U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Sand-sized heavy-mineral distributions in offshore insular shelf sediments of north-central Puerto Rico

by

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

Open-File Report 93-341

[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 6.3 percent by weight in the sand-sized fraction of insular shelf sediments off north-central Puerto Rico, with concentrations near the mouths of rivers averaging 12.8 percent. Minerals identified include magnetite, ilmenite, pyroboles (pyroxenes plus amphiboles), epidote, sphene, garnet, apatite, zircon, rutile, tourmaline, corundum, and piedmontite. Piedmontite is identified for the first time in detrital Puerto Rican sands. Monazite was not detected. No gold, silver, platinum, palladium, or tungsten was detected in any sample; tin was detected in one sample. Chromium values commonly exceeded 1000 parts per million (ppm) in all analyzed samples. Copper values never exceeded 70 ppm.

INTRODUCTION

As part of the U.S. Geological Survey's effort to assess the potential of the continental shelves for placer deposits within the U.S. Exclusive Economic Zone, 20 sand (2.0-0.062 mm) samples from the insular shelf of north-central Puerto Rico (Fig. 1) were analyzed for their heavy-mineral content. The heavy minerals from the silt-sized fraction (<0.062 mm) of these samples are dealt with in a separate study (Poppe and others, 1992). Sediments from three major river systems--the Río de la Plata, Río Grande de Manati, and Río Cibuco--have recently been analyzed (Luepke and Poppe, 1992); these sediments are among those eroded from the island and transported to the northern shelf of Puerto Rico (Schneidermann and others, 1976). The shelf is narrow and subjected to a trade wind-dominated, high-energy regime (Schneidermann and others, 1976). These present-day oceanographic conditions serve to keep the surficial sediment in equilibrium and promote strong seaward sorting (Schneidermann and others, 1976; Pilkey and Lincoln, 1984).

METHODS

Splits of samples from the insular shelf off north-central Puerto Rico were collected from sediment archived at the Duke University (Durham, North Carolina) sample repository. These sediments were originally collected as grab samples and therefore represent surficial sediment. Depths were not recorded for the original samples, but none were taken at depths greater than 100 m (Fig. 1).

Initial samples ranged in weight from 12 to 544 grams. These samples were digested in cold, dilute (10 percent) acetic acid to remove the carbonate fraction. Acetic acid was used instead of hydrochloric acid to avoid removal of apatite. The remaining siliciclastic fractions, ranging in weight from about 3 to nearly 253 g, were separated in entirety in tetrabromoethane (specific gravity, 2.96). The siliciclastic fraction comprised from 4.5 to 66 percent by weight of the total sample.

Depending on the amount of sample available, mineral proportions were determined either by visual estimation or point-counting. Eight samples that contained sufficient volume of material (>3 g) were examined under a binocular microscope following the procedures described by Luepke and Grosz (1986). After removal of the highly magnetic fraction with a hand magnet, the remaining sample was divided with a Frantz isodynamic separator into three paramagnetic fractions: 0-0.5, 0.5-0.75, and >0.75 ampere, the same paramagnetic fractions used in a companion study of river sediments from north-central Puerto Rico (Luepke and Poppe, 1992).

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).

Microsplits of all paramagnetic fractions of the 8 samples containing sufficient sample volume (>0.4 g) were made for geochemical analyses. These analyses were performed at the U.S. Geological Survey analytical laboratories in Denver, Colorado, using a direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). Compared to the inductively-coupled semi-quantitative (ICP) process used on the river samples in the companion study (Luepke and Poppe, 1992), the following elements were not analyzed: aluminum, potassium, cerium, europium, holmium, lithium, neodymium, tantalum, uranium, and ytterbium. These elements were either not present or were present only in insignificant amounts within the sand-sized heavy minerals from rivers (Luepke and Poppe, 1992). Therefore the different analytical methods used will probably not yield significantly different results.

Twelve samples contained a total heavy-mineral fraction of 1 gram or less, an insufficient volume for the visual-estimation technique. Heavy-mineral grain mounts were made of the 0.062-0.125 mm fraction of these samples and point-counted using standard techniques. The average number of grains counted per sample was 379 (range 323-465), with an average number of 264 (range 237-327) nonopaque, non-micaceous grains. The number of grains sufficient for accuracy is around 300 (Dryden, 1931, p. 237). The entire slide was examined after the requisite number of grains were counted, to account for any mineral species present but not encountered during the point-count.

