U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Economic heavy minerals in glaciofluvial sediments of Minnesota

by

Gretchen Luepke[1]

Open-File Report 93-345

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[1]U. S. Geological Survey, Menlo Park, California

1993

ABSTRACT

Heavy minerals, ranging in concentrations between 2.2 and 9.2 percent by weight, were examined in samples collected from glaciofluvial sediments of Minnesota. Minerals identified include magnetite, ilmenite, zircon, rutile, scheelite, aluminosilicates (kyanite, andalusite, and sillimanite), pyroboles (pyroxenes and amphiboles) epidote, garnet, sphene, apatite, and tourmaline. The weight percent of the economically important minerals--ilmenite, zircon, rutile, scheelite, and aluminosilicates--constitutes about 0.1 percent in the 6 samples analyzed for this study.

INTRODUCTION

As part of a pilot study, heavy minerals in glaciofluvial sediments from Minnesota (Fig. 1) were analyzed for their economic potential. Funding was provided by the Minnesota Department of Natural Resources, Division of Minerals. I thank Henk Dalhberg, Sherry Nelson, and Dennis Martin of the Minnesota Department of Natural Resources for their help during this study.

Deposits from the Superior and Rainy glacial lobes of late Wisconsin age are represented by the six samples examined in this report (Table 1; Nelson and others, 1992). Bedrock terranes underlying the sample locations include the Penokean Orogen, the Midcontinent Rift System, and the Superior province (Fig. 2).

The Penokean Orogen bedrock map unit is a medium grain equigranular to porphyritic granite of Early Proterozoic age (Southwick and others, 1988). The Midcontinent Rift System bedrock map unit consists of Middle Proterozoic troctolitic and gabbroic rocks of the Duluth and Beaver Bay complexes (Morey and others, 1982). The Superior Province bedrock map unit of Late Archean age is composed of undivided metamorphosed volcanic and sedimentary rocks, including pillowed greenstone, intermediate to felsic tuffaceous rocks, and associated volcaniclastic and epiclastic sedimentary rocks metamorphosed under greenschist-facies conditions (Southwick and others, 1988).

METHODS

A summary of sample descriptions is found in table 1; complete sample descriptions are found in Nelson and others (1992). The heavy-mineral percentages of the samples were calculated from bulk sample volumes using 1.9 g/cc as the average specific gravity of sand/gravel. The six samples taken for this test were chosen because they contained the highest calculated heavy-mineral weight percents in the bulk samples (2.2 to 9.2 percent).

The six samples in this study ranged in grain size from medium gravel to medium sand. Heavy minerals were separated using a combination of Wilfley table, gold-pan, and bromoform (Nelson and others, 1992). The heavy-mineral concentrate was separated into three fractions using a modified Frantz isodynamic magnetic separator. This modified separator, in which the magnetic pole pieces are mounted horizontally, uses a current of 0.25 ampere to remove the strongly magnetic fraction. A current of 1.75 amperes is then used to separate the paramagnetic fraction from the nonmagnetic fraction. These magnetic fractions are the same as would be produced by using a Frantz separator set at a slope of 15 degrees and a tilt of 10 degrees with currents of 0.2 ampere to remove the highly magnetic fraction and 0.6 ampere to separate the other two fractions (Nelson and others, 1992).

Each magnetic fraction was weighed and studied through binocular and petrographic microscopes. Filtered short-wave ultraviolet light was used to detect zircon and scheelite. Selected mineral grains were examined by use of a scanning electron microscope (SEM) and an energy dispersive x-ray analyzer (EDAX). Thin sections of the paramagnetic fraction were point-counted to determine the ratios of clinopyroxene to orthopyroxene, and of pyroxenes to amphiboles, as well as to confirm presence of other mineral species .

Visually estimated percentages of individual mineral species were summed across magnetic fractions and were calculated as percentages of the total heavy minerals in a sample (Luepke and Grosz, 1986). This method does not take into account the different specific gravities of the mineral species; however, the average of specific gravities of all species in each subfraction are generally similar. Therefore, although the calculated percentages are not true weight percentages, the difference is probably insignificant.

