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Results of grid sampling and large-scale geologic mapping for the Silsilah tin deposit

by

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ABSTRACT

A large-scale geologic map and detailed surface sampling have been completed for the two intensely mineralized greisens that occur associated with the Fawwarah alkali-feldspar granite at Jabal as Silsilah. The geologic map further refines previously described geologic relations between various phases of greisenized rock and its host.

Composited 10 m interval samples collected across the greisens contain 0.1 to 12 percent tin, although the tin content of the samples is highly erratic. Anomalously high concentrations of W, Ag, As, Bi, and Pb also occur in samples of the greisens.

The occurrence of greisenized and mineralized Fawwarah alkali-feldspar granite beneath a carapace of Hadhir aplite is well demonstrated. Hadhir aplite is exposed extensively extensively throughout the southwest part of the ring complex and weakly to moderately mineralized quartz-topaz-zinnwaldite-cassiterite greisen occurs beneath the aplite in many of these areas. The geologic setting in the southwest part of the complex suggests that additional sheet-form or cupola-like bodies of greisen may exist beneath thin veneers of Hadhir aplite and the overlying Maraghan lithic graywacke. The potential for a large, low-grade deposit of tin and associated metals in a near-surface setting is encouraging and suggests that a significant amount of additional work is warranted.

INTRODUCTION

Previous work (du Bray, 1984, unpub. data) reported that local, high-grade accumulations of the tin mineral cassiterite are associated with greisenized granite found in the Silsilah ring complex. The ring complex is located in the Jabal as Silsilah quadrangle (sheet 26/42 D) in the northeastern Arabian Shield (fig. 1) and is centered at lat 26°07' N. and long 42°42' E. Small areas of greisenized granite that contains minor cassiterite and of hydrothermally altered rock are abundant in the southwest part of the ring complex. A set of quartz

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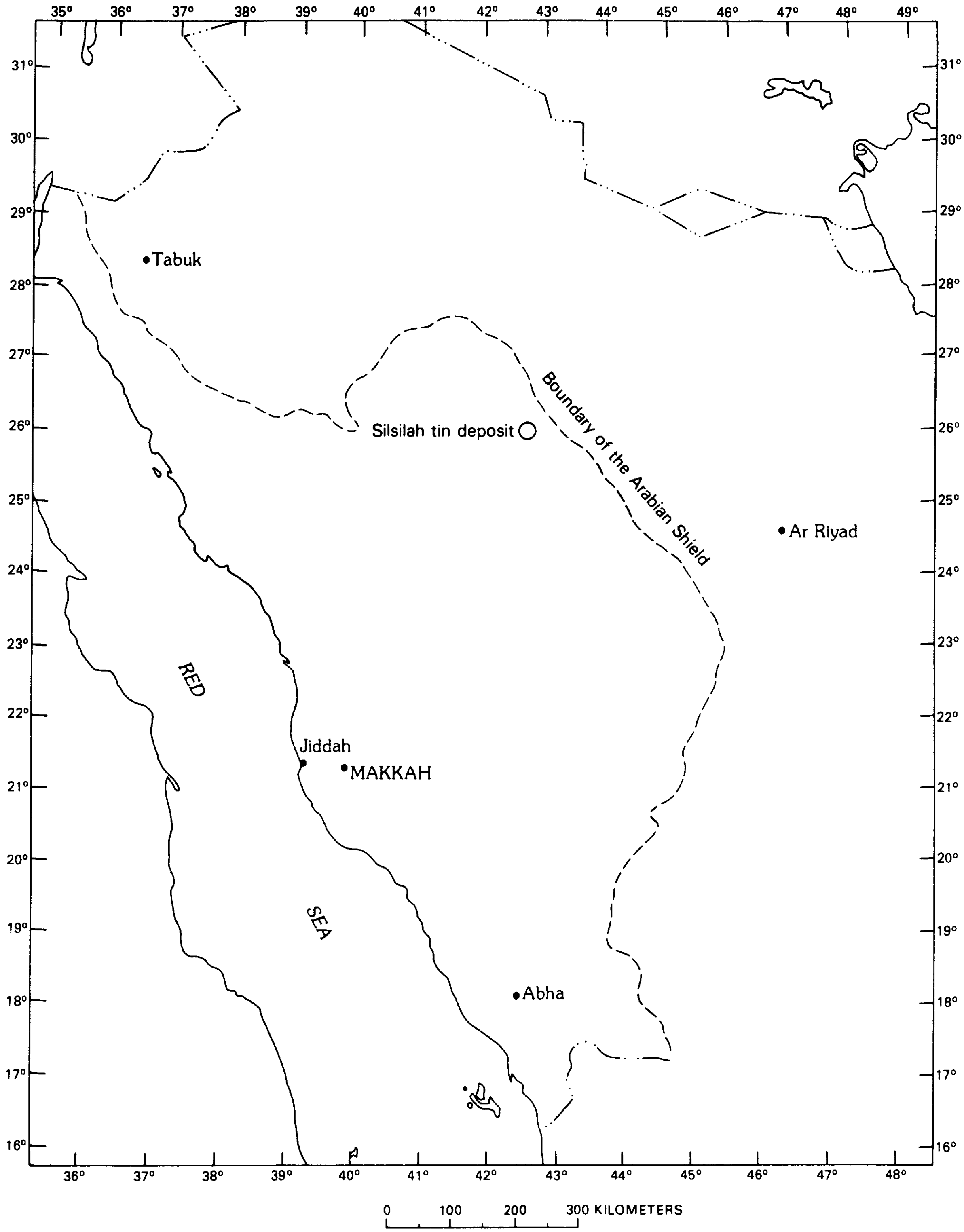


Figure 1.—Index map of western Saudi Arabia showing the location of the Silsilah tin prospect.

veins, located at the south part of the ring complex about 2 km southeast of the greisens, contain high-grade though erratic accumulations of the tungsten mineral wolframite. Granites of the ring complex intrude immature graywacke and siltstone of the Murdama group. The geology and geochemistry of the rocks that form the Silsilah ring complex are described in detail by du Bray (1983, 1984, unpub. data).

The Fawwarah alkali-feldspar granite crops out in the southwest part of the Silsilah ring complex. The apical part of the alkali-feldspar granite, immediately beneath a carapace of the Hadhir aplite and a 1- to 10-m-thick zone of coalesced pegmatite pockets in a matrix of layered aplite, was locally converted to greisen by fluorine-rich fluids that exsolved from the magma as it crystallized. These fluids carried the tin that was ultimately deposited in the greisens as cassiterite. Completely greisenized rock consists of a quartz-cassiterite-topaz assemblage, and is found in two low hills located just inside the southern edge of the ring structure (plate 1, map B). Incompletely greisenized rock that contains minor cassiterite is characterized by a quartz-zinnwaldite-topaz assemblage and is found peripheral to and beneath completely greisenized rock and in small pods located throughout the southwest part of the ring complex. Alkali-feldspar granite, slightly altered to an argillic assemblage, crops out in small areas within the main greisens. Quartz veins that penetrate the intensely mineralized greisens are uncommon, although massive accumulations of milky white quartz are found in adjacent areas.

This study provides a preliminary appraisal of the Silsilah tin deposit. It was clear from the initial study of the deposit (du Bray, 1984, unpub. data) that significant accumulations of cassiterite are present and that its distribution is highly irregular. Rock chip sampling on a grid base was conducted to study the distribution of tin and other elements at the present level of exposure, to determine whether the deposit requires additional study, and if so to identify where within the suite of mineralized rocks to concentrate such study. The initial work (du Bray, 1984, unpub. data) also indicated that the mineralogy within the greisenized rock is variable and that mineralogic zonation probably exists within the greisens. The present study was also undertaken to examine mineralogic variation within the greisen and to determine how the distribution of tin might be related to this variation. Once mineralogic variation within the greisens had been studied and the distribution of tin and other metals more thoroughly understood a model could be constructed to indicate how the deposit might have evolved.

The work on which this report is based was performed in accordance with the work agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey (USGS).

METHODS

The work reported here was conducted from the USGS Fawwarah field camp, located at lat 26°06' N. and long 42°39' E., during March, 1983. A 1:2,000 scale geologic map of the two intensely mineralized greisens located in the southwest part of the ring complex was prepared using standard plane table and alidade techniques (plate 1, map B). After the mapping was completed a grid of sample lines was laid out to provide location for representative, evenly-spaced sample coverage across both greisen hills. The grids are approximately perpendicular to the long axis of each hill. Each sample line was divided into 10 m intervals; several intervals less than 10 m long were made where outcrop is absent. Within each interval approximately 10 kg of rock were collected on and near the the surveyed line, an effort being made to collect a fragment of outcropping rock every 10 to 20 cm within each interval. This mode of sample collection is subjective and is susceptible to bias in sample collection and may yield samples not representive of the rock exposed in the interval. The method was probably adequate for the present study, however. The results probably provide a reasonable estimate of the overall grade of the deposit and helped identify large-scale zoning that exists.

Incompletely greisenized rock that occurs in pods throughout the southwest part of the ring complex and the quartz vein system that penetrates the Silsilah alkali granite at the south end of the complex were also sampled (plate 1, map A). Sampling in these areas was less systematic and at a much lower density than that conducted in the area of the two intensely mineralized greisens. Samples consisted of 2 to 3 kg of rock chips composited from outcrops within several meters of the sample site. A sufficient number of samples were collected at each of these weakly mineralized greisens to facilitate an approximate evaluation of their mineral potential. Samples of the quartz veins were collected in order to document whether ore minerals are present and, if so, what the metal contents of the veins might be. Samples consisted of 2 to 3 kg of quartz characterized by the most intensely mineralized appearance and were composited from chips collected along between 1 and 10 m of vein strike length.

Thirty-element semiquantitative analyses, by emission spark spectrography, were obtained for all of the samples collected. Determinations of gold (Au), cadmium (Cd), cobalt (Co), lanthanum (La), and antimony (Sb), were made in addition to the elements indicated in table 1 but concentrations of these elements in the samples do not exceed their detection limits. The analyses were performed by the Saudi Arabian Directorate General of Mineral Resources (DGMR)/ USGS chemical laboratory, Jiddah. All data were reported as the midpoints, numbers in the infinite series 1, 1.5, 2, 3, 5, 7, 10,..., of logarithmically spaced intervals. A split of each sample was also submitted to Computerised Analytical Laboratories (COMLABS), Australia, for quantitative determinations of rubidium (Rb), tungsten (W), molybdenum (Mo), tin (Sn), arsenic (As), and fluorine (F). All but fluorine, determined by selected ion electrode, were assayed by X-ray fluorescence. The results of quantitative determinations were used in preference to those produced by semiquantitative spectrographic methods, in cases throughout this study for which data by both analytical methods is available.

RESULTS

Strongly mineralized greisens

The mean and standard deviation of concentration was calculated for each element determined in the set of 68 samples collected across the two intensely mineralized greisens (table 1). These data provide a basic measure of the elemental concentrations in the greisens. The mean concentrations of Ag, B, Bi, Mo, Nb, Pb, Zn, As, Sn, W, and F which are present in anomalous to highly anomalous concentrations relative to the low-calcium granite of Turekian and Wedepohl (1961), are of particular interest. Most of these elements are not present in sufficiently high concentrations to be of economic interest, but they serve as pathfinders to tin and associated deposits (Tischendorf, 1977), and also reflect the geochemical processes that caused evolution of the greisens.

The elements Sn, W, As, Bi, Pb, and Zn are all present in highly anomalous concentrations and are characterized by wide ranges of abundances, as indicated by the standard deviations of their concentrations. Each of these elements is of potential interest as a component of an ore phase. The abundances observed, however, suggest that only tin and tungsten occur at potentially economic grades.

Table 1.--Elemental means and standard deviations for 68 samples collected from the two intensely mineralized greisens in the southwest part of the Silsilah ring complex.

Samples composited from rock chips collected in 10 m intervals. Determinations by the DGMR/USGS chemical laboratory, Jiddah using semiquantitative spectrographic techniques, unless otherwise indicated. All values in parts per million, except iron, magnesium, calcium, and titanium which are in percent

Element	Detection limit	Mean	Standard deviation	Number of unqualified data
Fe	0.05	2.76	1.15	68
Mg	.02	0.04	0.03	68
Ca	.05	.84	.61	68
Ti	.002	.01	.03	43
Mn	10	429	524	68
Ag	.5	9	5	63
B	10	13	4	22
Ba	20	61	33	68
Be	1	2	2	24
Bi	10	53	54	66
Cr	10	296	93	68
Cu	5	106	68	68
Mo	5	12	8	57
Nb	20	64	19	68
Ni	5	7	2	59
Pb	10	661	477	68
Sc	5	6	2	7
Sr	100	130	42	23
V	10	16	5	54
Y	10	12	3	22
Zn	200	324	137	21
Zr*	10	83	20	68
As*	2	1367	1913	64
Sn*	4	9527	21347	64
W *	10	175	241	64
Rb**	2	361	393	64
F	50	1489	1328	64

* Determined by X-ray fluorescence, COMLABS, Australia.
** Determined by selected ion electrode, COMLABS, Australia.

Other elements, including Ba, Sr, Ni, and V, are present in anomalously low abundances and their distribution in several samples of the intensely mineralized greisens is interesting. These elements acted compatibly in silicic magmatic environments and were removed from the magma in crystallizing phases before the onset of the hydrothermal process. As a consequence they were not present in large concentrations during the late magmatic stage and were not appreciably partitioned into the ore-forming fluid.

The relative concentration of the elements in individual samples was considered to enable evaluation of the possibility that systematic geochemical zonation exists within the intensely mineralized greisens. Accordingly, a series of single-element concentration variation figures were prepared to facilitate comparison of elemental variations with geology. Plots were generated for all elements determined. Plots for those elements that showed systematic variation or were deemed to be of either economic or genetic interest are presented (figs. 2-10). The concentrations of the elements Fe, Ca, Ti, Mn, B, Ba, Bi, Cr, Cu, Mo, Nb, Ni Pb, Sc, Y, Zn, and Zr in the samples of the two intensely mineralized greisens do not display systematic variation and so their univariant distributions are not further considered. The concentrations of the elements Ag, Be, Sr, V, As, W, Rb, F, and Sn are characterized by significant variation and vague spatial zonation.

