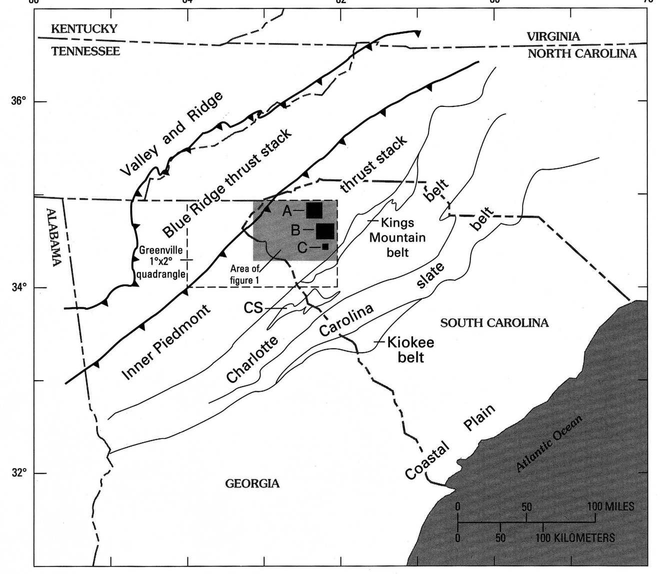
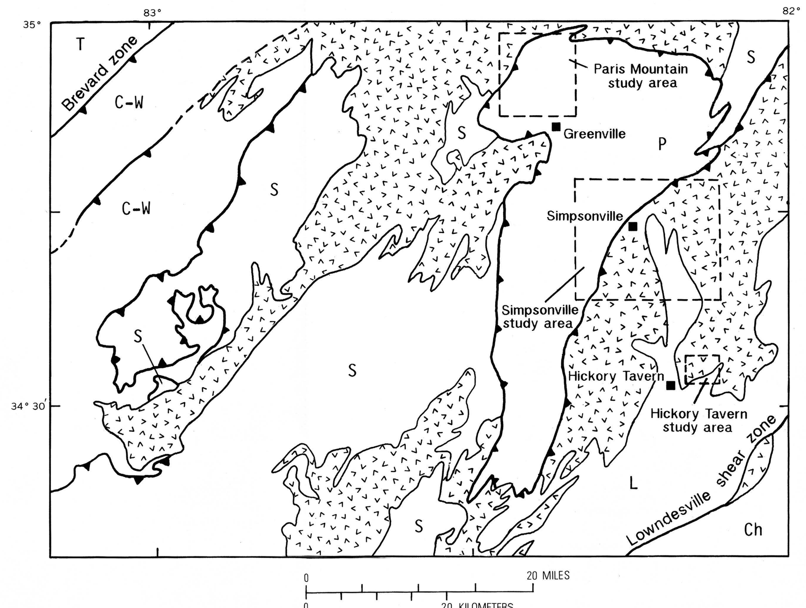


EXPLANATION

Intrusive contact

Thrust fault--Sawteeth on upper plate

Index map showing location and geologic setting of the three study areas (shaded black). A, Paris Mountain study area; B, Simpsonville study area; C, Hickory Tavern study area; CS, Carolina slate belt. The Blue Ridge thrust stack includes the Richard Russell, Young Harris, Helen, and Tallulah Falls thrust sheets. The Inner Piedmont thrust stack includes the Chauga-Walhalla thrust complex and the Six Mile, Paris Mountain, and Laurens thrust sheets. Belts are modified from King (1955), Overstreet and Bell (1965a, b), and Hatcher (1972).



