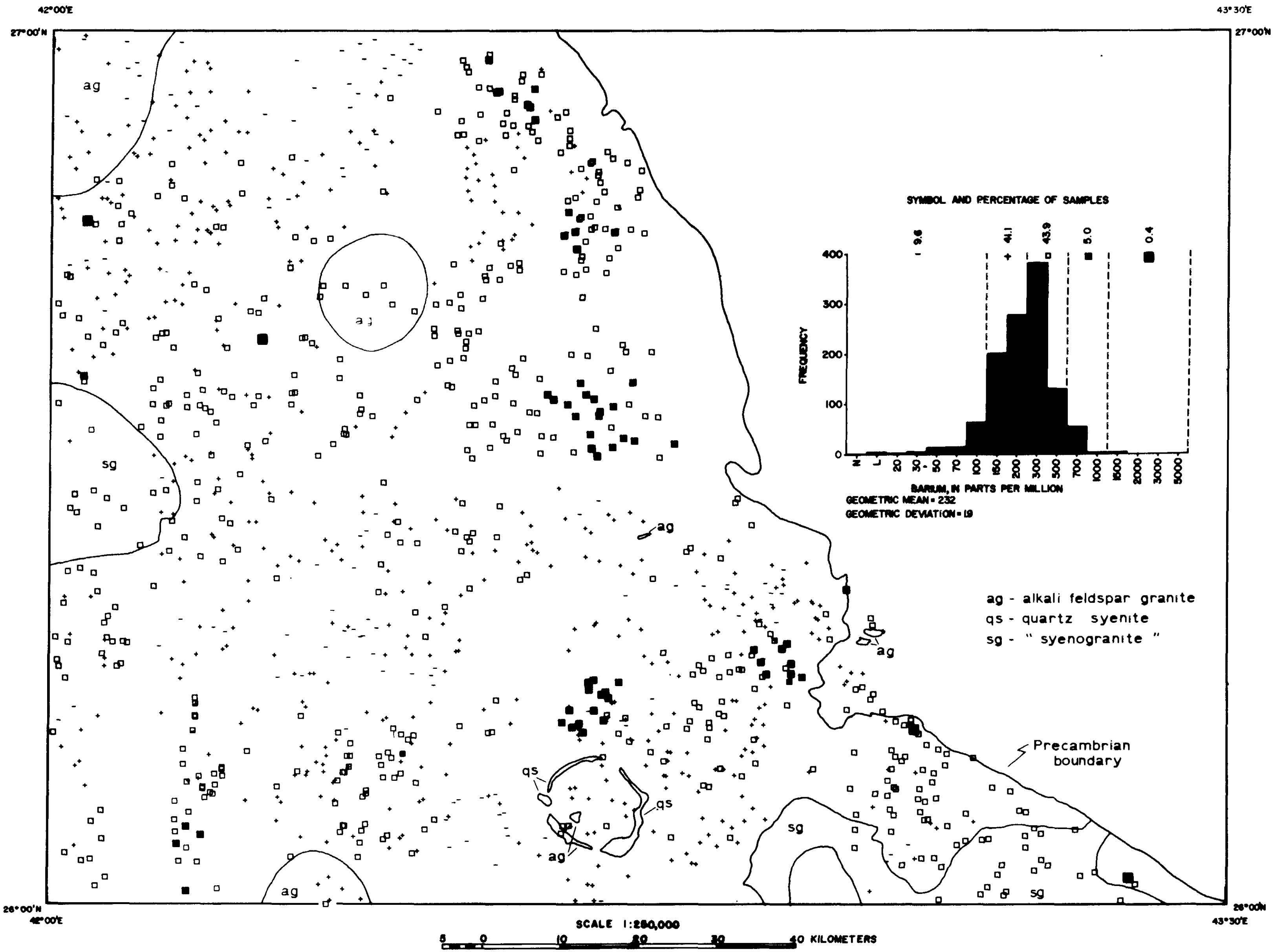

Figure 19.--Barium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

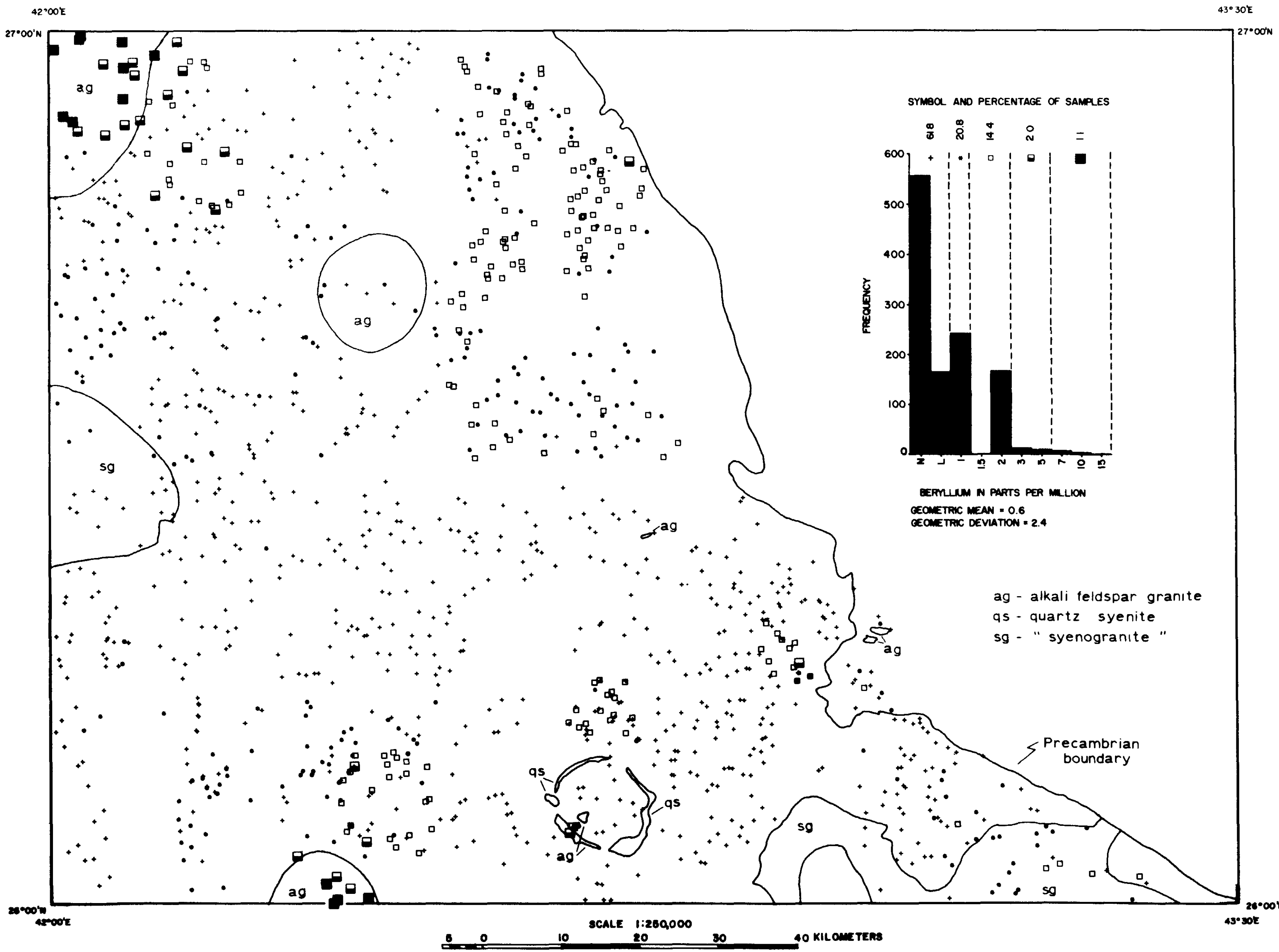

Figure 20.--Beryllium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

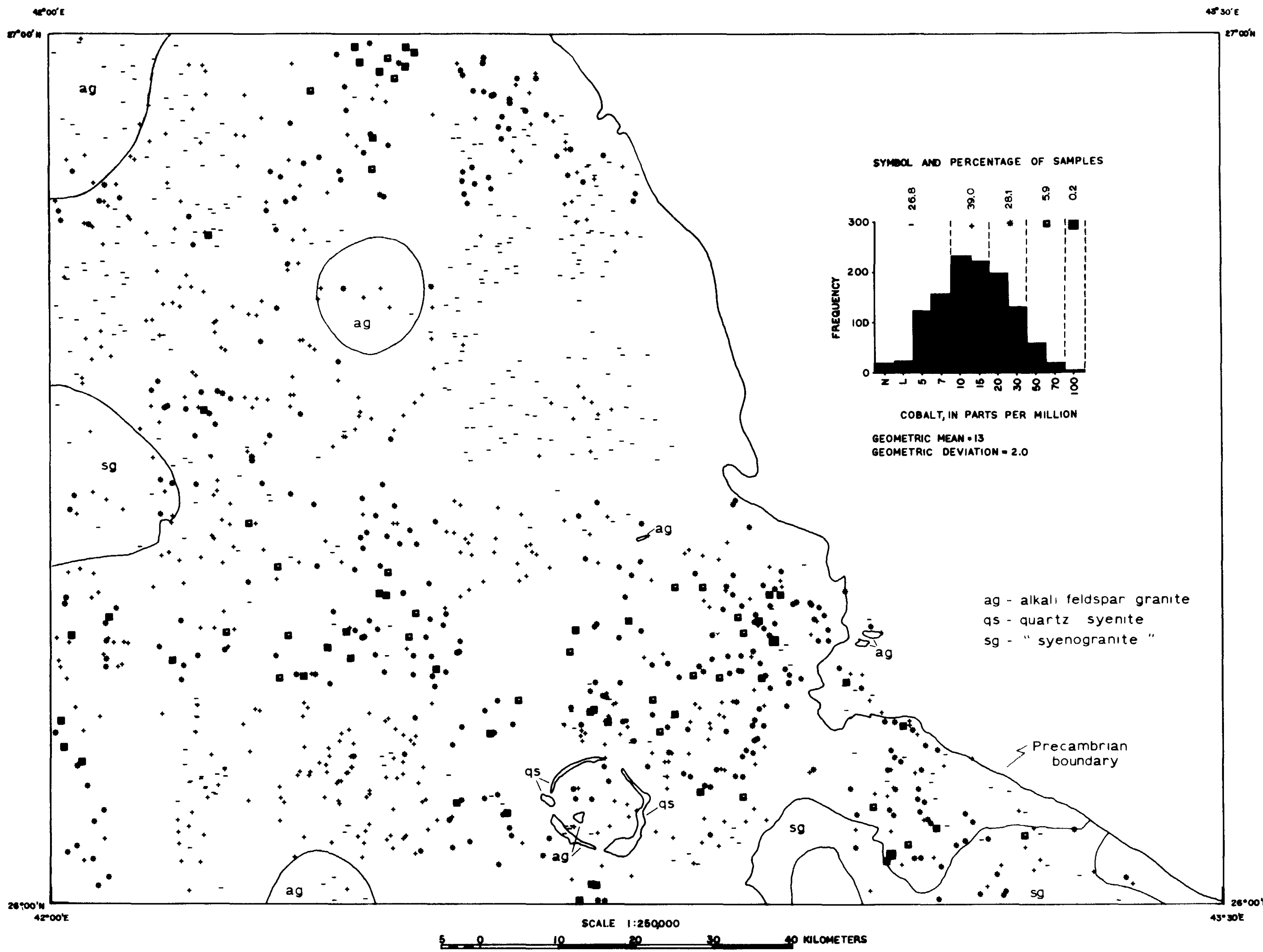

