Geochemical Study of Heavy Mineral Concentrates from the Northeastern Part of the Greenville 1°x2° Quadrangle, South Carolina

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Geochemical Study of Heavy Mineral Concentrates from the Northeastern Part of the Greenville $1^\circ \times 2^\circ$ Quadrangle, South Carolina

By JOHN C. JACKSON and WILLIAM J. MOORE

Analytical data for heavy mineral concentrate samples reveal geochemically anomalous areas within the Inner Piedmont physiographic province of South Carolina

U.S. GEOLOGICAL SURVEY BULLETIN 1983

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1992

For sale by
Book and Open-File Report Sales
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging in Publication Data

Jackson, John C. (John Carl), 1959–
Geochemical study of heavy mineral concentrates from the northeastern part of the Greenville 1°×2° quadrangle, South Carolina / by John C. Jackson and William J. Moore.
p. cm. — (U.S. Geological Survey bulletin ; 1983)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:1983
1. Heavy minerals—South Carolina—Analysis. 2. Geochemistry—South Carolina. 3. Piedmonts (Geology)—South Carolina. I. Moore, William J. (William Joseph), 1938– . II. Title. III. Series.
QE75.B9 no. 1983
[QE364.2.H4]
553.4'09757'2—dc20 91–13747
CIP

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By John C. Jackson *and* William J. Moore

Abstract

A geochemical investigation of heavy mineral concentrate samples from the northeastern part of the Greenville 1°×2° quadrangle was conducted to aid in the assessment of the mineral resource potential of the region. Samples were analyzed spectrographically, and element distribution maps were made for 19 selected elements (barium, beryllium, bismuth, boron, chromium, cobalt, copper, gold, lanthanum, lead, nickel, niobium, scandium, silver, thorium, tin, vanadium, yttrium, and zinc). Areas revealing anomalous concentrations of tin, beryllium, barium, thorium, and the rare earth elements lanthanum and yttrium are identified as possibly warranting additional study. Lanthanum and thorium values are consistently high in a large part of the study area, and thorium and yttrium values are associated in one region; monazite was identified in concentrates from throughout the study area. Values for certain lithophile elements, including tin, beryllium, and boron, are higher in concentrates from the northeastern part of the study area, where anomalous tin and beryllium values are associated. Cassiterite was identified in samples containing anomalous amounts of tin. The distribution of several elements, including tin, niobium, and vanadium, appears to be lithotectonically controlled and conforms generally with the thrust sheet boundaries that underlie the study area.

INTRODUCTION

This study is a regional geochemical reconnaissance of a part of the Inner Piedmont physiographic province of South Carolina (fig. 1). The emphasis of our interpretations is placed on element distribution maps that highlight those areas containing the most elevated values for 19 selected elements. Of primary interest are regions within the study area that reveal on the distribution maps a clustering of anomalous values for certain elements; this clustering indicates that a more rigorous sampling effort may be justified in those areas. Also, isolated single-element and multiple-element anomalies that are not a part of any obvious regional trend are reported for a number of locations, but these are given limited consideration.

The heavy mineral concentrate samples used for this study represent an area of about 4,000 km^2 (fig. 2). This regional collection of heavy mineral concentrates lends itself more to a comparison with regional geologic structures than to a detailed geologic map, given the relatively large size of the drainage basins that the collection covers and the variety of rock types that the samples represent. The geologic framework used for this report is shown on a generalized tectonic map (fig. 3) of the Greenville 1°×2° quadrangle prepared by Nelson (1988, fig. 5) and Nelson and others (1987).

Previous reports of mineral resource occurrences within the study area are extremely limited (fig. 4). Perhaps the most noteworthy are the numerous occurrences and prospects of the rare-earth-bearing mineral monazite ((RE, Th)PO_4) in this region. Monazite was mined from several of the small prospects found within the study area (fig. 4) in the early 1900's, although production was minimal (Sloan, 1908). Production of gold from the prospects shown on figure 4 was also minimal. Total historic gold production in Greenville and Spartanburg Counties was about 2,200 troy ounces (U.S. Bureau of the Mint, 1882–83, 1884–1906), but most of this production came from the Wolf and Tyger placers on the east bank of the Middle Tyger River near the Spartanburg-Greenville County line, northeast of the study area (not shown on fig. 4) (McCauley and Butler, 1966).

This report supplements a quadranglewide assessment prepared under the Conterminous United States Mineral Resource Assessment Program (CUSMAP) of the U.S. Geological Survey (USGS). Assessment of mineral resources under this program routinely employs semi-quantitative spectrographic analyses of heavy mineral

Manuscript approved for publication March 15, 1991.

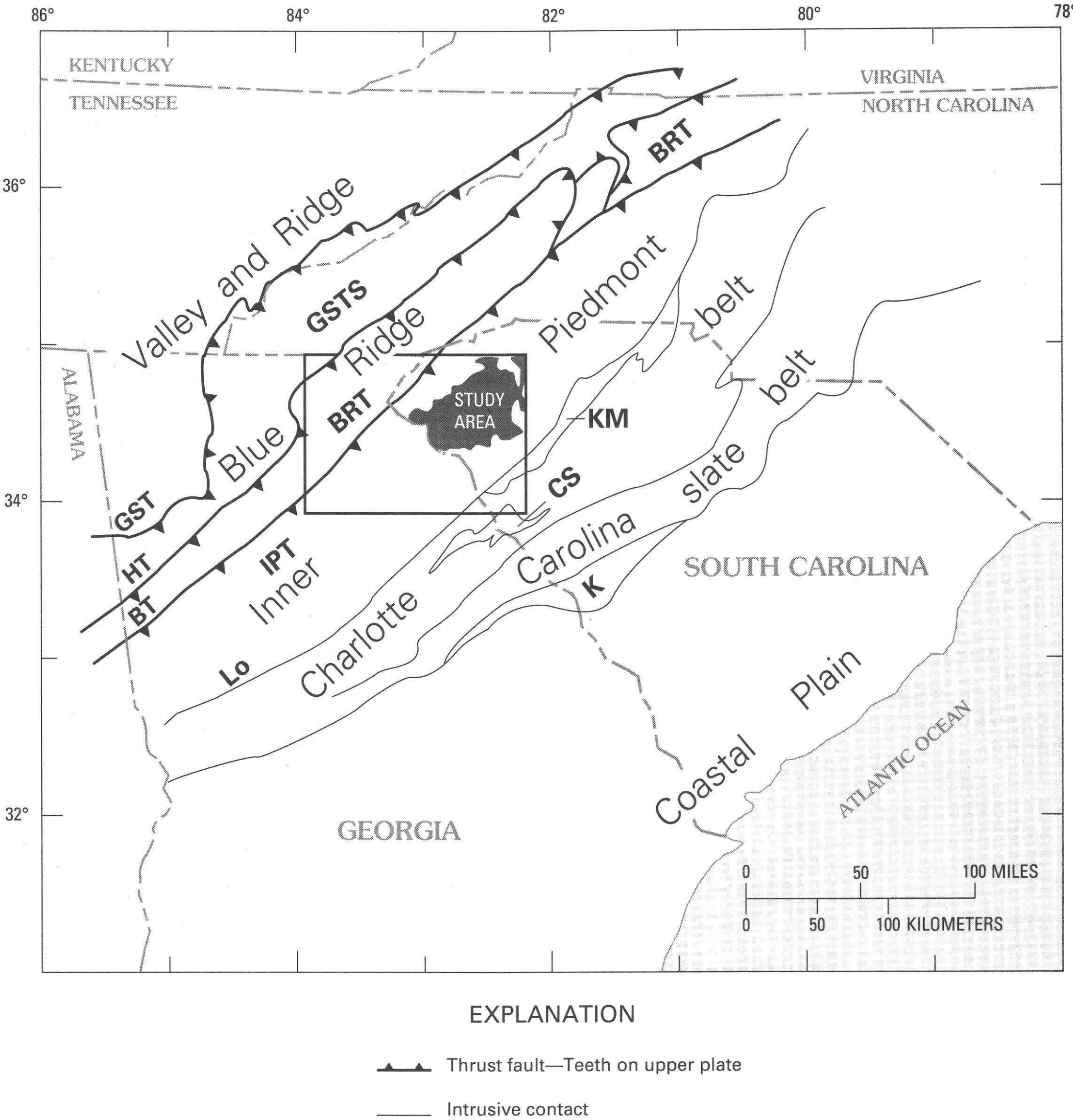


Figure 1. Location of study area (shaded) and location and geologic setting of the Greenville 1°×2° quadrangle, South Carolina. GSTS, Great Smoky thrust sheet; BRT, Blue Ridge thrust stack, which includes the Richard Russell, Young Harris, Helen, and Tallulah Falls thrust sheets; IPT, Inner Piedmont thrust stack, which includes the Chauga-Walhalla thrust complex and the Six Mile, Laurens, and Paris Mountain thrust sheets; KM, Kings Mountain belt; CS, Carolina slate belt; K, Kiokee belt; GST, Great Smoky thrust fault; HT, Hayesville and other thrust faults; BT, Brevard thrust fault; Lo, Lowndesville shear zone. Belts modified from King (1955), Overstreet and Bell (1965a,b), and Hatcher (1972).

concentrates of stream sediments in conjunction with other geochemical, geological, and geophysical data. To reduce costly and time-consuming field sampling for this study, 608 pan concentrate samples were selected from archived samples collected by the USGS in the early 1950's (fig. 2). These samples were reprocessed by using heavy liquid and magnetic separation methods, then analyzed spectrographically.

Previous Work

In the early 1950's, several thousand pan concentrates were collected by the USGS to appraise fluvial placers in the Southeastern United States as possible sources for rare earth elements, uranium, and thorium in monazite (Overstreet, 1967; Overstreet and others, 1968; Caldwell and White, 1973; Cuppels and White, 1973). On the basis

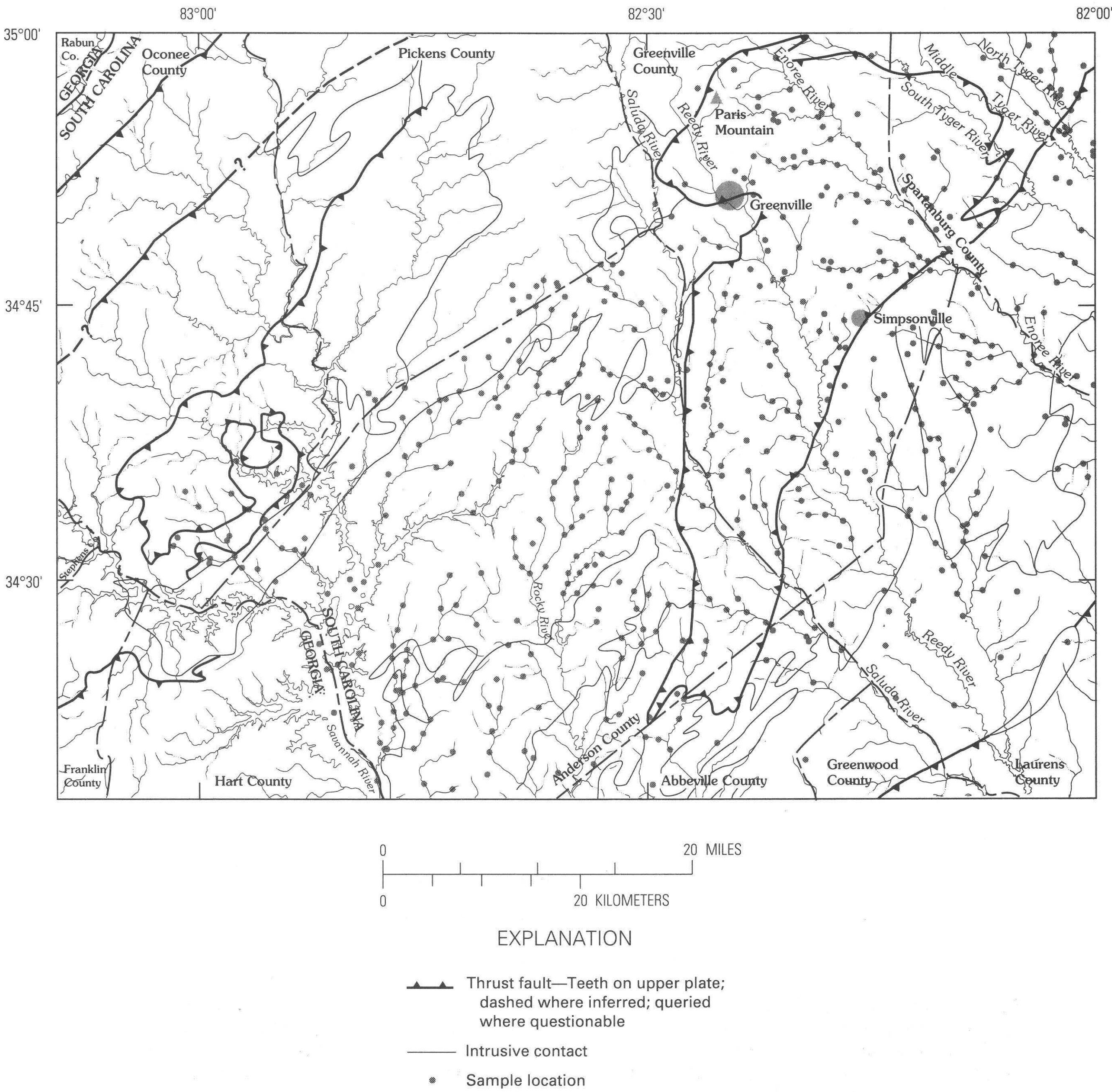


Figure 2. Distribution of heavy-mineral concentrate sample locations across the study area showing major drainages and selected geographical locations. See Overstreet and others (1968, pl. 8) and Jackson and Adrian (1991) for more detailed locations. See figure 3 for names and locations of tectonic features.

of this work, an area between the Savannah and Catawba Rivers, N.C. and S.C., was reported as having the highest potential for monazite deposits in the Inner Piedmont (Overstreet and others, 1968). Furthur investigations of monazite in fluvial placers and granitic rocks of the Southeastern United States by Mertie (1975, 1979) defined three subparallel monazite belts, the longest of which extends from Virginia to Alabama and includes the areas of monazite-bearing concentrates reported by Overstreet and others (1968). Locations of monazite-bearing saprolite or unweathered granite reported by Mertie (1979) are shown in figure 4 as occurrences.

One hundred and forty of the concentrate samples collected by the USGS from the monazite-belt area of the Inner Piedmont were analyzed spectrographically; the results are summarized by Overstreet and others (1968). These analyses evaluated the monazite placers for possible economic concentrations of tin, tungsten, niobium, and

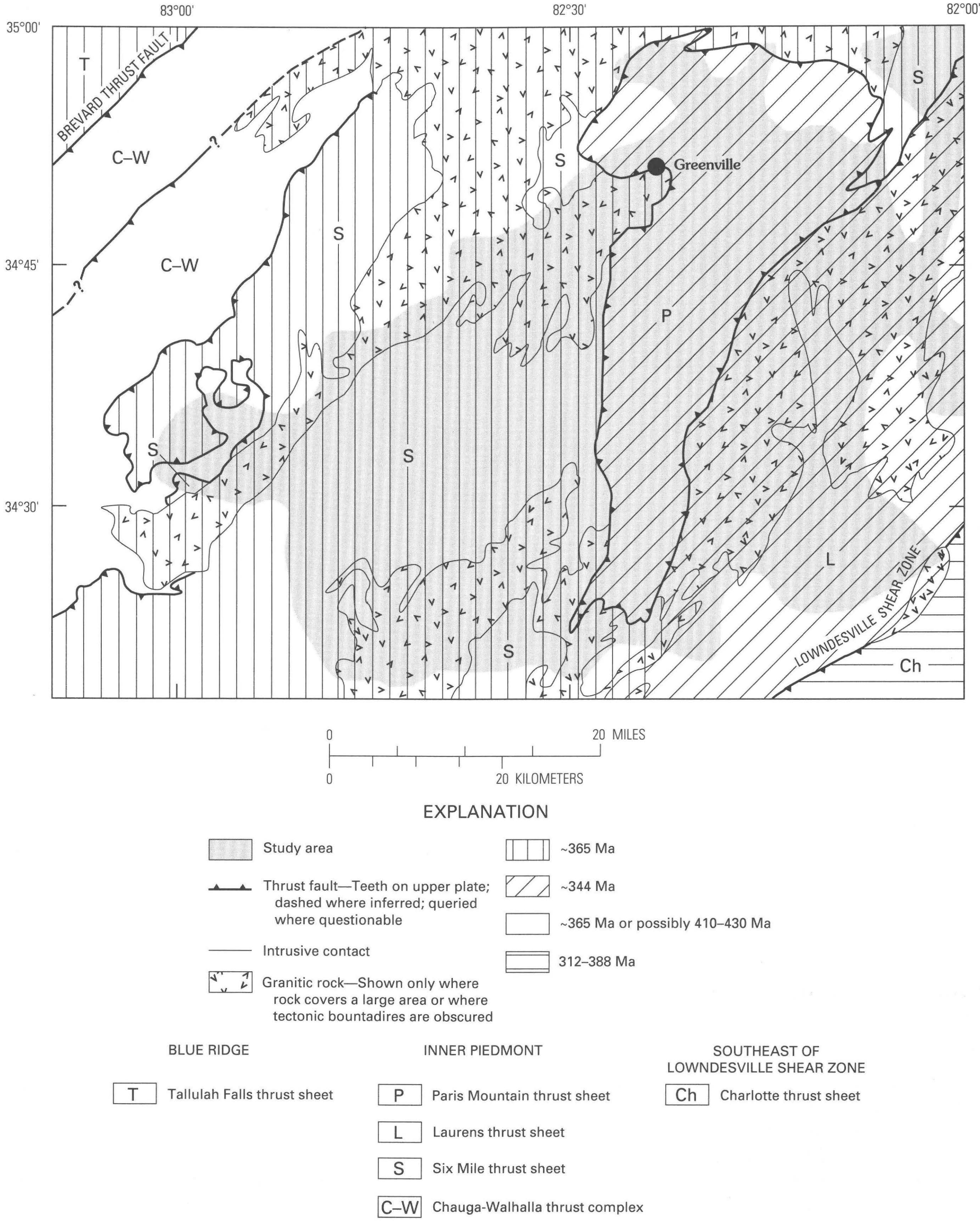


Figure 3. Generalized tectonic map of the Greenville 1°×2° quadrangle, South Carolina, showing interpreted regional metamorphic ages for various thrust sheets and area of sample coverage. Tectonic features from Nelson and others, 1987; metamorphic ages from Nelson, 1988, fig. 5.