RESULTS

Heavy-mineral concentrations for the sand-sized fraction average 6.3 percent and range from 0.3 to 45.1 percent by weight. The 12 point-counted samples averaged 2 percent heavy minerals;

the remaining 8 samples, most of which were collected close to river mouths, average about 13 percent heavy minerals.

Mineralogical results are shown in Table 1. The differences between the methods of point-counting and visually-estimating mineral percentages are responsible for some of the variation seen among the mineral groups. The point-counted samples were examined in only the 0.125-0.062 mm fraction. Minerals such as zircon, rutile, epidote, and altered grains are more abundant within this grain size. The entire sand-sized fraction (2.0-0.062 mm) was examined in the visually-estimated samples. Pyroxenes and amphiboles are more common in size fractions greater than 0.125 mm.

Minerals identified include magnetite, ilmenite, pyroboles (pyroxenes plus amphiboles), epidote, garnet, sphene, zircon, apatite, tourmaline, corundum, and piedmontite. Altered grains and rock fragments were also present. Only two samples (4254 and 4339) near the mouth of the Río Grande de Manati contain magnetite in percentages exceeding 20 percent.

Pyroboles and epidote dominate the unaltered, sand-sized mineral grains. Amphiboles are dominantly green and blue-green hornblende; pyroxenes are mostly clinopyroxene with minor orthopyroxene. Among the 12 point-counted samples, the ratios of pyroxene to amphibole were about 3:1 for the samples off the Río de la Plata, about 2:1 off the Río Grande de Manati, and nearly 1:1 off the Río Cibuco. Epidote percentages include some clinozoisite.

Mica and unknowns were identified only in the point-counted samples. The presence of sand-sized (2.0-0.062 mm) mica within a sediment indicates that winnowing is not being carried out efficiently (Doyle and others, 1968); this situation by definition would not exist within a strong heavy-mineral concentration. Therefore, the lack of mica within the visually-estimated samples is probably real. Unknowns constitute between 0.5 and 1.5 percent of any sample and are not statistically significant as a group.

Geochemical analyses are presented in Table 2. Elements tested for but not detected in any sample were antimony, arsenic, bismuth, germanium, gold, silver, palladium, platinum, thorium, and tungsten. Beryllium and lanthanum were either not detected or below the limits of detection in all samples. Lead is present in detectable amounts in all samples but one. Chromium values are over 1000 ppm in most samples. Cadmium is present in Sample 4924; tin is present in Sample 4914; niobium is present in Sample 4339. Statistical values for each paramagnetic fraction are given in Table 3.

Boron, when detected, occurred only in the 0-0.5 amp or 0.5-0.75 amp fraction, and never in amounts greater than 20 ppm, the lower limit of detection (Table 2). Although tourmaline was not visibly detected in any analyzed sample, the presence of boron in samples 4248, 4339, 4736, 4759, and 4924 suggests the presence of tourmaline.

DISCUSSION

Possible commercial concentrations of minerals found in the river sediments (Bush and others, 1988; Luepke and Poppe, 1992; Poppe and others, in press) may also occur in placer deposits on the insular shelf. Results from this study and earlier work on the sand fraction (Schneidermann and others, 1976; Pilkey and Lincoln, 1984) have shown that the heavy-mineral distributions on northern Puerto Rico's narrow, high-energy shelf are in equilibrium and exhibit strong seaward sorting. This sorting is probably based on the seaward decrease in the energy of wave-driven bottom currents and the specific gravities and characteristic sizes of the heavy-mineral grains.

Samples with elevated heavy-mineral content in the silt-sized fraction, such as 4254 and 4736, were collected near river mouths. Samples with lower heavy-mineral contents in the silt-sized fraction, such as 4228 and 4224, tend to be from further offshore (Poppe and others, in press). These results are mirrored in the sand-sized fraction. Elevated percentages of magnetic minerals in the Río Grande de Manati and, possibly, Río de la Plata suggest that the shelf sediments off these rivers contain more magnetite than those present off the Río Cibuco. Taking the three richest heavy-mineral concentrations off the mouth of each river (Table 2), the average magnetite values within these concentrations are 10.4 percent for the Río de la Plata, 2.6 percent for the Río Cibuco, and 30.9 percent for the Río Grande de Manati.