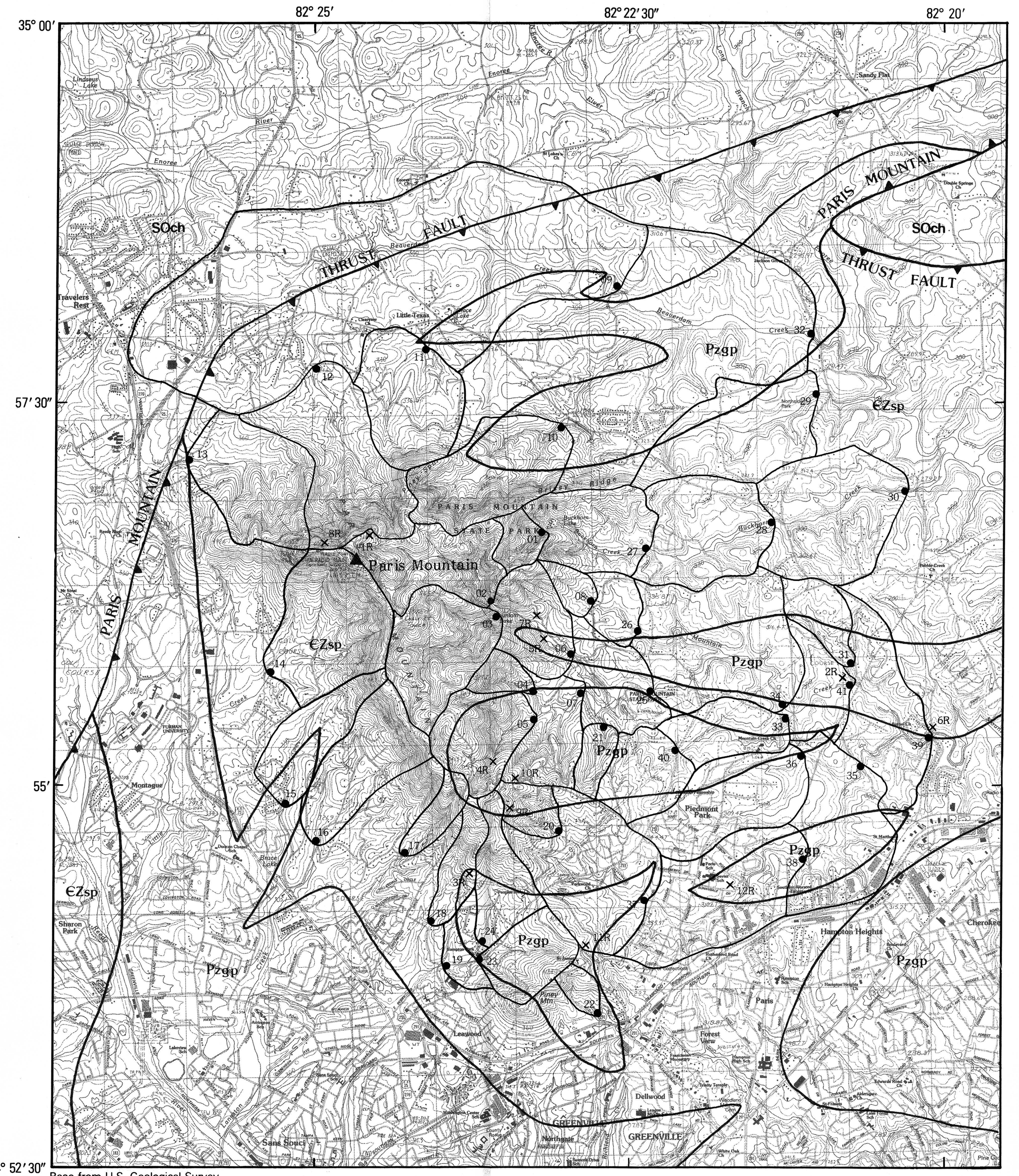
EXPLANATION

Intrusive contact

Thrust fault--Sawteeth on upper plate; dashed where inferred

Granitic rock--Shown only where rock covers a large area or where tectonic boundaries are obscured

Figure 1.--Generalized tectonic map of the northeastern part of the Greenville 1° x 2° quadrangle and boundaries of the three study areas. C-W, Chauga-Walhalla thrust complex; Ch, Charlotte thrust sheet; L, Laurens thrust sheet; P, Paris Mountain thrust sheet; T, Tallulah Falls thrust sheet. Modified from Nelson and others (1987).