Figure 21.--Cobalt concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

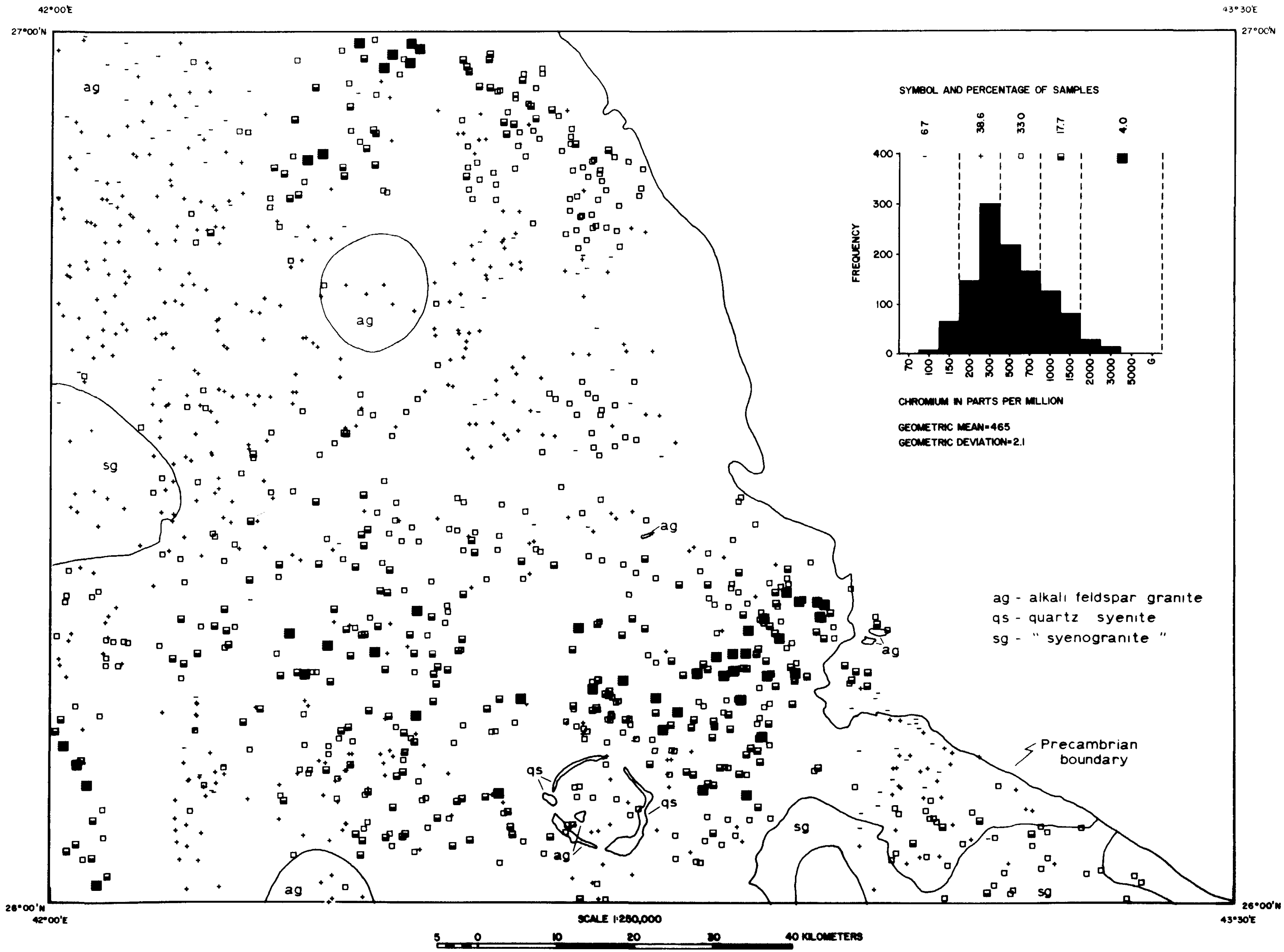

Figure 22.--Chromium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

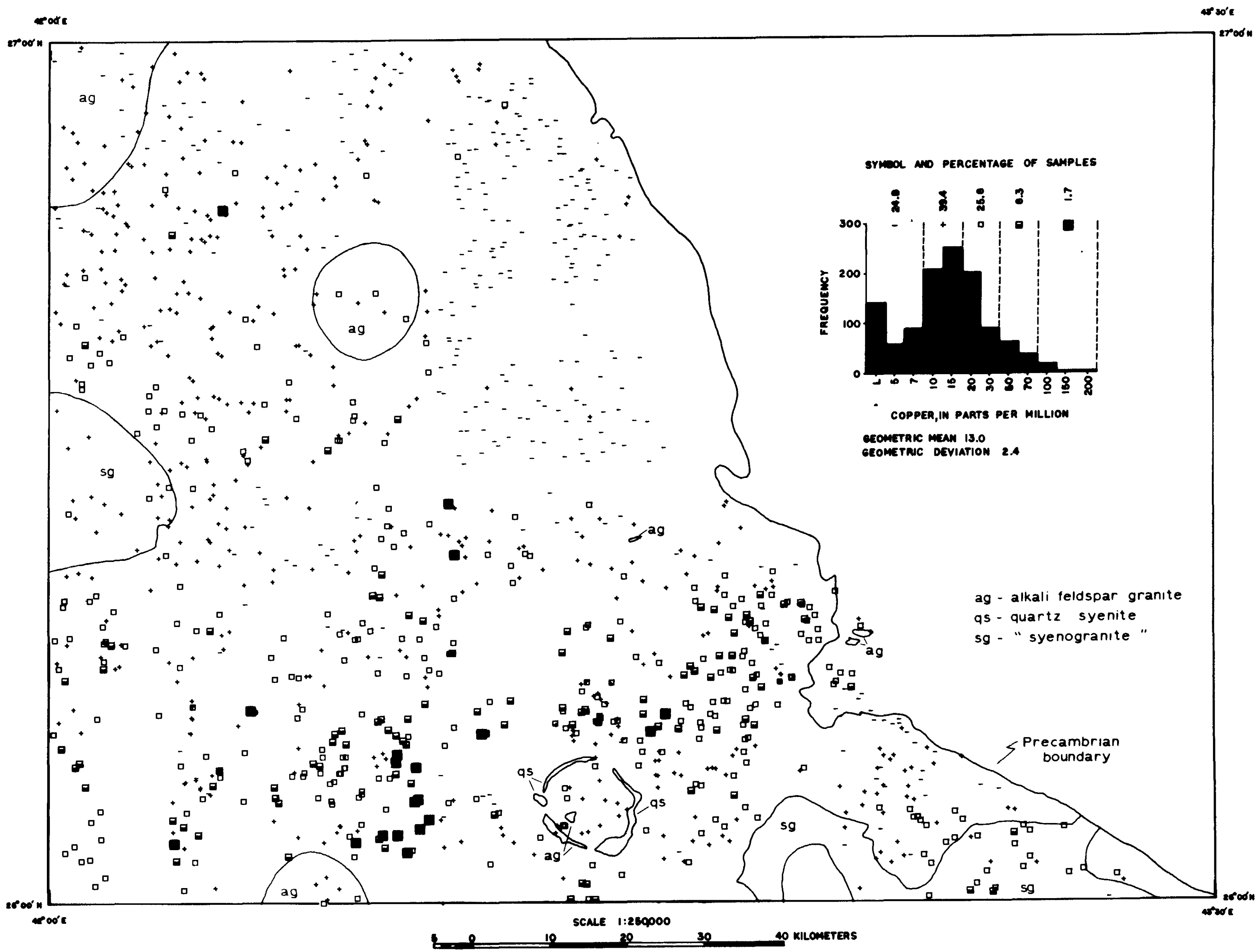