Monazite, a rare-earth phosphate, has been reported in enriched concentrations on Puerto Rico's inner shelf (Pilkey and Lincoln, 1984). In this study the concentrations of thorium, lanthanum, and phosphorus in all samples were below the limits of detection (Table 2). The presence of monazite cannot be substantiated from the data presented in this report.

Piedmontite, a manganese-bearing epidote, has been identified for the first time in Puerto Rican offshore sediments; it has not been previously identified in rocks on Puerto Rico (Johannes Schellekens, oral communication, 1993). Piedmontite is considered moderately stable and rare in detrital sediments (Milner, 1952, p. 499); its appearance in samples 4228 and 4241 (Fig. 1) is significant in that it is seen in samples with only a small volume of heavy minerals. It is found mostly in schists and gneisses, but also in acid volcanic rocks and manganese deposits of metasomatic or hydrothermal origin (Mange and Mauer, 1992, p. 63). The location of the samples containing piedmontite suggest the Río Cibuco as the conduit from its ultimate source.

CONCLUSIONS

Heavy-mineral concentrations on the insular shelf of north-central Puerto Rico average 6.3 percent of the sand-sized fraction; near the mouths of rivers the average concentration is 12.8 percent. For comparison, heavy-mineral concentrations within the sand-sized fraction of rivers of north-central Puerto Rico average 11.9 percent (Luepke and Poppe, 1992).

Economically important heavy minerals include ilmenite, chromite, zircon, and rutile. Rutile is present only in trace amounts (<0.5 percent) and zircon is present in greater than trace amounts only in Sample 4254 (at the mouth of the Río Grande de Manati), which contains the richest heavy-mineral concentration in this study. No gold, silver, platinum, palladium, or tungsten was detected in any sample. Tin was detected in one sample near the mouth of the Río Cibuco; tin has been detected previously.in 11 samples from the Río Cibuco and its tributaries (Luepke and Poppe, 1992).

REFERENCES

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

Doyle, L. J., Cleary, W. J., and Pilkey, O. H., 1968, Mica--its use in determining shelf-depositional regimes: Marine Geology, v. 6, no. 5, p. 381-389.

Dryden, A. L., Jr., 1931, Accuracy in percentage representation of heavy mineral frequencies: National Academy of Sciences Proceedings, v. 17, p. 233-238.

Grimes, D. J. and Marranzino, A. P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geological materials: U. S. Geological Survey Circular 591, 6 p.

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.

Luepke, Gretchen, and Poppe, L. J., 1992, Sand-sized heavy-mineral distributions in the Rio Cibuco system and adjacent rivers of north central Puerto Rico: U. S. Geological Survey Open-File Report 92-703, 28 p.

Mange, M. A. and Mauer, H. F. W., 1992, Heavy minerals in colour: Chapman and Hall, London, 147 p.

Milner, H.,B., 1952, Sedimentary petrography (3rd edition): Thomas Murby, & Co., London. 666 p.

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.

Schneidermann, Nahum, Pilkey, O. H., and Saunders, Craig, 1976, Sedimentation on the Puerto Rico insular shelf: Journal of Sedimentary Petrology, v. 46, no. 1, p. 167-173.