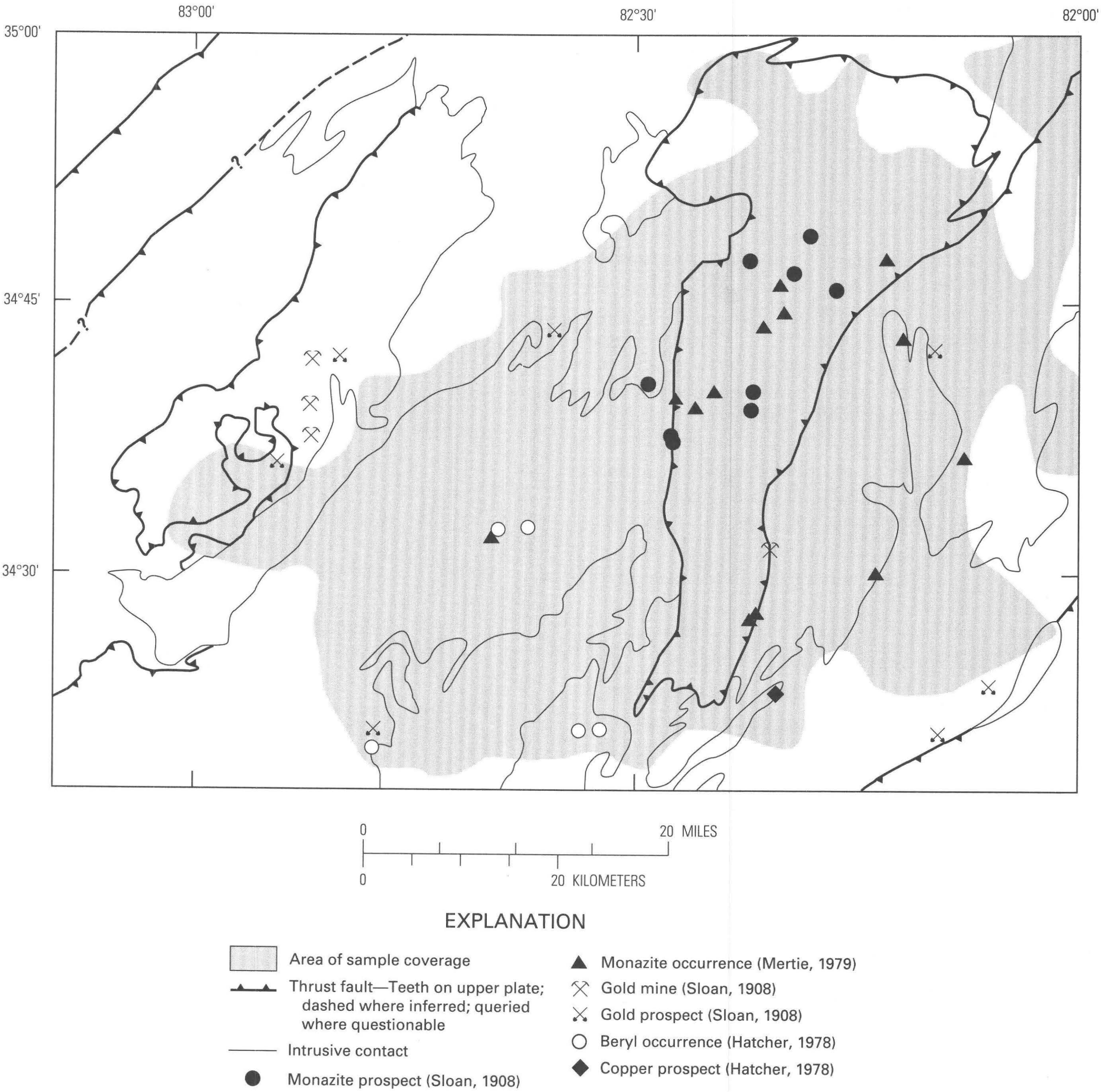


Figure 4. Mineral mines, prospects, and occurrences in the study area. See figure 3 for names and locations of tectonic features.

tantalum. Traces of tin and niobium were detected in a number of samples, but tungsten and tantalum were not. Ilmenite, the predominant heavy mineral in the concentrates, was determined to be responsible for most of the niobium but not to be economic. Tin was detected in 43 of these samples, and 39 of the 43 were from the North and South Carolina Piedmont. Beryllium was associated commonly with tin in many of these samples, and Overstreet and others (1968, p. 73) suggested that its presence indicates a common source for the tin-bearing and beryllium-bearing minerals in the samples. However, no cassiterite (SnO_2) was recognized in the concentrates (Caldwell, 1962; Cuppels, 1962; Theobald, 1962).

A study of minor elements in magnetite from pan concentrates by Theobald and others (1967) demonstrated that the regional distribution of certain trace elements, including Ba, Be, Cr, Cu, Pb, Mn, Sn, Ti, V, and Zn, was controlled by detrital magnetite that contained high amounts of those elements. For example, Theobald and others noted that the distribution of tin and beryllium was controlled by specific postkinematic granitic rocks containing magnetite having high amounts of those elements. Because tin was detected in 284 of 291 magnetite samples, Overstreet and others (1968, p. 73) reasoned that, in the absence of cassiterite, tin-enriched magnetite may account for the spectrographically determined tin encountered in their study.

Exploration interest in certain lithophile elements, especially tin, in the Charlotte 1°×2° quadrangle was generated by the report of coarse-grained, detrital cassiterite in pan concentrates of alluvium from nearly 40 stream sites southwest of Shelby, N.C. (D'Agostino and Whitlow, 1985). In subsequent work, Gair (1986) defined a broad, northeast-trending belt of moderate potential for tin that is generally coincident with the trend of the Kings Mountain belt. Some of these occurrences, traditionally treated as micaceous pegmatites (Griffitts and Olson, 1953), were found to be stratiform (Carr and others, 1984; Rowe, 1987). The apparent strike continuation of the zone of tin-bearing rocks into the Greenville 1°×2° quadrangle gave impetus to test for similar geochemical signatures in the previously collected heavy mineral concentrates from the study area.

Acknowledgments

We thank Jesse W. Whitlow, whose careful cataloging and archiving of the samples used in this study enabled us to make expedient use of them. We appreciate the assistance of James Marlowe in drafting the figures and the analyses by John Evans on the scanning electron microscope and by John Hosterman on the X-ray diffractometer. We also greatly appreciate the helpful reviews of Frank Lesure, Andrew Grosz, Gary Curtin, and Terry Klein.

GEOGRAPHIC SETTING

The study area is located in the northeastern part of the Greenville 1°×2° quadrangle and includes the generally east- and south-flowing Savannah, Reedy, Rocky, Saluda, Enoree, and Tyger Rivers and their tributaries. Local relief in this gently rolling part of the Piedmont province is generally less than 300 m but reaches 600 m at Paris Mountain, S.C., near the northern edge of the area.

GEOLOGIC SETTING

The heavy mineral concentrate samples collected for this study represent the heavy resistate minerals derived from rocks of the Inner Piedmont physiographic province (fig. 1). The Inner Piedmont is separated from the Blue Ridge province to the northwest by the Brevard thrust fault and from the Charlotte belt to the southeast by the Lowndesville shear zone. The rocks in the study area have undergone multiple events of metamorphism and deformation and contain a wide variety of metamorphic rock types that have been subjected to continuous weathering and erosion probably since before Late Cretaceous time (Overstreet and others, 1968, p. 29). A saprolite layer, commonly tens of meters thick, is the source of much of the present detritus in the stream channels. The geologic relations within the study area are complex (fig. 3) and have been the subject of recent investigations by the USGS (Nelson and others, 1987, 1989; Nelson, 1988).

According to Nelson (1988, p. 13), the Inner Piedmont is underlain by four, possibly five, thrust sheets; in order of ascending structural position, these are the Chauga-Walhalla thrust complex (possibly two different sheets), the Six Mile thrust sheet, the Paris Mountain thrust sheet, and the Laurens thrust sheet. Nelson (1988, p. 13) states that these assemblages appear to have been subjected to regional metamorphism at progressively later intervals from west to east. He estimated that the Chauga-Walhalla thrust complex and the Six Mile thrust sheet probably were metamorphosed at about 365 Ma and that the Laurens and Paris Mountain thrust sheets were metamorphosed later, at about 344 Ma (fig. 3). The rocks of the three easternmost thrust sheets of the Inner Piedmont found within the study area underwent mostly sillimanite-muscovite-grade metamorphism, but locally within the Six Mile sheet, rocks were subjected to kyanite-grade metamorphism (Nelson, 1988, p. 9). Only a small part of the Chauga-Walhalla thrust complex is found in the sampling area, and it also was subjected to kyanite-grade metamorphism (Griffin, 1975).

Each of these major lithotectonic units has a distinctive assemblage of rock types, which have been described in detail by Nelson and others (1989). The Laurens sheet is primarily a layered biotite gneiss, interlayered with biotite schist that locally grades to sillimanite schist. The Paris Mountain thrust sheet is composed primarily of sillimanite schist. Minor amphibolite also occurs in both these sheets. The Six Mile thrust sheet consists of many rock types; the most abundant includes various schists and gneisses. The small part of the Chauga-Walhalla thrust complex covered by the study area is principally hornblende gneiss and amphibolite. Compositional layering occurs in each of these sheets at all scales.

Extensive areas of granitic rocks are present throughout the study area (fig. 3) and include layered or banded granitic gneisses containing bodies of syn- or posttectonic granitoids. These granitic rocks have obscured tectonic borders and intrusive contacts locally. Large areas of granite that are interlayered with other metamorphic rock types within the thrust sheets (Nelson and others, 1989) are not shown on figure 3. Nelson (1988, p. 7) states that granite plutons constitute as much as 50 percent of the volume of the Paris Mountain thrust sheet, but these plutons were not shown on the tectonic map (Nelson and others, 1987) that was used as a framework for this study. Pegmatite bodies, generally discordant with the foliation of the host rocks, are present throughout the study area.

SAMPLE COLLECTION AND PREPARATION

All of the samples used in this study were panned by D.W. Caldwell or N.P. Cuppels in 1952. The availability of these samples precluded the need for labor-intensive resampling. The 608 samples represent 535 sample sites; the remainder are replicates. The distribution of the concentrate samples is reasonably even within the study area, and the average area of the drainage basins sampled is about 7.5 km^2.

As described by Overstreet and others (1968, p. 51–53), these detrital heavy mineral concentrates were prepared by panning samples of gravel or sand dug from riffles in the active channels of small streams. The samples were wet sieved through a 1/8-in. screen; the oversized material was discarded prior to panning a volume of material that roughly filled a 16-in.-diameter stainless steel gold pan. Between 5 and 20 percent quartz was left in the concentrate to avoid loss of heavy minerals in the final stages of panning.

For this study, the low density minerals including quartz and feldspar were removed by floatation in bromoform (2.85 g/cm^3). The ferromagnetic and strongly paramagnetic fractions of the samples were separated by using a Frantz isodynamic magnetic separator. This set of procedures resulted in a high-density, paramagnetic mineral concentrate for spectrographic analysis.

The procedure used for magnetic separation was somewhat unconventional. The magnet of the Frantz isodynamic separator was positioned horizontally and covered with a sheet of thin mylar. A sample was placed on a paper-covered tray, then raised up to the mylar-covered magnet, which was set at 0.3 A; this procedure effectively removed the ferromagnetic fraction of the sample. The procedure was repeated with settings at 1.0 and 1.8 A; as a result, three groups of fractions, each having a different magnetic susceptibility, were created. The 1.8-A fractions were analyzed for this study. The horizontal orientation of the Frantz isodynamic separator has two distinct advantages over the more conventional chute method (where inclined tracks pass between the pole pieces of the separator); first, cleaning between samples is easier, and so the risk of sample contamination is reduced; second, processing the samples is much faster. However, the tray method is not as precise as the chute method, and the tray method effectively reduces the pulling power of the magnet on the sample by as much as 50 percent, thus broadening the range of minerals found in the processed sample.

Heavy mineral samples and resultant analytical data are highly skewed toward particular mineral phases and element associations. The accumulation of detrital minerals from fluvial sediments in small stream channels will vary as a complex function of many factors, including source material, stream regimen, position of the sampling site with respect to longitudinal distance from a stream's headwaters and transverse distance from the center of the present channel, and the size of the drainage basin containing a given stream. Overstreet and others (1968) and Mertie (1979) give thoughtful discussions concerning the natural factors affecting the tenor of different materials in a panned concentrate. Subsequent laboratory processing further modifies these patterns and results in enhanced abundances of certain minerals and elements and diminished abundances of others. Even the reproducibility of analytical results for replicate samples at a given site is limited.

Table 1. Ranges and median concentrations in ppm for 19 elements in heavy mineral concentrates from the northeastern part of the Greenville 1°×2° quadrangle, South Carolina, compared with average values for granite, shale, and basalt

[Lower detection limits in parentheses next to element. N, not detected; L, detected but less than the number value shown in the first reporting interval; —, data are missing or unreliable. All values in parts per million]

Element	Range		Median	Average granite[1]	Average shale[2]	Average basalt[3]
	Low	High				
Barium (50)	N	1,500	N	[4]840	580	330
Beryllium (2)	N	500	2	5	3	1
Bismuth (20)	N	500	N	.01	—	—
Boron (20)	N	5,000	20	[4]10	100	5
Chromium (20)	N	700	100	15	90	170
Cobalt (10)	N	50	N	3	19	48
Copper (10)	N	3,000	N	15	45	87
Gold (20)	N	1,000	N	.004	.005	.002
Lanthanum (50)	N	>2,000	300	[4]55	39	17
Lead (20)	N	50,000	20	20	20	6
Nickel (10)	N	700	15	7	68	130
Niobium (50)	N	2,000	150	20	11	19
Scandium (10)	N	>200	70	[4]7	13	30
Silver (1)	N	20	N	.04	.07	.11
Thorium (200)	N	>5,000	N	17.5	12	2.7
Tin (20)	N	>2,000	50	3	6	1.5
Vanadium (20)	L	1,000	150	42	130	250
Yttrium (20)	N	>5,000	500	[4]41	35	25
Zinc (500)	N	5,000	N	[4]39	95	105

[1]Guilbert and Park, 1985.
[2]Average shale of Turekian, 1977.
[3]Average basalt of Turekian, 1977.
[4]Average low-calcium granite of Turekian, 1977.

ANALYTICAL METHODS

All of the samples were analyzed for 31 elements by using a six-step, semiquantitative emission spectrographic method (Grimes and Marranzino, 1968; Matooka and Grimes, 1976). These results are summarized in table 1 of this report and are available in their entirety in Jackson and Adrian (1991). A small split of unground sample was saved for mineral grain identification; however, no systematic attempt was made to determine the abundances of minerals in the splits of the analyzed concentrates. Distribution of the abundance of 15 selected minerals in the samples is given by Overstreet and others (1968, pls. 1–4).

DISCUSSION

The data permit some generalizations regarding geologic and lithotectonic controls, and they draw attention to parts of the study area that contain anomalous concentrations of certain elements. We present the geochemical attributes of the analytical data in frequency distribution histograms (fig. 5) and in single-element or multiple-element distribution maps (figs. 6–28). For most elements, the values representing the high end of the sample population, which include high background values as well as anomalous values, were plotted on the distribution maps. Reporting intervals representing high background values were included on the distribution maps to avoid unduly emphasizing values not truly anomalous.

Using a single set of statistical parameters to define anomalous values was precluded because the heavy mineral concentrates reflect a wide range of rock types representing various geochemical terranes and because a relatively large number of elements were plotted for each sample. Instead, threshold limits for data intervals used on the element distribution maps were determined by visual inspection of the histograms for anomalous data. The average abundances of selected elements in granite, basalt, and shale (table 1) generally were considered as background values for unmineralized materials and were compared to our data as an additional aid in identifying anomalous values. Median concentration intervals are indicated on the frequency distribution histograms by arrows, and the intervals used in plotting distribution maps are bracketed.

Although the geochemical data for heavy mineral concentrates are not representative of the composite chemistry of rock units in a particular drainage basin, our reconnaissance data show median concentrations for most elements that differ by a factor of only 4 or less from concentrations in the average granite or shale, despite field and laboratory concentration factors of several thousand (table 1). Further, some of the observed variability is probably due to the relatively large analytical uncertainty associated with the spectographic method; this uncertainty is ±1 reporting interval 83 percent of the time (Matooka and Grimes, 1976). Median values having a greater than fourfold enrichment compared to the average granite or shale values shown in table 1 are noted only for the elements La (sixfold), Nb (tenfold), Sc (sevenfold), Sn (elevenfold), and Y (thirteenfold).

For certain elements, most notably lanthanum, scandium, and vanadium, most samples fall in the higher reporting intervals, and generalizations regarding geologic controls or areal distribution may be unwarranted. Other elements, including gold, silver, and bismuth, were detected in so few samples that generalizations are, likewise, unwarranted. Selected elements of economic interest are plotted with geochemically associated elements (figs. 8, 12, and 24) to help characterize any associations within the study area that may indicate a mineralized zone. Concentrations of other elements, such as zirconium and titanium, exceeded the upper detection limit for the six-step semiquantitative method in many samples, and they are not considered separately in our discussion. The high zirconium and titanium values indicate the persistence of zircon and the titanium minerals ilmenite and rutile across the entire study area.

DISTRIBUTION OF SELECTED ELEMENTS

Barium

Barium was not detected in the vast majority of samples. Only one sample contains more than the 580–840 ppm barium found in the average shale or granite (table 1), and the six remaining samples showing values more than 150 ppm are widely scattered (fig. 6). Samples having concentrations in the 100-ppm to 150-ppm range are clustered in the north-central and southwestern parts of the study area, many of them in or along the edge of areas containing granitic rocks delineated within the Six Mile thrust sheet by Nelson and others (1987). Alkali feldspar, which is the likely host mineral for barium in most rocks, was largely removed from the samples before analysis; its removal probably accounts for the generally low abundance of barium in the concentrates. Thus, the occurrences of barium reported in this study may be due to a less common mineral such as barite ($BaSO_4$), and the scattered higher concentrations, as well as the obvious clustering of samples having concentrations less than 200 ppm, may have intrinsic assessment significance.

Barite associated with gold has been reported at localities in the nearby Kings Mountain belt and Carolina slate belt (Bell and others, 1980; Butler, 1981). Two of the samples from our study area that contained detectable gold and barium come from the Six Mile thrust sheet. One sample contained 20 ppm gold and 300 ppm barium; the other contained 70 ppm gold and 100 ppm barium.

Beryllium

Concentrations of beryllium above the 30-ppm reporting interval are found mostly in samples from the northern part of the Paris Mountain thrust sheet (fig. 7). The highest concentrations are reported from samples clustered immediately west of Paris Mountain. This zone of high beryllium concentrations may extend farther north or west, beyond our sampling area.

The elevated beryllium values are substantially higher than would be expected in the average granite or shale, although the median beryllium content for our sample set is not appreciably different (table 1). Thus, the high beryllium values near Paris Mountain probably are not due to common rock-forming minerals, but to the presence of a beryllium-bearing mineral. The mineral beryl, which has a specific gravity of only 2.65–2.80, should have been removed during the processing of the samples through bromoform (specific gravity=2.85). Griffitts, Duttweiler, and others (1985, p. 3) speculated that chrysoberyl (specific gravity=3.75) may account for high beryllium contents of heavy mineral concentrates from the Inner Piedmont and thus may explain the high beryllium contents of samples from this study.

The beryllium distribution pattern is very similar to the pattern shown by certain other lithophile elements (fig. 8), particularly tin (see Tin section). A number of pegmatites in which minor amounts of beryl occur are found in the southwestern part of the study area (fig. 4), but these do not fall within the region of elevated beryllium values shown in this report.