EXPLANATION

Contact

Thrust fault--Sawteeth on upper plate

Drainage basin boundary

Heavy-mineral concentrate sample locality

Rock sample locality

SOch Caesars Head Granite (Early Silurian to Ordovician?)--Biotite granitoid gneiss or gneissic granitoid

Pzgp Biotite granite gneiss (Paleozoic)

€Zsp Biotite-muscovite-sillimanite schist (Early Cambrian and (or) Late Proterozoic)

Figure 2.--Heavy-mineral concentrate sample and rock sample localities in the Paris Mountain study area. Generalized geology modified from Nelson and others (1987).

EXPLANATION

Contact--Dashed where inferred

Thrust fault--Sawteeth on upper plate

Drainage basin boundary

Heavy-mineral concentrate sample locality

Dgg Granite gneiss of Gray Court (Devonian)

Pzgf Biotite granite gneiss (Paleozoic)

Pzgp Biotite granite gneiss (Paleozoic)

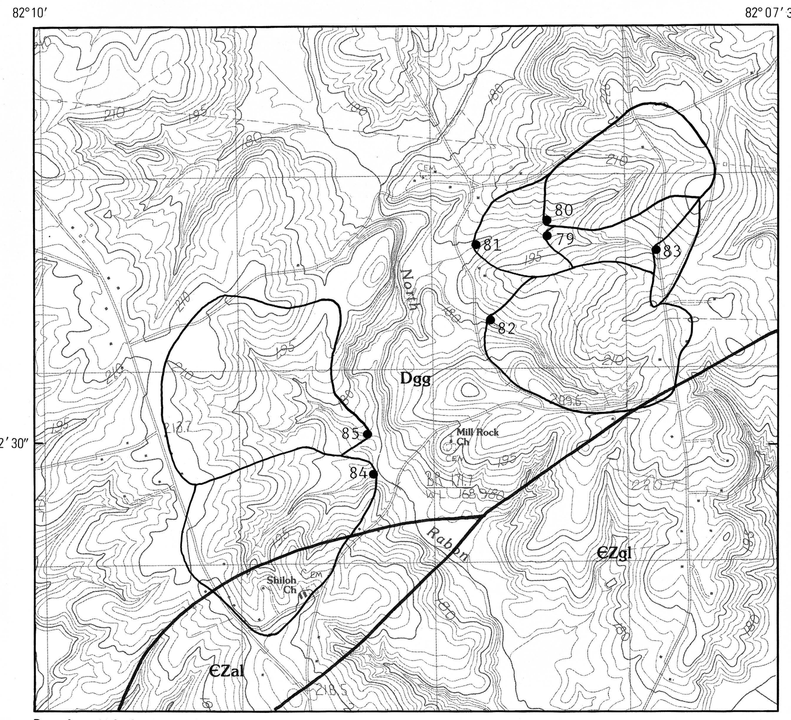
€Zal Amphibolite (Early Cambrian and (or) Late Proterozoic)

€Zgl Biotite gneiss (Early Cambrian and (or) Late Proterozoic)

€Zsl Biotite-sillimanite schist (Early Cambrian and (or) Late Proterozoic)

€Zsp Biotite-muscovite-sillimanite schist (Early Cambrian and (or) Late Proterozoic)

Figure 3.--Heavy-mineral concentrate sample localities in the Simpsonville study area. Generalized geology modified from Nelson and others (1987).



EXPLANATION

Contact

Drainage basin boundary

Heavy-mineral concentrate sample locality

Dgg Granite gneiss of Gray Court (Devonian)

€Zal Amphibolite (Early Cambrian and (or) Late Proterozoic)

€Zgl Biotite gneiss (Early Cambrian and (or) Late Proterozoic)

Figure 4.--Heavy-mineral concentrate sample localities in the Hickory Tavern study area. Generalized geology modified from Nelson and others (1987).