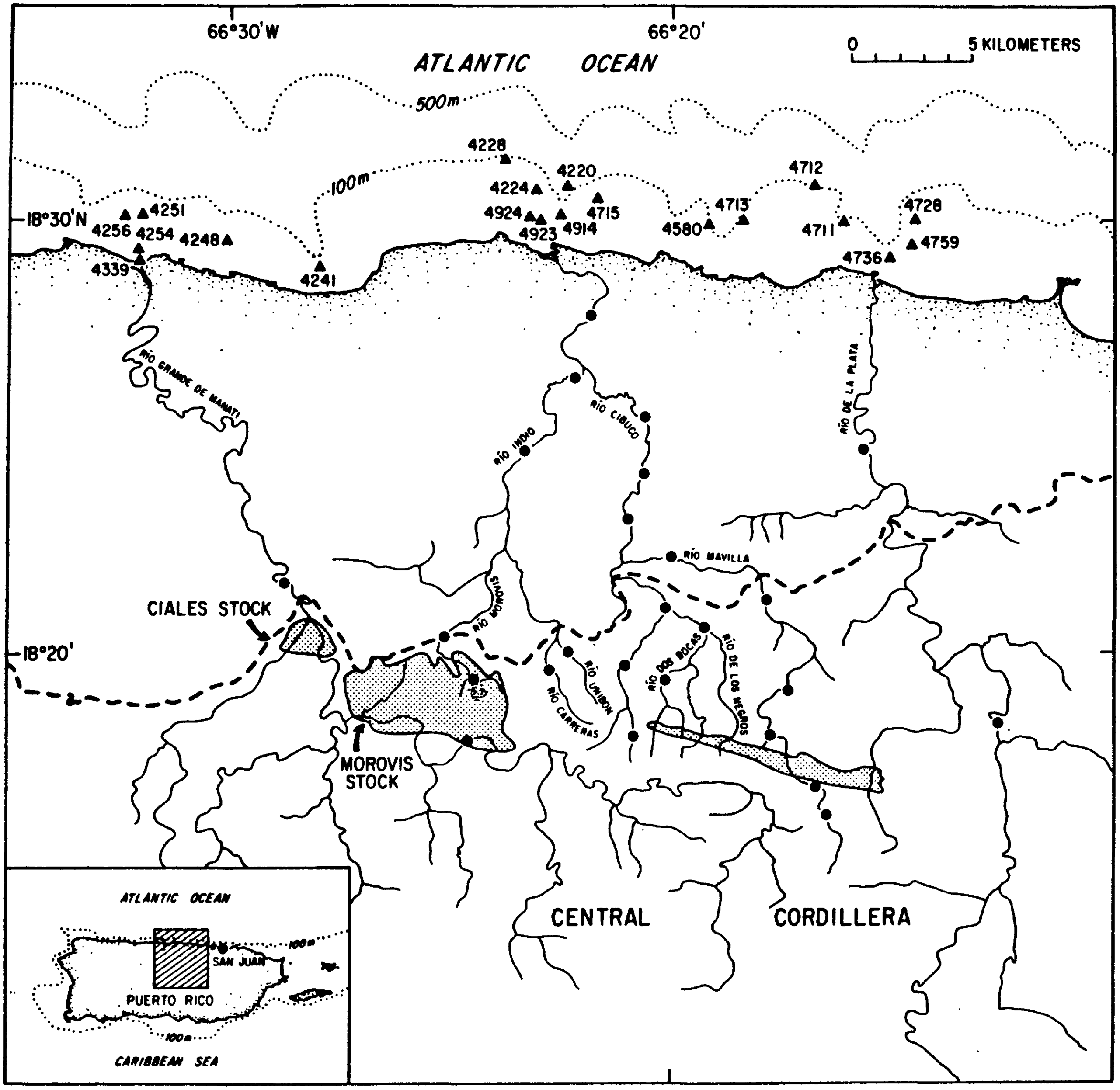

Figure 1. Map showing the locations of shelf samples (solid triangles) from north-central Puerto Rico. Solid circles show locations of river samples from another study (Luepke and Poppe, 1992). Inset shows location of study area on the island of Puerto Rico.