The average silver content of samples from the northern greisen appears to be slightly higher than that in samples from the southern greisen (fig. 2); and except for the south end of the southern greisen, the distribution of silver within each of the two greisens is fairly homogeneous. Silver is distinctly depleted in the parts of the southern greisen underlain by the quartz-zinnwaldite greisen (plate 1, map B). The physicochemical conditions which resulted in the quartz-zinnwaldite assemblage evidently did not favor concentration of silver.

The beryllium content of samples from the southern greisen is slightly higher than that of samples from the northern greisen (fig. 3). In particular, the southern part of the southern greisen, where the quartz-zinnwaldite assemblage prevails, is characterized by distinctly higher concentrations of beryllium. This phenomenon may be a function of beryllium's substitution for lithium in zinnwaldite. Beryllium is therefore a very good pathfinder to rock of this composition in the study area.

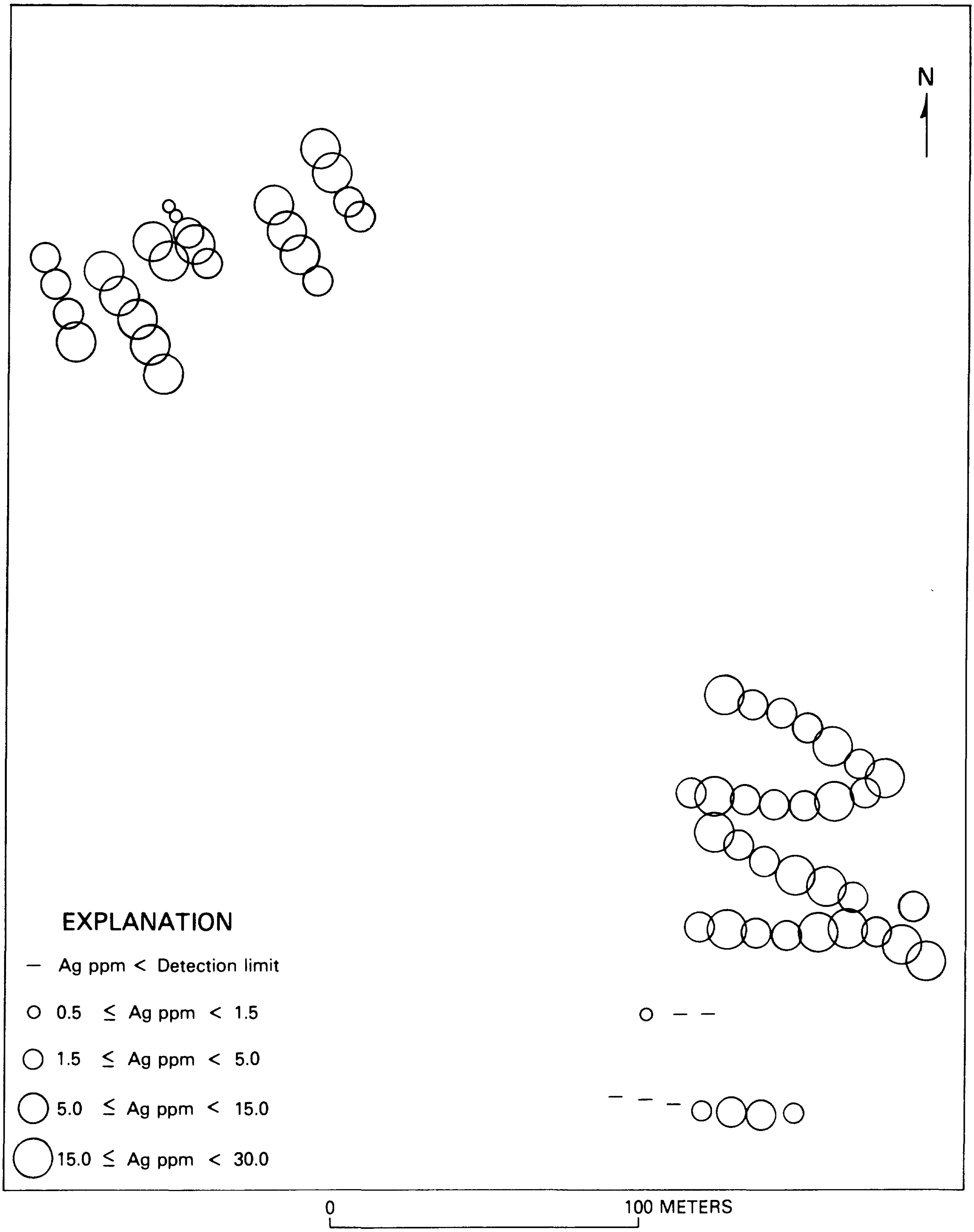


Figure 2.—Map showing the distribution of silver in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A

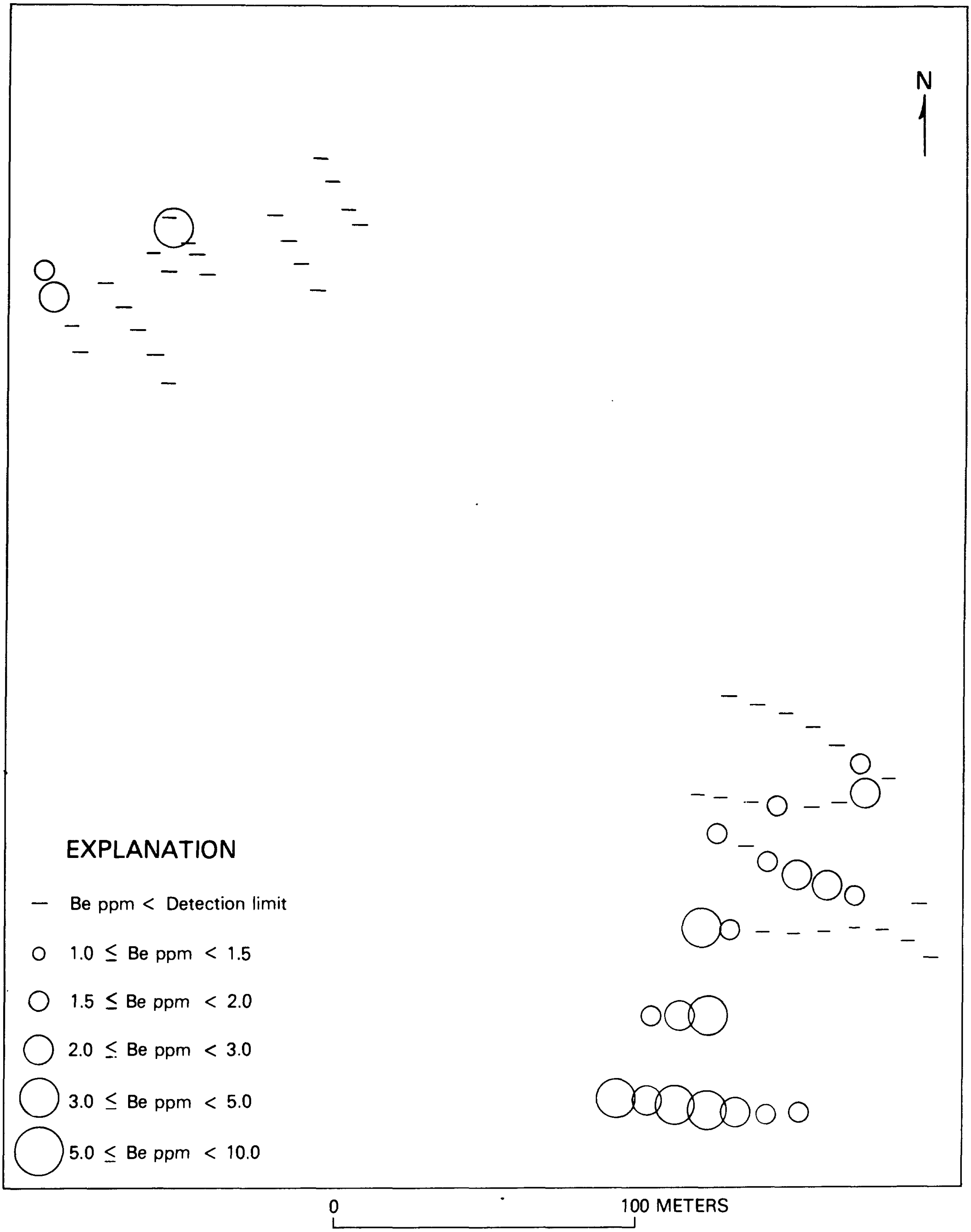


Figure 3.--Map showing the distribution of beryllium in in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A

The strontium content of samples of the northern greisen is distinctly higher than that characteristic of samples from the southern greisen (fig. 4). This observation exemplifies the geochemical distinction between the two intensely mineralized greisens. Strontium is preferentially partitioned into the solid phase because of its compatible behavior in granitoid magmatic systems (Hanson, 1978), and is therefore less abundant in subsequently solidified materials. The higher strontium content of samples from the northern greisen may indicate that the northern greisen represents conditions of hydrothermal alteration and mineralization that occurred earlier than those that prevailed in the southern, strontium-depleted greisen. The northern greisen may represent an early incarnation of the hydrothermal fluid, characterized by conditions less favorable for intense mineralization than the metal-rich residuum that ultimately evolved and was responsible for genesis of the tin deposit.

The vanadium content of samples from the northern greisen is more homogeneous and slightly higher than that characteristic of the southern greisen (fig. 5). Vanadium is depleted or present in very low concentrations from most samples collected where the host rock was either quartz-zinnwaldite rock or argillically altered granite.

The distribution of arsenic displays the strongest zonation of any element determined (fig. 6). The arsenic content of samples from the northern greisen is about five times that of samples from the southern greisen and is highly anomalous relative to the arsenic content of most rocks (Turekian and Wedepohl, 1961). Three samples from the northeast corner of the southern greisen also contain highly anomalous concentrations of arsenic. The geochemical affinities of arsenic and sulfur are similar and arsenic is usually a major constituent of sulfide mineralized rock. The dissimilarity of arsenic content between samples of the two greisens suggests that the northern greisen either experienced a sulfide-dominated hydrothermal event not experienced by the southern greisen or that both greisens experienced this event and that evidence of this event was subsequently overprinted by another event that affected only the southern greisen. The variation of arsenic content between samples of the two greisens may result from geochemical zonation of one hydrothermal system or may represent the effects of superposed hydrothermal events.

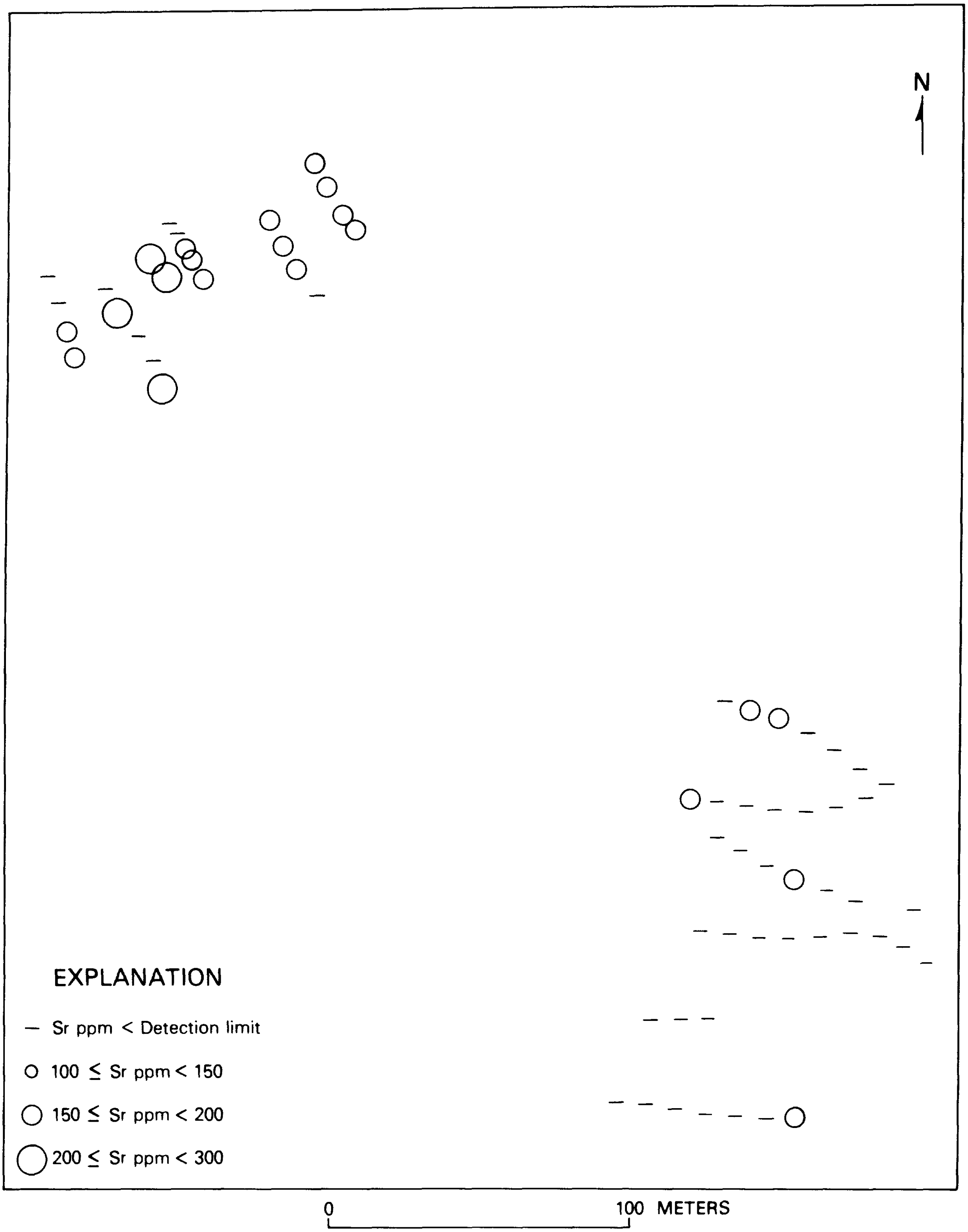


Figure 4.--Map showing the distribution of strontium in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A

