U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Sand-sized heavy-mineral distributions in the Rio Cibuco system and adjacent rivers of north-central Puerto Rico

by

Gretchen Luepke[1] and Lawrence J. Poppe[2]

Open-File Report 92-703

[1]U. S. Geological Survey, Menlo Park, California
[2]U. S. Geological Survey, Woods Hole, Massachusetts

1993

Table of Contents Page

List of figures

List of Tables

ABSTRACT

Heavy-mineral concentrations average 11.9 percent in the sand-sized fraction of rivers from north central Puerto Rico. Minerals identified include magnetite, ilmenite, pyroboles (pyroxenes plus amphiboles), epidote, sphene, garnet, rutile, apatite, hematite, and tourmaline. Monazite was not detected. No gold, tantalum, or uranium was detected in any sample. Silver was detected in one sample, tin in 13, and copper in all samples.

INTRODUCTION

This report describes the heavy minerals of the sand-sized fraction (2.0-0.062 mm) of sediment from selected rivers in north-central Puerto Rico and complements a mineralogical study of the silt-sized fraction (< 0.062 mm) from these same samples (Poppe and others, in press). Previous studies of heavy minerals in Puerto Rico have focused only on the sand-sized fraction and include a reconnaissance study of beach sands (Guillou and Glass, 1957), and studies of the Río de la Plata (Bush and others, 1988), the Río Grande de Manati (Grossman, 1978), and the north coast of Puerto Rico in general (Lincoln, 1981; Pilkey and Lincoln, 1984).

Puerto Rico, the smallest and easternmost island of the Greater Antilles, can be divided into an Early Cretaceous-Eocene volcanic-plutonic terrane and an Oligocene-Miocene carbonate terrane (Weaver, 1964; Fig. 1). The volcanic-plutonic terrane forms an east-west mountain range (the Central Cordillera) composed mainly of volcanic tuffs, volcanic breccias, and andesitic and basaltic lavas of the Los Negros, Avispa, Pozas, and Perchas formations (Berryhill, 1965; Nelson, 1967; Cox and Briggs, 1973). The Los Negros Formation in particular is rich in clinopyroxene (Nelson, 1967). Associated with these volcanic deposits are intrusive igneous rocks, mostly granodiorites and hornblende-rich quartz diorites. Secondary mineralization associated with vein deposits of hydrothermal origin is also common.

The carbonate terrane rests on the flanks of the volcanic-plutonic terrane and displays spectacular karst topography along the northern coast (Monroe, 1976). This terrane is composed mainly of limestones and minor clastics of the Cibao Formation, Lares Limestone, and Mucarabones Sand (Nelson, 1967; Monroe, 1973).

The island's rainfall is controlled by moisture-laden cloud systems driven by northeast trade winds into the higher elevations of the Central Cordillera (Ehlmann, 1968; Bush and others, 1988). Because most of the precipitation falls on the northern side of the mountains, most of the major rivers of the island head in the Central Cordillera and drain to the north. The upstream portions of the Río Cibuco, Río de la Plata, and Río Grande de Manati, like many of the northward-flowing rivers (Weaver, 1958), are actively cutting into the Central Cordillera.

METHODS

Twenty-five river samples were collected from the banks of the Río de la Plata, Río Grande de Manati, and rivers of the Río Cibuco system (Fig. 1). As in a previous study of the sand fraction of the Río de la Plata (Bush and others, 1988), particular emphasis was placed on taking samples at points where placer-mineral accumulations were likely to occur--for example, at upstream ends of point bars and at channel bars located just downstream from rapids. The samples are texturally representative of the fluvial bedload at these sites; no field processing, such as sieving of gravel or pan-concentrating of heavy minerals, was attempted.

Processing these samples followed a modification of the procedure established by Luepke and Grosz (1986). Large samples were taken to reduce possible particle-sparsity biases that can result when a limited number of grains significantly influences the concentration of an economically important mineral species (see Clifton and others, 1969). The samples' sand-sized (2.0-0.062 mm) fractions, separated from gravel- and silt-sized material by sieving, ranged in weight from 100 to 900 grams.

The heavy minerals were separated from one entire sample (Sample 11) in tetrabromoethane (S.G., 2.96), but the larger volumes of the other 24 samples required different treatment. A raw split from each sample was separated in tetrabromoethane and the percentage of heavy minerals determined. The remaining sample was pan-concentrated in tap water by Norman M. Maher. The pan-concentrate was then separated in tetrabromoethane to collect the heavy minerals.

To check the efficiency of the pan-concentrating process, a representative split from the air-dried overwash of six selected samples, including those containing the lowest and highest weight percentages of heavy minerals in the raw split, were separated in tetrabromoethane. A comparison, using the general-purpose statistical software program MINITAB, of the heavy-mineral percentages obtained from the raw splits with that from the overwash splits of the 6 samples, yielded a regression equation of

$$y = -0.966 + 0.769x$$

where x=percentage from the raw split, and y=percentage from the overwash split. This formula was used to calculate the weight of heavy minerals remaining in the overwash of the other 18 samples. When the total weight of heavy minerals from all splits was divided by total weight of whole sample, the calculated heavy-mineral percentages correlated strongly ($r^2=0.986$) with the percentages as determined from the raw splits. The calculated percentages are therefore considered accurate within.2 percent and are used in Table 1.

The heavy-mineral percentages of the overwash samples were, as expected, lower than, and directly proportional to the concentration of heavy minerals in the raw splits. This is in contrast to an overall 5 percent by weight of heavy minerals not recovered by the wet-milling process of the Humphrey's spiral, regardless of the initial concentration of heavy minerals (Luepke and Grosz, 1986). The heavy-mineral species separated from the overwash were pyroboles, epidote, and altered grains, which are lighter heavy minerals (S.G.<3.5). It has long been known that the panning process tends to eliminate the lighter heavy minerals from the final panned concentrate (Smithson, 1930).

Heavy-mineral concentrates obtained from the raw splits and pan-concentrates were combined for each sample. After removal of the highly magnetic (HMAG) fraction with a hand magnet, the remainder of the sample was divided with a Frantz isodynamic separator into three paramagnetic fractions (0-0.5, 0.5-0.75, and >0.75 ampere) with 15-degrees forward and 25-degree side slopes. Microsplits of all paramagnetic samples containing sufficient sample volume were made for geochemical analysis. These analyses were performed at the U.S. Geological Survey analytical laboratories in Denver, Colorado, using optical spectroscopy and a modified inductively-coupled semi-quantitative process (Lichte and others, 1987).

Each magnetic fraction was weighed and studied under binocular and petrographic microscopes. The visual scanning method (Luepke and Grosz, 1986) provides an approximate weight percent of each mineral species. In addition, long-wave and unfiltered short-wave ultraviolet illumination were used to detect zircon and monazite, respectively. Selected mineral grains were examined by use of a scanning electron microscope (SEM) and an energy dispersive X-ray analyzer (EDAX).

RESULTS

Mineralogical results are shown in Table 1. The calculated total heavy-mineral percentages of the sand-sized fraction among the samples average 11.9 and range from 2.9 to 28.2. Minerals identified include magnetite, ilmenite, chromite, pyroboles (pyroxenes plus amphiboles), epidote, sphene, zircon, garnet, rutile, apatite, hematite, and tourmaline. Limonitic weathering is present in most samples, giving an overall rust-colored cast especially to samples 3, 10, and 20 (Río Mavilla), 22 (Río Cibuco), and 25 (Río Morovis).

Except in the Río Morovis, where magnetite is most abundant, the dominant heavy minerals in the rivers are the pyroboles. Amphiboles are dominantly green and blue-green hornblende; pyroxenes are mostly clinopyroxene, with minor orthopyroxene. Amphiboles are more abundant than pyroxenes in samples from the Ríos Mavilla, Morovis, and Manati; in the other rivers the amounts are subequal. Altered grains average 22.5 percent in all samples. Epidote percentages include some clinozoisite.

Magnetite is the mineral with the most variable abundance among the river samples, ranging from 2.4 percent in the Río Unibon to over 60 percent in the Río Morovis. Based on geochemical analyses (tables 2 and 3), much of the magnetite is probably titanomagnetite. Ilmenite abundances range up to 19.3 percent; this maximum value is also from the Río Morovis sample. Differentiating between ilmenite and chromite grains commonly is difficult. However, geochemical data show that chromite is probably present only as a trace mineral (<0.5 percent).