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

Sample	% Heavy Minerals*	Magnetite	Ilmenite	Pyroboles	Epidote	Altered Grains	Sphene	Zircon	Garnet	Apatite	Mica	Unknowns	Others
	Río de la Plata												
4728**	4.3	10.3	1.6	51.3	17.4	15.8	- - -	trace	0.8	trace	1.3	1.5	
4759	7.1	10.2	4.4	62.4	13.0	9.7	trace	trace	- - -	- - -	- - -	- - -	rutile
4736	9.2	10.8	4.9	60.4	14.4	9.5	trace	- - -	- - -	- - -	- - -	- - -	rutile
4711**	2.4	9.0	2.1	50.2	15.5	22.1	trace	trace	trace	trace	2.2	0.5	
4712**	0.7	6.5	1.8	46.2	24.3	18.6	trace	- - -	trace	trace	3.1	0.8	
	Río de la Plata - Río Cibuco												
4713**	2.0	6.2	4.0	44.5	12.2	18.7	0.8	trace	trace	- - -	3.7	1.4	
4580**	2.0	4.2	2.9	50.0	16.1	26.7	trace	- - -	trace	trace	2.2	0.5	
	Río Cibuco												
4715**	0.7	7.7	1.0	51.3	19.4	16.3	trace	- - -	0.6	trace	3.1	0.6	
4220**	0.5	9.7	1.7	46.8	19.6	15.9	1.3	trace	1.3	trace	2.4	0.9	corundum
4914	0.9	4.2	6.2	63.8	15.0	9.9	0.6	trace	trace	trace	- - -	- - -	rutile
4923	12.8	2.3	7.9	68.2	12.6	7.1	0.9	trace	- - -	0.9	- - -	- - -	rutile
4924	6.4	1.2	6.1	71.1	12.0	8.8	trace	trace	- - -	trace	- - -	- - -	rutile
4224**	0.3	5.0	6.0	44.9	22.2	19.0	trace	- - -	trace	- - -	1.8	0.5	rutile, tourmaline
4228**	0.8	7.1	3.2	59.1	17.6	12.4	0.6	trace	trace	trace	1.2	1.2	piedmontite
	Río Cibuco - Río Grande de Manati												
4241**	0.8	2.9	4.1	46.5	23.2	19.5	0.6	trace	trace	- - -	2.9	1.2	piedmontite
4248	7.9	18.6	4.4	57.5	12.3	6.9	trace	- - -	- - -	trace	- - -	- - -	rutile
	Río Grande de Manati												
4251**	5.0	13.9	2.8	45.3	21.1	15.3	trace	- - -	trace	trace	3.0	0.8	tourmaline
4339	12.8	34.3	8.6	45.7	9.1	1.7	0.5	trace	- - -	- - -	trace	- - -	rutile
4254	45.1	44.6	16.8	25.9	5.8	3.0	0.9	0.9	trace	trace	- - -	- - -	rutile
4256**	4.6	15.3	0.1	47.3	15.0	19.9	0.5	- - -	trace	trace	1.1	0.5	
Minimum	0.3	1.2	0.1	25.9	5.8	1.7	trace	trace	trace	trace	1.2#	0.5#	
Mean	6.3	11.2	4.5	51.9	15.9	13.8	- - -	- - -	- - -	- - -	2.3#	0.9#	
Maximum	45.1	44.6	16.8	71.1	24.3	22.1	1.3	0.9	1.3	0.9	3.7#	1.5#	
St. Dev.	10.0	10.7	3.7	10.3	4.8	6.6	- - -	- - -	- - -	- - -	0.8#	0.4#	

* weight percent in entire sand fraction **point-counted samples #statistics for point-counted samples only

Table 2. Emission spectrographic analyses of the sand-sized heavy-mineral fraction of some insular shelf 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; N, not detected; L, may be present but at less than limit of detection (Grimes and Marranzino, 1968)]

Element	Sample 4759 (Río de la Plata)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Ca (pct)	0.5	1.5	3	3
Fe	15	10	7	3
Mg	0.5	2	3	3
Na	N	L	L	L
P	N	L	L	L
Ti	1	1	0.3	0.7
Ag (ppm)	N	N	N	N
As	N	N	N	N
Au	N	N	N	N
B	L	L	20	N
Ba	50	70	L	N
Be	N	N	N	N
Bi	N	N	N	N
Cd	N	N	N	N
Co	50	30	30	20
Cr	3000	3000	300	1500
Cu	30	50	30	10
Ga	30	30	20	15
Ge	N	N	N	N
La	N	N	N	N
Mn	500	700	700	200
Mo	10	15	20	15
Nb	N	L	N	N
Ni	100	70	70	100
Pb	20	L	N	N
Pd	N	N	N	N
Pt	N	N	N	N
Sb	N	N	N	N
Sc	15	50	50	50
Sn	N	N	N	N
Sr	N	L	500	L
Th	N	N	N	N
V	1000	500	200	100
W	N	N	N	N
Y	L	20	20	20
Zn	700	N	N	N
Zr	30	30	20	200