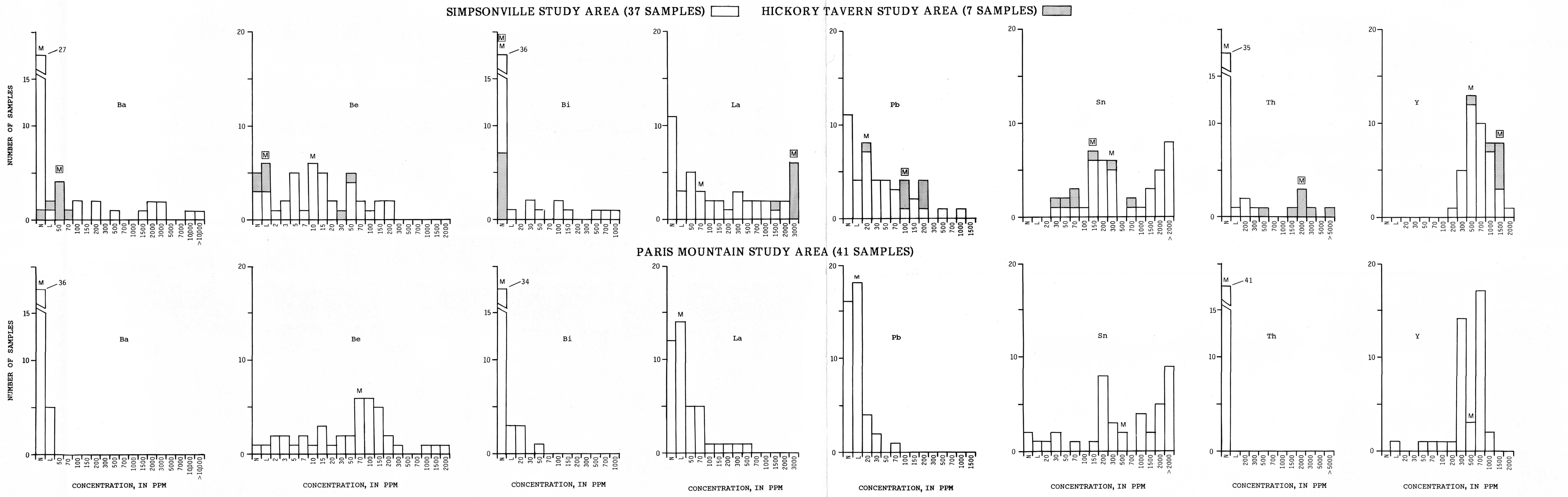


Figure 5.--Histograms showing frequency distributions of selected elements in heavy-mineral concentrate samples. Abbreviations used: N, not detected; L, detected but less than the number value shown in first reporting interval; ppm, parts per million; M, median reporting interval; M, median reporting interval for Hickory Tavern study area.

INTRODUCTION

The purpose of this study is to geochemically evaluate three areas within the Greenville 1° x 2° quadrangle (see index map) that have been shown by previous studies to contain anomalously high amounts of tin. Jackson and Moore (1992) reported the presence of cassiterite (SnO_2)-bearing heavy-mineral concentrates from stream sediment samples that were collected during a regional geochemical reconnaissance of the Greenville 1° x 2° quadrangle. The data reported here confirm anomalously high abundances of tin in the three areas; cassiterite was identified in selected heavy-mineral concentrate samples. In addition, anomalously high concentrations of barium, beryllium, lanthanum, and thorium are also reported for parts of the same areas. No significant mineral deposits are known to occur in the study areas. There was, however, minor production of monazite from several nearby localities (Sloan, 1908), and gold was produced from deposits in the northeastern part of Greenville County and nearby Spartanburg County (McCauley and Butler, 1966).

The three areas selected for resampling are located in the Inner Piedmont physiographic province of South Carolina (see index map). The generalized tectonic setting of the region and the locations of the study areas are shown in figure 1. The northernmost study area, Paris Mountain, is just north of Greenville, S.C. Much of it is within the moderately to steeply sloped terrane of Paris Mountain State Park where elevations reach approximately 600 m. Simpsonville, S.C., is near the center of the second study area, and the southernmost study area is near Hickory Tavern, S.C. Both the Simpsonville and Hickory Tavern study areas are in more gently rolling Piedmont terrane. Each of the sampled areas is drained by tributaries of the Enoree and Reedy Rivers.