Except the Rio de la Plata, sphene is present in all rivers in amounts up to 2 percent. As much as 0.6 percent zircon occurs in the Río Morovis, but none to trace amounts occur in all other rivers. Garnet, rutile, apatite, hematite, and tourmaline are present only in trace amounts.

Geochemical results are presented in Table 2. The geochemical procedure used in the analysis did not permit screening for the elements boron, germanium, tungsten, and zirconium. Values for gold, bismuth, tantalum, and uranium were below the limits of detection in all samples. Statistical values for each paramagnetic fraction are given in Table 3. Means, variances, and standard deviations for elements appearing in only a few samples of a given paramagnetic fraction (arsenic, cadmium, europium, holmium, tin, and thorium) are omitted.

Elements present in amounts generally exceeding 1000 ppm include chromium, manganese, and vanadium. Sample 28 (Río Dos Bocas) contains the maximum concentration of chromium, sample 12 (Río Indio) for manganese, and sample 8 for vanadium (Río Cibuco).

Cadmium is present in 21 samples, arsenic in 11. Both arsenic and cadmium are mostly likely to show up in the 0.5-0.75 ampere fractions of a sample. Tin, which is present in 13 samples, is equally likely to show up in the HMAG and in the >0.75 ampere fraction. Eight samples contained copper in amounts exceeding 100 ppm; sample 24 (Río de la Plata) contains the maximum values of copper in all paramagnetic fraction (see Tables 2 and 3).

Two samples show the most anomalous elemental concentrations in the >0.75 ampere fraction--sample 26 (Río Morovis) and sample 18 (Río Mavilla). Sample 26 shows the maximum concentrations for barium, cerium, lanthanum, lead, molybdenum, niobium, neodymium, thorium, yttrium, and ytterbium (see Tables 2 and 3) and is the only sample to show a detectable concentration of holmium. Sample 18 contains higher than average concentrations of cerium, lanthanum, lead, niobium, neodymium, yttrium, and ytterbium, and is the only sample to show a detectable concentration of silver.

Both samples 18 and 26 contain measurable amounts of europium, sample 26 containing the maximum; only two other samples [samples 11 (Río Cibuco) and 12 (Río Indio)] also contain measurable europium. Measurable amounts of both europium and holmium correlate with values of yttrium exceeding 85 ppm.

DISCUSSION

Prolonged rainfall and intermittent dry seasons under the tropical conditions of north-central Puerto Rico are conducive to lateritic weathering of the mafic source terrane (including the granitic stocks) underlying the highland areas near the island divide. Because of these lateritic conditions, the exposed bedrock in the study area and elsewhere along the Central Cordillera (Weaver, 1958) is weathered to a yellowish brown. Laterization concentrates silicon, iron, aluminum, and titanium (Allen, 1948); SEM examination of altered grains in the sand-sized fraction show compositions mainly of silicon, iron and aluminum, plus small amounts of calcium and magnesium. This is evidence that most of the altered grains probably originated as pyroxenes, amphiboles, or epidote. Furthermore, garnet is found in only trace amounts in the sand-sized fraction, whereas it averages around 24 percent of the silt-sized heavy-mineral fraction (Poppe and others, in press). This difference is probably also due to the effects of laterized weathering.

Guillou and Glass (1957) examined the geochemistry of many minerals in Puerto Rico beach sands and reached the following conclusions: niobium is always present in sphene; any nickel present is mostly in magnetite; vanadium is present in magnetite, hematite, ilmenite, and sphene. The study also concluded that cobalt, copper and scandium are not sufficiently concentrated in any mineral to serve as an index for that mineral, and he source of molybdenum, tin, lead, zinc, yttrium, and lanthanum are problematical.

Sample 28 from the Río Dos Bocas contains the largest concentration of chromium; chromium also exceeds 1 percent of the silt heavy-mineral fraction of this sample (Poppe and others, in press). Chromium also occurs within magnetite (Guillou and Glass, 1957), which accounts for the high concentrations in the HMAG fractions of the present study. However, chromium values in the >0.75 amp fraction are most commonly the second highest concentrations, with 6 samples showing values equal or greater than values in the HMAG fraction. Chromium must therefore be present in minerals other than chromite and magnetite. Analyses of one sample from SEM observations showed some pyroxene grains contain small amounts of chromium. Samples 25 and 26 (Río Morovis), which show chromium concentrations generally less than 1000 ppm (Table 2), also contain the lowest pyrobole percentages (Table 1). It is unclear whether high percentages of pyroboles within a sample invariably account for relatively high chromium concentrations in the >0.75 ampere fraction.

Only Sample 18 (Río Mavilla) contains a detectable amount of silver. Silver in the form of cerargyrite grains is, however, present in the silt-sized fraction of 19 of the 25 samples, evidence that this element may be mobilized and removed from the source rocks in the dissolved state and therefore not generally represented in the sand-sized fraction of fluvial sediments (Poppe and others, in press). Although copper is detected in all paramagnetic fractions of the sand-sized heavy minerals, no specific copper minerals were visually identified in the sand fraction, nor were they detected in the silt-sized fraction (Poppe and others, in press). Copper minerals, if present, may therefore be confined to the sand-sized fraction.

Monazite has been reported in concentrations as high as 9 percent of the sand-sized heavy-mineral fraction in samples from the Río de la Plata and Río Cibuco (Pilkey and Lincoln, 1984; Bush and others, 1988) Although two samples, both from tributaries of the Río Cibuco, show anomalously high concentrations of rare-earth elements (cerium, lanthanum, neodymium, and thorium), which could indicate the presence of monazite, phosphorus percentages (average 0.07-0.09) are very low in all samples from this study. The presence of monazite in greater than trace amounts (>0.5 percent) cannot be substantiated from this report.

CONCLUSIONS

Heavy-mineral concentrations are high in river sediments of north-central Puerto Rico, averaging 11.9 percent of the sand-sized fraction. The sand-sized heavy-mineral suite from nearly all rivers is dominated by pyroboles (pyroxenes plus amphiboles), altered grains, and epidote; magnetite dominates the Río Morovis samples. Garnet is present in only trace amounts in the sand-sized fraction. These mineralogies reflect the extensive outcrops of clinopyroxene-rich basaltic tuffs and localized hornblende-bearing quartz diorites of the Early Cretaceous-Eocene volcanic plutonic terrane, into which the rivers head. Epidote indicates widespread hydrothermal alteration within the source rocks. The abundance of altered grains (average 22.5 percent) and rarity (<0.5 percent) of sand-sized garnets reflect the effects of laterization.

Economically important heavy minerals include ilmenite, chromite, zircon, and rutile. Of these, only ilmenite is present in greater than trace amounts (0.5 percent) and is most common in the Río Morovis and Río Grande de Manati. Zircon occurs in greater than trace amounts only in the Río Morovis. Monazite was not detected. Among the more important economic elements, no gold, tantalum, or uranium was detected in any sample; silver was detected only in sample 18 (Río Mavilla). Copper, present in all samples, was detected in concentrations greater than 100 ppm in all paramagnetic fractions only in Sample 24 (Río de la Plata). Tin was detected in 13 samples and above 100 ppm in samples 4 (Río Cibuco), 19 (Río Mavilla), and 16 (Río Grande de Manati). Anomalously high concentrations of rare-earth elements (cerium, lanthanum, niobium, neodymium, thorium, yttrium, and ytterbium) are present in Sample 26 (Río Morovis) and 18 (Río Mavilla).

REFERENCES

Allen, V. T., 1948, Formation of bauxite from basaltic rocks of Oregon: Economic Geology, v. 43, p. 619-625.

Berryhill, H. I., 1965, Geology of the Ciales Quadrangle, Puerto Rico: U. S. Geological Survey Bulletin 1184, 116 p.

Bush, D. M., Hyman, L., and Priddy , R., 1988, Heavy mineral resource potential--Río de la Plata, Puerto Rico: Report to the Puerto Rico Department of Natural Resources, Duke University, Durham, North Carolina, 128 p.

Clifton, H. E., Hunter, R. E., Swanson, F. J., and Phillips, R. L., 1969, Sample size and meaningful gold analysis: U. S. Geological Survey Professional Paper 625-C, 17 p.