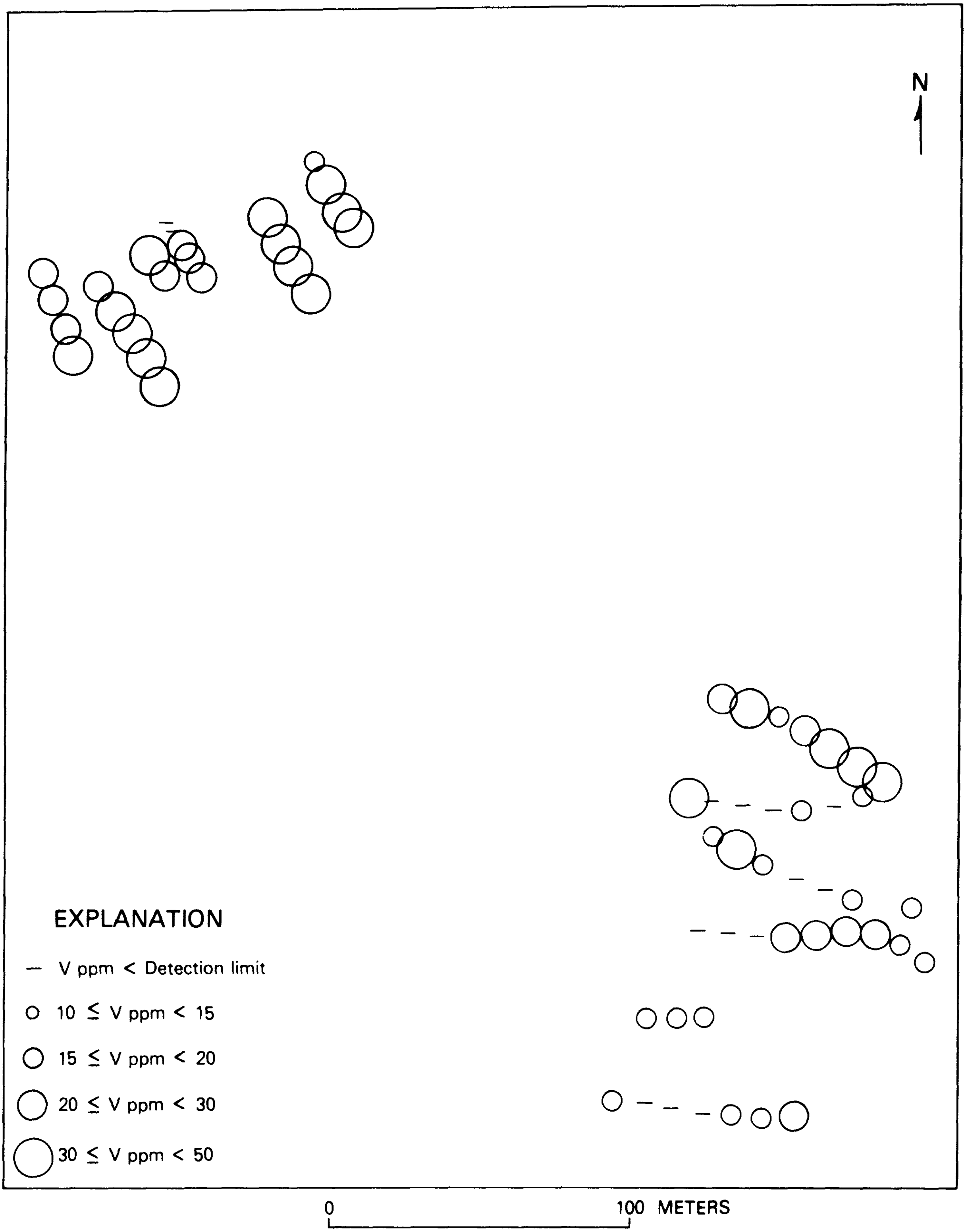


Figure 5.--Map showing the distribution of vanadium in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A

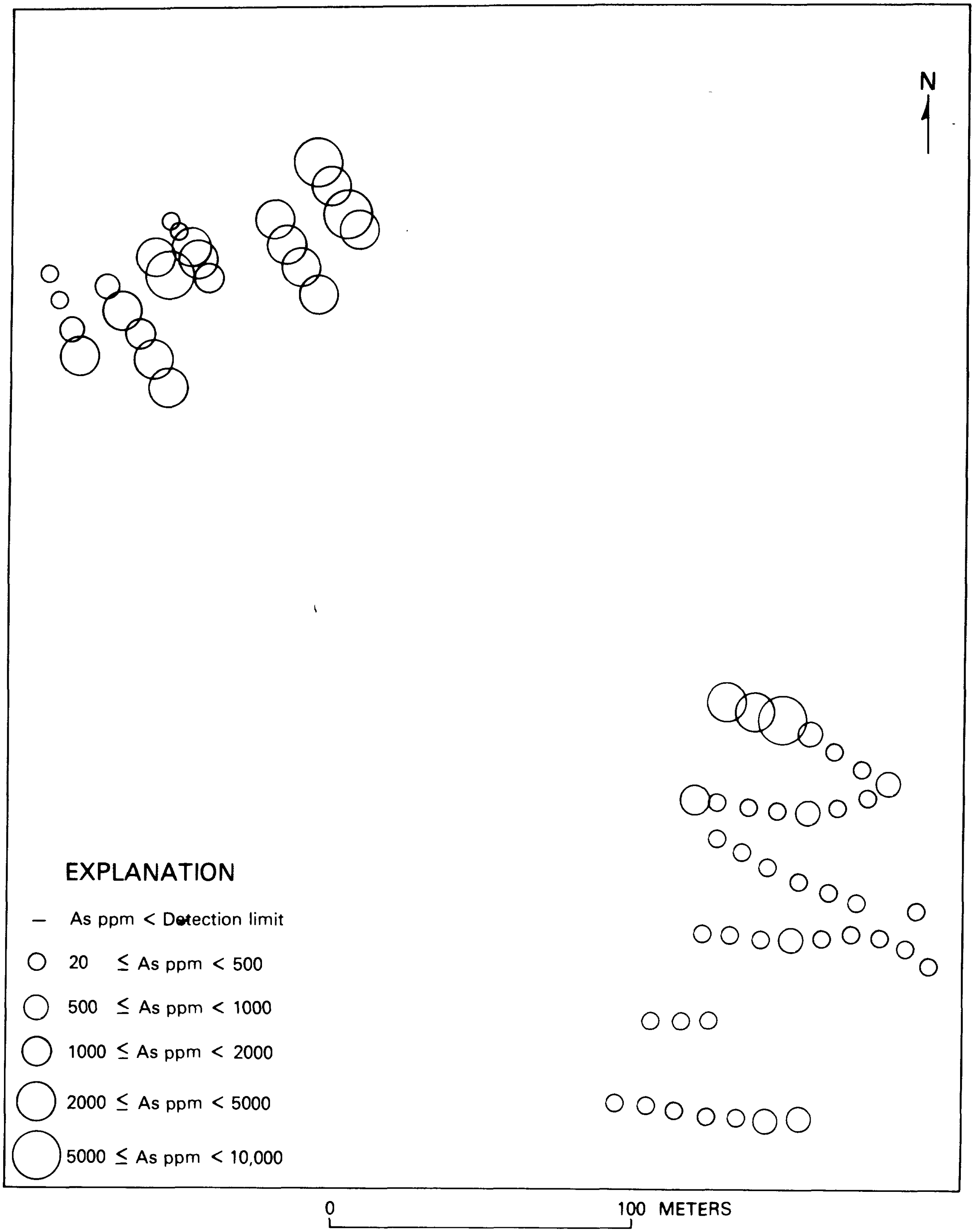


Figure 6.—Map showing the distribution of arsenic in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A

The tungsten content of samples from the southern greisen is slightly higher than that characteristic of samples from the northern greisen (fig. 7). No systematic zonation of tungsten content is apparent, however. Tungsten, like niobium, substitutes for tin in cassiterite (Dudykina, 1959). The low content of tungsten, relative to that in tungsten ore, in samples of the two greisens suggests that tungsten does not form minerals of its own in the Silsilah greisens but is a constituent of cassiterite. The tungsten content of the samples is anomalous but does not indicate the likely existence of a significant tungsten resource in the currently exposed part of the Silsilah greisens.

The rubidium content of samples from the southern greisen is consistently higher than it is in samples from the northern greisen (fig. 8). Rubidium tends to act incompatibly in granitoid magmatic systems (Hanson, 1978) and, as is observed in this case, its distribution should be antithetic to that of strontium. Again, there is a suggestion that different physico-chemical conditions prevailed during genesis of the two greisens. The rubidium content of samples from the south part of the southern greisen, where the mineral assemblage quartz-zinnwaldite prevails, are distinctly higher than it is elsewhere in the two greisens. The rubidium content of samples from the northern greisen is somewhat erratic. The principal mineralogic site of rubidium in these samples is zinnwaldite. High rubidium content therefore indicates samples that contain higher concentrations of the mica and areas in which the type and extent of hydrothermal alteration favored stabilization of zinnwaldite. The relation between zinnwaldite abundance and distribution of cassiterite in the Silsilah greisens is not clearly established, though the fact that the mica occurs in less intensely greisenized rock suggests that the cassiterite content of these rocks will be lower than in samples of the quartz-topaz greisen.

The fluorine content of the samples is, in general, surprisingly low for a greisen environment (fig. 9). The distribution of fluorine is relatively homogeneous between samples of the two greisens except for samples from the south half of the southern greisen. The fluorine content of samples from this area is homogeneous and distinctly higher than it is in other samples of the two greisens. The enhanced fluorine content of these samples is attributable to zinnwaldite, which contains 4 to 8 percent fluorine (Deer and others, 1962), since the abundance of topaz, the other fluorine-bearing mineral in samples of the greisens, is approximately constant in the greisen samples.

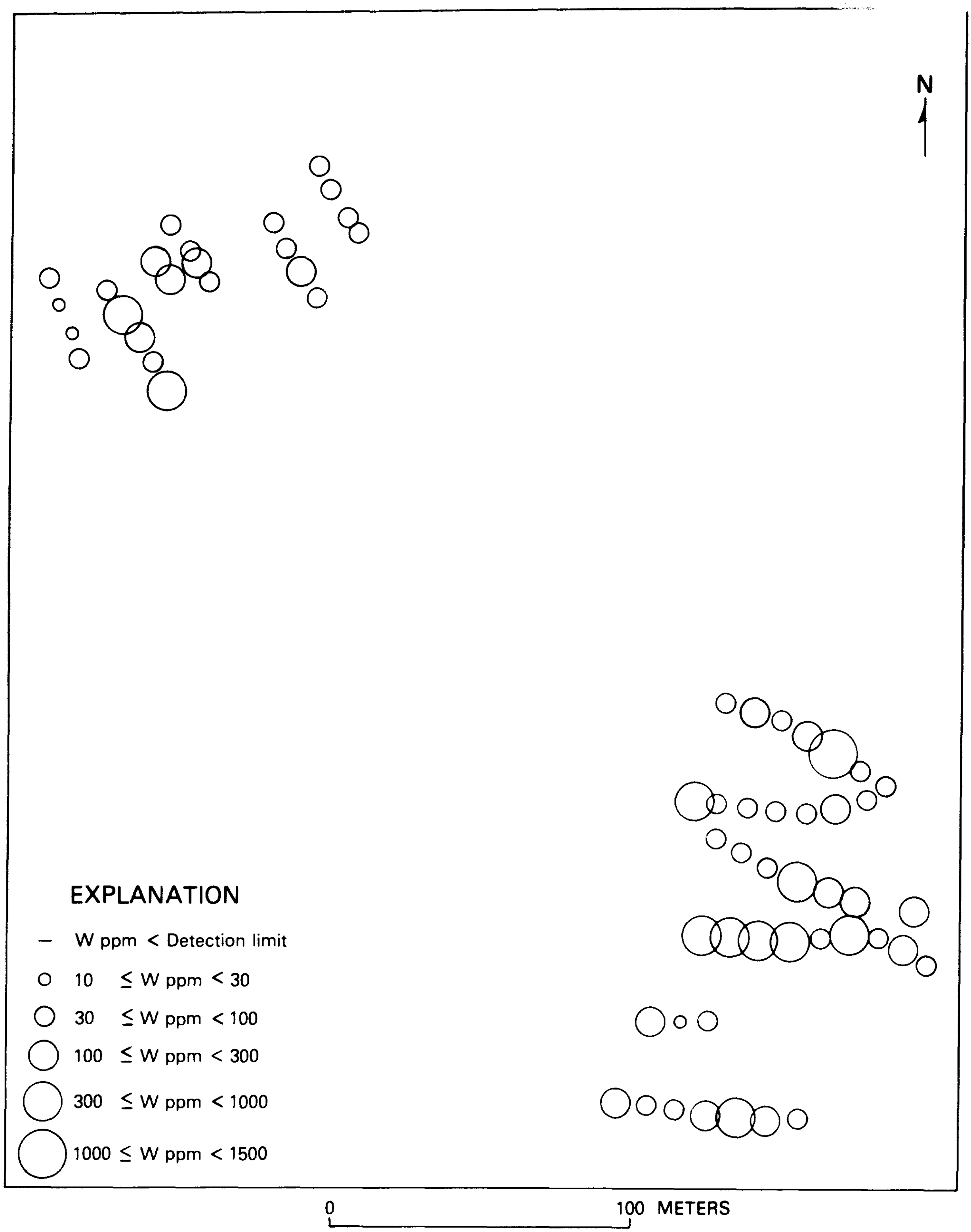


Figure 7.—Map showing the distribution of tungsten in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A