Figure 23.--Copper concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

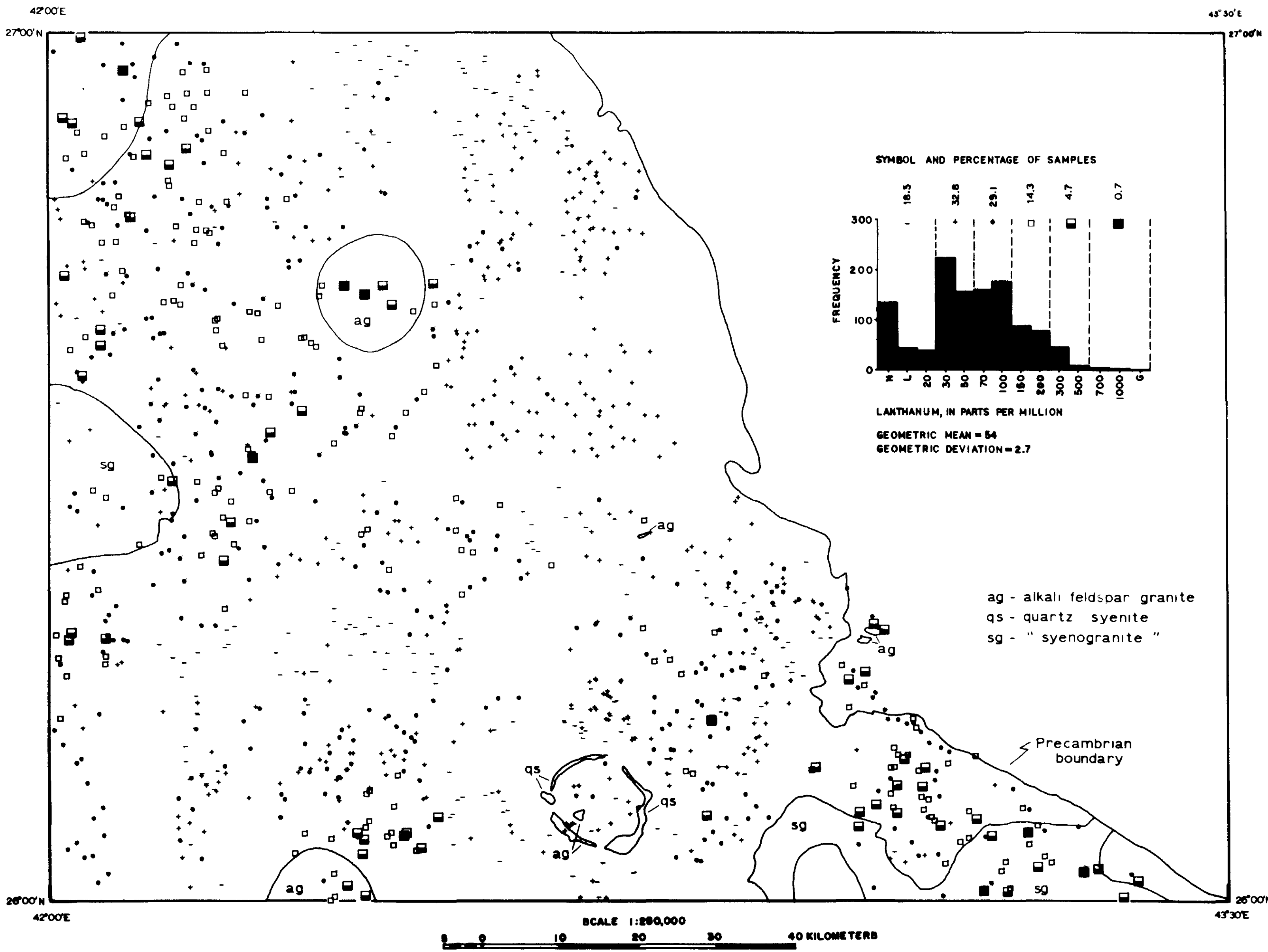

Figure 24.--Lanthanum concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

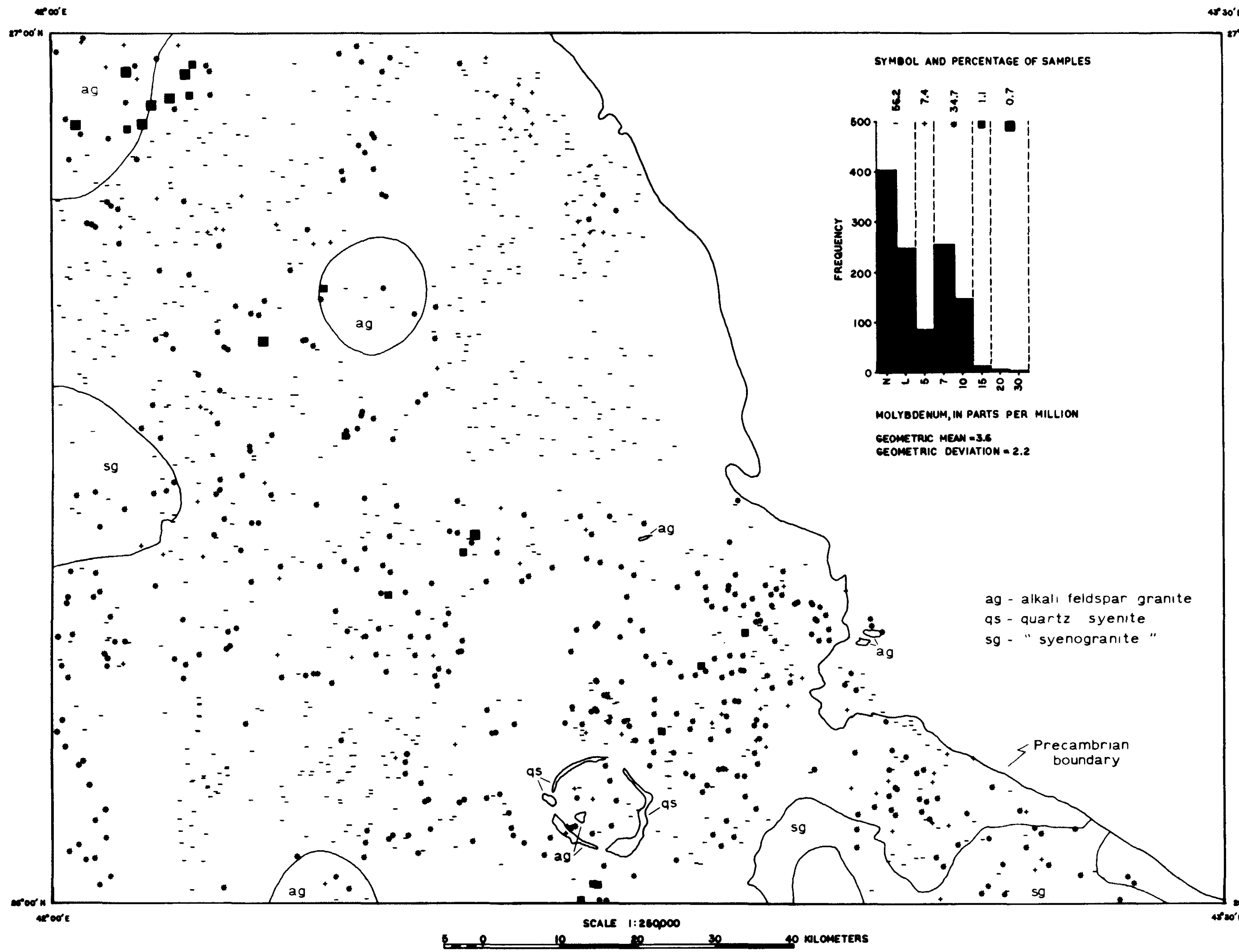

Figure 25.