Parts of three different thrust sheets underlie the region covered by this study (fig. 1); in ascending structural position, they are the Six Mile, Paris Mountain, and Laurens thrust sheets (Nelson and others, 1987). Nelson (1988, p. 7) described the contacts between these sheets as being along unnamed faults. The rocks in and around the study areas have undergone sillimanite-muscovite-grade metamorphism (Nelson, 1988, p. 9). Nelson (1988, p. 13) reports that the Six Mile thrust sheet was metamorphosed about 365 Ma and that the Laurens and Paris Mountain thrust sheets were metamorphosed about 344 Ma. The geology of these sheets as described in this study, including geologic contacts, rock descriptions, and unit names, generally follows that of Nelson and others (1987, 1989).

Within the Paris Mountain study area, rocks of the Paris Mountain thrust sheet predominate (fig. 2) and consist of a biotite-muscovite-sillimanite schist (€Zsp) that has extensive lenses of fine- to medium-grained biotite granite gneiss (Pzgp). Areas of biotite granite gneiss that occur in the southern part of the Paris Mountain study area contain extensive pegmatitic and leucogranitic phases. These pegmatitic zones consist mostly of coarse-grained microcline feldspar and quartz with minor amounts of muscovite, biotite, and garnet. Smaller pegmatite lenses (<0.5 m thick) that occur within the biotite-muscovite-sillimanite schist of the Paris Mountain study area are generally of similar mineralogy, although some contain tourmaline crystals up to 5 cm in length. The Six Mile thrust sheet underlies the northern edge of the Paris Mountain study area, where it is composed of gneissic biotitic granites of the Caesars Head Granite (figs. 1 and 2).

The northwestern part of the Simpsonville study area (figs. 1 and 3), within the Paris Mountain thrust sheet, is underlain by a biotite-muscovite-sillimanite schist (€Zsp) that contains lenses of biotite granite gneiss (Pzgp). In the southeastern part of the Simpsonville study area, within the Laurens thrust sheet, biotite gneiss (€Zgl), biotite granite gneiss (Pzgf), and minor amphibolite (€Zal) are interlayered. The Hickory Tavern study area contains interlayered biotite gneiss (€Zgl), granite gneiss (Dgg), and amphibolite (€Zal) of the Laurens thrust sheet (fig. 4).

PROCEDURES

Eighty-five pan concentrate stream sediment samples and 12 rock samples were collected by the author and William J. Moore of the U.S. Geological Survey (USGS) in March 1987. Pan concentrate samples were obtained by panning two brimful 16-in. gold pans of sand and gravel collected from the riffles of active streams. The panned materials were further concentrated by heavy-liquid separation using bromoform (specific gravity 2.85) and by magnetic separation using a Frantz isodynamic separator at USGS laboratories in Denver, Colo. High-density, nonmagnetic heavy-mineral concentrates for spectrographic analysis were obtained as a result.

Rock samples were collected by taking chip samples of a single lithology. Where compositional layering or foliation occurred, samples were taken across such features. The rock samples were crushed to approximately 5 to 7 mm in a jaw crusher and then powdered to approximately 140 mesh in a vertical grinder with ceramic plates in USGS laboratories in Reston, Va.

ANALYTICAL TECHNIQUES

The heavy-mineral concentrates were analyzed by using a semiquantitative, six-step, direct-current arc, optical emission spectrographic method (Grimes and Marranzino, 1968). The spectrographic method reports values in percent or parts per million (ppm) as one of six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, 0.15, and multiples of 10 of these numbers); these values are the approximate geometric midpoints of the concentration ranges. The analytical uncertainty of the method is ±1 reporting interval 83 percent of the time and ±2 reporting intervals 96 percent of the time (Matooka and Grimes, 1976). John R. Evans of the U.S. Geological Survey, Reston, Va., identified cassiterite in selected heavy-mineral concentrates by scanning electron microscopy; cassiterite was also identified by X-ray diffraction.