Bismuth

Bismuth, which was detected in only seven samples (fig. 9), is a common accessory element in many precious and base metal deposits (Rose and others, 1979, p. 106). Although bismuth is associated with tin in areas of the Inner Piedmont and in the tin-spodumene belt to the northeast in the Charlotte 1°×2° quadrangle (Griffitts, Whitlow, and others, 1985a), it showed no obvious association with tin in this study. The elevated values encountered here may be due to manmade contaminants, such as lead shot, which was present in some samples.

Boron

Sites having concentrations of boron 100 ppm or greater generally are confined to the Paris Mountain thrust sheet and the adjoining granitic rocks to the east; the highest values are found in the northeastern part of the study area (fig. 10). Tourmaline was noted in some of the heavy mineral concentrates and may be the source of the boron. Pegmatitic tourmaline-bearing lenses and dikes are common to the area and are the probable source of the tourmaline in the samples.

The distribution pattern of boron is similar to that of certain other lithophile elements, most notably beryllium (figs. 7, 8), which is associated commonly with boron in pegmatites (Rose and others, 1979, p. 553).

Chromium

Sites having the highest concentrations of chromium are located mostly to the west of the Paris Mountain thrust sheet (fig. 11). Overall, the distribution of chromium shows some similarity to the distribution of the geochemically associated element nickel, as shown in figure 12 (see Nickel section).

Cobalt

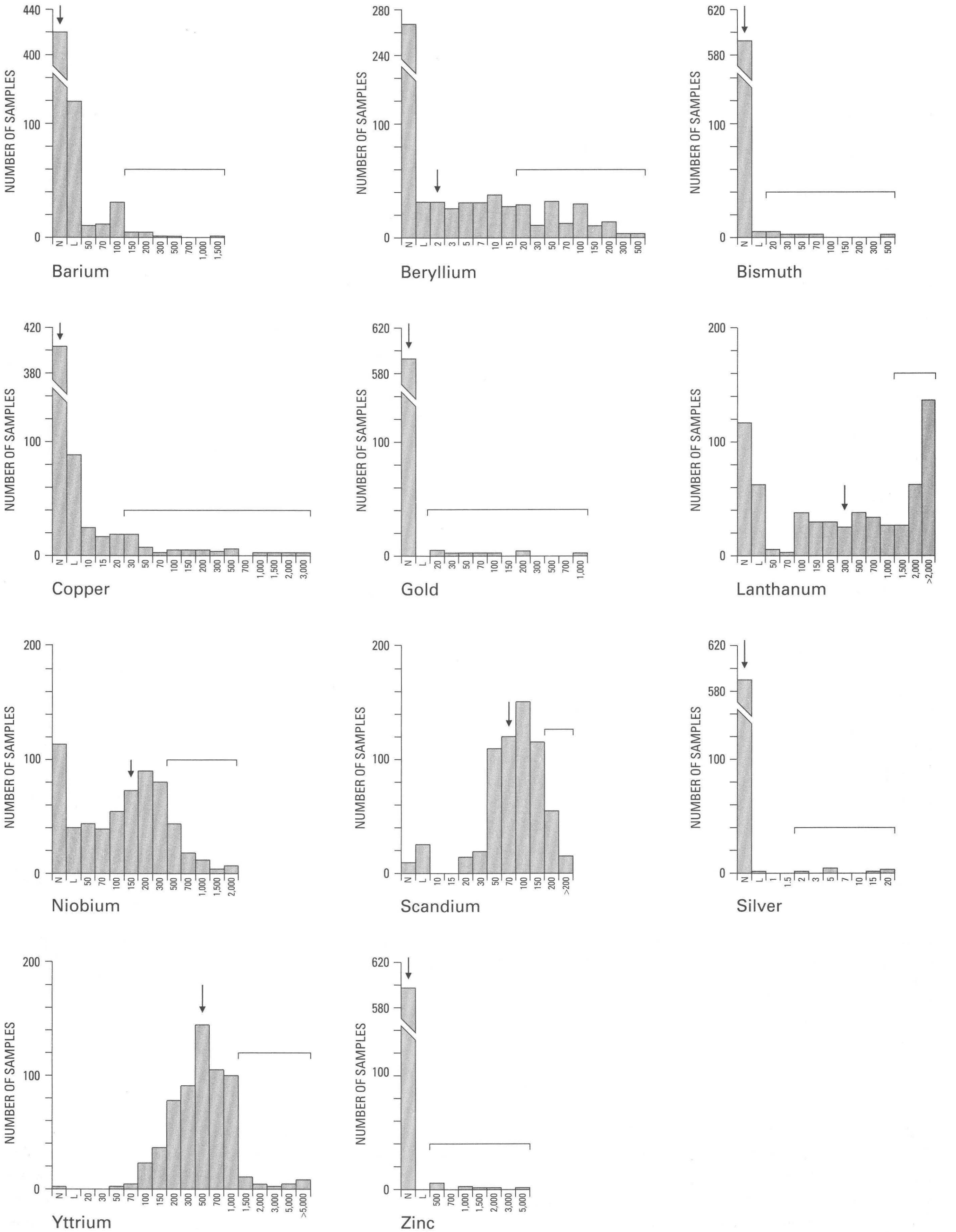
Cobalt was detected in relatively low concentrations in a number of samples from across the study area (fig. 13). None of these values significantly exceed the value for an average basalt (table 1), and some of the higher values may be related to mafic rocks in the drainage basins of those samples. Griffitts, Whitlow, Siems, and others (1984) reported that, in the nearby Charlotte 1°×2° quadrangle, cobalt was associated commonly with gold, and they speculated that both elements were involved in common episodes of mineralization. However, no similar correlations were found within the study area.

Copper

The relatively even distribution of samples containing concentrations of copper greater than 30 ppm over the study area indicates no apparent lithologic or structural control of these values (fig. 14). Overall, there are few associations evident between higher copper values and higher values for any other chalcophile elements. One sample from near the southeastern border of the study area containing 1,000 ppm copper and 2,000 ppm zinc is located approximately 5.5 mi northeast of a known massive sulfide occurrence, the Saluda copper prospect (fig. 4). Upon visual examination with a binocular microscope of splits of the heavy mineral concentrates from sample sites reporting greater than 300 ppm copper, no copper minerals or sulfides were noted. However, traces of lead shot were found in some samples, and copper commonly is used as plating on lead shot. Therefore, some of the elevated copper values may not be indicative of copper mineralization but may be due to manmade contaminants (see also Lead section).

Gold

Gold was detected in 11 samples from widely scattered locations (fig. 15). All but one of the sites are in rocks structurally below the Paris Mountain thrust sheet, but there is no obvious lithologic or structural control to the distri-


NUMBER OF SAMPLES
Barium
440
400
100
0
N L 50 70 100 150 200 300 500 700 1,000 1,500
Beryllium
280
240
100
0
N L 2 3 5 7 10 15 20 30 50 70 100 150 200 300 500
Bismuth
620
580
100
0
N L 20 30 50 70 100 150 200 300 500
Copper
420
380
100
0
N L 10 15 20 30 50 70 100 150 200 300 500 700 1,000 1,500 2,000 3,000
Gold
620
580
100
0
N L 20 30 50 70 100 150 200 300 500 700 1,000
Lanthanum
200
100
0
N L 50 70 100 150 200 300 500 700 1,000 1,500 2,000 >2,000
Niobium
200
100
0
N L 50 70 100 150 200 300 500 700 1,000 1,500 2,000
Scandium
200
100
0
N L 10 15 20 30 50 70 100 150 200 >200
Silver
620
580
100
0
N L 1 1.5 2 3 5 7 10 15 20
Yttrium
200
100
0
N L 20 30 50 70 100 150 200 300 500 700 1,000 1,500 2,000 3,000 5,000 >5,000
Zinc
620
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N L 500 700 1,000 1,500 2,000 3,000 5,000

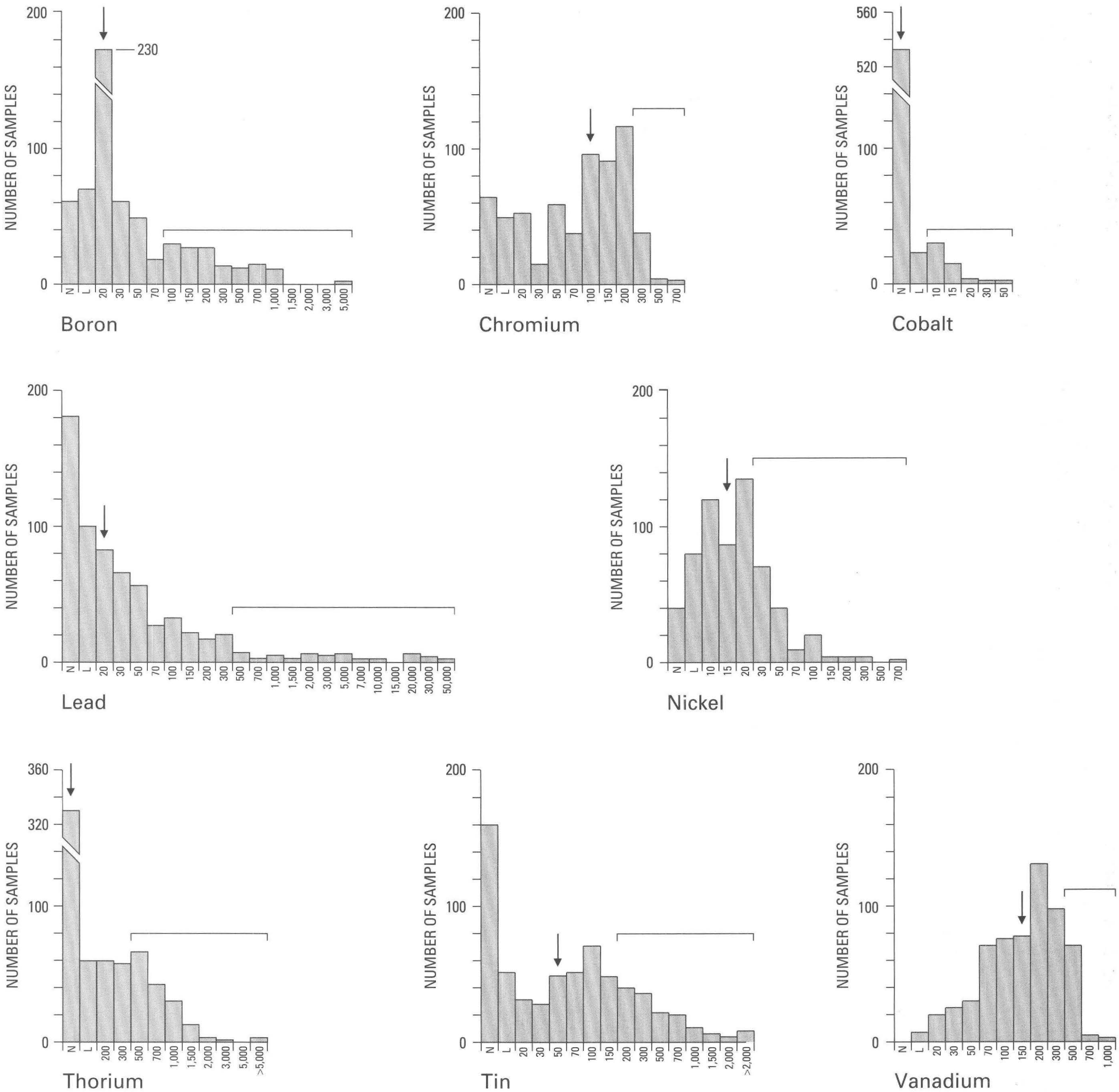

Figure 5. Histograms showing frequency distribution in parts per million for 19 selected elements in panned concentrate samples from the study area. N, not detected; L, detected but less than the number value shown in first reporting interval. Vertical arrows denote median reporting interval; horizontal brackets indicate range of intervals used in element distribution maps (figs. 6–28).

bution pattern of gold. In five of these samples, detectable gold and silver are reported, and in two samples gold and barium are reported (see Barium section). The only other noted association is the presence of 2,000 ppm copper and 200 ppm gold in one sample from the western edge of the sampling area.

Particulate gold was identified from splits of the heavy mineral concentrates in all but one of the samples containing 20 ppm or more gold by using a binocular microscope. Because of the scattered distribution and the lack of obvious elemental associations, no effort was made to systematically identify either deposit type or source

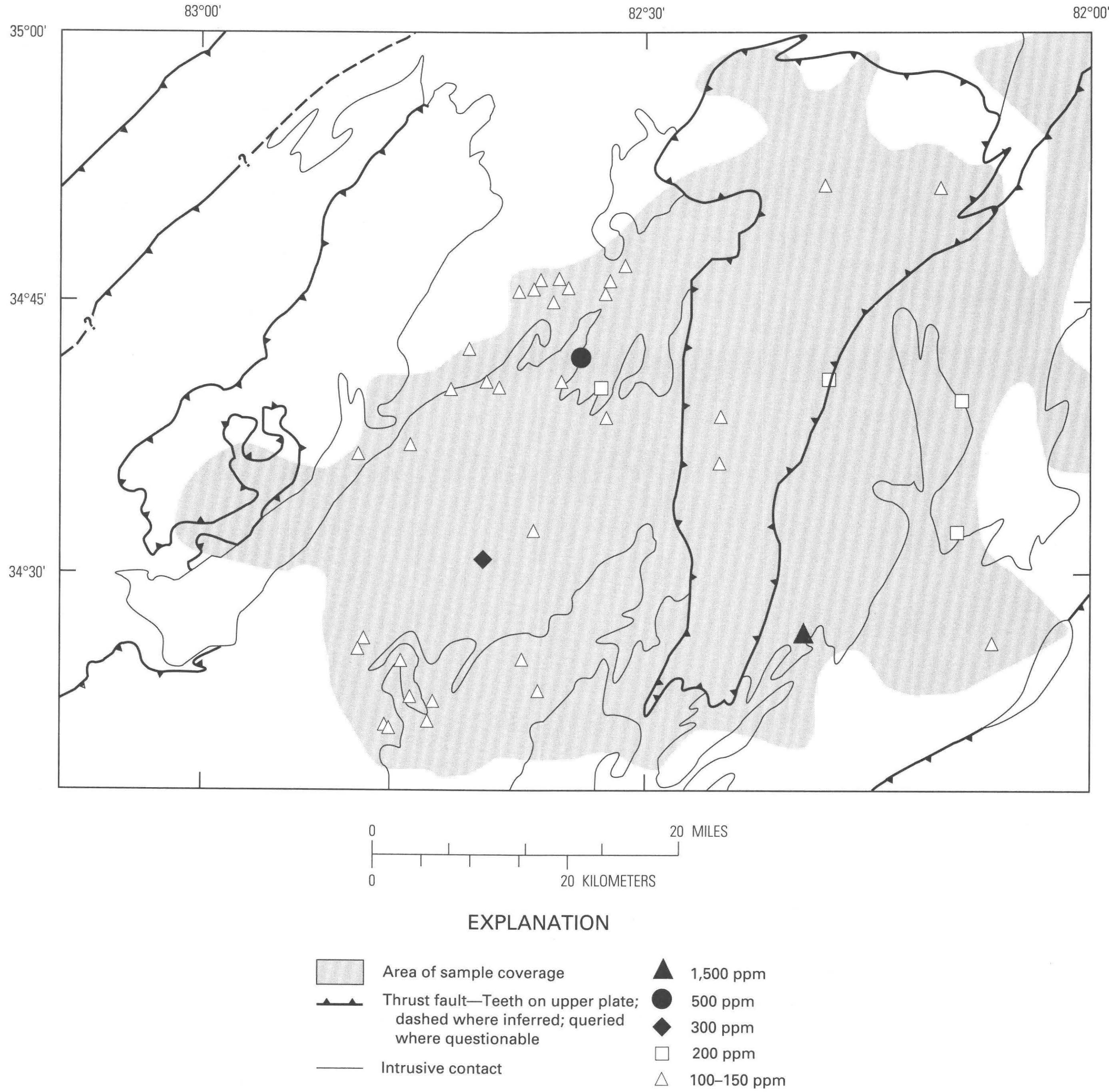

Figure 6. Distribution of barium in the study area. See figure 3 for names and locations of tectonic features.

material for the precious metals encountered in the study area.

Lanthanum

Lanthanum contents of the heavy mineral concentrates are consistently skewed toward higher values (fig. 5). Median contents are about six times that of the average granite or shale (table 1). The lanthanum-bearing heavy mineral monazite was found in all of the samples reporting more than 2,000 ppm lanthanum. Given that these samples were collected in the monazite belt of Mertie (1975), the presence of monazite in many of the streams of the study area was expected. However, its presence was not expected in the paramagnetic fractions of the samples that were analyzed spectrographically, because monazite is generally magnetic at the amperage these samples were subjected to and should have been removed during sample preparation. Obviously the magnetic separation methods used for this study incompletely removed monazite from most of those

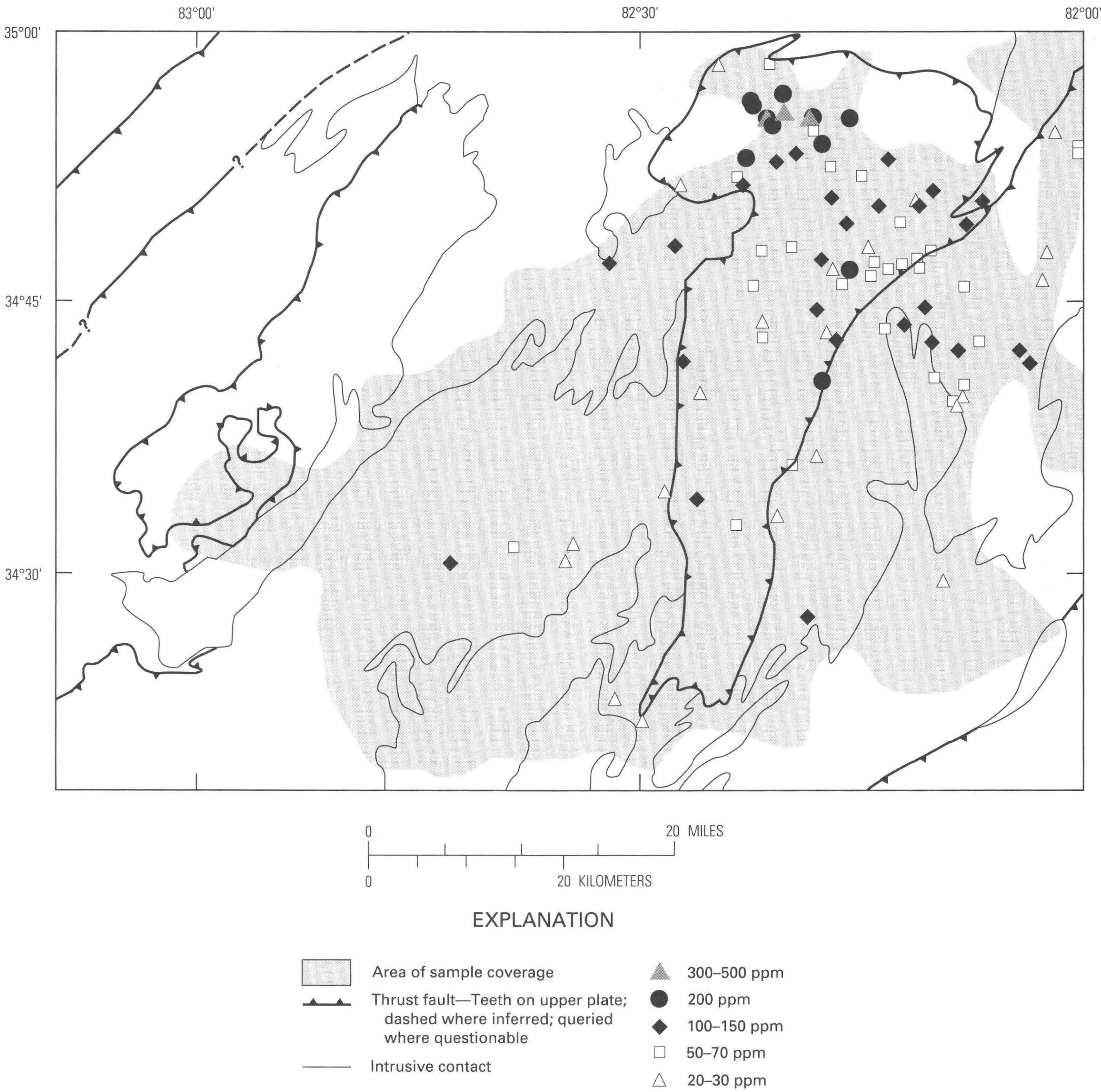

Figure 7. Distribution of beryllium in the study area. See figure 3 for names and locations of tectonic features.

samples that contained the highest percentages of monazite, possibly due in part to monazite's variable magnetic susceptibility.