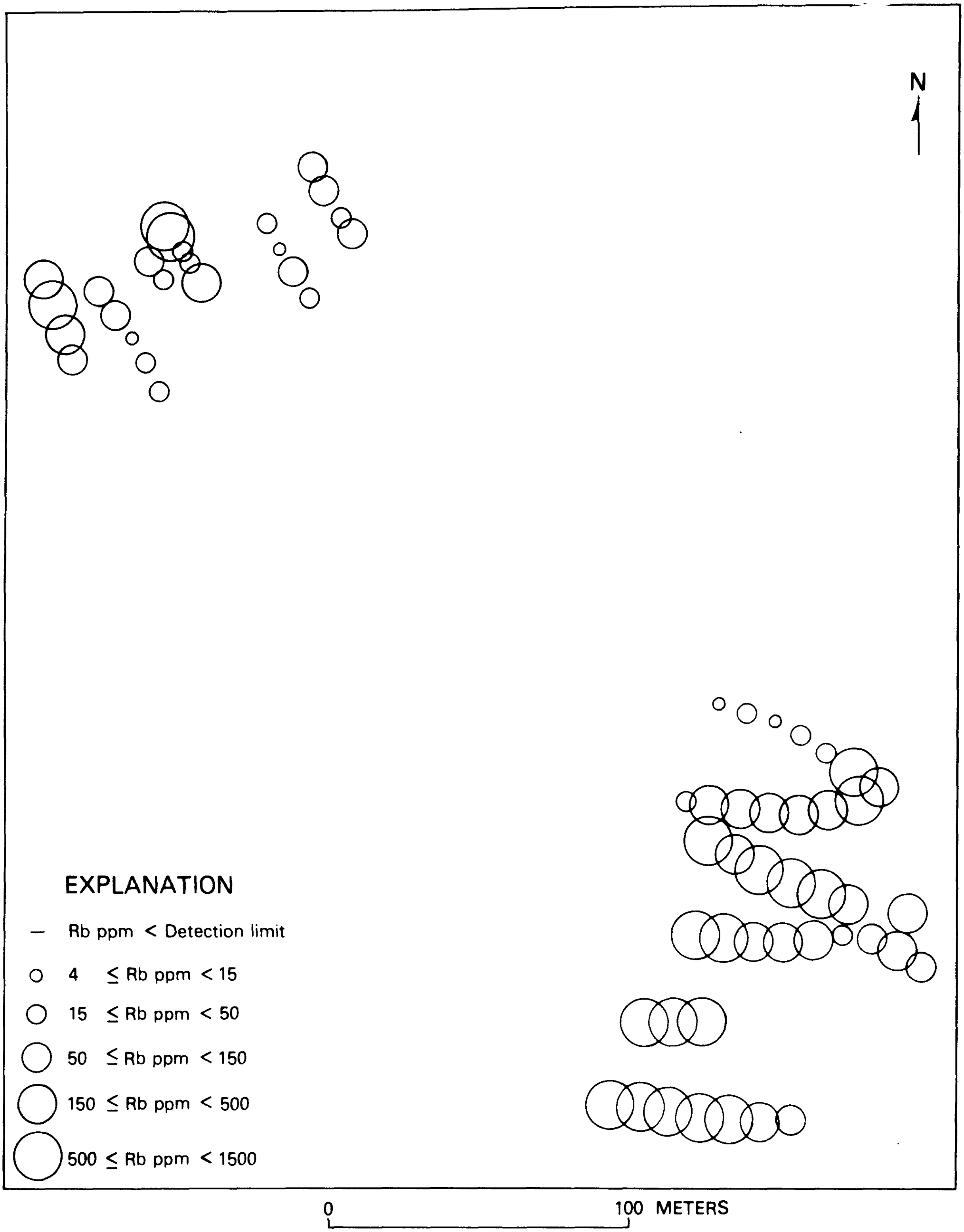


Figure 8.—Map showing the distribution of rubidium in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A.

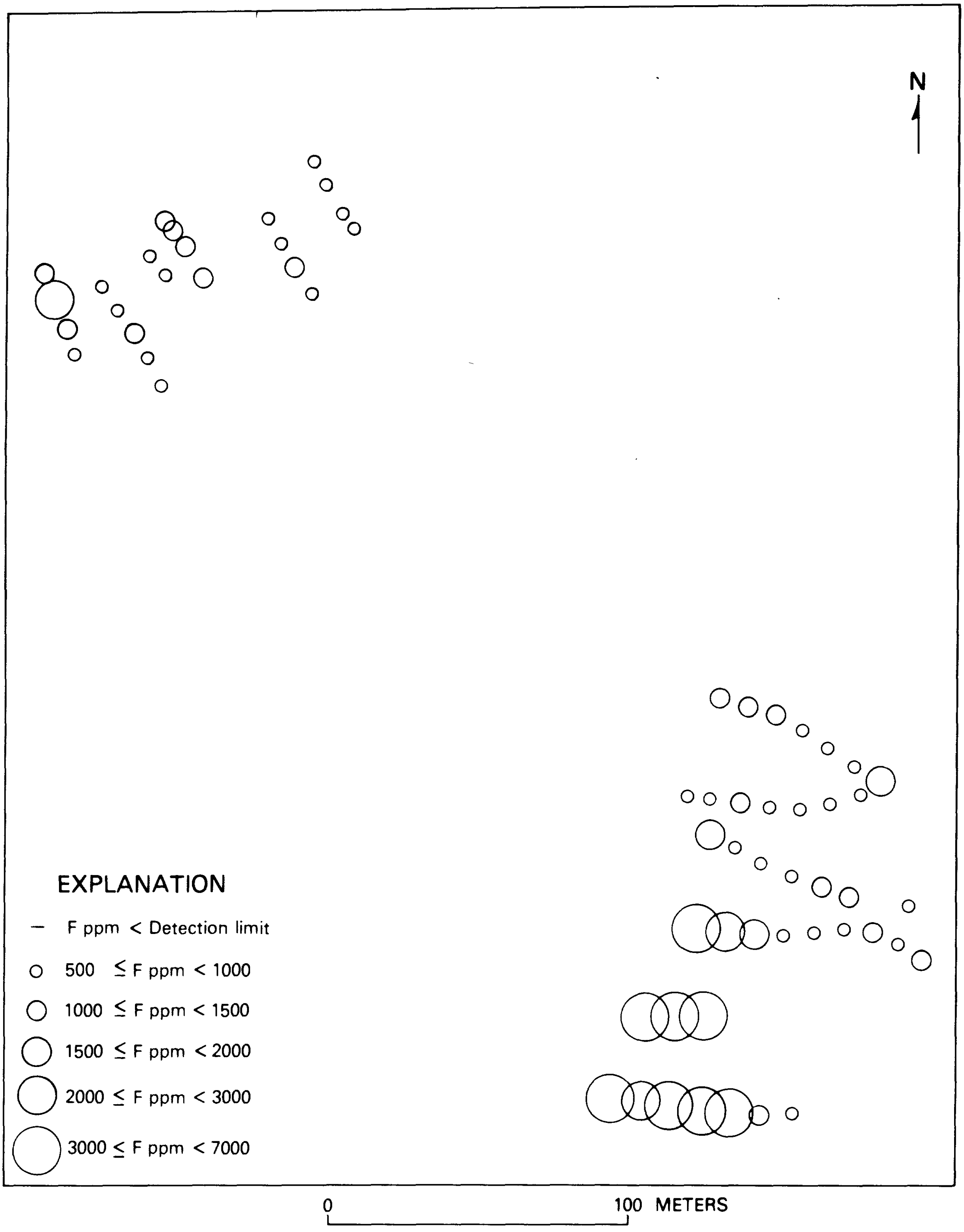


Figure 9.—Map showing the distribution of fluorine in samples of the two strongly mineralized greisens. Area of figure indicated on Plate 1, map A.

The tin content of both greisens is highly anomalous (fig. 10) and suggests that an economically exploitable resource of tin may exist associated with the Silsilah greisens. Samples of the greisens contain between 75 ppm and 12.1 percent tin, although few contain less than 1000 ppm. The average tin content of samples from the southern greisen is 1.0 percent tin whereas that for samples from the northern greisen is 0.5 percent (du Bray, 1983). Systematic zonation of tin content within the two greisens is apparently absent. The insignificant difference in tin content of samples from the north and south parts of the southern greisen is surprising, in light of the mineralogic variation that exists between the greisen in these two areas. Tin occurs as cassiterite.

A correlation coefficient matrix was computed using the geochemical data for the interval samples from the intensely mineralized greisens (table 2). Entries in the matrix indicate the degree to which variance between elements of the sample set is correlated. Correlation coefficients greater than 0.5 are considered significant; the element pairs that meet this criterion are listed in table 3.

The correlation matrix also facilitates qualitative identification groups of elements that display positively correlated covariation. Elemental covariation of this type is a consequence of coherent geochemical behavior by members of the association. The five most easily identifiable associations are:

Mn + F + Rb
Sn + Sc + W + Nb
Fe + Pb + Ag + Sr
V + Ca + Sc
Zn + Y + Mg

Zinnwaldite, the lithium mica, is likely the principal mineralogic site of Mn, F, and Rb in rocks of this type. The close association of these elements in the greisen samples suggests that their concentrations are mutually controlled by the zinnwaldite content of individual samples. Similarly, Sn, Sc, W, and Nb are concentrated in cassiterite and their abundances are caused to covary by the cassiterite content of samples. Pb is a major constituent of galena and Ag, Sr, and Fe are concentrated in galena (Deer and others, 1966). Their mutual covariation in samples of the Silsilah greisens suggests that galena is the controlling mineral. Ca and to a lesser extent V and Sc are components of feldspars and their mutual covariation in the greisen samples suggests that feldspars controlled their distribution. The final group of associated elements, Zn, Y, and Mg, is enigmatic. The controlling mechanism for this assemblage is unknown.

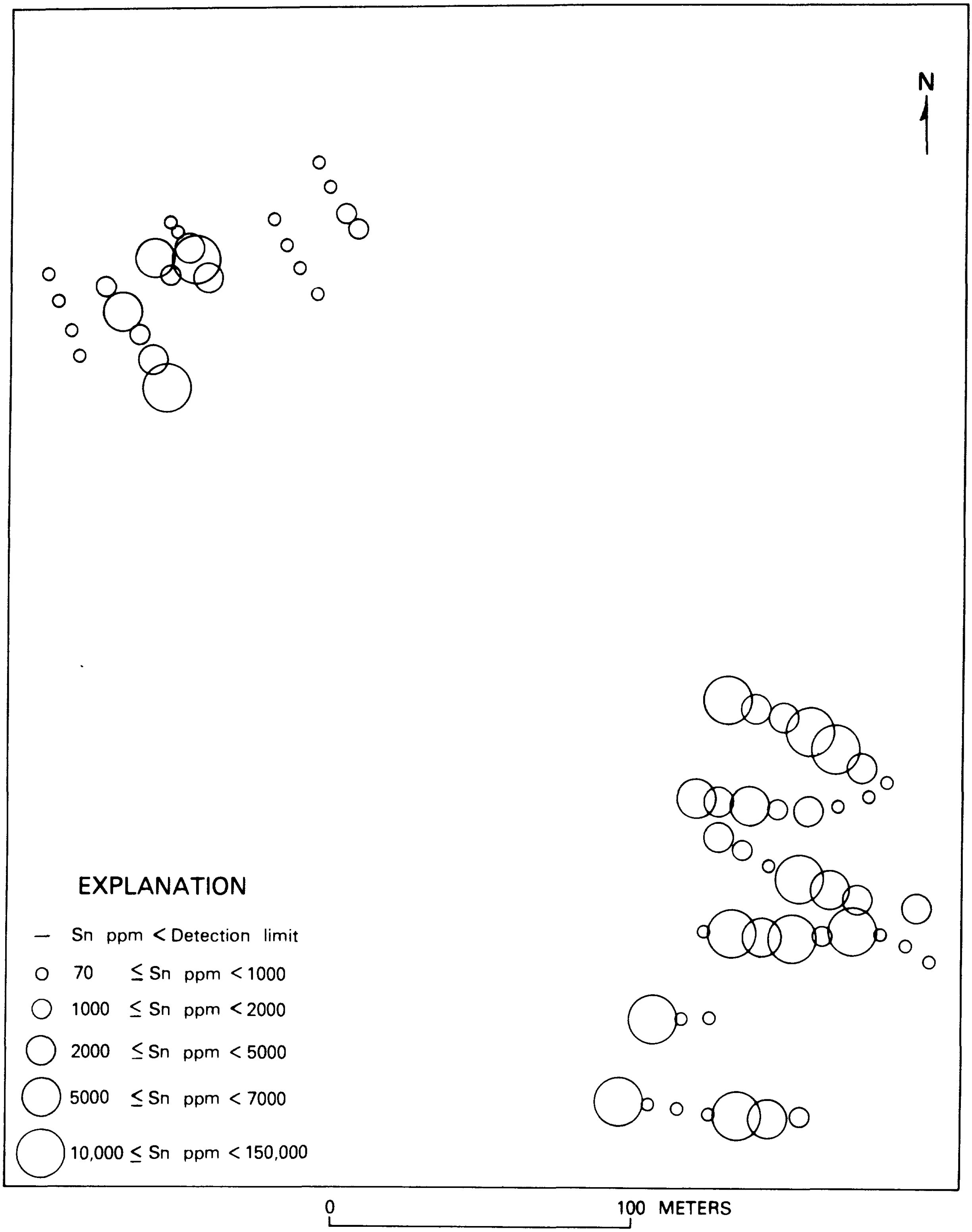


Figure 10.—Map showing the distribution of tin in samples. Area of figure indicated on Plate 1, map A.