--Molybdenum concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

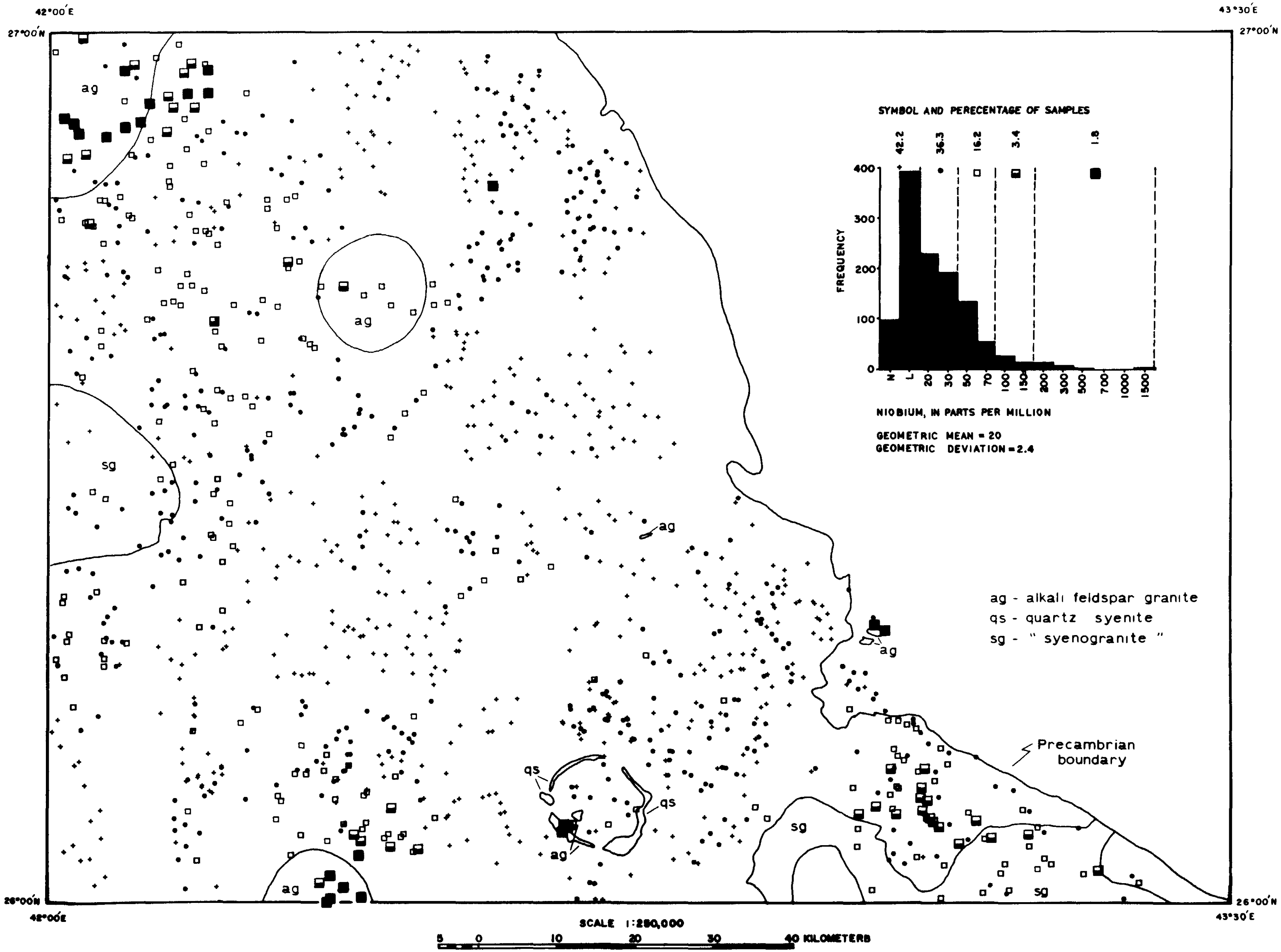

Figure 26.--Niobium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

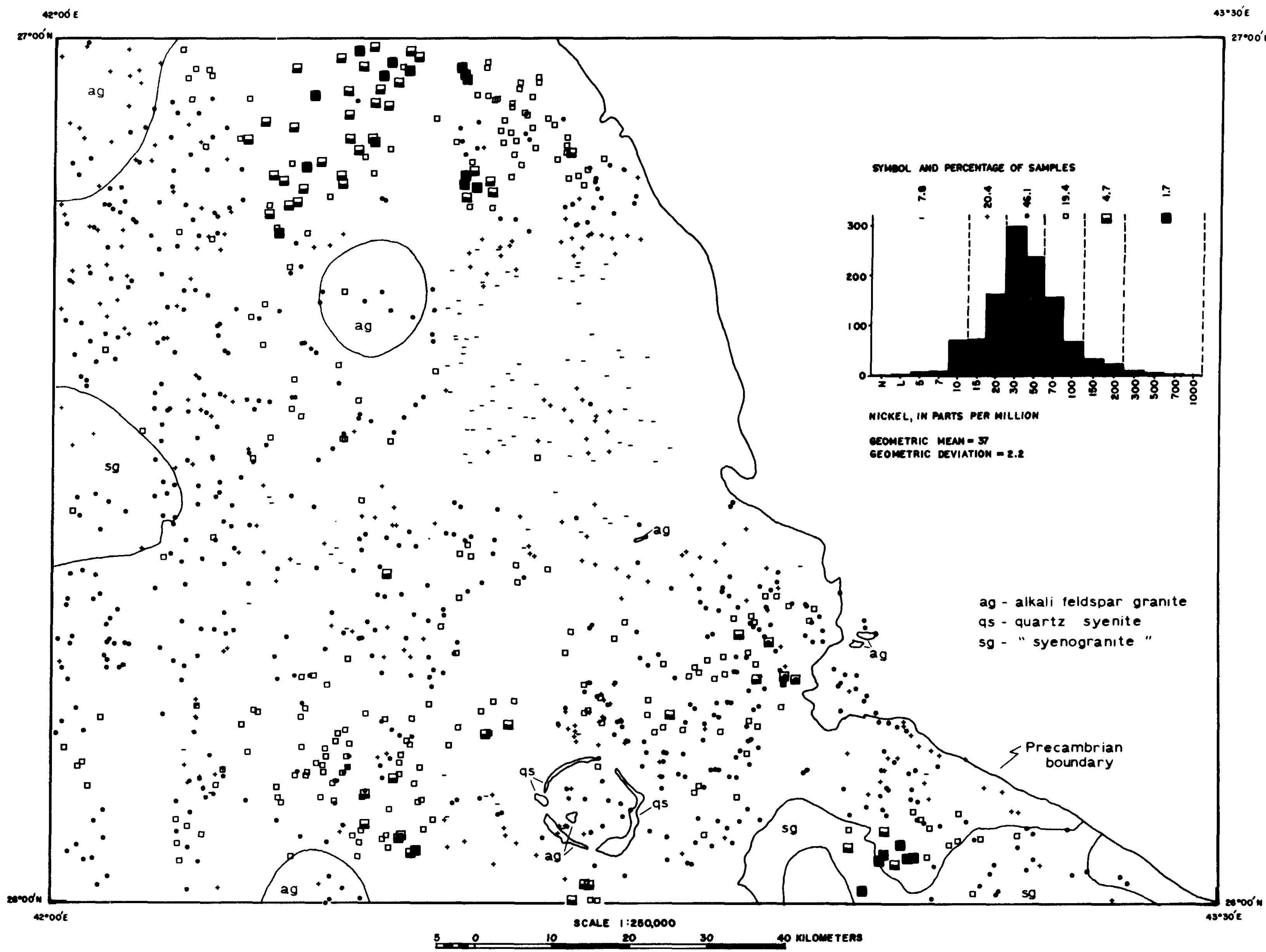

Figure 27.--Nickel concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