Lanthanum is most abundant in samples from the northeastern half of the study area (fig. 16). Visual inspection of the magnetic fractions of the concentrates from the southwestern half of the study area, which have low lanthanum values, revealed that many of these samples also contain monazite, although in lesser amounts than samples from the northeastern half of the area. A comparison of the lanthanum values greater than 2,000 ppm from this study to contours drawn by Overstreet (1968, pl. 3) for samples that contain more than 10 percent monazite (from visual inspection) is shown in figure 17. Although a number of the samples that contain high lanthanum values fall outside of these contours, overall the two data sets correlate closely; this relation suggests that monazite is the source of the elevated lanthanum values. All but one of the monazite occurrences shown on figure 4 also are located in the northeastern half of the study area.

Mertie (1979, p. 2, 37) described the distribution of monazite as variably present in many types of granitic rocks

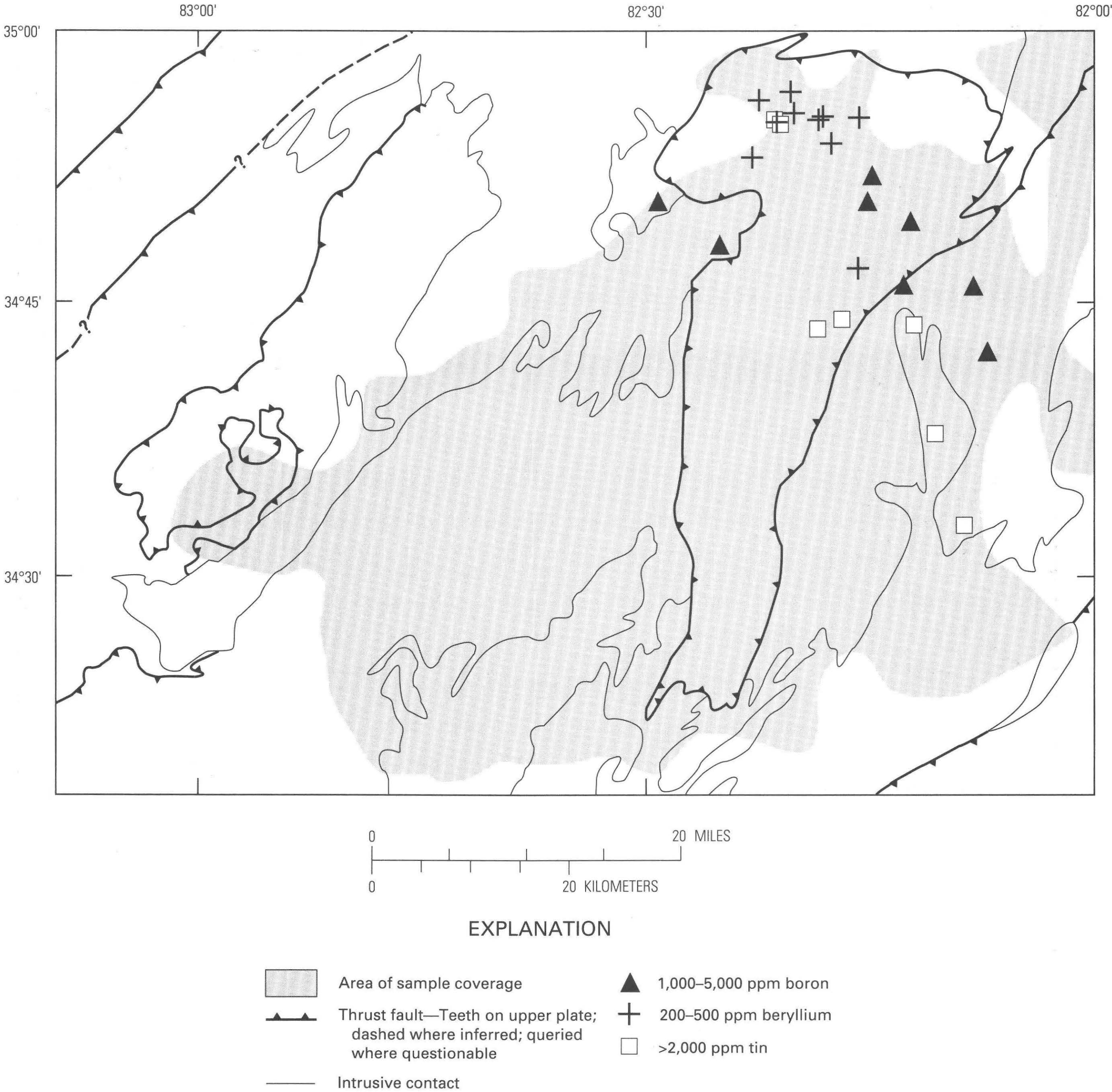

Figure 8. Multiple-element distribution map of the study area for boron, beryllium, and tin. See figure 3 for names and locations of tectonic features.

from within the belt and concluded that in South Carolina granitic gneisses are more important sources of monazite than are massive granitic rocks. Overstreet and others (1968, p. 24) reported that sillimanite schists are more important as source rocks contributing monazite to stream placers than are biotite schists and biotite gneisses. Overstreet and others (1968, p. 24) observed wide variations in the amount of monazite within similar rock types, as well as wide overlaps in the range of monazite present within different rock types. The high lanthanum values from the present study are widely distributed and cross major geologic boundaries. These characteristics indicate that monazite is a pervasive constituent of stream placers probably derived from different rock types throughout the study area. Another possible source for lanthanum in the samples is the mineral zircon ($ZrSiO_4$), which may contain small amounts of light rare earth elements and is found throughout the study area.

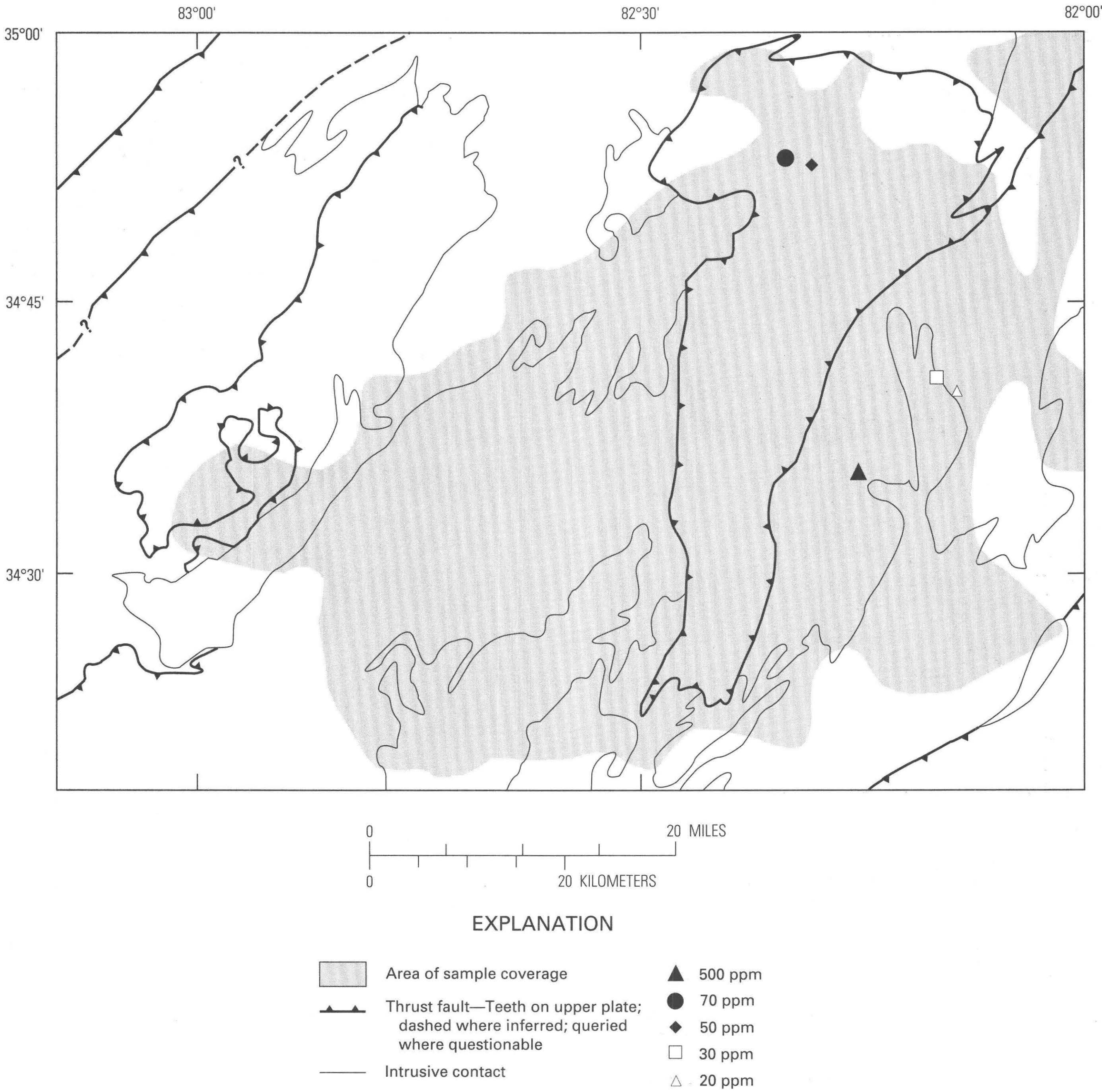

Figure 9. Distribution of bismuth in the study area. See figure 3 for names and locations of tectonic features.

Lead

The distribution of lead in the study area is random (fig. 18). The median content of 20 ppm is the same as would be expected in the average granite or shale. The most likely lead-bearing mineral in the raw stream sediment is alkali feldspar; however, virtually all feldspar was removed during sample preparation. Although values for some samples greatly exceeded the median content, lead shot was detected in splits of several of these samples. Bismuth, a common alloying element in lead shot, is anomalous in several of these samples.

Nickel

All sample sites having concentrations of nickel greater than 100 ppm are found in rocks structurally below the Paris Mountain thrust sheet (fig. 19). Many of the higher values to the west of the thrust sheet are paired with elevated chromium values (see fig. 12). However, the

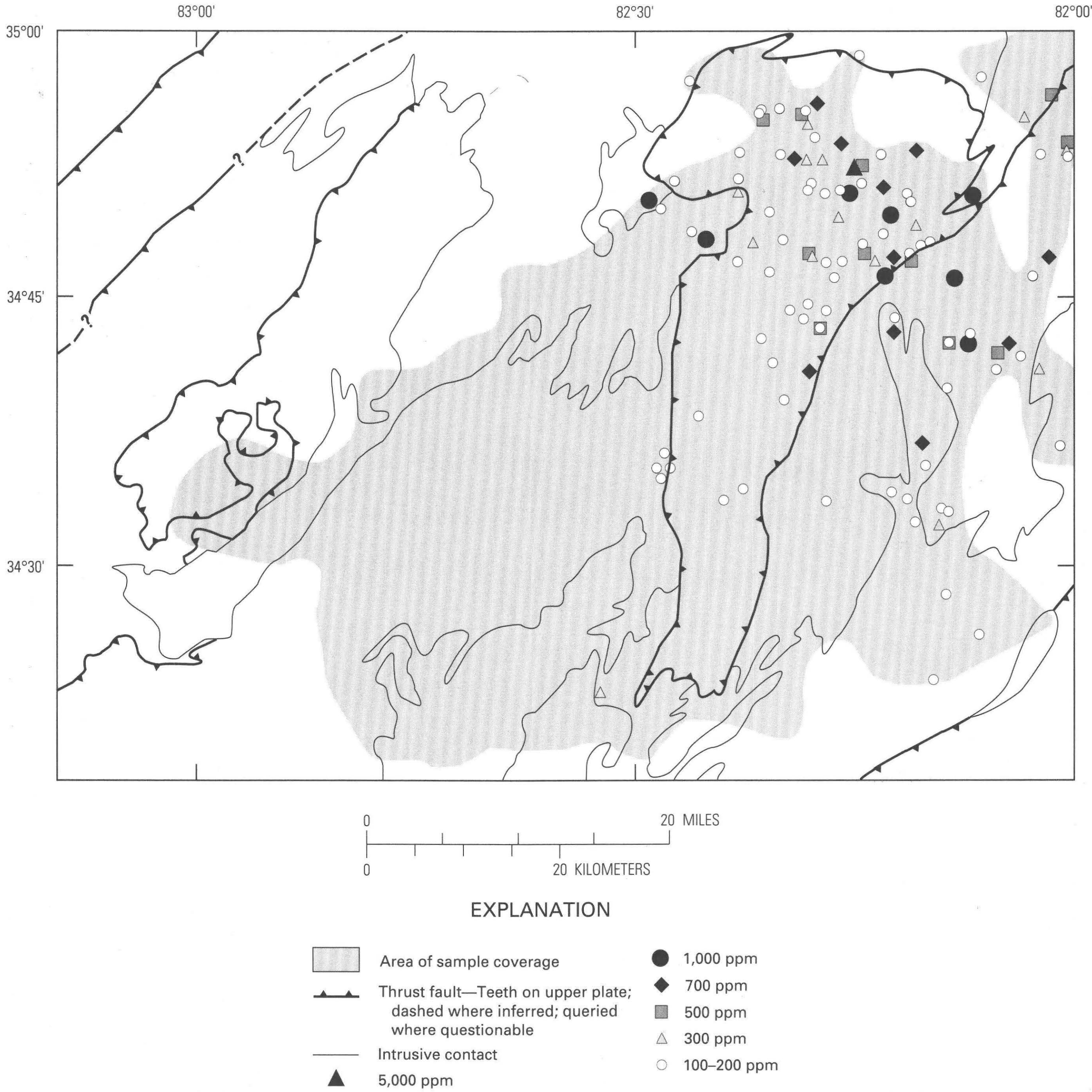

Figure 10. Distribution of boron in the study area. See figure 3 for names and locations of tectonic features.

concentrations for these geochemically associated elements fall well within the expected range for the average basalt (table 1) and probably are related to nearby mafic bodies, such as the Anderson metagabbro in the Six Mile thrust sheet or smaller unmapped mafic or ultramafic units in the other thrust sheets.

Niobium

Many of the heavy mineral concentrates from the Paris Mountain thrust sheet and immediately to the east of it contain elevated niobium values (fig. 20). Most notable, however, is a pronounced clustering of high values from the

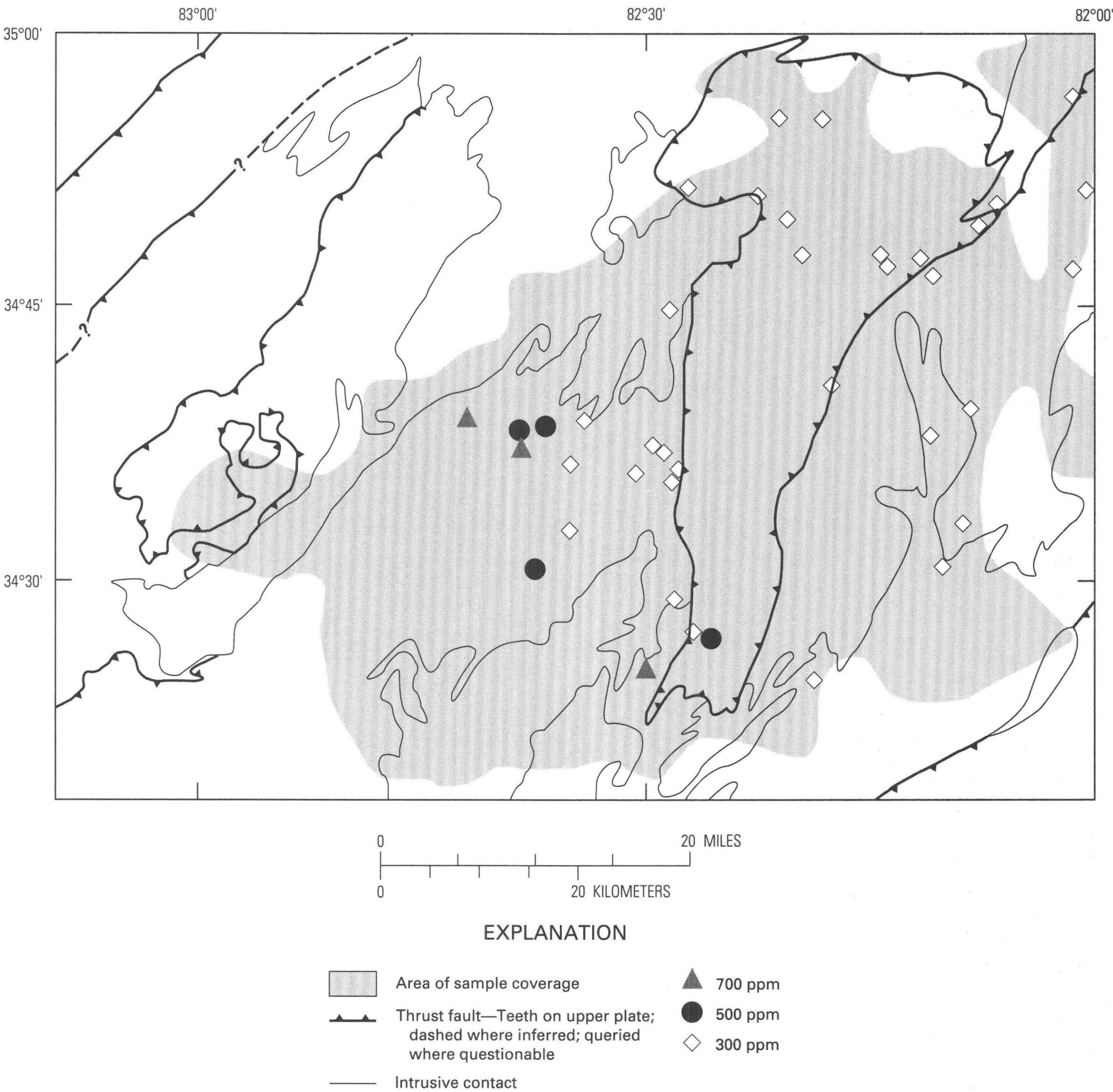

Figure 11. Distribution of chromium in the study area. See figure 3 for names and locations of tectonic features.