RESULTS

Heavy-mineral analyses are found in table 2. Minerals identified include magnetite, ilmenite, scheelite, zircon, rutile, andalusite, kyanite, sillimanite, mica (mainly biotite), garnet, apatite, sphene, tourmaline, pyroboles (pyroxenes and amphiboles), and epidote group minerals. Pyroxenes include clinopyroxene and orthopyroxene (mainly hypersthene). Aegerine-augite was identified in 4 of the 6 samples. The ratio of clinopyroxene to orthopyroxene is approximately 1:1 in all samples, usually with slightly greater amounts of clinopyroxene. Pyroxenes greatly exceed amphiboles (by at least 3:1) in 5 of 6 samples. Amphiboles present are mostly hornblende, including green, blue-green, and brown varieties. The green and blue-green varieties occurred in subequal proportions, with the brown variety the least abundant. Basaltic hornblende was seen in one sample only. Glaucophane was seen in 5 of the 6 samples.

Epidote group minerals include both epidote and clinozoisite. Epidote and blue-green hornblende occur together in some rock fragments. Most tourmaline is brown, but some is blue. One thin section showed a brown tourmaline with blue overgrowth. Sphene and apatite occur in strongly subequal amounts; no immediate explanation for this is available, although a similar relationship has been seen previously in sediments of Saco Bay, Maine (Luepke and Grosz, 1986).

Economic heavy minerals identified include ilmenite, zircon, rutile, scheelite, and the aluminosilicates kyanite, sillimanite, and andalusite. Of these minerals, only ilmenite exceeds 5 percent. The nonmagnetic fraction, in which zircon, rutile, scheelite, and the aluminosilicates comprise the major portion, is invariably the smallest in both weight and volume of the 3 magnetic fractions. This accounts for the scarcity of these minerals as percentages of the total sample.

The highest percentages of the economic heavy minerals belong to sample 23934. Only this sample contained distinctive heavy-minerals layers (Table 1). This sample also contains a ratio of pyroxene to amphibole of nearly 1:1, which further distinguishes it from the other 5 examined samples. The geochemistry for the paramagnetic (0-0.6 amp) and nonmagnetic (>0.6 amp) fractions for the six samples are reproduced here from Nelson and others (1992). All but one sample are geochemically similar; again, the dissimilar sample is 23934.

The sum of the percentages of the economic minerals within the heavy-mineral concentrates (S.G., >2.96) range between 14.8 and 38.6 percent; if these percentages are calculated without including mica and rock fragments, the range becomes 19.7 and 40.5 percent. For comparison, a pilot operation in Sierra Leone showed values of 0.6 percent rutile, 0.8 percent ilmenite, and 0.06 percent zircon (Anonymous, 1989b); these values were considered promising. However, most economic heavy-mineral mining operations show percentages of ilmenite+zircon+rutile between 70 and 80 percent of the heavy-mineral concentrate (e.g., Anonymous, 1989a; Lynd, 1990).

CONCLUSIONS

The weight percentages of the economically important heavy minerals (EHM/T column, Table 2) in the 6 samples examined for this report constitute a range of from 0.05 to 0.1 percent of whole samples or 14.8 to 38.6 percent of the heavy-mineral fraction (EHM/C column, table 2). Ilmenite comprises the largest proportion of these minerals, which also include zircon, rutile, scheelite, and aluminosilicates. Further study is warranted to evaluate the economic potential of glaciofluvial sediments in Minnesota where heavy-mineral concentrates exceed 2 percent of the total sample, based on experience with.heavy-mineral concentrates from beach sediments.

REFERENCES

Anonymous, 1989, The sands of Cooljarloo: Mining Magazine, v. 161 (July 1989), p. 6-7.

Anonymous, 1989, Rotifunk rutile project, Sierra Leone: Mining Magazine, v. 161 (July 1989), p. 9-10.