Table 2.--Correlation matrix of geochemical data for sixty eight samples from the two intensely mineralized greisens located in the southwest part of the Silsilah ring complex

The upper half of the matrix gives correlation coefficients for element pairs. The lower half indicates the number of valid sample pairs from which the statistics are computed. Valid sample pairs are those for which data for both elements considered are either qualified or unqualified. Asterisks indicate the nonexistence of valid sample pairs for the considered element pair. The data diagonal from top left to bottom right, underlined values, gives the standard deviation for the element in the corresponding column

		1 S-FE	2 S-MG	3 S-CA	4 S-TI	5 S-MN	6 S-AG	7 S-B	8 S-BA	9 S-BE	10 S-BI
1	S-FE	1.1508	-0.2165	0.4229	-0.4184	-0.1685	0.3387	-0.0376	0.3067	-0.3167	0.0198
2	S-MG	68	0.0320	0.2714	0.6474	-0.3371	-0.0520	0.0972	0.0954	0.3087	-0.1840
3	S-CA	68	68	0.6087	0.0235	-0.4653	0.2798	-0.1671	0.2741	-0.1833	-0.0855
4	S-TI	43	43	43	0.0328	-0.0580	-0.3880	-0.5148	-0.0539	0.7123	-0.1072
5	S-MN	68	68	68	43	524.1119	-0.4082	0.2087	-0.1839	0.3739	-0.1369
6	S-AG	63	63	63	39	63	4.5991	0.1527	0.1183	-0.3851	0.0792
7	S-B	22	22	22	7	22	21	4.1936	0.2256	0.0795	-0.4038
8	S-BA	68	68	68	43	68	63	22	32.9578	-0.2245	-0.2151
9	S-BE	24	24	24	15	24	19	11	24	1.5598	0.0414
10	S-BI	66	66	66	41	66	61	22	66	22	54.4121
11	S-CR	68	68	68	43	68	63	22	68	24	66
12	S-CU	68	68	68	43	68	63	22	68	24	66
13	S-MO	57	57	57	36	57	55	15	57	16	57
14	S-NB	68	68	68	43	68	63	22	68	24	66
15	S-NI	59	59	59	39	59	57	17	59	17	57
16	S-PB	68	68	68	43	68	63	22	68	24	66
17	S-SC	7	7	7	6	7	6	0	7	2	7
18	S-SR	23	23	23	18	23	23	1	23	2	23
19	S-V	54	54	54	38	54	51	13	54	14	54
20	S-Y	22	22	22	17	22	19	4	22	11	20
21	S-ZN	21	21	21	14	21	17	7	21	12	19
22	S-ZR	68	68	68	43	68	63	22	68	24	66
23	XRF-AS	64	64	64	39	64	59	22	64	24	62
24	SI-F	64	64	64	39	64	59	22	64	24	62
25	XRF-SN	64	64	64	39	64	59	22	64	24	62
26	XRF-W	64	64	64	39	64	59	22	64	24	62
27	XRF-RB	64	64	64	39	64	59	22	64	24	62

Table 2.--Correlation matrix of geochemical data for sixty eight samples from the two intensely mineralized greisens located in the southwest part of the Silsilah ring complex--Contunued

		11 S-CR	12 S-CU	13 S-MO	14 S-NB	15 S-NI	16 S-PB	17 S-SC	18 S-SR	19 S-V	20 S-Y
1	S-FE	-0.1627	0.3577	0.5528	-0.0505	0.0356	0.3707	0.3568	0.2216	0.4210	-0.2017
2	S-MG	0.0333	0.1707	0.0562	-0.1413	0.1067	0.0272	0.1834	0.2263	0.2164	0.5271
3	S-CA	-0.2781	0.4092	0.2373	-0.1031	-0.0079	0.3161	0.3784	0.4766	0.5642	0.1297
4	S-TI	-0.1255	-0.1527	-0.1561	0.0100	0.0988	-0.2863	0.6261	-0.0936	-0.0650	0.5343
5	S-MN	0.0841	-0.5299	-0.2096	0.0163	-0.1022	-0.3943	-0.1650	-0.2468	-0.3865	-0.0420
6	S-AS	-0.1961	0.2977	0.5326	0.0032	-0.0706	0.6451	0.3907	0.5041	0.3777	-0.1357
7	S-B	0.0979	-0.0930	-0.3154	-0.0911	0.0959	-0.1647	**********	**********	-0.6050	1.0000
8	S-BA	0.0397	0.0731	0.1692	0.1151	0.3320	0.1498	0.0000	0.1977	0.2613	0.1019
9	S-BE	-0.1097	-0.3959	0.0963	0.0960	0.1050	-0.5856	**********	**********	-0.2475	0.3730
10	S-BI	-0.1360	0.2483	-0.0988	0.3022	0.1763	0.1622	-0.2174	-0.2342	0.0369	-0.3310
11	S-CR	93.3359	0.0434	-0.1506	0.1407	0.4251	-0.1798	0.7193	-0.4017	-0.0496	0.0841
12	S-CU	68	67.8432	0.2507	-0.0378	0.2487	0.3681	0.2553	-0.2825	0.4203	0.0181
13	S-MO	57	57	7.9888	0.1137	0.0452	0.3819	0.3896	0.1543	0.3421	0.2795
14	S-NB	68	68	57	19.0236	0.2887	0.1340	0.0000	0.1124	-0.0184	-0.1816
15	S-NI	59	59	51	59	2.1358	-0.1230	0.3665	-0.3393	0.0480	0.2385
16	S-PB	68	68	57	68	59	477.2461	-0.0909	0.5256	0.4012	0.0387
17	S-SC	7	7	7	7	4	7	1.9149	**********	0.7568	-0.3333
18	S-SR	23	23	23	23	22	23	1	41.9392	0.3889	0.5449
19	S-V	54	54	51	54	50	54	7	22	5.3535	0.0230
20	S-Y	22	22	17	22	19	22	4	8	17	3.3306
21	S-ZN	21	21	15	21	15	21	1	8	14	9
22	S-ZR	68	68	57	68	59	68	7	23	54	22
23	XRF-AS	64	64	53	64	55	64	7	22	50	21
24	SI-F	64	64	53	64	55	64	7	22	50	21
25	XRF-SN	64	64	53	64	55	64	7	22	50	21
26	XRF-W	64	64	53	64	55	64	7	22	50	21
27	XRF-RB	64	64	53	64	55	64	7	22	50	21

Table 2.--Correlation matrix of geochemical data for sixty eight samples from the two intensely mineralized greisens located in the southwest part of the Silsilah ring complex--Continued

		21	22	23	24	25	26	27
		S-ZN	S-ZR	XRF-AS	SI-F	XRF-SN	XRF-W	XRF-RB
1	S-FE	-0.2407	-0.0732	0.3884	-0.0904	-0.0251	0.1883	-0.3742
2	S-MG	0.5654	0.1471	0.0525	-0.3848	-0.1620	-0.2506	0.0291
3	S-CA	-0.1612	-0.1052	0.5583	-0.4320	0.0754	-0.0532	-0.5409
4	S-TI	0.4425	0.2675	-0.1052	-0.0793	-0.1366	-0.1713	0.3206
5	S-MN	-0.1642	0.0768	-0.3939	0.9519	-0.0410	0.1042	0.8340
6	S-AG	-0.2960	-0.1241	0.3030	-0.4226	0.0558	0.1285	-0.4998
7	S-R	0.4136	-0.2124	-0.5543	0.0372	0.2443	0.2592	0.4733
8	S-BA	0.0817	-0.0136	0.2841	-0.2473	-0.0225	0.0123	-0.1980
9	S-BE	0.1771	0.1169	-0.4176	0.3370	-0.0047	-0.0400	0.7923
10	S-BI	-0.1073	-0.1112	0.0375	-0.1159	0.2583	0.2292	-0.2475
11	S-CR	0.4456	0.1631	-0.2036	-0.0313	0.2602	0.1485	0.1247
12	S-CU	-0.0782	-0.2358	0.3301	-0.4828	0.1381	0.0968	-0.5454
13	S-MO	0.6179	0.1584	0.2447	-0.2298	0.0413	0.0936	-0.3467
14	S-NB	-0.0490	0.3616	-0.0529	-0.0811	0.6213	0.4738	-0.1001
15	S-NI	0.6087	0.1766	0.0247	-0.2066	0.1726	0.1161	-0.0319
16	S-PB	-0.0229	0.0608	0.2290	-0.3520	0.1108	-0.0187	-0.4439
17	S-SC	**********	0.4885	0.1013	-0.2955	0.6137	0.7611	-0.2557
18	S-SR	-0.0590	0.2660	0.2924	-0.3452	0.0511	-0.0385	-0.1667
19	S-V	-0.0921	-0.0165	0.1987	-0.3901	0.0590	0.1151	-0.4514
20	S-Y	0.7352	0.4296	-0.2759	-0.1489	-0.1462	-0.0068	0.3616
21	S-ZN	137.4946	0.5257	-0.2826	-0.3623	-0.3477	-0.3499	0.2518
22	S-ZR	21	20.4316	-0.1499	-0.0238	0.1713	0.0503	0.1520
23	XRF-AS	19	64	1913.0463	-0.3160	-0.0445	-0.1467	-0.5262
24	SI-F	19	64	64	1327.9695	-0.0615	0.0180	0.7628
25	XRF-SN	19	64	64	64	21347.2578	0.5988	-0.1669
26	XRF-W	19	64	64	64	64	241.4745	-0.0621
27	XRF-RB	19	64	64	64	64	64	392.6096

Table 3.--Element pairs showing significant covariation

Pairs whose correlation coefficient is greater than 0.5 are considered significant. + column indicates positively correlated pairs; - column indicates negatively correlated pairs

+	-
Ti : Mg	B : Ti
Be : Ti	Cu : Mn
Mo : Fe	Pb : Be
Mo : Ag	V : B
Pb : Ag	Zn : Sn
Sc : Ti	As : B
Sc : Cr	Rb : Ca
Sr : Ag	Rb : Ag
Sr : Pb	Rb : Cu
V : Ca	
V : Sc	
Y : Mg	
Y : Ti	
Y : Sr	
Zn : Mg	
Zn : Mo	
Zn : Ni	
Zn : Y	
Zr : Zn	
As : Ca	
F : Mn	
Sn : Nb	
Sn : Sc	
W : Sc	
W : Sn	
Rb : Mn	
Rb : Be	
Rb : F	

A more rigorous treatment of elemental associations was conducted using R-mode factor analysis. The data were transformed to logarithms and then analyzed by the R-mode, multivariate factor analysis procedure (Miesch, 1980) which is based on the correlation coefficients between all the variables. Correlation coefficients express the association of one element to another but factor analysis considers all correlations simultaneously and identifies 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 in many cases be related to a specific rock type or specific locality where the controlling features of the association might be inferred (Allen and others, 1983).

The use of factor analysis, in this case, helped clarify the associations that were tentatively identified by the correlation matrix. A five factor model, the simplest model that can be reasonably explained in geologic terms, was selected. Several of the factors identified include antithetic associations. That is, one group of strongly associated elements displays strong negative correlation with a second group of strongly associated elements. The factors and their components are listed in table 4.

High values for the first factor are concentrated in the samples of the northern greisen (fig.11); high values for the antithetic part of factor 1 occur in samples collected in the southwestern part of the southern greisen where zinnwaldite is especially abundant (fig. 12). This first factor indicates the existence of a profound geochemical difference between the two greisens and suggests that some aspects of their respective petrogeneses were dissimilar.

The distribution of high values for the second factor, as previously indicated by univariant statistics, is controlled by the distribution of cassiterite (fig. 13).

The elemental association depicted by factor 3 is enigmatic but again denotes the geochemical dissimilarity that exists between the two intensely mineralized greisens (fig. 14). High values for the antithetic part of the third factor show good correspondence with outcrops of argillically altered granite (fig.15). The geochemical processes that caused evolution of this rock appear to have been operative in a small volume of the hydrothermally altered rock (plate 1, map B).

Table 4.--Components of factors in five factor model for samples of the two strongly mineralized greisens

Factor	Elements Associated	Antithetic Element Association
1	As, Ca, Ag, Cu, Sr	Mn, F, Rb, Be
2	Sn, W, Sc, Nb	
3	Fe, Mo, V	Mg, B
4	Ti, Y	Pb, B
5	Ni, Cr	

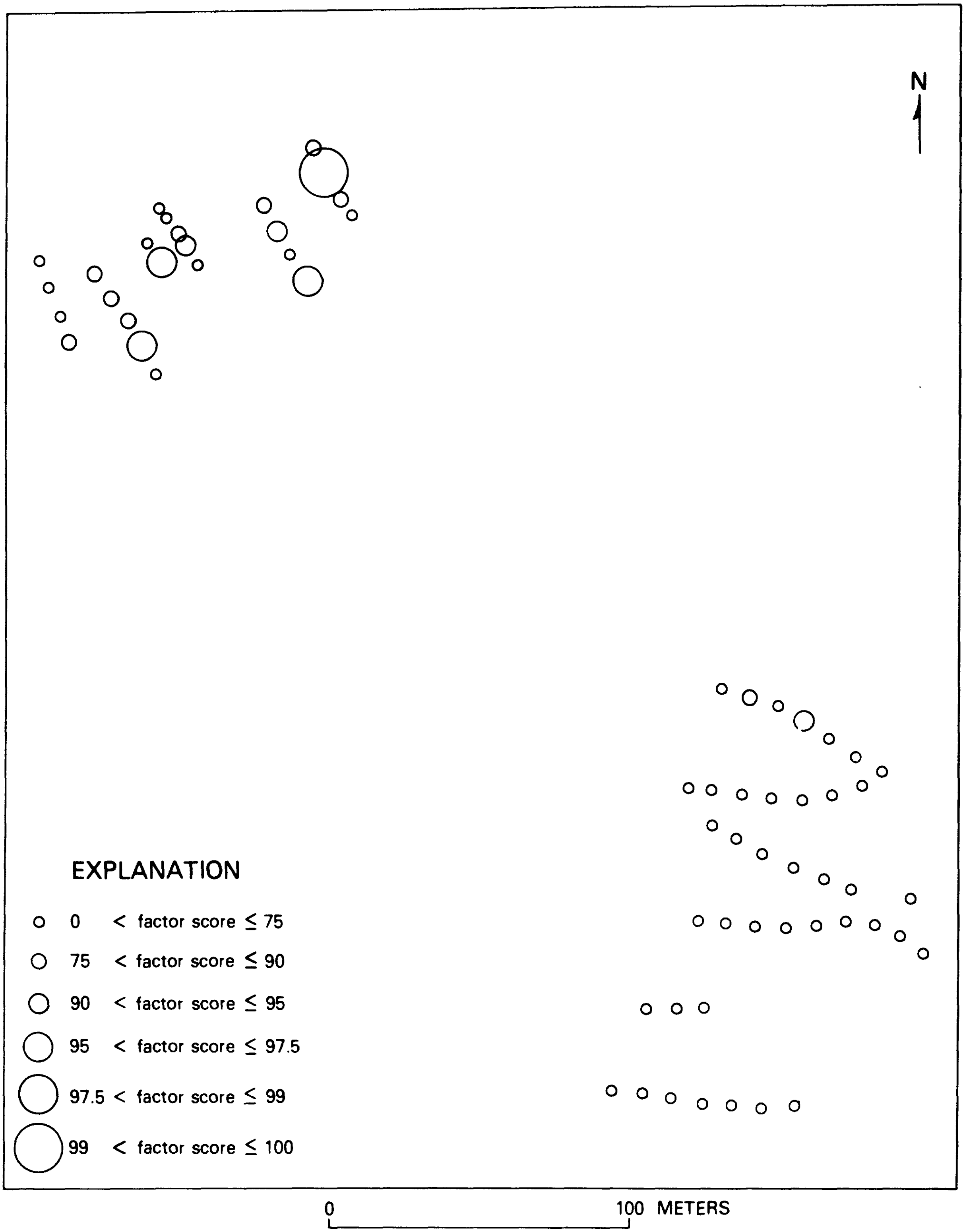


Figure 11.—Map showing factor 1 scores, As-Ca-Ag-Cu-Sr association. Area of figure indicated on Plate 1, map A.