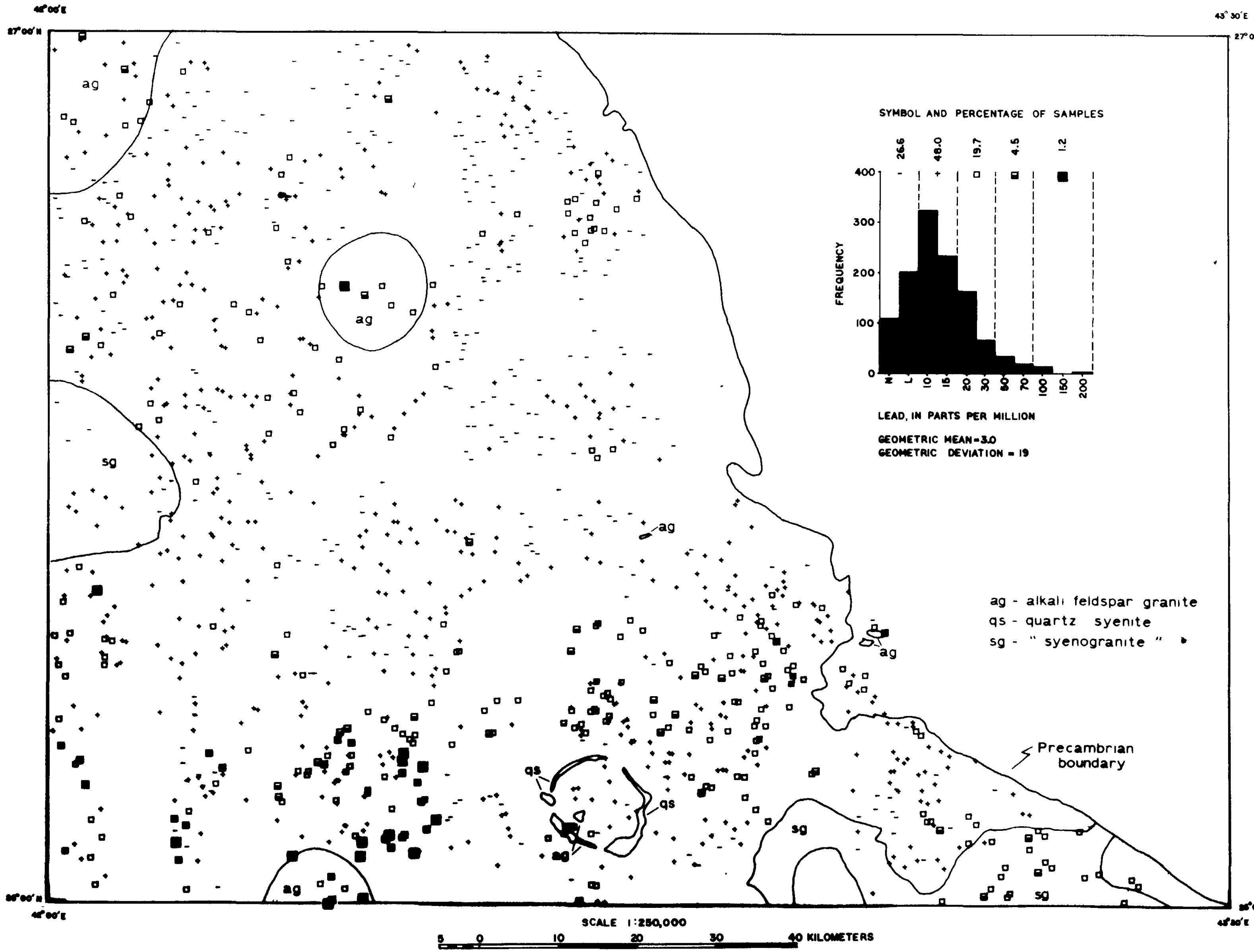

Figure 28.--Lead concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

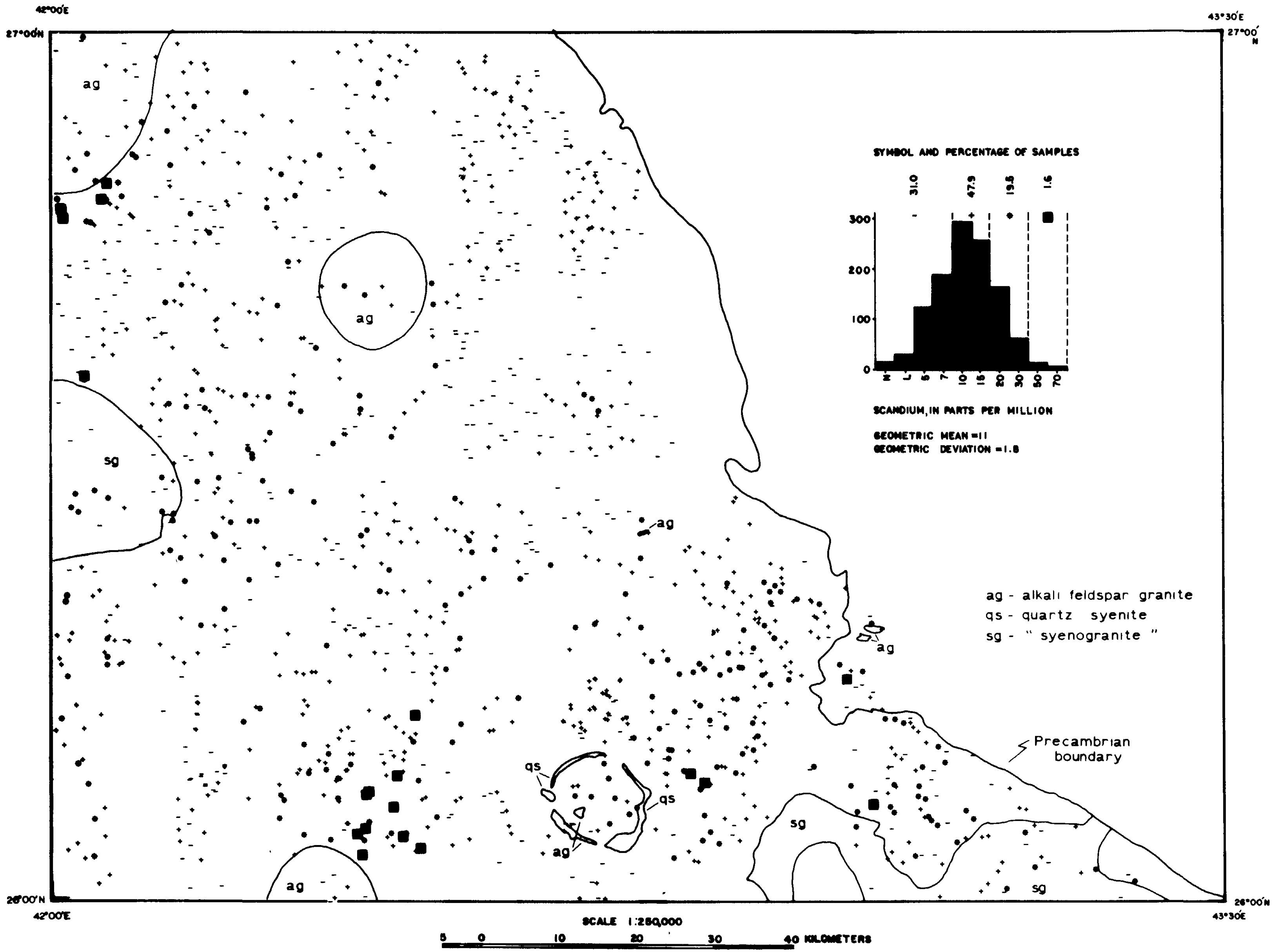

Figure 29.--Scandium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