Reedy River and Saluda River drainages, in rocks along the edge of and adjoining the Paris Mountain thrust sheet. This cluster is a localized feature in the terrane of granitic rocks delineated by Nelson and others (1987) and may represent a specialized pluton or pegmatitic lenses containing either a niobium mineral such as columbite or minerals such as ilmenite, sphene, or rutile incorporating niobium as an accessory component. Rutile grains in several of the concentrates from this area were analyzed qualitatively by energy-dispersive X-ray fluorescence spectroscopy and were found to contain both niobium and tantalum. Fleischer and others (1952) showed that rutile having high niobium content is generally found in granitic pegmatites and alkalic rocks. Rutile, possibly as ilmenorutile, a phase containing iron in the form of ferrous niobate and tantalate, is a likely source of the elevated niobium values in the samples of this study.

Scandium

Scandium was detected in most samples, and the enrichment of scandium in the concentrates relative to the

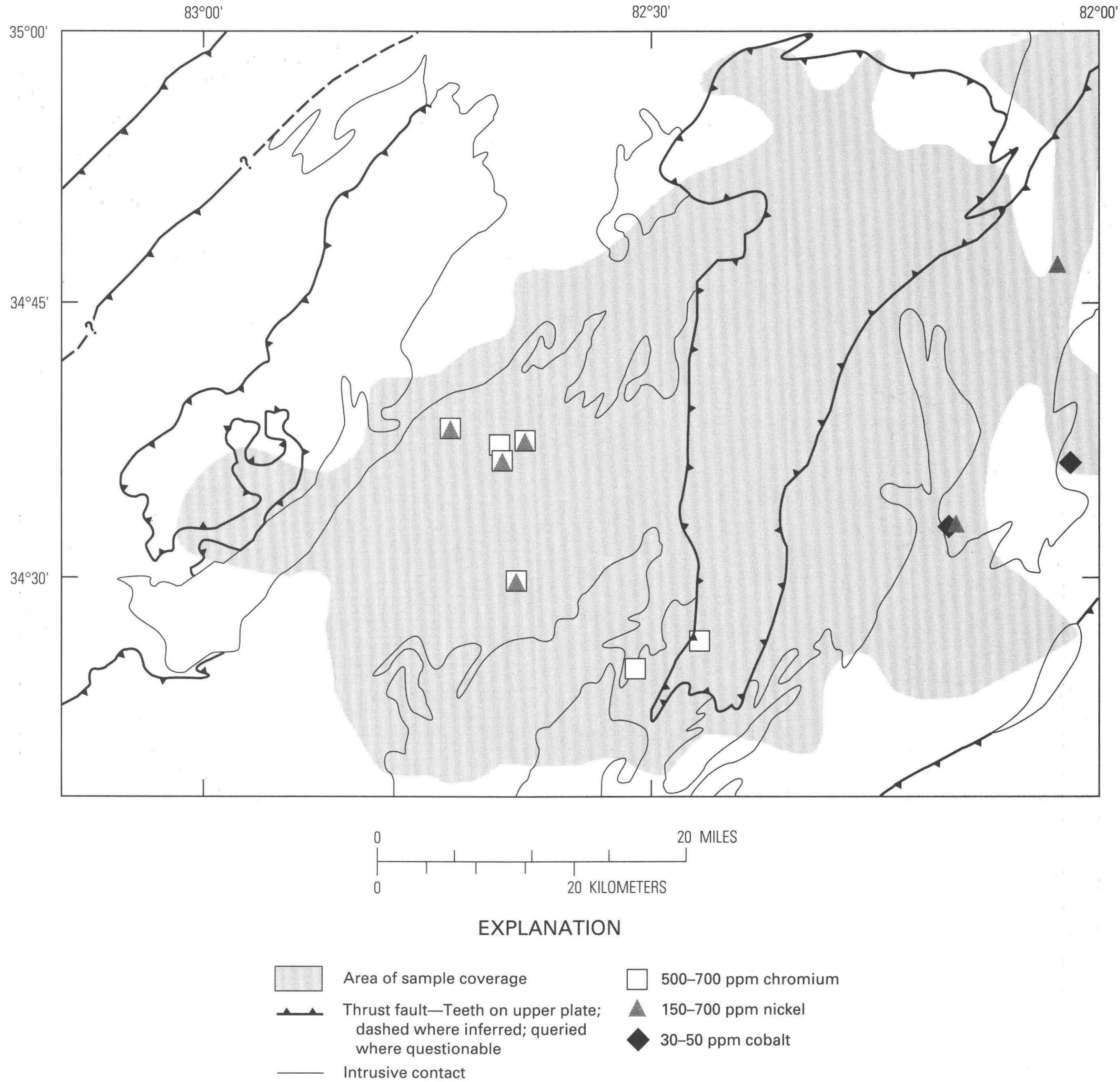

Figure 12. Multiple-element distribution map of the study area for chromium, nickel, and cobalt. See figure 3 for names and locations of tectonic features.

average granite or shale is about six times, but only about twice that of the average basalt (table 1). The overall variability around the median of 70 ppm (fig. 5) approaches that of normal distribution and indicates that the highest values may reflect little more than analytical uncertainty. Nevertheless, the distribution map for scandium shows a clustering of the highest values near Paris Mountain and in the east-central part of the study area, where yttrium and scandium appear to be associated (fig. 21). Scandium does not always accompany the lanthanide rare earth elements in minerals due to its smaller ionic radius; however, scandium has a close chemical relationship with yttrium and can occur as an accessory component in monazite (Rankama and Sahama, 1950, p. 508–517).

Silver

Silver was detected spectrographically in 10 samples, 5 of which also have detectable gold (see Gold section). These samples are widely scattered throughout the study area and show no obvious lithologic or structural control to their distribution pattern (fig. 22).

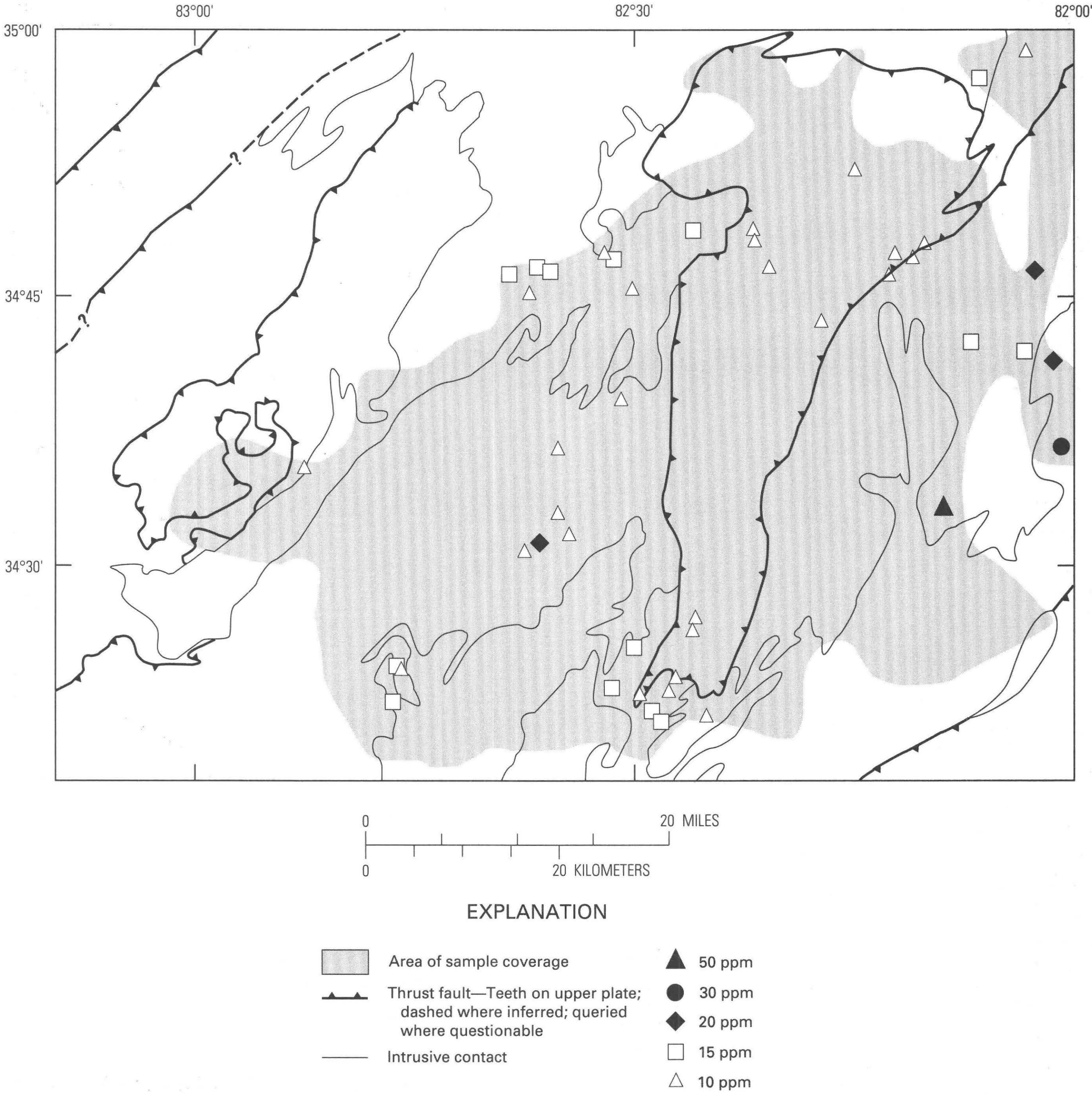

Figure 13. Distribution of cobalt in the study area. See figure 3 for names and locations of tectonic features.

Anomalous lead values as much as 5,000 ppm are associated with three samples containing anomalous silver, but because these lead values may be related to manamde contaminants (see Lead section), the significance of this geochemically important association is suspect.

Thorium

Thorium values, like the lanthanum values discussed earlier, appear to show a preferential enrichment in samples taken from the northeastern part of the study area (fig. 23). We determined that the high lanthanum values probably reflect, at least in part, a sample preparation bias in which monazite was incompletely removed from some samples (see Lanthanum section). Although this same sample preparation bias may account for the overall pervasiveness of the higher thorium values in the northeastern part of the study area, these samples do reveal a secondary clustering of anomalously high thorium values near the eastern edge of the study area, and the elevated values appear to be associated with yttrium (fig. 24).

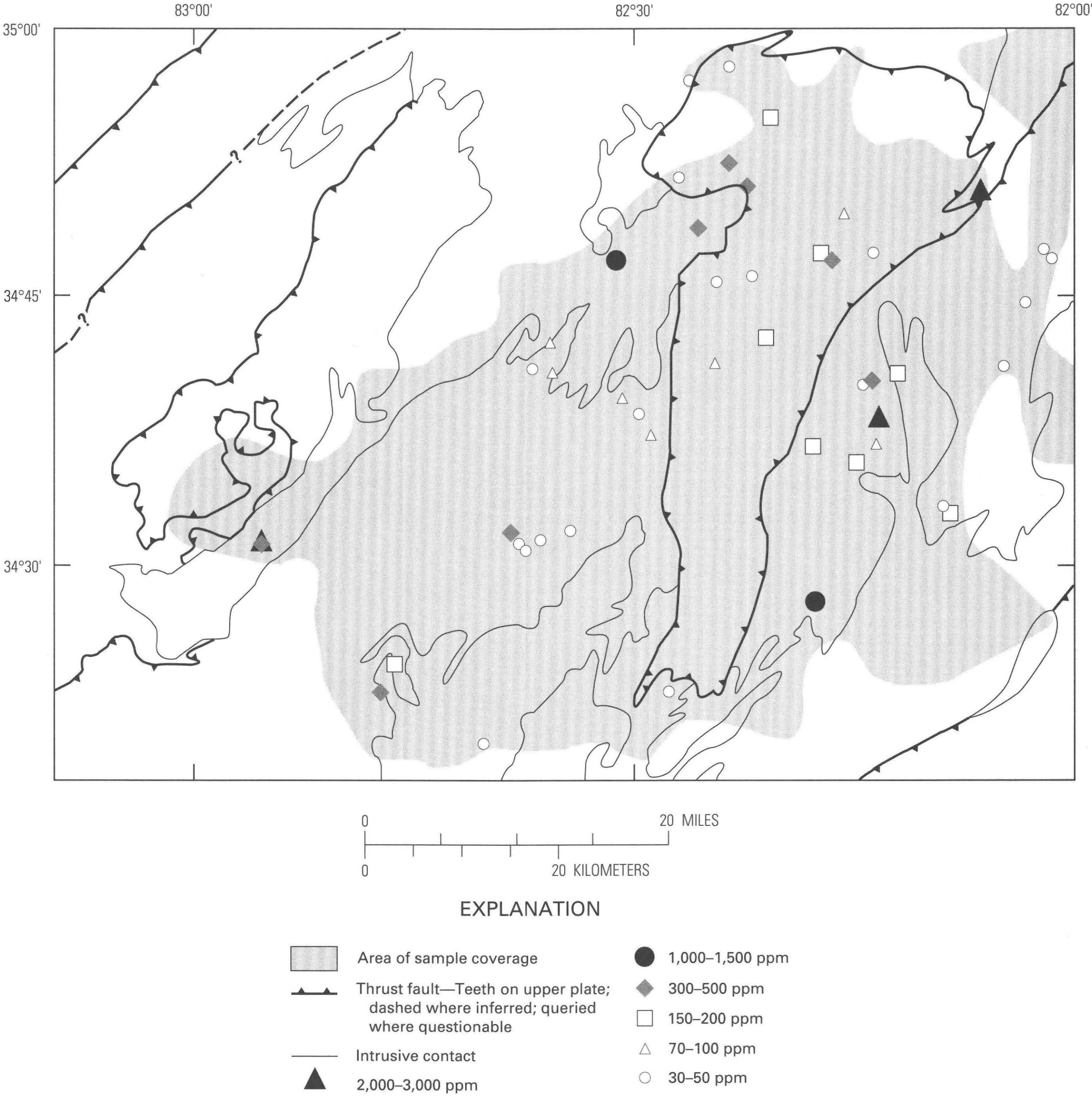

Figure 14. Distribution of copper in the study area. See figure 3 for names and locations of tectonic features.

The content of ThO_2 in monazite is highly variable (Mertie, 1979, p. 21). The high thorium values near the eastern edge of the study area suggest that the monazite from there may have a higher ThO_2 content relative to monazite from elsewhere in the study area. Most of the high thorium values occur in or near the edge of an area of biotite gneiss delineated by Nelson and others (1987) that in places grades to a sillimanite schist.

Tin

Tin is by far the most abundant of the ore metals encountered in this study and has a median value of 50 ppm, which represents an elevenfold enrichment relative to the average granite or shale. Tin is present in amounts greater than 1,000 ppm in 15 samples. The presence of elevated tin values throughout the study area suggests a tin-anomalous

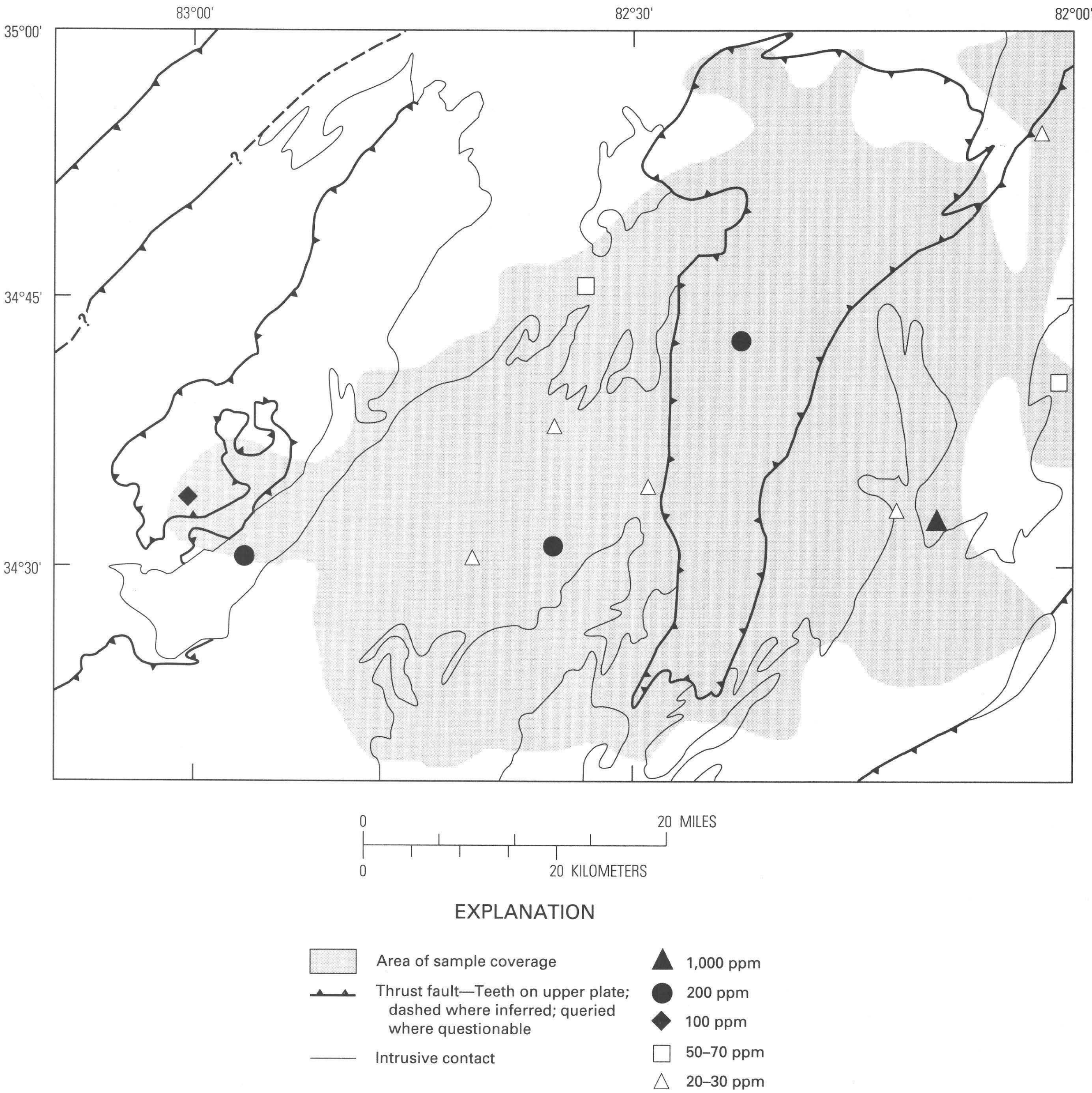

Figure 15. Distribution of gold in the study area. See figure 3 for names and locations of tectonic features.

region (fig. 25). A number of the samples containing the highest amounts of tin were examined by both X-ray diffraction and scanning electron microscope. Cassiterite in the 200- to 500-μm range was positively identified in each of these samples.