Luepke, Gretchen and Grosz, A.E., 1986, Distribution of economic heavy minerals in sediments of Saco Bay, Maine: U.S. Geological Survey bulletin 1681. 12 p.

Lynd, L. E., 1990, Titanium: Mining Engineering, v. 42, no. 6, p. 579-580.

Morey, G. B., Sims, P. K., Canon, W. F., Mudrey, M. G., Jr., and Southwick, D. L., 1982, Geologic map of the Lake Superior region--Minnesota, Wisconsin, and northern Michigan, bedrock geology: Minnesota Geological Survey State Map Series S-13, scale 1:1,000,000.

Nelson, S.L., Sutley, S.J., and Tripp, R.B, 1992, Chemical and mineralogical analyses and geological characteristics of heavy minerals from glaciofluvial sediments in Minnesota--test and pilot study data: Minnesota Department of Natural Resources Open-File Report 284, 100 p.

Southwick, D. L., Morey, G. B., and McSwiggen, P. L., 1988, Geologic map (scale 1:250,000) of the Penokean orogen, central Minnesota, and accompanying text: Minnesota Geological Survey Report of Investigations R-37, 25 p., 1 plate.

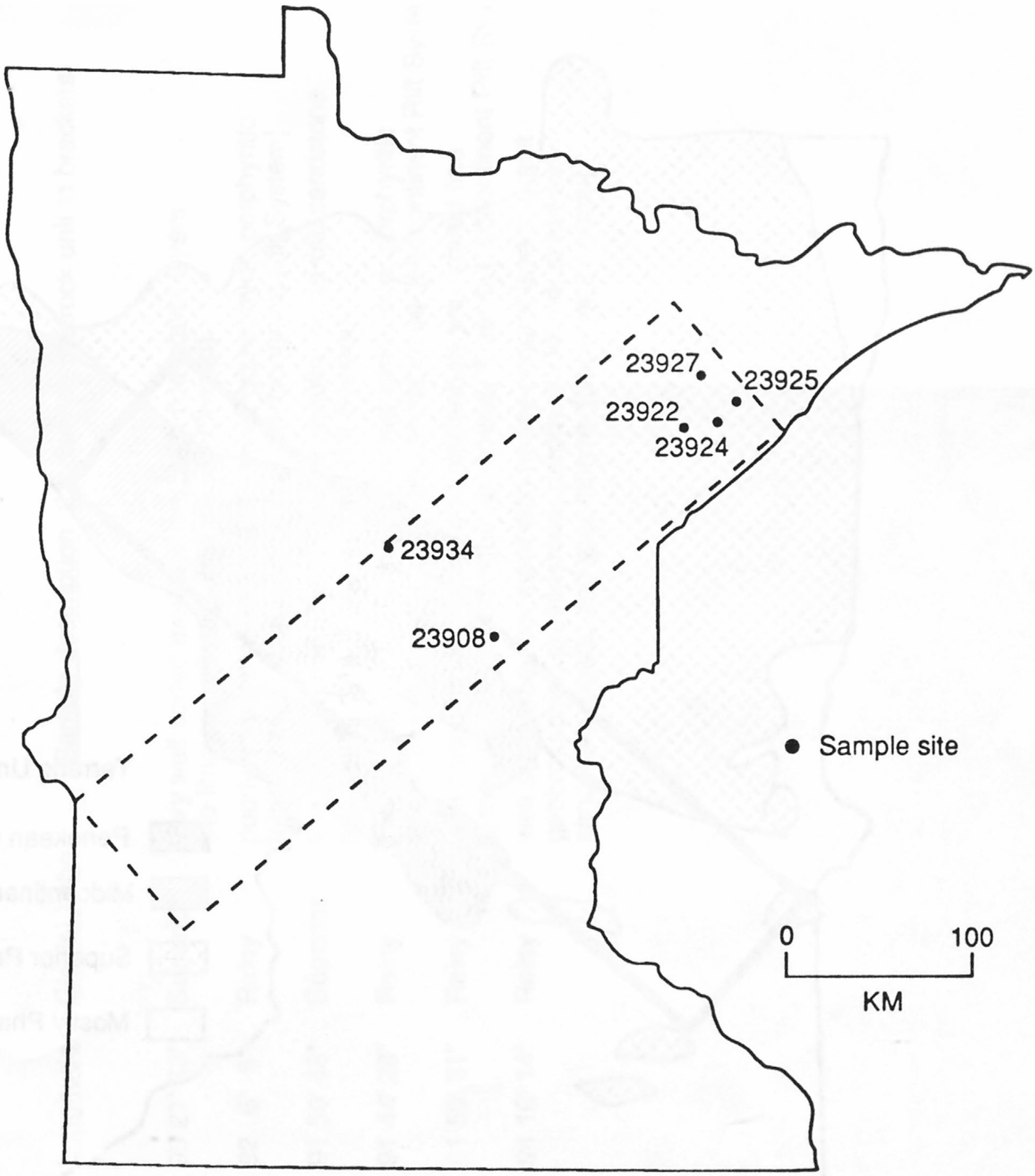

Figure 1. Index map of Minnesota showing sample locations (after Nelson and others, 1992)