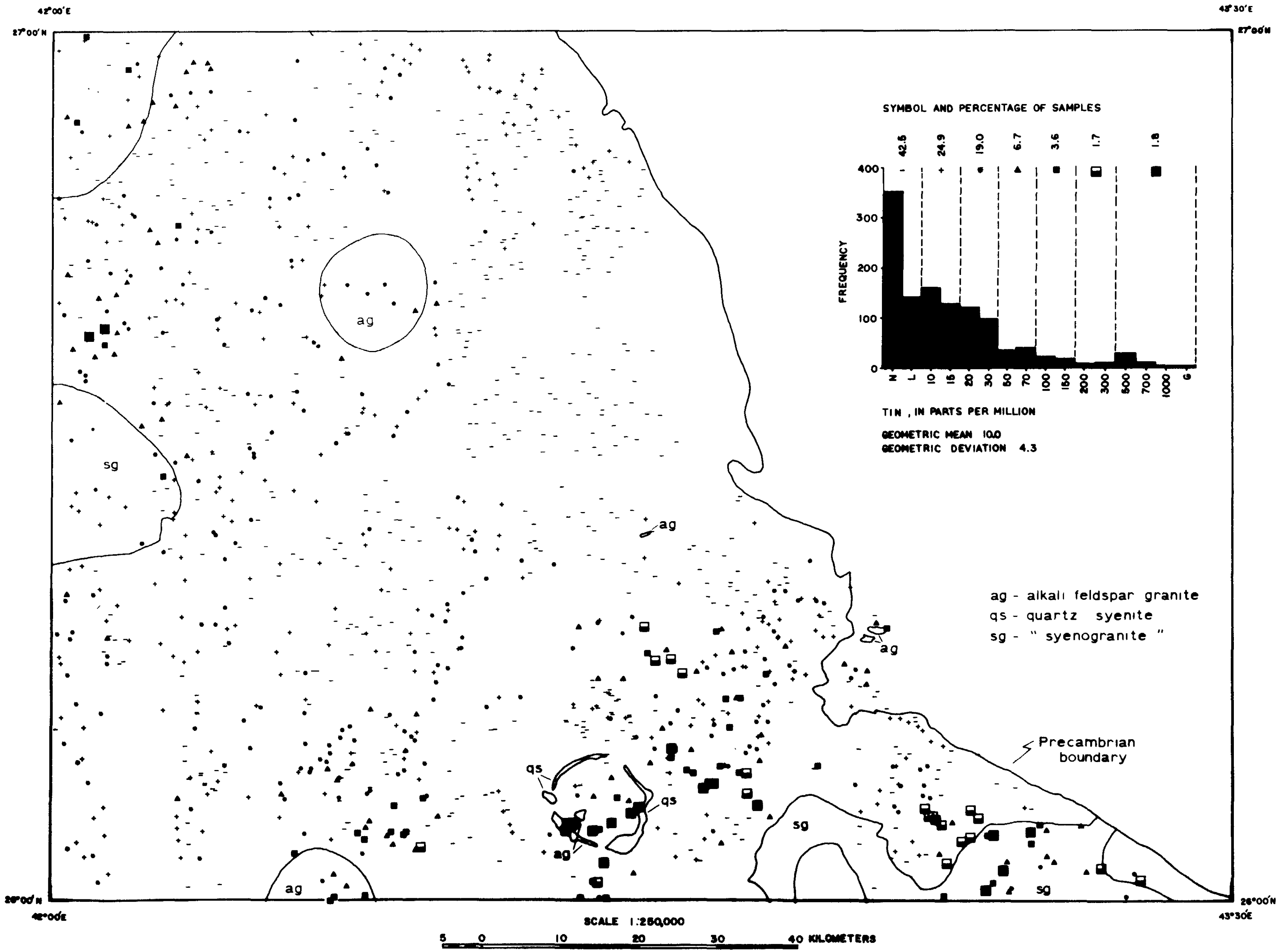

Figure 30.--Tin concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

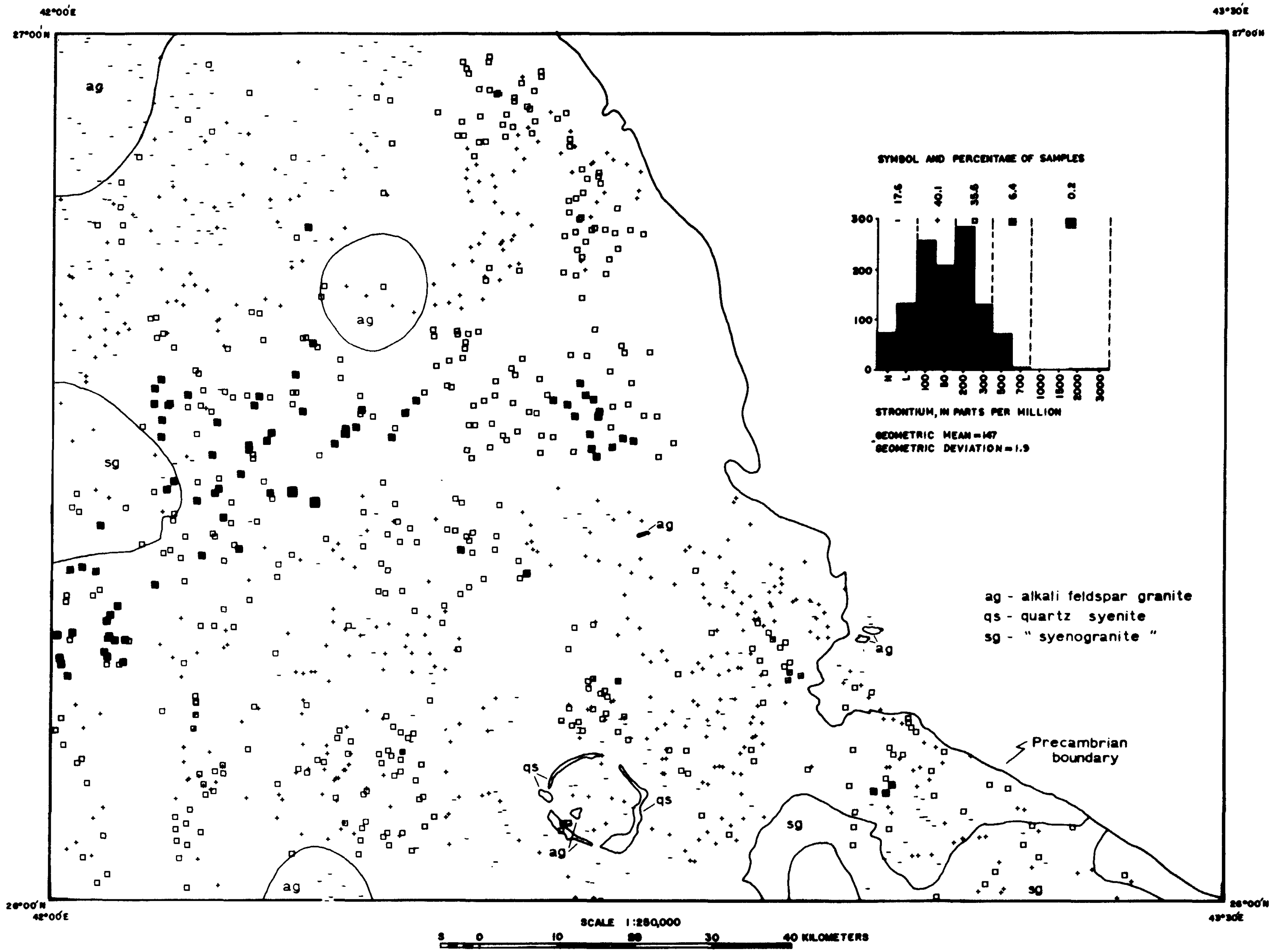

Figure 31.--Strontium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

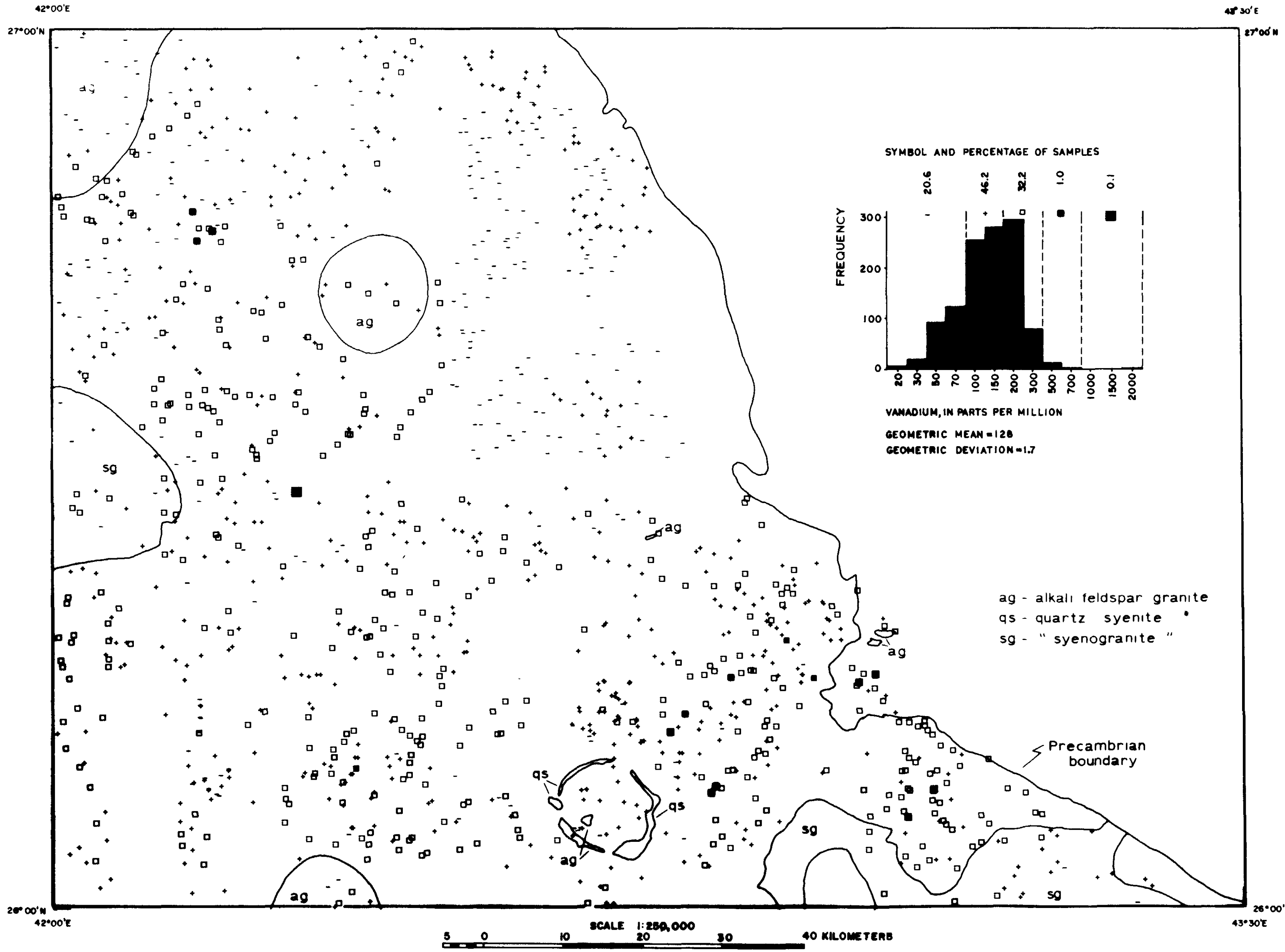