The frequency distribution histogram for tin (fig. 5) reveals two (and possibly three) populations: (1) samples having tin values below the lower detection limit of 20 ppm (not detected (N) or detected but less than the first reported value (L)), (2) samples having values above the upper detection limit of 2,000 ppm, and (3) a distinctly Gaussian population between these two extremes having a median at 100 ppm. The values above detection may simply represent the upper end of the intermediate Gaussian population.

Samples having tin values in the N or L reporting intervals are restricted almost entirely to the Six Mile thrust sheet (195 of 209 sample locations), whereas samples having values in the 70 to 150 ppm range (the median interval of population 3 and the two adjacent intervals) occur predominantly in the Paris Mountain and Laurens

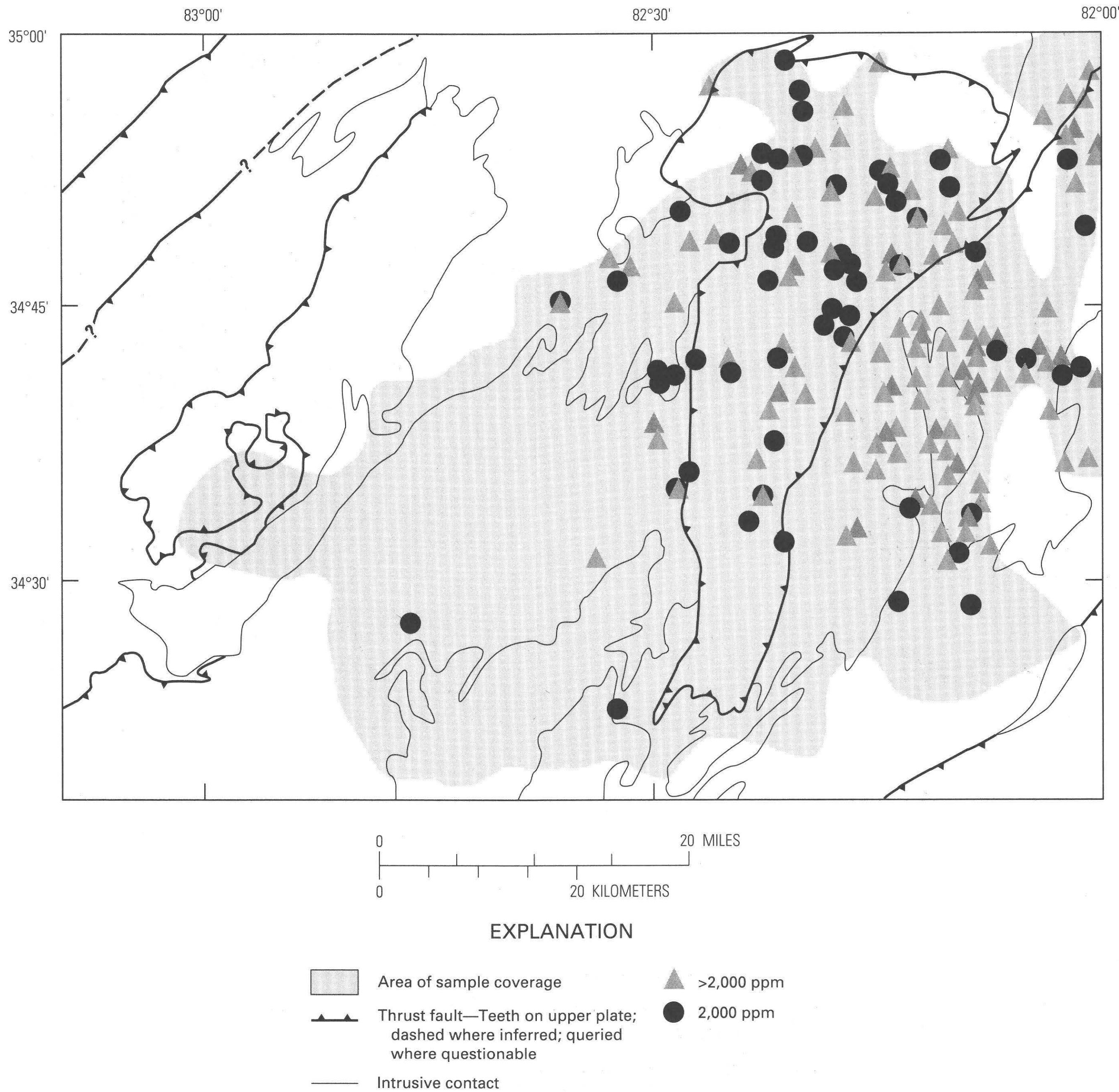

Figure 16. Distribution of lanthanum in the study area. See figure 3 for names and locations of tectonic features.

thrust sheets (117 of 156 sample locations). These relations suggest that the distribution of tin values within the study area may be lithotectonically controlled and that each population may favor a certain terrane.

The most anomalous of the three groupings, those samples having values above detection (population 2), cluster near Paris Mountain and in a belt extending southeast from Simpsonville, S.C. These samples are widespread and commonly are found near sample sites having much lower tin values; these characteristics suggest that the anomalous values probably represent localized mineralized pods or lenses in the schists, gneisses, or granites.

Gair and Horton (1989) reported that tin anomalies in the nearby Inner Piedmont of North Carolina are generally indicative of individual mineralized zones, the most important of which are greissens of the tin-spodumene belt. The greissens are generally less than 1 m thick and no more than 15 m long. Thin (<0.6 m) tin-bearing leucosomes are present in the Goodes Creek unit of the Inner Piedmont, located west of the tin-spodumene belt near Shelby, N.C.,

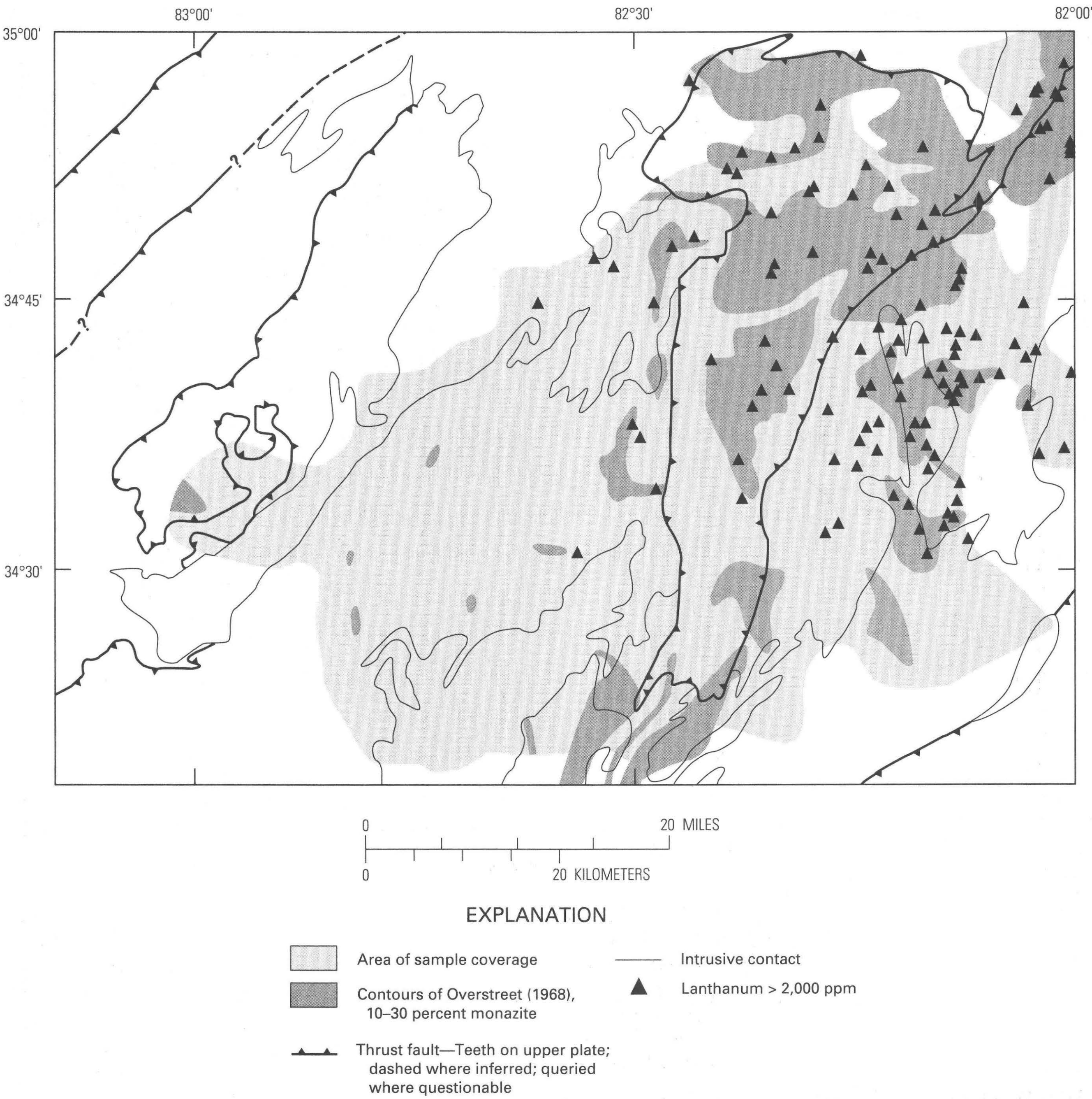

Figure 17. Distribution of lanthanum >2,000 ppm and monazite contours of Overstreet (1968). See figure 3 for names and locations of tectonic features.

but most leucosomes of that unit are geochemically barren of tin (Rowe, 1987). Rowe (1987) reported that these tin-bearing leucosomes occur within gneisses of the Goodes Creek unit that have slightly anomalous tin values, although the anomalous tin values are not evenly distributed within the gneisses. The spotty, uneven distribution of samples having elevated tin values from our study area may reflect the uneven distribution of tin-enriched rocks. We did not determine whether the elevated tin values represent cassiterite-bearing leucosomes or anomalous tin-bearing schists, gneisses, and (or) granites.

The possibility of cassiterite-bearing leucosomes in the study area appears to be highest near Paris Mountain, where the tin values are associated with elevated beryllium values (fig. 8). A tin-beryllium association has been documented in the Inner Piedmont by Theobald and others

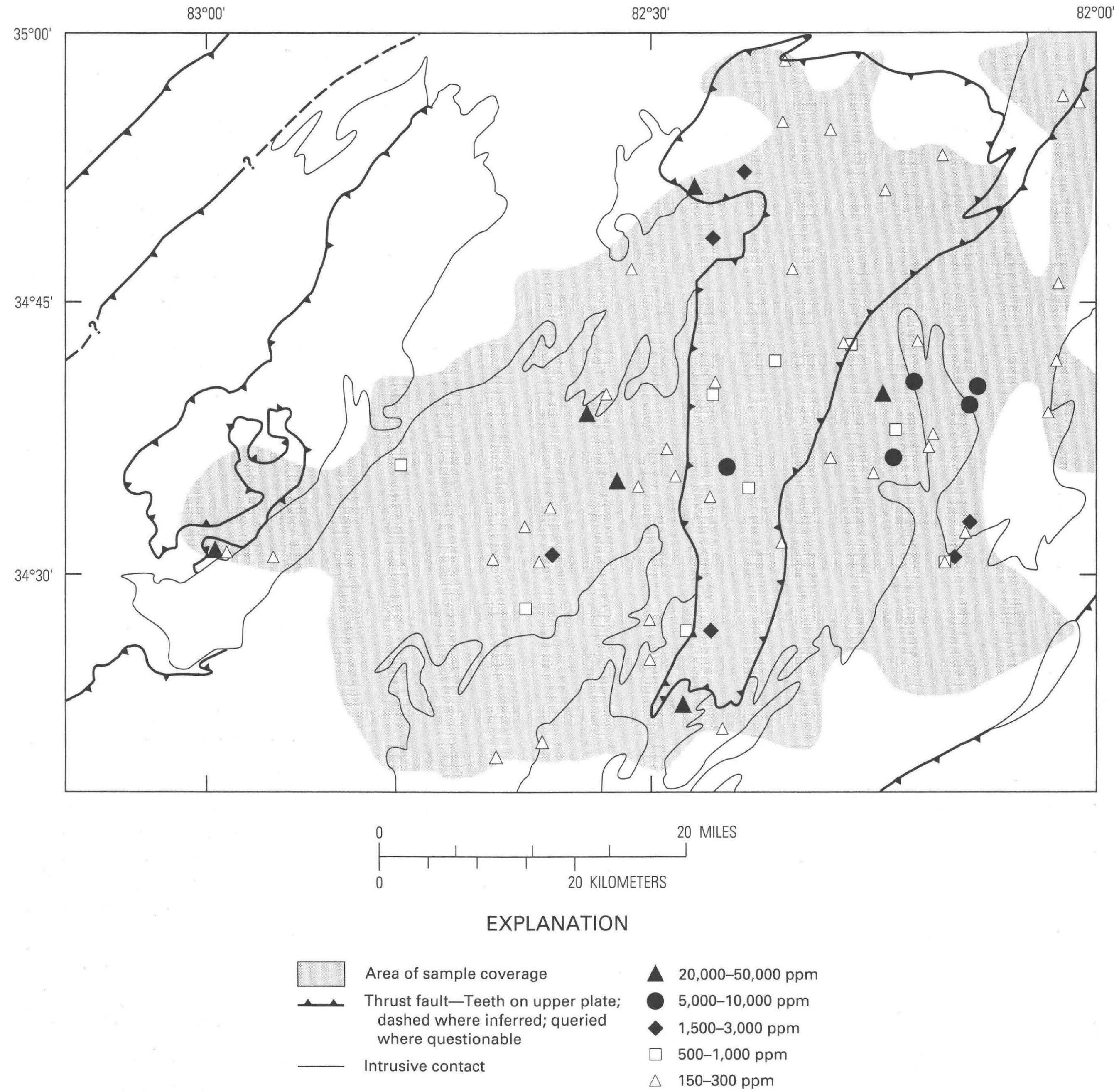

Figure 18. Distribution of lead in the study area. See figure 3 for names and locations of tectonic features.

(1967) in their magnetite study, as well as by Griffitts (1954); Griffitts, Whitlow, Duttweiler, and others (1984); Griffitts, Duttweiler, and others (1985); and Gair (1986).

Vanadium

Vanadium was detected spectrographically in every sample. Higher concentrations of vanadium are rather evenly distributed across a northeast-southwest-trending belt that cuts through much of the study area (fig. 26). An apparent eastern limit to the higher values coincides roughly with the boundary between the Paris Mountain thrust sheet and granitic rocks to the east. The data suggest that vanadium is enriched in the predominantly schistose rocks of the Six Mile and Paris Mountain thrust sheets relative to the granitic rocks to the east. Because no vanadium minerals were noted upon inspection of the concentrates, the apparent lithologic control of vanadium likely occurs as a result of the enrichment of a mineral hosting vanadium, possibly a titanium-bearing mineral phase.

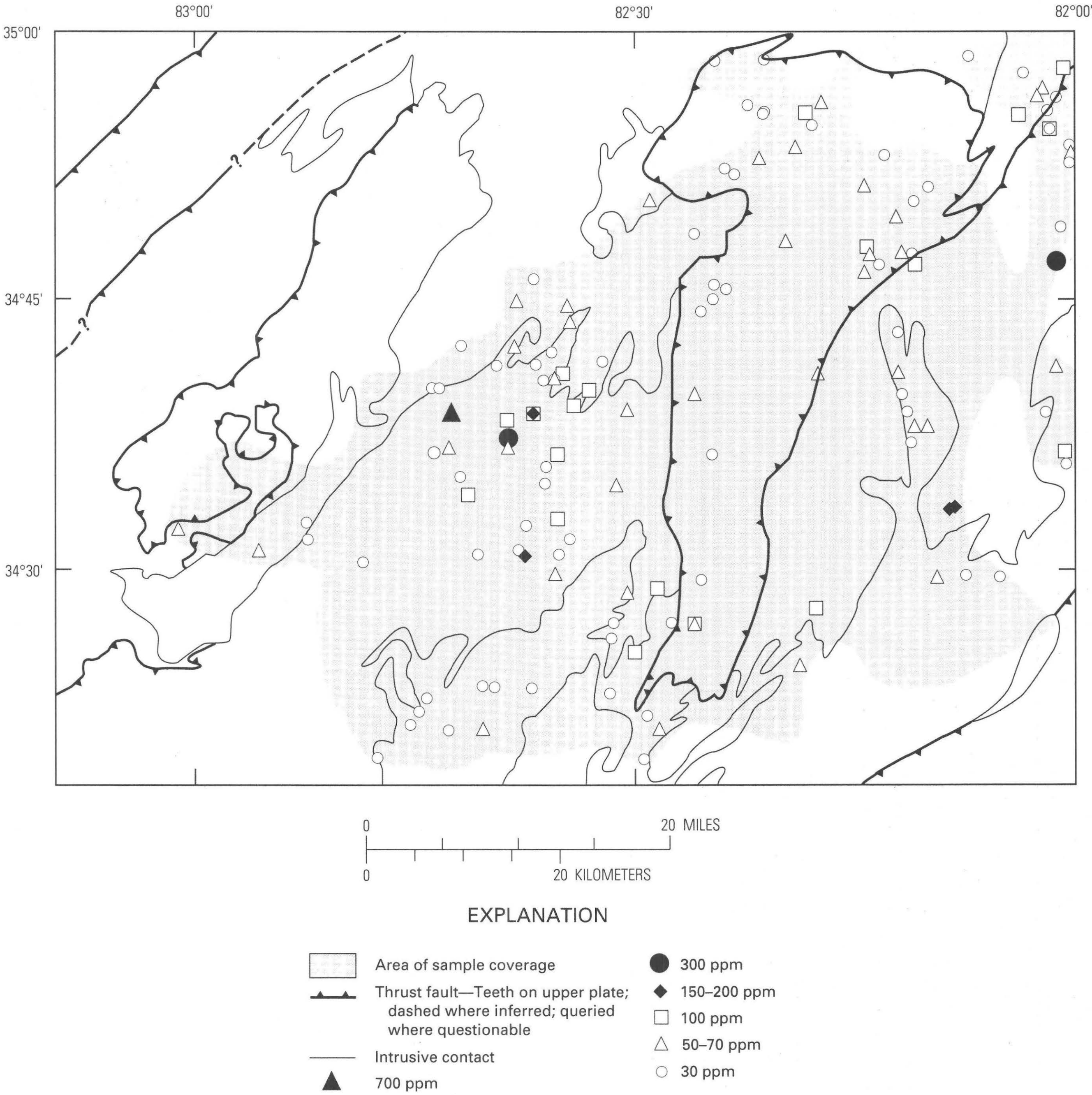

Figure 19. Distribution of nickel in the study area. See figure 3 for names and locations of tectonic features.

Yttrium

Yttrium concentrations are moderately high in many samples from the study area; the overall sample population has a median concentration interval of 500 ppm (table 1). The thirteenfold enrichment relative to the average granite or shale of these yttrium concentrations indicates the likely presence of one or more rare-earth-bearing minerals within the study area. The distribution of yttrium may be related, in part, to the abundance of monazite in many samples.