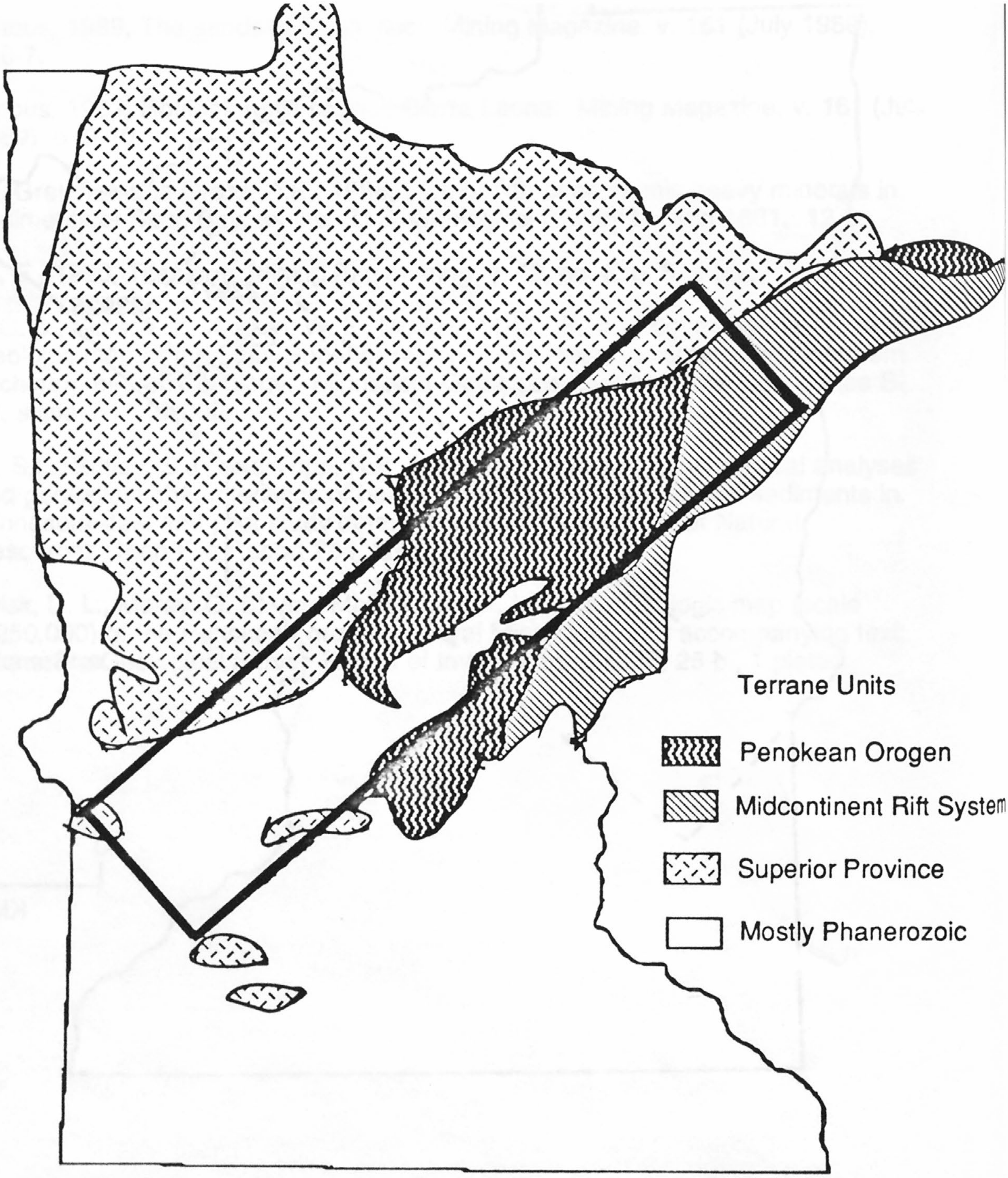

Figure 2. Modified map of Precambrian geologic terranes of Minnesota referred to in this report (After Morey and others, 1982)

Table 1. Summary of sample descriptions (from Nelson and others, 1992)

Sample	Latitude	Longitude	Glacial Lobe	Sample description [Underlying bedrock unit in brackets]
23908	46 11' 4"	93 27' 33"	Superior	very well sorted medium sand with fine gravel layers (no lithologies listed) [Penokean Orogen]
23922	47 13' 27"	92 6' 5"	Rainy	poorly sorted medium to fine gravel; granophyre, porphyritic felsite, basalt, slate, and granite [Midcontinent Rift System]
23924	47 15' 21"	91 50' 48"	Superior	fine pebbly gravel; felsite, basalt, granite, some red sandstone and granophyre [Midcontinent Rift System]
23925	47 21' 55"	91 44' 28"	Rainy	fine gravel; gabbro, granophyre, red sandstone, porphyritic felsite, basalt, granite, slate, and some agate [Midcontinent Rift System]
23927	47 29' 20"	91 59' 31"	Rainy	well sorted medium sand and moderately well sorted fine gravel; basalt, gabbro, granite, gneiss, & felsite [Midcontinent Rift System]