Figure 32.--Vanadium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

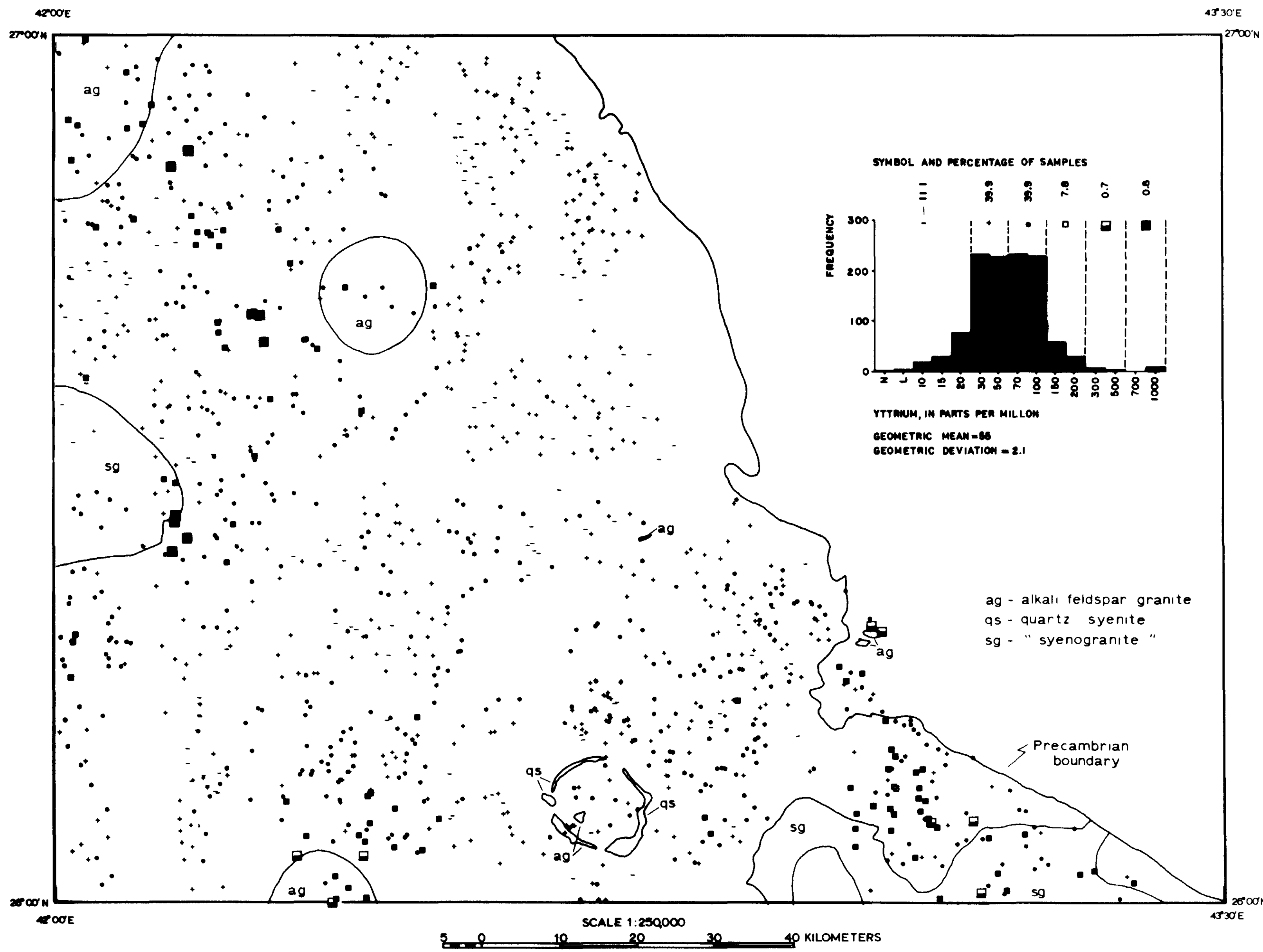

Figure 33.--Yttrium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

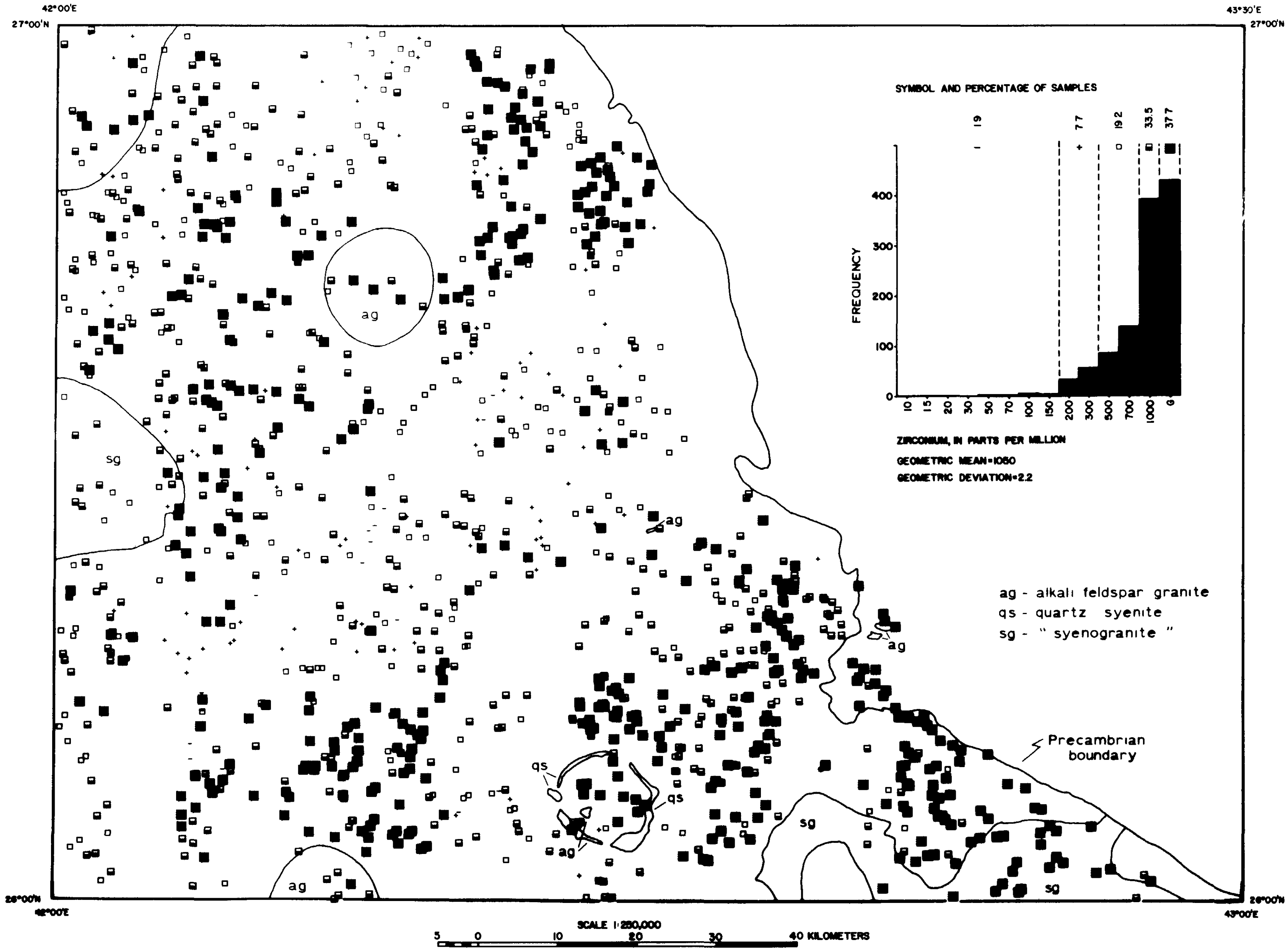

Figure 34.