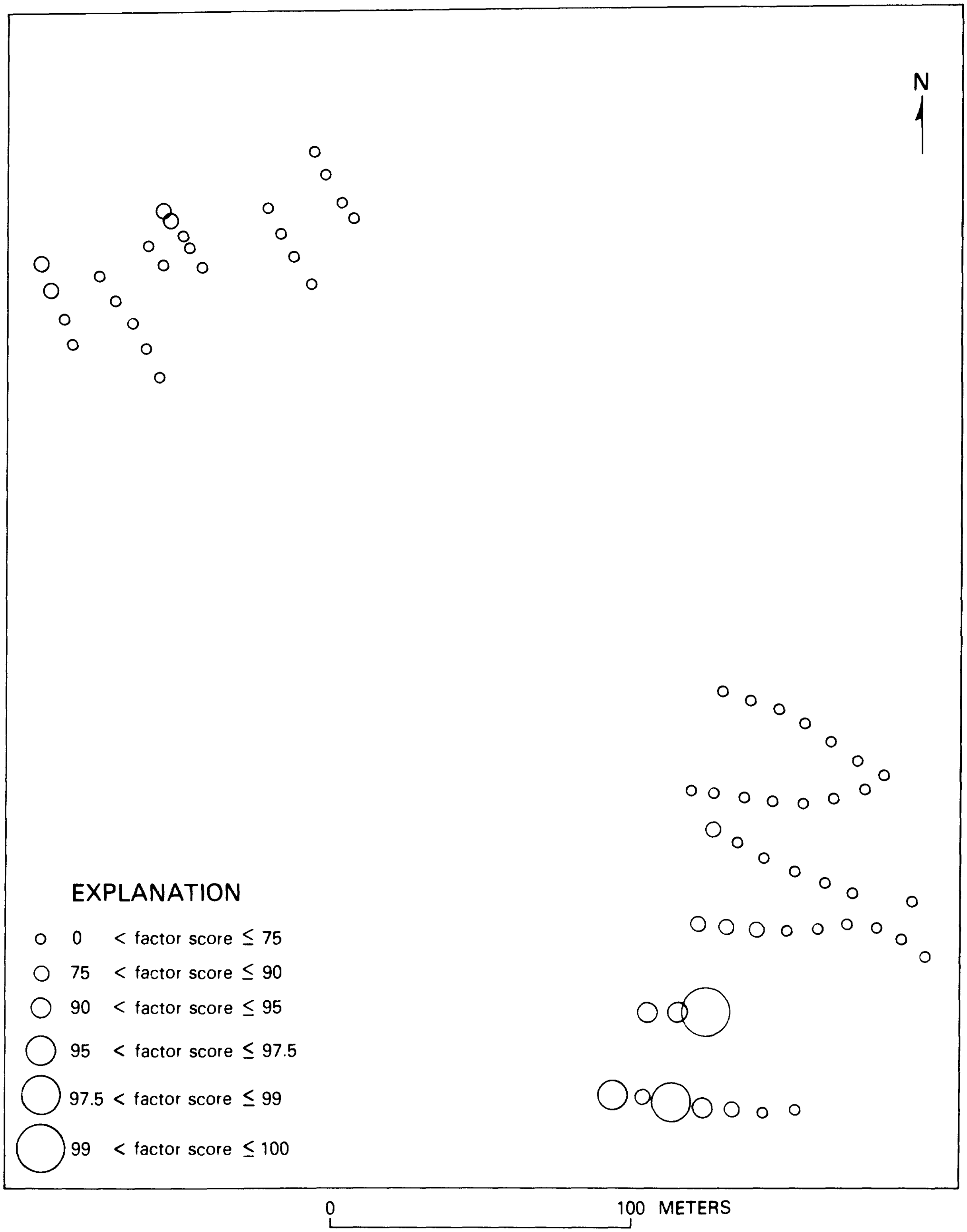


Figure 12.—Map showing factor 1 scores, antithetic component, Mn-Rb-F-Be association. Area of figure indicated on Plate 1, map A.

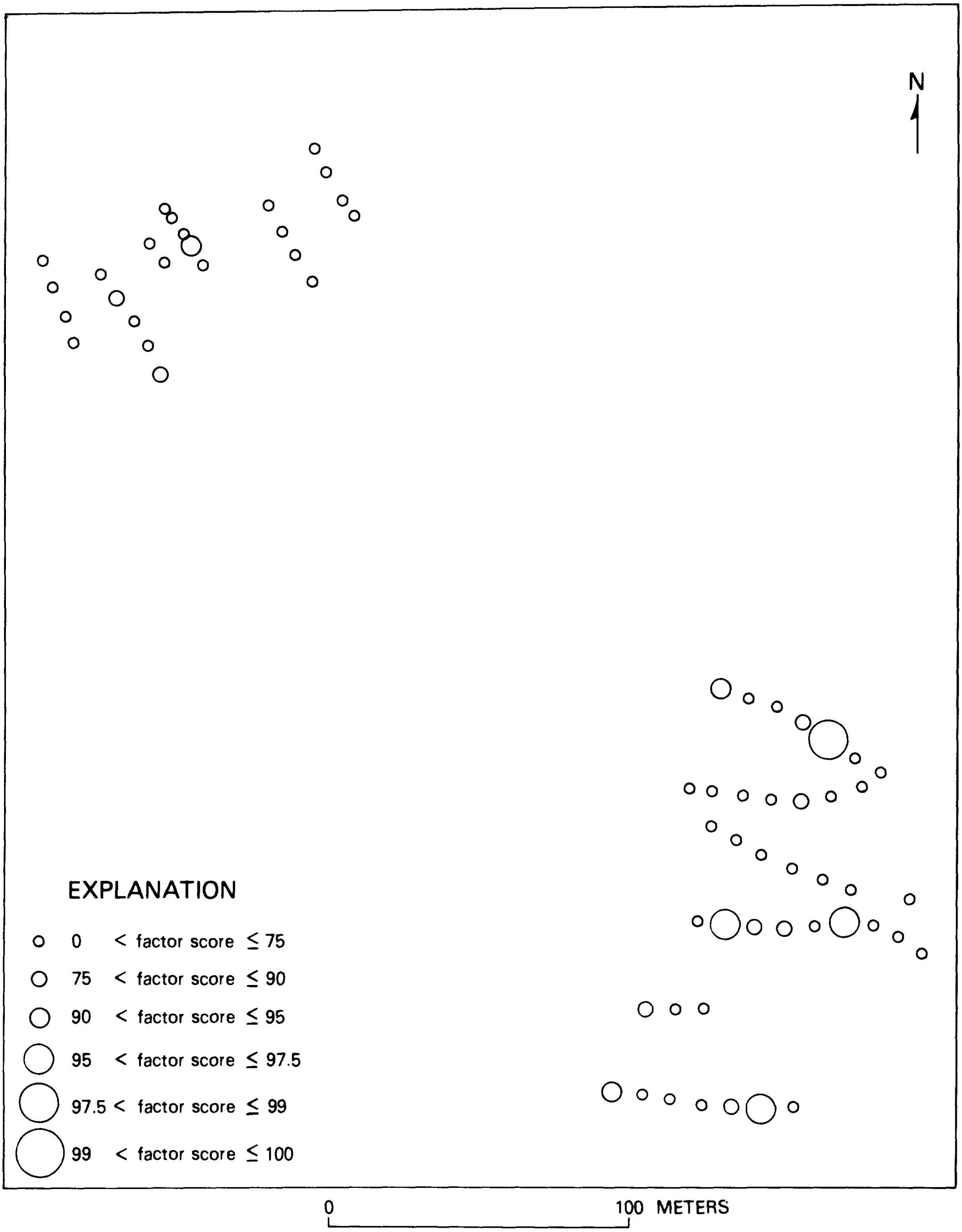


Figure 13.—Map showing factor 2 scores, Sn-W-Sc-Nb association. Area of figure indicated on Plate 1, map A.

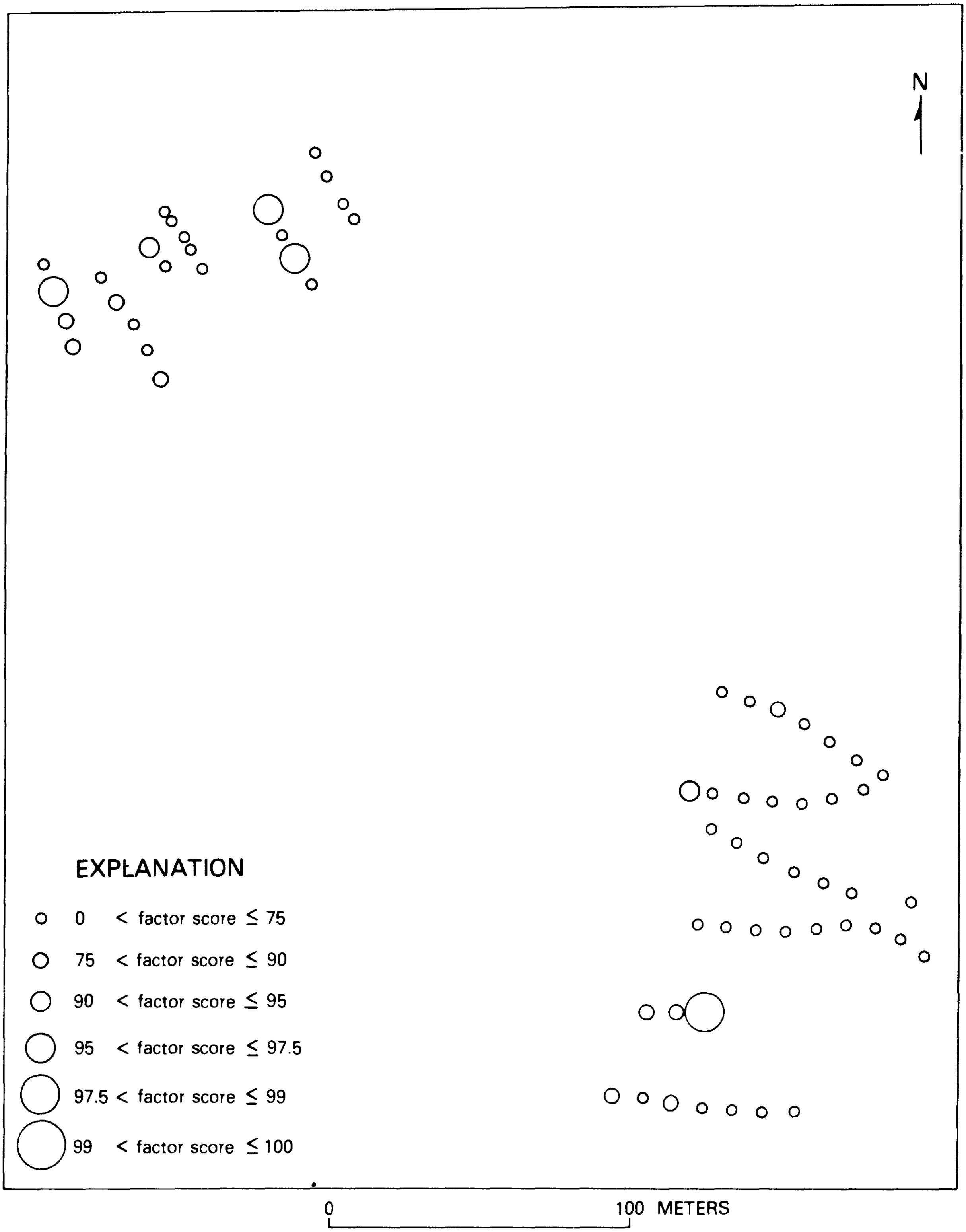


Figure 14.—Map showing factor 3 scores, Fe-Mo-V association. Area of figure indicated on Plate 1, map A.