Cox, D. P. and Briggs, R. P., 1973, Metallogenic map of Puerto Rico: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-721, 7 p. Map scale 1:240,000.

Ehlmann, E. J., 1968, Clay mineralogy of weathered products and of river sediments, Puerto Rico: Journal of Sedimentary Petrology, v. 38, no. 3, p. 885-894.

Grossman, Z. N., 1978, Distribution and dispersal of Manati river sediments--Puerto Rico north insular shelf: Unpublished. M.S. thesis, Duke University, Durham, North Carolina, 72 p.

Guillou, R. B. and Glass, J. J., 1957, A reconnaissance study of the beach sands of Puerto Rico: U. S. Geological Survey Bulletin 1042-I, p. 272-305.

Lichte, F. E., Golightly, D. W., and Lamothe, P. J., 1987, Inductively-coupled plasma-atomic emission spectrometry, In Baedecker, P. A., ed., Methods for geochemical analysis, U. S. Geological Survey Bulletin 1770, Chapter B, p. B1-B10.

Lincoln, R. B., 1981, Heavy mineral distribution in fluvial and marine environments--north coast of Puerto Rico: Unpublished. M.S. thesis, Duke University, Durham, North Carolina, 101 p.

Luepke, Gretchen and Grosz, A. E., 1986, Economic heavy mineral deposits of Saco Bay, Maine: U.S. Geological Survey Bulletin 1681, 12 p.

Monroe, W. H., 1973, Stratigraphy and petroleum possibilities of middle Tertiary rocks in Puerto Rico: American Association of Petroleum Geologists Bulletin, v. 57, no. 6, p. 1086-1099.

Monroe, W. H., 1976, The karst landforms of Puerto Rico: U. S. Geological Survey Professional Paper 899, 69 p.

Nelson, A. E., 1967, Geologic map of the Corozal Quadrangle, Puerto Rico: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-473. Scale 1:20,000.

Pilkey, O. H. and Lincoln, R. B., 1984, Insular shelf heavy mineral partitioning--northern Puerto Rico: Marine Mining, v. 4, no. 4, p. 403-414.

Poppe, L. J., Commeau, J. A., and Luepke, Gretchen, in press, Silt heavy-mineral distributions in the Rio Cibuco system and adjacent rivers of north-central Puerto Rico: NAMRAP atlas of Puerto Rico.

Smithson, Frank, 1930, The reliability of frequency-estimations of heavy mineral suites: Geological Magazine, v. 67, p. 134-136.

Thomas, C. P., 1979, A minicomputer-based emission spectrographic analysis system dependent on scanning microphotometry: Applied Spectroscopy, v. 33, no. 6, p. 604-612.

Weaver, J. D., 1958, Utado Pluton, Puerto Rico: Geological Society of America Bulletin, v. 69, no. 9, p. 1125-1141.

Weaver, J. D., 1964, Guidebook for a field trip in Puerto Rico, 22-24 November, 1964: Mayaguez, University of Puerto Rico, 40 p.

Figure 1. Map showing the locations of river samples (solid circles) from north-central Puerto Rico. The dashed line separates rocks of the volcanic-plutonic terrane (south) from the limestone terrane (north). Major intrusives (the Ciales and Morovis granodiorite stocks and a quartz diorite to the east) are shown as stippled areas. Inset shows location of study area on the island of Puerto Rico.

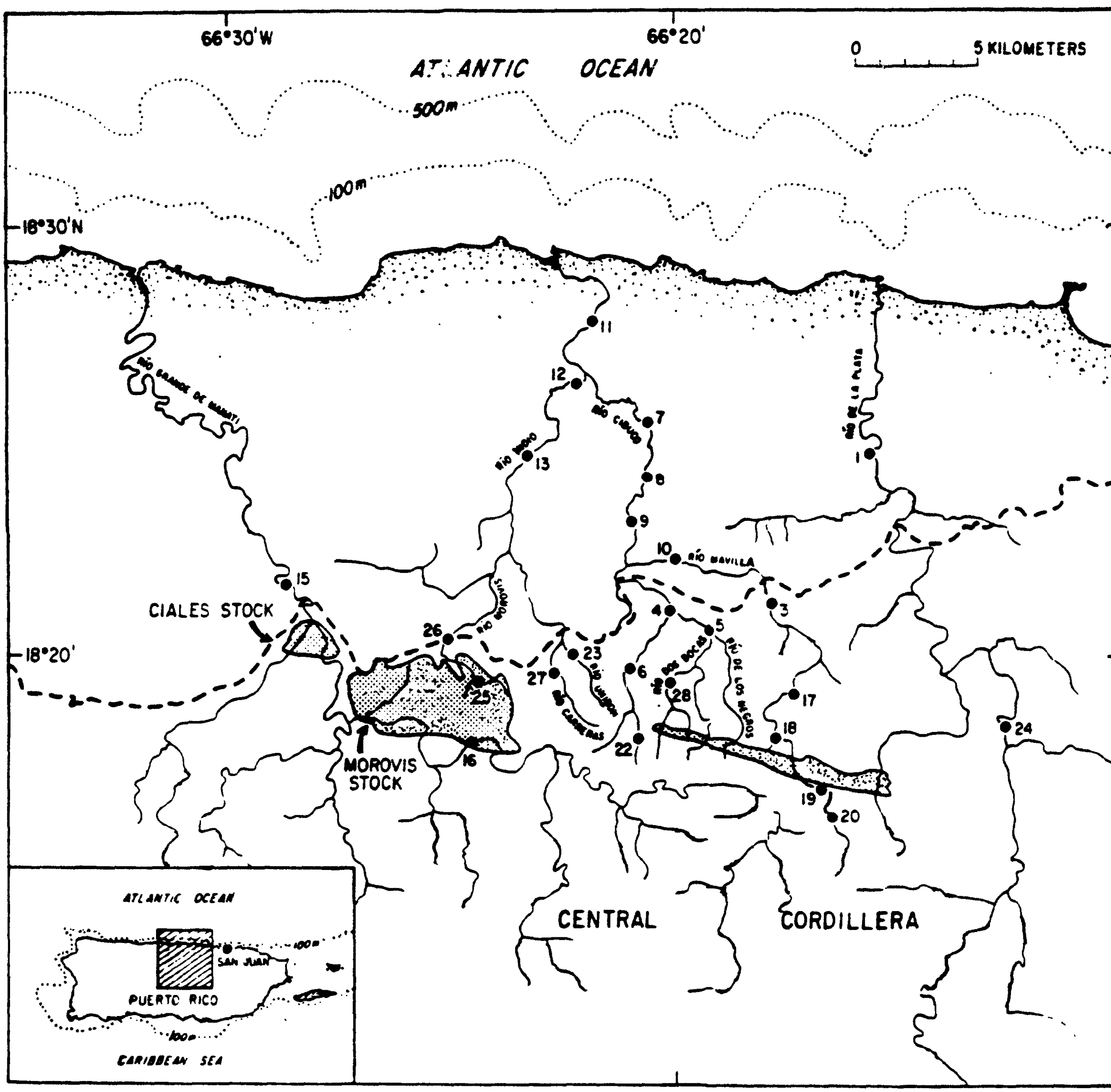

Table 1. Heavy-mineral analyses of the sand-sized fraction (2.0-0.062 mm) of river samples from north-central Puerto Rico [Pyroboles=pyroxenes + amphiboles; altered grains include rock fragments; trace minerals constitute <0.5 percent; --, mineral not detected, value or not calculated because results would be statistically meaningless]