--Zirconium concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

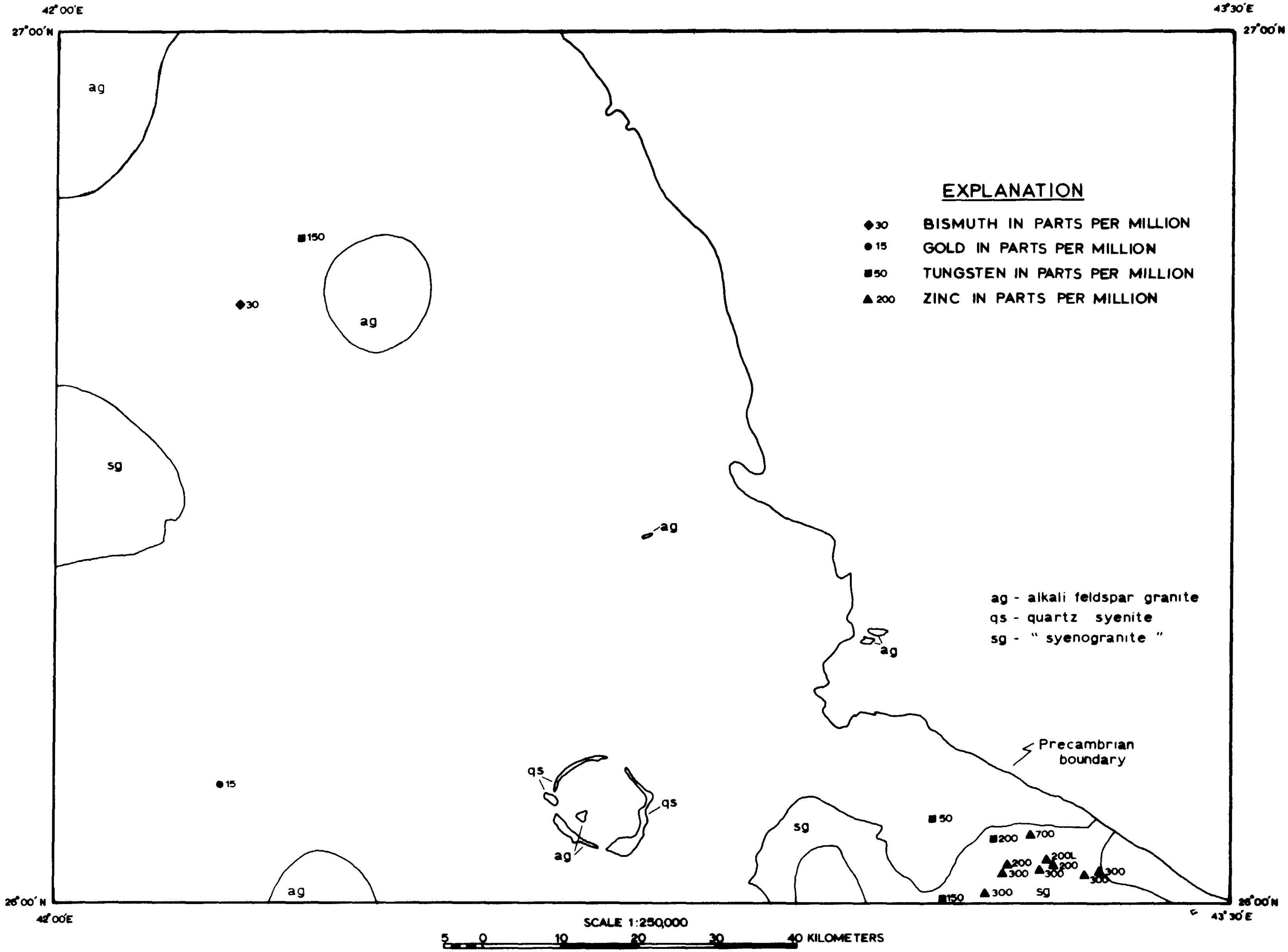

Figure 35.--Bismuth, gold, tungsten, and zinc concentrations in panned concentrates, Jabal Habashi quadrangle, 26F, Saudi Arabia

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