Element	Sample 4736 (Río de la Plata)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Ca (pct)	0.3	2	3	5
Fe	20	10	7	5
Mg	0.5	2	2	3
Na	N	0.5	L	L
P	N	N	L	L
Ti	1.5	1	0.3	1.5
Ag (ppm)	N	N	N	N
As	N	N	N	N
Au	N	N	N	N
B	L	20	L	L
Ba	50	100	L	L
Be	N	N	N	N
Bi	N	N	N	N
Cd	N	N	N	N
Co	30	50	30	30
Cr	3000	700	500	2000
Cu	50	70	30	15
Ga	20	20	15	10
Ge	N	N	N	N
La	N	N	N	N
Mn	500	1000	500	500
Mo	10	15	20	15
Nb	N	L	L	L
Ni	70	70	70	100
Pb	L	20	N	N
Pd	N	N	N	N
Pt	N	N	N	N
Sb	N	N	N	N
Sc	15	50	70	70
Sn	N	N	N	N
Sr	N	200	500	N
Th	N	N	N	N
V	1000	700	300	150
W	N	N	N	N
Y	N	20	30	30
Zn	700	N	N	N
Zr	30	50	30	150

Element	Sample 4914 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Ca(pct)		1.5	2	3
Fe		10	5	3
Mg		2	3	3
Na		L	L	L
P		N	L	L
Ti		1.5	0.3	2
Ag(ppm)		N	N	N
As		N	N	N
Au		N	N	N
B	insufficient	L	L	L
Ba		70	50	L
Be		N	N	N
Bi		N	N	N
Cd	sample	N	N	N
Co		20	20	L
Cr		3000	700	3000
Cu		30	20	10
Ga		20	30	10
Ge	for	N	N	N
La		N	N	L
Mn		1000	700	300
Mo		10	15	15
Nb		L	N	L
Ni	analysis	100	100	150
Pb		L	L	70
Pd		N	N	N
Pt		N	N	N
Sb		N	N	N
Sc		30	50	70
Sn		N	N	70
Sr		200	500	N
Th		N	N	N
V		200	150	100
W		N	N	N
Y		20	20	30
Zn		N	N	N
Zr		50	20	700

Element	Sample 4923 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Ca(pct)	0.2	2	3	5
Fe	20	7	7	3
Mg	0.7	3	3	3
Na	N	L	L	N
P	N	L	L	L
Ti	0.7	1	0.3	0.5
Ag(ppm)	N	N	N	N
As	N	N	N	N
Au	N	N	N	N
B	N	L	L	N
Ba	L	100	150	N
Be	N	N	N	N
Bi	N	N	N	N
Cd	N	N	N	N
Co	30	30	30	L
Cr	3000	3000	1000	3000
Cu	30	50	20	10
Ga	50	30	30	10
Ge	N	N	N	N
La	N	N	N	N
Mn	500	1000	700	300
Mo	20	15	20	15
Nb	N	L	L	L
Ni	100	150	150	150
Pb	L	L	N	N
Pd	N	N	N	N
Pt	N	N	N	N
Sb	N	N	N	N
Sc	10	30	50	70
Sn	N	N	N	N
Sr	N	200	500	N
Th	N	N	N	N
V	700	300	200	100
W	N	N	N	N
Y	N	20	L	30
Zn	500	N	N	N
Zr	20	150	20	150

Element	Sample 4924 (Río Cibuco)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Ca (pct)	0.3	2	2	7
Fe	20	7	7	3
Mg	0.7	3	3	3
Na	N	0.5	0.5	L
P	N	L	L	L
Ti	1	0.7	0.2	0.5
Ag (ppm)	N	N	N	N
As	N	N	N	N
Au	N	N	N	N
B	N	N	20	N
Ba	70	150	150	L
Be	N	N	N	N
Bi	N	N	N	N
Cd	N	1000	N	N
Co	30	30	30	L
Cr	5000	2000	700	3000
Cu	20	30	30	10
Ga	70	20	30	15
Ge	N	N	N	N
La	N	N	N	N
Mn	500	700	700	500
Mo	10	15	20	15
Nb	N	L	N	L
Ni	150	150	150	200
Pb	L	20	L	N
Pd	N	N	N	N
Pt	N	N	N	N
Sb	N	N	N	N
Sc	15	50	30	100
Sn	N	N	N	N
Sr	N	200	500	N
Th	N	N	N	N
V	700	300	150	150
W	N	N	N	N
Y	N	L	L	30
Zn	700	1500	N	N
Zr	50	70	20	700