Yttrium concentrations are elevated in samples clustered near the eastern boundary of the study area (fig. 27). These anomalous yttrium values are associated with elevated thorium values (fig. 24) and high scandium values (see Scandium section), both of which also may be attributed to the presence of monazite in the concentrates. Xenotime, a mineral commonly associated with monazite in the North and South Carolina Piedmont (Overstreet and others, 1968), is a likely source for additional yttrium in the samples, as is zircon, which was abundant in most samples.

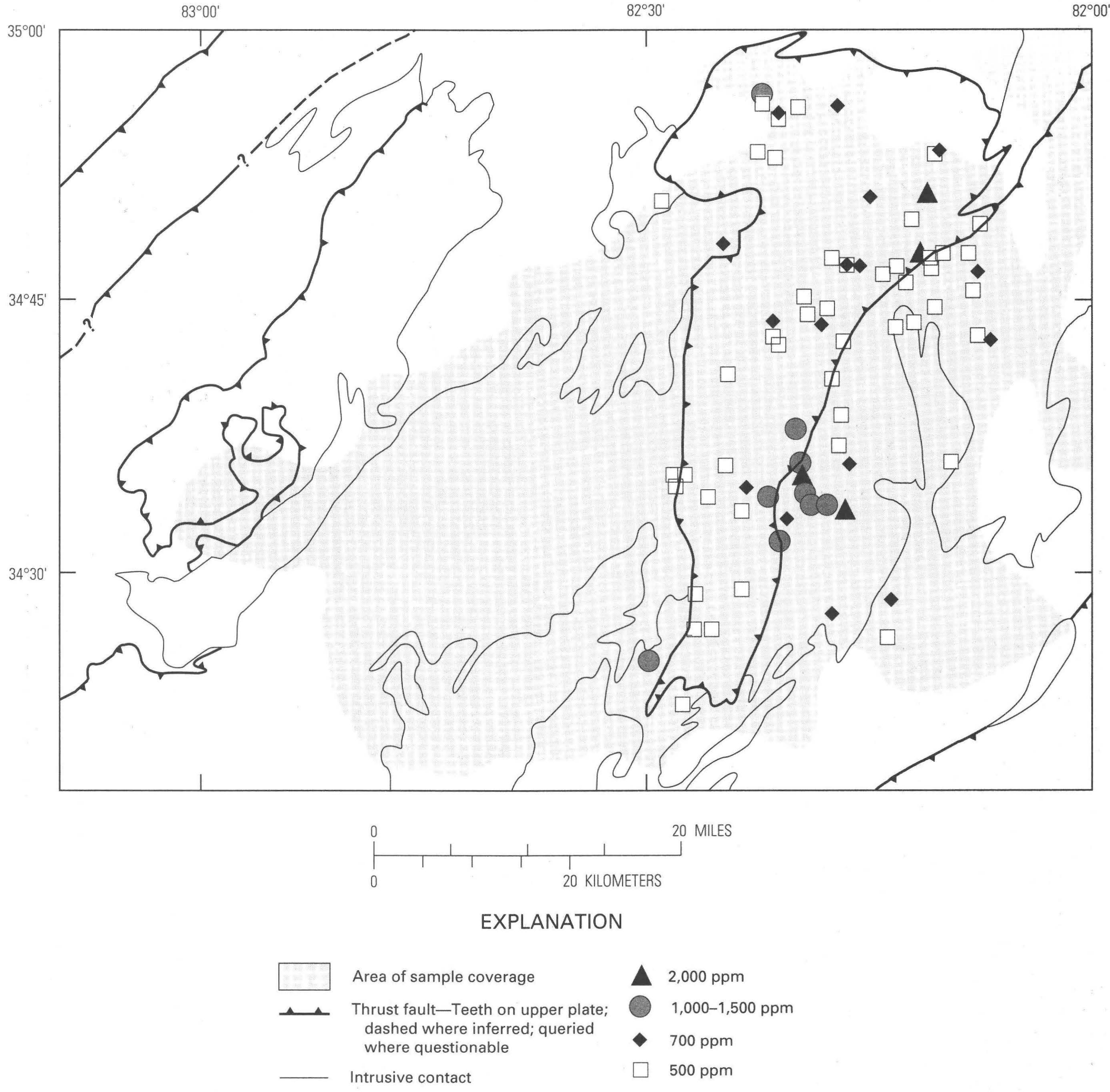

Figure 20. Distribution of niobium in the study area. See figure 3 for names and locations of tectonic features.

Zinc

Zinc was detected in only nine widely scattered samples and thus shows no obvious pattern in its distribution (fig. 28). Only two of the samples appear to be associated with elevated values for other elements. One sample having 2,000 ppm zinc, from the southeastern part of the study area, contains anomalous copper and tin, and one sample having 5,000 ppm zinc was collected near sites containing anomalous tin near Paris Mountain.

In the Inner Piedmont of North Carolina, in the nearby Charlotte 1°×2° quadrangle, zincian spinel is relatively widespread, and zincian staurolite also occurs there, although not as commonly (Griffitts, Whitlow, and others, 1985b). Either of these two zinc-rich minerals, or sphalerite, may be responsible for the zinc values reported within our study area.

CONCLUSIONS

The geochemistry of the heavy mineral concentrates reveals anomalous abundances of tin, beryllium, barium,

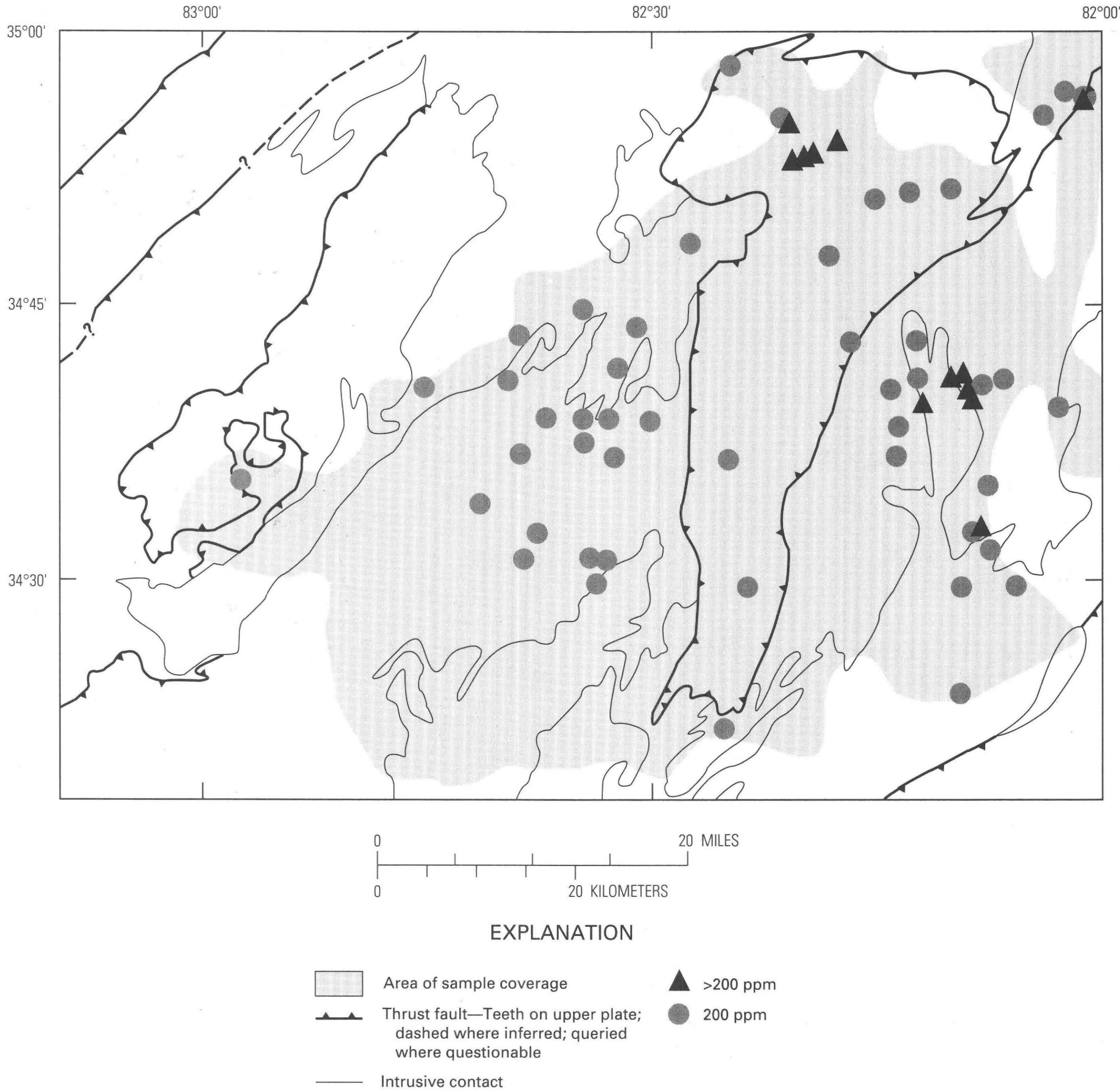

Figure 21. Distribution of scandium in the study area. See figure 3 for names and locations of tectonic features.

thorium, and the rare earth elements lanthanum and yttrium within the study area, but direct source rocks have not been identified. Generalizations relating the geochemical data to the geologic and lithotectonic framework of Nelson and others (1987, 1989) do little to identify or favorably predict zones that may be linked to mineral resource occurrences. However, the spatial distribution of values reported for certain elements, including tin, niobium, and vanadium, do conform generally with the thrust sheet boundaries and seem to affirm the viability of the sheets as geochemically distinct units.

The distribution of tin suggests that, overall, tin mineralization was a more widespread process in the metamorphically younger Laurens and Paris Mountain thrust sheets than in the older Six Mile thrust sheet. Thus, the younger thrust sheets appear to be the more favorable terrane for tin resource potential. Many of the tin values for the study area are anomalously high and appear to reflect a tendency shown by certain other lithophile elements, most notably beryllium and boron, to be higher in the northeastern part of the study area. Areas near Paris Mountain, S.C., and around Simpsonville, S.C., show a clustering of high

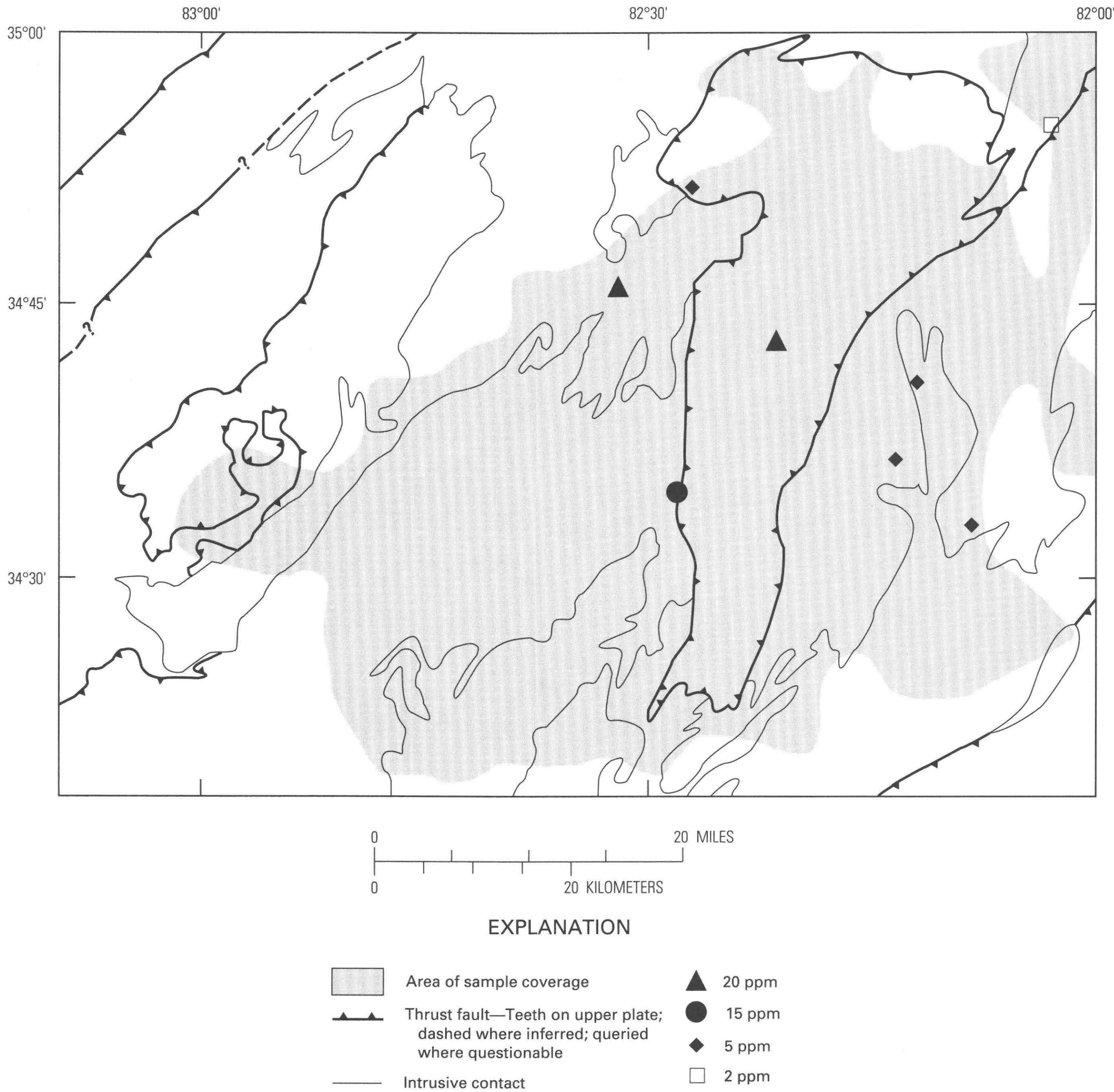

Figure 22. Distribution of silver in the study area. See figure 3 for names and locations of tectonic features.

tin values, and cassiterite was identified in samples from those areas; its presence suggests that a more detailed investigation may be justified there.

The barium values reported in this study may warrant a more detailed study, especially where associated with gold. These barium values may reflect the presence of barite.

The rare-earth-bearing mineral monazite is found throughout the study area, and its presence is reflected by high lanthanum values in many samples. The association of anomalous concentrations of lanthanum, yttrium, and scandium, as well as elevated thorium values, near the eastern edge of the study area suggests that additional rare-earth-bearing minerals may be present there, possibly hosting rare earth elements not analyzed for in this study.

The scattered distribution patterns and apparent lack of lithotectonic controls for certain base metals, including nickel, copper, zinc, and lead, effectively limit the assessment significance of the isolated anomalies reported for these elements. Low level traces of gold and silver are not

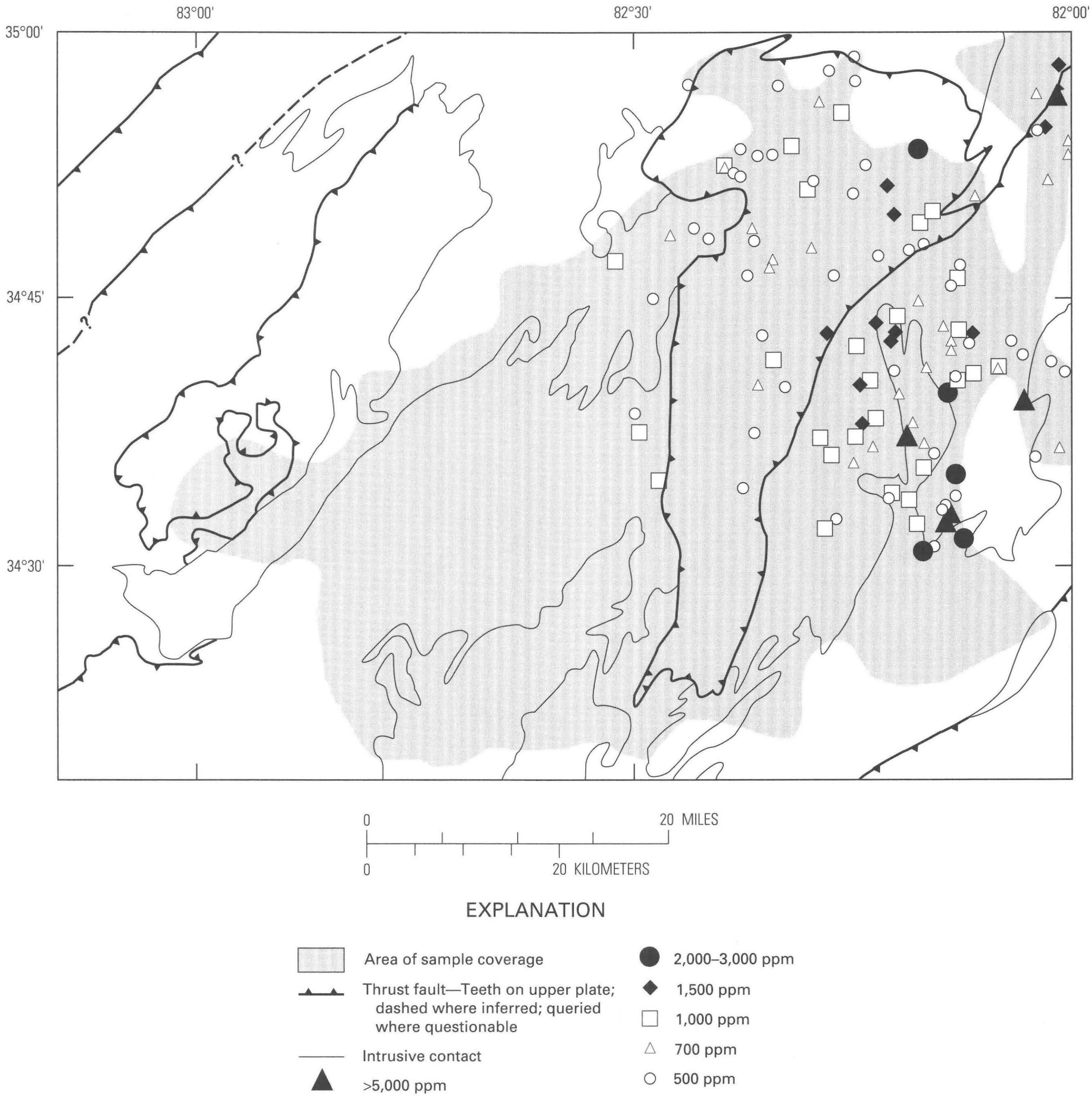

Figure 23. Distribution of thorium in the study area. See figure 3 for names and locations of tectonic features.

uncommon in the North and South Carolina Piedmont; thus, the few scattered values reported here probably do not in themselves justify additional study for the precious metals.