Sample	% Heavy Minerals*	Magnetite	Ilmenite	Pyroboles	Altered Grains	Epidote	Sphene	Zircon	Trace minerals*
Rio de la Plata									
1	13.7	16.7	5.8	40.8	24.3	12.4	- -	- -	garnet
24	4.6	27.8	5.8	34.9	21.2	10.3	- -	- -	garnet, rutile
Rio Cibuco									
4	13.1	25.9	9.4	32.1	20.6	10.5	1.3	trace	- -
6	13.1	9.6	7.2	43.0	25.2	12.9	2.0	- -	garnet
7	14.5	20.8	10.8	32.0	21.1	13.5	1.8	- -	- -
8	14.1	27.9	8.7	30.3	21.7	10.1	1.1	trace	rutile
9	13.1	8.8	10.5	34.6	33.9	11.5	0.6	- -	rutile
11	9.1	16.4	9.9	32.4	25.5	15.1	trace	trace	garnet, rutile
22	5.7	41.9	5.5	20.1	25.9	6.3	trace	- -	- -
Rio Mavilla									
3	18.5	25.4	10.3	27.9	23.2	13.0	trace	- -	garnet, rutile
10	9.5	13.1	10.6	34.1	25.4	16.3	trace	trace	garnet, rutile, apatite
17	23.9	13.2	9.4	32.2	31.2	13.3	trace	trace	rutile, hematite
18	21.3	28.5	4.9	25.8	29.6	10.9	trace	trace	rutile, apatite
19	28.2	23.6	7.3	27.6	34.7	6.5	trace	trace	rutile, hematite
20	11.4	29.3	11.6	26.9	21.6	10.3	trace	- -	rutile
Rio de Los Negros									
5	13.9	16.1	12.6	33.8	27.5	8.6	1.4	- -	rutile
Rio Dos Bocas									
28	19.4	15.8	6.0	41.1	27.2	9.3	0.6	- -	- -
Rio Indio									
12	2.9	16.3	16.6	41.9	12.8	11.1	1.0	trace	garnet
13	3.6	21.4	14.7	37.4	13.0	12.3	0.9	trace	garnet
Rio Unibon									
23	8.0	2.4	15.4	34.9	20.0	15.5	1.5	n.d.	garnet, rutile
Rio Las Carreras									
27	15.8	3.8	7.7	48.0	27.7	11.5	0.8	trace	- -
Rio Morovis									
25	7.2	66.4	19.3	4.7	5.1	2.0	1.3	0.6	garnet, rutile, apatite tourmaline
26	5.8	77.4	11.3	3.5	4.0	1.6	1.3	0.6	rutile, apatite
Rio Manati									
15	4.3	14.0	17.3	37.0	20.4	11.1	trace	trace	rutile
16	3.7	29.4	11.9	28.8	18.6	11.0	trace	n.d.	- -
Minimum value	2.9	2.4	4.9	3.5	4.0	1.6	trace	trace	
Mean value	11.9	23.7	10.4	31.4	22.5	10.7	- -	- -	
Maximum value	28.2	77.4	19.3	48.0	34.7	16.3	2.0	0.6	
Standard deviation	6.7	17.1	3.9	10.3	7.6	3.6	- -	- -	

*total calculated heavy-mineral percent

Table 2. Emission spectrographic analyses of the sand-sized heavy-mineral fraction of river samples from north-central Puerto Rico. Samples are grouped by rivers [Samples separated by hand magnet (HMAG) and electromagnet (0-0.5 amp, 0.5-0.75 amp, and >0.75 amp); pct, percent; ppm, parts per million; L, may not be present or is less than limit of detection (Thomas, 1979)]

Element	Sample 1 (Río de la Plata)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	2.3	3.8	5.1	3.7
Ca	1.6	8.8	11	13
Fe	48	16	8.7	5.3
K	0.21	0.29	0.2	0.1
Mg	0.97	4.9	5.1	6.8
Na	0.28	0.55	0.42	0.44
P	0.05	0.04	0.03	0.06
Ti	2.7	1.1	0.40	0.64
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	150	140	82	72
Be	4	L	L	L
Bi	L	L	L	L
Cd	8	4	35	L
Ce	30	32	33	43
Co	46	40	38	33
Cr	3100	800	440	1200
Cu	51	79	43	20
Eu	L	L	L	L
Ga	32	10	20	10
Ho	L	L	L	L
La	9	20	20	20
Li	6	6	5	4
Mn	2100	2300	1600	1200
Mo	L	L	L	L
Nb	L	L	L	8
Nd	10	20	20	28
Ni	120	82	83	120
Pb	22	10	9	20
Sc	25	71	74	86
Sn	L	L	L	L
Sr	86	250	460	220
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	2100	590	380	250
Y	10	24	26	31
Yb	L	2	2	3
Zn	590	90	89	30

Element	Sample 24 (Río de la Plata)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	2.1	4.1	5.9	5.5
Ca	0.62	5.5	8.7	10
Fe	54	22	17	12
K	0.36	0.49	0.42	0.50
Mg	0.58	3.2	3.5	4.7
Na	0.26	0.49	0.46	0.53
P	0.08	0.1	0.2	0.1
Ti	2.8	1.4	0.53	0.99
Ag (ppm)	L	L	L	L
As	L	52	93	53
Au	L	L	L	L
Ba	180	380	350	570
Be	3	L	2	L
Bi	L	L	L	L
Cd	110	24	L	29
Ce	27	43	48	68
Co	32	52	75	54
Cr	2300	520	400	1100
Cu	150	400	590	320
Eu	L	L	L	L
Ga	23	10	20	20
Ho	L	L	L	L
La	9	20	27	35
Li	6	7	7	7
Mn	1600	2900	2600	1900
Mo	7	6	9	7
Nb	10	10	L	10
Nd	8	21	26	40
Ni	84	66	88	100
Pb	34	31	70	87
Sc	21	58	66	74
Sn	L	L	L	L
Sr	63	200	590	390
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1900	830	560	410
Y	10	27	38	44
Yb	L	2	3	5
Zn	680	150	120	120

Element	Sample 4 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al(pct)	1.1	3.2	4.4	1.9
Ca	0.95	5.3	9.8	14
Fe	58	22	8.0	4.1
K	0.1	0.36	0.24	0.04
Mg	0.64	3.2	5.5	8.1
Na	0.1	0.42	0.45	0.23
P	0.06	0.08	0.05	0.02
Ti	1.7	1.6	0.41	0.39
Ag(ppm)	L	L	L	L
As	L	30	L	L
Au	L	L	L	L
Ba	95	490	150	28
Be	2	L	L	L
Bi	L	L	L	L
Cd	L	L	20	L
Ce	22	40	24	10
Co	39	53	42	35
Cr	1200	890	700	3100
Cu	61	52	34	120
Eu	L	L	L	L
Ga	30	10	10	L
Ho	L	L	L	L
La	7	20	20	10
Li	L	7	6	L
Mn	2100	4700	1500	900
Mo	10	L	L	L
Nb	10	20	L	L
Nd	10	20	20	10
Ni	79	110	160	200
Pb	74	23	9	L
Sc	10	36	50	100
Sn	120	L	L	39
Sr	55	300	540	87
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1800	740	300	150
Y	7	20	20	20
Yb	L	L	L	L
Zn	560	100	64	20

Element	Sample 6 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al(pct)	2.3	4.0	4.2	1.7
Ca	1.5	8.8	10	14
Fe	54	14	8.0	4.0
K	0.33	0.43	0.2	0.03
Mg	0.93	5.2	6.9	8.1
Na	0.33	0.59	0.41	0.20
P	0.05	0.08	0.07	0.01
Ti	2.4	0.78	0.40	0.26
Ag(ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	160	190	89	21
Be	3	L	L	L
Bi	L	L	L	L
Cd	130	L	37	L
Ce	27	36	20	L
Co	39	44	47	35
Cr	2100	950	940	3300
Cu	59	68	43	10
Eu	L	L	L	L
Ga	28	10	10	L
Ho	L	L	L	L
La	10	20	10	L
Li	7	7	7	L
Mn	1600	1700	1600	880
Mo	L	L	L	L
Nb	9	L	L	L
Nd	10	20	10	L
Ni	110	170	230	200
Pb	30	10	L	L
Sc	20	56	57	100
Sn	79	L	L	L
Sr	200	430	460	78
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1700	510	300	140
Y	9	20	20	10
Yb	L	L	L	L
Zn	900	79	110	20