23934	46 37' 15"	94 16' 14"	Rainy	well sorted medium sand with heavy-mineral layers; granite, gabbro, schist, greesnstone, porphyritic felsite, some red sandstone, agate, and granophyre [Superior Province]

Table 2. Heavy-mineral analyses of glaciaofluvial sediments from Minnesota [T, trace amount, <0.1 percent; N, not detected; aluminosilicates=andalusite, kyanite, and sillimanite; pyroboles=pyroxenes and amphiboles; epidote group=epidote and clinozoisite; EHM/C= sum of percentages of economic heavy minerals (ilmenite, zircon, rutile, aluminosilicates, and scheelite) in the heavy-mineral concentrate; EHM/T=weight percentage of economic heavy minerals in the total sample]

Sample	% heavy minerals	Magnetite	Ilmenite	Zircon	Rutile	Alumino-silicates	Scheelite	Pyroboles	Epidote group	Garnet	Sphene	Apatite	Tourmaline	Mica	Rock fragments	EHM/C	EHM/T
23908	2.8	4.4	23.9	0.4	0.1	0.3	T	42.2	5.4	2.3	0.3	0.9	0.1	2.4	17.2	24.8	0.1
23922	2.2	5.7	13.8	0.1	T	0.9	N	45.6	7.9	0.1	0.1	0.1	T	2.4	23.2	14.8	0.05
23924	2.9	0.5	20.9	0.2	T	0.1	T	33.7	4.8	1.3	0.1	0.1	T	0.8	37.5	21.2	0.07
23925	2.2	4.0	18.4	0.2	T	0.1	T	38.6	11.0	0.7	0.1	0.1	T	0.8	26.0	18.7	0.08
23927	3.3	4.6	15.4	0.3	T	0.4	T	38.5	20.2	2.5	0.2	0.2	N	1.0	16.6	16.2	0.1
23934	9.2	28.9	32.1	5.0	0.5	1.1	T	10.2	7.6	5.9	2.8	1.4	T	1.1	3.3	38.6	0.1