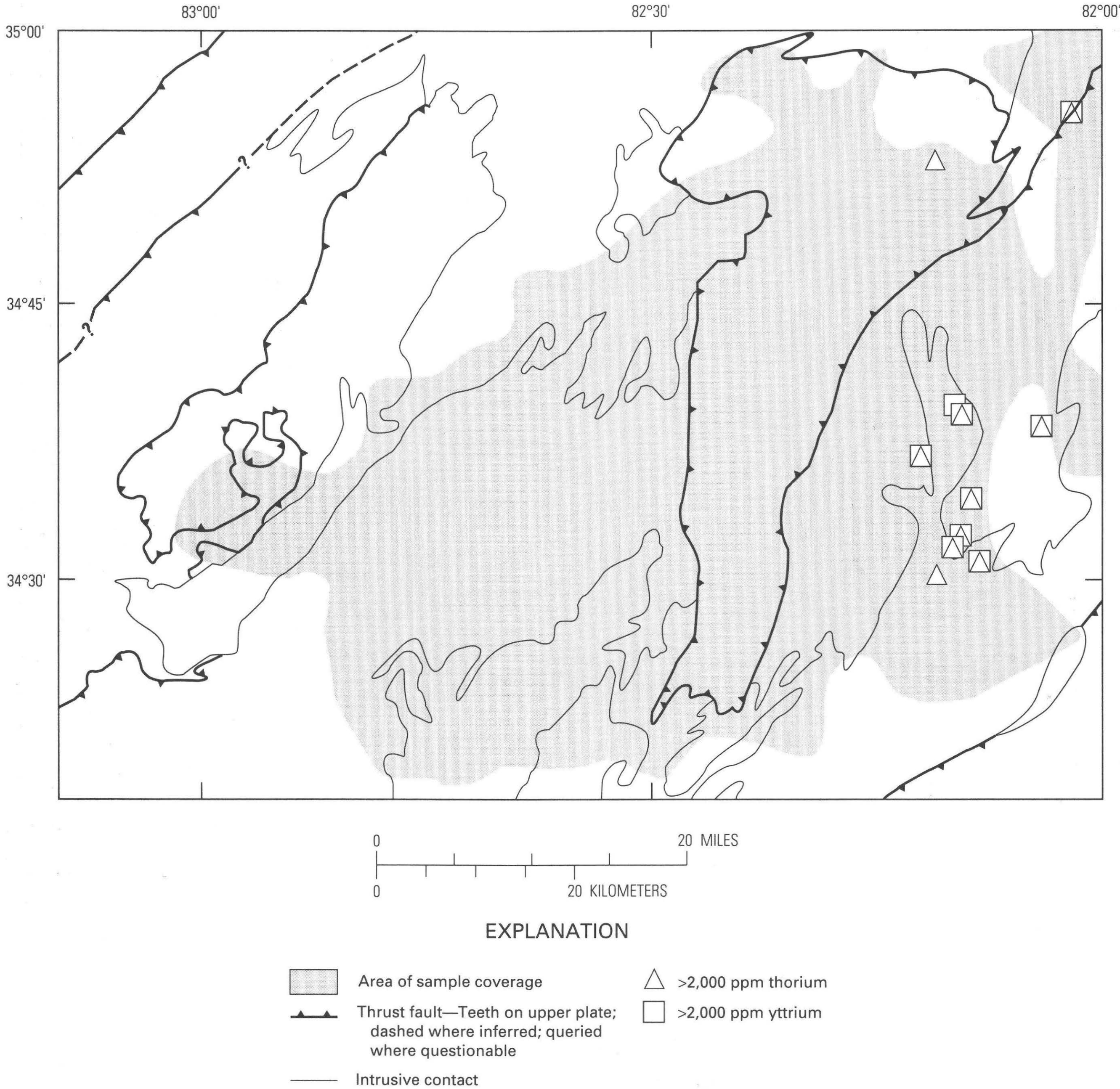

Figure 24. Multiple-element distribution map of the study area for thorium and yttrium. See figure 3 for names and locations of tectonic features.

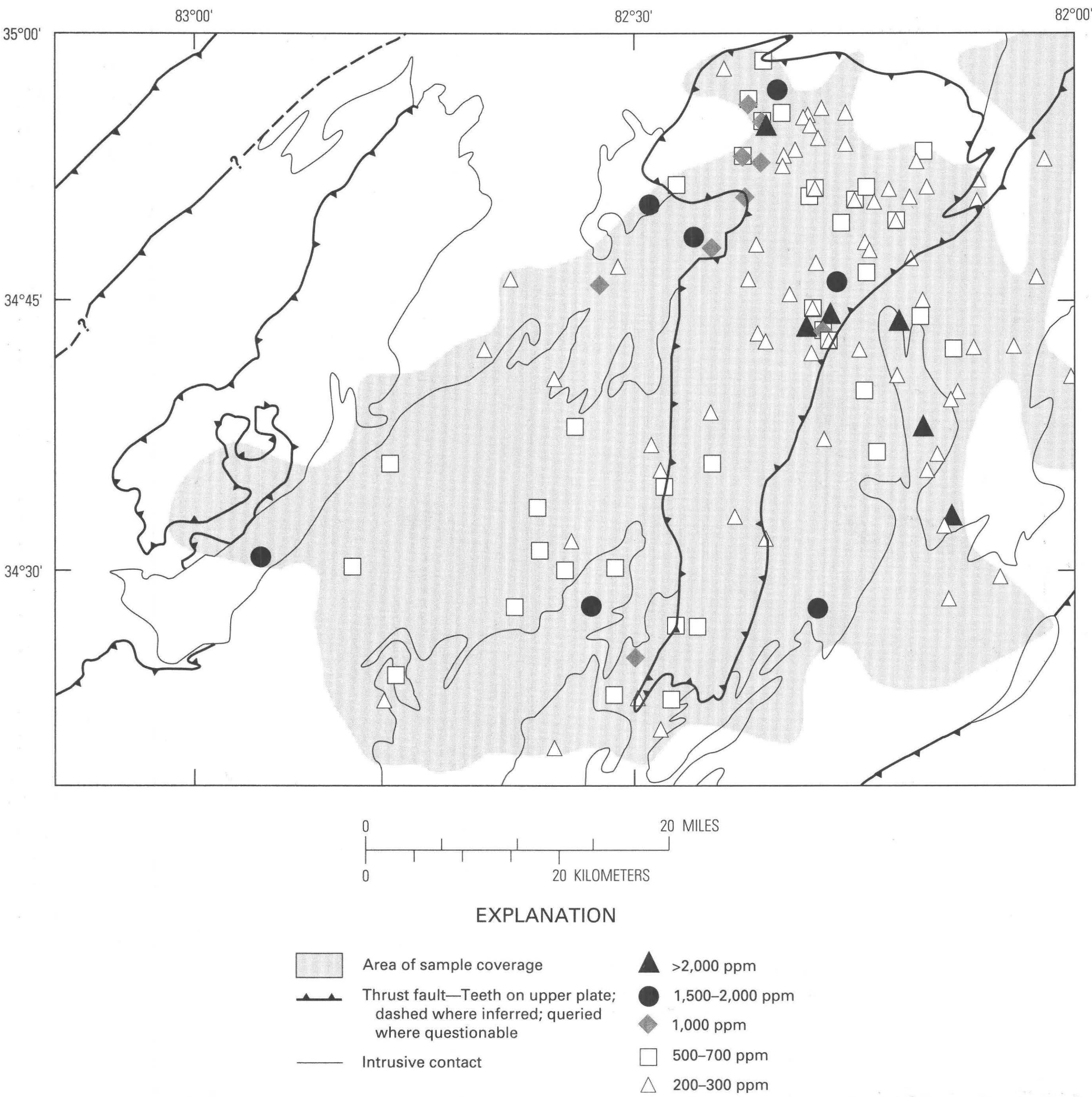

Figure 25. Distribution of tin in the study area. See figure 3 for names and locations of tectonic features.

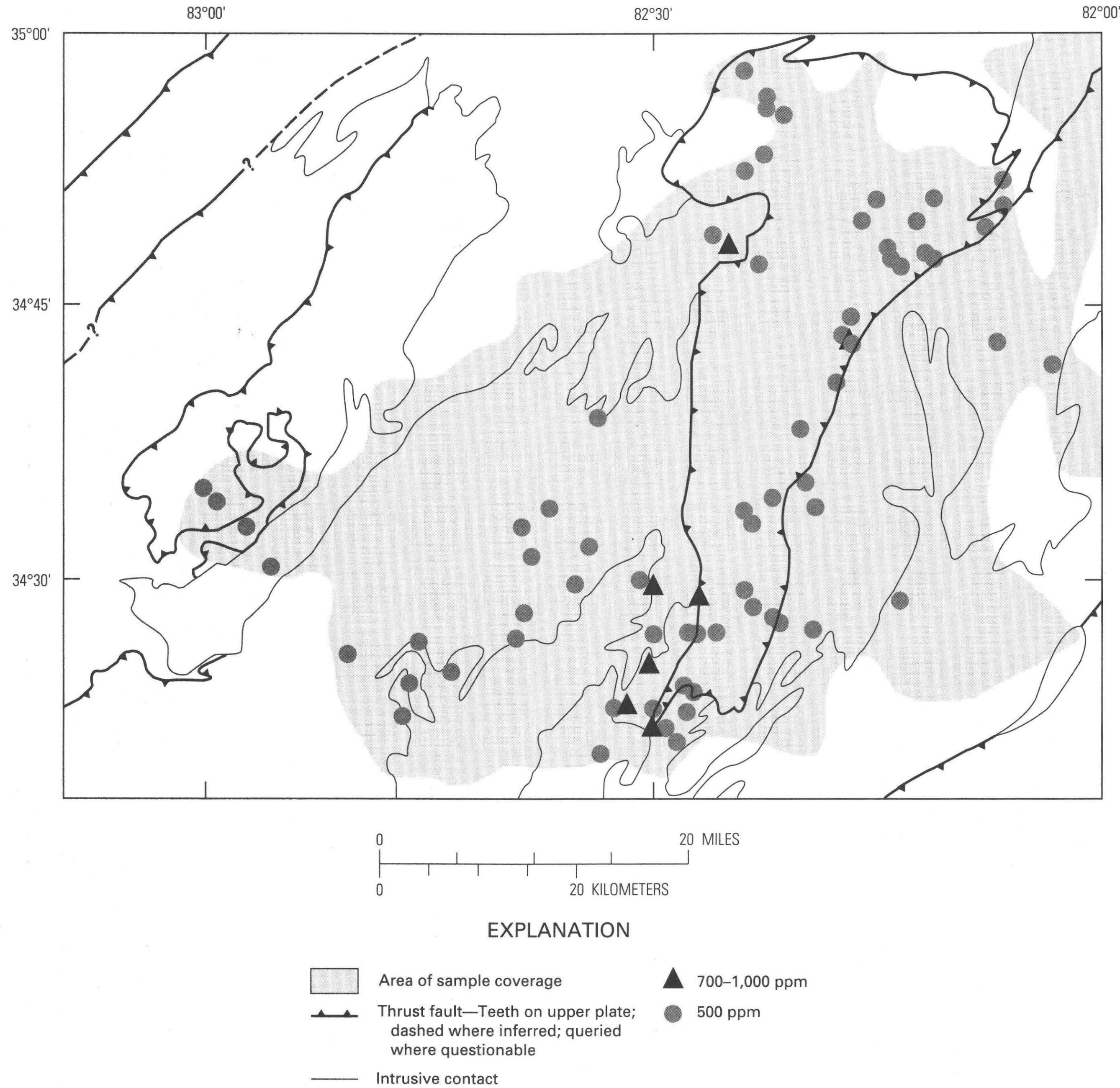

Figure 26. Distribution of vanadium in the study area. See figure 3 for names and locations of tectonic features.

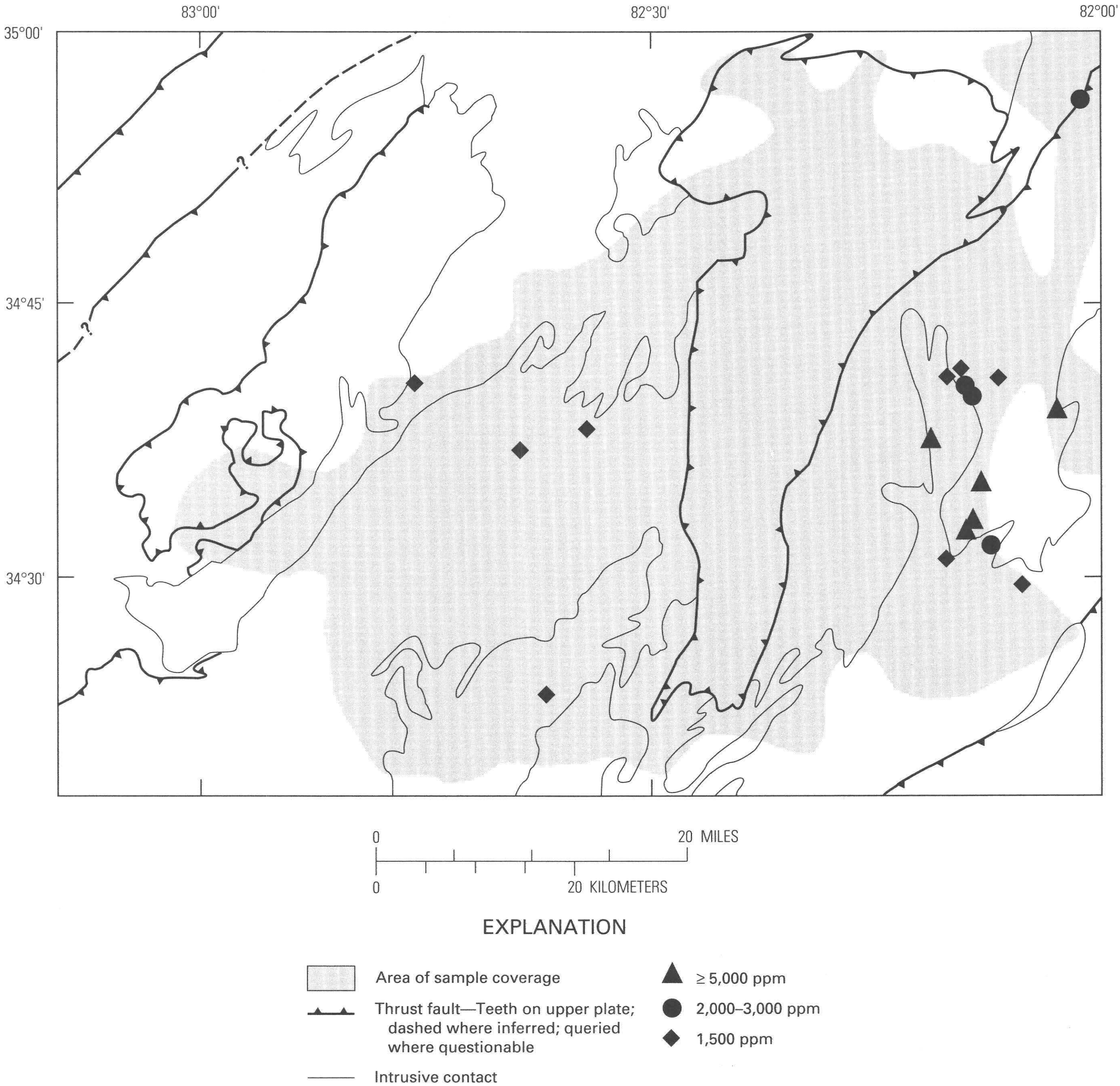

Figure 27. Distribution of yttrium in the study area. See figure 3 for names and locations of tectonic features.

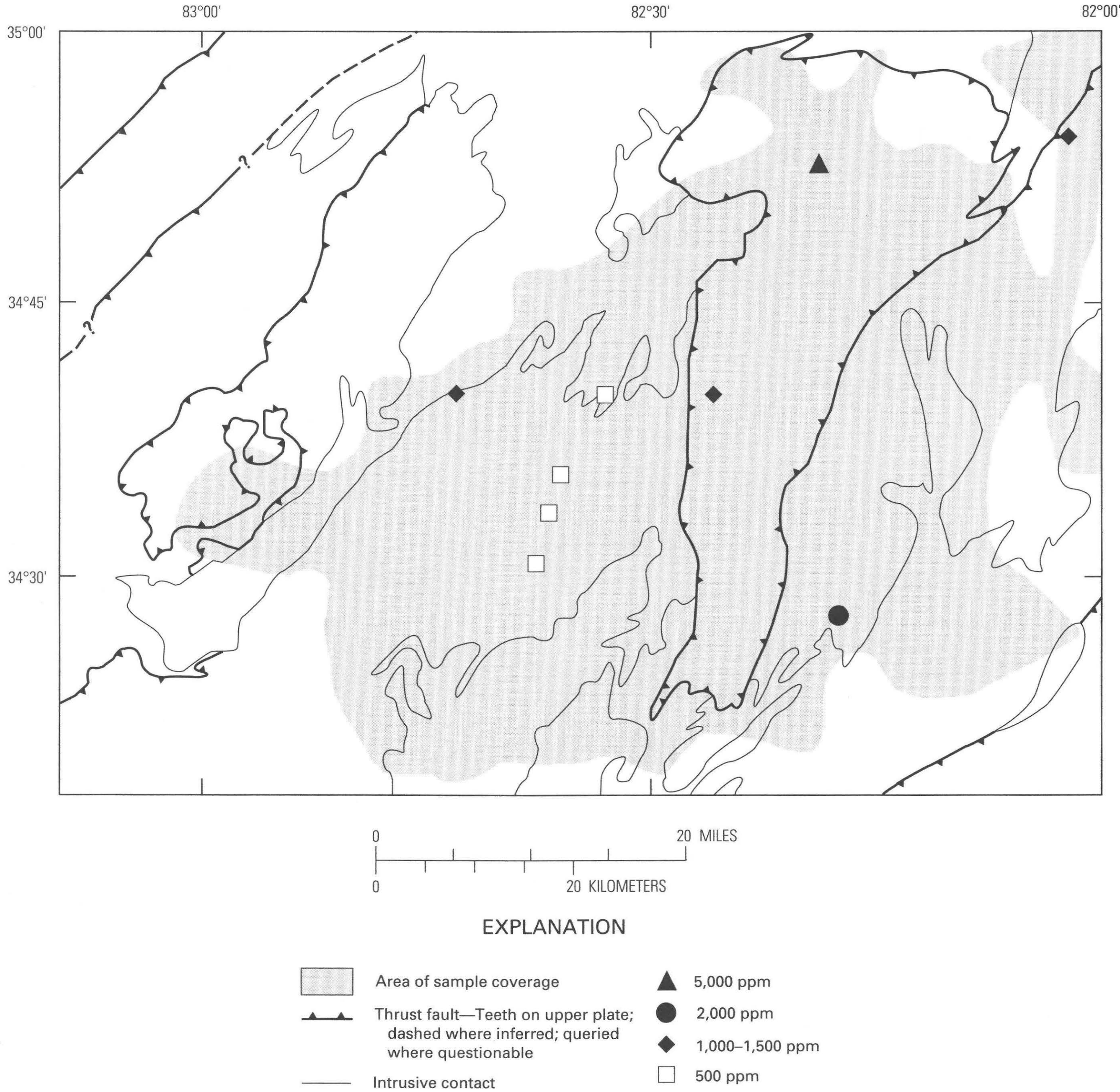

Figure 28. Distribution of zinc in the study area. See figure 3 for names and locations of tectonic features.

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