Element	Sample 7 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.3	3.4	6.7	4.5
Ca	0.63	6.1	11	12
Fe	60	21	11	6.6
K	0.1	0.27	0.26	0.24
Mg	0.58	4.7	5.1	6.9
Na	0.09	0.46	0.56	0.57
P	0.05	0.05	0.05	0.06
Ti	2.6	1.6	0.46	0.80
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	86	140	120	110
Be	3	L	L	L
Bi	L	L	L	L
Cd	L	L	20	10
Ce	27	37	57	65
Co	48	55	46	39
Cr	4900	1800	510	1400
Cu	43	64	54	23
Eu	L	L	L	L
Ga	34	20	26	10
Ho	L	L	L	L
La	8	20	36	31
Li	L	4	L	L
Mn	2700	3200	1900	1400
Mo	7	L	L	L
Nb	10	10	L	9
Nd	10	21	35	40
Ni	120	150	140	170
Pb	25	20	10	10
Sc	20	50	56	77
Sn	L	L	L	L
Sr	45	280	830	420
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	2200	720	420	280
Y	10	21	29	40
Yb	L	2	3	4
Zn	750	140	88	57

Element	Sample 8 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.3	3.6	6.1	4.2
Ca	0.61	6.1	10	12
Fe	60	19	12	6.0
K	0.1	0.39	0.33	0.26
Mg	0.58	5.1	5.0	6.6
Na	0.09	0.57	0.53	0.53
P	0.05	0.06	0.06	0.06
Ti	2.7	1.6	0.47	0.80
Ag (ppm)	L	L	L	L
As	L	L	20	L
Au	L	L	L	L
Ba	80	190	150	140
Be	3	L	L	L
Bi	L	L	L	L
Cd	L	L	10	L
Ce	23	34	44	60
Co	47	50	53	35
Cr	5000	1100	710	1900
Cu	50	74	75	24
Eu	L	L	L	L
Ga	35	10	21	10
Ho	L	L	L	L
La	9	20	26	31
Li	4	5	4	5
Mn	2800	3000	1800	1300
Mo	9	L	L	L
Nb	10	10	L	9
Nd	L	20	23	31
Ni	120	160	140	160
Pb	27	26	20	9
Sc	20	48	54	73
Sn	L	L	L	L
Sr	50	270	740	330
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	2300	690	430	250
Y	10	20	28	40
Yb	L	L	3	4
Zn	710	110	86	38

Element	Sample 9 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.8	4.0	4.8	3.8
Ca	1.4	7.4	8.6	12
Fe	50	14	9.4	6.0
K	0.31	0.37	0.42	0.29
Mg	1.4	6.4	6.5	7.5
Na	0.22	0.70	0.68	0.62
P	0.08	0.07	0.07	0.04
Ti	2.4	0.85	0.39	0.42
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	150	250	220	150
Be	2	L	L	L
Bi	L	L	L	L
Cd	9	L	L	34
Ce	27	32	22	22
Co	47	52	56	39
Cr	3000	1300	900	2200
Cu	69	93	73	29
Eu	L	L	L	L
Ga	29	10	10	8
Ho	L	L	L	L
La	10	20	20	10
Li	4	5	5	L
Mn	2700	2400	1800	1300
Mo	7	L	L	L
Nb	10	L	L	L
Nd	10	20	10	10
Ni	110	200	280	280
Pb	25	20	10	9
Sc	23	54	52	75
Sn	20	L	L	L
Sr	97	310	380	270
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1800	470	320	220
Y	10	20	20	22
Yb	L	L	L	2
Zn	540	110	84	80

Element	Sample 11 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.7	3.7	5.8	2.8
Ca	1.5	6.5	10	14
Fe	48	18	9.6	4.3
K	0.2	0.30	0.28	0.2
Mg	1.3	5.0	5.9	7.4
Na	0.20	0.59	0.65	0.43
P	0.09	0.09	0.1	0.2
Ti	2.2	1.9	0.55	1.9
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	110	190	160	120
Be	3	L	L	L
Bi	L	L	L	L
Cd	4	L	L	26
Ce	31	48	45	140
Co	47	53	51	32
Cr	4300	2000	650	2500
Cu	42	58	45	32
Eu	L	L	L	4
Ga	31	20	20	10
Ho	L	L	L	L
La	10	25	30	63
Li	5	6	5	4
Mn	2200	4100	2000	1000
Mo	5	L	L	L
Nb	L	10	L	31
Nd	10	25	28	91
Ni	120	170	170	160
Pb	33	24	20	20
Sc	20	50	58	92
Sn	L	L	L	L
Sr	89	270	570	190
Ta	L	L	L	L
Th	L	L	L	20
U	L	L	L	L
V	1800	580	370	220
Y	10	31	29	87
Yb	L	3	3	10
Zn	630	150	94	56

Element	Sample 22 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	2.0	4.2	5.2	
Ca	0.33	4.0	7.2	
Fe	53	22	17	
K	0.21	0.43	0.22	
Mg	0.27	2.5	2.8	
Na	0.1	0.42	0.36	
P	0.08	0.27	0.25	
Ti	3.3	0.56	0.30	
Ag (ppm)	L	L	L	insufficient
As	L	93	66	
Au	L	L	L	
Ba	160	750	150	
Be	4	2	2	sample
Bi	L	L	L	
Cd	L	L	L	
Ce	26	33	32	for
Co	38	72	54	
Cr	840	410	870	
Cu	90	190	180	
Eu	L	L	L	analysis
Ga	32	20	21	
Ho	L	L	L	
La	6	20	20	
Li	6	6	5	
Mn	1600	4000	1800	
Mo	5	L	L	
Nb	L	L	L	
Nd	L	10	10	
Ni	94	78	81	
Pb	21	27	26	
Sc	21	38	42	
Sn	78	L	L	
Sr	45	240	550	
Ta	L	L	L	
Th	L	L	L	
U	L	L	L	
V	2200	740	580	
Y	5	20	22	
Yb	L	L	L	
Zn	1100	120	78	

Element	Sample 5 (Río de Los Negros)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.7	4.0	5.3	4.2
Ca	0.96	7.2	10	12
Fe	53	17	9.8	6.4
K	0.2	0.45	0.30	0.30
Mg	1.0	6.3	6.5	7.1
Na	0.2	0.74	0.63	0.58
P	0.07	0.07	0.05	0.07
Ti	2.5	1.1	0.42	0.48
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	110	300	170	200
Be	3	L	L	L
Bi	L	L	L	L
Cd	20	L	L	L
Ce	33	31	44	30
Co	51	67	54	41
Cr	4500	1200	740	1400
Cu	73	98	68	84
Eu	L	L	L	L
Ga	33	20	20	10
Ho	L	L	L	L
La	10	20	26	20
Li	5	6	5	L
Mn	3300	2500	1800	1300
Mo	L	L	L	6
Nb	L	9	L	L
Nd	10	10	20	20
Ni	140	220	200	190
Pb	56	30	10	10
Sc	20	53	57	71
Sn	L	L	L	L
Sr	61	250	570	320
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	2100	610	360	260
Y	10	20	22	23
Yb	L	L	2	2
Zn	740	130	74	110

Element	Sample 3 (Río Mavilla)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.3	3.6	6.1	4.0
Ca	0.64	6.0	9.2	12
Fe	59	15	10	5.0
K	0.20	0.32	0.41	0.42
Mg	0.55	5.3	5.6	5.8
Na	0.1	0.55	0.71	0.52
P	0.07	0.06	0.07	0.04
Ti	2.2	0.75	0.36	1.2
Ag (ppm)	L	L	L	L
As	L	20	L	L
Au	L	L	L	L
Ba	100	190	230	220
Be	3	L	L	L
Bi	L	L	L	L
Cd	L	L	L	L
Ce	30	27	29	81
Co	46	84	56	34
Cr	3100	980	500	1600
Cu	72	130	110	35
Eu	L	L	L	L
Ga	33	10	20	10
Ho	L	L	L	L
La	8	10	20	32
Li	L	4	L	L
Mn	2400	2200	1900	860
Mo	6	L	L	L
Nb	10	L	L	10
Nd	10	20	20	58
Ni	77	170	160	130
Pb	25	20	22	60
Sc	20	49	51	73
Sn	L	L	L	L
Sr	51	220	600	200
Ta	L	L	L	L
Th	L	L	L	10
U	L	L	L	L
V	1900	500	370	190
Y	10	20	22	57
Yb	L	L	L	6
Zn	510	120	93	27