Table 3. Geochemical analyses for paramagnetic (0-0.6 Amp) fraction of glaciofluvial samples from Minnesota (from Nelson and others, 1992)

Element	23908	23922	23924	23925	23927	23934
Ca (%)	2	3	3	2	2	0.5
Fe	10	10	10	15	10	20
Mag	7	7	10	7	10	1.5
Na	0.5L	0.5L	0.5L	0.5L	0.5L	0.5N
Ti	2	2	2	2	2	2G
B (ppm)	50	20L	50	20	20	30
Ba	100	100	150	100	70	70
Co	70	70	100	70	100	50
Cr	300	300	300	200	200	500
Cu	50	70	70	30	30	50
Ga	10	10	10	10	10	10
La	100L	100N	100N	100N	100N	200
Mn	5000	5000	5000	3000	5000	5000
Nb	50L	50N	50	50L	50L	50
Ni	100	150	150	150	200	50
Pb	20	20N	20L	20N	20N	50
Sc	30	30	30	30	20	20
Sr	200L	200N	200N	200L	200	200N
V	200	200	200	200	200	300
Y	50	50	70	50	50	100
Zr	150	150	150	100	100	150

Elements not detected at limits: Ag, Be, Mo, Sn, Th (see Table 4)

L=below limits of detection; N=Not detected at limit

Table 4. Geochemical analyses for the nonmagnetic (>0.6 amp) fraction of glaciofluvial samples from Minnesota (from Nelson and others, 1992)

Element	23908	23922	23924	23925	23927	23934
Ca (%)	20	50	30	30	20	20
Fe	0.2	0.3	0.3	0.2	0.2	0.2
Mg	0.5	0.5	0.7	0.7	0.2	0.2
Na	0.5L	0.5	0.5L	0.5L	0.5L	0.5N
P	20	20	20	20	20	10
Ti	2G	2G	2G	2G	2G	2G
B (ppm)	100	50	150	30	50	50
Ba	200	150	200	150	150	150
Be	2L	2N	2N	2N	2N	2N
Cr	200	150	200	200	200	300
Cu	100	10	15	10L	10	10N
Ga	10	30	15	15	20	20
La	300	500	500	500	500	300
Mn	1000	500	500	500	500	300
Nb	50L	50N	50L	50L	50L	50N
Pb	70	5000	70	70	100	100
Sc	20	10	20	10	10	50
Sn	300	150	100	100	20	150
Sr	500	300	200	300	200	200
V	100	100	100	100	150	100
Y	500	500	500	500	500	500
Zr	2000G	2000G	2000G	2000G	2000G	2000G

Not detected at limits: Ag, As, Au, Bi, Co, Mo, Ni, Sb, Th, W, Zn (see Table 4)

L=below limits of detection; G=greater than limit of detection; N=not detected at limit.

Table 5. Lower limits of determination for the spectrographic analysis of the heavy-mineral-concentrate samples, based on a 5 -mg subsample (from Nelson and others, 1992)

Element	Lower Limit
	Percent
Ca	0.1
Fe	0.1
Mg	0.05
Na	0.5
P	0.5
Ti	0.005
	Parts per million
Ag	1
As	500
Au	20
B	20
Ba	50
Be	2
Bi	20
Cd	50
Co	20
Cr	20
Cu	10
Ga	10
Ge	20
La	100
Mn	20
Mo	10
Nb	50
Ni	10
Pb	20
Sb	200
Sc	10
Sn	20
Sr	200
Th	200
V	20
W	50
Y	20
Zn	500
Zr	20