The rock samples were analyzed by using energy-dispersive X-ray fluorescence spectroscopy; the method is described in detail in Jackson and Ayuso (1988) and Evans and Jackson (1989). Our experience has shown the analytical uncertainty of this method to be approximately ±5 percent (at one sigma).

DISCUSSION

The heavy-mineral concentrates collected for this study represent heavy resistate minerals derived from a variety of rock types in the Inner Piedmont physiographic province. The rock samples are representative of the major lithologies around Paris Mountain.

Analytical data for the heavy-mineral concentrates are summarized in table 1 and are given in their entirety in Jackson and others (1992); analytical data for the rock samples are shown in table 2. Histograms depicting frequency distributions for selected elements in heavy-mineral concentrates are shown in figure 5. Distribution plots highlighting drainage basins containing anomalous abundances of Sn, Be, Ba, La, Y, Th, Pb, or Bi in heavy-mineral concentrates are shown in figures 6 to 13. Anomalous thresholds for elements discussed here were determined by visual inspection of the histograms for outlier populations. Samples representing the high end of the normal distributions were included on distribution plots as well, to avoid emphasizing values not truly anomalous.

Because spectrographic analysis required use of the entire sample for many of the heavy-mineral concentrates, a systematic mineralogic analysis was not done. Samples for which a mineralogy split was available were spot checked for cassiterite, monazite, and barite by using a binocular microscope.

Heavy-Mineral Concentrates

Tin was detected in 83 of the heavy-mineral concentrates, and beryllium was detected in 79. In all three sample areas, the highest beryllium values generally correlate with the highest tin values (figs. 6, 8, and 12). Histograms of tin and beryllium abundances (fig. 5) reveal that samples having <1,000 ppm tin and (or) beryllium approach normal distributions, whereas samples containing ≥1,000 ppm may represent separate anomalous populations. The highest tin abundances (>2,000 ppm) are found in samples that were collected on the eastern side of Paris Mountain (fig. 6) and in samples clustered in the northeastern and western parts of the Simpsonville area (fig. 8). Cassiterite was identified by X-ray diffraction and scanning electron microscopy in the 200- to 500-micron size range in selected samples from the Paris Mountain and Simpsonville study areas (figs. 6 and 8, sample nos. 28, 29, 36, 49, 67, 69). Cassiterite occurs as vitreous, translucent, subangular to angular, amber-brown to brown grains. Samples that contain anomalous beryllium (>1,000 ppm) also were collected on the eastern side of Paris Mountain (fig. 6); the highest beryllium concentrations from the Simpsonville study area (100-200 ppm) (fig. 8) may just represent the high end of the normal sample population and may not be anomalous. Samples from the Hickory Tavern study area contain <700 ppm tin and <50 ppm beryllium (fig. 12).

Drainage basins that contain anomalous abundances of tin are underlain by a variety of gneissic lithologies within the Laurens thrust sheet and by schists and granites of the Paris Mountain thrust sheet. A tin-beryllium association similar to that noted in this study has been reported in heavy-mineral concentrates collected near granite plutons in the nearby Charlotte 1° x 2° quadrangle (Griffitts and others, 1990). Overall, the tin values obtained in this study tend to decrease systematically in samples collected downstream from the anomalous occurrences, indicating locally derived sources for the tin.

Detectable lead and bismuth are consistently associated in samples from the Paris Mountain (fig. 7) and Simpsonville (fig. 9) study areas. The highest lead and bismuth concentrations (as much as 1,000 ppm each) are found in samples from the Simpsonville study area, but these samples may only represent the high end of the normal sample population (fig. 5). Samples from the Hickory Tavern study area contain lead concentrations up to 200 ppm; bismuth, however, was not detected in samples from this area. The distribution of lead- and (or) bismuth-bearing samples within the Paris Mountain study area is confined generally to the southern part of the area (fig. 7) where lenses of biotite granite contain extensive pegmatites.