Element	Sample 10 (Río Mavilla)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	2.2	4.4	6.3	4.4
Ca	1.4	6.9	9.4	11
Fe	47	16	12	7.0
K	0.33	0.33	0.35	0.36
Mg	1.4	5.5	5.5	6.8
Na	0.24	0.57	0.66	0.64
P	0.07	0.07	0.08	0.08
Ti	2.7	1.0	0.41	1.2
Ag (ppm)	L	L	L	L
As	L	L	20	L
Au	L	L	L	L
Ba	190	240	250	320
Be	3	L	L	L
Bi	L	L	L	L
Cd	L	L	66	L
Ce	41	39	46	78
Co	47	70	60	43
Cr	3400	1300	560	1300
Cu	110	160	130	55
Eu	L	L	L	L
Ga	29	20	20	10
Ho	L	L	L	L
La	10	20	24	37
Li	4	5	5	4
Mn	2400	2700	2300	1500
Mo	5	L	L	4
Nb	L	L	L	20
Nd	10	20	22	50
Ni	110	170	160	170
Pb	68	30	28	46
Sc	29	57	54	70
Sn	L	L	L	L
Sr	90	330	590	290
Ta	L	L	L	L
Th	L	L	L	10
U	L	L	L	L
V	1500	570	400	280
Y	20	23	26	51
Yb	L	L	2	5
Zn	560	150	180	65

Element	Sample 17 (Río Mavilla)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.6	3.7	5.0	4.1
Ca	1.2	7.4	8.5	9.9
Fe	56	8.2	8.7	6.6
K	0.2	0.27	0.34	0.39
Mg	1.2	7.0	6.6	7.2
Na	0.2	0.85	0.84	0.84
P	0.08	0.08	0.07	0.1
Ti	1.5	0.39	0.39	0.91
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	97	220	210	210
Be	2	L	L	L
Bi	L	L	L	L
Cd	L	L	L	460
Ce	22	10	24	54
Co	52	61	62	51
Cr	4600	950	720	1100
Cu	68	74	69	54
Eu	L	L	L	L
Ga	30	L	10	10
Ho	L	L	L	L
La	8	7	10	24
Li	L	L	L	L
Mn	2100	1800	1800	1500
Mo	5	L	L	L
Nb	10	L	L	10
Nd	10	L	10	32
Ni	110	260	210	200
Pb	20	L	L	L
Sc	20	52	51	60
Sn	L	L	L	65
Sr	67	180	420	300
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1900	280	320	260
Y	10	10	20	36
Yb	L	L	L	4
Zn	430	70	70	540

Element	Sample 18 (Río Mavilla)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.1	3.5	4.0	2.5
Ca	0.46	6.5	7.9	13
Fe	60	14	8.9	4.1
K	0.2	0.25	0.24	0.30
Mg	0.44	7.1	7.4	7.4
Na	0.1	0.81	0.92	0.43
P	0.09	0.09	0.07	0.1
Ti	1.3	0.53	0.35	1.7
Ag (ppm)	L	L	L	10
As	L	L	20	L
Au	L	L	L	L
Ba	72	160	160	230
Be	2	L	L	L
Bi	L	L	L	L
Cd	L	6	42	25
Ce	25	43	10	150
Co	46	79	85	33
Cr	3200	1600	970	3100
Cu	59	95	72	92
Eu	L	L	L	5
Ga	30	L	9	L
Ho	L	L	L	L
La	9	27	9	59
Li	L	4	L	L
Mn	1900	1900	1900	1100
Mo	8	L	L	5
Nb	10	L	L	25
Nd	L	20	10	100
Ni	72	280	250	180
Pb	10	L	8	160
Sc	10	49	50	87
Sn	L	L	L	L
Sr	31	200	270	130
Ta	L	L	L	L
Th	L	L	L	10
U	L	L	L	L
V	2000	440	270	190
Y	8	20	10	100
Yb	L	L	L	10
Zn	400	81	110	49

Element	Sample 19 (Río Mavilla)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.5	3.7	4.1	2.6
Ca	0.38	7.3	8.7	12
Fe	64	11	8.9	4.0
K	0.20	0.28	0.22	0.39
Mg	0.48	6.7	7.4	7.2
Na	0.09	0.77	0.85	0.42
P	0.07	0.1	0.1	0.04
Ti	1.9	0.47	0.36	0.55
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	82	210	130	140
Be	3	L	L	L
Bi	L	L	L	L
Cd	L	4	26	L
Ce	24	20	10	32
Co	48	61	63	33
Cr	4400	950	840	2300
Cu	51	80	69	41
Eu	L	L	L	L
Ga	32	9	10	8
Ho	L	L	L	L
La	7	8	10	20
Li	L	10	4	4
Mn	1900	1800	1600	890
Mo	5	L	L	L
Nb	10	L	L	L
Nd	8	9	10	20
Ni	120	310	260	180
Pb	20	L	L	150
Sc	10	45	51	85
Sn	L	L	L	230
Sr	39	240	440	120
Ta	L	L	L	L
Th	L	L	L	8
U	L	L	L	L
V	2000	360	310	150
Y	10	10	10	23
Yb	L	L	L	3
Zn	590	83	91	30

Element	Sample 20 (Río Mavilla)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	2.9	4.0	4.9	2.6
Ca	0.40	7.0	9.7	16
Fe	53	24	14	5.0
K	0.36	0.42	0.35	0.1
Mg	0.49	4.0	5.1	8.5
Na	0.20	0.40	0.45	0.34
P	0.1	0.1	0.1	0.04
Ti	3.3	0.85	0.34	0.47
Ag (ppm)	L	L	L	L
As	L	L	41	L
Au	L	L	L	L
Ba	170	380	240	47
Be	4	L	L	L
Bi	L	L	L	L
Cd	L	10	L	L
Ce	34	43	45	20
Co	42	57	92	38
Cr	2600	830	930	2900
Cu	89	120	160	20
Eu	L	L	L	L
Ga	25	10	20	L
Ho	L	L	L	L
La	9	27	20	9
Li	8	8	10	L
Mn	1600	2600	2300	1100
Mo	5	L	L	L
Nb	10	L	L	L
Nd	L	20	20	10
Ni	120	130	180	580
Pb	21	51	10	L
Sc	28	50	59	100
Sn	L	L	L	L
Sr	57	330	550	150
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	2100	870	480	170
Y	10	20	20	20
Yb	L	L	L	L
Zn	710	130	59	25

Element	Sample 12 (Río Indio)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	0.85	2.7	4.9	2.0
Ca	0.38	5.8	12	16
Fe	56	22	9.4	4.5
K	0.1	0.2	0.1	0.04
Mg	0.26	2.8	5.8	8.3
Na	0.07	0.28	0.49	0.29
P	0.06	0.07	0.1	0.04
Ti	1.3	3.1	0.51	1.4
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	54	89	79	31
Be	3	L	L	L
Bi	L	L	L	L
Cd	21	200	10	L
Ce	20	58	36	160
Co	42	43	44	36
Cr	2900	1600	690	2900
Cu	23	48	28	6
Eu	L	L	L	4
Ga	35	21	20	9
Ho	L	L	L	L
La	8	29	24	71
Li	5	7	5	L
Mn	1300	5600	2000	1000
Mo	L	L	L	L
Nb	10	22	L	27
Nd	L	43	20	100
Ni	85	95	160	200
Pb	22	20	23	L
Sc	8	41	55	100
Sn	L	L	24	L
Sr	35	220	600	110
Ta	L	L	L	L
Th	L	L	L	10
U	L	L	L	L
V	2000	620	380	190
Y	7	40	26	99
Yb	L	4	3	10
Zn	480	380	87	22

Element	Sample 13 (Río Indio)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.1	3.0	4.6	2.1
Ca	0.69	6.4	11	15
Fe	62	21	9.7	4.4
K	0.2	0.23	0.1	0.05
Mg	0.47	3.6	6.0	8.1
Na	0.1	0.38	0.49	0.30
P	0.08	0.1	0.09	0.05
Ti	1.4	2.7	0.46	0.90
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	79	110	74	33
Be	2	L	L	L
Bi	L	L	L	L
Cd	L	L	26	7
Ce	22	42	35	76
Co	43	49	45	33
Cr	2100	3100	680	3200
Cu	45	58	47	10
Eu	L	L	L	L
Ga	32	20	20	L
Ho	L	L	L	L
La	8	22	23	36
Li	4	5	5	L
Mn	1500	4100	1900	970
Mo	9	L	L	L
Nb	20	20	L	10
Nd	L	23	23	52
Ni	85	120	180	200
Pb	21	21	10	L
Sc	10	43	54	100
Sn	81	L	L	10
Sr	49	280	510	130
Ta	L	L	L	L
Th	L	L	L	10
U	L	L	L	L
V	1800	700	380	170
Y	9	26	23	52
Yb	L	3	2	6
Zn	430	140	100	31