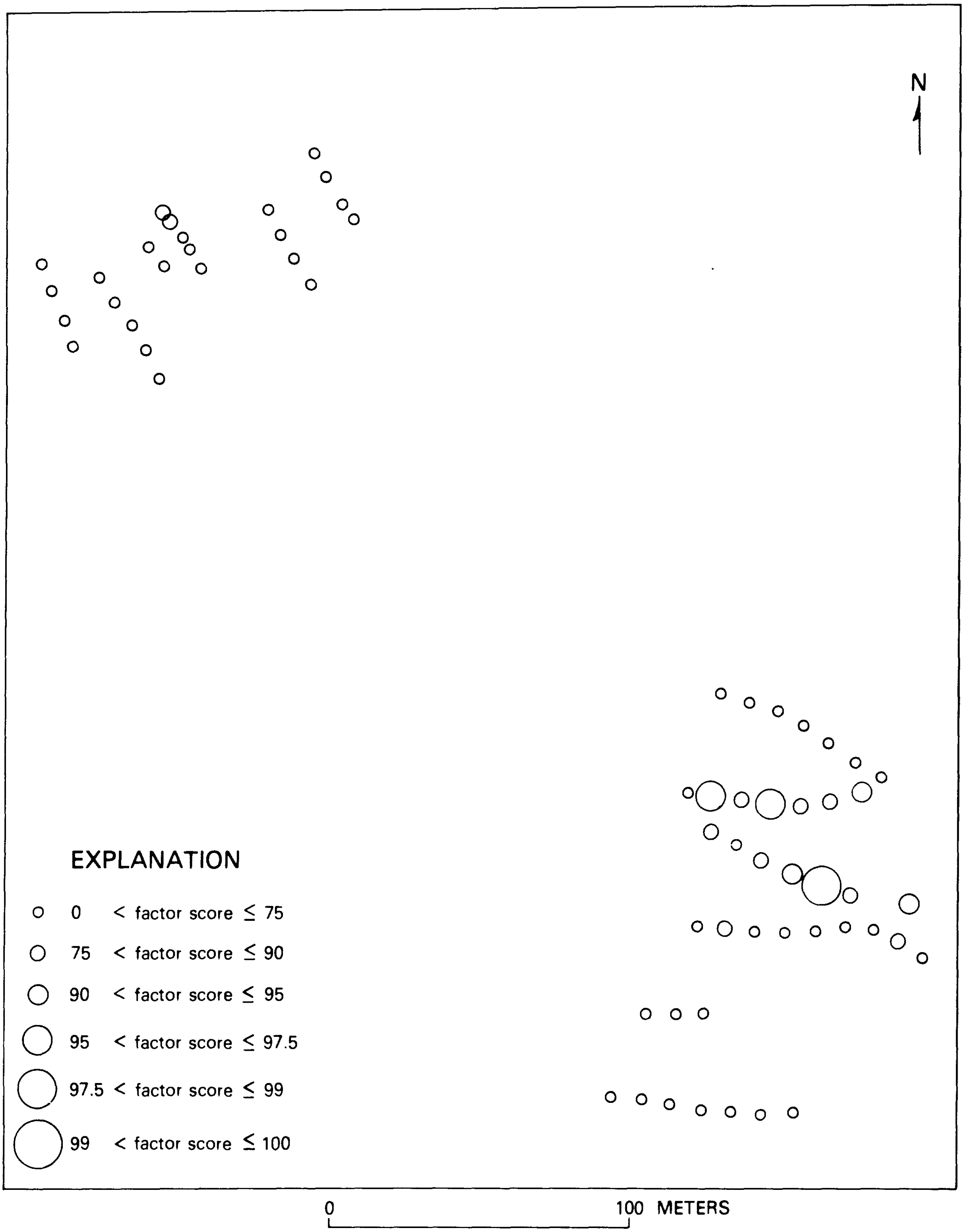


Figure 15.—Map showing factor 3 scores, antithetic component, Mg-B association. Area of figure indicated on Plate 1, map A.

The distribution of high values for factor 4 is restricted to small, discrete areas within the two greisens and probably represents the occurrence of an as yet unidentified ore phase (fig. 16). Titanium is the dominant element controlling this factor which suggests that a titanium mineral such as rutile or ilmenite controls the factor. Rutile has been identified in several polished thin sections of the quartz-topaz-cassiterite rock (Mike Allen, written communication, 1983). The distribution of high values for the antithetic part of this factor mimics that of factor 3's antithetic component (fig. 17) and suggests that the factors that governed argillic alteration of the rock exposed in this area are also responsible for the antithetic component of factor 4.

The distribution of high values for factor 5 is erratic and seems to be unrelated to geology or mineralogy (fig. 18). These characteristics and the components of the association suggest that this factor is attributable to some random process such as contamination in the analytical laboratory. The concentrations of nickel and chromium should be very low and not necessarily as strongly correlated as they are in a geochemical setting such as that of the Silsilah greisens. The samples may have been contaminated by the random addition of steel chips from the jaw crushers used to crush the samples.

Other mineralized areas

Mineralized rock in a number of other small areas located in the southwest part of the Silsilah ring complex was studied and sampled in a reconnaissance fashion. These areas are indicated by a series of circled numbers (1 to 5) on plate 1, map A). Several of these areas consist of weakly mineralized rock similar to the less intensely mineralized, quartz-zinnwaldite-topaz-alkali feldspar rock encountered in the two intensely mineralized greisens. Some of the occurrences consist of mineralized quartz veins and one is a small complex composed of Hadhir aplite and Fawwarah alkali-feldspar granite. Grab samples were collected and submitted for analyses to determine whether the mineral potential of these areas warrants additional consideration.

Nine composited grab samples were collected from area 1, an area of greisenized rock located 500 m west-northwest of the large central cupola of Fawwarah alkali-feldspar granite (plate 1, map A). Several greisens located immediately south of this area are lithologically similar but were not sampled. The area is underlain by quartz-topaz-zinnwaldite greisen that is barely emergent through erosional windows in

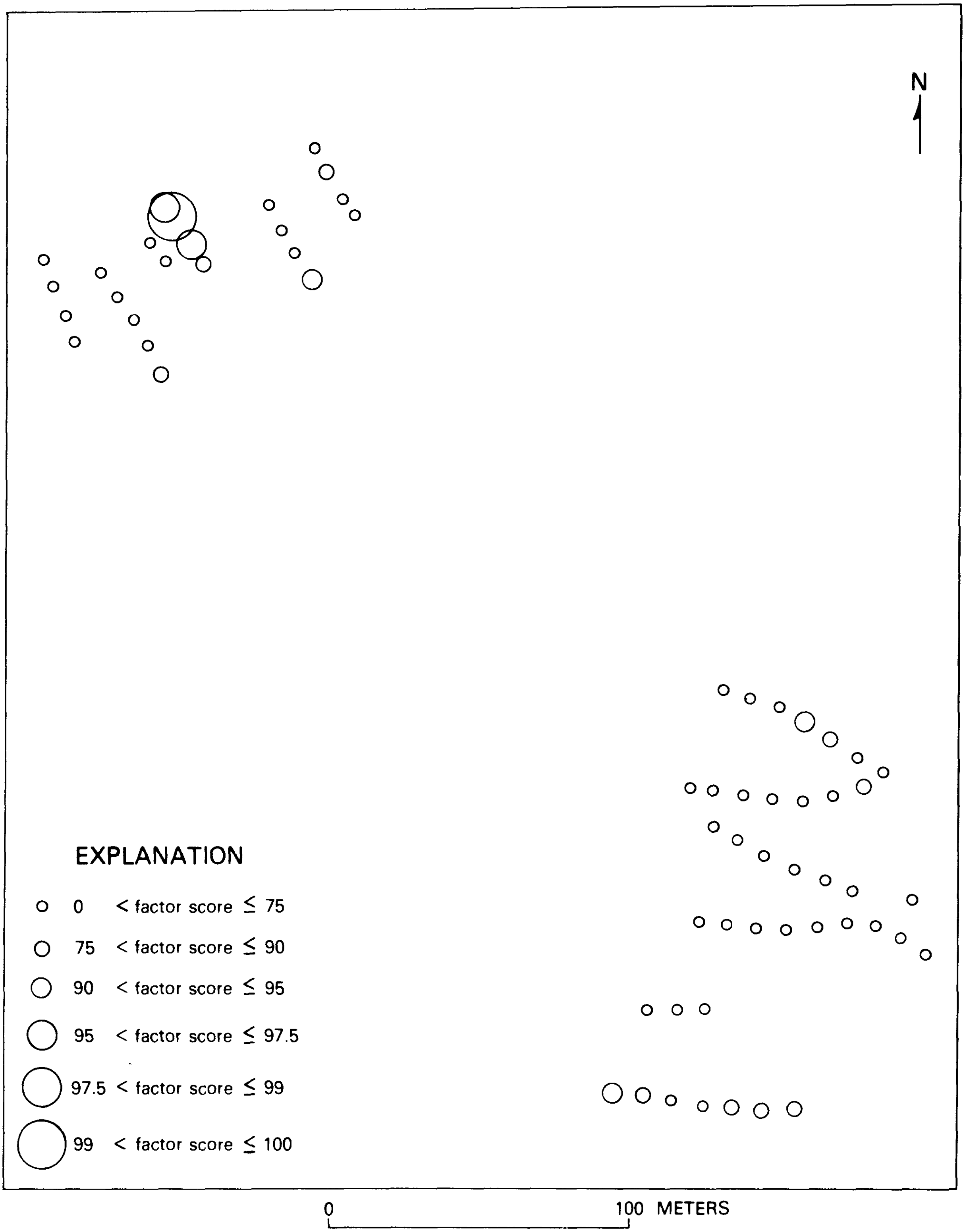
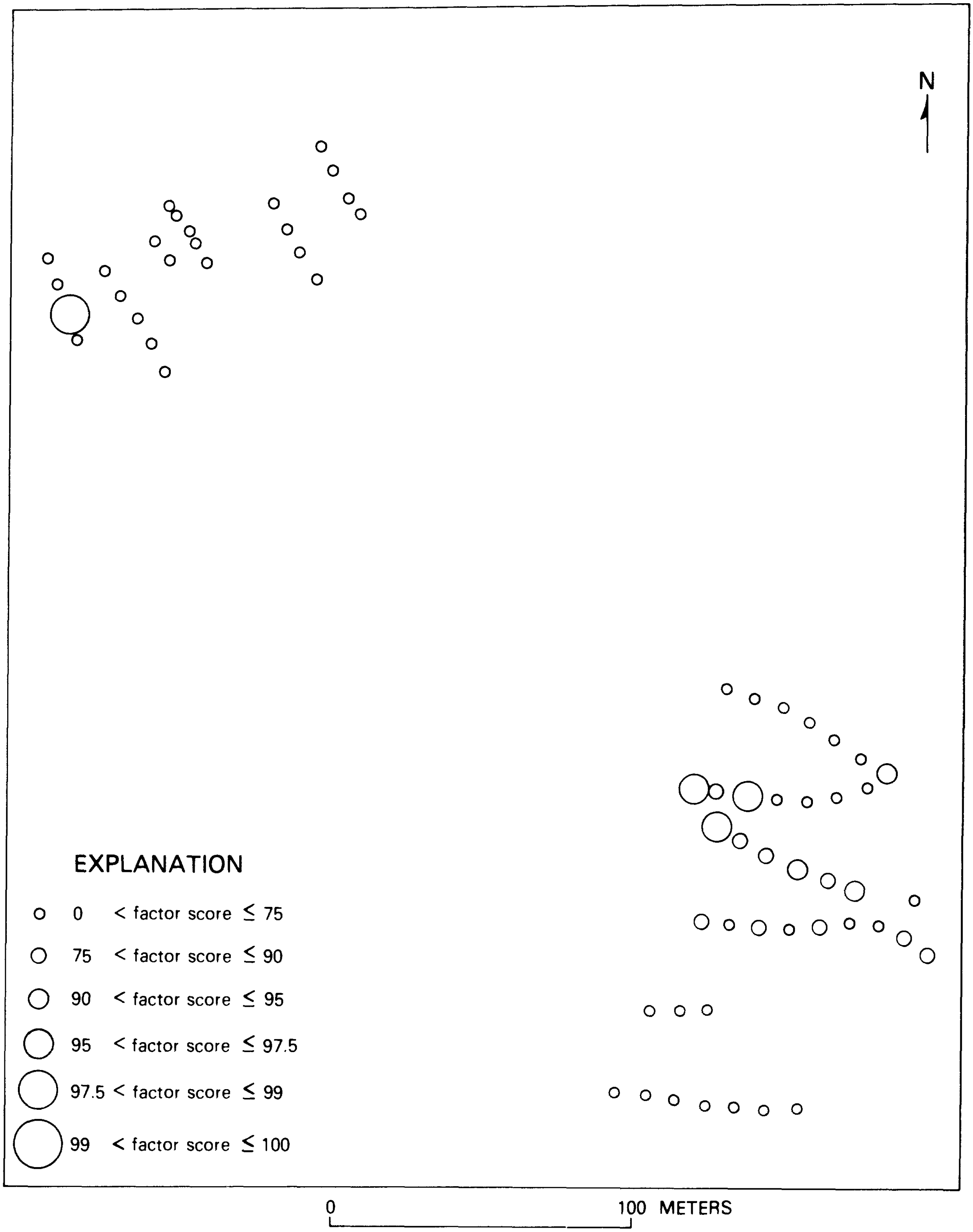


Figure 16.—Map showing factor 4 scores, Ti-Y association. Area of figure indicated on Plate 1, map A.



igure 17.—Map showing factor 4 scores, antithetic component, Pb-B association. Area of figure indicated on Plate 1, map A.