Element	Sample 4248 (Río Cibuco-Manati)			
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp
Ca (pct)	0.3	1.5	2	3
Fe	20	10	5	5
Mg	0.5	1.5	2	3
Na	N	L	L	L
P	N	L	L	L
Ti	2	1.5	0.3	0.7
Ag (ppm)	N	N	N	N
As	N	N	N	N
Au	N	N	N	N
B	L	20	L	L
Ba	150	150	N	50
Be	L	N	N	N
Bi	N	N	N	N
Cd	N	N	N	N
Co	50	50	30	30
Cr	2000	1000	300	1000
Cu	50	70	30	20
Ga	50	30	20	15
Ge	N	N	N	N
La	N	N	N	L
Mn	700	1000	700	700
Mo	10	15	15	20
Nb	N	N	N	L
Ni	70	50	50	70
Pb	30	L	L	N
Pd	N	N	N	N
Pt	N	N	N	N
Sb	N	N	N	N
Sc	20	30	50	70
Sn	N	N	N	N
Sr	N	200	500	200
Th	N	N	N	N
V	1500	500	150	150
W	N	N	N	N
Y	L	20	20	30
Zn	700	N	N	N
Zr	30	70	20	100

Element	Sample 4339 (Río Grande de Manati)				Element	Sample 4254 (Río Grande de Manati)				Lower Detection Limits	
	HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp		HMAG	0-0.5 amp	0.5-0.75 amp	>0.75 amp		
Ca (pct)	0.2	1.5	3	5	Ca (pct)	0.15	0.7	1.5	3	Ca (pct)	0.1
Fe	30	20	5	5	Fe	20	15	7	5	Fe	0.1
Mg	0.3	1.5	2	3	Mg	0.3	1	2	3	Mg	0.05
Na	N	N	L	L	Na	N	N	L	L	Na	0.5
P	N	N	L	L	P	N	N	L	L	P	0.5
Ti	1.5	1.5	0.3	1	Ti	1	1.5	0.5	0.7	Ti	0.005
Ag (ppm)	N	N	N	N	Ag (ppm)	N	N	N	N	Ag (ppm)	1
As	N	N	N	N	As	N	N	N	N	As	500
Au	N	N	N	N	Au	N	N	N	N	Au	20
B	N	20	L	N	B	N	L	L	N	B	20
Ba	50	100	70	N	Ba	N	70	50	70	Ba	50
Be	L	N	N	N	Be	N	N	N	N	Be	2
Bi	N	N	N	N	Bi	N	N	N	N	Bi	20
Cd	N	N	N	N	Cd	N	N	N	N	Cd	50
Co	50	70	30	20	Co	50	70	50	30	Co	20
Cr	1500	2000	700	2000	Cr	2000	2000	1500	1500	Cr	20
Cu	30	70	30	15	Cu	50	70	30	15	Cu	10
Ga	30	30	15	10	Ga	50	50	30	20	Ga	10
Ge	N	N	N	N	Ge	N	N	N	N	Ge	20
La	N	N	N	L	La	N	N	N	L	La	100
Mn	700	1000	700	500	Mn	700	1000	700	500	Mn	20
Mo	L	15	20	20	Mo	L	10	15	20	Mo	10
Nb	N	N	N	50	Nb	N	N	N	L	Nb	50
Ni	100	70	70	150	Ni	70	70	70	150	Ni	10
Pb	20	30	L	N	Pb	L	20	20	L	Pb	20
Pd	N	N	N	N	Pd	N	N	N	N	Pd	100
Pt	N	N	N	N	Pt	N	N	N	N	Pt	100
Sb	N	N	N	N	Sb	N	N	N	N	Sb	200
Sc	15	30	50	100	Sc	15	30	30	70	Sc	10
Sn	N	N	N	N	Sn	N	N	N	N	Sn	20
Sr	N	L	500	300	Sr	N	N	300	200	Sr	200
Th	N	N	N	N	Th	N	N	N	N	Th	200
V	1500	1000	200	150	V	1000	700	300	150	V	20
W	N	N	N	N	W	N	N	N	N	W	50
Y	N	30	20	70	Y	N	20	20	70	Y	20
Zn	1000	N	N	N	Zn	700	N	N	N	Zn	500
Zr	30	100	30	2000	Zr	20	100	20	1000	Zr	20