Anomalous concentrations of barium (>1,000 ppm) were seen in samples collected from drainage basins clustered in the eastern part of the Simpsonville study area (fig. 10). These basins are confined in large part to a biotite gneiss unit (€Zgl) occurring there. Samples that contain from 50 to 70 ppm barium are found in the Hickory Tavern study area. Anomalous barium concentrations in heavy-mineral concentrates may indicate the presence of barite ($BaSO_4$). However, because splits of samples containing anomalous barium were not available for mineralogical analysis, barite was not directly identified within the study areas.

In the heavy-mineral concentrates, lanthanum abundances range from the detection threshold of 50 ppm to >2,000 ppm with no apparent break indicative of an anomaly threshold in the population distribution (fig. 5). Samples that contain the highest amounts of lanthanum are from the Hickory Tavern study area (>2,000 ppm, fig. 13) and along the eastern edge of a biotite gneiss unit (€Zgl) in the Simpsonville study area (>1,000 ppm, fig. 11). The rare earth-bearing mineral monazite ((RE,Th) PO_4) is a pervasive constituent of many of the streams of the region (Overstreet and others, 1968) and is a likely source for lanthanum in the heavy-mineral concentrates. Monazite that occurs as small (<1 mm), rounded, yellowish grains was visually identified in selected splits of the heavy-mineral concentrates from the Simpsonville and Hickory Tavern study areas (figs. 11 and 13, sample nos. 46, 48, 53, 79, 82, 84). The large number of samples from the Hickory Tavern study area that contain >2,000 ppm lanthanum suggests that there is more monazite in this study area than in the other study areas. Samples from the Paris Mountain and Simpsonville study areas representing the high end of the normal distribution of lanthanum (as much as 500 ppm and 2,000 ppm, respectively) probably reflect varying, but lesser, abundances of monazite. Anomalous lanthanum values reported from the Hickory Tavern study area are associated with elevated thorium and yttrium values (fig. 13). Monazite is probably also controlling the distribution of yttrium and thorium. Thorium abundances >1,500 ppm in samples from the Hickory Tavern study area may represent an anomalous population, suggesting that monazite from this area is probably enriched in thorium relative to monazite from the other study areas.

Samples that contain detectable concentrations of nickel, copper, cobalt, molybdenum, and tungsten are few and reveal no significant distribution patterns. Consequently, no distribution maps were compiled for these elements. Gold was detected only in two samples (samples 10 and 11) that were collected from adjacent drainage basins within the Paris Mountain study area. No distribution map was compiled for gold. No other precious metals were detected.

Rock Samples

In an effort to identify potential source rocks for anomalous heavy-mineral concentrate values, 12 rock samples from the Paris Mountain study area were analyzed for 14 trace elements (table 2). In general, few of the element abundances vary appreciably from the ranges of values normally expected for these types of rocks (Turekian, 1977). One sample of biotite granite gneiss contains 35 ppm tin. This sample was collected from a drainage basin that contains >2,000 ppm tin and is a likely source rock contributing to anomalous tin contents in the heavy-mineral concentrates from Paris Mountain. However, the rock sampling was neither rigorous enough nor systematic enough to exclude the possibility of other source rocks contributing tin to the heavy-mineral concentrates from the area.

IMPLICATIONS FOR MINERAL RESOURCES

The likelihood of undiscovered mineral occurrences of significant grade and size within the study areas is considered to be minimal for all elements analyzed in this study. The potential for tin, barium, lanthanum, or thorium mineralization within the study areas is probably highest in the drainage basins containing anomalous amounts of those elements. The potential for tin is enhanced by the occurrence of cassiterite in heavy-mineral concentrates from the study areas and for lanthanum by the occurrence of monazite throughout the region. It is possible that some high tin values from heavy-mineral concentrate samples collected around Paris Mountain reflect tin enrichment in the granite bodies there and may warrant furthur investigation. The absence of systematic anomaly distributions for base metals and precious metals in the study areas suggests there is little potential for deposits of these types.

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A GEOCHEMICAL INVESTIGATION OF SELECTED AREAS IN GREENVILLE AND LAURENS COUNTIES, SOUTH CAROLINA—IMPLICATIONS FOR MINERAL RESOURCES

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1992

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