Element	Sample 15 (Río Grande de Manatí)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	4.2	4.5	5.4	
Ca	4.5	7.6	9.5	
Fe	21	13	8.7	
K	0.71	0.36	0.37	
Mg	2.8	4.6	3.7	
Na	1.1	1.1	0.68	
P	0.1	0.1	0.07	
Ti	1.2	0.49	0.50	
Ag (ppm)	L	L	L	insufficient sample for analysis
As	20	L	L	
Au	L	L	L	
Ba	380	220	160	
Be	3	L	L	
Bi	L	L	L	
Cd	L	L	L	
Ce	35	39	62	
Co	34	45	26	
Cr	430	400	530	
Cu	92	61	45	
Eu	L	L	L	
Ga	20	10	20	
Ho	L	L	L	
La	20	26	34	
Li	9	9	6	
Mn	1600	1400	1200	
Mo	10	L	L	
Nb	10	L	10	
Nd	20	22	42	
Ni	75	98	75	
Pb	10	9	28	
Sc	34	47	43	
Sn	75	L	L	
Sr	310	320	660	
Ta	L	L	L	
Th	L	L	L	
U	L	L	L	
V	760	420	350	
Y	20	26	41	
Yb	L	2	4	
Zn	210	62	52	

Element	Sample 16 (Río Grande de Manatí)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	1.8	3.5	4.0	2.2
Ca	0.64	8.7	12	15
Fe	55	14	8.5	4.2
K	0.26	0.42	0.1	0.2
Mg	0.57	5.0	6.0	7.6
Na	0.22	0.63	0.40	0.28
P	0.08	0.09	0.05	0.09
Ti	2.6	0.54	0.43	1.7
Ag (ppm)	L	L	L	L
As	L	190	L	L
Au	L	L	L	L
Ba	150	340	75	160
Be	3	L	L	L
Bi	L	L	L	L
Cd	L	L	5	240
Ce	27	21	25	160
Co	39	45	45	32
Cr	2700	830	970	2500
Cu	75	120	72	20
Eu	L	L	L	L
Ga	28	8	10	8
Ho	L	L	L	L
La	7	10	10	72
Li	5	8	6	4
Mn	2000	2200	1700	950
Mo	9	L	L	4
Nb	10	L	L	32
Nd	L	10	10	93
Ni	120	110	120	150
Pb	20	10	10	41
Sc	20	63	78	92
Sn	190	L	L	10
Sr	61	170	290	100
Ta	L	L	L	L
Th	L	L	L	22
U	L	L	L	L
V	2000	440	360	190
Y	10	20	23	96
Yb	L	L	3	10
Zn	490	96	67	290

Element	Sample 23 (Río Unibon)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)		4.1	3.9	2.0
Ca		11	12	16
Fe		14	7.3	4.5
K		0.37	0.1	0.04
Mg		5.8	5.9	8.8
Na		0.56	0.38	0.26
P		0.1	0.07	0.02
Ti		0.53	0.34	0.33
Ag (ppm)		L	L	L
As		L	L	L
Au		L	L	L
Ba	insufficient	150	57	26
Be		L	L	L
Bi		L	L	L
Cd		10	L	10
Ce	sample	32	23	10
Co		48	36	39
Cr		1600	1200	3200
Cu		84	34	10
Eu	for	L	L	L
Ga		10	10	9
Ho		L	L	L
La	analysis	20	10	5
Li		9	5	L
Mn		1600	1100	940
Mo		L	L	L
Nb		L	L	L
Nd		20	9	L
Ni		190	150	220
Pb		20	20	62
Sc		69	72	110
Sn		L	L	33
Sr		510	720	94
Ta		L	L	L
Th		L	L	L
U		L	L	L
V		470	310	150
Y		20	20	10
Yb		L	L	L
Zn		120	34	33

Element	Sample 27 (Río Las Carreras)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	2.6	3.7	2.8	1.9
Ca	1.6	11	12	16
Fe	45	11	6.6	4.7
K	0.34	0.27	0.1	0.03
Mg	1.1	5.7	7.2	8.7
Na	0.30	0.50	0.42	0.26
P	0.1	0.1	0.09	0.02
Ti	2.6	0.35	0.33	0.27
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	170	150	240	24
Be	4	L	L	L
Bi	L	L	L	L
Cd	L	L	L	L
Ce	29	26	23	L
Co	50	61	140	40
Cr	3500	1100	1300	3400
Cu	82	61	72	20
Eu	L	L	L	L
Ga	27	10	10	L
Ho	L	L	L	L
La	9	10	10	5
Li	10	5	10	L
Mn	1800	1500	2600	960
Mo	6	L	L	L
Nb	9	L	L	L
Nd	10	10	L	L
Ni	160	180	220	220
Pb	30	10	9	L
Sc	22	61	63	110
Sn	24	L	L	L
Sr	140	340	210	110
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1700	390	250	160
Y	10	20	10	10
Yb	L	L	L	L
Zn	1000	74	48	22

Element	Sample 26 (Río Morovis)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	0.91	1.9	4.6	3.7
Ca	0.23	2.1	8.0	9.2
Fe	59	33	13	3.6
K	0.2	0.31	0.44	0.86
Mg	0.2	1.3	5.5	2.3
Na	0.07	0.20	0.65	0.57
P	0.06	0.08	0.1	0.2
Ti	0.49	1.2	1.0	4.8
Ag (ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	110	160	220	2000
Be	L	2	3	L
Bi	L	L	L	L
Cd	L	62	L	L
Ce	29	72	140	880
Co	34	34	54	20
Cr	260	850	220	420
Cu	37	93	90	32
Eu	L	L	L	20
Ga	30	20	26	20
Ho	L	L	L	10
La	10	31	31	370
Li	L	4	7	4
Mn	1000	1700	4500	1200
Mo	4	5	L	10
Nb	10	20	20	120
Nd	20	41	46	540
Ni	34	42	51	36
Pb	10	25	23	240
Sc	6	22	71	39
Sn	L	L	L	45
Sr	21	73	370	320
Ta	L	L	L	L
Th	L	20	10	130
U	L	L	L	L
V	1800	1300	460	280
Y	9	41	50	500
Yb	L	5	6	55
Zn	170	210	190	45

Element	Sample 25 (Río Morovis)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al (pct)	0.66	1.5	5.8	
Ca	0.23	1.4	9.1	
Fe	58	35	14	
K	0.09	0.23	0.36	
Mg	0.2	0.78	3.8	
Na	0.04	0.1	0.49	
P	0.07	0.08	0.1	
Ti	0.48	1.7	1.3	
Ag (ppm)	L	L	L	insufficient
As	L	L	30	
Au	L	L	L	
Ba	49	96	250	
Be	3	3	3	sample
Bi	L	L	L	
Cd	27	5	41	
Ce	23	40	120	for
Co	38	35	48	
Cr	490	1300	250	
Cu	40	70	120	
Eu	L	L	L	analysis
Ga	30	20	28	
Ho	L	L	L	
La	9	20	58	
Li	4	4	8	
Mn	940	2000	3800	
Mo	6	5	5	
Nb	8	10	22	
Nd	L	20	58	
Ni	40	42	54	
Pb	20	34	45	
Sc	6	20	59	
Sn	L	L	L	
Sr	20	45	800	
Ta	L	L	L	
Th	L	L	9	
U	L	L	L	
V	1900	1300	480	
Y	6	20	62	
Yb	L	L	6	
Zn	210	140	180	