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

A. Strongly paramagnetic/ferromagnetic heavy-mineral fraction separated by hand magnet. Statistics based on 7 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Ca	0.15	0.5	0.3	0.01	0.11
Fe	15	30	20.7	20.25	4.5
Mg	0.3	0.7	0.5	0.03	0.16
Ti	0.7	2	1.2	0.19	0.44
Minor elements, values in parts per million					
Co	30	50	41.4	114	10.7
Cr	1,500	5,000	2,785	$1.3x10^6$	1,149
Cu	20	50	37.1	156	12.5
Ga	20	70	42.9	289	17.0
Mn	500	700	586	$1.1x10^4$	107
[1]Mo	10	20	12	20.25	4.5
Ni	70	150	94.3	829	28.8
Sc	10	20	15	8.4	2.9
V	700	1,500	1,057	$1.1x10^5$	331
Zn	500	1,000	714	$2.1x10^5$	146
Zr	20	50	30	100	10

[1]based on 5 samples

B. Moderately magnetic 0.0-amp to 0.5-amp heavy-mineral fraction separated by electromagnet. Statistics based on 8 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Ca	0.7	2	1.6	0.19	0.44
Fe	7	20	11.1	19.36	4.4
Mg	1	3	2	0.50	0.71
Ti	0.7	1.5	1.2	0.10	0.32
Minor elements, values in parts per million					
Ba	70	150	101	$1.1x10^4$	33.1
Co	20	70	43.7	369	19.2
Cr	700	3,000	2,087	$8.0x10^5$	897
Cu	30	70	55	313	17.7
Ga	20	50	28.7	98	9.9
Mn	700	1,000	925	$1.9x10^4$	139
Mo	10	15	13.7	5.3	2.3
Ni	50	150	91.2	1,498	38.7
Sc	30	50	37.5	106	10.3
V	200	1,000	525	$7.1x10^4$	266
[1]Y	20	30	21.4	14.4	3.8
Zr	30	150	77.5	1,452	38.1

[1]Based on 7 samples

C. Less magnetic 0.5-amp to 0.75-amp heavy-mineral fraction separated by electromagnet. Statistics based on 8 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Ca	1.5	7	3.1	2.89	1.7
Fe	3	7	5.7	2.25	1.5
Mg	2	3	2.5	0.25	0.5
Ti	0.3	0.5	0.35	0.01	0.09
Minor elements, values in parts per million					
[1]Co	20	50	31.4	81	9.0
Cr	300	3,000	1000	$8.1x10^5$	899
Cu	10	30	25	58	7.6
Ga	15	30	21.9	49	7.0
Mn	500	700	650	8,575	92.6
Mo	15	20	17.5	7.29	2.7
Ni	50	200	97.5	2,652	51.5
Sc	30	100	56.2	428	20.7
[1]Sr	300	500	471	5,715	75.6
V	150	300	206	3,881	62.3
[1]Y	20	30	22.9	24	4.9
Zr	20	700	107	$5.7x10^4$	239

[1]based on 7 samples

D. Nonmagnetic >0.75-amp heavy-mineral fraction separated by electromagnet. Statistics based on 8 samples unless otherwise noted. [Elements detected by emission spectrographic analysis (Table 2)]

ELEMENT	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION
Major elements, values in percent					
Ca	3	7	4.2	2.25	1.5
Fe	3	5	4	1.21	1.1
Mg	3	3	3	0	0
Ti	0.5	2	0.95	0.28	0.53
Minor elements, values in parts per million					
[1]Co	20	30	26.0	30.2	5.5
Cr	1,000	3,000	2,125	$6.3x10^5$	791
Cu	10	20	13.1	13.7	3.7
Ga	10	20	13.1	13.7	3.7
Mn	200	700	437	$2.6x10^4$	160
Mo	15	20	16.9	6.8	2.6
Ni	70	200	134	1,681	41
Sc	50	100	75	286	16.9
V	100	150	131	671	25.9
Y	20	70	38.7	384	19.6
Zr	100	2000	625	$4.2x10^5$	649

[1]based on 5 samples