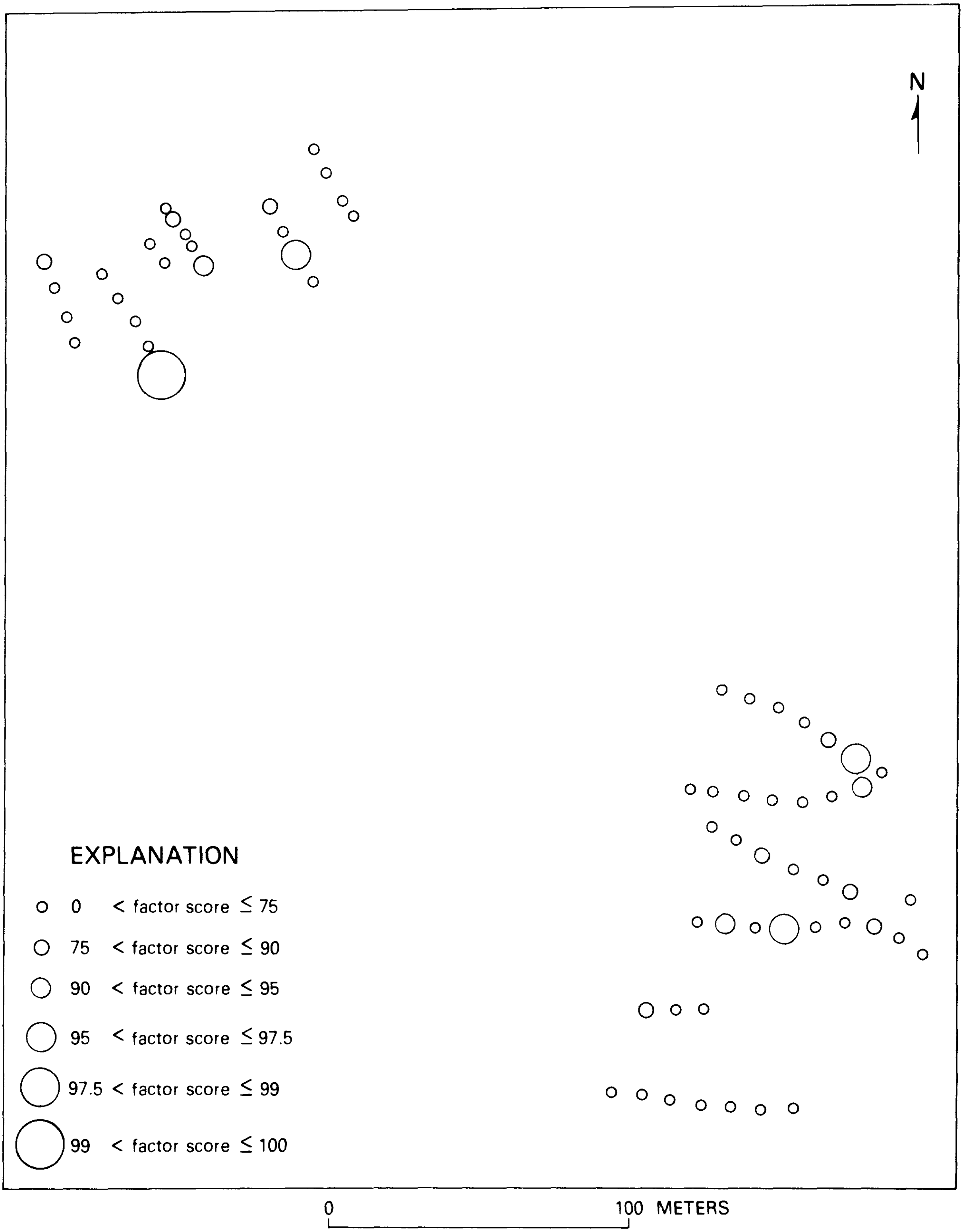


Figure 18. Map showing factor 5 scores, Ni-Cr association. Area of figure indicated on Plate 1, map A.

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the overlying Maraghan lithic graywacke (du Bray, 1984) and contains some cassiterite. A geochemical summary of selected elements in the samples collected in this area is presented in table 5. The geochemical signature of the rock in this area is very similar to that characteristic of the two intensely mineralized greisens, although the abundances of the various elements are not as anomalous as they are in the latter setting.

The northernmost outcrop of the Fawwarah alkali-feldspar granite is another area in which weakly mineralized rock was identified. This area, area 2 on plate 1, map A is located about 2 km east northeast of area 1. The alkali-feldspar granite is cut by a series of narrow quartz veins that trend N. 70° W. Most of these veins are 1 to 2 cm across and are enclosed in greisenized envelopes 0.5 to 3 cm wide. Six samples of the quartz veins that appeared to be most intensely mineralized were collected to determine the metal contents of the rock in this area (table 5). The geochemical results indicate that these quartz veins contain low, but anomalous, concentrations of many of the elements that occur in highly anomalous concentrations in the intensely mineralized greisens.

In area 3 (plate 1, map A), a series of quartz veins, similar to those in area 2, cut the large central cupola of the Fawwarah alkali-feldspar granite. These veins trend N. 70° W. and are enclosed in greisen envelopes like those that enclose the veins in area 2. The veins in area 3 are more variable in width, are 1 to 10 cm wide, and are enclosed in proportionally wider greisen envelopes. Several weakly to moderately greisenized pods of the alkali-feldspar granite also crop out in this area. The greisenized rock forms tabular bodies that are approximately parallel to the trend of the quartz veins and their origin may have been controlled by the same fracture pattern that seems to have localized the quartz veins. Five composited quartz vein samples were collected (table 5). These samples, like the quartz vein samples from area 2, contain anomalous concentrations of the selected elements. The concentrations of Sn, W, Ag, Bi, Mo, and Pb are not as highly anomalous as they are in samples from the intensely mineralized greisens, but they indicate that the rock in this area was subjected to a hydrothermal event similar to the one that is responsible for the genesis of the intensely mineralized greisens.

Area number 4 (plate 1, map A) is underlain by a complex composed of Hadhir aplite and Fawwarah alkali-feldspar granite. The textural attributes of these rocks suggest that a fluid phase was significantly involved in the solidification of these rocks. The geometric relations of these rocks, with the Hadhir aplite in contact above the Fawwarah alkali-feldspar granite, is similar to that observed elsewhere in the

Table 5.--Geochemical summary for other mineralized areas within the southwest part of the Silsilah ring complex

Area numbers keyed to plate 2. N indicates not detected; L indicates less than detection limit. Uncensored data used for calculation of means. All values in parts per million. Leader indicates no unqualified data

Element	Area	1	2	3	4	5
Ag	Range	N-5	L-5	L-20*	L-2*	L-50
	Mean	3	3	3	-	16
As	Range	34-8550*	190-3550*	155-1650*	18-55	90-2800*
	Mean	402	424	320	28	386
B	Range	L-20	L-30	20-30	-	-
	Mean	17	17	22	-	-
Be	Range	3-10	2-7	2-5	5-10	-
	Mean	7	4	4	7	-
Bi	Range	N-50	-	N-50*	-	10-1000*
	Mean	33	-	N	-	43
Mo	Range	4-115	6-20	4-10	10-65*	20-260*
	Mean	27	10	6	11	30
Nb	Range	20-70	20-30	30-50	30-50	L-500*
	Mean	43	27	38	40	-
Pb	Range	30-300	30-150	20-2000*	50-70	20-20,000*
	Mean	113	88	218	58	618
Sn	Range	26-2150*	30-170	145-290	12-210	42-1200*
	Mean	110	88	218	66	230
W	Range	20-260	15-210	40-135	10-25	10-189,000*
	Mean	103	81	67	17	438
F	Range	535-2093	292-876	876-2969*	438-2530	292-1509
	Mean	1244	487	1083	1567	1003

* The high value indicated in the data range is a single highly anomalous value and was not used in calculating the mean.

ring complex. The subhorizontal boundary between these units is known to be the locus of greisenization within this system. Averaged geochemical data for six samples of these rocks are presented in table 5. These samples contain slightly higher concentrations of some of these elements relative to other granitoid rocks but do not seem to be mineralized to any great extent.

The geologic setting in area 5 (plate 1, map A) is unique in the Silsilah ring complex. A series of nearly vertical quartz veins that trend N. 40° E. cut the Silsilah alkali granite which in turn overlies and has been intruded by the Fawwarah alkali-feldspar granite and the Hadhir aplite in this area. The composition of the alkali granite has been affected by the upward migration of hydrothermal fluid from the top of the alkali-feldspar granite, where fluid evolved by exsolution, but its textural characteristics were preserved. A genetic relation may exist between the hydrothermal alteration of the alkali granite and the emplacement of a major quartz vein system in this area. The veins demonstrably emanate from the top of the Fawwarah alkali-feldspar granite. Approximately five veins per 10 m of outcrop are encountered along the ridge that strikes eastward through area 5. The veins are significantly wider at the east end of the area than at the west end. The western veins are 1 to 5 cm in width and are enclosed in very weakly greisenized envelopes. The eastern veins are 5 to 30 cm wide and are enclosed in well developed greisen envelopes that are 0.5 to 2 m wide. Blades of wolframite 2 to 10 cm long are especially common in the easternmost veins. The wolframite content in these veins is generally quite low and is very erratic. Geochemical data for five veins in this area are summarized in table 5. The high values for lead suggest that there is also some galena in these veins. The high tin values suggest that the veins may also contain cassiterite.

Three other, very small, areas in which weakly mineralized rock was identified were briefly studied. These areas are not numbered on plate 1, map A but a single sample site denotes the location of two of these three areas.

One-half kilometer west of area 5 (plate 1, map A) a very small elliptically shaped area of greisenized rock was identified within the Fawwarah alkali-feldspar granite. The greisenized rock seems to follow the trend of the prevailing joint set in this area and is composed of quartz, topaz, and a minor amount of zinnwaldite. A single sample of this greisen contains 5 ppm Ag, 520 ppm As, 20 ppm Bi, 1500 ppm Pb, 1650 ppm Sn, and 690 ppm W. The greisen is similar in geologic setting and petrographic attributes to two small, isolated greisens located about 1 km to the northwest, also in the alkali-feldspar granite. The geochemistry of these small pods is probably similar to that of the pod described here.

A small isolated pod of quartz-topaz-zinnwaldite greisen is located about one-half kilometer northwest of the intensely mineralized greisens, on the northwest flank of the large hill underlain by quartz. A single sample of this material contains 300 ppm As, 100 ppm Bi, 200 ppm Pb, 550 ppm Sn, and 25 ppm W. The rock is petrographically similar to the quartz-topaz-zinnwaldite rock that is found peripheral to the two intensely mineralized greisens.

The area near the northwest end of the Fawwarah alkali-feldspar granite is cut by a series of quartz veins that contain variable amounts of wolframite. Samples collected by du Bray (1983) indicated that the tungsten content of these veins is generally low and very erratic. One vein is traceable across the entire width of the alkali-feldspar granite. The vein attains a maximum width of about 2 m midway along its strike and thins to a series of anastomosing veins at both ends. The vein is enclosed in a greisenized envelope 0.5 to 2 m wide and contains blades of wolframite 2 to 5 cm long in the central area. The overall wolframite content of this vein and of the entire vein set in this area seems to be low and does not warrant additional study.

CONCLUSIONS AND RECOMMENDATIONS

Large-scale geologic mapping of the intensely mineralized greisens in the Silsilah ring complex has delineated several distinctive types of greisenized rock. Intensely mineralized quartz-topaz-cassiterite greisen is encountered immediately beneath the Hadhir aplite and pegmatitic rock found at the base of the aplite. The aplite itself crops out subhorizontally beneath the Maraghan lithic graywacke. The intensity of greisenization decreases downward and within a few meters the mineral assemblage quartz, zinnwaldite, topaz, and feldspar, with minor cassiterite, prevails. This less intensely mineralized greisen grades downward into progressively less altered Fawwarah alkali-feldspar granite. The quartz-topaz-cassiterite greisen is resistant in the weathering environment whereas the quartz-zinnwaldite-topaz-feldspar-cassiterite greisen has been more readily eroded. As a consequence of this differential weathering, the intensely mineralized rock forms low hills encircled by less intensely mineralized rock that crops out peripherally, on the flanks of the hills. Greisen is seen emergent beneath aplite throughout the southwest part of the ring complex. These geologic relations suggest that additional sheet-form or cupola-like bodies of greisenized rock may exist beneath thin veneers of aplite and possibly unexposed positions below the Maraghan lithic graywacke.

The tin content of samples of the two intensely mineralized greisens ranges between 0.1 and 12 percent, which suggests the greisens include mineralized rock that may reach a minable grade. These samples also contain anomalous to highly anomalous concentrations of W, Ag, As, Bi, and Pb which could be by-products of tin production. Grab samples of other mineralized greisens within the southwest part of the ring complex contain anomalous concentrations of some of these elements and suggest that the locus of potentially ore grade material is not restricted to the two intensely mineralized greisens. Features characteristic of hydrothermal alteration are abundant in the southwest part of the ring complex and further indicate the high mineral potential of this area. Wolframite-bearing quartz veins at the south end of the complex represent yet another potential resource.

Statistical analyses of data for samples of the intensely mineralized greisens indicate the existence of distinctive differences between them. The hydrothermal fluids that affected greisenization were probably not of a homogeneous composition. This observation and the existence of numerous elliptical greisens located throughout the southwest part of the ring complex seems to indicate that numerous small cupolas of Fawwarah alkali-feldspar granite, each having exsolved a hydrothermal fluid with its own distinctive composition, have intruded the Maraghan lithic graywacke in this area.

Further evaluation of the mineral potential of the southwest part of the Silsilah ring complex should proceed with two principal objectives. An evaluation of the tin grade in the two intensely mineralized greisens must be completed. This may be achieved by sampling the products of a fairly closely spaced percussion drilling program. The erratic distribution of tin in the deposit necessitates the close spacing of drill sites. An attempt should be made to determine, in detail, the mineral potential of the remainder of the southwest part of the ring complex. Geophysical techniques, including microgravity, induced polarization, magnetics, and radiometrics that are capable of discriminating unexposed granite cupolas and or greisenized rock should be applied in order to identify all cupolas in the target region. All exposed greisen bodies should be sampled by percussion drilling and analyzed for metal content. Preliminary estimates of grade and tonnage (Tony Williamson, oral communication, 1984) for the two intensely mineralized greisens indicate that significantly more mineralized rock must be found before the deposit can be considered to be potentially economic. At present it seems that the deposit is of the low-grade, high-tonnage type. The need to identify all mineralized rock in the area is apparent.

In addition to determination of the deposit's resource potential, further studies of the deposit should include creation of an ore genesis model that is consistent with the accumulated data. Sophisticated analytical work including detailed mineralogic investigations, fluid inclusion studies, and stable isotopic analyses, will be essential to development of such a model. Identification of minor accessory phases and study of their trace element contents will provide information concerning partitioning and the geochemical behavior of trace elements during the hydrothermal processes that caused the evolution of the greisens and associated mineralization. It should be possible, in particular, to determine the chemical composition and therefore the approximate metal-bearing capacity of the alteration fluids. It should also be possible to determine the temperatures and pressures that prevailed during mineralization, the degree to which the mineralizing fluids were derived from the melts themselves, or if they include a significant component of meteoric water derived from the host Maraghan lithic graywacke. Finally, it may be possible to determine whether the hydrothermal process was a single- or multi-stage event. These data will facilitate construction of a genetic model that documents the evolution of the rocks that compose the tin deposit at Jabal as Silsilah.

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