Element	Sample 28 (Río Dos Bocas)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Al(pct)	2.1	3.7	4.2	3.9
Ca	1.6	6.7	9.0	13
Fe	50	9.8	9.8	6.4
K	0.20	0.22	0.21	0.2
Mg	1.6	6.6	6.6	7.1
Na	0.29	0.90	0.67	0.50
P	0.09	0.1	0.1	0.06
Ti	2.3	0.73	0.37	0.47
Ag(ppm)	L	L	L	L
As	L	L	L	L
Au	L	L	L	L
Ba	110	140	190	110
Be	4	L	L	L
Bi	L	L	L	L
Cd	6	L	L	L
Ce	23	24	33	42
Co	48	60	69	42
Cr	5700	1000	670	1500
Cu	51	65	69	33
Eu	L	L	L	L
Ga	26	9	10	10
Ho	L	L	L	L
La	9	10	10	21
Li	7	5	8	4
Mn	1800	1800	2000	1400
Mo	6	L	L	L
Nb	L	9	L	L
Nd	9	9	10	27
Ni	170	260	260	210
Pb	28	L	10	8
Sc	21	41	42	72
Sn	L	L	L	L
Sr	100	250	440	400
Ta	L	L	L	L
Th	L	L	L	L
U	L	L	L	L
V	1700	320	320	250
Y	10	10	20	28
Yb	L	L	L	2
Zn	880	73	67	37

	Lower Detection limits
Al(pct)	0.02
Ca	0.02
Fe	0.02
K	0.02
Mg	0.02
Na	0.02
P	0.02
Ti	0.02
Ag(ppm)	4
As	20
Au	20
Ba	2
Be	2
Bi	20
Cd	4
Ce	10
Co	2
Cr	2
Cu	4
Eu	4
Ga	8
Ho	8
La	4
Li	4
Mn	8
Mo	4
Nb	8
Nd	8
Ni	4
Pb	8
Sc	4
Sn	10
Sr	4
Ta	80
Th	8
U	200
V	4
Y	4
Yb	2
Zn	4

Table 3. Statistics of major and minor elements in designated heavy-mineral fractions of river samples from north-central Puerto Rico

A. Strongly paramagnetic/ferromagnetic heavy-mineral fraction separated by hand magnet. Statistics based on 24 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Al	0.66	4.2	1.8	0.59	0.77
Fe	21	64	53.5	74	8.6
Mg	0.20	2.8	0.83	0.35	0.59
Ca	0.23	4.5	1.0	0.77	0.88
Na	0.04	1.1	0.21	0.04	0.21
K	0.09	0.71	0.24	0.02	0.13
Ti	0.48	3.3	2.1	0.61	0.78
P	0.05	0.1	0.07	0.0004	0.02
Minor elements, values in parts per million					
Ba	49	380	129	4,542	67.4
[1]Be	2	4	3	0.4	0.7
Ce	20	41	27.4	25.0	5.0
Co	32	52	43.5	32.5	5.7
Cr	260	5,700	2,942	2.4×10^6	1,538
Cu	23	150	65.9	745	27.3
Ga	20	35	29.7	13.7	3.7
La	6	20	9.1	6.8	2.6
[2]Li	4	10	5.8	3.4	1.8
Mn	940	3,300	1,956	3.2×10^6	568
[3]Mo	4	10	6.7	3.5	1.9
[2]Nb	8	20	10.3	6.5	2.5
[4]Nd	8	20	10.9	13.0	3.6
Ni	34	170	103	1,050	32.4
Pb	10	74	28.0	262	16.2
Sc	6	34	18.5	54.8	7.4
Sr	20	310	77.6	4.020	63.4
V	760	2,300	1,873	9.2×10^5	303
Y	5	20	10.1	10.9	3.3
Zn	170	1,100	595	5.7×10^5	236

[1]based on 23 samples
[2]based on 17 samples
[3]based on 20 samples
[4]based on 16 samples

B. Moderately magnetic 0.0-amp to 0.5-amp heavy-mineral fraction separated by electromagnet. Statistics based on 25 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Al	1.5	4.5	3.6	0.49	0.70
Fe	8.2	35	17.8	42.25	6.5
Mg	0.78	7.1	4.7	2.89	1.7
Ca	1.4	11	6.7	4.84	2.2
Na	0.10	1.1	0.56	0.05	0.22
K	0.20	0.49	0.33	0.01	0.08
Ti	0.35	3.1	1.1	0.50	0.71
P	0.04	0.27	0.09	0.002	0.04
Minor elements, values in parts per million					
Ba	89	750	235	2.1×10^4	145
Ce	10	72	36.1	156	12.5
Co	34	84	54.8	161	12.7
Cr	400	3,100	1,174	3.2×10^5	569
Cu	48	400	99.8	5,084	71.3
[1]Ga	8	21	13.8	27.2	5.2
La	7	31	19.3	44.9	6.7
[2]Li	4	10	6.0	2.7	1.6
Mn	1,400	5,600	2,628	1.2×10^6	1,099
[2]Nd	9	43	19.7	71.8	8.5
Ni	42	310	154	5,344	73.1
[3]Pb	9	51	22.4	100	10.0
Sc	20	71	48.9	146	12.1
Sr	30	510	249	1.1×10^4	106
V	260	1,300	614	6.9×10^4	262
Y	10	41	21.4	41.0	6.4
Zn	62	380	124	4,007	63.3

[1]based on 23 samples
[2]based on 24 samples
[3]based on 21 samples

C. Less magnetic 0.5-amp to 0.75-amp heavy-mineral fraction separated by electromagnet. Statistics based on 25 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Al	2.8	6.7	5.0	0.85	0.92
Fe	6.6	17	10.4	7.29	2.7
Mg	2.8	7.4	5.6	1.44	1.2
Ca	7.2	12	9.8	1.96	1.4
Na	0.36	0.92	0.57	0.03	0.16
K	0.10	0.44	0.27	0.01	0.11
Ti	0.30	1.3	0.47	0.05	0.22
P	0.03	0.25	0.09	0.0025	0.05
Minor elements, values in parts per million					
Ba	57	350	168	5,198	72.1
Ce	10	140	41.2	894	29.9
Co	26	140	57.6	511	22.6
Cr	220	1,300	716	$7.0x10^4$	264
Cu	28	590	95.7	$1.2x10^4$	110
Ga	9	28	16.8	38.4	6.2
La	9	58	21.5	128	11.3
[1]Li	4	10	6.1	3.0	1.7
Mn	1,100	4,500	2,040	$5.4x10^5$	732
[2]Nd	9	58	21.3	166	12.9
Ni	51	280	162	4,422	66.5
[3]Pb	8	70	19.5	215	14.7
Sc	42	78	56.8	90.2	9.5
Sr	210	830	524	$2.6x10^4$	160
V	250	580	379	7,293	85.4
Y	10	62	25.4	139	11.8
Zn	34	190	92.6	1,576	39.7

[1]based on 21 samples
[2]based on 24 samples
[3]based on 22 samples

D. Nonmagnetic >0.75-amp heavy-mineral fraction separated by electromagnet. Statistics based on 22 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Al	1.7	5.5	3.2	1.21	1.1
Fe	3.6	12	5.4	3.24	1.8
Mg	2.3	8.8	7.1	1.96	1.4
Ca	9.2	16.0	13.0	4.41	2.1
Na	0.20	0.84	0.44	0.03	0.16
K	0.03	0.86	0.24	0.04	0.20
Ti	0.26	4.8	1.02	0.94	0.97
P	0.01	0.20	0.07	0.0025	0.05
Minor elements, values in parts per million					
Ba	21	2,000	226	$1.7x10^5$	416
[1]Ce	10	880	109	$3.5x10^4$	189
Co	20	54	37.1	47.6	6.9
Cr	420	3,400	2,160	$8.1x10^5$	900
Cu	6	320	49.5	4,489	67.0
[2]Ga	8	20	10.7	13.7	3.7
[3]La	5	370	46.7	5,907	76.8
Mn	860	1,900	1,161	$7.1x10^4$	266
[4]Nd	10	540	71.2	$1.4x10^4$	117
Ni	22	580	184	$1.1x10^4$	106
[5]Pb	8	240	62.1	4,845	69.6
Sc	39	110	83.9	303	17.4
Sr	78	420	216	$1.3x10^4$	114
V	140	410	219	4,096	64.0
Y	10	500	61.5	$1.0x10^4$	101
[6]Yb	2	55	8.3	153	12.4
Zn	20	540	79.4	$1.4x10^4$	118

[1]based on 20 samples
[2]based on 16 samples
[3]based on 21 samples
[4]based on 19 samples
[5]based on 15 samples
[6]based on 17 samples